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ENERGY TRANSITION, GREEN GROWTH AND EMISSION ON ECONOMIC GROWTH USING SPLINE APPROACH: EVIDENCE FROM ASIA-PASIFIC COUNTRIES

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ABSTRACT

This study examines the impact of energy transition, green growth, and emissions on economic growth across 36 Asia-Pacific countries using the spline approach. By utilizing cross-sectional data from 2022 and 2023, the research explores the nonlinear relationships between these variables and provides insights into achieving sustainable economic growth. The results show that countries with an Energy Transition Index below 47.02 can achieve a 0.41% increase in economic growth, while those within the range of 47.02 to 54.44 experience a higher growth potential of 0.67%. However, countries with an index exceeding 65.71 see a slightly lower growth rate of 0.59%, indicating that advanced transitions require more targeted strategies to sustain economic performance. Similarly, the Green Growth Index exhibits a nonlinear effect. Countries with an index below 43.19 show a 0.16% increase in economic growth, but those within the 43.19 to 53.82 range face a 0.13% decline in potential growth. Notably, countries with very high green growth scores above 65.75 manage to reverse the trend and achieve a modest 0.04% growth. In contrast, emissions have a predominantly negative impact. Countries with emissions below 265.53 MtCO2e still manage a 0.01% growth, but those with emissions exceeding 522.51 MtCO2e face a decline in economic growth of up to 0.10%. This study provides actionable insights for policymakers to develop tailored strategies that promote renewable energy investments, green innovations, and emissions reductions to achieve sustainable economic growth in the Asia-Pacific region.. The study emphasizes the need for tailored strategies that focus on renewable energy investments, green innovation, and emission reductions to achieve sustainable economic development. By adopting spline regression models, this research offers new insights for policymakers to develop data-driven strategies that enhance economic growth while promoting green transitions in the Asia-Pacific region.

Keywords: *Economic Growth, Energy Transition, Emission, Green Growth, Spline Approach*

1. INTRODUCTION

The concept of sustainable development has gained significant importance in global discussions as countries work towards harmonizing economic growth, social fairness, and environmental preservation. Its goal is to address present-day needs while safeguarding resources and opportunities for future generations to flourish (Aye & Edoja, 2017); (Pratiwi et al., 2024). The economic crisis of 2008-2009 prompted a heightened emphasis on green economic strategies aimed at fostering environmentally sustainable growth and combating environmental degradation (Mihai et al., 2021). Since the mid-20th century, rapid globalization has introduced significant challenges for humanity, including accelerated climate change and the deterioration of ecosystems (Xue et al., 2022). Non-renewable energy has long been regarded as a crucial factor in driving economic growth in developing Nations (Polat, 2021). However, the reliance on fossil fuels has raised significant concerns regarding energy supply security, price fluctuations, and the environmental impacts of energy production and consumption (Apergis & Payne, 2012). These challenges have compelled developing countries to shift towards renewable energy sources as an alternative to fossil fuels (A. Jha & Singh, 2020).

Climate change and environmental degradation significantly impact the sustainability of the economy, influencing both financial and non-financial institutions (Haigh, 2011); (Ozili, 2020). The potential adverse effects of climate change on economic activities are highlighted by climate risks, which pose threats to human livelihoods and overall well-being (Puška, et al., 2023). Addressing these risks and mitigating losses require societal decision-making, proactive management strategies, and the ability to predict climate trends tied to future greenhouse gas emissions, as well as broader socio-economic development and equity patterns (F. Li et al., 2022).

Nations worldwide are striving to establish effective agreements aimed at transitioning from fossil fuels to cleaner energy sources and enhancing energy efficiency to meet carbon neutrality goals (Wiseman, 2018). However, this transformation is far from straightforward (Moraliyska, 2023). According to the Shell Energy Transition Report 2019, while the demand for fossil fuels is projected to be higher in 2030 than it is today, their overall contribution to the global energy mix is expected to decline. Additionally, the World Economic Forum (2018) highlights the need for an "Effective Energy Transition," which entails a timely shift to address global energy challenges while generating value for both businesses and societies. Achieving such a transformation is a complex process, requiring comprehensive studies to explore its various dimensions and implications.

The Asia-Pacific region holds a critical position globally, particularly regarding the urgency of accelerating energy transitions. The region's significant industrial output and large population make its energy transition pivotal in contributing to a cleaner planet in the future. The United Nations Economic and Social Council (2018) has also emphasized the importance of energy transition in Asia, pointing to the rising consumption of fossil fuels and the region's high industrial production potential. Within Asia, countries like China and India are at the forefront of global renewable energy generation, undergoing simultaneous energy transitions and economic transformations (Mamat et al., 2019). Numerous studies, underscore the significance of examining energy transition dynamics across the Asia-Pacific region, given its importance to both regional and global sustainability goals (Jairah & Kumar, 2019); (Al-Shamma's et al., 2020).

