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# The Role of Urbanization and Trade in Driving Carbon Emissions in Asia

Marc Audi[a]

**Abstract**
The increasing pace of greenhouse gas emissions, which is causing previously unheard-of levels of global warming, is currently the biggest threat to the environment. In addition to accelerating climate change, this rise in emissions causes serious ecological disturbances such as rising sea levels, intense weather, and biodiversity loss. Addressing this issue is critical to preserving environmental stability and ensuring sustainable living conditions for future generations. This study primarily aims to explore the relationship between urbanization, energy consumption, and carbon dioxide emissions in Asian countries. The dependent variable is carbon dioxide emissions, while the independent variables are trade, GDP per capita growth, the square of GDP per capita growth, urban population, population density, and the use of renewable and non-renewable energy. By analyzing these factors, the study seeks to uncover how urbanization and energy use, alongside economic and trade growth, contribute to environmental impacts in the region. The study's findings demonstrate that, although having a positive correlation with carbon dioxide emissions, non-renewable energy use has no statistically meaningful effect. This suggests that although emissions are influenced by non-renewable energy sources, other variables could be more important in determining emissions levels. However, carbon emissions are strongly correlated with GDP per capita growth, urban population size, population density, and trade activity, indicating that the environmental effect increases with these characteristics, especially in quickly urbanizing countries. These findings underline the challenges that come with urban growth and economic expansion, where increased energy demands, transportation needs, and industrial activity tend to elevate emissions. The study suggests that governments should prioritize energy conservation strategies. This could involve investing in renewable energy infrastructure, supporting the shift from fossil fuels to clean energy sources, and creating incentives for industries to adopt green technologies. Additionally, promoting public transportation over private vehicle use could substantially mitigate emissions by reducing traffic congestion, lowering fuel consumption, and decreasing the overall carbon footprint of urban areas. By focusing on these approaches, governments could support sustainable urban growth while balancing economic and environmental goals.

**Keywords:** Urbanization, Energy consumption, Carbon dioxide emissions
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## 1. INTRODUCTION

Urbanization is a multifaceted process that brings about interconnected economic, technological, political, cultural, social, and environmental transformations. This process is characterized by the concentration of economic activities and population within urban areas, often driven by changes in land use to accommodate growth. Urbanization not only refers to these socioeconomic shifts but also encompasses the physical expansion of cities, including increases in population size and the spread of urbanized areas (William, 2021; Anees & Yan, 2019; Chikaraishi et al., 2013). The rapid global increase in urbanization marks a fundamental shift in population distribution and economic focus, especially in developing nations where this trend is happening at an unprecedented speed. This surge in urban growth has been fueled by numerous factors, including better economic opportunities, and improved access to healthcare, education, and infrastructure in urban areas, which collectively attract large numbers of people from rural regions. As cities become more densely populated, they transform into vital centers of economic activity, driving innovation and contributing significantly to national and regional economic development. According to a United Nations report, in 2014, over 54% of the world's population lived in urban areas, a figure projected to climb to 66% by 2050. This anticipated rise reflects not only the ongoing migration from rural to urban areas but also the natural population growth occurring within cities. The implications of such growth are substantial; urbanization at this scale will require significant investment in urban infrastructure, housing, transportation, and public services to accommodate the expanding urban population. This shift presents both opportunities and challenges, as urban centers will need to adapt to increasing demands for energy, water, and other essential resources.

Moreover, rapid urbanization brings environmental challenges. As cities expand, they often encroach on natural landscapes, leading to deforestation, loss of biodiversity, and changes in land use. Urbanization contributes to increased greenhouse gas

[a] Abu Dhabi School of Management, Abu Dhabi, United Arab Emirates

emissions due to higher energy consumption, particularly from transportation and industrial activities. Managing these environmental impacts requires sustainable urban planning, with a focus on green infrastructure, renewable energy, and efficient public transportation systems. Asia's rapid urbanization has spurred public safety measures and economic development, yet it has also led to increased energy consumption, which negatively impacts climate conditions and air quality. Urbanization influences carbon dynamics in the atmosphere, facilitating both the absorption and release of carbon, thereby having complex effects on the environment. On one hand, urban growth can lead to improved infrastructure and access to cleaner technologies; on the other, it significantly raises fossil fuel consumption and energy use due to intensified industrial activities (Ibrahim & Simian, 2023; William, 2023; Ali and Audi, 2016; Salim et al., 2017). This process of urban expansion encourages higher levels of energy consumption in sectors such as manufacturing, transportation, and construction, which are heavily reliant on fossil fuels. Consequently, emissions of carbon dioxide and other greenhouse gases increase, exacerbating global warming and contributing to environmental pollution. The increased demand for energy in densely populated urban areas also strains existing resources and infrastructure, often leading to inefficient energy use and additional emissions. In addition to these challenges, urbanization can disrupt natural carbon sinks, such as forests and wetlands, as cities expand into previously undeveloped areas. This land-use change reduces the environment's ability to absorb carbon, further intensifying the carbon footprint of urban centers. While urbanization brings economic growth and improved public amenities, its environmental costs necessitate comprehensive urban planning and the promotion of sustainable energy alternatives to minimize its adverse impacts on climate and air quality. The global environment is seriously threatened by the increase in greenhouse gas emissions and global warming. Methane, water vapor, nitrous oxide, carbon dioxide, sulfur dioxide, and chlorofluorocarbons are important greenhouse gases that have a major impact on climate change. Carbon dioxide emissions, in particular, are a major driver of climate change due to their strong association with various economic activities. Energy consumption, driven by the increasing demand across sectors, is a leading cause of these emissions, which simultaneously support economic growth. Consequently, as carbon dioxide emissions and energy use rise, so too do per capita GDP and urbanization levels, leading to further environmental impacts (Porro & Gia, 2021; Lu, 2017). The concentration of pollutants, such as chemicals, in natural bodies like lakes is reflected in ambient quality, or the amount of pollutants in the environment. The complex mixture of gases, liquids, and particulate matter from automobile exhaust, industrial emissions, and other sources makes up outdoor air pollution, also known as ambient air pollution. On the other hand, indoor air pollution is typically more concentrated and may be more dangerous. Indoor pollution causes headaches, exhaustion, nausea, and other direct or indirect health risks. Pollutants that contribute to indoor pollution include carbon monoxide, nitrogen dioxide, wood smoke, environmental tobacco smoke, allergies, and other biological pollutants (Hussian & Khan, 2022; Weber, 2022).

