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HOW DO URBANIZATION, URBAN AGGLOMERATION, AND LARGEST CITY RATIO AFFECT CO_2 EMISSIONS? INVESTIGATING NON-LINEARITY DYNAMIC STIRPAT (STOCHASTIC IMPACTS BY REGRESSION ON POPULATION, AFFLUENCE, AND TECHNOLOGY) MODEL IN 10 ASIAN ECONOMIES

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Abstract

This study investigates how do urbanization, urban agglomeration, and largest city ratio affect CO_2 emissions in 10 Asian Economies namely Bangladesh, India, Pakistan, Nepal, China, Indonesia, Malaysia, Thailand, the Philippines and Vietnam over the period 1990- 2020. Based on STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) framework, we applied dynamic seemingly unrelated regression (DSUR) to establish long-run term effects. The empirical findings revealed that urbanization and urban agglomeration have inverted U shaped effect, meanwhile largest city ratio have U shaped. Urbanization and urban agglomeration improve environment quality in the long term and supports ecological modernization theory. Urbanization and urban agglomeration improves environmental quality after reaching a significant level of urban development due to efficient energy structures, population awareness, environmentally friendly technologies, and strict urban and environmental policies. However, the finding of largest city ratio revealed U shaped. This result rejects compact city theory. It implies that excessive concentration in the largest cities have severely affected the environmental quality and violates the notion of compact-city efficiencies which could be attributed to extreme population density, overcrowding, traffic congestion and extensive demand for energy consumption. The results of the panel granger causality approach unveil bidirectional causality in urban agglomeration and its quadaratic term of urban agglomeration, largest city ratio, and quadaratic term of largest city ratio on CO_2 emissions. Bidirectional causality also found in GDP and CO_2 emissions. Meanwhile, unidirectional causality found in energy intensity and CO_2 emissions, trade openness and CO_2 emissions, financial development and CO_2 emissions, furthermore urbanization and CO_2 emissions. The current study has implications for policymakers and respective governments to green urban infrastructures, eco-friendly dwellings, smart cities, country-specific trade policies, and renewable energy options to adhere more stringent urban planning and enhancing the environmental quality.

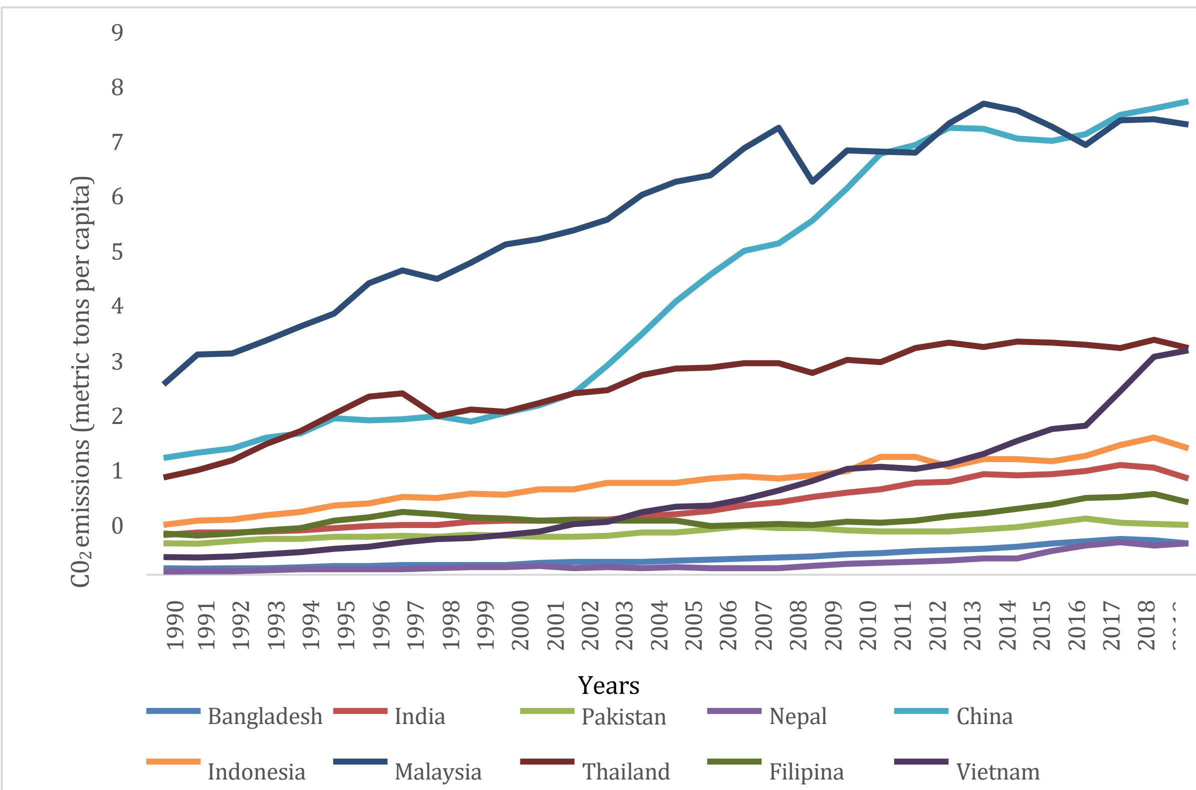
Keywords: Urbanization, Urban Agglomeration, Largest City Ratio, CO_2 Emissions, Ecological Modernization Theory, Compact City Theory, STIRPAT, DSUR

INTRODUCTION

Accelerating urbanization causes urban areas contribute significantly to energy consumption and CO_2 emissions in Asian economies. The effect of urbanization on the use of fossil fuel energy has increased CO_2 emissions which cause global warming and climate change. Global climate change is one of the major challenges. The Intergovernmental Panel on Climate Change (IPCC) reports more than 95% probability that human activities are responsible for increasing global temperatures. Since the early 1970s, it has been increasing understanding among individuals and governments to address environmental issues. In 2015, the United Nations Framework Convention on Climate Change (UNFCCC) responded to the risks of climate change by adopting the Paris Climate Change Agreement which aims to reduce global warming levels below 2 to 1.5 degrees Celsius, compared to pre-industrial levels. Globally, countries are being urged to develop mitigation to reduce CO_2 emission levels. Understanding the relationship between economic, social activities and climate change has become increasingly essential for adopting appropriate policies to achieve sustainable development and environmental quality.

Industrial growth has caused a massive structural shift in the workforce from rural to urban areas in the last few decades. Urbanization refers to the dynamic socio-economic modernization and population concentration resulting from the shifting of people and other capabilities from rural to urban areas.The urbanization process is highly helpful in optimal utilization of resources to encourage economic. The historical perspective of economic growth shows that cluster development has contributed to the development of manufacturing/production units. Cluster development is the result of migration that drives urbanization (Huo et al., 2021; Munir and Ameer, 2022., Xie and Liu, 2019).The evolution of industrial structure promotes urbanization due to the shift of jobs from the agricultural sector to the industrial sector. The expansion of the service sector also creates several business opportunities that encourage urbanization (Hashmi et al., 2021; Munir & Ameer, 2022). Economic activities are mostly concentrated in urban areas and urbanization contribute to social, economic transformation, prosperity and economic development (Ahmed et al., 2019; Wang., 2021). The urbanization process is becoming more complex in terms of public services due to continuous rural migration resulting in urban agglomeration (Huo et al., 2021; Munir & Ameer, 2022). Along with rapid economic growth, challenges arise related to the expansion of urban populations, known as modernization. Indeed, the world has gone through aprocess of rapid urbanization over the last six decades. In 1950, more than two-thirds (70%) of the world's population lived in rural areas and less than one-third (30%) lived in urban areas. In 2014, 54% of the world's population lived in urban areas. New urban infrastructure will be needed to accommodate urban populations to promote growth.

Figure 1.Trends of CO_2 emissions for 10 Asian Economies over 1990–2020.



Source: Authors' draw based on WDI data.

However, the wave of rapid urbanization in recent decades has led to the potential for increased energy demand and environmental issues simultaneously.This has increased challenges related to environmental sustainability and aspects of ecological modernization (Wang et al., 2021). As societies increase in size and get more urbanized, they consume more energy at an aggregate level than rural areas. The increasing energy consumption levels in the urban areas, especially the extensive use of fossil fuels, have tremendously raised Green House Gas (GHG) emissions. These GHG emissions are considered to be one of the main driving forces of global warming anthropogenic climate changes in the world (Ali et al., 2017; Wang et al., 2021). The recent figures indicate that the cities in the world consume approximately two-third of the energy consumption resulting in 70% of global carbon emissions. Growth in urban population stimulates energy consumption by increasing the demand for food, housing, land usage, public utilities, residential home appliances, and urban transportation (Shahbaz et al. 2016). Moreover, poor urban population management highlights concerns, such as disposal of the massive amount of waste, high use of energy-intensive products, traffic congestion, water shortage, and lack of sanitation which ultimately leads to detrimental health and environmental consequences.

