https://doi.org/10.52131/joe.2023.0504.0171

*i*RASD Journal of Economics

Volume 5, Number 4, 2023, Pages 929 – 943

Journal Home Page:
https://journals.internationalrasd.org/index.php/joe

Impacts of Climate Change on Economic Growth: Empirical Evidence from the Asian Region

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ARTICLE INFO

Article History:
Received: September 22, 2023
Revised: December 12, 2023
Accepted: December 13, 2023
Available Online: December 14, 2023

Keywords:
Economic Growth
Climate Change
Deceleration
Urbanization
High Climate Risk
High Water Stress

JEL Classification Codes:
O40, O44, C33, Q51, O51, Q54

Funding:
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

This Panel data study analyzed the long-run effects of anthropogenic climate change on economic growth in Asia during the period 1971-2021 using PMG-ARDL approach. The Panel consisted of thirty one countries from the whole Asian region. The empirical results of the study highlight four key findings. First, the rising temperature impacts economic growth negatively at national level and positively in urban agglomerations, where the latter impact is smaller. Second, the overall net effect of rising temperature on economic growth is negative. Third, the impact of rising rainfall in urban agglomerations is found to be negative on economic growth. Fourth, in long run, the effect of temperature on economic growth, in absolute terms, remained to be the highest among other key factors in the model including exports, gross capital formation, government expenditures and private consumption. These findings highlight the crucial role of climate change in sustainable economic growth and explain substantially the higher negative effects of future climate change in selected Asian countries. The study concludes that efforts are required both at national and regional levels to limit the temperature levels through mitigation and adaptation measures as agreed upon by United Nations' member countries under Paris Agreement 2017 in order to achieve sustainable economic growth.

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Citation: Ahmed Gulzar, & Aziz, B. (2023). Impacts of Climate Change on Economic Growth: Empirical Evidence from the Asian Region. *IRASD Journal of Economics*, *5*(4), 929 – 943. https://doi.org/10.52131/joe.2023.0504.0171

1. Introduction

During past half century, the significant anthropogenic changes in Asia are causing extreme weather conditions; more frequent and severe in the form of heat waves, cold snaps, floods, droughts and natural disasters, resulting into significant loss of GDP, increasing death toll, huge damages of infrastructure and physical capital on yearly basis. The region of Asia is at second after Africa in terms of potential climate risk (Masson-Delmotte et al., 2022). According to Raitzer et al. (2015), Southeast Asia is the most vulnerable region to changes in climate across the World. The unimpeded climate change could eliminate 11 percent of total GDP base of the region by ending this century while hitting mainly three key contributing sectors including agriculture, fishing and tourism. These catastrophes led to an inter-disciplinary debate and development of various climate-economy models based on the Circulation Models of Climate Change (CMCC) to estimate the impacts of changes in climate on economic growth in long run. These Circulation Models entail the whole cycle of climate change i.e. starting from the emissions of GHGs to increase in average temperature, thereby resulting into increasing weather severity and affecting labour productivity in a more scientific way. These Circulation Models of Climate Change establishes long run relationship between economic growth and factors of climate change which generally include mean surface temperature and mean surface precipitation. Under climate-economy domain, the connection between economic output and temperature & precipitation has been analyzed using two distinct approaches. The first approach, stressed in the growth literature, has analyzed the connection between output (level and growth) and average temperature and precipitation in cross-sections of economies. The other approach depends on the micro level data to analyze the related climate variables and then added up these to provide overall effect on output. This method is adopted in Integrated Assessment Models (IAMs) to provide the basis of climate and environmental policies regarding the emission of $CO2$ and other greenhouse gases (Auffhammer, 2018; Gallup, Sachs, & Mellinger, 1999). We used relatively novel approach to comprehend the nature and quantum of future challenges of climate change in achieving climate resilient sustainable economic growth. In this study, we used an alternative approach, i.e. PMG-ARDL approach to examine long run linkages between climate change and output growth.

The recent climate-economy literature highlights that temperature and precipitation i.e. indicators of climate change significantly impacts long run output growth. Further, these impacts are positive in some areas and negative in others. The effect of rising temperature on output growth was observed to be good for cold regions and found to be worst in hot countries. Likewise, the negative impacts of increase in temperature was found to be elevated in poor countries and lower in rich countries through the means of labour efficiency and decisions pertaining to new investments in long run (Brown, Li, Jiang, & Su, 2016; Burke, Hsiang, & Miguel, 2015; Gallup et al., 1999; Moore & Diaz, 2015; Moyer, Woolley, Matteson, Glotter, & Weisbach, 2014; Newell, Prest, & Sexton, 2021; Nordhaus, 2017; Rosen, 2019). Asian region encompasses almost all types of countries including hot, cold, dry, water-stressed, climate risk, rich, poor and densely populated. Keeping this fact in view, there is need to re-investigate the effect of climate change on output growth at regional level encompassing all featuring countries to estimate the combined impacts of climate change and key economic factors on real economic growth with reference to an open economy model to assess the sustainability of the growth at regional level. The rationale of estimating the effects of climate change on output growth under presence of other key economic variables is that from last more than twenty five years, the many developed and developing countries of Asia (like Japan, Korea, Singapore etc.) are restructuring their economies from shifting of carbon technology to greener one and promoting urban agglomeration to achieve climate resilient sustainable growth.