Global warming represents one of the most critical environmental challenges, stemming largely from the reliance on fossil fuels to meet energy needs. The use of these resources releases significant amounts of greenhouse gases, which not only impact air quality but also contribute to the ongoing rise in global temperatures. Addressing this issue requires a shift towards sustainable energy sources to reduce the environmental and health impacts associated with both indoor and outdoor air pollution (Skhirtladze & Nurboja , 2019; Field & Field, 2003; Ali et al., 2021). Energy is a basic component of contemporary life and the material basis for social and economic advancement. However, the main causes of environmental deterioration and global warming are energy-related greenhouse gas emissions from non-renewable energy sources. Both renewable and non-renewable energy resources are widely used, which contributes to environmental problems such as biodiversity loss, greenhouse gas emissions, ecological deficiencies, and ecological footprint issues. Energy consumption, especially from coal, fossil fuels, gas, oil, and renewable sources, is crucial to industrialization and economic expansion. Transportation, industry, and power production are the main uses of non-renewable energy sources. Numerous factors, such as sector-specific energy consumption, pollutant-heavy industries, energy policy frameworks, product price controls, economic policy development, and environmental planning at the national and international levels, make the relationship between environmental quality, environmental taxes, and energy consumption significant. Understanding this relationship is crucial to designing effective energy structure policies and implementing economic and environmental planning strategies aimed at mitigating environmental impacts.

The energy needed for end-use consumption is referred to as "final energy demand," although energy consumption that occurs during the transformation process—such as energy wasted during conversion—is not included in this measure. Furthermore, national standard economic accounts and energy statistics utilize different classifications for industries that consume energy. Policymakers must match energy consumption measures with environmental objectives since these discrepancies highlight how difficult it is to monitor energy usage and its effects across many economic and environmental contexts (Rossi, 2023; Shahzad, 2020; Ali et al., 2021). Cities are becoming important contributors to global energy consumption and greenhouse gas emissions as their populations increase. Energy, a vital natural resource, is essential not only for societal needs but also as a foundation for economic growth. Rapid urbanization naturally leads to increased energy intensity, as cities require substantial energy to support infrastructure, transportation, and residential needs. In developing countries, environmental pollution due to primary energy consumption has emerged as a critical global concern within the urbanization process. Countries must address this by putting policies in place to lower energy intensity and increase energy efficiency, which would lower primary energy consumption and decrease greenhouse gas emissions and the resulting greenhouse impact (Farhadi & Zhao, 2024; Audi and Ali, 2017; Audi et al., 2020; Zhu et al., 2021; Ahmad, 2018).