Green growth refers to promoting economic growth and development while ensuring that natural resources continue to provide the essential services and materials upon which human well-being depends (Pata & Kartal, 2024). To achieve this, it must stimulate investment and innovation that support long-term growth and create new economic opportunities.

The concept of a green growth emerges as a response to human behavior that often prioritizes profit over sustainability (Ogundele et al., 2023). In the fast-paced dynamics of today's economy, there is a tendency to pursue gains with little regard for environmental preservation, leading to practices that prioritize large profits over sustainability. Therefore, developing countries tend to compete to develop financial institutions, especially stock market and banking, to encourage their economic growth, both in the short and long term (Rahman Razak & Soedarmono, 2023). Many industrial production activities heavily rely on natural resources without implementing adequate conservation measures. If such practices continue unchecked, they will pose significant threats to both the environment and human well-being (Houssam et al., 2023).

Policymakers must prioritize creating a sustainable economic environment that ensures the welfare of both current and future generations in each countries, focusing on economic activities that produce goods and generate employment (Yulitasari et al., 2023). The green growth framework is essential to promote the welfare and equity of domestic market participants while contributing to national economic growth (Wang et al., 2024). The primary goal of a green growth is to achieve a balance between enhancing prosperity and maintaining environmental sustainability. Therefore, government efforts in both micro and macroeconomic development must align with the principles of a green economy (Chaaben et al., 2022).

Emissions from human industrial activities play a critical role in driving climate change, representing one of the most urgent global challenges (Zoundi, 2017). With atmospheric carbon dioxide levels rising annually, finding solutions to environmental issues becomes essential, even though energy remains a fundamental driver of economic development. The evolution of energy demand at various stages of economic growth necessitates sustainable approaches. Existing literature offers diverse perspectives and hypotheses regarding the complex relationship between economic growth and environmental pollution (Onofrei et al., 2022).

Since the onset of the industrial revolution, the global economy has experienced substantial growth. As industries flourished, the standard of living for citizens improved, and the global population increased. However, while the economic boom was accompanied by the exploitation of natural resources, it also led to a rise in CO_2 emissions and a steady increase in global temperatures. Between 1900 and 2021, annual carbon dioxide emissions from fossil fuels and industrial activities grew from 1.95 billion tons to 37.12 billion tons, not accounting for factors like land use changes (Olabi & Abdelkareem, 2022).

The advantageous effect of solar energy generation on energy efficiency aligns with research indicating potential reductions in emissions from clean energy sources. In summary, the research findings offer significant new insights about Natural Resource utilization, financial management, and economic development (Paddu et al., 2024). Comprehensive policy measures are necessary to achieve equilibrium due to the interrelation of these components. The important, examine institutional aspects and political systems to have a fuller understanding of the processes behind these linkages. The modifications highlight the beneficial environmental impacts of shifting to renewable energy sources, including the reduction of air pollution and the carbon footprint, in accordance with global sustainability and climate change mitigation objectives (Saudi et al., 2024).

This raises an important question about the true impact of human development on the environment, as the benefits of a thriving economy come at the cost of increased suffering. Consequently, a controversial debate has emerged over the relationship between carbon emissions and economic growth, as many nations implement policies to limit CO_2 emissions. Numerous studies have explored this relationship using complex models and data from various countries and regions, yet the issue remains unresolved. In response, many countries have established their own targets for achieving carbon neutrality (Minghao, 2022).

This study uses the Spline approach to investigate the potential for economic growth in Asia-Pacific countries based on energy transition, green growth, and emissions variables in each country. The spline method is highly effective in modeling data with fluctuating patterns over specific subintervals (Perperoglou et al., 2019). Spline is a regression approach that has the ability to interpret data both statistically and visually, and is used for generalizing complex and intricate statistical modeling forms (Brugnano et al., 2024);(Zhang & Goh, 2013);(Lu & Loomis, 2013);(Zhan & Yeung, 2011).

The Asia Pacific region is pivotal to the decarbonization of the global energy sector and the transition to net zero emissions worldwide. Energy-related emissions in the region increased by 151% from 2000 to 2023, propelled by robust economic development, population expansion, and industrialization. Nonetheless, emissions must reach a peak and swiftly decline for the world to fulfill the objectives of the Paris Agreement (BloombergNEF, 2024). The nation is Asia Pasific must significantly enhance its investments in the energy industry, particularly in the development of renewable energy, the government should reallocate funds to the development of renewable energy power facilities and must provide financial incentives to promote the advancement of innovative technology in energy storage capacity to expedite the transition to a green economy in the Asia Pasific region (Lin et al., 2024).

It is interesting to conduct further research on the potential for economic growth in Asia-Pacific countries based on factors related to energy and green growth. This potential analysis will be explored in greater depth based on the clustering of Asia-Pacific countries formed by the factors used. To date, no research has been conducted on the analysis of economic growth potential using energy transition, green growth, and emissions indicators in Asia-Pacific countries with the spline approach.