This study investigated long run average impacts of climate change (i.e. increase in temperature and precipitation) on real economic growth in the Panel of thirty one Asian countries- hot, cold, water-stressed, climate risk, rich, poor and densely populated- to evaluate either the overall impacts of climate change on output growth is positive or negative at regional level with reference to an open economy model. Further this study investigated long run impacts of climate change in urban agglomerations within these regions to evaluate the adaptation policy of promoting urban agglomerations. The findings of this study would help in developing a framework for optimal mitigation & adaptation strategies to achieve climate resilient growth at regional level in future.

The study is structured as goes: Section 2 encompasses literature review. Section 3 entails theoretical framework. Section 4 elucidates the data and empirical methodology. Section 5 describes the results of empirical analysis and their implications. Section 6 consists of conclusion, key findings of the study and available policy options of adaptation strategic framework.

2. Literature Review

Since the end of 20th century, an inter-disciplinary debate on the connection between climate change and its macroeconomic impacts was started among academicians and policy topnotchers across the globe, which later led to the development of climate-economy models to develop a structural association between climate change and economic variables for the estimation of climate change impacts on output at level and growth. The key indicator of climate change as taken in almost all relevant literature is the temperature or population weighted temperature (at national / local / urban levels) taken in various forms- mean surface temperature, mean ocean surface temperature, max temperature, min temperature, hot days max / min temperature, cold days max/min temperature- to measure climate change in long run and its 'impacts on climate change. The precipitation is also taken an indicator of climate change in short, medium and long run, which explains the changes in weather behavior and frequency and quantum of rain fall causing river and urban floods. The General Circulation Models of Climate Change explain that increasing consumption of fossil fuels to meet the energy demand of an economy leads to emission of GHGs much higher than sustainable level. Since GHGs remain in the air and more quantum of GHGs absorb more heat and causing increasing in precipitation in short, medium and long run and increase in temperature in long run. The nexuses between Scientific General Circulation Models of Climate Change and Economy are called Climate-Economy Models. Climate Economy Models explain that increasing in temperature and precipitations have different but significant macroeconomic impacts (Brown et al., 2016; CHANGE, 2007; Gallup et al., 1999). The recent literature highlights that persistent increase in temperature has negative impacts both on level and growth rates of sectoral and aggregated outputs Burke et al. (2015); Dumrul and Kilicaslan (2017); Moyer et al. (2014); Newell et al. (2021); Rosen (2019) through the means of labour productivity and decisions pertaining to new investments in long run (Moore & Diaz, 2015).

The empirical literature is divided on whether climate variables have an effect on the level or growth of GDP. Growth effects have compounding tendency which is not found in level effects. The choice of using growth or level of economic outcomes as dependent variable drastically changes the forecasts of future damages from climate change. Temperature effects on growth rate of GDP explain somehow the impacts on future levels of GDP Dell, Jones, and Olken (2012); Deryugina and Hsiang (2014); Kahn et al. (2021). Ditta, Bashir, Hussain, and Hashmi (2023) investigated the role of climate change on the food security in case of South Asian countries during using ARDL approach. The study uses temperature for climate change. Furthermore, the study finds that relationship between climate change and food security is positive.

Early literature on growth and climate change connection used regression analysis in cross-sections exhibiting the issue of omitted variable bias (Nordhaus & Boyer, 2000; Sachs & Warner, 1997). These cross-sectional regression analyses though provide short run analysis but omit the impacts of political and economic institutions on output growth. To overcome the issue of omitted variable bias, recent literature went for panel regression options (with fixed effect) to analyze the connection between temperature shock, labour productivity and output growth based on panel data (Dell et al., 2012; Kolstad & Moore, 2020). Fixed effect panel models remove the bias arising from omitted variable by controlling for time-invariant group heterogeneity which is unobservable. These are being used to study the connection between climate variables (temperature and precipitation) and economic growth, energy demands, labour productivity, human capital and crop yields (Burke & Tanutama, 2019; Dell, Jones, & Olken, 2009; Deschenes, 2014; Wenz, Levermann, & Auffhammer, 2017). However, the fixed effect panel regression may not account for short term effects of sever oscillations in weather. In recent years, new 'hybrid' approaches have been used to exploit different means of variation in panel data for estimating climate damages while handling the issue of omitted variable bias (Auffhammer, 2018; Auffhammer, Hsiang, Schlenker, & Sobel, 2013; Kolstad & Moore, 2020). In this regard, Burke and Emerick (2016) used long difference method to analyze the adaptability to climate change.