However, it is also assumed that urbanization contributes to environmental quality by stimulating technological innovation in energy use efficiency, environmental awareness, and green technology (Charfeddine and Mrabet, 2017). Ecological modernization theory reveals that high level of modernization will promote ecological understanding, environmentally friendly technology, energy efficiency, and structural changes that reduce pollution in a country (Poumanyvong and Kaneko., 2010). Ecological modernization theory, urban environmental transition, and compact city theory support nonlinear relationship of urbanization to environmental degradation. Interestingly, this theory provides a base to analyze the possible non-linear relationship between urbanization and environment (Shahbaz etal. 2016). Bekhet and Othman (2017) argued that the relationship between urbanization and environment may follow U-shape or inverted U-shape pattern, and a linear relationship is unrealistic.Urban agglomeration in large cities also increases residential CO_2 emissions caused by higher economic and urban development, further stimulating household energy consumption. In addition, technological advances contribute to define the relationship between urban agglomeration and environmental quality (Chen et al., 2019). Previous findings suggest that urbanization could have adverse effect on the environment due to ineffective urban planning and environmental policies.

Several previous studies have examined the non-linear relationship between urbanization and CO_2 emissions. However, the results are quite mixed and controversial regarding the exact nature of this non-linear relationship caused by regional factors, varying patterns of economic development, sample heterogeneity, inconsistent econometric models, and omitted variable bias (Chen et al., 2019; Hashmi et al., 2021). Bekhet & Othman (2017) documented an inverted U-shaped relationship between urbanization and CO_2 emissions. These findings support the ecological modernization theory which suggests that higher levels of urban development will improve environmental quality. Zhang et al. (2017) revealed that increasing urbanization can lead to the development of energy efficient infrastructure and green technology, environmentally friendly industrial and production processes, increased labor productivity, and increased living standards in mitigating environmental issues.

Ecological modernization theory is concerned with the phenomenon of urbanization and assumes the existence of inverted U-shaped relationship between urbanization and CO_2 emissions. Urbanization improves environmental quality after reaching a significant level of urban development due to efficient energy structures, population awareness, environmentally friendly technologies, and strict urban and environmental policies (Poumanyvong & Kaneko, 2010). Ecological modernization theory does not only focus on the economy as a whole, but also consider institutional factors and structural modernity that encourage the spread of ecological rationality to all dimensions of society (Chen et al., 2019).

Su et al. (2017) stated that ecological modernization theory provides useful policy insights for understanding the inverted U-shaped relationship between urbanization and environmental degradation. However, there are several shortcoming in the theory of ecological modernization theory. This theory postulated that urban trends improve the environment automatically by optimizing energy resources, improving governance mechanisms, designing environmentally friendly products and processes, and formulating and implementing effective urban systems. Therefore, several empirical studies found contradictory findings and documented U-shaped relationship of urbanization to environmental degradation, the findings support the role of urban development in increasing pollution at higher stages of urban development. For example, Shahbaz et al. (2016) found a U- shaped relationship between urbanization and CO_2 emissions in the case of Malaysia. Some findings failed to observe inverted U-shaped relationship between urbanization and CO_2 emissions in certain countries. For example, Zhu et al. (2012) found little evidence of an inverted U-shaped relationship in some developing countries.

Several findings revealed the benefits of urban agglomerations and explained that largest cities improve environmental quality in the long term because city compactness reduces pollution caused by proximity to city residents, energy-efficient housing and infrastructure, and efficient transportation (Bibri & Krogstie, 2019; Su et al al., 2018). Otherwise, the concentration of urban agglomeration can damage environmental sustainability. Urban expansion and urban migration to large cities have drastically affected the urban climate and environmental pollution due to increased infrastructure and buildings, increased energy use, paved roads, excessive transportation mobility such as bus services and motorization, reduction of agricultural land for urban development, and excessive population concentration (Emadodin et al., 2016; Su et al., 2018). Zhang et al. (2017) also revealed that excessive concentration in big cities reduces environmental quality in big cities in developing countries in Asia. These cities lack effective urban planning, inefficient urban structure, non-compact urban design, excessive population density, urban sprawl issues, traffic congestion, and inefficient transportation mechanisms (Gren et al., 2019; Mouratidis, 2019).

This study contributes to the existing literature in the following ways. First, this research studies multilevel analysis by examining how do urbanization, urban agglomeration and largest city ratio affect on environmental degradation at at regional, country, and city levels. Previous literatures provide different and inconclusive results regarding non-linear relationship between urbanization and environmental degradation. These findings vary between regions due to demographics, income levels, structural and cultural characteristics specific to each region (Wang et al., 2021; Zhang et al., 2017). These contradictory results are quite heterogeneous across countries and regions due to varying trends in economic growth, urban development, and urban management issues (Du & Xia, 2018).

Second, this research examined the nonlinear relationship of urbanization, urban agglomeration and largest city ratio on CO_2 emissions in 10 Asian economies, namely Bangladesh, India, Pakistan, Nepal, China, Indonesia, Malaysia, Thailand, the Philippines and Vietnam for the period 1990-2020. The countries selected in this sample, such as China, India, Indonesia, Pakistan, Bangladesh, are included in the list of the ten most populous countries in the world (Bureau, 2020). Furthermore, China, India, Indonesia, and Pakistan, are among the top seven countries represent for half of the world's population with a total of 3.97 billion tremendous growth in urbanization and has raised concern for environmental issues (Hackett, 2018).

Third, this study investigated the largest cities' role in affecting environmental quality. According to the latest report from the World Population Review, most of the largest cities in the world are located in countries in South Asia and East Asia, which include the seven largest cities in the world, including Delhi, Shanghai, Dhaka, Mumbai, and Beijing (World Population Review). The majority of these largest cities are located in India and China along with other cities with populations of 22 million and 25 million respectively. According to the latest WHO report, cities with populations of more than 100,000 residents in low- and middle-income countries do not meet air quality standards (WHO, 2018). These larger cities are still dealing with challenges of traffic congestion, inefficient infrastructure, weak sanitation mechanism, and urban sprawls This statistic is quite worrying because all the countries in this sample, according to the World Bank are categorized in low- and middle-income countries. Finally, this research links the main findings to urbanization theories and provides useful insights for policy makers to devise appropriate strategies for efficient urban planning for sustainable development in the region.

The rest of the paper has been organized as follows. Section 2 provides theoretical background and literature review. Model construction, data and variables description are elaborated in Section 3. Section 4 describes the results and findings supported and contradicted with prior studies to provide useful insight. The conclusion, policy implications, and recommendation for future research are stated in the last section.

REVIEW OF LITERATURE

Urbanization not only refers to a dynamic process in which rural labour migrates from agriculture sector to manufacturing and service sectors in urban areas due to socio-economic modernization and higher growth rates of productivity, but it also connotes a phenomenon of structural transformation of the rural areas into more developed urban areas (Poumanyvong and Kaneko;2010) Urbanization leads to increased income levels, better infrastructure, health and education facilities. The relationship between urbanization and environmental degradation can be explained through three theories: urban environmental transition, ecological modernization theory, and compact city theory. Ecological modernization theory focuses on environmental issues at the national level, while urban environmental transition and compact city theory focus on environmental issues at the city level.

Urban environmental transition theory explains the different urban environmental issues that occur according to the city's development stage (McGranahan et al., 2001), which are caused by limited resources, low levels of development, and poverty related to environmental issues (lack of clean water supply and inadequate sanitation). According to ecological modernization theory, in the early stages of development, urbanization will increase environmental pollution due to the high rapid increase in demand for electricity, fuel, transportation and construction. However, after reaching a significant level of development, urbanization will tend reducing CO_2 emissions through technological processes, government policies and advanced energy structures. By increasing urbanization, the accelerated level of education will increase environmental awareness through knowledge spillover. According to compact city theory, when urban areas become wealthy they will consume more energy which causes an increase in CO_2 emissions (McGranahan et al., 2001). However, this theory also highlights the positive effect of urbanization on resource allocation in combating pollution in urban areas that have higher per capita income (Capello & Camagni, 2000). In addition, as cities grow and become wealthy, as living standards improve, urbanization and the use of energy- saving products simultaneously

(Sadorsky,2013). Compact city theory also discusses the positive ideas of urbanization in combating pollution by promoting the concept of the positive effects of urbanization through economies of scale (Poumanyvong & Kaneko, 2010).

Several previous studies directly tested the linear relationship between urbanization and CO_2 emissions or added a quadratic to urbanization to examine the nonlinear relationship. However, findings vary between countries and regions due to heterogeneity, which is a common issues with panel data. For countries or regions in different stages ofdevelopment, with different production technologies and environmental issues, the relationship between urbanization and environmental degradation will differ along with these differences in characteristics. In addition, the relationship between urbanization and environmental degradation is not only related to the level of urbanization and CO_2 emissions, but also depends on economic growth, efficiency of energy use, population size, etc. The relationship between urbanization and CO_2 emissions has been documented extensively in several previous studies which can be synthesized as follows:

Several previous studies have examined the linear relationship between urbanization and CO_2 emissions and were found that urbanization has a positive effect on urbanization such as: Asghar et al., (2022), Al-Mulali et.al (2013), Dogan and Turkekul (2016). Asghar et al., (2022) documented the effect of urbanization on CO_2 emissions in Pakistan for the period 1984-2020 using the ARDL approach. The findings revealed that urbanization has a positive effect on urbanization of 1% which will increase CO_2 emissions by around 0.428% in Pakistan. High urbanization has increased the need for education, health and infrastructure. Urbanization has increased the demand for fossil fuels which has negative effect on the environment. Al-Mulali et.al (2013) found a positive effect of urbanization on CO_2 emissions using a panel for MENA countries during 1990-2013. The FMOLS and VECM results showed that urbanization, financial development and economic growth have positive effect on CO_2 emissions. However, trade openness and renewable energy reduced CO_2 emission levels. Dogan and Turkekul (2016) examined the effect of real output (GDP), square of real output (GDP^2), energy consumption, trade openness, urbanization, financial development on CO_2 emissions for the period 1960-2010 in the USA. The findings indicated that energy consumption and urbanization have positive effect on CO_2 emissions. The findings rejected the EKC hypothesis in the USA because real output (GDP) leads to environmental improvements while (GDP^2) increases CO_2 emissions. Financial development has no effect on CO_2 emissions and trade openness has negative effect on CO_2 emissions.