A specific study is needed to analyze the rate of economic growth improvement in Asia-Pacific countries as an effort to enhance this growth, strengthen energy resilience, promote green economic growth, and encourage the economic revival of Asia-Pacific nations, while still considering environmental aspects. This analysis is based on energy transition, green growth, and emissions indicators in the Asia-Pacific region using the spline approach. Therefore, this paper aims to formulate the results of the analysis of the impact of energy transition, green growth, and emissions on economic growth in each Asia-Pacific country, which will then be interpreted in the form of visualizations. Based on these interpretations, a strategy will be developed to enhance the potential for economic growth and stabilize environmental aspects in the Asia-Pacific countries.

This study introduces a novel approach by providing a detailed examination of the economic growth levels across Asia-Pacific countries, based on the indicators of energy transition, green growth, and emissions. Unlike previous research, this study not only analyzes the impact of these variables but also clusters countries according to their economic performance, offering a deeper understanding of the nuanced relationships between these factors. By utilizing spline regression models and country-specific data, this research goes beyond general trends, offering tailored insights into how different levels of energy transition and green growth affect economic outcomes, thus providing a more granular perspective compared to prior studies.

To differentiate this research from previous studies, this study introduces a more comprehensive and nuanced analysis by not only examining the impact of energy transition, green growth, and emissions on economic growth but also by clustering Asia-Pacific countries based on their specific economic outcomes. Unlike earlier research that often explores these factors in isolation or at a broader level, this study provides a detailed, country-specific approach, utilizing spline regression models to capture the nonlinear relationships between the variables. Additionally, the clustering methodology allows for a more tailored understanding of how countries at different stages of energy transition and green growth are performing economically, offering unique insights that previous studies may not have provided. This detailed analysis and country-specific clustering set this research apart from related work, offering new dimensions of understanding in the relationship between sustainable energy policies and economic growth.

The research gap addressed in this study stems from the limited examination of the Asia-Pacific region as a whole, despite its critical role in global energy transitions and economic growth. Existing studies tend to focus on either developed or developing nations in isolation, neglecting the heterogeneity within this region. Furthermore, many prior works fail to consider the nonlinear interactions among green growth indicators, emissions, and economic growth. This study's uniqueness lies in its ability to capture these dynamics and provide actionable insights for policymakers. By identifying optimal levels of emissions and green growth investments that maximize economic performance, this research offers a practical framework for fostering sustainable development in one of the world's most economically and environmentally significant regions.

2. LITERATURE REVIEW

The related literature can be divided into three different strands. First focuses on energy transition issues on economic growth. The second investigates green growth on economic growth. And the last emissions on economic growth. All indicator use for countries in Asia-Pasific Regional. And also shows some research related to the use of the spline approach.

The energy transition, which focuses on shifting from fossil fuels to more environmentally friendly energy sources, remains a critical topic among scholars. A central question is how macroeconomic variables influence the pace of energy transition across different regions, potentially leading to shared patterns of transition. The study aims to explore the dependency of energy transition patterns on economic variables in Asian economies, categorized by income levels. Using data from 45 Asian countries between 1993 and 2018, the study employs the generalized method of moments (GMM) for analysis. The findings indicate that economic growth positively impacts energy transition, while CO2 emissions have a negative effect. Additionally, population growth slows the energy transition process in both high and upper-middle-income groups and low and lower-middle-income groups. The study recommends that Asian economies adopt tailored policies based on their income levels to enhance and accelerate energy transition efforts. For developing and emerging economies, where rapid economic growth and rising energy demand are prominent, governments should implement supportive measures to improve access to green energy sources, aligning with sustainable development goals (SDGs). This becomes even more critical in the context of the current low oil price environment (Taghizadeh-Hesary & Rasoulinezhad, 2020).

Numerous studies have explored the effects of energy transition by examining the relationships between renewable and non-renewable energy sources and various economic factors. Some researchers suggest that there is both a short-term and long-term relationship between economic growth and energy consumption (Carfora et al., 2019); (Pandey & Rastogi, 2019); (Saud et al., 2018); (Kyophilavong et al., 2017); (Hossein et al., 2012); (Socotar & Gabor, 2024). This indicates that energy use plays a vital role in production processes and either drives or supports economic growth (Ram et al., 2020). Additionally, other studies reveal a bidirectional relationship between renewable energy usage and economic growth (Dogan, 2015); (Al-mulali & Sab, 2012). Further findings emphasize the positive impact of industrial production on energy consumption (Keho, 2016); (Ubani, 2013); (Adom et al., 2012); (Shahbaz & Lean, 2012).

The recognition of these phenomena gave rise, in the late 1960s and early 1970s, to the concept of sustainable development, which has continued to evolve over time. Alongside this, concepts such as eco-development and the "*Green economy*" emerged, focusing specifically on the natural environment. Other related ideas, including Green growth, Green governance, Greening the economy, and Green transformation, also gained prominence. Concerns over the depletion of natural resources, environmental degradation, and climate change have emphasized the urgency of protecting nature, preserving the biosphere and ecological values, and restoring the functionality of natural ecosystems. Efforts in this direction, encompassing economic, social, and political dimensions, are collectively referred to as "*Greening*" (Adamowicz, 2022).