The recent literature used PMG-ARDL approach to estimate long run impacts of climate change on output at aggregated and sectoral levels (Kahn et al., 2021). Dell et al. (2012) estimated the impacts of rising temperature and precipitation as indicators of climate change on output growth across the world with special focus on poor countries. They took temperature and precipitation as an indicator of climate change and per capital income as an indicator of economic output. They used only climate change variables to estimate their impacts of economic growth exclusively. They concluded that higher temperature hit the economic growth in poor countries substantially. They highlighted that higher temperature also reduced economic growth and not just the economic output al level. They showed that increase in temperature had positive impacts on output growth in cold countries while, it had negative impacts on output growth in hot countries.

Alagidede, Adu, and Frimpong (2016) analyzed long run impacts of climate change on the economic growth of Sub-Saharan African countries using PMG-ARDL methodology for the period 1970-2009. They used temperature and precipitation as indicator for climate change along with economic variables including openness to trade, financial development and foreign inflows. They concluded that the increase in temperature level from beyond 24.9 °C significantly reduced output growth.

Kahn et al. (2021) estimated long run impacts of climate change on output for a panel of 174 countries over the period 1960-2014 using stochastic growth model. They discussed that climate change affected output through the channel of labour productivity. With the increase in temperature, weather becomes hot and, therefore, labours productivity as well as working hour's decreases. Hence, increase in temperature through negative impacts on labour productivity decreases output or output growth. They highlighted that 0.04°C increase in temperature caused decrease in per capita output by more than seven percent in next eighty years.

The structural connection between climate change and economic variables is still an unresolved question. The impacts of climate change on economic outcomes is directly dependent on the assumed structural connection between the foresaid. Dell et al. (2012) found that temperature shocks affect economic outcome linearly. Burke et al. (2015) found a quadratic connection between climate change variables and economic growth. By using quadratic relationship between the foresaid, he found that there is direct relationship between temperature and economic growth in cold regions and indirect connection in hot regions. They further, found an optimal level of mean temperature at 13^{o} C where, GDP growth is maximized.

Further, there are several methodologies in the literature to calculate mean temperature which is used as the control variable in the climate change-macroeconomic models. Annual mean surface air temperature of a country is normally calculated as an average of local monthly temperatures. However, this methodology is more relevant in a meteorological perspective. Since the population density is different in different regions of a country or countries, it is therefore, more relevant to calculate population weighted annual mean temperature and cropping area weighted annual mean temperature to depict the true impacts of climate change on labour productivity and economic growth (Dell, Jones, & Olken, 2014; Taylor, 1981).

Based on the review of literature, we found that there is still gap for investigating the impacts of climate change on economic growth to find out not only the economic impacts of climate change but also the responsiveness of economic growth to climate change, as if, there is elastic relationship between climate change and economic growth, then a small change in average temperature or precipitation would result into a much bigger damage to economic output and infrastructure. The studies discussed above general estimated the one-on-one relationship between temperature and economic output did not entail the impacts of other key economic variables on economic output along with climate change variables. Further, their findings did not clearly explain about the overall effects of climate change on economic output at regional level i.e. either the region as a whole would be in benefit or loss. Further, if the whole region suffers from the atrocities of climate change, then the idea of internal and international migration would only add up to more difficulties. There is still gap in the literature in taking population weighted mean surface temperature, urban agglomeration population weighted mean surface temperature and urban population weighted mean rainfall (as indicator of rainfall) as indicators of climate change to capture the anthropogenic climate change based on the country-wise quantum of the human economic activity at national level and in urban agglomerations in the particular region. Further, most of the studies discussed estimated the impacts of climate change on economic output with reference to closed economy context. However, there is a need to re-estimate the impacts of climate change on real economic growth with reference to an open economy context to take into account the dynamics of international trade and relations while estimating the economic impacts of climate change. To study on all these aspects is needed to develop a comprehensive mitigation and adaptation framework at regional level to cope with the future economic challenges of climate change. This study encompasses all these aspects / domains as highlighted and contributed to the existing literature.

3. Theoretical Framework

The recent literature highlights that temperature and rainfall (as an indicator of precipitation) have widely been used as climate change variables. (Abdouli & Hammami, 2017; Alagidede et al., 2016; Cai, Lu, & Wang, 2018; Dell et al., 2014; Kahn et al., 2021; Somanathan, Somanathan, Sudarshan, & Tewari, 2021). Based on the review of literature, we assume that change in temperature and precipitation affect the economic growth over the period through labour productivity and investment decisions (Dell et al., 2012; Kahn et al., 2021). We assume that historical norm values of mean surface temperature and precipitation in year 1971 are technological and climatic neutral and hence have no impacts on economic growth. According to Keynesian Model, exports, investment and consumption are the key factors, which affect positively on economic growth. In this study, to examine the impacts of climate change on output growth, we extended the model of Dell et al. (2012) already embedded on Solow's growth model by incorporating new dimensions and other key independent variables from the domain of climate- economy which impacts economic growth in addition to temperature and precipitation. Under new dimensions, we took population weighted mean surface temperature in place of surface mean temperature as used by Dell et al. (2012). Dell et al. (2012) used the following basic model;

