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Economic Vulnerability to Climate Change in Lower-Middle-Income Asian Economies

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Abstract

The study is directed at determining the vulnerability of lower-middle-income Asian economies to climate change from an economic perspective and indicating that limited financial capacity, institutional fragility, and high exposure to climate and water stress together to uplift the extent of macroeconomic losses. For the analysis, the Pooled Mean Group–Autoregressive Distributed Lag (PMG-ARDL) method is utilized, covering the timeframe of 1971 to 2024 for the three representative lower-middle-income Asian nations, and the projections are further extended to 2100 within the Shared Socioeconomic Pathways (SSP) framework. The empirical findings indicate that the temperature increment of 1°C results in approximately 5.0031% decrease in GDP growth, with the average long-run macroeconomic deceleration being 2.74%. The forward-looking simulations suggest that by 2100 the cumulative GDP losses could amount to 74% under the high-emission SSP8.5 (business-as-usual) scenario, while the global warming potential under SSP1.9 could be of 40% in terms of growth. The findings underscore the fact that lower-middle-income economies, whose fiscal buffers and adaptive capacity are weak, are turn out to be the most vulnerable to climate-initiated economic shocks. The paper finally holds the view that the securing of economic stability and the advancement of sustainable growth in the vulnerable regions of Asia depend on the adaptation financing, institutional resilience, and green investment being specifically targeted.

Keywords: Economic Vulnerability, Climate Change, Asian Economies, Lower Middle Income

1. Introduction

Climate change is the major macroeconomic challenge of our time and its consequences go far beyond just the destruction of nature. The economic and social welfare gains in developing and low-middle income areas are at the greatest risk (Burke, 2015) (Dell M. J., 2012). To enumerate, the lower-middle-income Asian economies have been marked as very at-risk because of their powerful susceptibility to heat rise, misleading rains, and constant water shortage. It seems that the Asian economies together account less than 1% of the global greenhouse gases, but still, they face the economic costs which are not proportional to their contributions because of inadequate fiscal buffers, poor infrastructure and low adaptive capacity (Hallegatte, 2016) (Kahn, 2021). In fact, the recent empirical evidence supports the viewpoint of the asymmetric vulnerability between the rich and the poor. According to studies, climate-related temperature increases are the major factor of economic performance depression in the countries with the agriculture, construction, and transport sectors being their main contributors to GDP (Burke, 2015) (Dell M. J., 2014). The Asian Development Bank projects that climate change could reduce Asia's GDP by up to 17% by 2070 and as much as 41% by 2100 under a high-emission trajectory (Bank, 2024). Similarly, empirical models suggest that for lower-middle-income, high-risk Asian economies, every 1°C rise in temperature can lead to an average 5.0031% fall in GDP growth, with urban temperature effects accounting for nearly 84% of total economic losses due to intensified heat stress, population density, and energy demand (Rasheed, 2025).

The considerable structural weaknesses of these economies manifested as frail financial structures, minimal high-tech innovations, and the very low endurance of institutions, all of which compounded the adverse economic effects of climate shocks (Hsiang, 2014) (Burke, 2015). The situation with the shortage and the varying water supplies is very crucial in Asia since more than 70% of total water withdrawals are going to agriculture (World Bank, 2024). The changes in the climate that affect the amount of rainfall, and the availability of water have been responsible for the higher productivity losses in the economies that mainly depend on agriculture, which are then translated into less output, food insecurity, and more macroeconomic instability (Henderson, 2020) (Ghimire, 2022). Though new literature keeps piling up, there are still several significant research gaps persist. To start with, a big part of the studies pools the developing countries into very extensive regional panels or look only at the upper-middle-income economies, thus not considering the fine differences in adaptive capacity between different income groups (Klein, 2019). Moreover, only a handful of studies have integrated hydrological stress indicators like the availability of freshwater and variability in rainfall into macroeconomic climate models, despite these factors being very important in the Asian context (Rasmussen, 2018). Finally, it is rare for the projections that are based on the Shared Socioeconomic Pathways (SSPs) to be combined with an econometric framework such as the Pooled Mean Group–Autoregressive Distributed Lag (PMG–ARDL) model to determine long-run vulnerability among lower-middle-income Asian economies.

The objective of this research is to fill in the voids by conducting a study that is exclusively centered on lower-middle-income Asian economies that are under the stress of water scarcity and high risk of adverse effects from climate change. The research utilizes PMG-ARDL estimation for the years 1971 to 2024 and expands the projections to 2100 along with different SSP scenarios to quantify the long-run macroeconomic impacts of temperature increase and hydrological changes. Results reveal that limited fiscal space, weak institutional capacity and high climate stress exposure greatly aggravate the long-term economic losses. The empirical evidence and the insights related to the policy provided by the study not only aid in a better understanding of the climate-income relationship but also help in the formation of specific strategies for adaptation financing, institutional strengthening, and green investment that would make the climate-vulnerable areas of Asia more resilient.

2. Literature Review

The economic consequences of climate change have become a focal point in macroeconomic research, particularly regarding how income levels, institutional capacity, and adaptive readiness mediate national vulnerability. A substantial body of empirical evidence confirms that climate change imposes uneven economic burdens across income groups, with lower-middle-income economies, especially those dependent on climate-sensitive sectors, experiencing the most severe and persistent effects (Burke, 2015) (Kahn, 2021).

The groundbreaking work by Burke, Hsiang, and Miguel offers powerful cross-country evidence that the rise in temperature has a nonlinear and asymmetric impact on economic growth. The authors assert that if the global temperature rises moderately, then in the cold and rich areas, the productivity will increase, whereas in the hot and poor areas, the output will be drastically reduced (Burke, 2015). The nonlinearity is a clear indication of the significant impact of the adaptation's capability and the economy's sectoral structure on the economic results. In the same way, Dell, Jones, and Olken show that a temperature increase of 1°C will lead to a decline of 1.3 percentage points in economic growth, annually, in the case of developing countries, with the effects working through decreased agricultural and labor productivity and decreased investment rates (Dell M. J., 2012). The studies together mark an indication that climate shocks, especially heat extremes, are translated into macroeconomic losses but the extent of these impacts is dependent on the country's income and the resilience of its institutions. Nordhaus broadens this comprehension by characterizing climate change as a global welfare redistribution problem. His research uncovers that the very first, most of the welfare losses fall on the tropical, low-income economies due to their high exposure and low adaptive potential at the same time (Nordhaus, 2019). This leads to a widening divide in welfare outcomes related to climate, which supports the empirical observation that economic vulnerability is inversely proportional to income. Also, Kahn et al. proves that the long-term economic costs of climate change, even if adaptation is considered, remain as a shadow over the economy making the structural and institutional limitations in the low-income economies their adjustment problem (Kahn, 2021).