The concept of economic growth that contributes to social welfare needs to be broadened in both its interpretation and criteria. It should encompass not only economic activities but also their effects on society, both now and in the future. The study aims to evaluate Indonesia's inclusive green growth in 2015 and 2019. The analysis uses the Inclusive Green Growth Index (IGGI) developed by the Asian Development Bank (ADB). IGGI is a composite index that includes three key pillars: economic growth, social equity, and environmental sustainability. The study revealed that Indonesia's inclusive green growth has improved, with the average score rising from 3.21 in 2015 to 3.36 in 2019. However, this progress is not optimal, as it is primarily driven by the economic growth pillar. In contrast, the environmental sustainability pillar's average score declined from 4.19 in 2015 to 4.00 in 2019, and the social equity pillar score decreased in 15 out of 34 provinces. Efforts to achieve a more balanced IGGI include enhancing and maintaining environmental quality, improving access to economic and political activities, upgrading public services and infrastructure across provinces, and fostering growth in key sectors to reduce economic disparities between provinces (Aminata et al., 2022).

Numerous studies have attempted to define and measure inclusive green growth, identifying various indicators. GGKP (2016) defines indicators such as natural assets, resource efficiency, decoupling, risk and resilience, economic opportunities, efforts, and inclusiveness. WEF (2017) considers factors like GDP per capita, employment rate, labor productivity, life expectancy, median household income, poverty rate, income Gini, wealth Gini, adjusted net savings, dependency ratio, public debt, and carbon intensity of GDP. In addition, the United Nations Economic and Social Commission for Asia and the Pacific (UN ESCAP, 2014) uses indicators such as equitable distribution and access, structural transformation, eco-efficiency, investment in natural capital, and planetary limits to measure inclusive green growth. Apply a directional distance function and output-oriented slack-based measure to assess inclusive green growth in Chinese cities, using labor, capital, energy, GDP (as desirable output), and wastewater and emissions (as undesirable outputs) as variables (Sun et al., 2020). Despite their contributions, these studies have limitations due to the incompleteness of the indicators used, which do not fully encompass key aspects of inclusive green growth (S. Jha et al., 2018).

In another study, used the IGGI method to assess inclusive green growth across all Indonesian provinces in 2017, finding that the level of inclusive green growth in most regions was moderate (Liderson & Pasaribu, 2020). Also used the IGGI method, along with factor analysis, and identified economic development as a key determinant of inclusive green growth. Their findings emphasized the need to accelerate economic development, enhance institutional frameworks, and foster stronger international cooperation in the Asia-Pacific region (M. Li et al., 2021). Meanwhile, found that inclusive green growth in Europe varied significantly, with Romania scoring the lowest and Luxembourg the highest (Šneiderienė et al., 2020).

The connection between economic growth and CO2 emissions has been a focal point of extensive research in recent decades. Countries worldwide face a significant challenge: balancing the need for sustained economic growth with the imperative to safeguard the environment. The rise in CO2 emissions stands as a primary contributor to the threat of climate change. Economic expansion often drives increased energy consumption, leading to higher CO2 emissions, thereby establishing a direct link between pollution and economic development (Kasperowicz, 2015). However, economic progress also fosters the adoption of innovative, energy-efficient, and low-carbon technologies, gradually replacing older, more energy- and carbon-intensive systems.

Another paper examines the connection between economic growth and CO2 emissions in eight ASEAN countries over the period from 1994 to 2018, utilizing a panel data approach. The analysis employs the Panel ARDL Pooled Mean Group method, yielding several key findings. First, the panel cointegration analysis reveals a significant long-term relationship between GDP and CO_2 emissions. Second, the error correction mechanism indicates stability and consistency in the results. Third, GDP is found to have a notable long-term impact on CO_2 emissions across ASEAN countries. Fourth, the short-term analysis highlights that GDP significantly influences CO_2 emissions in four specific countries: Indonesia, Malaysia, Thailand, and Cambodia. Based on these findings, the study provides implications and policy recommendations, emphasizing that ASEAN nations should adopt green growth strategies to promote economic progress while minimizing environmental degradation (Feriansyah et al., 2022).

There is a strong link between the development of renewable energy and economic growth, highlighting that the negative environmental impact and carbon dioxide emissions associated with energy expansion can be mitigated by increasing the share of renewable energy in a country's energy mix. This aligns with findings by Radmehr, Rastegari, and Shayanmehr (2021), who observed that within the European Union, a 1% increase in per capita renewable energy consumption leads to a 0.05% reduction in carbon emissions.

As an organization focused on fostering economic growth among Southeast Asian nations, particularly low-income countries, ASEAN has achieved one of the fastest economic growth rates globally. Between 2000 and 2008, ASEAN experienced an average growth rate of 6.5% (Saboori & Sulaiman, 2013). However, this rapid economic development remains heavily reliant on fossil fuels, which account for 90% of the region's energy consumption, primarily coal, oil, and gas. With continued population growth and GDP expansion, ASEAN's energy demand is projected to rise by an average of 4.4% annually through 2030 (Sulaiman & Saboori, 2013).