$$Y_{it} = e^{\alpha(T_{it})} AL_{it} \tag{1}$$

$$\frac{\Delta A_{it}}{A_{it}} = g_{it} + \beta(T_{it}) \tag{2}$$

Where $\mathrm{Y_{it}}$ is the GDP of country i at time t; A represents labour productivity; T measures climate change; g measures economic growth rate. Equation (1) explains the level effect of climate change on output while equation (2) explains the growth effect. We extended the Dell et al. (2012) by introducing precipitation as an indicator of climate change along with temperature and other key economic variables which affect economic growth. These economic variables include export of goods and services, Investment (i.e. value addition in gross capital formation), government expenditures and private consumption. Further, Dell et al. (2012) used mean surface temperature in Celsius Degree. However, to incorporate the impacts of quantum of economic activity with respect to regional average, we used population weighted mean surface temperature. The extended form of equation 1 is as follows;

$$Y_{it} = e^{\alpha(T_{it} + UT_{it} + UP_{it})} A_{it} L_{it} I_{it} EGS_{it} G_{it} PC_{it} \tag{3}$$

Where;

Y_{it} stands for GDP; $e^{\alpha(T_{it}+UT_{it}+P_{it})}$ stands for climate change term; T_{it} stands for population weighted mean surface temperature, which indicates climate change; UT_{it} stands for urban agglomeration population weighted mean surface temperature, which indicates of climate change; UP_{it} stands for urban agglomeration population weighted mean precipitation (rainfall), which is an indicator of climate change; A_{it} stands for State of technology in country i at time t;I_{it} stands for Value addition in gross fixed capital formation in country i at time t; EGS_{it} stands for exports of goods and services in country i at time t;G_{it} stands for government expenditures in country i at time t; PC_{it} stands for private consumption in country i at time t. A_{it} Stands for technology; L_{it} stands for labour. Taking log in both sides of equation 4 and differencing with respect to time, we have the following growth equation;

$$GGDPU_{it} = a_0 + a_1PWMT_{it} + a_2PUAWR_{it} + a_3PUAWMT_{it} + a_4GEGS_{it} + a_5GHCC_{it} + a_6GGG_{it} + a_7GGCF_{it} + \varepsilon_i \quad (4)$$

Where $i = 1,2,\dots,N$ shows groups number; $t = 1,2,\dots\dots,T$ shows number of periods; $GGDPU$ represents the GDP growth rate which indicates of economic growth; PWMT is the population weighted surface mean temperature: $PUAWR$ presents population weighted mean rainfall in urban agglomeration; $PUAWMT$ presents population weighted mean surface temperature in urban agglomeration; $GEGS$ represents exports growth rate; $GHCC$ represents the growth rate of household consumption expenditures; GGG represents government expenditures' growth rate; $GGFC$ represents gross capital formation's growth rate.

Where, as per existing literature; $a_1 \lesseqgtr 0$ depending upon the region. Dell et al. (2012) empirically found that rise in temperature reduces economic growth in hot regions and stimulates output growth in cold countries; a_2 < 0 indicating that more rainfall causes urban flooding and hence damages economic infrastructure, thereby, reduces economic growth till the time of recovery; a_3 > 0 indicating that increase in temperature affects economic growth positively in urban agglomeration as urban agglomerations are environmentally sustainable planned urban areas, where the economic activity does not damage the ecology. The urban agglomerations are also known as the smart cities; a_4 > 0 indicates that according to the Keynesian expenditure equation, increase in growth in exports increase increases the growth rate of an economy. In the exiting economic literature, those economies, where the major portion of economic growth is coming from exports are called export-led growth; a_5 > 0 indicates that increase in government expenditure contributes to economic growth positively; a_6 > 0 indicates that increase in the growth of private consumption leads to an increase in economic growth; a_7 > 0 indicates increase in growth of value addition to gross capital formation (i.e. new investments) leads to an increase in economic growth. All the coefficients in equation 4 are basically the elasticities. These elasticities provide two important results, which includes (i) the quantum of impacts and (ii) responsiveness. The rationale of using population-weighted mean surface temperature was to smoothen the fluctuations in the series of surface mean temperature over the given period and to capture the anthropogenic change in temperature based on the country-wise quantum of the human economic activity in the particular region. The population weighted surface mean temperature for each sample country has been calculated using the following formula;

$$T_{it}^{p} = \frac{1}{\sum_{n=1}^{N} P_{i,t}} \sum_{n=1}^{N} T_{i,t}P_{i,t} \quad (5)$$

Where $\mathrm{T_{it}^{p}}$ = Population weighted surface mean temperature of country iat time ;
$\mathrm{P_{i,t}}$ = Population of country i at year t; $\mathrm{T_{ti}}$ = Annual increase in land temperature for country i at year t

The rationale of introducing the impacts of population weighted mean surface temperature and rainfall in urban agglomeration on economic growth was to assess either that the impacts of climate change is similar across different regions within a country subject to quantum of economic activity. Our Null (H_0) and Alternative Hypotheses (H_A) is as under:

H_{01} : *There is no long run relationship between economic growth and population weighted surface mean temperature in a panel of selected thirty one Asian countries.*

H_A : *There is long run relationship between economic growth and population weighted surface mean temperature in a panel of selected thirty one Asian countries.*

