Growth, Population and Pollution: Understanding Carbon Emissions in ASEAN Countries

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Abstract

This study examines the impact of human resources, population density, industrial activity, and economic growth on atmospheric carbon dioxide emissions in 11 ASEAN member nations from 1999 to 2022. Using a dynamic threshold panel data model and dynamic analysis, the variables are assessed to determine their effects. The research finds that the threshold value of human resources is 2.772, beyond which its relationship with other factors becomes significant. A human resources value of -0.057 indicates that increased human resources lead to a decrease in emissions. Population density (correlation of 0.332), industrial activity (coefficient of 0.007), and economic growth (coefficient of 0.297) are positively correlated with higher emissions. The baseline for carbon dioxide emissions is 1.113, serving as the model constant. The study suggests that while economic expansion and improved human resources can increase emissions, surpassing a certain threshold in human resources can significantly reduce them. This research provides new insights into the effects of industrial activity and population density on emissions, highlighting varying impacts from different development rates.

Keywords: Population Density, CO2 Emissions, Human resources, Southeast Asia

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Introduction

Southeast Asia, a dynamic and diverse region, faces significant challenges in managing economic growth and population density while minimizing environmental impacts. One crucial aspect in achieving this balance is reducing greenhouse gas emissions, where human resources play a critical role (Maja & Ayano, 2021). Skills Development and Innovation Human resources, which includes knowledge, skills, and public health, is critical to innovation and adoption of environmentally friendly technologies. Quality education can raise awareness of environmental issues and equip individuals with the skills to develop and implement technologies that can reduce greenhouse gas emissions, such as renewable energy and energy efficiency (Wen, Okolo, Ugwuoke, & Kolani, 2022).

Government Policies and Regulations in Southeast Asia can leverage human resources through policymaking that supports research and development in clean energy. This includes incentives for industries that reduce greenhouse gas emissions and investment in infrastructure that supports low-carbon mobility (Nong, Wang, & Al-Amin, 2020).

Community Participation Human resources also plays a role in increasing community participation in emission reduction efforts. Through education and awareness campaigns, the public can be encouraged to adopt more sustainable lifestyles, such as using public transportation, reducing energy consumption, and supporting green policies (Dai, Ahmed, Alvarado, & Ahmad, 2024). Industry Collaboration Industries in Southeast Asia should collaborate with educational and research institutions to develop innovative solutions that reduce greenhouse gas emissions (Nepal, R., Phoumin, H., & Khatri, A. (2021). Investing in human resources through employee training and development can accelerate the adoption of cleaner and more efficient industrial practices (Bag & Gupta, 2020).

Sustainable Economic Growth Increasing human resources can drive sustainable economic growth. With a skilled and innovative workforce, Southeast Asia can become a leader in the green economy, creating new jobs and increasing competitiveness in the global market (Prasetyo & Kistanti, 2020).

According to Triatmanto, Bawono, and Wahyuni (2023), investing in human resources is an investment in a sustainable future. Southeast Asia may attain equitable and sustainable economic growth while balancing environmental health and population density by enhancing human resources, which will also help the region cut greenhouse gas emissions (Huang, Chien, & Sadiq, 2022).

With its dense population and quick economic expansion, Southeast Asia confronts significant difficulties in controlling greenhouse gas emissions. Elevated population density, particularly in metropolitan regions, considerably contributes to rising greenhouse gas emissions. The impact of population density on greenhouse gas emissions will be examined in this article, along with potential solutions (Chen, Chiu, & Lin, 2020).

Higher economic activity and energy use are frequently linked to dense populations. Increased greenhouse gas emissions can result from unchecked urban growth. In addition to altering the features of the land and air circulation, tall structures and factories in metropolitan areas also significantly increase greenhouse gas emissions. Densely inhabited cities are significant contributors to climate catastrophe since they are hubs of economic Growth (Rahman & Alam, 2021).

Southeast Asia's high population density contributes significantly to rising greenhouse gas emissions. However, this harmful effect may be minimized, and we can advance toward a more sustainable future with the appropriate plan and everyone's active involvement (Le & Nguyen, 2024). Reducing greenhouse gas emissions in densely populated places requires investments in clean technology, green infrastructure, and public education (Cheshmehzangi, Butters, Xie, & Dawodu, 2021). One of the regions experiencing significant economic expansion is Southeast Asia, which needs help striking a balance between industrial development and the control of greenhouse gas emissions. An essential factor in the rise in greenhouse gas emissions that fuel global climate change is industry. The contribution of industry to Southeast Asia's rising greenhouse gas emissions will be covered in this article, along with mitigation measures that may be implemented (Tan, Hong, & Chan, 2020).

Industry in Southeast Asia contributes significantly to greenhouse gas emissions through various sectors, including power generation, transportation, and energy combustion for industrial activities. Uncontrolled industrial development can lead to increased greenhouse gas emissions. Production processes that rely on fossil fuels, such as coal, contribute significantly to emissions (Abdul Latif, Chiong, Rajoo, Takada, Chun, Tahara, & Ikegami, 2021). Industry in Southeast Asia plays a vital role in increasing greenhouse gas emissions. However, with the adoption of effective decarbonization strategies, the region can reduce its negative impact on the environment while still supporting economic growth. Measures such as the use of clean energy, environmentally friendly technologies, and supportive regulations can help Southeast Asia in its transition to a sustainable green economy (Le, 2021).

Economic Growth is often associated with increased industrial activity and energy consumption, which in turn increases greenhouse gas emissions (Romero & Gramkow, 2021). In Southeast Asia, from 1990 to 2010, carbon dioxide emissions grew faster than in other parts of the world. Economic Growth in Southeast Asia has a significant role in the increase in greenhouse gas emissions. However, with the right strategy and commitment from all parties, including government, industry, and society, we can reduce these negative impacts and move towards a more sustainable future. Steps such as clean energy transition, technological innovation, strong environmental policies, and public education are crucial to achieving this goal (Zhang, Fan, Chen, Gao, & Liu, 2020). This study aims to investigate the role of human resources, population density, industrial Activity, and Economic Growth in shaping carbon dioxide emissions in the atmosphere in 11 ASEAN member countries.

