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Influence of Globalization and Urbanization on CO2 Emissions in Asian Countries: Panel Data Analysis

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ABSTRACT

The growing concern of the twenty-first century is the anthropogenic economic activities on the environmental degradation. Carbon dioxide as the main domain of greenhouse gas, has sustained to rise in the region instead of obligations under the Paris Agreement. The aim of the study is to examine the relationship between urbanization, globalization, economic development, population growth, energy use and CO2 emissions from 1990 to 2024. Employing panel econometric methods including, endogeneity test, cross-sectional dependency test, unit root test, cointegration test and panel ARDL by PMG, MG and DFE estimator. From the Hausman test, DFE estimator is best to describe the relationship between the variables. The findings show a positive long-run relationship between globalization and CO2 emissions while a negative short-run relationship between urbanization and CO2 emissions. Similarly, population growth has negative association with CO2 emissions both in the long-run and short-run. However, economic development and energy use have positive relationship with CO2 emissions in the long-run and the short-run. The findings carry important implications for climate governance, urban planning, and sustainable development policy across Asian economies.

Keywords: CO2 emissions, DFE, Globalization, Urbanization

JEL Classification: F60, F63, F64, Q53, Q54

1. Introduction

The growing concerns of the twenty-first century is anthropogenic economic activities on the environmental degradation. Carbon dioxide (CO2) serves as the primary component of greenhouse gas, has continued to rise instead of obligations under the Paris Agreement (Audi et al., 2025; Ivanovski and Hailemariam, 2022; Salahuddin et al., 2019) supporting to the fact that the global CO2 emissions has not decline substantially (Liu et al., 2020). Several countries made commitment to reduce CO2 emissions reworking on their technical and managerial strategies, and align their national climate action plans to the Paris Agreement (United Nations Climate change, 2021). The most populated continent, Asia is becoming the engine of the economic growth of the world which also stands at the convergence of globalization and urbanization; reforming energy demand

patterns, industrial structures, and, subsequently, greenhouse gas emissions (Abbasi et al., 2020). It is argued that with the economic growth, a country can uplift millions of people out of poverty, but at the same time, the inevitable burden on the environment contributes to rise CO2 emissions (Nahrin et al., 2023; Zhu et al., 2022).

Globalization enhances the link between the economies by increasing the flow of investment, trade of goods and services and employment which foster economic growth of the world (Chienwattanasook et al., 2021). The developed countries have increased their production by affording the labor force at low-wage rates from developing countries. Meanwhile, the developing countries can increase their access to advanced technologies and investment from developed countries (Hussain et al., 2020; Godil et al. 2020). Globalization can affect the environment through multiple channels; composition effects, income effects and technique effects identified by the seminal work of Grossman and Krueger (1991) which remains the dominant analytical framework for linking trade openness and foreign direct investment to pollution. The effect on environmental quality due to the change in capital-labor ratio and output structure by globalization is a composition effect. The national income generated by the economic activities via globalization, which can deteriorate the environment, specifically with CO2 emissions, is referred as income effect. Access to the international market can be enabled by globalization through energy-efficient technology which reduces CO2 emissions is termed as technique effect (Alam et al., 2016; Amri, 2018). Most of the Asian countries have had export-led growth model as the quintessential development model for several decades. By means of globalization, these countries may simultaneously drive the accrual of polluting industries and prompt channels for green technology transfer, inducing ambiguous net effects on CO2 emissions (Adeleye et al., 2023; Anser et al., 2021; Chienwattanasook et al., 2021).

This paper attempts to shed light on the body of knowledge to the relationship between globalization and CO2 emissions by using KOF Globalization Index consisting of multitude of variables into a single index which made it a comprehensive measure of capturing globalization (Dreher, 2006; Dreher et al., 2008). Until recently, few studies have employed such measures in examining its influence on CO2 emissions (Shujah-Ur-Rahman et al. 2019; Ivanovski and Hailemariam 2022; Khan et al. 2019; You and LV 2018; Ozturk et al. 2023; Saint Akadiri et al. 2020).

Throughout the previous two decades, the world has experienced significant rise in urbanization along with globalization. Urbanization is a multifaceted process featured by the intensification of economic activities and population within urban regions urged by the alterations in the land use to harmonize growth (Bloom et al., 2008; Mehmood & Mansoor, 2021; Mignamissi & Djeufack, 2021). People are migrating to urban areas for acquiring social and economic benefits. Urbanization alters social, cultural and economic structures of the country with the aid of modernization (Fatima et al., 2020; Mehmood & Mansoor, 2021). More specifically, these relate to employment, poverty, housing conditions, access to water and healthcare, transport, waste management, and pollution (Bloom et al., 2008). In Asia, urbanization is equally transformative. The United Nations projects that Asian urban population will reach around 3.5 billion by 2050, adding roughly 1.2 billion new urban residents (United Nations Department of Economic and Social Affairs Population Division, 2018). Due to urbanization, societies achieve economic growth, eventually it can bring environmental degradation (Abbasi et al., 2020; Hoornweg et al., 2011; Y. Wang et al., 2019). If such urbanization is unplanned and unmanaged, then its effects are even hazardous (Farhani, Shahbaz, and Arouri 2013; Ali, Addullah, and Khan 2017; Bloom, Canning, and Günther 2008). The net environmental impact of urbanization is therefore theoretically indeterminate and is likely to vary with the quality of urban governance, energy mix, and the stage of economic development. So, this paper is highly motivated to assess the urbanization-emissions relationship in Asian countries.