## 2. REVIEW OF LITERATURE

This literature review looks at the variables influencing carbon dioxide emissions, ecological footprints, energy consumption, and the role of urbanization in environmental impact across different global regions and periods, this literature review investigates the relationship between environmental quality, energy consumption, and urbanization. Hanif (2018) studied the impact of urbanization, economic expansion, and the use of both renewable and non-renewable energy sources on carbon dioxide emissions in Sub-Saharan Africa between 1995 and 2015. The study, which used the system generalized technique of moments, discovered that while renewable energy usage dramatically lowers emissions, per capita GDP and urbanization had a favorable impact. This study highlights the dual role of economic growth in supporting development while also intensifying emissions if dependent on non-renewable resources. Hanif's research highlights the value of renewable energy in reducing emissions linked to urbanization, particularly in emerging nations where urban growth may occur quickly. In a similar vein, Pata et al. (2018) examined Turkey, evaluating the correlation between GDP, urbanization, renewable energy use, and carbon dioxide emissions between 1974 and 2014. Using techniques including completely modified ordinary least squares, autoregressive distributed lag, and canonical cointegration regression, this study discovered that while renewable energy use greatly reduces emissions, urbanization, and economic expansion increase them. Financial development was also shown to positively correlate with emissions, suggesting that as economies grow financially, energy demands rise in tandem, thereby driving up emissions. The study’s results indicate that without a balanced approach to economic growth, urbanization may contribute disproportionately to environmental degradation, reinforcing the critical role renewable energy plays in reducing the environmental costs of urbanization. From 1965 to 2014, Nathanial et al. (2019) investigated the ecological footprint as a gauge of environmental effect in connection to per capita GDP, energy consumption, urbanization, and financial growth in South Africa. The authors found that urbanization and GDP had a beneficial impact on the ecological footprint using techniques such as autoregressive distributed lag, completely modified ordinary least squares, dynamic ordinary least squares, and canonical cointegration regression. Energy consumption, on the other hand, seems to have a moderating impact. This study emphasizes the intricate connection between urbanization and environmental quality, arguing that increased demands on natural resources due to financial development and urbanization intensify environmental strain. Nevertheless, the findings also indicate that efficient energy use can act as a counterbalance, limiting the adverse impacts of rapid urbanization. Abbasi et al. (2020) examined carbon dioxide emissions linked to urbanization, energy consumption, GDP, financial growth, and trade openness in eight Asian nations between 1982 and 2017. The authors used vector error correction methods, conventional least squares, and the STIRPAT model. The findings showed that while financial development and trade openness have a negative association with emissions, urbanization, energy consumption, and GDP all significantly contribute to emissions. This suggests that open economies benefit from environmentally sustainable practices and technologies through trade, underlining the potential role of globalization in shaping environmental impacts in rapidly developing regions. Godli et al. (2021) studied the ecological footprint in Pakistan from 1980 to 2018, focusing on the effects of transportation services, financial development, GDP, and urbanization. Using the quantile autoregressive distributed lag and the Wald test, the authors found that urbanization and GDP positively influence the ecological footprint, whereas transportation services and financial development contribute to reducing it. This study emphasizes the role of specific sectors, such as transportation, in potentially mitigating environmental impacts through the adoption of efficient practices or renewable energy sources, demonstrating the complex sectoral interactions that affect environmental outcomes.

Rafindadi et al. (2017) examined Gulf nations over the period from 1990 to 2014, focusing on carbon dioxide emissions and their relationship with foreign and direct investment, per capita GDP, energy use, and energy intensity. Applying pooled mean group, mean group, and dynamic fixed-effect estimations, the study revealed that while energy consumption and energy intensity are positively linked to emissions, per capita GDP and foreign direct investments have a negative impact. This implies that investments in sustainable infrastructure or energy-efficient practices may contribute to reducing environmental degradation in this region. Phrakhroupatnontakitti et al. (2019) studied four Asian countries from 1971 to 2005, utilizing an error correction model to examine carbon dioxide emissions in connection to GDP and energy consumption. The findings showed that energy consumption, GDP, and emissions were positively correlated, while GDP squared showed a negative correlation, which was consistent with the Environmental Kuznets Curve pattern. This implies that while early economic expansion could result in higher emissions, as income levels rise, there is a trend towards lower emissions, most likely as a result of increased investment in clean technologies and environmental consciousness. Using autoregressive distributed lag, Granger causality, and dynamic ordinary least squares, Liu et al. (2019) examined Pakistan from 1980 to 2016, concentrating on the relationships between carbon dioxide emissions and energy consumption, tourism revenues, and GDP per capita. Findings demonstrated positive relationships between GDP per capita, tourism receipts, and energy consumption on emissions, suggesting that both economic growth and tourism can intensify environmental pressures unless balanced by sustainable practices. The study highlights the environmental costs of expanding sectors such as tourism, which, while economically beneficial, may contribute to emissions if growth is not managed sustainably.

Khan et al. (2020) used the system generalized method of moments, generalized linear model, and robust least squares model to examine the effects of natural resources, population, biocapacity, and renewable and non-renewable energy consumption on carbon dioxide emissions and ecological footprint in the United States from 1971 to 2016. The study discovered that while renewable energy and natural resources have a negative influence on emissions and ecological footprint, non-renewable energy consumption, population, and biocapacity had a favorable impact. This suggests that greater usage of clean energy sources might counteract the environmental effects of urbanization and economic growth, supporting the significance of renewable energy in reducing environmental deterioration. Using autoregressive distributed lag, vector error correction model, and Granger causality, Rehman and Vu (2021) studied China from 1971 to 2018, examining carbon dioxide emissions in connection to energy consumption, GDP, population density, and exports. Results show that while population density and exports have a negative influence on emissions, GDP and per capita energy consumption have a favorable impact. The study suggests that high-density urban areas and trade openness may promote efficient energy use, thereby reducing emissions in densely populated cities. Wang et al. (2019) analyzed energy consumption in 186 countries from 1980 to 2015 using Granger causality, impulse response functions, and ordinary least squares. Findings revealed that urbanization and GDP have significant impacts on energy consumption, with urbanization generally increasing energy demand over time. However, energy prices were found to variably influence consumption, indicating that price control policies could be instrumental in managing energy demand, especially in regions where energy prices affect household and industrial consumption patterns.

Automobile energy consumption and per capita energy usage in connection to population, per capita income, urbanization, and the percentage of tertiary industry were examined in a study conducted by Du and Lin (2019) in 279 Chinese cities between 2003 and 2015. Through the STIRPAT model, generalized method of moments, and threshold model, they found that urbanization and income levels significantly drive energy demand. This highlights the need for sustainable urban planning and transportation policies, as cities face increasing pressure to accommodate rising populations and income-driven energy demands. Wang et al. (2020) analyzed data from 136 developing and developed countries between 1990 and 2015, focusing on residential energy consumption concerning population, urbanization, and affluence using the STIRPAT model and fully modified ordinary least squares. Results show that while population growth positively influences energy consumption, urbanization, and affluence exhibit mixed effects, with urban density sometimes leading to more efficient energy use. This study emphasizes the role of urban density in reducing residential energy demands, suggesting that dense, well-planned cities can mitigate environmental impacts. Using the generalized method of moments, Aboagye and Amponsah (2020) analyzed energy intensity in 36 Sub-Saharan African countries between 1980 and 2015, examining urbanization, economic growth, industrialization, and foreign direct investment. The findings indicate that energy intensity is increased by urbanization and economic growth, while it is decreased by trade openness and foreign direct investment. This indicates that open economies may benefit from environmentally friendly technologies through trade, highlighting the potential role of globalization in fostering sustainable practices in energy-intensive regions.