Literature Review

Southeast Asia's attempts to cut carbon dioxide emissions depend heavily on human resources, which are defined as the workforce's health, knowledge, and abilities (Sulisnaningrum, Mutmainah, Bawono, & Drean, 2023). Increasing funding for training and education can raise people's knowledge of and capacity for implementing sustainable practices and green technology. Communities can create and execute renewable energy solutions and use resources more creatively and efficiently when they have more excellent human resources (Lin & Zhou, 2022). Workers with higher levels of education and training can decrease waste, including greenhouse gas emissions, and increase operational efficiency at the company level. Additionally, they are more inclined to advocate for or start adjustments to more ecologically friendly procedures, such as switching to cleaner fuels and carbon footprint-reducing technology (Wang & Zhang, 2020). At the policy level, decision-makers who possess a thorough understanding of both sustainable economics and environmental challenges may create and carry out policies that facilitate the shift to a low-carbon economy. This includes laws that promote spending on energy-efficient appliances, public transit, and renewable energy. Vital human resources can also hasten research and development in the renewable energy sector (Kannan, Solanki, Kaul, & Jha, 2022). Southeast Asia has enormous potential for renewable energy sources, including solar, wind, and bioenergy, which makes this significant. Raising human potential in this area can significantly lower carbon dioxide emissions and lessen reliance on fossil fuels (Pratiwi & Juerges, 2020).

Sustainable behavioural changes may be encouraged at the individual level by raising awareness and educating people about the effects of climate change. These include cutting back on energy use, adopting more eco-friendly transportation, and leading lifestyles with smaller carbon footprints. Each knowledgeable person may contribute to the group's efforts to fight climate change and cut emissions (Whitmarsh, Poortinga, & Capstick, 2021). The literature review's findings lead us to develop the following hypothesis (H1):

H1. Human resources plays a role in reducing carbon dioxide emissions in Southeast Asia

Southeast Asia's population density has a significant influence on rising carbon dioxide emissions. The region is seeing a sharp rise in population, particularly in its major cities, which is driving up demand for resources and energy. Increased household consumption, transportation, and industrial activity are all substantial contributors to CO2 emissions, and they are frequently linked to high population densities (Rahman, Saidi, & Mbarek, 2020).

Economic growth driven by population growth also contributes to increased emissions. As the population increases, there is an increased need for infrastructure development, such as roads, buildings, and other facilities. This development process not only requires large amounts of energy but also often relies on fossil fuels, which produce high CO2 emissions (Sarkodie, Owusu, & Leirvik, (2020).

High population density can exacerbate the problem of deforestation. The need for land for settlements, agriculture, and other economic activities drives deforestation, which reduces the ability of forests to absorb CO2. This deforestation not only reduces the natural "lungs" that absorb carbon but also releases carbon stored in forest biomass into the atmosphere (Miyamoto, 2020).

Transportation is one of the main sectors affected by population density. In large cities in Southeast Asia, the number of motorized vehicles continues to increase along with population growth. This results in higher transportation-related CO2 emissions, which are made worse by the regular traffic jams in crowded cities. However, high population density also offers chances to cut emissions by utilizing environmentally friendly technology and creating effective public transit networks. Despite the difficulties associated with high population density, cities in Southeast Asia may lower their CO2 emissions with the correct investment in green infrastructure and supporting policies (Rith, Fillone, & Biona, 2020). Our literature review's findings lead us to develop the following hypothesis (H2):

H2. Population density increases carbon dioxide emissions in Southeast Asia

Southeast Asian industry contributes significantly to rising carbon dioxide emissions, which presents a significant obstacle to attempts to stabilize the global climate. Due to industrial development and rapid economic expansion, there has been a direct increase in the use of energy, mainly from fossil fuels, which has boosted CO2 emissions (Lin, Yu, Wen, & Liu, 2022).

One of the primary sources of carbon dioxide emissions is the industrial sector, particularly industries like cement, iron and steel, textiles, pulp and paper, and ammonia, which are needed for high-heat manufacturing processes. Burning coal, which results in significant CO2 emissions, is a common way to meet this growing energy demand (Gür, 2022). The industry's reliance on fossil fuels and the use of less efficient technology both make the pollution issue worse. The industrial sector will remain a significant contributor to carbon dioxide emissions until there is a transition towards more eco-friendly and productive technology. This emphasizes the significance of industrial decarbonization or the shift from carbon-intensive to more sustainable and ecologically friendly technology. Nonetheless, innovations and policy adjustments present chances to cut emissions (Li & Haneklaus, 2021).

Government action is essential to industrial decarbonization. Reducing carbon dioxide emissions from the industrial sector may be achieved with the assistance of innovation, strong laws, and incentives for the use of green technologies. Southeast Asia may lessen the effect of industry on climate change if there is a supporting regulatory framework and a commitment to reaching net-zero emissions (Nurdiawati & Urban, 2021). Our literature review's findings lead us to develop the following hypothesis (H3):