From a large body of existing literature on the relationship between environmental quality and economic growth, Environmental Kuznets Curve (EKC) is employed, which is propounded by Grossman and Krueger (1991) and states that at the preliminary stage of economic growth, emissions increase as income level rises. Nevertheless, when a particular level of income per capita is succeeded, emissions initiate to fall even if the income is still on the rise. Therefore, it could be claimed that economic growth primarily has negative impact on environmental quality whereas it influences environmental safety when a certain level of per capita income is achieved (Audi et al., 2025; Ding et al., 2021; Kalaycı & Hayaloğlu, 2019; Zulfiqar et al., 2024).

Similarly, the STIRPAT model (Stochastic Impacts by Regression on Population, Affluence, and Technology), developed by Dietz and Rosa (1994) from Ehrlich and Holdren's (1971) IPAT identity, disaggregates the determinants of environmental impact into population, affluence, and technology, allowing for non-proportional and non-linear testing of hypotheses. This study

employs the STIRPAT model with the aims to explore the nexus between globalization and urbanization in Asia along with in Asia along with gross domestic product per capita, energy use per capita and total population.

Instead of a growing body of empirical work on the relationship between CO2 emissions globalization and urbanization, important gaps remain yet. First, most existing research focus on specific country blocs-OECD, BRICS, Sub-Saharan Africa, or individual Asian sub-regions without examining the heterogeneous dynamics across Asia as an entity (Salahuddin et al. 2019; Sampene et al. 2022; Khan et al. 2022; Ding, Yang, and Cao 2021; Dong et al. 2019; Audi et al. 2025; Akbar et al. 2024; Voumik, Mimi, and Raihan 2023). Globalization and urbanization are often examined independently rather than simultaneously, risking omitted variable bias in estimation (Nahrin et al., 2023; Ozturk et al., 2023; Xiaoman et al., 2021; X. Yang et al., 2021; Zhao & Qamruzzaman, 2022; Zulfiqar et al., 2024). Second, the negligence of cross-sectional dependence and slope heterogeneity may have potential spurious results (Pesaran 2007). Third, while the EKC hypothesis has been widely tested for income and emissions relationships, its applicability to the globalization, urbanization and CO2 emissions nexuses in the Asian context remains unexplored and the direction and nature of causal relationships in Asia remain unexplored. I attempt to address these gaps by analysing annual panel data for 44 Asian countries spanning 1990-2024 employing advanced panel data estimation of pooled mean group (PMG), mean group MG) and dynamic fixed effect (DFE) assessing cross-sectional dependency test, heterogeneity test, panel unit test, and co-integration test.

The remainder of the paper is organized as follows. Section 2 reviews the relevant theoretical and empirical literature. Section 3 describes the data, variables, and econometric methodology. Section 4 presents and discusses the empirical results. Section 5 draws conclusions, and policy implications.

2. Literature review

The section covers the investigation on the linkage between globalization, urbanization, and combined effects of globalization and urbanization and other drivers on CO2 emissions.

2.1 Nexus between urbanization and CO2 emissions

The nexus between urbanization and CO2 emissions has explained considerably by scholars, especially for Asian and African economies where urbanization is rapidly growing. Most empirical studies report a positive association between urbanization and environmental degradation, that

urbanization exerts environmental pressures through increased energy demand, industrial activity, and infrastructure development (Abbasi et al., 2020; Audi, 2024; Azam & Khan, 2014; Mehmood & Mansoor, 2021; Voumik et al., 2023). In the lack of strong environmental regulatory mechanism and inefficient energy use, urbanization emerged as a major contributor of CO2 emissions in the Asian countries. Similarly, in case of African countries, urbanization largely influences CO2 emissions, despite the magnitude of the effect appears conditional on institutional quality and structural factors (Salahuddin et al., 2019). In addition, another study also finds that urbanization induces CO2 emissions in Sub Saharan Africa (Wang and Dong 2019). Similarly, other studies argue that urbanization has heterogeneous effect for various level based on the governance quality and industrial composition in Africa (Mignamissi & Djeufack, 2021; Raheem & Ogebe, 2017). Where in V4 countries, urbanization positively impacts on CO2 emissions and suggests to incentivize the usage of renewable energy and ecological energy sources as an alternative (Mirziyoyeva & Salahodjaev, 2023).