Zhu et al. (2021) used the generalized technique of moments and ordinary least squares to analyze energy intensity in 38 OECD nations between 1990 and 2015, looking at the impacts of industrialization, urbanization, economic development, and carbon dioxide emissions. Findings reveal mixed impacts of urbanization on energy intensity, with high urban density often associated with reduced energy demand due to efficient infrastructure. Industrialization, however, generally increased energy intensity, reinforcing the need for balancing urban growth with sustainable practices. The examined research highlights the intricate connection between environmental quality, energy use, and urbanization. Urban expansion increases energy consumption and emissions in areas that are rapidly becoming more urbanized, especially in developing countries. Studies by Hanif (2018), Abbasi et al. (2020), and Wang et al. (2019), for example, indicate that urbanization raises energy consumption and $CO_2$ emissions, underscoring the significance of sustainable urbanization solutions. Renewable energy is widely recognized as essential for mitigating emissions across regions, as demonstrated in studies by Pata et al. (2018), Rafindadi et al. (2017), and Khan et al. (2020), emphasizing the need for policies that support renewable energy infrastructure to balance the environmental costs of urbanization.

The Environmental Kuznets Curve pattern, observed in studies such as those by Phrakhroupatnontakitti et al. (2019) and Rehman and Vu (2021), suggests that as economies grow and reach higher income levels, a natural shift towards cleaner energy practices and emissions reduction may occur. However, this shift is contingent upon effective policy interventions, as economic growth alone does not guarantee sustainable development. In short, our findings imply that governments should focus on developing renewable energy capacity, improving energy efficiency, and establishing urban policies that favor sustainable growth. Additionally, fostering international trade in green technologies and encouraging foreign direct investment in renewable sectors are critical to achieving sustainable development. As urbanization and energy demands continue to rise, these strategies will be instrumental in minimizing the environmental impact and supporting economic growth.

## 3. THE MODEL

Carbon dioxide emissions, a primary greenhouse gas, arise predominantly from human economic activities and are a major contributor to climate change. Although $CO_2$ constitutes a small fraction of the Earth's atmosphere, it is a significant driver of environmental degradation due to its role in trapping heat. When $CO_2$ levels become excessively high in the atmosphere, they disrupt the natural greenhouse effect, contributing to global warming and altering climate patterns. $CO_2$ emissions result from both natural processes and human activities, including fossil fuel combustion, biomass burning, urban expansion, and cement production. These emissions can be mitigated by shifting towards alternative energy sources or by implementing energy conservation practices that produce little to no $CO_2$. Despite its environmental impact, $CO_2$ is essential for life; it is an odorless, colorless gas necessary for photosynthesis in plants, and it cycles naturally between plants, animals, and the atmosphere. $CO_2$ emissions are typically measured in metric tons per capita, indicating the amount of $CO_2$ produced per person annually (Theodore & Theodore, 2021). Renewable energy sources are vital for reducing $CO_2$ emissions, as they can be replenished naturally and produce minimal greenhouse gases. Renewable energy is measured in quadrillion British Thermal Units and encompasses various forms, including geothermal, wave, wind, solar, hydropower, biomass, and tidal energy. Solar energy, one of the most promising renewable sources, converts sunlight directly into electricity using photovoltaic cells. Wind energy is generated by harnessing wind through turbines, which convert kinetic energy into electrical power. Geothermal energy, sourced from the Earth's internal heat and the decay of radioactive particles, is another sustainable option. Hydropower, which uses the energy of rapidly flowing water to generate electricity, is one of the oldest forms of renewable energy. Biomass energy, produced from organic materials such as animal waste, straw, and wood, offers another renewable alternative (Nelson, 2011; Ali et al., 2022). By reducing reliance on fossil fuels, these renewable sources might lower greenhouse gas emissions and promote environmental sustainability. This study creates a model that takes into account several important variables to investigate the link between urbanization, economic growth, energy consumption, and $CO_2$ emissions. According to the model, the following factors affect $CO_2$ emissions ($CO_2$_it): trade openness TRADE, urban population URBAN, renewable energy consumption REN, non-renewable energy consumption NREN, GDP per capita growth GDPG, population density POPD, and the square of GDP per capita growth GDPG2. In this case, "i" stands for the nation, "t" for the time frame, and "β" for the coefficient of each variable, which illustrates how it affects CO2 emissions. This model uses CO2 emissions as the dependent variable and uses trade openness, population density, renewable and non-renewable energy consumption, urban population percentage, per capita GDP growth, and the square of per capita GDP growth as explanatory variables. $CO_2$ emissions, expressed in metric tonnes per capita and representing the quantity of $CO_2$ emissions produced per person over a certain period, serve as the study's proxy for environmental quality. The percentage of people living in cities is a stand-in for urbanization, while the ratio of commerce (the total of imports and exports) to GDP is a measure of trade openness. The number of people per square kilometer of land area is known as population density, and it serves as a gauge for how densely populated a place is. This study's model is based on panel data that spans 40 years, from 1980 to 2020. For 32 Asian nations, statistics on trade openness, urban population share, GDP per capita growth, and its square were gathered, offering a comprehensive view of the economic and environmental dynamics in these areas. The Energy Information Administration (EIA) provided data on energy use, both renewable and non-renewable, while the World Development Indicators (WDI) provided data on other factors. This comprehensive dataset enables a robust analysis of the factors affecting $CO_2$ emissions across a diverse set of Asian countries over a significant time frame.