4. Data and Empirical Methodology

This panel data study is based on secondary data of thirty one countries of Asian region. These countries with their climatic characteristics include Myanmar (hot / dry), Philippines (tropical /maritime) , Bangladesh (warm / humid), Pakistan (temperate- hot and cold based on topography), Thailand (warm) , Nepal (warm), Vietnam (tropical & temperate) , Cambodia (warm) , Afghanistan (extreme weather), India (tropical / hot), Oman (hot /dry), Russian Federation (continental temperature – warm / hot summer & very cold winter with temperature less than – 30°C), China (hot / cold), Mongolia (continental climate), Japan (hot humid / cold), Indonesia, Yemen, Republic., Korea Republic, Iran, Islamic Republic., Saudi Arabia, Malaysia, Turkey, Lebanon, Israel, Jordan, Kazakhstan, Azerbaijan, Armenia, Kuwait, Uzbekistan, and Singapore.

Table 1
Details of the Variables Used in this Study

Name of Variable	Abbreviation used in this study	Unit of Measure	Frequency	Sources of Data
Dependent Variable				
Growth rate of GDP	GGDPU	percentage	Annual	Data in US $ (Constant 2015) was taken from UN Stat. Growth rates were calculated by the authors
Independent Variables				
Population weighted Mean Temperature	PWMT	degree Celsius (°C)	Annual	Data of population (in millions) was taken from Online WDI data base: data on surface mean temperature was taken from Climate Change Portal
Population weighted Mean Temperature in Urban Agglomeration	PUAWMT	degree Celsius (°C)	Annual	Data of population (in millions) in urban agglomeration was taken from Online WDI data base: data on surface mean temperature was taken from Climate Change Portal
Population weighted rainfall in Urban Agglomeration	PUAWR	Milli meter (mm)	Annual	Data of population (in millions) in urban agglomeration was taken from Online WDI data base: data on rainfall was taken from Climate Change Portal
Growth rate of Exports of Goods and Services	GEGS	Percentage	Annual	UN Stat.
Growth rate of Gross Capital Formation.	GGCF	Percentage	Annual	UN Stat.
Growth rate of General Government Consumption.	GGG	Percentage	Annual	UN Stat
Growth rate of Household Consumption Expenditure	GHCC	Percentage	Annual	UN Stat.

According to World Bank's income categorization of countries, thirteen countries from them fall under the category of lower middle income countries, nine fall under the category of upper middle, two falls under the category of low income, seven falls under the category of high income category. Further, as per the three categories of climate risk on the basis of scores awarded to countries around the globe in Global Climate Risk Index 2020 published by German Watch, fifteen countries from them fall under the category of high climate Risk, twenty eight countries fall under the category of medium climate risk and three countries fall under the category of low climate risk. The selection of countries was made on the basis of availability of data from authentic source from the whole Asian region. The data sources include World Bank's World Development Indicators (WDI), Online UN data portal (UN Stat) of United Nations Organization and online Climate Knowledge Portal of World Bank over the period i.e. from 1971 to 2021. To eliminate the impacts of all types of inflation and currency devaluation / evaluation in an open economy concept, the data on economic variables were taken in US $ 2015 to calculate growth rates. The details of the variables including unit of measure, frequency and sources of data used in this study are listed in Table 1.

The data of country-wise mean surface temperature used in this study was the annual aggregation of monthly holdings of actual observations in Celsius degree gathered by Climate Research Unit (CRU), University of East Angelia over the period of analysis and taken The World Bank (2023) from World Bank's Climate Change Portal.

In this study, Pooled Mean Group (PMG-ARDL) approach was used to allow for mixed order of integration, cross-sectional heterogeneity and homogeneity of coefficients in long run (Blackburne III & Frank, 2007). Thus PMG-ARDL was used to determine the impacts of climate change variables on economic growth. This balanced panel data study used panel unit root tests including Levin, Lin, and Chu (2002) and (Im, Pesaran, & Shin, 2003). Levin et al. (2002) test assumes that all panels have common autoregressive parameter. In this test, additional lags of the dependent variables are taken to handle the likely issue of serial correlation. Levin et al. (2002) test is estimated through the following equation;

$$\Delta y_{it} = \varphi y_{i,t-1} + \vartheta_{it}^{`}\gamma_i + \sum_{j=1}^{P}\theta_{ij}\Delta_{y_i,t-j} + u_{it} \quad (6)$$

Here, y_{it} shows the data series of the variable for country i at t time period. p explains the maximum number of lags such that $u_{it}$is white noise. Under the Null hypothesis, the variable is non-stationary. (Im et al., 2003) test is the set of Dickey-Fuller regressions of the following form;

$$\Delta y_{it} = \varphi_i y_{i,t-1} + \vartheta_{it}^{`}\gamma_i + \epsilon_{it} \quad (7)$$