Heidari, Katircioğlu, and Saeidpour (2020) Identified a non-linear relationship between economic growth, carbon emissions, and energy consumption in five ASEAN countries: Malaysia, Indonesia, the Philippines, Singapore, and Thailand. Their regression analysis suggests that while an increase in GDP per capita initially raises carbon emissions, these emissions begin to decline once GDP reaches a certain threshold. Data from the ASEAN Secretariat (2019) indicate that the average real GDP growth rate across ASEAN countries exceeded 5% in 2018 (Heidari et al., 2020).

The other previous research has results is employed the ARDL panel approach to investigate the relationship between energy consumption, economic growth, and CO_2 emissions. However, this study focused only on five ASEAN nations. To address this limitation, further research is needed to explore how the region's economic expansion has influenced CO_2 emissions across all ASEAN countries. This study contributes to the literature by analyzing data from eight ASEAN nations between 1994 and 2018. Using the ARDL panel approach, it examines both the short- and long-term effects of economic growth on CO_2 emissions, providing new insights into this critical relationship (Shaari et al., 2020).

A previous study using the Spline nonparametric regression approach has been done in several previous studies. Wahidah Alwi et all (2023) Examined the modeling of poverty levels in South Sulawesi utilizing a Spline Nonparametric Regression Approach. Due to the absence of a definitive pattern in the relationship between poverty levels in South Sulawesi and the influencing factors, the researchers employed nonparametric regression modeling utilizing a Spline technique. The findings indicated that the optimal spline model consisted of three knot points, with a minimum GCV value of 11.1155. Furthermore, the R^2 value is 79.75%. The variables of unemployment, population growth, and literacy rate account for 79.75% of the variation in the poverty variable, whilst other variables account for the remaining 20.25% (Alwi et al., 2023). Ali Nasser et all (2022), Employ this technique to construct a machine learning model for forecasting the compressive strength of eco-friendly concrete utilizing Multivariate Adaptive Regression Splines (MARS), which a recognized method for developing predictive modeling equations from experimental data. The outcomes of 5-fold cross-validation demonstrate that the optimal MARS model had the highest coefficient of determination at 0.889 and the lowest Root Mean Squared Error (RMSE) at 4.110 MPa. The performance metrics demonstrated the superiority of the MARS model in comparison to RF and SVM. The final MARS optimum prediction equations were constructed utilizing a comprehensive training set and subsequently assessed with unseen data (testing set) and the model possesses the capability to assist civil engineers in the design of resilient infrastructure (Naser et al., 2022).

Asia-Pacific region is characterized by significant diversity in energy policies, economic structures, and stages of development. The spline regression model is particularly suited for this region, as it can accommodate these variations and provide more precise insights into the non-linear relationships between energy transition, green growth, and economic performance. This approach allows for a detailed understanding of how different countries with distinct economic contexts experience the impact of energy transitions. Although specific studies applying spline regression to energy transition in the Asia-Pacific region are scarce, the method has been widely used in other areas of economic research, such as the analysis of income distribution, growth trajectories, and environmental impacts, where non-linear relationships are prevalent.

3. DATA AND METHODOLOGY

3. 1. DATA

This study employs a single dependent variable representing economic growth in the countries under investigation, alongside three independent variables: Energy transition, Green growth, and Emissions, in Asia-Pacific countries with complete data on the variables used. These countries include the following: Armenia, Australia, Azerbaijan, Bahrain, Bangladesh, Brunei Darussalam, Cambodia, China, Cyprus, India, Indonesia, Iran (Islamic Republic), Japan, Jordan, Kazakhstan, Republic of Korea, Kuwait, Kyrgyz Republic, Lao PDR, Lebanon, Malaysia, Mongolia, Nepal, New Zealand, Oman, Pakistan, Philippines, Qatar, Saudi Arabia, Singapore, Sri Lanka, Tajikistan, Thailand, United Arab Emirates, Viet Nam, and Yemen (Republic). The data used in this research consists of cross-sectional secondary data for each country from 2022 and 2023, comprising 36 countries as the research units. The variables used in the study are detailed in Table 1 below.