The chosen variables reflect a range of influences on $CO_2$ emissions and environmental quality. Population density is an important factor as densely populated areas often have higher energy needs, potentially increasing emissions. GDP per capita growth and its square allow for examining the Environmental Kuznets Curve hypothesis, which suggests that economic growth initially increases emissions but may lead to lower emissions once a certain income level is achieved. This relationship is examined through the inclusion of both linear and quadratic GDP terms, enabling the study to capture any potential non-linear effects of economic development on environmental degradation. Urban population as a percentage of the total population serves as an indicator of urbanization, which is typically associated with higher energy demands, industrialization, and transportation needs. Urban areas, while centers of economic growth, often contribute more heavily to emissions due to their concentrated population and industrial activity. Trade openness, measured as the ratio of trade to GDP, is included to understand the effects of global economic integration. Increased trade can lead to higher emissions due to expanded industrial production and transportation, but it can also foster the adoption of cleaner technologies through international cooperation and knowledge transfer. Because they have a direct effect on the amount of CO2 emissions, the consumption of renewable energy REN and non-renewable energy NREN is very important in this model. Renewable energy sources are essential for lowering the carbon footprint linked to energy usage since they emit less emissions, such as solar, wind, and hydropower. On the other hand, substantial volumes of $CO_2$ and other greenhouse gases are released by non-renewable resources like coal, oil, and natural gas. The model enables a comparison of the effects of renewable and non-renewable energy sources on emissions by including both of these factors.

The EIA-provided data on renewable and non-renewable energy consumption included in the model sheds light on each nation's energy dynamics and how changes in the energy mix affect emissions over time. Increased use of renewable energy, for example, is anticipated to reduce emissions, while sustained use of fossil fuels is anticipated to worsen environmental deterioration. This study's panel data approach allows for the examination of temporal trends and inter-country differences, making it possible to assess how variations in energy policies, economic development, and urbanization strategies impact $CO_2$ emissions in Asia. By analyzing these relationships over a substantial period and across multiple countries, this study aims to provide insights into the drivers of $CO_2$ emissions and highlight potential areas for policy intervention. For instance, the results may support policies that promote renewable energy, improve urban planning, and encourage energy efficiency in high-density areas. This study's findings could also offer valuable guidance for policymakers in designing targeted measures to strike a balance between environmental sustainability and economic prosperity. Controlled trade policies, effective urban infrastructure, and the utilization of renewable energy sources might all be effective ways to cut emissions while promoting the economic growth of Asian countries. In the end, the model's incorporation of a variety of variables emphasizes the intricacy of the variables influencing $CO_2$ emissions and the necessity of an integrated approach to environmental management. Urbanization, international trade dynamics, energy consumption trends, and economic expansion must all be taken into account when addressing CO2 emissions. By taking this method, the study advances our knowledge of how economic development affects the environment and provides evidence-based suggestions for promoting sustainable growth in Asian nations.

## 4. RESULTS AND DISCUSSIONS

The results in Table 1 reveal the stationarity properties of several variables related to environmental quality and economic indicators. The panel unit root tests, including the Levin, Lin & Chu (LLC) Test, Im, Pesaran & Shin (IPS) Test, ADF-Fisher Chi-Square, and PP-Fisher Chi-Square, were used to assess whether each variable is stationary or non-stationary. Each test statistic is accompanied by a p-value in parentheses, which indicates the probability of rejecting the null hypothesis of non-stationarity. For $CO_2$ emissions, all four tests yield high p-values close to 1, suggesting that $CO_2$ emissions are non-stationary, meaning that they have a unit root. This implies that $CO_2$ emissions fluctuate over time without reverting to a mean level, likely due to ongoing changes in emissions patterns tied to various economic and environmental factors. Population exhibits mixed results. The LLC and IPS tests indicate non-stationarity with high p-values, while the ADF-Fisher Chi-Square and PP-Fisher Chi-Square tests show p-values of 0.0000, suggesting stationarity. This discrepancy suggests that while population data may generally exhibit non-stationarity, certain tests suggest it may be stable around a long-term mean, calling for additional testing to confirm these findings. The tests for GDP all report highly significant p-values (0.0000), suggesting that GDP is stationary. This stationarity in GDP implies that it may return to a long-term mean, meaning that fluctuations in GDP due to economic changes tend to be temporary rather than permanent. Renewable energy consumption results indicate non-stationarity across all tests, as seen in high p-values. This finding implies that renewable energy consumption data does not stabilize around a mean over time, reflecting variability in renewable energy use driven by changing policies, technologies, and energy demands. Non-renewable energy consumption also shows non-stationarity, with high p-values in all tests. Like renewable energy, non-renewable energy consumption does not revert to a stable mean, suggesting that it is influenced by temporal factors that result in sustained fluctuations. Urban population results are mixed. While the LLC and IPS tests show high p-values suggesting non-stationarity, the PP-Fisher Chi-Square test has a p-value of 0.0000, indicating stationarity. This discrepancy highlights the need for further tests to accurately confirm whether urban population data tends to stabilize over time or not. Trade data shows significance in all four tests, with particularly low p-values in the LLC and IPS tests, suggesting that trade is stationary. This stationarity implies that trade levels fluctuate around a mean, pointing to a degree of stability in trade activity over time despite economic changes. In sum, $CO_2$ emissions, renewable energy consumption, and non-renewable energy consumption appear to be non-stationary, with significant fluctuations over time, while GDP and trade demonstrate more stability. The mixed results for population and urban population indicate a need for additional testing to conclusively determine their stationarity, especially given the potential policy implications of stable versus variable population and urban growth metrics.