Under IPS test φ is panel-specific, indexed by i, whereas under LLC, φ is constant. IPS assumes that ϵ_{it} has independently normal distribution for all i / t and heterogeneous variances across panels. To determine panel co-integration, this study used Pedroni (2000a, 2019b) criteria by using the following specifications:

$$y_{i,t} = \beta_i + \gamma_{1i}x_{i,t} + \gamma_{2i}x_{2i,t} + \ldots\ldots + \gamma_{mi}x_{mi,t} + \varepsilon_{i,t} \quad (8)$$
$$\Delta y_{i,t} = \sum_{m=1}^{m}\gamma_{mi}\Delta x_{mi,t} + \eta_{i,t}$$
$$e_{i,t} = \delta_i e_{i,t-1} + \mu_{i,t}$$
$$e_{i,t} = \delta_i e_{i,t-1} + \sum_{m=1}^{k}\delta_{i,k}\Delta e_{i,t-k} + \mu_{i,t}^{*} \quad (9)$$

Where $i = 1,2, \ldots \ldots, N$ explains the individual panel and $t = 1,2, \ldots., T$ shows the number of time periods, $m = 1,2, \ldots \ldots, M$ explain number f regressors and $k = 1,2, \ldots \ldots, K$ shows number of lags in the ADF regression. For empirical analysis we used the following specification of ARDL dynamic panel;

$$y_{it} = \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij} Z_{i,t-j} + \mu_i + \epsilon_{it} \quad (10)$$

Where $i = 1,2,\dots,N$ shows groups number; $t = 1,2,\dots\dots,T$ shows number of periods; $Z_{i,t}$ shows $k \times 1$ vector of explanatory. variables; δ_{it} are the $k \times 1$ coefficient. vectors; λ_{ij} are scalars; μ_i is the group specific effect. The T must be large enough to cater the model fitting for each group separately. If variables in above equation are $I(1)$ and co-integrated, then the error term exhibits $I(0)$ process for all i. The responsiveness of co-integrated variables to any deviation from long run equilibrium is their principal feature, which implies an error correction model. Thus, to re-parameterize the above equation into error- correction model is as follows;

$$\Delta y_{it.} = \emptyset_i (y_{i.,t-1.} - \theta'_i Z_{it}) + \sum_{j=1.}^{p-1.} \lambda^*_{ij} \Delta y_{i,t-j} + \sum_{j=0.}^{q-1.} \delta'^*_{ij} \Delta Z_{i,t-j.} + \mu_{i.} + \epsilon_{it} \quad (11)$$

$Where\ \emptyset_i = -(1 - \sum_{j=1}^{p} \lambda_{ij}) = explaining\ speed\ of\ adjustment$, $\theta_i = \frac{\sum_{j=0}^{q} \delta_{ij}}{(1-\sum_k \lambda_{ik})}$, $\lambda^*_{ij.} = -\sum_{m=j+1.}^{p} \lambda_{im.}$, $j = 1,2,\dots\dots,p-1, and\ \delta^*_{ij.} = -\sum_{m=j+1}^{q} \delta_{im}$, $j = 1,2,\dots\dots,q-1.$

Where λ_{ik} represents long run parameters of panel k; $\emptyset_{ik}$ are the error- correction terms. for measuring the speed of adjustment. to long run equilibrium.

5. Results and Discussion

Panel Unit. root tests. Including Westerlund (2006) and Harris, Harvey, Leybourne, and Sakkas (2010) were applied to check the stationarity of the variables. The results of Westerlund (2006) and Harris et al. (2010) are shown in tables 2 & 3 below. These results highlight that the selected variables have shown mixed order of integration. Under this scenario, ARDL approach is best suited to find out both the short run and long run relationships among variables.

Table 2
Results of Panel Unit Root LLC (2002) Test

Variables	Level.		First Difference.	
	Intercept	Intercept & Trend	Intercept	Intercept & Trend
GGDPU	-6.6418 (0.0000)***	-6.2446 (0.0000)***	-27.4635 (0.0000)***	-25.6423 (0.0000)***
PWMT	8.0744 (1.0000)	-3.9833 (0.0000)***	-12.9292 (0.0000)***	-12.1511 (0.0000)***
PUAWR	-1.1426 (0.1266)	-1.12864 (0.1061)	-16.2291 (0.0000)***	-14.3665 (0.0000)***
PUAWMT	7.8757 (1.0000)	-3.4718 (0.9230)	-13.0405 (0.0000)***	-12.4434 (0.0000)***
GEGS	-10.8932 (0.0000)***	-11.1074 (0.0003)***	-35.2348 (0.0000)***	-32.8119 (0.0000)***
GHCC	-4.6016 (0.0000)***	-3.3848 (0.0004)***	-27.8261 (0.0000)***	-25.7762 (0.0000)***
GGG	-10.1500 (0.0000)***	-9.1414 (0.0000)***	-35.1719 (0.0000)***	-32.6447 (0.0000)***
GGCF	-13.7831 (0.0000)***	-12.7965 (0.0000)***	-34.3784 (0.0000)***	-31.8639 (0.0000)***

Note: * Sign shows significance level at 10% , ** at 5%. *** at 1 %.