Table 1. Symblos, Data Sources and Units of Measurement

Data	Symbol	Source	Unit of Measurement
Dependent variable			
GDP Growth Annual	GDP	Data.worldbank.org	Percent of GDP, 2023
Independent variabel			
Energy Transition Index	ETI	www.weforum.org/publications	Score (1-10), 2022
Green Growth Index	GGI	ggindex-simtool.gggi.org	Score (1-10), 2022
Total Emissions	TE	www.climatewatchdata.org	MtCO2e, 2022

Source: Processed Data By Author, 2024

3. 2. METHODOLOGY

Spline is defined as a flexible segment of polynomial pieces that can effectively adapt to the characteristics of the data used. These polynomial segments play a significant role due to their flexibility and efficiency in processing attributes or data. One of the most critical polynomial segments is the Spline, which originates from an optimization problem. Estimation in Spline depends on the knot points, which are the points where the pattern of a function changes within different intervals (Eiilers & Marx, 2010). Spline excels in handling data patterns with sharp fluctuations by utilizing knot points, resulting in a well-fitted curve. The Spline estimator can independently estimate its parameters, thereby producing a model that conforms to the data's structure, even for dynamic data. For instance, given data (x_{1i}, x_{2i}, … , x_{pi} , y_i), where (x_{1i}, x_{2i}, … , x_{pi}) are predictors and y_i is the response, the nonparametric regression model can be expressed as follows.

$$y_i = \sum_{j=i}^{p} f(x_{ji}) + \varepsilon_i \quad (1)$$

Where:

$$y_i = \sum_{h=0}^{q} \beta_{hj} x_{ji}^{h} + \sum_{i=0}^{m} \beta_{(q+1)j} (x_{ji} - k_{ij})_{+}^{q} + \varepsilon_i \quad (2)$$

The truncated function is defined as (Brugnano et al., 2024).

$$(x_{ji} - k_{ij})_+^q = \begin{cases} (x_{ji} - k_{ij})_j^q, x_{ji} \geq k_{ij} \\ 0, x_{ji} \leq k_{ij} \end{cases} \quad (3)$$

Where $k_{1j}, k_{2j}, ..., k_{mj}$ are the knot points indicating changes in the function at specific intervals, and q represents the polynomial degree. The equation can be expanded as (Perperoglou et al., 2019)

$$y_i = \beta_{01} + \beta_{11}x_{1i} + ...+\beta_{q1}x_{1i}^q + a_{11}(x_{1i} - k_{11})_+^q...a_{m1}(x_{1i} - k_{m1})_+^q + \beta_{02} + \beta_{12}x_{2i} + ...+\beta_{q2}x_{2i}^q + a_{12}(x_{2i} - k_{12})_+^q...a_{m2}(x_{2i} - k_{m2})_+^q + \beta_{0p} + \beta_{p1}x_{pi} + ...+\beta_{qp}x_{pi}^q + a_{1p}(x_{pi} - k_{1p})_+^q...a_{mp}(x_{pi} - k_{mp})_+^q + \varepsilon_i \quad (4)$$

The method used for Spline Regression estimation is Ordinary Least Squares (OLS). The OLS model can be expressed as follows

$$y = X\beta + \varepsilon \quad (5)$$

Where

$$\mathrm{y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}, X = \begin{pmatrix} 1\ x_{11}\ (x_{11} - k_{11}) + \cdots x_{p1}(x_{p1} - x_{mp})_+ \\ 1\ x_{12}\ (x_{12} - k_{11}) + \cdots x_{p2}(x_{p2} - x_{mp})_+ \\ \vdots \\ 1\ x_{1n}\ (x_{1n} - k_{11}) + \cdots x_{pn}(x_{pn} - x_{mp})_+ \end{pmatrix} \quad (6)$$

$$\beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \vdots \\ \beta_{mp} \end{bmatrix} \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_{mp} \end{bmatrix} \quad (7)$$

Based on Equation $y = X\beta + \varepsilon$, the residuals are expressed as

$$\varepsilon = y - X\beta \quad (8)$$

The residual sum of squares in matrix form is written as

$$\sum_{i=1}^{n} \varepsilon_i^2 = \varepsilon'$$
$$= (y - X\beta)^\wedge{'}.(y - X\beta)$$
$$= y'y - y'X\beta - \beta'X' + \beta'X'X\beta$$
$$= y'y - 2\beta'X'y + \beta'X'X\beta \quad (9)$$

Simplifying yields

$$\frac{\vartheta(\varepsilon'\varepsilon)}{\vartheta} = 0 \quad (10)$$

Optimal knot points are critical in nonparametric spline regression. Data behavior changes at certain intervals, and the best Spline estimator is determined based on the minimum Generalized Cross Validation (GCV) criterion.

$$GCV\ (k_1, k_2, ..., k_j) = \frac{MSE(k_1, k_2, ..., k_j)}{(n^{-1}Trace[I - A(k_1, k_2, ..., k_j)])^2} \quad (11)$$

The coefficient of determination measures the model's explanatory power

$$R^2 = \frac{\hat{\beta}^T X^T y - n\bar{y}^2}{y^T y - n\bar{y}^2}\ x\ 100\% \quad (12)$$

Spline regression is known for its ability to handle non-linear relationships between variables, which is particularly useful in modeling complex data, such as the interactions between energy transition, green growth, emissions, and economic growth. Unlike traditional linear models, spline regression can adapt to varying degrees of change across the data, making it a more accurate tool for capturing the nuances of economic transitions in the diverse Asia-Pacific region

4. RESULT AND DISCUSSION

4. 1. DATA ANALYSIS RESULTS USING SPLINE APPROACH

The characteristics of GDP values used to measure economic growth in Asia-Pacific countries, along with the independent variables presumed to influence it, are presented in Table 2. The independent variables include the Energy Transition Index, Green Growth Index, and Emissions.