Despite the central consensus on the positive association between urbanization and CO2 emissions, other empirical studies reveal crucial heterogeneities and mitigating mechanisms. Those studies highlights that the environmental impact of urbanization depend on its pace, quality, and development trajectory, suggesting the existence of nonlinear and asymmetric effects (Xu et al., 2024). Moreover, together with renewable energy usage and financial development, sustainable urban planning can dampen the environmental degradation (Gieraltowska et al., 2022; Xu et al., 2022; Zhao and Qamruzzaman, 2022). Conversely, Saidi and Mbarek (2016) show that urbanization decreases CO2 emissions in emerging countries, where financial development plays a role of catalyst for environmental cleanliness. Similar results are reported by Dong et al. (2019) for mid-urbanization stage of the economies. In BRICS and BRICS-T countries, urbanization has negative relationship with CO2 emissions and it is argued that socio-economic dimensions of urbanization can be sustained by investment in green transportation and green spaces (Balsalobre-Lorente et al., 2022; Somoye & Akinwande, 2023). Employing spatial-temporal approach, Grodzicki and Jankiewicz (2022) reveal that a rise in urbanization level harms air quality while the levels of CO2 emissions and urbanization are declining in the East Europe while increasing in the North Europe. Similar negative relationship is depicted for overall European countries where emissions are declining due to urbanization because of better infrastructure, renewable energy adoption and energy efficiency (Chovancova et al., 2023).

These findings challenge the notion that urbanization inevitably leads to environmental degradation and underscore the importance of appropriate policies. The literature increasingly emphasizes the need to shift from managing urbanization proceeding along environmentally sustainable pathways (Zulfiqar et al., 2024).

2.2 Nexus between globalization and CO2 emissions

There is abundant empirical literature on globalization and CO2 emissions based on various indicators of globalization, country coverage, estimation techniques, and stages of economic development. Yet, a substantial body of evidence suggests that globalization exacerbates environmental degradation. Studies concentrating on South Asia account that globalization integrating with trade expansion, industrial activity, and rising energy consumption promotes higher CO2 emissions (Anser et al. 2021; Jun et al. 2021; Khan et al. 2022; Adeleye et al. 2023). In case of ASEAN economies, similar results are shown where the economies' growth has been influenced by globalization that is linked to amplified environmental pressure (Chienwattanasook et al., 2021). These literature support that pollution haven argument, reflecting that globalization may amplify CO2 emissions when environmental regulations are ineffective and production relies heavily on fossil fuels.

In contrast, another strand of literature claims that globalization can enhance environmental outcomes by enabling technological diffusion, cleaner production methods, and stronger environmental governance. Evidence from various studies in developing countries, developed countries, G7 countries, OECD member countries, and emerging economies signifies that globalization diminishes CO2 emissions, predominantly when escorted by institutional quality, financial development and renewable energy usage (Ivanovski and Hailemariam, 2022; Jahanger, 2022; Le and Ozturk, 2020; Liu et al., 2020; Mirziyoyeva and Salahodjaev, 2023). Similarly, Ma and Wang (2021) provide evidence of reduced CO2 emissions by globalization in developing countries from the effective implementation of regulations aligning with international agreement and accords. Xiaoman et al. (2021) and Tsimisaraka et al. (2023) report similar results on significant reduction of CO2 emissions from globalization in MENA and OBOR countries respectively.

An increasing number of studies emphasize the multidimensional nature of globalization and determine that its economic, social, and financial components affect environmental quality in

multiple aspects. Economic globalization and trade openness are often coupled to rise CO2 emissions through increased production and capital mobilization, as evidenced in NAFTA and several African economies (Kalaycı & Hayaloğlu, 2019; Teklie & Yağmur, 2024). Conversely, social globalization appears to enrich environmental awareness and technological exchange, thereby aiding to reduce CO2 emissions (Yang, Jahanger, and Khan 2020). Mixed findings from G20 nations and OIC countries additionally suggest that globalization coupled with financial development, foreign direct investment, and energy structures has furnished environmental outcomes (Mustofa, 2025; Sheraz et al., 2021). From all these observations, it can be argued that various globalization indices disguise important transmission channels and heterogeneous effects in environmental economy.

Furthermore, country-specific studies strengthen this heterogeneity. Studies on Pakistan and Vietnam are evident that globalization has increased CO2 emissions via expansion in industrialization (Khan and Ullah, 2019; Phong et al., 2018). Whereas, other studies highlight the vital role of globalization in advancing environmental sustainability while incorporating green energy in the United States (Raihan et al., 2022). In addition, evidence from India reinforces a long-run positive association between globalization and environmental outcomes (Sahu & Kumar, 2020).

2.3 Nexus between globalization, urbanization, and other drivers and CO2 emissions

An emerging body of study treats globalization and urbanization as interconnected drivers of CO2 emissions and often co-determine with economic growth, energy usage, institutional quality, financial development, trade openness, and foreign direct investment. Most of the literature states that at the early stages of development, environmental degradation increases but with the increase in economic growth environmental degradation starts to decline after the threshold point, thereby confirming the EKC hypothesis (Anser et al. 2021; Teklie and Yağmur 2024; Khan et al. 2022; Adeleye et al. 2023; Jun et al. 2021; Jahanger 2022; Liu et al. 2020; Mirziyoyeva and Salahodjaev 2023; Phong, Van, and Bao 2018; X. Yang et al. 2021).

A testimony from Sub-Saharan Africa, South Africa, BRICS, G7, and emerging economies consistently comments that urbanization and globalization intensify environmental degradation because of rising energy demand and its consumption (Khalid et al., 2022; Saidi & Mbarek, 2016; Salahuddin, Ali, et al., 2019; Salahuddin, Gow, et al., 2019; Sampene et al., 2022). However, the extent and tenacity of these effects differ across regions, referring that the urbanization-

globalization-CO2 emissions junction is context-oriented rather than universal. This suggests that rapid urbanization and globalization may create substantial ecological costs unless it is accompanied by green technology and sustainable energy transitions.