The next step is to check the existence of co-integration between economic and climate change variables by using Pedroni (2001, 2004, 2019) seven test statistics that test the Null hypothesis of no co-integration in non-stationary panels. The results as shown in table 4 below. These resutls explain that in all specifications, the co-integration exist between economic and climate variables at 1% significance level.

Table 3
Results of Panel Unit Root IPS (2003) Test

Variables	Level.		First Difference.	
	Intercept.	Intercept & Trend.	Intercept.	Intercept & Trend.
GGDPU	-11.4100 (0.0000)***	-12.6893 (0.0000)***	-26.6550 (0.0000)***	-26.9214 (0.0000)***
PWMT	17.6636 (1.0000)	-6.4037 (0.0000)***	-21.3974 (0.0000)***	-22.4495 (0.0000)***
PUAWR	-3.1936 (0.0003)***	-7.6606 (0.1061)	-25.2086 (0.0000)***	-25.4843 (0.0000)***
PUAWMT	17.2635 (1.0000)	-6.1394 (0.9230)	-21.5473 (0.0000)***	-22.5335 (0.0000)***
GEGS	-18.6697 (0.0000)***	-19.9299 (0.0003)***	-29.8169 (0.0000)***	-29.9147 (0.0000)***
GHCC	-14.0987 (0.0000)***	-15.3118 (0.0004)***	-28.3855 (0.0000)***	-28.5972 (0.0000)***
GGG	-19.0989 (0.0000)***	-19.9439 (0.0000)***	-30.0019 (0.0000)***	-30.1298 (0.0000)***
GGCF	-20.1622 (0.0000)***	-20.5375 (0.0000)***	-29.4124 (0.0000)***	-29.4996 (0.0000)***

Note: * Sign shows significance level at 10% , ** at 5%. *** at 1 %.

Table 4
Results for Panel Co-integration Test

Common Co-integration Tests.		
	Statistics Value.	**Probability Value.**
V	1.962	0.0000***
Rho	-7.471	0.0000***
T	-18.38	0.0000***
Adf	-13.56	0.0000***
Group Co-integration Tests		
	Statistics Value	**Probability Value**
Rho	-6.161	0.0000***
T	-19.56	0.0000***
Adf	-12.35	0.0000***

Note: * Sign shows significance level at 10% , ** at 5%. *** at 1 %.

Long run and short run results of PMG-ARDL are shown in the tables 5 & 6 accordingly. The results show that all three variables of climate change affect economic growth significantly and the combined impacts of climate change on economic growth, in absolute term, is much higher than combined impacts of economic variables. The results highlight that 1 °C increase in population weighted mean temperature caused decrease in economic growth rate by 7.41% and 1 °C increase in population weighted mean temperature in urban agglomeration caused increase in economic growth by 5.908% in long run. We found that 1 mm increase in rainfall in urban agglomeration caused decrease in economic growth by 0.005%. The net impacts of one unit change in climate caused decrease in economic growth by 1.51% in long run. However, the impacts of climate change on economic growth remained insignificant in the short run. Our results are in consistent with the exiting literature Kahn et al. (2021); Masson-Delmotte et al. (2022) that climate change is a long run phenomenon and it impacts economic growth in long run.

From economic domain, we found that 1% increase in growth of exports of goods and services caused increase in economic growth by 0.085 %; 1 % increase in growth of gross household /private consumption caused increase in economic growth by 0.505%: 1% increase in government expenditures caused increase in economic growth by 0.083% and 1% increase in growth of gross capital formation caused increase in economic growth by 0.112%. The combined impacts of selected economic variables on economic growth remained 0.79% in long run. The results show that all selected economic variables had significant and positive impacts on economic growth both in the short run and long run.

Moreover, the results highlight that that the combined impacts of both climate change and economic variables on economic growth remained – 0.72%. This empirical finding highlights that although the region registered on average, impressive economic growth over the period of analysis. However, the climate resilient sustained growth remained in negative terms. Our results are in consistent with the finding of Masson-Delmotte et al. (2022) that to achieve the economic growth, the region's energy demand was largely met through burning fossil fuels, which caused increase in emissions of greenhouse gases (GHG) much higher than the sustainable level. This led to increase in mean temperature, which on one side, caused decrease in labours productivity and productivity of agricultural products and products directly dependent on environment conditions. On other side, it became responsible for increase in variability in weather conditions; uncalled for raining, floods (both river & urban flooding) and droughts which damaged economic infrastructure and hence made reductions in existing and potential economic growth. Another insight from the results elucidate that in the wake of consistent increase in population weighted surface mean temperature, more resources will be required every year just to keep up the current level of physical capital stock and economic development leading to increase the financing gap to cope with the atrocities of climate change eroding indigenous resources on one side and meeting the challenge of poverty and unemployment on the other side- converting into food security threat in high climate risk & water stressed lower middle income countries.

Table 5
PMG-ARDL Results for Long Run Impacts on Economic Growth

Variables	Coefficient	Standard Error	z-Statistics	Probability Value
PWMT	-7.41	3.612	-2.05	0.040**
PUAWR	-0.005	0.003	-1.69	0.091*
PUAWMT	5.908	3.22	1.83	0.067*
GEGS	0.085	0.007	11.12	0.000***
GHCC	0.505	0.021	24.50	0.000***
GGG	0.083	0.013	6.46	0.000***
GGCF	0.112	0.008	13.41	0.000***

Note: * Sign shows significance level at 10% , ** at 5%. *** at 1 %.