H3. Industrial activities increase carbon dioxide emissions in Southeast Asia

Economic Growth in Southeast Asia has contributed to increasing carbon dioxide emissions, which poses a serious challenge to global climate stability. This growth reflects solid economic dynamics but also indicates an increasing need for energy, which is still mostly met through fossil fuel sources (Hasni, Dridi, & Ben Jebli, 2023). Increasing economic activities, such as industrial production, transportation, and construction, require large amounts of energy (Osobajo, Otitoju, Otitoju, & Oke, 2020). GDP growth and energy consumption in several ASEAN countries have been shown to reduce CO_2 emissions positively. This suggests that without policy and technology changes, economic growth may continue to drive emissions increases (Munir, Lean, & Smyth, 2020). However, economic growth also provides opportunities for investment in clean technologies and sustainable development (Jaiswal, Chowdhury, Yadav, Verma, Dutta, Jaiswal, & Karuppasamy, 2022). With the right policies, economic growth can be directed to support the transition to renewable energy, energy efficiency, and reduced dependence on fossil fuels, which will ultimately reduce CO_2 emissions (Zhao, Mahendru, Ma, Rao, & Shang, 2022). On the other hand, the increase in carbon emissions in several ASEAN countries is more due to the large energy consumption generated by the community and economic growth rather than due to deforestation and population growth. This emphasizes the importance of managing energy consumption and encouraging innovation in cleaner energy production (Chopra, Magazzino, Shah, Sharma, Rao, & Shahzad, 2022). Drawing on the findings of the literature research, we propose the subsequent hypothesis (H4).:

H4. Economic growth increases carbon dioxide emissions in Southeast Asia

Research Method

This study examines 11 ASEAN Member Countries with a research period from 1999 to 2022. Table 1 lists the 11 nations that were the subject of the study.

Table 1. List of Countries Studied

ASEAN Member Countries studied
1. Brunei Darussalam 2. Cambodia 3. East Timor 4. Indonesia 5. Laos 6. Malaysia 7. Myanmar 8. Philippines 9. Singapore 10. Thailand 11. Vietnam

Using a dynamic threshold panel data model, dynamic analysis is used in this work. Human resources, population density, industrial Activity, Economic Growth, and carbon dioxide emissions are the variables used in this study. Table 2 presents an explanation of the variables.

Table 2. Variable Description

Variable	Description	Unit Analysis	Source
Human resources	Refers to the skills, knowledge, and experience possessed by the workforce.	Index Scale	www.worldbank.org
Population Density	The number of people living per unit area is usually per square kilometre.	people per sq. km of land area	globalcarbonatlas.org
Industrial Activity	The economic sector is concerned with the production of goods services, or the extraction of natural resources.	Per cent	www.bp.com
Economic Growth	The increase in a country's economic production capacity is measured by GDP growth.	Per cent	www.bp.com
Carbon Dioxide Emissions	The amount of CO2 released into the atmosphere as a result of human activities such as the burning of fossil fuels.	$MtCO_2$ per capita	www.worldbank.org

In econometric research, the Pesaran test of cross-sectional dependency statistics is a crucial analytical tool, particularly when utilizing dynamic threshold panel data models. The cross-sectional dependency issue, which arises when errors in panel data exhibit a correlation across several cross-sectional units, is the focus of this test. External factors that impact every unit in the sample, including significant economic events or system-wide policy changes, frequently cause this reliance. Cross-sectional dependency can result in erroneous and inconsistent parameter estimations in the setting of dynamic threshold models, where the model parameters might change when the independent variable reaches a given threshold value. In order to discover this reliance and modify the estimating approach, the Pesaran test is employed. This makes it possible for researchers to get reliable statistical conclusions and estimations.

To make sure that the observed behavioural or dynamic changes in the data are indeed caused by the variable exceeding the threshold and not by undetected cross-sectional dependency, the Pesaran test is crucial when using dynamic threshold models. Consequently, this test aids in elucidating whether the threshold effect has been seen as a result of causation or whether it is only a cross-sectional dependency artefact. Panel data analysis relies heavily on the Pesaran cross-sectional dependence test statistic, mainly when working with dynamic threshold models. This test enhances the validity of results derived from panel data analysis while also increasing the accuracy of parameter estimations. As a result, the Pesaran test is essential for guaranteeing the validity of panel data econometric studies and their ability to shed light on the economic and social issues under investigation. The following is the Pesaran cross-sectional dependence test statistic:

$$CD = \sqrt{(2T/N(N-1))}\ \left(\sum_{i=1}^{n-1} \sum_{k=i+1}^{n} \hat{U}_{ik}\right)$$

The coefficient of correlation The link between a number of variables from nations i and k is measured by Γik. The total number of nations and the total number of periods are represented by the symbols N and T, respectively. Cross-sectional dependency is demonstrated by the Pesaran CD method's testing of the null hypothesis (H0). We employ the modified procedure of Im, Pesaran, and Shin to perform the unit root test on panel data, taking cross-sectional dependency into account.

An econometric technique for analyzing data having a dynamic structure and individual heterogeneity is the dynamic threshold panel data equation with endogenous threshold variable. With this approach, the threshold variable—which establishes the model's shift in regime or condition—may alter endogenously in response to changes in the data's actual behaviour. Stated differently, the data determines the threshold rather than the researcher determining it exogenously.

This approach integrates time-series and cross-sectional data in panel data regression to produce more precise and effective results. This model considers the potential that, after the independent variable reaches a threshold value, the connection between the independent variable and the dependent variable may change. Since the data being examined is dynamic, these threshold values are not set in stone and may vary over time or across people. The use of a dynamic threshold model with endogenous threshold variables offers a flexible framework for evaluating complicated panel data. In addition to giving academics a better grasp of the mechanisms behind the correlations between economic variables, it enables them to capture the dynamism and heterogeneity contained in the data. The following is the equation for dynamic threshold panel data with endogenous threshold variables:

$$y_{it} = X_{it}'\beta + (1, X_{it}')\gamma 1 I(q_{it} \le \tau) + (1, X_{it}')\gamma 2 I(q_{it} > \tau) + \mu_i + \varepsilon_{it}$$

$$i = 1, \ldots, n;\ t = 1, \ldots, T$$

It is considered the dependent variable in this framework. Xit could have dependent variables that are laggard. For the boundary variable, use it. The boundary parameter is τ, and the vector of coefficients is denoted by β'. Two distinct regimes' coefficients are denoted by γ1 and γ2. I perform the role of an indication. A term for error, εit, is present, and μi is country-fixed effects. Using a first difference transformation, country-fixed effects may be removed.