A country's level of economic development may significantly moderate the relationship between urbanization and pollution. For example, Fan et al. (2006), Li and Lin (2015), Poumanyvong and Kaneko (2010), Sharma, (2011) found that urbanization has a negative effect on CO_2 emissions in upper-middle-income groups. Fan et al. (2006) divided all 208 countries into 4 groups, based on the level of GNP per capita: high-income groups, upper-middle-income groups, lower-middle-income groups, and low-income groups. The findings showed that urbanization has negative effect on CO_2 emissions in high- income groups and positive effect on other income groups. The effect of urbanization on reducing CO_2 emissions is limited by other variables, such as the level of economic development, energy structure and etc.

Li and Lin (2015) documented that the effect of urbanization on energy consumption and CO_2 emissions varies with different stages of development. The study groups 73 countries over 1971–2010 into four groups based on income level. In the low income groups, urbanization reduced energy consumption but increases CO_2 emissions. In the middle-/ low-income and high-income groups, industrialization reduces energy consumption but increases CO_2 emissions, while urbanization significantly increases energy consumption and CO_2 emissions. In the middle-/high- income groups, urbanization has no significant effect on energy consumption, but inhibits the increase in CO_2 emissions, while industrialization turns out to have an insignificant effect on energy consumption and CO_2 emissions. Population has a positive effect on energy consumption, and also increases CO_2 emissions except in the high income groups.

Poumanyvong and Kaneko (2010) examined 99 countries and divided them into three groups, namely low-income groups, middle-income groups, and high- income groups by empirically investigating the effect of urbanization on energy use and CO_2 emissions by considering different stages of development. The findings showed that the effect of urbanization on energy use and CO_2 emissions varied at each stage of development. The findings showed contradictory and surprising results that urbanization has negative effect on energy use in low-income groups and positive effect in middle and high-income groups. Urbanization has positive effect on all income groups, but is more pronounced in the middle income groups than in other income groups. Sharma, (2011) examined 69 countries in 3 income groups (high income groups, middle income groups, and low income groups). The findings showed that urbanization has negative effect on CO_2 emissions for all income groups. 1% increase in urbanization will reduce the level of CO_2 emissions by 0.7% . It can be concluded that urbanization is not one of the main factors determining CO_2 emissions in income groups.

Previous results examined the nonlinear relationship between urbanization and CO_2 emissions. For example, Zhu et al (2012) studied 20 developing countries over 1997-2013 period using semi- parametric fixed effects. Findings revealed little support for U-shape curve hypothesis. Several previous studies found U-shaped relationship between urbanization and CO_2 emissions Zi et al. (2016), Shahbaz et al., (2017), Muhammad et al., (2020). Zi et al. (2016), applied panel threshold regression at the regional level in China and found a U-shaped curve, but the findings varied for different regions in China. Shahbaz et al., (2017) also found U-shaped relationship for Pakistan using the Johnson cointegration method. Muhammad et al., (2020) documented 65 countries in 3 income groups in the Belt and Road Initiative (BRI) over 2000-2006 and documented inverted U-shaped relationship between urbanization and CO_2 emissions in the high income groups. Meanwhile, urbanization was found to have U-shaped relationship with CO_2 emissions in the low and lower middle income groups. The EKC hypothesis was confirmed in the upper middle and high income groups. Energy use increases CO_2 emissions in high income groups. FDI increases CO_2 emissions in lower income groups.

In contrast, urbanization has inverted U-shaped relationship with CO_2 emissions such as: Fan et al., (2020), Martinez-Zarzoso and Maruotti (2012). Fan et al., (2020) examined the relationship between urbanization and CO_2 emissions in 4 South Asian countries, namely Pakistan, India, Bangladesh and Nepal over 1974-2014 using Fully Modified Ordinary Least Squares (FMOLS). This study found inverted U-shaped relationship between urbanization and CO_2 emissions in these three countries, except Nepal. These findings supported ecological modernization theory and urban transition theory that as cities develop and incomes increase, residents will have higher awareness of pollution and environmental sustainability. Meanwhile, urban agglomeration has U-shaped relationship with CO_2 emissions for all samples. However, this study rejected the compact city theory because urban agglomeration showed U-shaped relationship to CO_2 emission levels. Urban agglomerations in these countries have high population densities and are faced with more environmental problems such as inadequate sanitation and drainage, lack of clean water, urban waste disposal, slum areas around metropolitan cities, and urban sprawl problems. Findings also confirmed the effect of urban agglomeration on CO_2 emissions except for Nepal which has the lowest level of urban agglomeration.

Martinez-Zarzoso and Maruotti (2012) examined the effect of urbanization on CO_2 emissions in developing countries over 1975-2003 using the STIRPAT model. This study found evidence that urbanization had inverted U shaped on CO_2 emissions.The findings rejected the EKC hypothesis for developing countries. The elasticity of CO_2 emissions-urbanization is positive for low levels of urbanization, this findings consistent with the reduction in environmental degradation in the upper middle income groups. Negative elasticity of urbanization and CO_2 emissions in the lower middle income groups. Increasing urbanization did not contribute to increasing CO_2 emissions. Only population and economic growth affected CO_2 emissions in the low income groups. The ecological modernization theory was confirmed in upper middle and low income groups. Bekhet and Othman (2017) also found similar findings for the Malaysian case using the ARDL and VECM approaches. Xu and Lin (2015) confirmed the inverted U- shaped nonlinear relationship between industrialization and CO_2 emissions of three regions in China. Urbanization had inverted U-shaped relationship with CO_2 emissions in the eastern region and U-shaped relationship in the central region. However, the result found that urbanization had no significant effect in the western region.

Several previous findings also found inconclusive results and documented an insignificant effect of urbanization on CO_2 emissions. Sadorsky, (2013) examined the effect of urbanization on CO_2 emissions in 16 developing economies. The findings revealed that urbanization had no effect on CO_2 emissions.One implication of this finding is that urbanization has little effect on CO_2 emission reduction strategies and sustainable development policies. Similar results were found by Rafiq et al., (2016) documented that urbanization have no effect on CO_2 emissions, it appeared to be a major factor behind increased energy use.

Model Construction

The Environmental Impacts of Population, Affluence and Technology (IPAT) proposed by

Ehrlich and Holdren (1971) has generally been used in several previous studies to capture the impact of human activities on environmental degradation. The IPAT model can be expressed in the multiplicative form:

$$I = PAT. \tag{3.1}$$

Explanation:
I: Environmental impact
P: Population
A: Affluence
T: Technology

Based on equation 3.1 I denotes the environmental impact (i.e. CO_2 emissions), P refers to the demographic impact (population); A denotes economic factors (prosperity or GDP per capita), and T denotes technological factors (i.e. efficiency of energy use). However, this model causes generalization issues because it captures neutral effects on one variable and holds other variables constant. One of the shortcoming of the IPAT model is that it does not guarantee the non-proportional or non-monotonic influence of GDP per capita as proposed by the EKC theory on the environment. Therefore, the static model is further modified and transformed into a known dynamic model Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) developed by (Dietz & Rosa, 1997). The basic STIRPAT model can be expressed in exponential form as follows

$$= \alpha P^{\beta} A^{\gamma} \; T^{\lambda} \mu \tag{3.2}$$

As in equation 3.1 equation 3.2 shows that I represents environmental degradation (CO_2 emissions), P represents the population of a country, A represents income (GDP per capita), T represents technology (energy efficiency), and μ is the error of the STIRPAT model which implies stochastic variables. Furthermore, several researchers have developed this model by adding additional variables such as urbanization, structural change, age structure, energy mix, financial development, income inequality, fixed asset investment, domestic investment, trade openness, and research and development intensity (Koçak and et al., 2015). Because this research examines the relationship between energy intensity, economic growth, urbanization, urban agglomeration, largest city ratio, and trade openness on CO_2 emissions, the model is as follows:

$$lnCO_{2it} = \alpha 0 + \alpha_1 lnEI_{it} + \alpha_2 lnGDP_{it} + \alpha_3 lnURB_{it} + \alpha_4 \ln UAG_{it} + \alpha_5 \ln LCR_{it} + \alpha_6 \ln TOP_{it} + \alpha_7 lnFDV_{it} + \mu_{it} \tag{3.3}$$

Trade openness and financial development (FDV) are additional variables considered in previous studies. Following previous studies (Shahbaz et al., 2016), energy intensity has been used as a proxy for technology because improved and environmentally friendly technology is assumed to increase efficient energy use, lower fossil fuel consumption, and encourage more reliance on renewable energy:

Furthermore, the results of Shahbaz et al. (2016) and Ahmed et al. (2019), quadratic terms on urbanization and urban agglomeration have also been added to this model to test an inverted U-shaped relationship. The logic behind adding a quadratic term to urbanization is based on ecological modernization theory and urban environmental transition which postulate that higher levels of urbanization bring more awareness of environmental degradation, quality of life, efficient use of energy, improved infrastructure, and environmentally friendly technologies (Poumanyvong & Kaneko, 2010). Therefore, ecological modernization theory and urban transition theory postulate a basis for testing the non-linear influence of urbanization and urban agglomeration on CO_2 emissions, the expected coefficient signs of the squared terms of urbanization and urban agglomeration should be negative to justify ecological modernization theory and urban environmental transition ($\alpha 4 < 0$).