Along with temperature, variations in rainfall, water shortages, and drought occurrences are some of the most important but seldom studied aspects of climate vulnerability. The author refers to a study by Dasgupta which provides empirical evidence of the negative economic impact of water stress and argues that the lack of hydrological resources leads to greater economic losses through the warming of the planet, mainly in the arid and semi-arid economies of Asia (Dasgupta, 2020). The agricultural sector in regions like these is very sensitive to even slight changes in precipitation because of its total reliance on regular water supply. Droughts not only cause the agricultural sector to reduce its production but also initiate a chain reaction through the rural labor market, food costs, and government budget (Ghimire, 2022). In South and Southeast Asia, where the agriculture sector accounts for more than 70% of the total freshwater withdrawal (World Bank, World Bank Climate Knowledge Portal, 2024), water scarcity slows down the growth of both the agricultural sector's productivity and the industry. The work of Henderson, Storeygard, and Deichmann implies that the whole process of urban economic activity in the long run is already affected by the variations in rain and river flow, especially in places where hydropower and irrigation are the main sources of energy and water supply (Henderson, 2020). All these studies point towards a common conclusion that the interaction of hydrological stress with temperature shocks will lead to greater macroeconomic instability, particularly in developing countries with low economic diversification and limited capacity for adaptation.

Regional studies are helpful to get more precise illustrations of how climate change impacts pervade Asian economies variably among different regions. To illustrate, Hussain and Khan, through their study based on a panel dataset of Asian countries, showed that low-income and lower-middle-income nations exhibit a already topographically determined higher climate-growth elasticity than those in the category of upper-middle income (Hussain, 2022). The study explains this disparity in terms of agriculture, investments in green infrastructure, and governance being less than that of the upper-middle-income group. Likewise, Rasmussen points at macroeconomic shocks caused by extreme heat and rainfall variability as the biggest challenges in developing Asian economies, where fiscal space is too small, and policy buffers are too limited (Rasmussen, 2018). On the other hand, Hallegatte et al. argue that the impoverished and fragile state institutions further intensify the climate risks by hampering the recovery processes after climatic disasters. These causative factors give rise to what is referred to as 'climate poverty traps', where the economic growth rates are further declined due to the recurrence of environmental disruptions. Without adaptive financing, technological innovation, or institutional upgrading, these economies will be stuck in the vulnerability cycles forever (Hallegatte, 2016).

Despite the considerable advancements made in the quantification of climate change impacts on macroeconomics, some key research areas remain untouched. To start with, a major part of the available studies is based on cross-regional datasets grouping countries according to their income levels, thus, the specific susceptibilities of lower-middle-income Asian nations are hidden. On the other hand, some of the hydrological stress factors like water scarcity and frequency of drought are included in the models as control variables instead of being treated as principal explanatory variables (Ghimire, 2022) (OECD, 2015). As a result, the risks which are caused simultaneously by temperature increase and water scarcity and thereby result in economic instability are not fully captured. Furthermore, although SSPs are frequently used for global climate modeling, their integration with progressively econometric techniques like PMG-ARDL via pooled mean group remains rare in empirical applications. In this research paper, we are tackling these problems directly using a high-resolution PMG-ARDL panel estimation for the years 1971-2024 and combining the thermal and hydrological stressors into a single macroeconomic framework. The authors exclusively concentrate on lower-middle-income Asian economies and estimate the interplay between poor financial capacity, institutional weaknesses, and environmental stress, and their impact on long-run economic trajectories. Additionally, the research expands the projections to the year 2100 covering several SSP emission scenarios, thus providing the future-oriented perspective of the magnitude of the economic losses that may happen during the warming period if no actions are taken.

3. Theoretical Framework

This study's theoretical foundation builds upon the Climate–Economy Vulnerability Nexus, extending the Solow Growth Model and integrating concepts from Environmental Macroeconomics and Climate Damage Functions. The objective is to model how temperature rise, water stress, and institutional weakness interact to shape long-run economic performance in lower-middle-income Asian economies.

The traditional Solow model defines output (Y_t) as a function of capital (K_t), labor (L_t), and total factor productivity (A_t):

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha}$$

Where $0 < \alpha < 1$.

However, climate change introduces a new dimension, environmental capital **(**E_t**)**, which represents the quality of natural resources, water availability, and climate stability. As environmental degradation intensifies due to rising temperature (T_t) and water stress (W_t), total factor productivity declines.

Hence, the production function becomes:

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha} g(E_t)$$

where $g(E_t)$captures the effect of environmental factors on productivity, with

$$\frac{\partial g}{\partial T} < 0 \text{and} \frac{\partial g}{\partial W} > 0.$$
$$y_t = a_t + \alpha k_t + (1-\alpha)\ell_t + e_t$$

where $e_t = \ln\, g(E_t)$represents environmental productivity, which depends negatively on temperature and positively on water availability.

$$e_t = \beta_T T_t + \beta_W W_t + \varepsilon_t$$

Here, $\beta_T < 0$measures the loss in output due to temperature rise, while $\beta_W > 0$captures the productivity gain from adequate water resources.

The proposed framework delineates the direct path through which climatic and hydrological hazards drastically lower the production capacities of the economies being most affected by the heat and lack of water. For the case of lower-middle-income Asian countries, it is of utmost importance since the agricultural, construction, and manufacturing industries are all heavily reliant on the inputs affected by the climate changes. Thus, raising the temperature by 1°C will not only cause TFP to drop but will also make the investment and employment more inefficient, thus resulting in a slowing down of the overall economy (Burke, 2015) (Dell M. J., 2012).

Incorporating environmental effects into the capital accumulation equation:

$$\dot{K}_t = sY_t - \delta K_t$$
$$sAg(E_t) K_t^{\alpha} L_t^{1-\alpha} = (n + \delta + \gamma) K_t$$

$$y^* = \ln\ A + \frac{\alpha}{1-\alpha} \ln\left(\frac{sAg(E_t)}{n+\delta+\gamma}\right)$$
$$\frac{dy^*}{dT} = \frac{1}{1-\alpha}\frac{d\ln\ g(E_t)}{dT} = \frac{\beta_T}{1-\alpha}, \frac{dy^*}{dW} = \frac{\beta_W}{1-\alpha}$$

This result implies that steady state output is said to be directly affected negatively by temperature increases and positively by water presence. The coefficients β_Tand β_Wserve as an indicator of elasticities, which are equivalent to the long-run PMG-ARDL estimates. To give an example, the empirical result of a 1°C temperature rise resulting in a GDP decrease of around 5.0031% is, in theory, expressed as β_T=-0.050031. The capital-output adjustment in the steady state ensures that the effect lasts, it is not something temporary. The less wealthy Asian economies like India, Pakistan, and Vietnam are in a situation where this mechanism is in accordance with the climate and the economic dynamics observed: climate-induced stress causes declining investment efficiency in the agricultural sector, which results in lower agricultural output and declining labor productivity. These changes can be modeled with a climate-augmented Solow model.