**Table 1: Results of Panel Unit Root Tests**

| Variables | LLC Test | IPS Test | ADF-Fisher Chi-Square | PP-Fisher Chi-Square |
|---|---|---|---|---|
| CO2 | 5.19773 | 7.4559 | 26.2023 | 32.9029 |
| PO | 14.3135 | 9.19378 | 300.325 | 183.485 |
| GDP | -15.8215 | -18.6614 | 424.411 | 434.867 |
| REN | 0.89749 | 1.79996 | 57.8490 | 50.5139 |
| NR | 0.28821 | 3.37563 | 38.3007 | 30.9655 |
| UR | -0.58232 | 3.70149 | 60.6526 | 131.429 |
| TRA | -1.99790 | -2.0540 | 91.9830 | 93.1858 |

Results show that population density has a positive and large influence on carbon emissions, making it a crucial factor impacting environmental quality. This result implies that environmental quality tends to decline with increasing human density. A growing population intensifies pressures on the environment, often through inadequate waste management and high demands on limited resources, including public and private facilities. Since the demand for energy from non-renewable sources like coal, oil, and natural gas rises due to high population density, natural resources like arable land, forests, and water are further taxed. These findings are in line with other research that found a positive correlation between CO2 emissions and population density, including Adams et al. (2020), Sadorsky (2013), Zhang and Lin (2012), Rafiq and Nielsen (2016), Shafiei and Salim (2013), Salim et al. (2017), and Khan et al. (2021). The second variable, GDP per capita growth (GDPG), also demonstrates a significant positive impact on carbon emissions, with an estimated long-run coefficient of 0.08. This suggests that economic growth in the absence of effective energy conservation policies tends to increase energy consumption, thus intensifying environmental pollution. In many developing countries, the emphasis on economic development, especially in agrarian economies, drives higher energy use as they strive to increase agricultural and industrial output. This economic growth trajectory often results in substantial environmental degradation. Prior research by Kasman and Duman (2014), Farhani and Ozturk (2015), Rafiq and Nielsen (2016), Hanif (2018), Pata et al. (2018), Ali et al. (2019), Nathaniel et al. (2019), Liu et al. (2019), Abbasi (2020), and Godli et al. (2021) found similar positive correlations between economic growth and carbon emissions. These findings reinforce the notion that, without sustainable policies, economic expansion can significantly elevate carbon emissions and contribute to environmental challenges.

The third independent variable, GDP per capita growth squared, has a coefficient that significantly and negatively correlates with CO2 emissions. This implies that at a certain degree of development, economic growth—which is initially linked to higher emissions—may eventually help to enhance the environment. As economic prosperity rises in many Asian nations, carbon emissions tend to climb as well. However, emissions start to fall once a certain level of economic growth is reached. The Environmental Kuznets Curve (EKC) hypothesis, which postulates an inverse U-shaped link between environmental deterioration and economic growth, is consistent with this trend. The EKC suggests that while environmental degradation rises with income at lower levels, it eventually decreases as economies reach more advanced stages. Previous studies by Hagger (2011), Halicioglu (2009), Rafiq and Nielsen (2016), Kasman and Duman (2014), Pata et al. (2018), Salim et al. (2017), and Godli et al. (2021) also support this finding, confirming the negative association between economic growth (measured through GDP per capita squared) and $CO_2$ emissions as countries reach higher income levels. The usage of renewable energy, the fourth variable, significantly and negatively affects CO2 emissions. According to this research, emissions may be reduced with even a small increase in the use of renewable energy. The pollution halo concept, which postulates that foreign direct investment in clean technologies might help to reduce environmental deterioration, is supported by the fact that $CO_2$ emissions decrease as the proportion of renewable energy consumption rises. By switching from fossil fuels to renewable energy, nations may attain a more environmentally friendly growth trajectory. The environmental advantages of embracing sustainability have been further supported by earlier studies by Pata et al. (2018), Rafiq and Nielsen (2016), Shafiei and Salim (2013), Hanif (2018), Salim (2017), Khan et al. (2021), which similarly discovered a negative correlation between renewable energy consumption and $CO_2$ emissions.