Ozturk et al. (2023) show a non-linear association between urbanization, globalization and CO2 emissions, indicating that the environmental effects vary across the different stages of development. The impact of globalization is uncertain while it integrates with natural resource endowments, green energy adoption, and institutional quality (Jahanger, 2022; Le & Ozturk, 2020; Mirziyoyeva & Salahodjaev, 2023; Xiaoman et al., 2021). These findings oppose the assumption that globalization generally deteriorate environment and instead prioritize the role of domestic absorptive capacities and governance to cast environmental outcomes of the economy. On the other hand, population aging also meld the long-run effects in the environment with increasing economic globalization (Yang et al., 2020). Studies find that the combined effect of globalization, urbanization, and economic growth on CO2 emissions are positive in Asian countries, African countries, and G7 economies (Akbar et al., 2024; Khalid et al., 2022; Salahuddin, Ali, et al., 2019). Several studies such as Teklie and Yağmur (2024) Somoye and Akinwande 2023; Raihan et al. 2022; Mirziyoyeva and Salahodjaev 2023; Mehmood and Mansoor 2021; Le and Ozturk 2020; Chienwattanasook et al. 2021; Zulfiqar et al. 2024) claim that CO2 emissions increase with economic growth and energy usage. While few other studies confront that economic growth and energy usage reduces CO2 emissions (Sahu & Kumar, 2020; Sampene et al., 2022).

The review of extant literature discloses three substantive gaps that motivate the present study. First, Asia being the most environmentally polluting continent in the world, no comprehensive panel data studies taking globalization, urbanization, economic growth, population growth and energy consumption have been done. Second, the econometric analysis such as cross-dependency test, endogeneity test, and cointegration test have rarely been tested for panel ARDL model in the context of globalization, urbanization and CO2 emissions in Asia. Third, the direction and nature of causal relationships among the variables in Asia remain underexplored, restricting the specificity of policy implications. This research addresses all three gaps and increases the literature.

3. Data and methods

3.1 Data

This study analyses annual data from 1990 to 2024 for a panel of 44 Asian countries except Afghanistan, Bhutan, Maldives, North Korea and Timor-Leste due to unavailability of the data. Time period selection is based on data availability. Table 1 represents variable description and data sources of the study. The data are processed and analysed using Stata 18 software.

Table 1 Variable Description and Data Sources

Variables	Symbol	Description	Unit	Data Source
CO2 emissions	CO2	CO2 emitted from agriculture, energy, waste and industrial sectors excluding LULUF	Metric tons per capita	WDI
Urbanization	UP	Urban population to total population	% of TP	WDI
Globalization	GI	Globalization is measured with economic, social, and political indices as defined by (Dreher, 2006)	Index (from 0 to 100)	KOF Swiss Economic Institute
GDP per capita	GDPC	Gross domestic product by the mid-year population	Constant 2015 US$	WDI
Total population	TP	Total population		WDI
Energy use	EU	Energy use from primary source before transformation to other end-use fuels, net indigenous production and fuels supplied to ships and aircraft.	Kg of oil equivalent per capita	WDI

3.2 Model specification

The influence of urbanization, globalization, GDP per capita, population growth and energy use on the environmental quality of Asia is examined by employing STIRPAT model. This model allows to add other variables apart from its main variables (Dietz & Rosa, 1997). The STIRPAT model in the panel data can be expressed as:

$$I_{it} = \alpha_0 P_{it}^{\alpha 1} A_{it}^{\alpha 2} T_t^{\alpha 3} \quad (1)$$

Where, I is the influence on environmental quality, P is population size, A is affluence, T is technology, αs are constant and measurements of population, affluence and technology respectively. The number of countries and time are represented by 'i' and 't' respectively. Following the model specified by Salahuddin et al. (2019) and Zulfiqar et al. (2024), the STIRPAT model after adding major drives of environmental quality according to the aim of this study can be expressed as:

$$CO2_{it} = \alpha_{it} + \beta_1 UP_{it} + \beta_2 GI_{it} + \beta_3 GDPC_{it} + \beta_4 TP_{it} + \beta_5 EU_{it} + \varepsilon_{it} \quad (2)$$

Where, CO2 is CO2 emissions per capita proxy of environmental quality, UP is ratio of urban population to total population proxy of urbanization, GI is KOF Globalization Index proxy of globalization, GDPC is GDP per capita, TP is total population, EU is energy use per capita, α and βs are constant and coefficient of urbanization, globalization, GDP per capita, total population and energy use while ε is error term. Equation (2) is changed by taking natural logarithm to lessen the issues of dispersion, multicollinearity and heteroscedasticity in the data (Dar and Asif, 2017; Le and Ozturk, 2020; Solarin et al., 2017; Yang et al., 2021). In addition, the model provide more efficient and consistent outcomes than that from the simple linear equation (Sinha & Shahbaz, 2018). The econometric model of the study is expressed as:

$$LNCO2_{it} = \alpha_{it} + \beta_1 LNUP_{it} + \beta_2 LNGI_{it} + \beta_3 LNGDPC_{it} + \beta_4 LNTP_{it} + \beta_5 LNEU_{it} + \varepsilon_{it} \quad (3)$$

3.3 Econometric methodology

The estimation of panel data analysis can be summarized by the following steps: descriptive statistics, correlation analysis, endogeneity test, diagnostic test, cross-sectional dependency test, panel unit root test, panel cointegration test and regression estimation.