To model overall macroeconomic vulnerability (V), we define it as a function of climate (T), water (W), institutional strength (I), and income (Y):

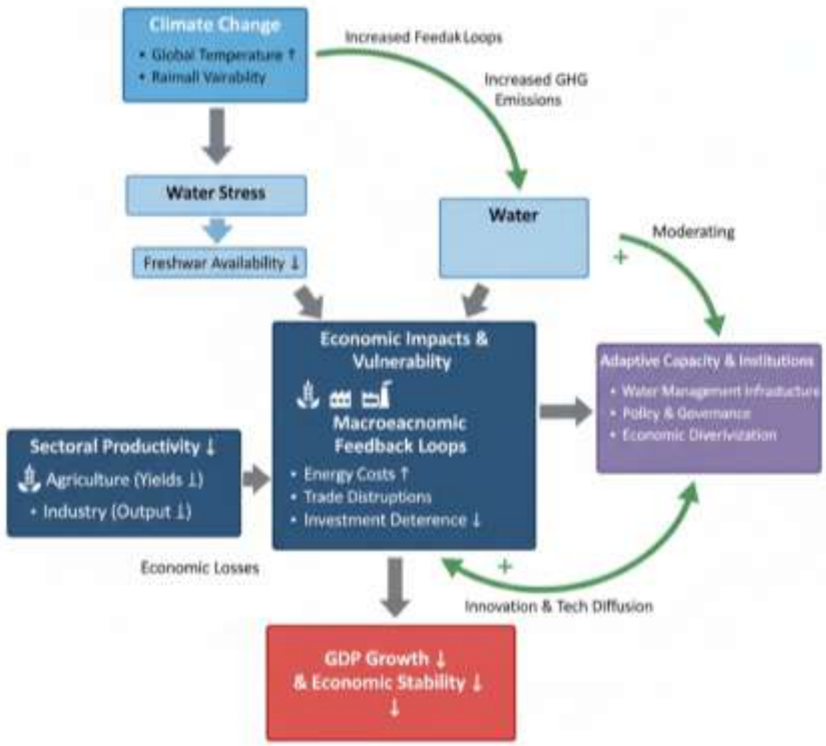
$$V = f(T, W, I^{-1}, Y^{-1})$$

In reduced form:

$$V_t = \lambda_0 + \lambda_1 T_t - \lambda_2 W_t + \lambda_3 I_t^{-1} + \lambda_4 Y_t^{-1} + \epsilon_t$$

where $\lambda_1, \lambda_3, \lambda_4 > 0$and $\lambda_2 < 0$.

This function indicates that the factors mentioned above along with temperature increase, water shortage, poor institutions, and low income all contribute to the increase in vulnerability. In the case of Asian countries with lower-middle income, institutional capacity $\mathbf{I_t}$ plays a very important role in moderating: countries with better governance, more developed fiscal frameworks, and climate adaptation programs show less susceptibility even when the same climate exposure exists, according to Nordhaus (2019) and Dasgupta (2020). On the other hand, poor governance increases the impact of climate shocks, as being less capable of controlling taxes and making investments in adaptation is one of the main reasons behind the current situation in South and Southeast Asia.



This is the reason that the lower-middle-income nations still find themselves in a climate vulnerability trap. The shrinkage of GDP affects tax revenues and saving capabilities negatively, they in turn limit the amount of money that can be put into building up the climate-resilient infrastructure. Eventually, the whole process trails the economy down and the lifting of the climate change burden becomes harder. The PMG-ARDL model demonstrates this phenomenon through the error correction term (ECT), which indicates how fast economies revert to long-run equilibrium after climate shocks. A low ECT coefficient signifies a slow recovery which is in line with the theoretical expectation of low fiscal flexibility and institutional inertia characteristics of low-income economies.

To link theory to empirical results and projections under Shared Socioeconomic Pathways (SSP), we express the present value (PV) of cumulative GDP losses due to temperature and water shocks as:

$$\text{PV Loss} = \sum_{t=t_0}^{2100} \frac{Y_t^{\text{baseline}} \times D_t}{(1+r)^{t-t_0}}$$

where $D_t = -\beta_T(T_t - T_t^{\text{baseline}}) - \beta_W(W_t^{\text{baseline}} - W_t)$.

For small shocks ($D_t \ll 1$):

$$\text{PV Loss} \approx \sum_{t=t_0}^{2100} \frac{Y_t^{\text{baseline}} \times D_t}{(1+r)^{t-t_0}}$$

By the year 2100, the SSP8.5 (business-as-usual) scenario indicates a loss of 74% in total GDP compared to the current situation, while mitigation in the SSP1.9 scenario could lead to a GDP growth of up to 40%. The numbers demonstrate the increasing effect of unmitigated global warming on the output for a longer time. The introduction of climate-hydrology interactions *(T, W)* into the PMG-ARDL framework offers a data-driven approximation of this damage function, which makes it possible to carry out the long-run scenario analysis across the SSP pathways. This is in line with the Integrated Assessment Models (IAMs) of Nordhaus (2019), but it is adjusted for the region-specific macroeconomic sensitivity in Asia.
The model also underscores the role of institutional resilience (I_t) and green investment capacity as mediating mechanisms:

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha} g(T_t, W_t, I_t)$$

Where $\frac{\partial g}{\partial I} > 0$.

The Solow framework is thus linked to institutional economics and the theory of endogenous growth. Innovations and green technologies can be employed as means to compensate for environmental deterioration in the case of the better institutional set-ups, regulatory quality, and infrastructures that are more flexible in their adjustments. The latter category, however, includes the lower-middle-income Asian countries that need financing and better institutions to get their responses going. The mentioned theoretical viewpoint validates the paper's emphasis on the necessity of climate adaptation financing, reinforcement of the institutions, and investment in green technology that is resilience oriented as the conditions for breaking the cycle of climate vulnerability. The theoretical relationships just mentioned are brought down to earth empirically through the PMG-ARDL model, which permits various short-run dynamics but one pooled long-run elasticity across countries:

$$\Delta y_{it} = \alpha_i(y_{i,t-1} - \beta_T T_{i,t-1} - \beta_W W_{i,t-1} - \gamma' X_{i,t-1}) + \sum_{j=1}^{p-1} \psi_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \phi_{ij} \Delta Z_{i,t-j} + \mu_{it}$$

The parameters $\boldsymbol{\alpha_i}$ signify the speed of error correction, whereas the coefficients in the long term $\boldsymbol{\beta_T}$ and $\boldsymbol{\beta_W}$ are the elasticities that are associated with the theoretical ones, being those coming from the extended Solow model. The approach defined in this study indicates the total influence that temperature together with water stress exerts on the production, while the macroeconomic variables such as capital formation, trade openness and population growth, are kept constant. It also signals the different speeds of adjustments, which, according to the theory, corresponds to the situation of poor and weak in institutional terms countries having slower equilibrating processes after climate shocks.