Table 2. Descriptive Statistics

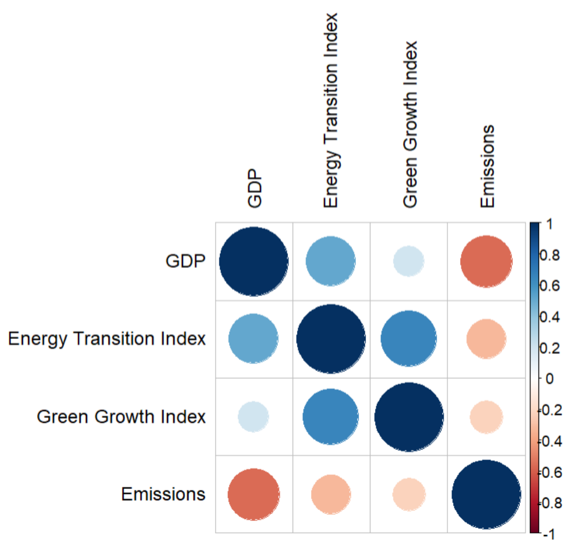
Variable	Mean	Variance	Std. Dev	Minimum	Maximum
GDP	25.90130276	3.494025927	1.869231373	23.21320994	30.5099238
ETI	54.41666667	31.43	5.606246516	43.6	64.3
GGI	51.78083333	70.924345	8.421659278	32.55	63.89
TE	696.4711111	4537984.588	2130.254583	8.54	12600.87

Source: Processed Data by Author, 2024

After reviewing the descriptive analysis above, a correlation analysis between the variables was conducted. Correlation analysis is generally used to measure and identify the relationship between two or more variables. Through this analysis, the strength of the relationship between the studied variables can be determined.

Based on the correlation analysis results shown in Figure 1, it can be observed that along the diagonal, each variable is highly correlated with itself. Additionally, there is a strong and positive correlation between GDP and the Energy Transition Index. The Green Growth Index also exhibits a positive but weaker correlation with GDP. On the other hand, the Emissions variable shows a strong negative correlation with GDP.

Figure 1. Correlation Analysis Plot



Source: Processed Data by Author, 2024

The first step in analyzing economic growth potential based on the variables of energy transition, green growth, and emissions using the Spline approach is selecting the most optimal knot point. The selection of the optimal knot point is determined by identifying the lowest GCV (Generalized Cross-Validation) value produced by each knot.

Table 3. GCV Values Produced by Each Knot Point

Knot Point	GCV Value
Knot Point 1	1.114008
Knot Point 2	1.114007
Knot Point 3	1.075127

Source: Processed Data by Author, 2024

Table 3 shows that the smallest GCV value is produced by Knot Point 3, with a value of 1.075127. Therefore, the modeling of the economic growth rate in the Asia-Pacific region will use Knot Point 3. The modeling is represented by the following model equation.

$$\hat{y} = 0.01775 + 0.41378ETI_1 + 0.26161(ETI_2 + 47.02245) - 0.10427(ETI_3 + 54.44490) + 0.05305(ETI_4 + 65.71224) + 0.16237GGI_1 - 0.23989(GGI_2 + 43.18959) + 0.06251(GGI_3 + 53.82918 + 0.11395(GGI_4 + 65.74796) + 0.01331TE_1 - 0.02064(TE_2 + 265.5263) - 0.01533(TE_3 + 522.5127 - 0.07826(TE_4 + 1293.472)$$

Next, parameter testing was conducted using two types of tests: simultaneous parameter testing and individual parameter testing.

Table 4. Simultaneous Parameter Test

Source	Df	SS	MS	F	P-Value
Regresi	12	99.69668	8.308057	8.457262	$7.582926e^{-06}$
Error	23	22.59423	0.9823577		
Total	35	122.2909			

Source: Processed Data by Author, 2024

The statistical value yields a p-value of $7.582926e^{-06}$. When compared to the significance level of the decision is to reject . This result indicates that at least one variable significantly influences the formed model. Rejecting suggests the need for individual testing to identify which variables significantly impact the model.