$$lnCO_{2it} = \alpha_0 + \alpha_1 lnEI_{it} + \alpha_2 lnGDP_{it} + \alpha_3 lnURB_{it} + \alpha_4 (lnURB)^2_{it} + \alpha_5 lnTOP_{it} + \alpha_6 lnFDV_{it} + \mu_{it} \tag{3.4}$$

$$lnCO_{2it} = \alpha_0 + \alpha_1 lnEI_{it} + \alpha_2 lnGDP_{it} + \alpha_3 lnUAG_{it} + \alpha_4 (lnUAG)^2_{it} + \alpha_5 lnTOP_{it} + \alpha_6 lnFDV_{it} + \mu_{it} \tag{3.5}$$

Similarly, a quadratic term has been added to the largest city ratio to test the compact city theory which states that as cities become larger and more compact, the use of efficient transportation and other infrastructure drives and enhances economies of scale to urban residents (Bibri & Krogstie, 2019). Therefore, the quadratic term coefficient of the largest city ratio is expected to have a negative sign ($\alpha 4 < 0$).

$$lnCO_{2it} = \alpha_0 + \alpha_1 lnEI_{it} + \alpha_2 lnGDP_{it} + \alpha_3 lnLCR_{it} + \alpha_4 (lnLCR)^2_{it} + \alpha_5 lnTOP_{it} + \alpha_6 lnFDV_{it} + \mu_i \quad (3.6)$$

Data and variables description

This study used annual data from 10 Asian economies, namely Bangladesh, India, Pakistan, Nepal, China, Indonesia, Malaysia, Thailand, the Philippines and Vietnam for the period 1990–2020 using World Development Indicators (WDI) data from the World Bank. This study began in 1990 because consistent data was available for all variables. All variables are converted into logarithmic to reduce the possibility of econometric issues heteroscedasticity, variable dimensions, and enhancing the reliability of estimates.

Table 3.1 Description of Variables

Variables	Proxy	Source	References
CO_2 emissions (CO_2)	CO_2 metric tons per capita	WDI	(Du and Xia,2018)
Energy intensity (EI)	Energy use kg of oil equivalent per capita	WDI	(Du and Xia,2018)
Economic growth (GDP)	GDP per capita (constant 2015 $)	WDI	(Du and Xia,2018
Urbanization (URB)	Urban population percent of total Population	WDI	(Niu & Lekse,2018)
Urban agglomeration (UAG)	Urban concentration more than 1 million in a country	WDI	(Niu & Lekse,2018)
Largest city ratio (LCR)	Urban population in the largest City (as percent of totalpopulation)	WDI	(Du and Xia,2018)
Trade openness (TOP)	Trade as percent of GDP	WDI	(Nasreen et al.,2018)
Financial development (FDV)	Domestic credit to private sectorby bank (% of GDP)	WDI	(Du and Xia,2018)

Source: Made by the authors based on prior studies

RESULT AND DISCUSSION

Table 4.1 reports the summary results and correlation analysis for 10 Asian economies. The values of mean, median, standard deviation, maximum, and minimum have been displayed without log transformation to have a better understanding of data. Table 4.1 explains the statistical summary which can be explained as follows: Average value of CO_2 emissions in 10 Asian economies for the period 1990-2020 is 1,960 metric tons per capita. The average energy intensity is 717,692 kg of oil equivalent per capita. The average value of GDP per capitais 9142,940 dollars per year. The average value of urbanization is 37.24%, which implies that more than a third of the population lives in urban areas. Moreover, the average value of urban agglomeration is 13.63%, which implies that around 13.63% of the population lives in metropolitan cities. The average value of the largest city ratio in is 20.02%. This implies that the proportion of the population living in the largest citiesis about 20.02% higher than the urban agglomeration ratio but lower than overall urbanization ratio. It indicates that urban concentration in the largest cities is increasing rapidly which can pose challenges to the environment. The average value of trade openness is 69.41% and the average value of financial development is 59.68%.

The correlation matrix shows the degree of relationship between variables. Multicollinearity issues can affect the accuracy of the results and make them biased and misleading. There is no multicollinearity issues because all correlation coefficients indicate the relationship between are lower than the 80% (Gujarati; 2018) threshold. In addition, a variance inflation factor (VIF) test has also been applied and this confirms that the results are not affected by multicollinearity issues because all VIF values are lower than the threshold level of 8. Summary statistics by country are also explained in Table 4.2.

Cross-Sectional Dependence Test

Prior studies generally used the Breusch and Pagan tests to test for cross-sectional dependence, but these methods pose several econometric issues. Therefore, Pesaran (2001) introduced more accurate tests such as the cross-sectional dependence (CD) and Langrage multiplier (LM) tests to address the weaknesses of previous methods. The results of the cross-sectional dependence are shown in Table 4.3. The cross-sectional dependence results are shown in Table 4.3. Almost all statistical values are significant at the 1% level which verifies the cross-sectionalsectional dependence on the variables of urbanization, urban agglomeration, and largest city ratio.

Table 4.1 . Summary statistics and correlation analysis in 10 Asian Economies

Variabel	Mean	SD	Min	Max	CO_2	EI	GDP	URB	UAG	LCR	TOP	FDV	VIF
CO_2	1.960	2.081	0.047	7.756	1								
EI	717.692	616.537	100.506	2930.848	0.745	1							1.630
GDP	9142.940	2229.032	825.352	14.616.413	0.538	0.358	1						1.733
URB	37.241	14.561	8.854	77.160	0.795	0.818	0.265	1					5.062
UAG	13.636	5.183	2.029	29.035	0.744	0.677	0.547	0.791	1				4.903
LCR	20.028	10.283	2.867	36.238	-0.078	0.028	-0.525	0.034	-0.135	1			1.413
TOP	69.411	45.981	15.506	220.406	0.568	0.608	-0.176	0.520	0.245	0.419	1		1.433
FDV	59.681	41.617	12.470	182.858	0.636	0.755	0.475	0.517	0.536	0.018	0.587	1	2.024

Note: SD denotes standard deviation; VIF denotes variance inflation factor; Min and Max show the minimum and maximum values, respectively. CO_2 is carbon dioxide emissions; EI is energy intensity; GDP denotes economic growth; URB is urbanization; UAG denotes agglomerations; LCR denotes the largest city ratio; TOP denotes trade openness, and FDV denotes financial development.

Table 4.2 Country-wise summary statistics

	Proxy	CO_2	EI	GDP	URB	UAG	LCR	TOP	FDV
Bangladesh	Mean	0.280	150.385	1265.167	27.672	11.618	32.683	32.214	29.544
	Maximum	0.586	227.128	2667.597	38.177	15.545	33.746	48.110	44.204
	Minimum	0.099	100.606	528.339	19.811	8.066	31.189	18.889	14.545
	Std. Dev.	0.154	37.915	641.456	5.753	2.185	0.523	8.440	10.150
India	Mean	1.133	427.304	12.861.995	29.584	13.086	5.688	35.408	38.290
	Maximum	1.795	630.900	26.89.2052	34.926	15.732	6.210	55.793	54.751
	Minimum	0.647	307.646	4.652528	25.547	11.068	5.465	15.506	22.510
	Std. Dev.	0.380	91.781	7088.770	2.851	1.353	0.234	12.783	12.266
Pakistan	Mean	0.693	403.161	2177.086	33.946	17.015	19.193	30.790	19.747
	Maximum	0.918	461.601	3632.420	37.165	19.789	20.252	38.499	25.474
	Minimum	0.505	325.912	1104.505	30.576	15.595	18.495	21.459	13.804
	Std. Dev.	0.101	36.207	785.894	1.934	1.266	0.581	4.879	4.152
	Mean	0.183	328.492	172.122	14.897	3.200	21.351	45.844	39.681

Table 4. 3 Result of cross-sectional dependence test

	URB		UAG		LCR	
Test	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
Breusch-Pagan LM	348.015***	(0.000)	475.735***	(0.000)	170.602***	(0.000)
Pesaran scaled LM	31.940***	(0.000)	45.403***	(0.000)	13.239***	(0.000)
Bias-corrected scaled LM	31.774***	(0.000)	45.236***	(0.000)	13.073***	(0.000)
Pesaran CD	-0.627	(0.530)	-2.498 **	(0.012)	-0.670	(0.502)

Note: *, **, *** indicates 1%, 5% and 10% levels of significance

4.2 Panel unit root test

Due to this data has cross sectional dependence, unit root first generation panel testing is not appropriate. Therefore, this research applies the unit root test in second generation proposed by Pesaran (2001) which explains cross sectional dependence using the cross sectional Im, Pesaran, and Shin (CIPS) and Dickey-Fuller augmented cross-sectional (CADF) methods.This technique proposed by Pesaran (2001). CIPS and CADF consider the issues of cross-sectional dependence from one country and the results are consistent and reliable in the presence of cross sectional dependence which clearly shows that all variables are stationary the first difference and have an integration order of (1) which provided in Table 4.4