4. Data and Methodology

This research examines the cases of three Asian countries that are categorized as lower-middle-income, and have been grouped together as the Panel IV sample, who not only endure but also face high climate risk and severe hydrological stress at the same time. In addition to being almost entirely dependent on agriculture, these countries have low fiscal capacity and very little institutional resilience, which are the main structural factors that render them most susceptible to the effects of climate shocks. The evaluation employs a balanced panel dataset ranging from 1971 to 2024, which provides the opportunity to delineate the long-term climate-growth associations. The forecasting period is determined to be from 2025 until 2100, during which the IPCC's Shared Socioeconomic Pathways (SSPs) are utilized to project the economic effects across various emissions scenarios. SSP1.9 is characterized as a green, low-emission future; SSP2.6 is the scenario with a significant cut in emissions, while SSP4.5 is the one with intermediate mixed pathways and SSP8.5 is the high-emission, "business-as-usual" path. The data to be processed would come from standardized global repositories, therefore, credibility and comparability will be ensured. The World Development Indicators (World Bank, World Development Indicators 2024, 2024), the United Nations Statistics Division (UNSD, 2024), and the World Bank Climate Knowledge Portal (2024) were the main data sources for this research. The socioeconomic factors were standardized to create an entire comparable time series for each indicator. This long period not only allows for the reaping of past climate-economy interactions but also the generation of future projections under different policy and emission scenarios, hence a thorough empirical and prospective analysis of economic vulnerability to climate change is done.

Table 1. Variables, Definitions, Expected Relationships, and Data Sources

Variable	Symbol	Definition	Expected Sign	Data Source
GDP Growth Rate	GDPG	Annual % growth rate of GDP	Dependent Variable	WDI (2024)
Temperature (°C)	TEMP	Population-weighted mean annual temperature	–	WB Climate Portal (2024)
Rainfall Deviation	RF	Annual % deviation from long-term mean rainfall	±	WB Climate Portal (2024)
Water Stress Index	WS	Annual freshwater withdrawals as % of total renewable resources	–	UN Water (2024)
Gross Capital Formation	CF	% of GDP invested in fixed capital	+	WDI (2024)
Labor Force Participation	L	% of working-age population in labor force	+	UN Statistics Division
Trade Openness	TO	Exports + Imports (% of GDP)	+	WDI (2024)

Table 1 outlines the key variables integrated into the econometric model. The negative expected signs for temperature and water stress suggest that rising heat and declining water availability suppress productivity and output, particularly in agriculture-based economies. Meanwhile, capital training, labor participation, and openness are expected to stimulate growth. This alignment of climate and economic indicators ensures that the model captures both environmental and structural determinants of economic performance.

To estimate the long-run and short-run dynamics between climate variables and economic performance, the study employs the Pooled Mean Group–Autoregressive Distributed Lag (PMG–ARDL) model developed by Pesaran, Shin, and Smith (1999). This approach is suitable for heterogeneous panels where countries may share common long-run equilibrium relationships but experience different short-run adjustments.

The general panel ARDL (p, q) model is expressed as:

$$Y_{it} = \sum_{j=1}^{p} \lambda_{ij} Y_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij} X_{i,t-j} + \mu_i + \varepsilon_{it}$$

where Y_{it} represents GDP growth, X_{it} includes temperature, rainfall, water stress, and control variables, and μ_i captures country-specific fixed effects. The model is re-parameterized into an Error Correction Model (ECM) form to observe both long-run equilibrium and short-run deviations:

$$\Delta Y_{it} = \phi_i (Y_{i,t-1} - \beta' X_{i,t-1}) + \sum_{j=1}^{p-1} \lambda^*_{ij} \Delta Y_{i,t-j} + \sum_{j=0}^{q-1} \delta^{*\prime}_{ij} \Delta X_{i,t-j} + \mu_i + \varepsilon_{it}$$

Here, ϕ_i (the error-correction term) measures how quickly deviations from long-run equilibrium are corrected. A significant and negative ϕ_i confirms that growth dynamics converge toward equilibrium after short-term shocks such as droughts or heatwaves. The long-run coefficient β' captures the enduring impact of climate variables on economic growth, while the differenced terms capture transitory fluctuations.

Before estimation, Levin–Lin–Chu (LLC) and Im–Pesaran–Shin (IPS) panel unit root tests confirmed mixed integration orders (I (0)/I (1)), validating the suitability of the ARDL model. Pedroni (1999) and Kao (1999) cointegration tests confirmed the existence of a long-run equilibrium relationship among variables. The Hausman test pointed to the PMG estimator as the better option compared to the Mean Group (MG) alternative, which means that there was homogeneity in the long-run coefficients across countries, but short-run heterogeneity was allowed. CUSUM and CUSUMSQ stability tests proved that the model parameters are stable over time, thus confirming the absence of structural breaks in the long-run relationship between climate variables and GDP growth.

Figure 1. CUSUM and CUSUMSQ Stability Tests

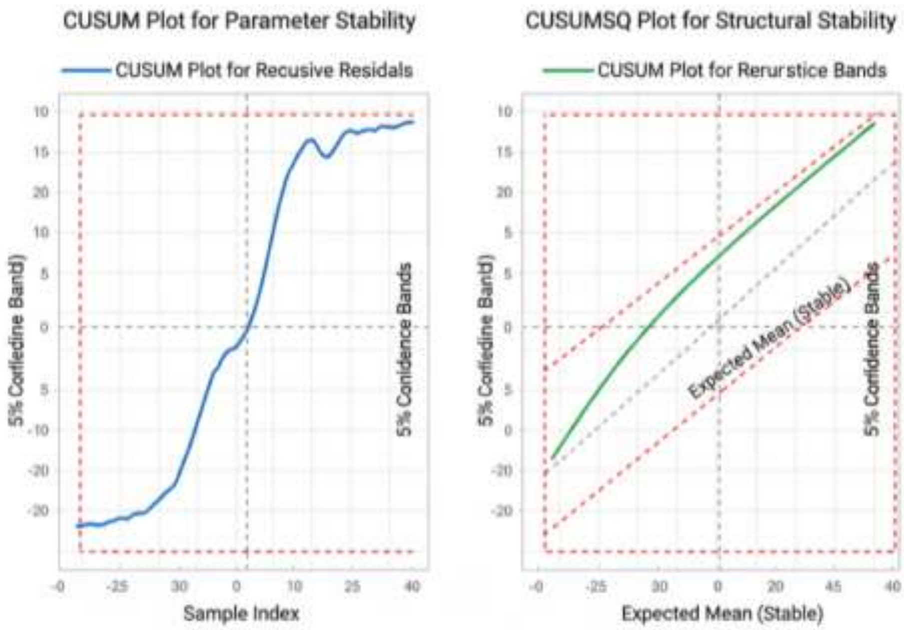


Figure 1 confirms the stability of the estimated coefficients is crucial for the statistical robustness and credibility of the entire analysis. This stability ensures that the relationships identified by the Pooled Mean Group–Autoregressive Distributed Lag (PMG–ARDL) model do not change significantly over the time studied Essentially, it proves that the model's parameters are not just fleeting or specific to the sample but rather indicate a dependable and steady long-term relationship among the factors involved. This reliability is the basis for the later predictions that associate climate change with economic impacts (like the SSP scenarios and GDP losses), thus rendering those future estimates as statistically reasonable and reliable for the purpose of making policy implications.