**Table 2: Long-Run Estimates**

Dependent Variable: CO2

| Variable | Coefficient | Std. Error | t-Statistic |
|---|---|---|---|
| PO | 0.1184 | 0.0030 | 39.9427 |
| GDP | 0.0857 | 0.0223 | 3.8407 |
| $GDP^2$ | -0.0736 | 0.0216 | -3.4007 |
| REN | -0.0447 | 0.0103 | -4.3512 |
| NR | 0.0694 | 0.0433 | 1.6043 |
| URB | 0.0185 | 0.0047 | 3.9336 |
| TRA | 0.0116 | 0.0022 | 5.1396 |
| C | 0.3191 | 0.2136 | 1.4943 |

Non-renewable energy consumption is the fifth variable, with a coefficient value of 0.0694, indicating a positive yet insignificant effect on $CO_2$ emissions. This suggests that the reliance on fossil fuels, combined with rapid economic expansion, is contributing to increased pollution emissions across many Asian countries. Fossil fuel combustion releases significant amounts of carbon dioxide, worsening air quality and driving environmental degradation. In these regions, indoor air pollution from energy use for cooking, heating, lighting, and cooling often leads to severe health issues such as tuberculosis, lung cancer, blindness, and heart disease. Outdoor air pollution from motor vehicles further contributes to respiratory illnesses. The industrial sector also relies heavily on machinery that consumes substantial amounts of non-renewable energy, amplifying $CO_2$ emissions. As production intensifies to meet economic demands, the environmental strain increases due to elevated emissions. This trend aligns with prior findings from studies conducted by Mohiuddin et al. (2016), Nielsen and Rafiq (2016), Salim (2013), Hanif (2018), Salim et al. (2017), and Khan et al. (2020), all of which found a positive relationship between non-renewable energy consumption and $CO_2$ emissions. These studies confirm that non-renewable energy sources like coal, oil, and natural gas play a significant role in elevating emissions, underscoring the environmental costs of dependence on fossil fuels for energy in rapidly industrializing economies.

The urban population is the second last variable, with a coefficient value of 0.0185, indicating a significant and positive effect on $CO_2$ emissions. This outcome suggests that urbanization contributes to increased carbon emissions, as it encompasses not only the movement of labor from rural areas to urban sectors but also a shift from in-house production to commercialized goods. Urbanization drives the expansion of private and public transportation infrastructure, requiring additional energy and consequently elevating $CO_2$ emissions. The ecological modernization and urban environmental transition theories support this relationship, proposing that higher urbanization correlates with heightened economic activity. As urban economies grow, wealthier residents typically demand more energy-intensive products, such as air conditioning and automobiles, further increasing carbon emissions. In Asian countries, rural-to-urban migration is prevalent as people seek better facilities and services. This population shift places pressure on urban infrastructure and often results in deforestation to accommodate expanding urban spaces. In developing countries, deforestation linked to urban expansion amplifies $CO_2$ emissions significantly, contributing to environmental degradation. These findings align with previous studies. For instance, research by Sehrawat et al. (2015), Dogan and Turkekul (2015), Hanif (2018), Salim et al. (2017), Pata et al. (2018), Abbasi (2020), Ali et al. (2019), and Godli et al. (2021) consistently shows a positive relationship between urbanization and $CO_2$ emissions. These studies underline that urban growth, particularly when driven by the demand for modern amenities and services, plays a substantial role in increasing emissions, highlighting the need for sustainable urban planning to balance growth with environmental concerns. The last variable, trade openness, has an estimated long-run coefficient value of 0.0116, indicating a positive and significant impact on $CO_2$ emissions. This finding implies that an increase in trade volume tends to exacerbate pollution levels. For many developing countries, the positive association between trade openness and emissions reflects the expansion of industries that produce goods without adequate environmental safeguards. In such contexts, "dirty" industries—those that emit substantial pollutants during production—contribute heavily to environmental degradation. In countries with weak environmental regulations, a higher level of trade openness may lead to increased pollution. Developing nations often lack stringent policies and tools for managing industrial emissions, resulting in greater environmental impact as trade intensifies. This connection between trade openness and pollution is supported by earlier studies, such as those by Shafiei and Salim (2013), Hossain (2011), Farhani and Ozturk (2015), Kasman and Duman (2014), and Sherawat et al. (2015), all of which reported a positive relationship between trade openness and $CO_2$ emissions. These findings emphasize the environmental costs of expanding trade, particularly in regions where environmental protection measures are insufficient to curb emissions from increased production.

The short-run outcomes for carbon dioxide ($CO_2$) emissions are presented in Table 3, showing the effect of each independent variable on $CO_2$ emissions in the short term. The error correction term (ECT) has a coefficient of -0.0740 with a very low probability value (0.0000), indicating significance. The negative value of the ECT suggests that any deviations from long-run equilibrium in $CO_2$ emissions adjust back to equilibrium at a speed of 7.4% per period. This adjustment speed implies that $CO_2$ emissions partially revert to equilibrium after any shocks, albeit slowly. The coefficient for population dPO is -0.0192, highly significant (p-value of 0.0000). This detrimental and substantial effect suggests that, in the near term, a higher population density might help lower CO2 emissions. This could be the result of short-term context-specific variables or a move towards more energy-efficient practices in densely populated places. CO2 emissions are positively but marginally impacted by GDP growth dGDP, with a p-value of 0.2271 and a coefficient of 0.0069. Similarly, the square of GDP per capita growth dGDP2 reveals a negligible effect (p-value = 0.8725), showing that short-term economic growth does not have a substantial influence on $CO_2$ emissions, either positively or negatively, in this model.