4.3 Panel cointegration test

This study utilized Kao (1999) residual-based cointegration test and Johnson–Fisher Test (Maddala and Wu, 1999) to check the robustness of results.The panel cointegration results for urbanization, urban agglomeration, and largest city ratio. As explained in the Pedroni test results if most of the tests are statistically significant, then this leads to the rejection of the null hypothesis that there is no cointegration.Therefore, this research accepts the alternative hypothesis that there is cointegration between urbanization, energy intensity, economic growth, trade openness, and financial development with CO_2 emissions. Similar findings were also explained for urban agglomeration where four of the seven statistical tests confirmed that there was cointegration between urban agglomeration and CO_2 emissions along with other variables likewise, the largest city ratio shows that five of the 7 statistics are significant along with other determinant variables which shown in Table 4.5

4.4 Dynamic Seemingly Unrelated Regressions (DSUR)

After investigating the long-term relationship in the three models, the next step is to determine the long-term elasticity and nonlinear effect of urbanization, urban agglomeration and largest city ratio on CO_2 emissions using dynamic seemingly unrelated regressions (DSUR) proposed by Mark et.al (2005) compared to first generation estimates such as FMOLS and DOLS. We have tested the nonlinear effect of urbanization ratio, urban agglomeration, and largest city ratio on carbon emissions using this estimation technique. In the first model, we documented that urbanization has an inverted U-shaped effect on CO_2 emissions in Asian economies. In the first model which explained in Table 4 we documented that urbanization has an inverted U-shaped effect on CO_2 emissions in Asian countries. These results show that urbanization increases environmental degradation in the early stages of growth, but after reaching a certain threshold, urbanization will reduce the level of emissions and environmental quality enhanced. This finding is consistent with Bekhet and Oman (2017), who also documented the inverted U-shaped effect of urbanization on CO_2 emissions in Malaysia.

In the second model, the findings documented that urban agglomeration has an inverted U-shaped influence on CO_2 emissions in 10 Asian developing economies. The

Table 4.2 Country-wise summary statistics

	Proxy	CO_2	EI	GDP	URB	UAG	LCR	TOP	FDV
Nepal	Maximum	0.531	425.666	306.052	20.576	4.850	23.682	64.035	88.340
	Minimum	0.047	290.501	82.535	8.854	2.028	19.321	32.188	12.470
	Std. Dev.	0.142	37.764	65.597	3.492	0.893	1.470	7.291	21.482
	Mean	4.665	1166.302	59.65.5327	43.024	19.773	3.049	41.608	118.577
	Maximum	7.756	2224.355	146.164136	61.428	29.035	3.144	64.478	182.858
China	Minimum	1.914	651.075	10.273792	26.442	10.328	2.867	22.199	83.097
	Std. Dev.	2.181	529.722	43.778069	11.031	5.779	0.075	11.527	26.758
	Mean	1.518	671.083	5.790.644	45.082	12.383	9.299	53.474	34.456
	Maximum	2.245	880.121	10.493.302	56.641	13.708	14.673	95.186	60.816
Indonesia	Minimum	0.814	3 91.632	2.702.593	30.584	11.720	6.994	32.972	18.155
	Std. Dev.	0.390	1 52.734	2.405.160	7.868	0.618	2.220	11.995	12.875
	Mean	5.963	1986.033	2.009.331	65.399	18.670	28.347	69.370	116.431
Malaysia	Maximum	7.719	2930.838	3.646.022	77.160	24.086	31.216	20.406	154.892
	Minimum	3.117	1029.126	746.275	49.794	11.974	24.049	16.788	69.412
	Std. Dev.	1.402	607.931	868.162	8.464	3.404	1.753	31.315	18.291
	Mean	3.056	1124.735	2848.174	37.688	14.700	30.833	113.052	108.500
	Maximum	3.824	1824.781	4566.828	49.949	19.576	36.238	140.437	166.503
	Minimum	1.593	459.599	1440.449	29.424	11.665	27.618	75.782	83.369
	Std. Dev.	0.654	413.602	893.918	7.324	2.687	2.908	21.620	21.252
Thailand	Mean	3.056	1124.735	2848.174	37.688	14.700	30.833	113.052	108.500
	Maximum	3.824	1824.781	4566.828	49.949	19.576	36.238	140.437	166.503
	Minimum	1.593	459.599	1440.449	29.424	11.665	27.618	75.782	83.369
	Std. Dev.	0.654	413.602	893.918	7.324	2.687	2.908	21.620	21.252
	Mean	0.924	458.160	2049.035	46.226	14.244	27.553	66.857	33.845
	Maximum	1.321	512.967	3962.244	47.408	15.021	29.157	87.574	52.035

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Table 4.2 Country-wise summary statistics

	Proxy	CO_2	EI	GDP	URB	UAG	LCR	TOP	FDV
Filipina	Minimum	0.641	410.843	1066.416	45.332	13.891	26.178	42.922	15.575
	Std. Dev.	0.174	27.803	893.547	0.563	0.323	0.736	13.422	9.497
	Mean	1.322	399.111	1492.824	27.816	11.864	13.030	119.670	66.173
	Maximum	3.676	673.964	3239.721	37.340	17.924	23.892	164.704	126.380
Vietnam	Minimum	0.288	254.904	450.579	20.257	7.852	22.308	66.212	13.656
	Std. Dev	0.958	145.081	837.940	5.289	3.155	0.508	30.583	36.292

Note: Std. Dev is standard deviation; CO_2 is carbon emissions; EI; energy intensity; GDP; economic growth or income per capita; URB; urbanization; UAG; urban agglomerations; LCR; largest city ratio; TOP; trade openness, and FDV denotes financial development.

Table 4.6 Result of non-linear relation Dynamic Seemly Unrelated Regressions (DSUR) test

Model 1 Urbanization and CO_2 emissions				Model 2 Urban agglomeration and CO_2 emissions				Model 3 Largest city ratio and CO_2 emissions			
Variabel	Coeff.	t-Stat.	Prob.	Variabel	Coeff.	t-Stat.	Prob.	Variabel	Coeff.	t-Stat.	Prob.
LnEI	0.001***	45.627	(0.000)	LnEI	0.002***	64.914	(0.000)	LnEI	0.002***	69.259	(0.000)
LnPDB	2.286***	18.652	(0.000)	LnPDB	2.295***	18.309	(0.000)	LnPDB	2.038***	16.704	(0.000)
LnURB	0.009***	5.276	(0.000)	LnUAG	0.076***	24.898	(0.000)	LnLCR	0.104***	35.718	(0.000)
$LnURB^2$	-0.000***	-15.842	(0.000)	$LnUAG^2$	-0.001***	-10.657	(0.000)	$LnLCR^2$	0.002***	37.027	(0.000)
LnTOP	0.004***	10.874	(0.000)	LnTOP	0.000***	13.852	(0.000)	LnTOP	0.008***	21.215	(0.000)
LnFDV	0.010***	24.324	(0.000)	LnFDV	0.000***	1.743	(0.000)	LnFDV	0.003***	10.639	(0.000)
Constant	-0.636			Constant	-1.239			Constant	0.144		
F statistic	5611.320			F statistic	4710.994			F statistic	5364.843		
(Prob.)	(0.000)			(Prob.)	(0.000)			(Prob.)	(0.000)		

Note: *, **, *** indicates 1%, 5% and 10% levels of significance, p-values denotes probability values of coefficients; furthermore, DSUR tests also examine and establish non-linear effects (squared terms) of urbanization, urban agglomeration and largest city ratio on carbon emissions in the overall panel.

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Table 4.4 Result of panel unit root test

Variables	LLC		IPS		ADF-Fisher		PP-Fisher		CADF		CIPS	
	C	C+T	C	C+T	C	C+T	C	C+T	C	C+T	C	C+T
$LnCO_2$	-0.808	0.344	2.001	0.626	14.473	20.842	16.308	14.002	0.867	0.672	-1.876	-2.719
LnEI	3.470	0.210	6.059	2.764	6.869	10.270	12.774	9.967	0.543	1.874	-2.916**	-2.871**
LnGDP	9.709	0.934	10.744	5.216	8.154	11.601	0.408	4.380	3.567	5.986	-1.820	-1.126
LnURB	-2.490***	-6.302***	0.451	-2.226***	46.041***	40.229***	55.485***	14.661	0.875	1.345	-1.265	-1.791
LnUAG	1.828	-4.589***	4.508	-0.636	12.132	29.814*	3.091	15.152	-1.754*	-0.213	-2.302**	-2.502
LnLCR	-3.366***	-6.103***	-1.649**	-3.754***	36.878**	56.582***	56.710***	27.448	-0.632	0.402	-1.965	-2.450
LnTOP	-1.042	0.783	0.329	2.107	17.866	12.102	19.290	17.270	1.215	3.456	1.765	1.765
LnFDV	0.378	0.562	1.150	0.285	19.858	16.747	12.675	10.098	2.241	4.568	1.670	2.345
$\Delta LnCO_2$	-1.247	0.445	-5.662***	-3.372***	66.227***	56.624***	116.379***	155.122***	-4.584***	-3.756***	-2.163***	-2.688***
ΔLnEI	-8.245***	-5.662***	-9.702***	-8.455***	128.663***	105.901***	163.280***	253.709***	-4.443***	-3.699***	-2.014***	-2.455***
ΔLnGDP	0.578	6.934***	-1.704**	-1.469*	36.085**	41.778***	43.379***	25.851	-5.167***	-3.383***	-3.002***	-1.927***
ΔLnURB	-0.419**	0.104	1.486*	0.272	11.037*	36.064**	9.384	29.990*	-3.015***	-3.553***	-0.947***	-2.306***
ΔLnUAG	-1.168**	1.393*	-0.171**	0.998	21.978**	21.438**	18.411*	16.945*	-3.211***	-2.871***	-1.800***	-1.660***
ΔLnLCR	-2.479***	-1.619*	-2.136**	-1.621*	-1.621*	29.373*	25.934	25.934	-1.125***	-4.717***	-0.389***	-2.610***
ΔLnTOP	-4.624***	-4.065***	-6.747***	-6.410***	84.298***	77.038***	150.963***	159.757***	-3.154***	-3.699***	-2.014***	2.455***
ΔLnFDV	-5.878***	-4.685***	-5.804***	-3.688***	71.554***	47.038***	120.796***	93.556***	-4.584***	-3.756***	-2.163***	2.688***