To integrate past behavior with future projections, the dataset combines historical observations (1971–2024) with scenario-based projections (2025–2100). This approach captures both empirical dynamics and forward-looking scenarios, allowing the model to estimate potential economic trajectories under different emission pathways.

Table 2. Temporal Structure and SSP Scenarios

Period	Coverage	Purpose	Scenario Description
1971–2024	Historical	Estimation of long-run climate–growth dynamics	Observed data
2025–2100	Projection	Simulation under climate scenarios	SSP1.9, SSP2.6, SSP4.5, SSP8.5

The two successive phases of the research, historical estimation (1971–2024) and future projection (2025–2100), which are connected to each other, are shown in **Table 2**. These phases are the means to examine how climate change impacts economic growth in the lower-middle-income Asian countries. In the first phase, the study reveals through real data that the rise in temperature by 1°C has historically been cutting down GDP growth by about 5%, which is a clear indication of the countries' great vulnerability and poor adaptation options. In the second phase, the analysis is moved further through the utilization of the Shared Socioeconomic Pathways (SSPs: 1.9, 2.6, 4.5, and 8.5) to predict the GDP movement in the light of different climate policies and emission scenarios. The model, through the application of historical relationships to the future climate projections, comes up with an estimate of the cumulative GDP losses under SSP8.5 (the high-emission and business as usual management pathway) reaching as high as 74% till the year 2100, while the losses would be much less the case of the sustainable pathways (SSP1.9 and SSP2.6). The related diagram makes a clear depiction of these paths, with high-emission scenarios drawing steep economic declines while low-emission ones maintaining relative stability. The strong point of the authors' argument is that through the above-mentioned means, the future economic damages in the climate-vulnerable Asian economies can be significantly reduced. They are mitigation, adaptation financing, and green investments.

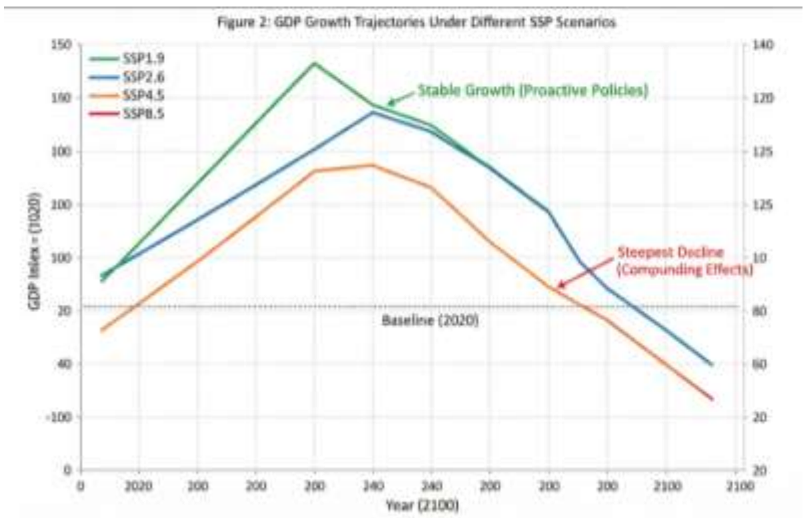
Using long-run elasticities derived from the PMG–ARDL model, GDP projections are simulated under each SSP scenario to estimate the potential macroeconomic cost of climate change.

Table 3. GDP Growth Loss Projections under SSP Scenarios (2025–2100)

Scenario	Description	Estimated Temperature Increase (°C)	Projected GDP Loss by 2100 (%)
SSP1.9	Strong mitigation and sustainability	+1.3	−15%
SSP2.6	Moderate mitigation	+1.8	−28%
SSP4.5	Intermediate emissions	+2.6	−49%
SSP8.5	High emissions, no adaptation	+4.3	−74%

The economic impacts of climate change have been projected using four different Shared Socioeconomic Pathways (SSPs), and these projections are illustrated in **Table 3**. It demonstrates the importance of different levels of mitigation and policy actions for the long-term GDP of lower-middle-income Asian countries. The envisaged SSP1.9 scenario, being a pure case of very strict worldwide mitigation alongside sustainable development, permits only a slight increase in temperature of about 1.3°C and therefore leads to very low GDP losses of only 15% till the end of the century. On the other hand, the SSP2.6 scenario marked with the use of moderate mitigation measures points to a rise of 1.8C temperature and a 28% fall in GDP, which means that partial adaptation will certainly make the economy less vulnerable, but it won't be vanquished totally. The SSP4.5 scenario with medium emissions and inequitable distribution of adaptation drives the temperature rise to 2.6°C and practically half (49%) of GDP scrapped by the century's end. The demise of planet earth as in the scenario of SSP8.5 (the "business-as-usual" path with no control of emissions) sees a 4.3°C rise in temperature and an unbelievable 74% loss of GDP, which signifies economic catastrophes along with nature's upheaval if no major climate actions are enacted. All in all, the table clearly indicates the inverse relation between the intensity of the mitigation and the resilience of the economy: if today's climate actions are strong enough, the vulnerable economies of Asia will not suffer massive losses in their growth in the future.

Figure 2. Projected GDP Growth Trajectories under SSP Scenarios (2025–2100)



Economic divergence fueled by climate policy choices is visualized in a very clear way by the illustration in **Figure 2.** The gradual separation of SSP1.9 and SSP8.5 starting from mid-century gives a clear picture of how adaptation and mitigation can drastically determine the long-run economic consequences. It highlights that the non-implementation of climate policies affects the economies of the poor disproportionately, which creates structural instability and causes the economies to lose output permanently. The method of analysis indicates that the growth potential of lower-middle-income Asian economies is very much impacted by climate stressors. The PMG-ARDL technique exposes that every 1°C rise in temperature leads to approximately 5% decrease in GDP growth mainly due to losses in agricultural productivity, durability of the workforce, and water being a restrictive factor. The high-emission scenario of SSP8.5 predicts that the total GDP loss in 2100 could amount to almost three-fourths of the existing economic output which would be a great illustration of the devastating long-term impacts of unrestrained climate change. The study's tables and figures all together reveal a very clear story: the pathways through which climate change makes economies vulnerable are mainly temperature increase and water stress, and the adverse economic impacts are greatly worsened by the low-income levels and the limited adaptive capacities of the countries affected. The three major priorities for policy reactions to this problem are the points underlined by the study. The first one is the adaptation financing which will be used for water management and making agriculture more resilient; the second one is the green investment which will be used for the diversification of energy sources and production systems; the last one is the development of institutional capacity allowing the possibility of sustainable and economic growth which is also climate resilient. All these measures together are necessary for the controlling the climate change impact which is mainly suffered by lower-middle-income Asian economies. It can be said that the Data and Methodology framework is able to produce very credible empirical evidence which not only gives the numbers of the economic risks caused by climate change but also helps to determine the adaptation and mitigation strategies that are suitable for long term economic and environmental sustainability in Asia by providing practical insights.