Results And Discussion

This study enriches the body of knowledge by introducing a proven methodological approach to explore and confirm the dynamics among economic variables in the Southeast Asian region, particularly among ASEAN member countries. Through this methodology, the study presents supporting empirical evidence, which not only strengthens the theoretical foundation for future in-depth investigations but also offers a solid foundation for informed and data-driven policymaking in the field of regional economics and environmental sustainability. The results obtained from this estimation process are essential as they provide reliable insights for a better understanding of cross-country economic interactions, which, in turn, can guide strategic decisions in the broader context of economic integration and environmental cooperation in Southeast Asia.

Results

A statistical technique for identifying inter-sectional dependence in panel data models is the Pesaran CD test. M. Hashem Pesaran created this technique as a diagnostic tool to determine whether variables in a panel dataset are connected. This can happen because of geographical dependency or because common factors impact all cross-sectional units (Wang, Zafar, Vasbieva, & Yurtkuran, 2024). The absence of inter-sectional dependency, or the idea that the variables in the model are independent of one another, is the null hypothesis for this test. We can reject the null hypothesis and conclude that there is inter-sectional dependency in the data if the CD statistic value is high enough and significant. Because it enables researchers to recognize and manage the impact of unobserved elements that might influence the model estimate results, this test is beneficial in panel data analysis. Researchers can thus provide estimations that are more trustworthy and accurate. Table 3 displays the test results.

Table 3. Uji CD Pesaran

Variable	CD test	p-value
Human resources	11.21	0.000
Population Density	10.12	0.000
Industrial Activity	11.41	0.000
Economic Growth	10.39	0.000
Carbon Dioxide Emissions	12.11	0.000

The results of the Pesaran CD test in Table 3 indicate a significant correlation between cross-sections for all variables tested. A p-value of 0.000 for each variable indicates that there is strong statistical evidence that these variables do not operate independently in the panel data but are likely influenced by the same or interrelated factors.

In the context of human resources, population density, industrial Activity, Economic Growth, and carbon dioxide emissions, this finding indicates that changes or policies that affect one of these variables can have a ripple effect on the other variables. Improvements in human resources, such as education or health, may not only have a positive impact on economic growth but can also affect carbon dioxide emission patterns and Industrial Activity. Furthermore, this finding may indicate that there are external factors that affect all of these variables simultaneously. Government policies or global climate change can be factors that affect economic Growth, Industrial Activity, and carbon dioxide emissions simultaneously. The results of this Pesaran CD test are beneficial for identifying areas that require further analysis and may guide more integrated and comprehensive policies.

After doing the Pesaran CD test, it is crucial to perform the Panel Unit Root Test since these two tests enhance each other's abilities in panel data interpretation. To find cross-sectional dependency between units in a panel, apply the Pesaran CD test. The assumption that the units are independent is no longer valid in the presence of cross-dependence, and this has an impact on how we estimate and draw statistical conclusions.

The Panel Unit Root Test should be used to ascertain if the data has a unit root or is stationary once cross-dependence has been established. A time series' ability to demonstrate that its statistical characteristics, such as its variance and mean, remain consistent across time is known as its stationarity. Regression analysis issues like estimate bias and statistical inference mistakes can arise from non-stationary time series.

Finding out whether or not the variables in the panel data are stationary is made easier with the use of the Panel Unit Root Test. Before performing more analysis, it is necessary to ensure stationarity if the variables are not stationary using differentiation or other transformations. This test is crucial since the analysis's conclusions might be false or deceptive if the variables have unit roots and we ignore them.

In order to guarantee that the model to be estimated has the correct statistical features and that the conclusions drawn from the model are trustworthy, the Panel Unit Root Test, which comes after the Pesaran CD test, offers further information. For the panel data analysis procedure to yield reliable and appropriately interpretable results, this is an essential stage. Table 4 displays the outcomes of the Panel Unit Root Test.

Table 4. Panel Unit Root Test

Variable	CIPS test	Hadri and Rao’s test
Human resources	-1.71	0.108***
Population Density	-1.41**	0.114***
Industrial Activity	-2.01	0.131***
Economic Growth	2.31**	0.118***
Carbon Dioxide Emissions	2.22**	0.103**

The Panel Unit Root Test results in Table 4 provide insight into the stationarity of the variables in the panel data. The CIPS test and Hadri and Rao's test are both used to assess stationarity but with different approaches.

In the case of human resources, the CIPS test value of -1.71 and Hadri and Rao's test p-value of 0.108*** indicate that this variable may be non-stationary but not at a very high level of significance. This means that human resources may have a long-term trend or pattern that needs to be considered in further analysis.

For population density, the CIPS test value of -1.41** and the p-value of 0.114*** also indicate possible non-stationarity. However, there are indications that this variable may be closer to the boundary of stationarity compared to human resources. This indicates that population density may be influenced by factors that change over time, and this should be taken into account in the analysis model.

Industrial activity, with a CIPS test value of -2.01, shows more substantial evidence of stationarity compared to the previous two variables. However, the p-value of 0.131*** from Hadri and Rao's test still shows that this variable is not completely stationary. This indicates that industrial activity may have a trend or cyclical component that needs to be identified and appropriately modelled.

Economic growth and carbon dioxide emissions, with positive CIPS test values (2.31** and 2.22**), indicate that these two variables are highly likely to be non-stationary. The significant p-value of Hadri and Rao's test (0.118*** and 0.103**) confirms this finding. The non-stationarity in economic growth and carbon dioxide emissions indicates that these two variables have long-term solid trends that should be taken into account in econometric analysis. Overall, the Panel Unit Root Test results indicate that most of the variables in the panel data have non-stationary characteristics, meaning that further analysis should consider techniques such as differentiation or co-integration to address this non-stationarity issue. The use of appropriate models will ensure that the estimates and inferences generated from the analysis are valid and reliable.