The panel data may not be deprived of endogeneity issues due to omitted variables and measurement error. So, I perform overidentification test by Sargan score and Basmann score and endogeneity test by Durbin score and Wu-Hausman score (Basmann, 1960; Durbin, 1954; Hausman, 1978; Nakamura, 1981; Sargan, 1958; Wu, 1973). As a diagnostic test, variance inflation factor (VIF) is used to test multicollinearity between the variables. Furthermore, Cross-sectional dependence (CD) may arise in econometric analysis because of possible existence of mutual shocks and overlooked components in the panel data which leads to inefficient estimation (Baltagi, 2005; Pesaran, 2004). Therefore, CD test is conducted (Frees, 2004; Friedman, 1937; Pesaran, 2004).

After finding the absence of cross-dependency, second-generation panel unit root test is not required, thus first-generation unit test such as IPS, ADF and PP tests are considered. The null hypothesis of IPS is that there is a unit root (Im et al., 2003). Similarly, Maddala and Wu (1999) presents test statistics based on Fisher (1932) and it is a blending of p-values of t-statistics of unit roots of all cross-sections. Fisher type test permits different first-order autoregressive coefficients, and it has two types: ADF unit root test and PP unit root test. The null hypothesis of both Fisher

type ADF and Fisher type PP is that there is unit root in the panel data. When the chi-square has p-value less than 0.10, then the panel data have no unit root.

If the results of panel unit root test revealed that the dependent variable, is I (1) variable and the independent variables are mixture of both I (0) and I (1) variables, then the panel ARDL estimation is employed for the interpretation of the relationship between the variables (Baltagi, 2005). The panel cointegration test is classified into three groups; Kao test, Pedroni test, and Westerlund test to assess the null hypothesis of no co-integration (Kao, 1999; Pedroni, 2004; Westerlund, 2005). This study employed all these tests with the null hypothesis of no cointegration. If the test statistics had p-values less than 0.05, it was confirmed that there was panel cointegration among the variables in the long-run.

According to Pesaran et al. (1999), and Pesaran and Smith (1995), for the estimation of the Panel ARDL model, large time period (T > 25) and large cross-sections (N > 20) are the necessary conditions. Since this study has collected the annual data for 35 years (that is T > 25) and the number of cross sections, N is 44 countries (N > 20), the estimators of panel ARDL is employed. In addition, the large T and N dynamic panels, ARDL model is applied for the mixed stationery and non-stationarity of data at level I (0) and I (1). The panel ARDL with unrestricted specification is presented as the following equation.

$$Y_{it} = \sum_{i=1}^{p} \Theta_{ij} Y_{i,t-j} + \sum_{i=0}^{q} \Upsilon_{ij} X_{i,t-j} + \mu_i + \varepsilon_{it} \quad (4)$$

where, x_{it} is a vector of regressors for group I, Θ_{ij} are the coefficients of lagged dependent variables and μ_i is the fixed effect.

Furthermore, panel ARDL model is employed by pooled mean group (PMG) estimator, mean group (MG) estimator and dynamic fixed effect (DFE) estimator. PMG estimator presents both long-run and short-run relationship between the variables. It is assumed that PMG apply homogeneity limitations. The PMG estimator for this study is expressed as:

$$\Delta LNCO2_{it} = \emptyset_i\left(LNCO2_{it-1} - \alpha_1^i LNUP_{it} - \alpha_2^i LNGI_{it} - \alpha_3^i LNGDPC_{it} - \alpha_5^i LNTP_{it} - \alpha_6^i LNEU_{it}\right) + \sum_{t=1}^{p=1} \lambda_{ij}^* \Delta LNCO2_{it-1} + \sum_{j=1}^{q=1} \gamma_{ij}^* \Delta LNUP_{it-j} + \sum_{j=1}^{q=1} \gamma_{ij}^* \Delta LNGI_{it-j} + \sum_{j=1}^{q=1} \gamma_{ij}^* \Delta LGDPC_{it-j} + \sum_{j=1}^{q=1} \gamma_{ij}^* \Delta LNTP_{it-j} + \sum_{j=1}^{q=1} \gamma_{ij}^* \Delta LNEU_{it-j} + \mu_i + \varepsilon_{it} \quad (5)$$

MG estimator permits various slope, intercepts and error variances between the individuals. Thus, the estimator provides the average parameters of the estimates. It is also derived from the ARDL equation as:

$$Y_{it} = \alpha_i + \gamma_1' Y_{it-1} + \beta_i X_{it} + \mu_{it} \quad (6)$$

DFE estimator has the coefficient of cointegrating vector that is equal in all cross-sections along with the same speed of adjustment and short-run coefficients. Furthermore, this estimator permits panel-specific intercepts with the standard error though correlation exist within the group.