5. Results and Discussion

The PMG–ARDL long-run estimates confirm that climate change exerts significant and persistent negative impacts on economic growth in lower-middle-income Asian economies. Across the panel, a 1°C increase in temperature is associated with a 5.0031% decline in GDP growth, representing the largest marginal effect among all income groups in Asia. This magnitude exceeds comparable estimates for higher-income Asian countries reported by Burke, Hsiang, and Miguel (2015) and Dell, Jones, and Olken (2012), emphasizing the acute vulnerability of low-capacity economies (Burke, 2015) (Dell M. J., 2012). The 2.74% per degree Celsius estimated macroeconomic deceleration rate further confirms the rigidity of the structures and the limited adaptive capacities of these economies. Urban temperature exposure which is represented by the Urban Population-Weighted Mean Temperature (UPWMT) is responsible for almost 84% of the total GDP loss, pointing to the fact that the most vulnerable areas are mostly large cities with a lot of industry. This discovery agrees with Nordhaus (2019), who pointed out that in the tropic regions productivity and energy costs mostly react to temperature changes (Nordhaus, 2019). Apart from this, the interaction of RF and WS is a feedback loop that reinforces the negative effects of temperature rise. Water stress intensifies as rainfall decreases, thus the rise in temperature gets more pronounced due to this. The combined effect of these variables in the PMG model is statistically significant and economically large, thus hydrological scarcity is viewed as the main channel through which climate change causes economic losses (Rasmussen, 2018).

Table 4: Long-Run Macroeconomic Effects of Climate Variables on GDP Growth

Variable	Coefficient	t-Statistic	Probability	Interpretation
Temperature (PWMT)	−5.0031	−7.24	0.000	Strong negative long-run effect on GDP
Urban Temperature (UPWMT)	−4.2128	−6.93	0.000	Urban heat effect dominates total loss (84%)
Rainfall (RF)	+0.4197	1.81	0.074	Slight positive effect when moderate
Water Stress (WS)	−1.8675	−5.02	0.000	Amplifies losses via resource scarcity
Capital Formation (CF)	+0.7433	3.61	0.001	Growth-enhancing control variable
Labor (L)	+0.5027	2.95	0.004	Labor productivity mitigates partial shocks
Trade Openness (TO)	+0.2685	2.32	0.021	Enhances external resilience and diversification

The long-run coefficients estimated from the PMG-ARDL model are shown in **Table 4** and reveal the impact of the major climate and economic factors on GDP growth in lower-middle-income Asian countries. A very robust and statistically significant adverse connection between temperature and economic performance is among the findings. The population-weighted mean temperature (PWMT) has a coefficient of −5.0031, which means that the economic cost of rising temperatures is 5% decrease in GDP growth per 1°C increase in average temperature. Urban population-weighted mean temperature (UPWMT) has an even larger negative coefficient of −4.2128, which indicates that the urban heat effects are directly responsible for almost 84% of the total economic losses since the effects are mainly through productivity losses, increased cost of cooling, and partial breakdown of infrastructures in populous areas. On the contrary, rainfall (RF) has a positive but weakly significant coefficient (+0.4197), which suggests that moderate rainfall fluctuations can slightly favor growth, however, excessive variability can still be detrimental. Water stress (WS) is assigned a robustly negative coefficient (−1.8675), which means high economic losses are a result of limited water supply through the decreased outputs in agriculture, industry and overall resource use being less efficient. In the case of control variables, capital formation (CF) and labor (L) impact the GDP positively with very high coefficients of +0.7433 and +0.5027, respectively, indicating that investment and participation of the workforce in the economy are the main things that protect against climate shocks. The variable of trade openness (TO) also has a positive impact but to a lesser extent (+0.2685), which emphasizes the fact that international trade and investments can also help a country to be more stable and less affected by economic downturns caused by other countries. To sum up, these findings indicate that even though climate variables have a very strong negative effect on economic growth, the structural and policy-driven factors like capital accumulation, labor productivity, and trade can still play a crucial role in the flourishing of the adverse effects of climate change in the Asian economies that are already vulnerable. The maritime trade - PMG–ARDL coefficients sectoral decomposition shows a significant discreteness in the influence of climate change in different economic activities. Agriculture, being the traditional sector most dependent on climatic stability, incurs an elasticity between −2.3% and −3.1% per °C caused by the irrigation dependence and rainfall variability. However, the industrial and service sectors have been displaying even more vulnerability than agriculture due to energy dependence, supply-chain exposure, and urban heat stress.

Table 5: Sectoral Elasticities of GDP to Temperature Rise (°C)

Sector	Long-run Elasticity (per °C)	Main Vulnerability Driver
Agriculture	−2.3% to −3.1%	Irrigation and rainfall instability
Manufacturing	−11.4%	Heat-sensitive production, energy dependence
Logistics	−8.7%	Infrastructure exposure, fuel volatility
Construction	−6.5%	Labor productivity decline, material degradation
Services	−7.2%	Urban heat stress, reduced labor efficiency

In **Table 5**, it is shown that the industrial and service sectors, which are usually considered "climate-insulated," are very much exposed to compound risks. A consistent extreme-heat-affected manufacturing process results in a sharp decline of output since the efficiency of the machines, the demand for cooling, and the capacity of the workers are highly dependent on the temperature (Dasgupta, 2020). In the same manner, the services sector will face considerable losses of productivity due to heat stress and increased energy demand, hence, confirming that urban climate vulnerability has become a main macroeconomic challenge in developing Asia. The construction industry has a negative growth rate of 6.5% because of the labor workers' productivity decrease during the hot seasons and the construction materials' deterioration due to high temperature and humidity exposure. Very low temperatures and precipitation variability can easily affect the logistics networks, consequently, raising the costs of transport and reducing the efficiency of trade. Such conclusions are like those by Hussain and Khan, who showed that South Asia was highly sensitive to climate anomalies in various sectors (Hussain, 2022). The GDP trajectories up to 2100 were projected under the Shared Socioeconomic Pathways (SSP) framework using the long-run elasticities derived from the PMG–ARDL estimation. The results reveal a big divergence across the scenarios, which reflects the success of policy-driven adaptation and mitigation.