The Dumitrescu-Hurlin (DH) Panel Causality Test is an essential step after the Panel Unit Root Test because it determines the direction of causality between variables in panel data. After ensuring that all-time series in the panel are stationary, meaning they do not have a unit root, we can proceed to test whether there is a causal relationship between the variables. The Dumitrescu-Hurlin Panel Causality Test is an essential analytical tool for understanding the dynamics and interactions between variables in panel data, which can ultimately provide deeper insights into the underlying economic and social mechanisms. The results of the Dumitrescu-Hurlin Panel Causality Test are presented in Table 5.

Table 5. Dumitrescu-Hurlin Panel Causality Test

Hypothesis	W-stat	Zbar-stat	Conclusion
Human resources → CO_2 emissions	1.65	1.96	Human resources ←→, CO_2 emissions
CO_2 emissions → Human resources	2.03	2.58	
CO_2 emissions → Population Density	0.85	1.28	CO_2 emissions, ←→ Population Density
Population Density → CO_2 emissions	1.47	1.75	
CO_2 emissions →	2.20	2.66	CO_2 emissions, ←→

Industrial Activity			Industrial Activity
Industrial activity → CO_2 emissions	1.10	1.34	
CO_2 emissions → Economic Growth	1.30	1.50	CO_2 emissions ←→ Economic Growth
Economic growth → CO_2 emissions	2.10	2.40	
Human resources → Population Density	0.95	1.20	Human resources, ←→ Population Density
Population Density → Human resources	1.60	1.85	
Human resources → Industrial Activity	2.05	2.45	Human resources, ←→ Industrial Activity
Human resources → Industrial Activity	0.98	1.22	

The results of the Dumitrescu-Hurlin Panel Causality Test in Table 5 show that there is a two-way causal relationship between several essential variables in the panel data. This interpretation does not focus on specific statistical figures but rather on the conclusions that can be drawn from the test results. From the test results, we can see that human resources and carbon dioxide emissions have a reciprocal relationship. This shows that investments in human resources, such as education and health, may have an impact on the level of carbon dioxide emissions. Conversely, changes in carbon dioxide emissions can affect the quality and quantity of human resources. This relationship is crucial because it indicates that policies aimed at increasing human resources or reducing carbon dioxide emissions must consider the possible effects on other variables.

The two-way relationship between population density and carbon dioxide emissions shows that increasing the number of people in an area can increase emissions. At the same time, changes in emissions can also affect the distribution and density of the population. This relationship is essential in urban planning and environmental policy. The reciprocal relationship between industrial activity and carbon dioxide emissions shows that industry may be a significant source of emissions. At the same time, changes in emissions can affect industrial activity through environmental regulations or changes in consumer demand.

The bidirectional relationship between economic growth and carbon dioxide emissions suggests that economic growth can lead to increased emissions. However, changes in emissions can also affect economic growth through impacts on public health or production costs. Overall, the results suggest that these variables are interrelated in a complex and dynamic way. Policies targeting one aspect must be designed with consideration of its effects on the other aspect to achieve optimal and sustainable outcomes.

Dynamic threshold panel data model estimation plays a vital role in panel data analysis following the Dumitrescu-Hurlin Panel Causality Test. This model is used to capture the dynamics and heterogeneity that may exist in the relationships between variables in panel data. After determining the existence of causality between variables with the Dumitrescu-Hurlin Test, the dynamic threshold model can be used to understand better how the relationship changes under certain conditions or thresholds.

Dynamic threshold models allow researchers to identify and model non-linear effects between variables that may not be revealed through traditional linear estimation methods. The relationship between economic growth and carbon dioxide emissions may be different at low levels of economic growth compared to high levels. This model can reveal threshold points at which the relationship between variables changes significantly.

In addition, the dynamic threshold model also takes into account time dependence, which means that the effect of the independent variable on the dependent variable does not only occur in the same period but can also occur over time. This is important because, in many economic and social phenomena, the effects of policies or changes in conditions may not be immediately visible but emerge gradually.

By using the dynamic threshold model, researchers can gain a better understanding of the complexity of the relationships between variables in panel data. They can make more accurate predictions about how these variables will interact in the future. This is very useful in policy planning and decision-making, where understanding the conditions under which relationships between variables become stronger or weaker can help in designing more effective interventions. The estimation results of the dynamic threshold panel data model are presented in Table 6.

Table 6. Dynamic threshold panel data model estimation

Threshold Variable	Human resources index
Threshold Estimate	2.772***
Human resources	- 0.057**
Population Density	0.332***
Industrial Activity	0.007***
Economic Growth	0.297***
Carbon Dioxide Emissions	0.281***
Constant	1.113***
Wald-test	111331.28***
Sargan teat	59.21
AR(1)	-3.521***
AR(2)	-1.248
SupWald Statistic	29.11***
Observations	253

Table 6's dynamic threshold panel data model estimate findings demonstrate a strong correlation, with a distinct threshold point, between human resources and other panel data variables. The significance underlying the numbers will be examined in this interpretation.

According to the model, the human resources index has a highly statistically significant threshold estimate of 2.772*, indicating that it functions as a threshold variable. This shows that once the human resources index is above this threshold number, the connection between human resources and other factors changes. As stated differently, there has been a significant shift in the relationship between human resources and population density, industrial Activity, Economic Growth, and carbon dioxide emissions since the index rose by over 2.772.

A rise in human resources is inversely correlated with the dependent variable, carbon dioxide emissions, according to the coefficient for human resources itself, which is -0.057 and significant at the 0.05 level. With a higher coefficient (0.332*), population density is a more powerful predictor of the dependent variable. Industrial activity has a lesser coefficient (0.007*), but it is nevertheless substantial, meaning that changes in industrial activity—no matter how tiny—have a significant impact on carbon dioxide emissions.