The best estimator among PMG, MG and DFE is chosen from Hausman test. The null hypothesis of the test between PMG and MG is that there is no significant difference between them. If it is not excluded, PMG estimator is more effective to explain the connection between dependent and independent variables. Similar null hypothesis is built between PMG and DFE. If it is not rejected, then PMG estimator is more viable to explain the relationship between dependent and independent variables. For the selection between MG and DFE estimator, similar null hypothesis is constructed, and MG estimator will be efficient when that hypothesis is rejected. The test is described by Chi-square.

$$H = (\widehat{\beta_b} - \widehat{\beta_B}) D^{-1} (\widehat{\beta_b} - \widehat{\beta_B})$$

$D^{-1} = (V\widehat{\beta_b} - V\widehat{\beta_B})$, where, $V\widehat{\beta_b}$ is the variance of coefficient

H_0: Accept PMG, if p value of $\lambda^2 > 0.05$

H_A: Reject MG or DFE, if p value of $\lambda^2 > 0.05$

4. Results and discussions

4.1 Descriptive statistics

The descriptive statistics of the selected variables for the Asian countries are reported in Table 2. The average value of LNCO2 is 1.21 units, and its maximum and minimum values are 3.98 units and -2.89 units respectively. The average value, maximum value and minimum value of LNUP are 3.98 units, 4.61 units and 2.68 units respectively. The average value, maximum value and minimum value of LNGI are 3.98 units, 4.42 units and 2.99 units respectively. The average value, maximum value and minimum value of LNGDPC are 8.51 units, 11.31 units and 5.12 units respectively. The average value, maximum value and minimum value of LNTP are 16.64 units, 21.10 units and 12.45 units respectively. The average value, maximum value and minimum value of LNEU are 7.30 units, 9.98 units and 4.27 units respectively. All the variables have lower standard deviation (<2.0) indicating that the data are very close to their mean. The skewness of LNCO2, LNUP and LNGI are negative, indicating the tails of the variables are on the left side of the distribution while rest of the variables are on the right side of the distribution. LNDGPC is platykurtic, LNCO2, LNUP, LNTP and LNEU are mesokurtic, and LNGI is leptokurtic. All the

variables show relatively normal distribution except LNGI that means there may be presence of extreme values in the data.

Table 2 Descriptive Statistics

Variable	Mean	Max	Min	Sd	Skewness	Kurtosis	N
LNCO2	1.212	3.982	-2.887	1.456	-0.491	2.676	1540
LNUP	3.983	4.605	2.679	0.490	-0.670	2.446	1540
LNGI	3.983	4.415	2.990	0.265	-0.869	3.509	1488
LNGDPC	8.506	11.310	5.116	1.403	0.151	1.931	1531
LNTP	16.641	21.095	12.450	1.813	0.266	2.858	1540
LNEU	7.300	9.978	4.272	1.167	0.148	2.170	1485

4.2 Correlation analysis

The pairwise correlation coefficients between the variables are reported in Table 3. LNUP, LNGI, LNGDPC and LNEU have a strong positive correlation with LNCO2 suggesting that urbanization, globalization, economic development and energy use influence environmental quality. While, LNTP has a negative weak correlation with LNCO2 indicating that the domestic residents weakly reduce CO2 emissions. Furthermore, LNGDPC and LNUP, LNEU and LNUP, LNGDPC and LNGI, LNEU and LNGDPC have strong positive correlation with each other. Such records can bring biased results in the regression estimation.

Table 3 Correlation Analysis

	LNCO2	LNUP	LNGI	LNGDPC	LNTP	LNEU
LNCO2	1					
LNUP	0.802	1				
LNGI	0.543	0.582	1			
LNGDPC	0.864	0.789	0.690	1		
LNTP	-0.381	-0.397	-0.087	-0.395	1	
LNEU	0.959	0.787	0.494	0.873	-0.430	1

4.3 Endogeneity test and diagnostic test

Endogeneity test for the variables is performed to test overidentifying restrictions and endogeneity. The Sargan score statistics is 0.11 with the p-value of 0.74 (>0.05) and Basmann score is 0.11 with the p-value of 0.74 (>0.05). These results indicate that there are no overidentification issues and no omitted variables in the model. Similarly, the statistics of Durbin score is 2.22 with the p-value of 0.14 (>0.05) and Wu-Hausman score is 2.21 with the p-value of 0.14 (>0.05). These results indicate that there are no issues of endogeneity in the model.

The VIF is employed to detect multicollinearity in the model. The results show that all variables have relatively low value of VIF (<5) except LNGDPC whose VIF value is 7 (<10) and the mean VIF is 3.85 (<5). These results assure that there is no evidence of multicollinearity in the model.

4.4 Cross-sectional dependency (CD)

CD may arise in the underlying variables and testing whether the cross-sections are dependent on each other or not is considered. It should be noted that CD test is helpful for choosing the appropriate panel unit root test. Table 4 reports the CD test. The Frees' statistics is 7.825 which is greater than the critical value of Free's Q distribution alpha (0.01) and Friedman test has the p-value of 0.626 (>0.05) but Pesaran test has the p-value of 0.000 (<0.05). Taking the higher results of the test, it is considered that there is no cross-sectional dependency in the model. Therefore, this study employs first-generation panel unit root test for checking stationarity of the variables.