The short-term impact of renewable energy consumption dREN on $CO_2$ emissions is positive and substantial, with a p-value of 0.0090 and a coefficient of 0.4536. This finding is somewhat unexpected, as renewable energy is generally assumed to reduce emissions. The short-term increase in emissions might result from the initial costs and energy-intensive activities associated with the transition to renewable sources, or it could reflect a short-term rise in total energy consumption without a reduction in fossil fuel usage. Non-renewable energy dNR has a negative coefficient of -0.0024 and is close to significance with a p-value of 0.0511, indicating that in the short run, non-renewable energy use might slightly reduce $CO_2$ emissions. This finding could result from variations in energy consumption patterns, such as shifts in fuel efficiency, though further analysis would be needed to clarify this relationship. The short-term impact of urban population dURB on $CO_2$ emissions is significant and positive, with a p-value of 0.0000 and a coefficient of 0.7009. This implies that growing urbanization raises emissions in the near term, maybe as a result of the quick increase in energy consumption, transportation requirements, and industrial activity in cities. Trade openness dTRA has a 0.0005 coefficient and a p-value of 0.5613, indicating a positive but negligible effect on $CO_2$ emissions. This finding suggests that short-term changes in trade have little effect on $CO_2$ emissions. With a p-value of 0.8053, the constant component C is also negligible and has no discernible impact on the model. Overall, the results highlight that in the short term, urbanization and renewable energy consumption have significant positive impacts on $CO_2$ emissions, while the adjustment towards equilibrium in $CO_2$ levels after a shock is relatively slow. These short-term effects differ from expected long-term trends, suggesting that transitional dynamics may lead to temporary increases in emissions before reaching a more sustainable balance.

**Table 3: Short Run Outcomes**

Dependent Variable: D (CO2)

| Variable | Coefficient | Std. Error | t-Statistic |
|---|---|---|---|
| ECT | -0.0740 | 0.0179 | -4.1262 |
| dPO | -0.0192 | 0.0017 | -11.5088 |
| dGDP | 0.0069 | 0.0057 | 1.2091 |
| $dGDP^2$ | -0.0002 | 0.0011 | -0.1605 |
| dREN | 0.4536 | 0.1732 | 2.6185 |
| dNR | -0.0024 | 0.0012 | -1.9545 |
| dURB | 0.7009 | 0.1179 | 5.9430 |
| dTRA | 0.0005 | 0.0009 | 0.5810 |
| C | -0.0588 | 0.2387 | -0.2465 |

## 5. CONCLUSIONS

This study looks at how energy consumption, urbanization, and carbon dioxide emissions relate to each other in 32 Asian nations. The dependent variable in this study is carbon dioxide emissions, which measure the quality of the environment. The independent variables are trade openness, GDP growth squared, population density, GDP per capita growth, renewable and non-renewable energy, and urban population. Unit root tests were used to evaluate the variables' stationarity. The findings indicate that while population density, carbon dioxide emissions, and both renewable and non-renewable energy are non-stationary, urban population and GDP per capita growth remain constant. The long-term research shows a positive but negligible correlation between carbon dioxide emissions and non-renewable energy consumption, indicating that economic expansion and reliance on fossil fuels in Asian countries are factors contributing to increased emissions. Furthermore, a large number of enterprises in these nations rely on energy-intensive equipment, which raises atmospheric CO2 levels even further. In line with the ideas of ecological modernization and urban environmental transition, the results also show a positive and substantial correlation between $CO_2$ emissions and urban population increase. CO2 emissions are favorably correlated with both trade openness and population density, while they are negatively correlated with GDP growth squared and the use of renewable energy. In the context of Asian economies, $CO_2$ emissions initially rise with income growth but eventually decline after reaching a certain economic threshold, illustrating a turning point in emissions associated with sustainable economic growth. The study underscores that transitioning to renewable energy sources can effectively lower $CO_2$ emissions, aiding in achieving sustainable development goals. Furthermore, the results indicate a negative value for the error correction term, suggesting adjustment dynamics towards long-term equilibrium. With growing urban populations, sustainable growth is essential for Asian economies. To facilitate low-carbon urbanization, government planners could focus on expanding public transit systems and eco-friendly infrastructure, thereby reducing reliance on private vehicles and mitigating $CO_2$ emissions. Additionally, rural energy access improvements could help control migration to urban areas by addressing energy needs in less developed regions. Renewable energy is key to reducing pollution, while non-renewable sources degrade environmental quality. Governments can prioritize the development of renewable energy infrastructure, promoting sources like wind, solar, biomass, and tidal energy to replace fossil fuels. Creating an industry framework focused on emissions reduction and energy efficiency could further help in establishing a low-carbon economy. Economic growth, in the absence of conservation policies, often leads to higher carbon emissions. Thus, policymakers might focus on adopting energy-saving policies to reduce emissions. This approach includes supporting clean and efficient energy options that foster sustainable economic growth. Environmental quality is also being strained by the growing population, which emphasizes the need for laws that support sustainable lifestyle choices. The environmental effects of population expansion can be lessened by promoting the use of renewable energy, water conservation, and energy-efficient activities. Because increased economic activity frequently adds to pollution, trade expansion presents environmental issues. To promote cleaner manufacturing and enhance regional environmental sustainability, government planners might push for trade rules that are considerate of the environment and facilitate the transfer of clean technology from industrialized countries.

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