Note: *, **, *** indicates 10%, 5% and 1% level of significance respectively; LLC = Levin, Lin and Chu test; IPS =Imp, Pesaran and Shin test; ADF = Augmented Dicky-Fuller test; PP= Philips Perron test; CADF is cross-sectional AFD panel unit root test, and CIPS cross-sectional Im Pesaran and Shin test. C means constant and C + T denotes constant plus trend. LLC, IPS, ADF Fisher, and PP-Fisher denote first-generation panel unit root tests, while CADF and CIPS denote second generation panel unit root tests. The results point out that all variables have an integration order of one, I (1).

findings from the second model support ecological modernization theory which states that higher levels of urban development will improve environmental quality. According to Ecological Modernization Theory, environmental issues increase in the early stages of urban development because urban residents pursue economic growth at the expense of environmental sustainability. However, at significant income levels, urban residents have high awareness of environmental issues and environmental quality. Urbanization enhances environmental quality after reaching a significant level of urban development due to efficient energy structures, population awareness, environmentally friendly technologies, and strict urban and environmental policies. This finding is consistent with Fan (2020), who also documented the effect of inverted U-shaped urban agglomeration on CO_2 emissions in South Asia.

In the third model, the findings documented that the largest city ratio has a U-shaped effect on CO_2 emissions at in 10 Asian economies. It indicates that the urban population in the largest cities of Asian economies causes more pollution. Initially, the largest cities reduced environmental degradation due to urban compactness and efficient infrastructure. However, overcrowding and concentration in these largest cities has raised concerns about environmental quality and increased carbon emissions. This finding is consistent with the findings of Zhang et.al. (2017), who found a positive effect of population density in Asian cities on CO_2 emissions. Other variables, such as energy intensity, economic growth, trade openness, and financial development also found long- term relationships with CO_2 emissions in the three cases of urbanization, urban agglomeration, and largest city ratio.

These findings explained that increasing energy consumption can have positive effect on CO_2 emissions in the long term. Increasing use of fossil fuel energy in the long term will have negative effect on the environment.This findings are consistnet with Du and Xia (2018) in 66 countries and Ahmed et. al (2019) for Malaysia, who documented the positive effect of energy consumption on environmental degradation. High levels of energy consumption cause environmental degradation, furhermore, policy makers need to focus on technological advances, which can reduce emission intensity. Renewable energy sources (e.g. solar wind)– associated with efficient technologies are also needed to improve environmental quality (Chen et.al 2019).

Economic growth also has positive and significant effect on CO_2 emissions at the critical level of 1% in all three models.This explains that growth reduces environmental quality and increases pollution. Higher economic growth has increased challenges to environmental quality and sustainability in 10 Asian economies over time. This result is consistent with Ahmed et.al (2019), who found a positive effect of GDP on ecological footprints and CO_2 emissions in G7 economies. Similar results also reported by Khoshnevis and Dariani (2019) for Asian economies.

Trade openness has a positive and significant effect on CO_2 emissions at the critical level of 1% in all three models. Trade openness also has a positive and significant effect on CO_2 emissions at the critical level of 1% in all three models These findings imply that trade openness reduces environmental quality. Trade openness can increase CO_2 emissions through scale effects. These results are consistent with the findings of Khan et al. (2019) for Pakistan, Shahbaz et.al (2016) for Malaysia, and Zhang et al. (2017) for 141 countries, who reported a positive effect of trade openness on pollution in the long run. Financial development also has positive and significant effect on CO_2 emissions at the critical level of 1% in all three models. Financial development can increase CO_2 emissions because financial development grows industrialization and results in more industrial pollution.Increased financial development causes more FDI inflow which causes an increase in CO_2 emissions. Financial development encourages infrastructure projects by providing medium and long term development loans.This infrastructure project includes the construction of roads, railways and seaports and

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Table 4.5 Result of panel cointegration test

	Model 1 Urbanization and CO_2 emissions				Model 2 Urban Agglomeration and CO_2 emissions				Model 3 Largest city ratio and CO_2 emissions			
Pedroni Test	t-Stat.	Prob.	Weighted test	Prob.	t-Stat.	Prob.	Wighted test	Prob.	t-Stat.	Prob.	Wighted test	Prob.
Panel v-Statistic	-0.604	0.727	-2.753	0.997	-3.079	0.998	-3.073	0.998	-0.736	0.769	-0.248	0.598
Panel rho-Statistic	4.175***	0.000	3.995	0.984	4.505***	0.000	4.352	0.999	4.196***	0.000	4.506	0.995
Panel PP-Statistic	1.568	0.941	-1.352**	0.048	2.812	0.887	-3.262***	0.000	1.006	0.843	-2.054**	0.020
Panel ADF-Statistic	-4.476***	0.000	-2.742***	0.003	3.336	0.994	-1.747**	0.040	-1.914**	0.027	-2.997***	0.001
Panel rho-Statistic	5.461***	0.000			5.484***	0.000			5.790***	0.000		
Panel PP-Statistic	-3.949***	0.000			-7.423***	0.000			-3.598***	0.000		
Panel ADF-Statistic	-4.118***	0.000			-3.193***	0.000			-3.721***	0.000		

	Urbanization and CO_2 emissions		Urban Agglomeration and CO_2 emissions		Largest city ratio and CO_2 emissions	
Kao test	t-Stat.	Prob.	t-Stat.	Prob.	t-Stat.	Prob.
ADF	2.7428***	0.003	1.8211**	0.034	2.4270***	0.007

Fisher test	Urbanization and CO_2 emissions				Urban Agglomeration and CO_2 emissions				Largest city ratio and CO_2 emissions			
Hypothesized No.of CE(s)	Fisher Stat*(from trace test)	Prob.	Fisher Stat* (from max – eigen test	Prob.	Fisher Stat*(from trace test)	Prob.	Fisher Stat*(from max –eigen test	Prob.	Fisher Stat*(from trace test)	Prob.	Fisher Stat*(from max – eigen test	Prob.
None	577.4***	0.000	417.1***	0.000	517.1***	0.000	319.1***	0.000	550.2***	0.000	417.8***	0.000
At most 1	410.1***	0.000	173.3***	0.000	371.4***	0.000	139.5***	0.000	420.6***	0.000	180.7***	0.000
At most 2	277.2***	0.000	124.4***	0.000	262.0***	0.000	108.5***	0.000	287.1***	0.000	140.0***	0.000
At most 3	178.9***	0.000	78.49***	0.000	176.4***	0.000	100.9***	0.000	178.4***	0.000	95.75***	0.000
At most 4	118.6***	0.000	67.93***	0.000	94.97***	0.000	49.16***	0.000	102.1***	0.000	65.73***	0.000
At most 5	74.24***	0.000	53.43***	0.000	69.31***	0.000	49.09***	0.000	57.55***	0.000	50.45***	0.000
At most 6	60.57***	0.000	60.57***	0.000	56.09***	0.000	56.09***	0.000	57.99**	0.012	36.79**	0.012

Note: *, **, *** indicates 1%, 5% and 10% levels of significance, , p-values denotes probability values of coefficients.

requires enormous land, water and air resources, causing environmental pollution. This finding is consistent with Shahzad et. Al (2016) illustrated that financial development growth of 1% will increase CO_2 emissions by 0.17% in the case of Pakistan, Mrabet and Alsamara 2017 for Qatar, Ali et al. (2017) for the case of Nigeria, Al Mulali et al. (2013) for MENA countries.

4.5 Augmented Mean Group (AMG)

The Augmented Mean Group (AMG) method is used to check non- linearity at the country level because this technique not only consider cross-country heterogeneity but is also reliable for several variables with second-order cointegration (Danish et al., 2019a). Non-linearity results by country are reported in Table 4.7.The first panel of these results capture the nonlinear effect of urbanization on CO_2 emissions in 10 Asian economies. We found that urbanization has an inverted U-shaped effect on pollution in two countries , Pakistan and Thailand. The urbanization quadratic term $(\ln URB)^2$ is negative, which confirms the inverse effect of URB on carbon emissions in these countries. These findings support the ecological modernization theory which assumes that urbanization improves environmental quality after reaching a certain threshold. These results are consistent with Zhang et al. (2017) for a cross-country panel and Ahmed et al. (2019) for Malaysia. On the other hand, in some countries, such as Bangladesh Nepal. Vietnam, urbanization has U shaped relationship on CO_2 emissions. It implies that urbanization initially reduces CO_2 emissions, but after reaching a certain threshold, urbanization will tend to increase emissions and reduce environmental quality. This finding is also supported by previous findings by Shahbaz et.al. (2016) for Malaysia and He et.al. (2017) for 29 provinces in China. This result found insignificant results in India, China, Indonesia, Malaysia, and Philippines by testing AMG, which requires further empirical investigation.