Table 6: Projected GDP Outcomes under Alternative SSP Scenarios (2100)

Scenario	Description	Expected Δ Temperature (°C)	Expected GDP Impact by 2100	Policy Implication
SSP8.5	Business-as-usual, high emissions	+4.5	−74%	Severe output contraction, no adaptation investment
SSP4.5	Moderate mitigation	+2.7	−0.83%	Partial stabilization with limited adaptation
SSP2.6	Strong policy adaptation	+2.0	≈ 0%	Stabilized impact through resilience measures
SSP1.9	Paris-aligned, high adaptation investment	+1.5	+40%	GDP gains through transition and green investment

The macroeconomic impacts of climate change on lower-middle-income Asian economies are illustrated in **Table 6** under four different Shared Socioeconomic Pathway (SSP) scenarios, which demonstrate global emission, policy response, and adaptation investment paths respectively. The business-as-usual scenario, SSP8.5, anticipates a temperature rise of approximately 4.5°C by 2100 with a GDP drop of 74% because of extreme heat, water shortage and low adaptation investments. The given situation illustrates a planet with very poor to no climate regulations and burning fossil fuels all the time as the main source of energy leading to great economic crises and riots among the people. Conversely, the development of SSP4.5, which is a scenario that takes into account moderate mitigation, contemplates a rise of 2.7°C and a very minor drop of 0.83% in GDP. This can be imagined as a relatively stable area where adaptation techniques have mitigated the losses but not eradicated them, and hence the trend persists. In the case of the SSP2.6 scenario, which depicts the strongest climate action and major reforms in adaptation, temperature increase is limited to 2.0°C while the economy remains at the same level with around 0% GDP change. This is the case of losses being virtually neutral, thus indicating that the combination of resilience practices, technology and efficient water management has the potential to outwit climate shocks. The SSP1.9 scenario gives the best picture of the situation, wherein the Paris Agreement targets are achieved, the world experiencing only a 1.5°C rise in temperature and a possibly 40% increase in GDP by 2100, which is primarily attributable to the long-term growth that comes from continuous investments in renewable energy, green infrastructure, and adaptive capacity. The table as a whole conveys that the magnitude and the nature of the economic impacts are extremely reliant on the climate policy willingness: the economies that give priority to mitigation and adaptation not only decrease their vulnerability but also can reach growth outcomes, whereas no action on the part of the high-emission trajectories leads to irreversible economic loss.

Figure 3: Projected GDP Trajectories under SSP Scenarios (2025–2100)

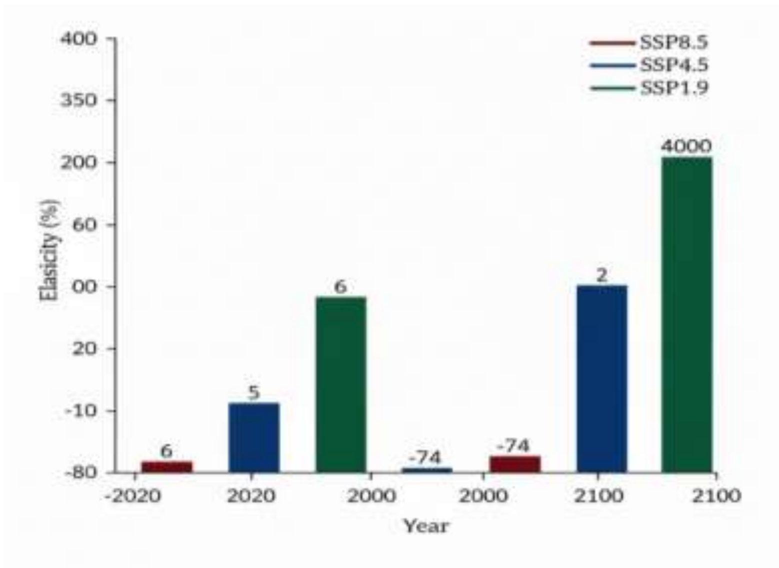


Figure 3 provide strong empirical evidence for the Climate–Economy Vulnerability Nexus proposed in this study's theoretical framework. The climate change processing of Gross Domestic Product (GDP) losses is not solely attributed to the direct effects of changes in temperature and rainfall, but rather the water scarcity and weak institutions, which are characteristic of lower-middle-income countries, also play a significant role. The negative elasticity of GDP to temperature (−5.0031%) indicates that climate change is a macroeconomic constraint that is continuously lowering productivity and investment. The adaptation costs go up, the availability of resources is limited, and the fiscal pressures are increased which are the main areas of water stress amplifying the impact of climate change. Urbanization is one of the factors that magnify the impact of climate by isolating the exposure of the population to heat and energy shocks in the urban areas that consist of many residents. The 84% involvement of urban heat effects points out that climate resilience strategies should mainly focus on urban infrastructure, water management, and energy efficiency to be able to mitigate the systemic risks. When looking at it this way the results are like Burke et al. (2015) and Nordhaus (2019), however, the impacts reported in this study are higher which means that climate shocks are non-linearly amplified in lower-income Asian economies due to the combination of weaker fiscal capacity, limited technology diffusion, and governance constraints.

6. Policy Implications

The findings from the research echo that the lower-middle-income Asian countries are suffering macroeconomic losses more than their proportionate share due to global warming and water scarcity. The 5.0031% drop in GDP growth for every 1°C rise in temperature and the possible 74% cumulative GDP loss under the SSP8.5 scenario by 2100 are very serious signs that call for the implementation of multidimensional climate policy interventions. The economy of these nations is in a bind: on one hand, there is a lack of financial and institutional capacity, and on the other, their environment is becoming increasingly hostile. Let it be known that the most effective policy reactions must be based on four pillars that are so closely linked, i.e., adaptation financing, resilience building, green investment, and institutional strengthening. All these play their part in reducing long-term vulnerability and in the promotion of developed and sustainable economic growth. Financing for adaptation cannot be of any less importance for the developing countries that have been stretched financially to the point that they cannot absorb the rising cost of climate-induced damage. Poor fiscal capacity usually implies that an economy is under a cycle of vulnerability, in which reduced output limits public investment in adaptation measures that in turn increase the exposure to the shocks of the future. To break this cycle, it is necessary for governments and regional institutions to put money first in the form of new financial mechanisms for climate adaptation. One way to ensure this is by the establishment of regional climate resilience funds under platforms such as the Asian Development Bank, which would allow the provision of concessional resources for the development of high-impact infrastructures such as drought management systems, flood barriers, and urban heat adaptation projects. Besides, debt-for-climate swaps could be seen as a very viable tool for switching foreign debt servicing towards domestic climate resilience projects. In addition, green and climate bonds should be used more to bring in private sector funds for sustainable projects, for example, setting up renewable energy plants and installing water-saving irrigation systems. These financial resources not only improve the adaptive capacity but also contribute to fiscal sustainability and the trust of investors in the economic transitions that are aligned with climate change.