Significant coefficients for both economic growth and carbon dioxide emissions (0.297* and 0.281*, respectively) show a substantial correlation between the two variables and carbon dioxide emissions. When all independent variables are zero, the dependent variable's baseline value is indicated by the model constant of 1.113*.

The Wald-test, which yields a value of 111331.28*, shows that the variables in the model are jointly significant and that the model fits the data well overall. The model's instruments are considered genuine, as indicated by the Sargan test result of 59.21. First and second autocorrelation in the model errors are shown by AR(1) and AR(2), respectively; AR(1) is significant at the 0.01 level, and AR(2) is negligible, suggesting that there is no autocorrelation issue at the second lag.

The choice of the dynamic threshold model is supported by the SupWald Statistic of 29.11*, which shows that there is substantial evidence of non-linearity in the model. This model is thought to have a large enough database—253 observations—to enable accurate calculations. This dynamic threshold model offers insightful information on the interactions between factors, including human resources, population density, industrial activity, economic development, and carbon dioxide emissions under certain circumstances. By understanding the intricate dynamics that exist in the economy and environment, policymakers and academics may create more focused solutions.

Discussion

The results of the study demonstrate that a nation's well-being is influenced by a multitude of factors, including the standard and amount of education, health, and skills that the people in the 11 ASEAN member states possess—a concept known as human resources. The study's model demonstrates that there is a notable shift in the relationship between human resources and other variables when the index hits 2,772. These variables include population density, industrial Activity, Economic Growth, and the quantity of airborne pollutants released into the atmosphere or factories (carbon dioxide emissions). Put another way, as people's health and education levels rise over 2,772, it not only increases their productivity but also has the potential to alter the course of economic growth, the direction of specific industries, and maybe even lessen adverse environmental effects. A more educated populace could decide to work in more eco-friendly and productive industries, which might result in more sustainable and environmentally friendly economic growth. The findings of this investigation are consistent with the studies conducted by Lin and Zhou (2022) and Sulisnaningrum, Mutmainah, Bawono, and Drean (2023). These findings are significant because they demonstrate that investing in human resources might be the secret to simultaneously accomplishing a number of objectives, including enhancing economic well-being and preserving the environment. It also highlights the fact that there is a tipping point beyond which the advantages of building human resources become pretty substantial, meaning that well-executed health and education programs may have far-reaching effects on the nation and its people. This study provides insight into how various factors in our society are interconnected, especially in the context of education and public health (human resources), the number of people living in an area (population density), how much factory and production activity (industrial activity), and its impact on the environment (carbon dioxide emissions). From the results of the study presented in Table 6, the better the education and health of the community, it turns out that this has an impact on reducing carbon dioxide emissions. This could be because, with increasing human resources, people become more aware of the importance of protecting the environment and choose to use more environmentally friendly technology or cleaner production methods. Meanwhile, the number of people living in an area has a more significant influence on the amount of carbon dioxide emissions. This makes sense because the more people there are, the more activities occur, and this can increase the amount of emissions produced. The results of this study are in line with research from Sarkodie, Owusu, and Leirvik (2020).

Industrial activity also has an impact, although population density is more minor. Any change in industry, even a small one, is still essential because it can increase the amount of carbon dioxide emissions. This shows that industry must continue to innovate to create more efficient and environmentally friendly processes in order to reduce its impact on climate change. Overall, this study emphasizes the importance of education and public health in helping to reduce negative impacts on the environment, as well as the role of population density and industrial activity in increasing carbon dioxide emissions. This illustrates that to reduce emissions and protect the environment, we need a comprehensive approach that involves increasing human resources, managing population numbers, and industrial innovation. The results of this study are in line with research from Gür (2022). This study explores how economic Growth and the amount of harmful gases released into the air (carbon dioxide emissions) are related. The results show that both have a significant influence on the amount of carbon dioxide emissions. In other words, as a country's economy grows, the amount of carbon dioxide emissions will also increase. The results of this study strengthen the research of Osobajo, Otitoju, Otitoju, and Oke (2020). This can happen because economic growth is often accompanied by an increase in industrial activity that produces emissions (Wang & Zhang, 2020).

The significant coefficients for economic growth (0.297*) and carbon dioxide emissions (0.281*) indicate that these two factors are closely related. So, if we want to reduce carbon dioxide emissions, we need to think of ways to ensure that economic growth only sometimes means an increase in emissions. The model constant of 1.113* gives an idea of what happens to carbon dioxide emissions when other factors, such as economic growth, population density, and industrial activity, are not taken into account. This is like the initial or baseline value of carbon dioxide emissions that would exist without considering these factors. Overall, this study highlights the importance of finding a balance between economic growth and environmental protection. It suggests that we should strive for sustainable economic growth, which does not harm our environment.

Conclusion

This study examines how human resources (the skills and knowledge possessed by humans) affect factors such as population density, industrial Activity, Economic Growth, and carbon dioxide emissions. The study found that there is a specific value of human resources, which is 2.772, which is called the ‘threshold value’. This means that when the human resources index exceeds 2.772, its relationship with other factors changes. Before reaching this value, human resources may not have a significant influence, but after passing this value, its effect becomes more significant. The coefficient for human resources is -0.057, which means that if human resources increases, carbon dioxide emissions tend to decrease. This shows that the more skills and knowledge people have, the more efficient they are in using resources, which can reduce emissions. Population density has a coefficient of 0.332, which is more significant than human resources. This shows that the more densely populated an area is, the higher the carbon dioxide emissions it produces. This could be because more people mean more activities that produce emissions. Industrial activity has a small coefficient of 0.007, but it is still significant. This means that any slight increase in industrial activity will increase carbon dioxide emissions, although it will be less than population density or economic growth. Economic growth and carbon dioxide emissions have relatively large coefficients (0.297 and 0.281), indicating that increased emissions often accompany rapid economic growth. The model constant of 1.113 is the baseline value of carbon dioxide emissions when there is no increase in human resources, population density, industrial Activity, or economic Growth. So, overall, this study shows that increases in human resources and economic growth can increase carbon dioxide emissions. However, if human resources are increased beyond a threshold value, the effect on emissions can be significantly reduced. Population density and industrial activity also contribute to emissions, but their effects vary depending on the growth rate.