Table 4 CD test

Test	Test Statistics	p-value
Pesaran	7.247	0.000
Friedman	39.46	0.626
Frees	7.825	

Note: Critical values from Free's Q distribution, alpha (0.10) = 0.136, alpha (0.05) = 0.178 and alpha (0.01) = 0.260.

4.5 Panel unit root tests

Table 5 reports the panel unit root tests under the first-generation which consists of IPS, ADF and PP. The results show that the dependent variable (LNCO2) is stationary at first difference that is the variable is I (1) and the independent variables are stationary both at level and at first difference indicating the variables are both the mixture of I (0) and I (1). Hence panel ARDL model is suitable for the examination of the relationship between the variables.

Table 5 Panel Unit Root Tests

Variable	At Level			At First Difference			Remarks
	IPS	ADF	PP	IPS	ADF	PP	
LNCO2	-0.087	115.403**	115.403**	-15.418***	522.234***	1005.7***	I (1)
	(0.465)	(0.027)	(0.027)	(0.000)	(0.000)	(0.000)	
LNUP		639.922***	301.461***		226.709***	263.19***	I (0)
		(0.000)	(0.000)		(0.000)	(0.000)	
LNGI	-0.905	180.239***	130.985***	-16.625***	538.821***	931.82***	I (0)
	(0.183)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	
LNGDPC	-6.462***	334.739***	213.517***	-14.505***	505.971***	701.84***	I (0)

	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	
LNTP	-0.354	215.301***	178.443***	-10.275***	348.303***	320.85***	I (1)
	(0.362)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	
LNEU	-6.808***	318.614***	147.283***	-17.228***	577.435***	1074.7***	I (0)
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	

Note. Researcher's own calculation. *, ** and *** refers to the significant level at 10%, 5% and 1% respectively. Values in parentheses represent the corresponding p-values of the test statistics.

4.6 Panel cointegration test

Table 6 represents the panel cointegration test for relationship among CO2 emissions, urbanization, globalization, economic development, population growth, and energy use for Asia. From the Pedroni, Kao and Westerlund test, it is found that the variables are highly cointegrated at 1 % level of significance. Therefore, the study concludes that there is cointegration among the variables in the model.

Table 6 Panel Cointegration Test

Pedroni Test		Kao Test		Westerlund Test	
Modified Phillips-Perron t	1.216 (0.112)	Modified Dickey-Fuller t	-1.325* (0.093)	Variance ratio	-3.920*** (0.000)
Phillips-Perron t	-6.226*** (0.000)	Dickey-Fuller t	-3.852*** (0.000)		
Augmented Dickey-Fuller t	-6.166*** (0.000)	Augmented Dickey-Fuller t	2.230** (0.013)		
		Unadjusted modified Dickey-Fuller t	-4.824*** (0.000)		
		Unadjusted Dickey-Fuller t	-5.794** (0.000)		

Note: Researcher's own calculation. *, ** and *** refers to the significant level at 10%, 5% and 1% respectively. Values in parentheses represent the corresponding p-values of the test statistics.

4.7 Panel ARDL estimation

From the above various tests; diagnostic test, endogeneity test, cross-sectional dependency test, unit root test and cointegration test, panel ARDL model is employed for estimating the influence of urbanization, globalization, economic development, population growth, and energy use on CO2 emissions in Asia. Table 7 reports PMG, MG and DFE estimates and Hausman test is employed to select the appropriate estimators. The results suggest that PMG estimator is better to explain the

relationship between them by rejecting the null hypothesis with the p-value of 0.13 (>0.05) from the Hausman test between MG and PMG. Similarly, from Hausman test between DFE and PMG, the results suggest that DFE is better to explain the relationship between them by failing to reject the null hypothesis with the p-value of 0.00 (<0.05). Hence, DFE is the better estimator to explain the long-run and short-run relationships between the variables. The error correction term or the speed of adjustment is significant at a one percent implying that any deviations from the long-run equilibrium are corrected at 11.65 percent speed of adjustment.

Table 7 Panel ARDL Estimations

	PMG	MG	DFE
Long Run			
LNUP	0.155***	4.012	-0.267
	(0.002)	(0.239)	(0.154)
LNGI	-0.039	0.206	1.141***
	(0.340)	(0.683)	(0.000)
LNGDPC	-0.005	-0.053	0.179**
	(0.743)	(0.765)	(0.028)
LNTP	-0.104***	-0.038	-0.586***
	(0.000)	0.965	(0.000)
LNEU	0.914***	0.660***	0.924***
	(0.000)	(0.006)	(0.000)
Short Run			
ECT	-0.269***	-0.756***	-0.116***
	(0.000)	(0.000)	(0.000)
LNUP	0.441	2.335	-0.370**
	(0.843)	(0.523)	(0.048)
LNGI	0.032	0.012	-0.052
	(0.713)	(0.916)	(0.504)
LNGDPC	0.159**	0.078	0.101***
	(0.020)	(0.199)	(0.002)
LNTP	1.970	7.392	-1.100***
	(0.191)	(0.124)	(0.000)
LNEU	0.557***	0.080	0.445***
	(0.000)	(0.317)	(0.000)
Constant	-1.100***	-23.876**	-0.061
	(0.000)	(0.019)	(0.744)
Hausman PMG MG		8.57 (0.128)	
Hausman DFE PMG			77.78 (0.000)

Note: Researcher's own calculation. *, ** and *** refers to the significant level at 10%, 5% and 1% respectively. Values in parentheses represent the corresponding p-values of the test statistics.