This research also examines the non-linear effect of urban agglomeration (UAG) on CO_2 emissions, and the results are reported in Case B. Quadratic term $(\ln UAG)^2$ of urban agglomeration has inverted U shaped in Pakistan and Thailand.The signs of these coefficients reveal an inverted U-shaped urban agglomeration affect on CO_2 emissions and supports the theory of ecological modernization.The AMG results are quite strong and support our previous findings based on DSUR entire panel.These findings imply that urban concentration in metropolitan cities initially causes environmental degradation. However, after reaching a certain optimal point, UAG improves environmental quality when urban residents have significant level of income and better awareness of environmental quality. The findings are consistent with Bekhet and Otsman (2017) for Malaysia and Zhang et.al (2017) for a cross-country panel. On the other hand, $(\ln UAG)^2$ was found to have a U-shaped effect in Nepal, China, Indonesia, and Vietnam. These results are consistent with the finding of Shahbaz et.al (2016) for Malaysia and Du and Xia (2018) for cross-country analysis. On the other hand, $(\ln UAG)^2$ had no significant effect on CO_2 emissions found in Bangladesh, India, Malaysia and Philippines.

The results empirical AMG for each country in model 3 largest city ratio (LCR). The quadratic term of largest city ratio $(\ln LCR)^2$ is used for examining the non-linear effect of LCR on carbon emissions in selected Asian economies. The results found that the population of largest city has a inverted U- shaped effect on CO_2 emissions in Thailand and India. These findings support the compact city theory which postulate that cities become larger and more compact, the use of efficient transportation and other infrastructure improve and increases economies of scale to urban residents and this finding is consistent with the prior study by

Table 4.7 Result of nonlinearity of urbanization, urban agglomeration and largest city ratio at country level using Augmented Mean Group (AMG) test

		LnEI		LnGDP		LnURB/LnUAG/LnLCR		$LnURB^2/LnUAG^2/LnLCR^2$		LnTOP		LnFDV		Shape of curve
		Coefficient	p-Value	Coefficient	p-Value	Coefficient	p-Value	Coefficient	p-Value	Coefficient	p-Value	Coefficient	p-Value	
Model 1	Bangladesh	0.003***	0.002	-1.776	0.142	-0.042**	0.018**	0.001**	0.011	-0.000	0.805	0.003	0.261	U
Urbanization	India	-0.004***	0.015	7.312***	0.000	0.216	0.274	-0.002	0.554	-0.002	0.663	-0.002	0.641	Not confirmed
	Pakistan	-0.004	0.619	3.714***	0.001	1.076***	0.001	-0.017***	0.001	-0.002	0.357	0.005*	0.098	Inverted U
	Nepal	-0.001***	0.011	1.325	0.234	-0.146***	0.001	0.006***	0.004	0.003***	0.001	-0.000	0.778	U
	China	-0.000	0.445	-1.514	0.709	0.002	0.989	0.004	0.215	-0.015	0.287	-0.028***	0.004	Not confirmed
	Indonesia	0.000	0.718	1.084*	0.099	0.033	0.554	-0.000	0.716	0.002	0.198	-0.002	0.316	Not confirmed
	Malaysia	0.000	0.944	1.036	0.841	0.276	0.471	-0.001	0.748	0.001	0.651	-0.004	0.121	Not confirmed
	Thailand	0.000**	0.020	8.176***	0.000	0.398***	0.000	-0.005***	0.000	0.000	0.937	0.006***	0.000	Inverted U
	Filipina	-0.001**	0.030	9.065***	0.000	1.225	0.609	-0.012	0.629	0.004***	0.000	0.008***	0.000	Not confirmed
	Vietnam	-0.003***	0.000	1.816***	0.001	-0.421***	0.000	0.007	0.035	-0.001	0.504	0.001	0.524	U
Model 2														
Urban Agglomeration	Bangladesh	0.004***	0.000	-1.758	0.914	-0.069	0.417	0.001	0.734	-0.000	0.788	0.004*	0.051	Not confirmed
	India	-0.003*	0.057	8.176***	0.000	0.380	0.269	- 0.012	0.412	-0.002	0.617	0.000	0.878	Not confirmed
	Pakistan	-0.000	0.299	7.557	0.268	1.255***	0.002	-0.033***	0.002	-0.007***	0.000	0.146***	0.000	Inverted U
	Nepal	-0.001***	0.008	1.507**	0.032	-0.231**	0.020	0.052***	0.000	0.001	0.165	0.000	0.612	U
	China	-0.001	0.517	-7.398	0.790	-0.540**	0.028	0.024**	0.012	-0.009	0.446	-0.149	0.140	U
	Indonesia	0.000	0.166	9.977**	0.040	-5.739**	0.005	0.225**	0.005	0.002	0.063	-0.005**	0.010	U
	Malaysia	-0.000	0.410	-6.917	0.210	0.268	0.459	0.005	0.660	-0.001	0.717	-0.005***	0.006	Not confirmed
	Thailand	0.000**	0.025	9.088***	0.000	0.761**	0.016	-0.030***	0.002	0.003	0.888	0.005***	0.000	Inverted U
	Filipina	-0.001***	0.001	1.637***	0.000	2.695	0.290	0.098	0.261	0.005***	0.000	0.006***	0.000	Not confirmed
	Vietnam	-0.003***	0.000	1.179*	0.056	-0.452***	0.000	0.024***	0.000	-0.002	0.409	0.001	0.542	U
Model 3														
Largest city Ratio	Bangladesh	0.003***	0.001	-4.595	0.939	0.003	0.996	-0.000	0.979	0.000	0.917	0.003	0.174	Not confirmed
	India	0.000	0.903	3.728***	0.002	21.726***	0.000	-1.851***	0.000	0.000	0.896	-0.008**	0.011	Inverted U
	Pakistan	0.000	0.951	1.086*	0.096	1.130	0.560	-0.293	0.564	-0.004	0.257	0.011***	0.008	Not confirmed
	Nepal	-0.000	0.291	2.740	0.002	0.513*	0.056	0.012*	0.052	0.001	0.122	0.001	0.310	+ Effect
	China	-0.005	0.539	4.887	0.712	-200.308***	0.002	32.122***	0.003	-0.125	0.211	-0.002	0.762	U
	Indonesia	0.003	0.668	9.563***	0.004	0.211	0.511	-0.009	0.426	0.002	0.233	-0.003	0.264	Not confirmed
	Malaysia	-0.000	0.598	-7.332	0.123	1.362	0.310	-0.020	0.397	0.000	0.935	-0.007**	0.021	Not confirmed
	Thailand	-0.000***	0.000	4.314***	0.004	1.007***	0.000	-0.018***	0.000	0.000	0.715	0.004***	0.002	Inverted U
	Filipina	-0.001**	0.010	1.951***	0.000	-1.542	0.113	0.028*	0.099	0.005***	0.000	0.006***	0.000	+ Effect
	Vietnam	-0.004***	0.000	2.034***	0.000	-25.337	0.066	0.550*	0.073	-0.002	0.328	0.002	0.482	+ Effect

Note: *, **, *** indicates 10%, 5%, and 1% level of significance; p-values denote probability values of coefficients; urban agglomerations and largest city ratio; $(lnURB)^2$, $(lnUAG)^2$ and $(lnLCR)^2$ examine the nonlinear effects of urbanization, urban agglomerations and largest city ratio on carbon emissions. Inverted U reveals the inverted U-shaped effect of urbanization , urban agglomerations and largest city ratio on carbon emissions; U reveals U-shaped effect of urbanization , urban agglomerations and largest city ratio on carbon emissions, Not Confirmed means neither found inverted U or U-shaped effect; and + (ve) Effect reveals the positive effect of urbanization , urban agglomerations and largest city ratio on carbon emissions.

Ahmed et.al (2019). $(LnLCR)^2$ has U-shaped effects on CO_2 emissions found in China.This finding indiactes that excessive population concentration in large cities will increase pollution in the long term. Based on empirical results, these findings reject the theory of ecological modernization because the phenomenon of overcrowding or excessive population density in big cities has a negative effect on environmental sustainability. The results are in consistent with previous researches by Zhang et.al. (2017) for a cross-country analysis and Makido et.al (2012) for fifty cities in Japan.These empirical results are also supported by Shen et.al (2019), which founds an increasing trend in residential emissions in the case of urban agglomeration in largest cities in China. This finding indicated that phenomenon of excessive concentration or high density of urban settlements in large cities with environmental damage, especially in developing countries in Asia. In addition, highly polarized urban agglomerations in the largest cities in Asian economies can cause more transportation-related emissions compared to spatially dispersed agglomerations. Moreover, this research documented positive effect of quadratic term of largest city ratio $(lnLCR)^2$ on CO_2 emissions in Nepal, Philippine, and Vietnam. In these countries largest city ratio causes environmental degradation in the long term. These results are consistent with similar findings by Behera and Dash (2017) for the region South Asia. On the other hand, $(lnLCR)^2$ has no significant effect on CO_2 emissions found in Bangladesh. Pakistan, Indonesia, and Malaysia.

4.6 Panel Granger Causality

If long-term relationship between variables is established, the next step is to apply panel Granger causality test to examine the unidirectional or bidirectional relation between variables.