Policy implications

This study on the effects of human resources, population density, industrial Activity, and economic Growth on carbon dioxide emissions in ASEAN countries offers essential insights for the formulation of effective environmental policies. Policy implications derived from this study emphasize the importance of investing in human resources as a key to reducing emissions. Quality education and training can strengthen individuals’ capacity to innovate and adopt cleaner and energy-efficient technologies. Furthermore, this study highlights the need for better urban planning to manage population density, which is directly related to emission levels. The development of green infrastructure and efficient public transportation systems can be strategic steps to reduce carbon footprints. On the other hand, monitoring industrial activity through regulations that encourage the use of renewable energy and environmentally friendly production processes can help curb industrial emissions. Sustainable economic growth should be a key focus of policy, balancing economic progress with environmental preservation. Policies that support the transition to a green economy, including the use of renewable energy and sustainable agricultural practices, can promote growth that is not detrimental to the environment. The discovery of a ‘threshold value’ of human resources in this study also suggests that there is a tipping point at which improvements in human resources can significantly reduce emissions, and education and human resource development policies should be designed to reach and exceed this threshold value. Overall, this study provides a basis for policymakers to formulate strategies that not only reduce carbon dioxide emissions but also support inclusive and sustainable economic growth. A holistic approach that takes all these factors into account will be essential in achieving sustainable development goals in the ASEAN region.

Limitations And Future Research Recommendations

This study has made an essential contribution to understanding the factors influencing carbon dioxide emissions in ASEAN countries. However, like all scientific studies, this study has limitations that must be acknowledged. One central area for improvement is the use of panel data that may not fully reflect the unique conditions of each ASEAN member country. Each country has different environmental policies, levels of industrialization, and socioeconomic conditions, which may affect the results of the study. In addition, the dynamic threshold model used may have limitations in capturing the complexity of the relationships between the variables studied. Although the model provides insight into the threshold value of human resources, there may be other factors that need to be captured in the model that also influence carbon dioxide emissions. Changes in environmental policies, technological innovation, and natural disasters can affect emissions but are not reflected in the model used. For future research, it is recommended that more detailed case studies or longitudinal data be incorporated for each ASEAN country. This will allow researchers to gain a deeper understanding of how country-specific factors influence carbon dioxide emissions. Future research can also expand the variables considered, such as environmental policies, access to clean technologies, and responses to climate change, to provide a more complete picture of carbon dioxide emission dynamics. In addition, research that examines the impact of policy interventions directly on carbon dioxide emissions would be valuable. This could include analysis of the long-term impacts of specific policies or comparisons between countries with different policy approaches. In this way, future research could provide more precise and evidence-based recommendations for policymakers in designing effective and sustainable emission reduction strategies.

References

Abdul Latif, S. N., Chiong, M. S., Rajoo, S., Takada, A., Chun, Y. Y., Tahara, K., & Ikegami, Y. (2021). The trend and status of energy resources and greenhouse gas emissions in the Malaysia power generation mix. Energies, 14(8), 1-10.

Bag, S., & Gupta, S. (2020). Examining the effect of green human resources availability in the adoption of reverse logistics and remanufacturing operations performance. International Journal of Manpower, 41(7), 1097-1117.

Chen, T. L., Chiu, H. W., & Lin, Y. F. (2020). How do East and Southeast Asian cities differ from Western cities? A systematic review of the characteristics of urban form. Sustainability, 12(6), 1-10.

Cheshmehzangi, A., Butters, C., Xie, L., & Dawodu, A. (2021). Green infrastructures for urban sustainability: Issues, implications, and solutions for underdeveloped areas. Urban Forestry & Urban Greening, 59(1), 1-10.

Chopra, R., Magazzino, C., Shah, M. I., Sharma, G. D., Rao, A., & Shahzad, U. (2022). The role of renewable energy and natural resources for sustainable agriculture in ASEAN countries: Do carbon emissions and deforestation affect agriculture productivity? Resources Policy, 76(1), 1-10.

Dai, J., Ahmed, Z., Alvarado, R., & Ahmad, M. (2024). Assessing the nexus between human resources, green energy, and load capacity factor: policymaking for achieving sustainable development goals. Gondwana Research, 129(1), 452-464.

Gür, T. M. (2022). Carbon dioxide emissions, capture, storage and utilization: Review of materials, processes and technologies. Progress in Energy and Combustion Science, 89(1), 1-10.

Hasni, R., Dridi, D., & Ben Jebli, M. (2023). Do financial development, financial stability, and renewable energy disturb carbon emissions? Evidence from Asia–Pacific economic cooperation economics. Environmental Science and Pollution Research, 30(35), 83198-83213.

Huang, S. Z., Chien, F., & Sadiq, M. (2022). A gateway towards a sustainable environment in emerging countries: the nexus between green energy and human resources. Economic research-Ekonomska istraživanja, 35(1), 4159-4176.

Jaiswal, K. K., Chowdhury, C. R., Yadav, D., Verma, R., Dutta, S., Jaiswal, K. S., & Karuppasamy, K. S. K. (2022). Renewable and sustainable clean energy development and impact on social, economic, and environmental health. Energy Nexus, 7(1), 1-10.

Kannan, D., Solanki, R., Kaul, A., & Jha, P. C. (2022). Barrier analysis for carbon regulatory environmental policies implementation in manufacturing supply chains to achieve zero carbon. Journal of Cleaner Production, 358(1), 1-10.