Table 6
PMG-ARDL Results for Short Run Impacts on Economic Growth

Variables	Coefficient	Standard Error	z-Statistics	Probability Value
ECM (t-1)	-0.559	0.048	-11.61	0.000
D(PWMT)	17.525	98.918	0.18	0.859
D(PUAWR)	0.125	0.114	1.10	0.271
D(PUAWMT)	-14.902	92.161	-0.16	0.872
D(GEGS)	0.045	0.012	3.80	0.000
D(GHCC)	0.102	0.027	3.69	0.000
D(GGG)	0.085	0.025	3.36	0.001
D(GGCF)	0.025	0.009	2.61	0.009

Note: * Sign shows significance level at 10% , ** at 5%. *** at 1 %.

The socio-economic implications of climate change in the Asian region on the basis of empirical results of this study are very alarming. First, the elastic relationship between climate change and economic growth at regional level implies that without implementing mitigation and adaptation policies, the increase in average population weighted mean surface temperature would decrease economic output at an increasing rate on yearly basis- resulting into ever increasing poverty and unemployment. Second, the overall wealth of the region would decline, thereby, resulting into a continuous decline in average buying capacity at regional level- squeezing both production and international trade volume. Third, the climate risk, water stressed and lower middle income countries (like Pakistan, India etc.) would be the biggest loser in terms of economic development and socio-economic parity in the region. Fourth, the issues of poverty, unemployment, food security and income-inequality would be more wide spread, perplexed and perpetual. Finally, the socio-economic unrest in the wake of climate change in long run could start internal and cross-border skirmishes and wars on limited resources.

6. Conclusion

This Panel data study analyzed long run effects of climate change on economic growth in Asia for the period of 1971-2021 using PMG-ARDL approach. Long run results of PMG-ARDL explain that all three variables of climate change used in this study impacted economic growth significantly and the combined effect of climate change on output growth, in absolute term, remained much higher than combined impacts of economic factors. We found that the rising temperature impacted economic growth negatively at national level and positively in urban agglomeration areas in long run, where the latter impacts is smaller. However, the overall net impacts of rising temperature on output growth remained negative. The effect of rising rainfall in urbanization agglomeration remained negative on output growth. In long run, the impacts of temperature on economic growth remained to be the highest among other key factors in the model including exports, gross capital formation, government expenditures and private consumption. We found that the combined impacts of both climate change and economic variables on economic growth remained – 0.72%. These results highlight that although the region registered on average, impressive economic growth over the period of analysis. However, the climate resilient sustained growth remained in negative terms. Further, these findings highlight that there is elastic negative connection between climate change and output growth, which warn us that if the temperature levels continue to grow at the current pace, then it would result into ever increasing reduction in the potential economic growth in the region in future. Another insight from the results elucidate that in the wake of consistent increase in population weighted surface mean temperature, more resources will be required every year just to keep up the current level of physical capital stock and economic development leading to increase the financing gap to cope with the atrocities of climate change eroding indigenous resources on one side and meeting the challenge of poverty and unemployment on the other side- converting into food security threat in high climate risk & water stressed lower middle income countries.

These findings highlight the crucial role of climate change in sustainable growth and explain substantially the higher negative effects of future climate change in selected Asian countries. The study concludes that efforts are required both at national and regional levels to limit the temperature levels through mitigation and adaptation measures as agreed upon by Burke, Davis, and Diffenbaugh (2018) United Nations' member countries under Paris Agreement 2017 for the achievement of sustainable economic growth. The findings of the study highlight that the one of the main components of the collaborated adaptation policy for sustained growth at regional level should be promoting urban agglomeration instead of urbanization. The other component of the adaptation policy should be facilitating the production and free trade of equipments of renewable energies- especially solar panels- within and across the region in order to drastically bring down the cost of installation & maintenance of renewable energies' equipment in the household and SME sectors. In this context, the countries should also enhance the capacity of technical and vocational training institute to produce skilled labour to meet the demands of domestic manufacturers of renewable energies' equipment. The impacts of solar energy attained through solar panels are manifolds in achieving environmentally sustained growth. First, the solar panels absorb extra heat responsible for increasing weather severity in short run and average temperature in long run. Second, it reduces the demands of energy attained through burning of fossil fuels and hence reduces the emission of GHGs in the air. Third, it helps in promoting conducive environment for working and hence enhances labour productivity. Fourth, it helps in providing clean environment and thereby guaranteeing a healthy society.

Authors Contribution

Ahmed Gulzar: Conceptualization., Methodology., Writing – original draft, Supervision, Validation., Writing. – editing & review, Data curation, Statistical analysis. Software
Babar Aziz: Supervision.

Conflict of Interests/Disclosures
The authors declared no potential conflicts of interest w.r.t the research, authorship and/or publication of this article.

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