The first six equations (3.7- 3.12) are to examine the causality between urbanization and CO_2 emissions and other determinant factors.

$$\Delta CO2_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta CO2_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(URB)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.7)$$

$$\Delta EI_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta EI_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(URB)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.8)$$

$$\Delta GDP_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta GDP_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(URB)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \sum_{i=a1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.9)$$

$$\Delta URB_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta URB_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.10)$$

$$\Delta TOP_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta TOP_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(URB)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.11)$$

$$\Delta FDV_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta FDV_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(URB)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \mu_{it} \quad (3.12)$$

The second six equations (3.13-3.18) are to examine the causality between urban agglomeration and CO_2 emissions and other determinant factors.

$$\Delta CO_{2it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta CO_{2\ it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(UAG)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.13)$$

$$\Delta EI_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta EI_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(UAG)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.14)$$

$$\Delta GDP_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta GDP_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(UAG)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.15)$$

$$\Delta UAG_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta UAG_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.16\ )$$

$$\Delta TOP_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta TOP_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(UAG)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.17)$$

$$\Delta FDV_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta FDV_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(UAG)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \mu_{it} \quad (3.18)$$

The third six equations (3.19-3.24) are to examines the causality between largest city ratio and CO_2 emissions and other determinant factors.

$$\Delta CO_{2it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta CO_{2\ it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(LCR)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.19)$$

$$\Delta EI_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta EI_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(LCR)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.20)$$

$$\Delta GDP_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta GDP_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(LCR)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.21)$$

$$\Delta LCR_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}LCR_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.22)$$

$$\Delta TOP_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta TOP_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(LCR)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(FDV)_{it-1} + \mu_{it} \quad (3.23)$$

$$\Delta FDV_{it} = \alpha_{it} + \beta_{it}ect_{it-1} + \sum_{i-1}^{l} \xi_{it}\Delta FDV_{it-1} + \sum_{i=1}^{l} \varphi_{it}\Delta(CO_2)_{it-1} + \sum_{i=1}^{l} \delta_{it}\Delta(EI)_{it-1} + \sum_{i=1}^{l} \Phi_{it}\Delta(GDP)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(LCR)_{it-1} + \sum_{i=1}^{l} \psi_{it}\Delta(TOP)_{it-1} + \mu_{it} \quad (3.24)$$

This study also examined panel granger causality provided inTable 4.8 which confirmed that urban agglomeration, largest city ratio, and its quadratic term of the largest city ratio affect on CO_2 emissions in the sample as a whole. Bidirectional causality also found in GDP and CO_2 emissions. Meanwhile, unidirectional causality found in energy intensity and CO_2 emissions, trade openness and CO_2 emissions, financial developmed and CO_2 emissions, as well as urbanization and CO_2 emissions.

Table 4.8 Result of Panel Granger Causality Test

Dependen Variable		Independent Variable										
		$\Delta lnC0_2$	$\Delta lnEI$	$\Delta lnGDP$	$\Delta lnURB$	$\Delta(lnURB)^2$	$\Delta lnUAG$	$\Delta(lnUAG)^2$	$\Delta lnLCR$	$\Delta(lnLCR)^2$	$\Delta lnTOP$	$\Delta lnFDV$
$\Delta lnC0_2$	Wald test		4.139	10.789***	9.182***	8.208***	16.204***	10.865***	9.328***	9.757***	2.644***	0.912
	p-value		(2.550)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.744)
$\Delta lnEI$	Wald test	4.373			17.685***	18.287***	7.638***	4.864	7.741	8.260***	2.653***	3.310
	p-value	(1.424)			(0.000)	(0.000)	(0.000)	(1.718)	(0.000)***	(0.000)	(0.002)	(1.397)
$\Delta lnGDP$	Wald test	2.921***	4.503		41.467***	65.726***	9.987***	7.978***	12.577***	13.629***	3.567	2.094**
	p-value	(0.000)	(2.604)		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(1.271)	(0.048)
$\Delta lnURB$	Wald test	3.350	5.892***	5.230							3.138	1.570
	p-value	(9.781)	(0.000)	(6.661)							(6.107)	(0.339)
$\Delta(lnURB)^2$	Wald test	2.872***	5.921***	6.015***							3.285	1.786
	p-value	(0.000)	(0.000)	(0.000)							(1.743)	(0.169)
$\Delta lnUAG$	Wald test	2.370**	3.641	4.770							4.293	1.851
	p-value	(0.012)	(6.106)	(6.676)							(3.963)	(0.132)
$\Delta(lnUAG)^2$	Wald test	2.571***	4.145	3.036***							4.358	2.106**
	p-value	(0.003)	(2.378)	(0.000)							(1.713)	(0.028)
$\Delta lnLCR$	Wald test	2.328**	2.511***	0.952							2.404***	1.300
	p-value	(0.015)	(0.005)	(0.805)							(0.009)	(0.567)
$\Delta(lnLCR)^2$	Wald test	2.372**	2.212**	0.951							2.358**	1.333
	p-value	(0.011)	(0.027)	(0.802)							(0.012)	(0.621)
$\Delta lnTOP$	Wald test	4.886	1.298	3.457	15.535***	19.568***	12.313***	11.358***	12.283***	12.219***		5.153
	p-value	(1.232)	(0.670)	(3.675)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		(2.220)
$\Delta lnFDV$	Wald test	2.994***	1.341**	2.200**	8.380***	9.961***	6.002***	6.269***	21.343***	21.728***	1.409	
	p-value	(0.000)	(0.0611)	(0.029)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.520)	

Note: *, **, *** indicates 1%, 5% and 10% levels of significance, p-value denotes probability values of the Wald test statistic; it estblish either unidirectional or bidirectional causal effects of explanatory variables on the carbon emissions based on Wald test statistic.

This research assumes that urbanization, urban agglomeration, and largest city ratio affect environmental degradation through energy intensity.This study found that there is bidirectional causality between urbanization, quadratic term of urbanization and energy intensity, urban agglomeration and energy intensity.These findings documented that urbanization and environmental degradation are closely linked, while urban agglomeration leads to greater energy consumption in metropolitan cities.

These findings also indicate that the largest city ratio and its quadratic term of the largest city ratio have bidirectional causal with energy intensity. Excessive concentration in the largest cities in 10 Asian developing economies leads to longterm energy consumption, which could be the cause of increasing pollution levels in densely populated cities in these countries.The strong interrelationship between urbanization, energy intensity, GDP,and trade openness, and financial development on environmental degradation requires the formulation and implementation of sustainable environmental policies because pollution mitigation efforts could have a reversing effect on socio-economic trends in economic growth and urban development.

CONCLUSION

This study examines the effect of urbanization, urban agglomeration, and the largest city ratio on CO_2 emissions in 10 Asian economies from 1990 to 2020 using the dynamic STIRPAT model.Employing advanced econometric techniques (CIPS, CADF, DSUR, AMG), the research confirms long-term relationships between urban factors and environmental degradation.Findings reveal inverted U-shaped relationship between urbanization/agglomerationand CO_2 emissions, supporting ecological modernization theory-where environmental quality improves after reaching a certain development threshold. On the contrary, the largest city ratio exhibits U-shaped effect, with excessive population concentration in large cities worsening pollution.

Energy intensity has a positive effect on environmental degradation. Higher energy consumption from fossil fuel resources results in more air pollution during certain periods. Similarly, economic growth has a positive effect on pollution for the entire panel.The high pressure of economic development in these countries has posed major challenges to sustainable growth. The pressure of economic growth, coupled with higher energy needs, has diminished the quality of the environment in a country. Trade openness can increase CO_2 emissions through scale effects due to less efficient production methods and technology that is not environmentally friendly to the host country.Government of each country must amend their trade policies for better synchronization with sustainable and green development goals. Financial development has a positive effect on CO_2 emissions. Financial development could increase CO_2 emissions when it involves FDI flows. It can be explained by the fact that investments will increase the amount of energy used which may increase the number and scale of manufacturing activities which will lead to increased land degradation, pollution and CO_2 emissions. In addition, relevant financial institutions should initiate more projects and support green planning and efficient city-level infrastructure that utilizes innovative and environmentally friendly technologies.

These findings indicate that Asian countries have high dependence on non-renewable energy which has deteriorated environmental quality in the long term. The government should take concrete steps to increase the proportion of clean energy production in the energy mix such as solar energy, biomass and wind energy sources to improve the environment. When these countries' rapidly growing economies will have a negative effect on sustainable environment, policymakers must encourage "green investments and financing" and provide taxes or other incentives to introduce and implement environmentally friendly technologies.Furthermore, trade policies must be reviewed and adapted to the specific conditions of each country. Each government authority must revise its trade policies to be more aligned with sustainable and environmentally friendly development goals.

This research highlights the need for sustainable urban planning, green infrastructure, energy diversification, and tailored trade policies. It calls for further city-level studies to better understand urban phenomena and recommends policy reforms to align urban growth with environmental sustainability across developing Asian economies. This research has made a comprehensive study of urbanization, urban agglomeration, and largest city ratio and non-linear effect on environmental degradation at regional, country, metropolitan and city levels. However, several areas or dimensions require further empirical studies to understand the phenomena of urbanization, urban agglomeration, and largest city ratio at the city level by utilizing city level data, related to infrastructure development, urban planning, industrial agglomeration, growth in the service sector, urban sprawl issues, transport intensity to broadly examine urban issues and address specific urban issues to understand urban phenomena at the city level by utilizing city-level data, including indicators of urban design and environmental degradation, which are currently not available in these countries.The findings could be further examined by expanding the scope of the study to include a cross-country analysis of other developed and developing countries.

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