Le, T. H. (2021). Drivers of greenhouse gas emissions in ASEAN+ 6 countries: a new look. Environment, Development and Sustainability, 23(12), 18096-18115.

Le, T. H., & Nguyen, C. P. (2024). Determinants of greenhouse gas emissions revisited: A global perspective. The Singapore Economic Review, 69(1), 141-167.

Li, B., & Haneklaus, N. (2021). The role of renewable energy, fossil fuel consumption, urbanization and economic Growth on CO2 emissions in China. Energy Reports, 7(1), 783-791.

Lin, B., & Zhou, Y. (2022). Measuring the green economic Growth in China: Influencing factors and policy perspectives. Energy, 241(1), 1-10.

Lin, H. I., Yu, Y. Y., Wen, F. I., & Liu, P. T. (2022). Status of food security in East and Southeast Asia and challenges of climate change. Climate, 10(3), 1-10.

Maja, M. M., & Ayano, S. F. (2021). The impact of population growth on natural resources and farmers' capacity to adapt to climate change in low-income countries. Earth Systems and Environment, 5(2), 271-283.

Miyamoto, M. (2020). Poverty reduction saves forests sustainably: Lessons for deforestation policies. World Development, 127(1), 1-10.

Munir, Q., Lean, H. H., & Smyth, R. (2020). CO2 emissions, energy consumption and economic growth in the ASEAN-5 countries: a cross-sectional dependence approach. Energy Economics, 85(1), 1-10.

Nepal, R., Phoumin, H., & Khatri, A. (2021). Green technological development and deployment in the association of Southeast Asian economies (ASEAN)—at crossroads or roundabout? Sustainability, 13(2), 1-10.

Nong, D., Wang, C., & Al-Amin, A. Q. (2020). A critical review of energy resources, policies and scientific studies towards a cleaner and more sustainable economy in Vietnam. Renewable and Sustainable Energy Reviews, 134(1), 1-10.

Nurdiawati, A., & Urban, F. (2021). Towards deep decarbonization of energy-intensive industries: A review of current status, technologies and policies. Energies, 14(9), 1-10.

Osobajo, O. A., Otitoju, A., Otitoju, M. A., & Oke, A. (2020). The impact of energy consumption and economic growth on carbon dioxide emissions. Sustainability, 12(19), 1-10.

Prasetyo, P. E., & Kistanti, N. R. (2020). Human resources, institutional economics and entrepreneurship as a driver for quality and sustainable economic growth. Entrepreneurship and Sustainability Issues, 7(4), 1-10.

Pratiwi, S., & Juerges, N. (2020). Review of the impact of renewable energy development on the environment and nature conservation in Southeast Asia. Energy, Ecology and Environment, 5(4), 221-239.

Rahman, M. M., & Alam, K. (2021). Clean energy, population density, urbanization and environmental pollution nexus: Evidence from Bangladesh. Renewable Energy, 172(1), 1063-1072.

Rahman, M. M., Saidi, K., & Mbarek, M. B. (2020). Economic Growth in South Asia: the role of CO2 emissions, population density and trade openness. Heliyon, 6(5),1-10.

Rith, M., Fillone, A. M., & Biona, J. B. M. M. (2020). Energy and environmental benefits and policy implications for private passenger vehicles in an emerging metropolis of Southeast Asia–A case study of Metro Manila. Applied Energy, 275(1), 1-10.

Romero, J. P., & Gramkow, C. (2021). Economic complexity and greenhouse gas emissions. World Development, 139(1), 1-10.

Sarkodie, S. A., Owusu, P. A., & Leirvik, T. (2020). The global effect of urban sprawl, industrialization, trade and economic development on carbon dioxide emissions. Environmental Research Letters, 15(3), 1-10.

Sulisnaningrum, E., Mutmainah, S., Bawono, S., & Drean, B. (2023). Investigating The Impact of ICT Developments on the Environment in the Digital Economy and Green Economy in Southeast Asia. International Journal of Professional Business Review: Int. J. Prof. Bus. Rev., 8(5), 1-10.

Tan, S. H., Hong, M., & Chan, T. H. (2020). Economic growth, urbanization and carbon emissions: evidence from selected Asian countries. International Journal of Industrial Management, 6(1), 9-16.

Triatmanto, B., Bawono, S., & Wahyuni, N. (2023). The contribution and influence of total external debt, FDI, and HCI on Economic Growth in Indonesia, Thailand, Vietnam, and the Philippines. Research in Globalization, 7(1), 1-10.

Wang, Q., & Zhang, F. (2020). Does increasing investment in research and development promote economic growth decoupling from carbon emission growth? An empirical analysis of BRICS countries. Journal of Cleaner Production, 252(1), 1-10.

Wang, S., Zafar, M. W., Vasbieva, D. G., & Yurtkuran, S. (2024). Economic Growth, nuclear energy, renewable energy, and environmental quality: Investigating the environmental Kuznets curve and load capacity curve hypothesis. Gondwana Research, 129(1), 490-504.

Wen, J., Okolo, C. V., Ugwuoke, I. C., & Kolani, K. (2022). Research on influencing factors of renewable energy, energy efficiency, and technological innovation. Does trade, investment and human resources development matter? Energy Policy, 160(1), 1-10.

Whitmarsh, L., Poortinga, W., & Capstick, S. (2021). Behaviour change to address climate change. Current Opinion in Psychology, 42(1), 76-81.

Zhang, J., Fan, Z., Chen, Y., Gao, J., & Liu, W. (2020). Decomposition and decoupling analysis of carbon dioxide emissions from economic growth in the context of China and the ASEAN countries. Science of the Total Environment, 714(1), 1-10.

Zhao, X., Mahendru, M., Ma, X., Rao, A., & Shang, Y. (2022). Impacts of environmental regulations on green economic Growth in China: New guidelines regarding renewable energy and energy efficiency. Renewable Energy, 187(1), 728-742.