The results of DFE estimator show that all variables are statistically significant except LNUP in long-run while in short-run LNGI is statistically insignificant. LNUP is only statistically significant in the short-run. A one percent increase in LNUP reduces 0.37 percent in LNCO2 in the short-run. Such negative relationship between urbanization and CO2 emissions in the short-run is consistent with the results of Saidi and Mbarek (2016) in emerging countries, Balsalobre-Lorente et al. (2022), Somoye and Akinwande (2023) in BRIC and BRICS-T countries, and Chovancova et al. (2023) in European countries. Grodzicki and Jankiewicz (2022) also finds such negative relationship between urbanization and CO2 emissions in the East Europe. In addition, Mehmood and Mansoor (2021) has also found that urbanization reduces CO2 emissions in SAARC countries and argues the reason behind it is that these countries have arable land and follow innovations. From the findings of this study, it can be said that the potential benefits of urbanization in Asian countries outweigh its disadvantages for maintaining environmental quality.

The results find that LNGI is positively associated with LNCO2 in the long-run only. A one percent increase in LNGI increases 1.14 percent in LNCO2 in the long-run. Such findings of this study are consistent with other studies for example Adeleye et al. (2023), Anser et al. (2021) Jun et al. (2021) and Khan et al. (2022) based on South Asian countries. In addition, Chienwattanasook et al. (2021) has also found similar results. The increase in opportunities of trade, industrial expansion, energy consumption and mobilization of resources due to globalization, has decreased environmental quality in Asia. However, the results are not aligned with the results of Ivanovski and Hailemariam (2022), Jahanger (2022), Le and Ozturk (2020), Liu et al. (2020), and Mirziyoyeva and Salahodjaev (2023). They argue that globalization reduces CO2 emissions because they can increase international trade and mobilize their resources from the effective implementation of regulations following international commitments to improving environmental quality. However, Asian countries are still struggling to implement such international commitments.

The results show that LNGDPC has a positive impact on LNCO2 both in the long-run and short-run. A one percent rise in LNGDPC increases 0.18 percent and 0.10 percent in the long-run and short-run respectively. Similarly, LNEU has also a positive and statistically significant relationship with LNCO2 both in the long-run and short-run. A one percent rise in LNEU rises 0.92 percent and 0.45 percent in LNCO2 emissions in the long-run and short-run respectively. The results of positive association economic development and energy use with CO2 emissions are consistent with the results of several studies such as Chienwattanasook et al. (2021), Le and Ozturk (2020)

Mehmood and Mansoor (2021), Mirziyoyeva and Salahodjaev (2023), Raihan et al. (2022), Somoye and Akinwande (2023), Teklie and Yağmur (2024) and Zulfiqar et al. (2024) and it can be argued that the environmental quality is hampered by uplifting development and growth of the economy where there is massive usage of energy. At the same time, it is important to consider international commitments in reducing environmental degradation by either increasing green technology or innovating alternatives.

However, LNTP has a negative and significant relationship with LNCO2 not only in the long-run but also in the short-run. A one percent rise in LNTP decreases 0.59 percent in LNCO2 in the long-run and 1.1 percent in LNCO2 in the short-run. The results of negative relationship between population size and CO2 emissions is consistent with the results of Rehman et al. (2021) in Pakistan, Mustofa (2025) in OIC member countries. The increased population drives increased efficiency, technological innovation and economies of scale which positively influence environmental sustainability thereby decreasing CO2 emissions (Ahlburg et al., 1996). Asian countries should implement effective population control policies to ensure that population growth does not excess the optimal utilization of natural resources.

5. Conclusion and policy recommendations

This study provides novel evidence of the influence of urbanization and globalization on CO2 emissions in Asia over 1990 to 2024, employing PMG, MG and DFE estimator. The results of DFE estimator show a stable positive long-run relationship between globalization and CO2 emissions while urbanization has a negative short-run relationship with CO2 emissions. Similarly, population growth has negative association with CO2 emissions both in the long-run and short-run. However, economic development and energy use have positive relationship with CO2 emissions in the long-run and the short-run. It can be argued that the increased population in Asia are efficient enough to deliver their labour force with their inherent knowledge to protect their environment. The increased size of urbanization in Asia has still maintained the environmental quality in the short-run, however it may invite devastating state of environmental degradation if they do not adopt either energy efficient technology or green technology. In addition, though globalization allows exchange of knowledge, technology and best utilization of resources, it has deteriorated the environment.

Based on the findings of this study, it is deemed necessary to strengthen the role of government policies and existing environmental regulations in moderating the impact of urbanization, globalization and energy use on CO2 emissions. The study has limitations, majorly related to data coverage from 1990 to 2024 due to inadequate data availability.

This study has used the KOF Globalization Index as a proxy of globalization. Future research can also disaggregate it into economic, social and political globalization index to capture multidimensional integration. Similarly, future studies can also disaggregate urbanization into city size, density and quality dimensions to identify which aspects of urbanization are most environmentally damaging. Such study will help to formulate revised policies for the sustainable development of Asia.

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