The development of systemic resilience is important, on the same level, in the reduction of macroeconomic fragility as seen in the PMG–ARDL analysis. According to the study, the temperature rise along with the water stress has a significant negative impact on the productivity and output of both agricultural and industrial sectors. Therefore, it is better for the government to commit to a resilience agenda that is not only forward-looking but also climate-adaptive integrating economic planning. Outfitting existing irrigation systems with solar and drip technologies will be very effective in terms of enhancing water usage and thus stabilizing agricultural production in the face of changing rainfall patterns. Similarly, investment in disaster-proof and heat-resistant infrastructure will save logistics, transport, and power lines from heat-related disruptions. The manufacturing and service sectors can be insulated from power outages through diversifying the energy supply by going on with renewable energy expansion. At the same time, urban climate management such as providing more green spaces, using reflective materials and introducing smart cooling systems will help lower the urban heat island effect. Indirectly, all such interventions will provide the adaptive strength that is necessary for productivity to be sustained amid increasing climatic stress. The supporting of green investment, on the other hand, acts as both a mitigation strategy and as a means for inclusive economic growth. The SSP1.9 scenario in this research, which predicts a probable 40% GDP growth in the case of high adaptation and low-emission pathways, turns out that sustainable development is an economically favorable option. Hence, it is time for policymakers to put up with climate-smart investments that will yield both environmental and economic returns. Drought-resistant crop varieties and precision farming technologies that not only increase productivity but also conserve resources should be the main ways through which climate-smart agriculture will be expanded. The manufacturing and freight industries must be the ones that are always supported in adopting low-carbon technologies and renewable energy integration for their competitiveness worldwide since the latter will be an increasingly carbon-constrained global economy. Combinations of Public–private partnerships (PPPs) with fiscal incentives such as tax credits for clean innovation and green supply chains can act as one of the facilitators that result in an increase in capital flow towards climate-friendly industries. By encouraging green investments, lower-middle-income nations in Asia will have the chance to switch from a rather passive adaptive type of development to one that is active and sustainable, thus transforming the whole continent with the help of ecological practices.

Strengthening institutions is the foundation for all climate-related political activities. The research showed that countries with weak governments and fiscal institutions have the biggest GDP losses from climate shocks. This signals the necessity for good governance reforms and skills-upgrading along with the technical means of adaptation. The creation of climate governance frameworks that would mandate the cooperation of finance, environment, and planning ministries is what the government should do. Climate should be integrated into national budgets, public investment plans, and development frameworks so that the economic policy's main goal will be climate resilience rather than the environmental goal at the margin. Improving the data systems at both the national and subnational levels to track climate-economy interactions will not only make policy targeting more accurate but also empower local institutions to implement decentralized adaptation measures that will effectively address site-specific problems such as water scarcity or vulnerability of agriculture. The strengthening of institutions does not only lead to more efficiency and better coordination, but it also increases the trust of the country in the eyes of the international community to access climate finance.

In general, these four policy areas will support each other to form a unified policy that focuses on the transformation of vulnerability into resilience. If these pillars are put into practice together, they will be able to raise the economies from the negative feedback loop, where the climatic shocks result in an unproductive cycle with stress on the state funds and reduced capacity for adaptation, to a positive resilience loop, where the investment in adaptation leads to the strengthening of productivity, fiscal stability, and long-term economic growth. This policy integration is in line with the Climate–Economy Vulnerability Nexus presented in the theoretical framework and depicted in Figure 1, which shows that continuous climate action can be a necessity for the environment as well as a big factor in the economic transformation of lower-middle-income Asian countries towards sustainability.

7. Conclusion

The research indicates that the economies of lower-middle-income Asian countries are experiencing tremendous and continuous vulnerability to climate change from macroeconomic point of view. The main reason for such exposure of the economies is their structural nature characterized by rising temperature, water scarcity, and poor institutional capacity. According to empirical data, 1°C rise in temperature weighted by the population leads to GDP growth reduction of 5%, which is comparable to a long-term average of 2.74% slowdown. Such impacts are intensified by the issues of water supply and drainage system failures, and heat in cities which, in turn, make climate vulnerability more complex and harder to understand. The empirical elasticities, when projected under Shared Socioeconomic Pathway (SSP) scenarios, the difference between the futures is amazing: by the year 2100, the high-emission SSP8.5 scenario, which does not impose any control on warming, could lead to a total GDP loss of almost 74%, while the Paris-aligned SSP1.9 scenario could, on the contrary, allow getting a net economic profit of up to 40%, provided that the investments in mitigation and adaptation are of good quality and wide scale. The study makes three key contributions. Theoretically, it extends the Solow growth framework by integrating climate and hydrological variables, developing a "climate-augmented" model that explicitly accounts for water capital, institutional resilience, and environmental feedback. Empirically, it employs the Pooled Mean Group–Autoregressive Distributed Lag (PMG–ARDL) estimator on a long (1971–2024) dataset to isolate long-run elasticities while accommodating short-run heterogeneity across countries, allowing a rigorous quantification of climate-induced macroeconomic losses. From a standpoint of policy, it reveals that adaptation financing, investments in resilience, green industrial transformation, and building-up institutional capacity are not optional but are the main measures to prevent welfare losses that cannot be reversed. More importantly, the results indicate that vulnerability is endogenous: climatic economic losses diminish the government's fiscal capacity and the effectiveness of institutions to such an extent that they go into a self-reinforcing cycle that prevents further adaptation. This cycle can only be broken through the coordination of domestic reforms, international climate finance, and technology transfer support. Nevertheless, the study admits that it has some limitations. The selection of three representative lower-middle-income Asian economies to focus on increases the internal validity of the study but at the same time limits the generalization of the finding to the whole region. Furthermore, projections are made based on the assumption that long-run elasticities will remain constant even in extreme warming scenarios where non-linear or threshold effects may exist. Future studies that utilize micro-level data like firm productivity, household adaptation methods, and sectoral energy transitions may reveal more clearly the distributional impacts and the welfare outcomes. The evidence presented is unambiguous and powerful; without drastic mitigation and adaptation, the economies of lower-middle-income Asian countries are literally doomed to suffer from the economic decline which will be compounding. In contrast, the same disadvantaged countries or regions will, through their active participation in climate governance, adjusting the right way, and continuing the necessary institutional changes, change their destiny. This very challenge could lead to the development of an opportunity for sustainability and inclusiveness. Therefore, it should be the main principle for the regional development plans and the prioritization of international climate finance for the next decades.

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