Table 5. Individual Parameter Test

Variable	Parameter	Estimator	P-value	Note
Constant	β_0	0.01775	0.0396903	Significant
ETI	β_1	.41478	0.0514155	Not Significant
	β_2	.26161	0.02794	Significant
	β_3	-.10427	0.0780007	Not Significant
	β_4	.05305	0.0578991	Not Significant
GGI	β_5	.16237	0.0219634	Significant
	β_6	-.23898	0.0705211	Not Signficant
	β_7	.06251	0.0970553	Not Significant
	β_9	.11395	0.0640514	Not Significant
TE	β_{10}	.01331	6.251975	Significant
	β_{11}	-.02064	0.001940115	Significant
	β_{12}	-.01533	0.03149306	Significant
	β_{13}	-.07826	0.03724912	Signifikan

Source: Processed Data by Author, 2024

The final step in this analysis is determining the coefficient of determination to show the goodness-of-fit of the model in explaining economic growth in the Asia-Pacific region using the variables of energy transition, green growth, and emissions.

$$R^2 = \frac{SS_{Regresi}}{SS_{Total}} x\ 100\% = \frac{99.69668}{122.2909} x100\% = 81.52\%$$

Based on these calculations, the value is 81.52%, indicating that the variables used in the model explain 81.52% of the variation in the economic growth rate of the Asia-Pacific countries. The remaining percentage is explained by other variables not included in the study.

4. 2. MODEL INTERPRETATION RESULTS

After conducting the analysis using the spline approach and ensuring that the residual assumptions have been met, the results show that the variables of energy transition, green growth, and emissions significantly influence the rate of economic growth in Asia-Pacific countries. Subsequently, the potential for economic growth improvement in each Asia-Pacific country will be examined based on the variables used.

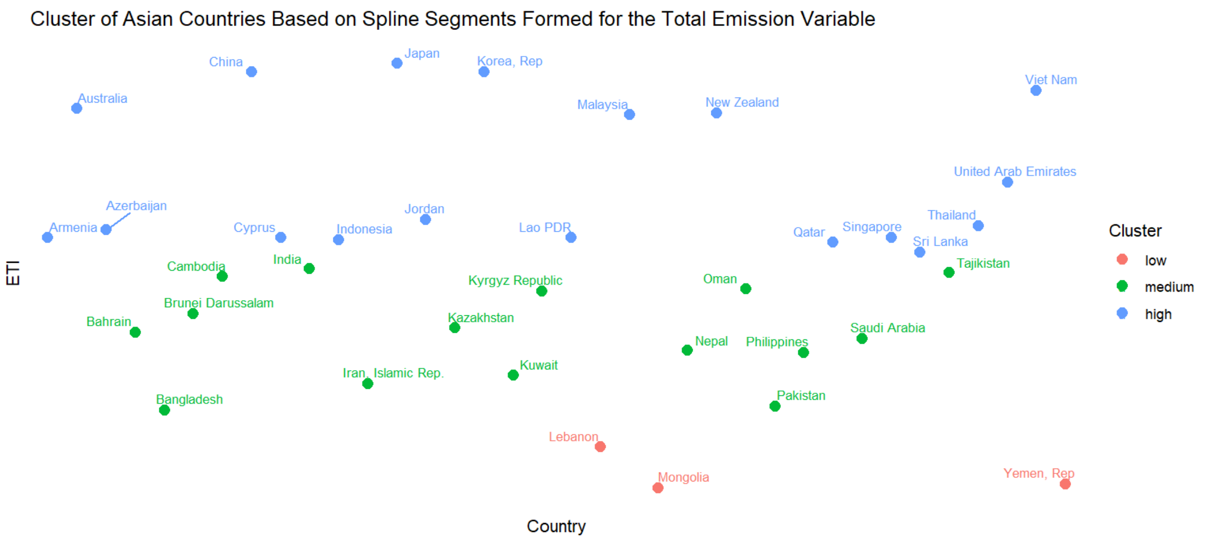
If green growth and emissions are considered constant, the influence of the energy transition variable on the economic growth rate of Asia-Pacific countries is as follows.

$$\hat{y} = 0.41378ETI_1 + 0.26161(ETI_2 + 47.02245) - 0.10427(ETI_3 + 54.44490) + 0.05305(ETI_4 + 65.71224)$$

$$\hat{y} = \begin{cases} 0.41378; ETI < 47.02245 \\ 0.67539; 47.02245 \leq ETI > 54.44490 \\ 0.57112; 54.44490 \leq ETI > 65.71224 \\ 0.59417; ETI > 65.71224 \end{cases}$$

Based on the equation model, it is identified that four clusters of countries are formed based on the energy transition indicators influencing the economic growth rate in Asia-Pacific countries, as determined by the spline segments created. The regional clusters formed can be observed in Figure 2 below.

Figure 2. Cluster of Asian-Pasific Countries based On Spline Segments Formed for Energy Transition Index



Source: Processed Data by Author, 2024

The interpretation is as follows: If a country has an energy transition index scale of less than 47.02245, its potential economic growth is likely to increase by 0.41278 percent, placing it in the low category. If a country has an energy transition index scale between 47.02245 and 54.44490, its potential economic growth is likely to increase by 0.67539 percent, placing it in the medium category. Furthermore, if a country has an energy transition index scale between 54.44490 and 65.71224, its potential economic growth is likely to increase by 0.571112 percent, placing it in the high category. Lastly, if a country has an energy transition index scale greater than 65.71224, its potential economic growth is likely to increase by 0.59417 percent, placing it in the very high category.

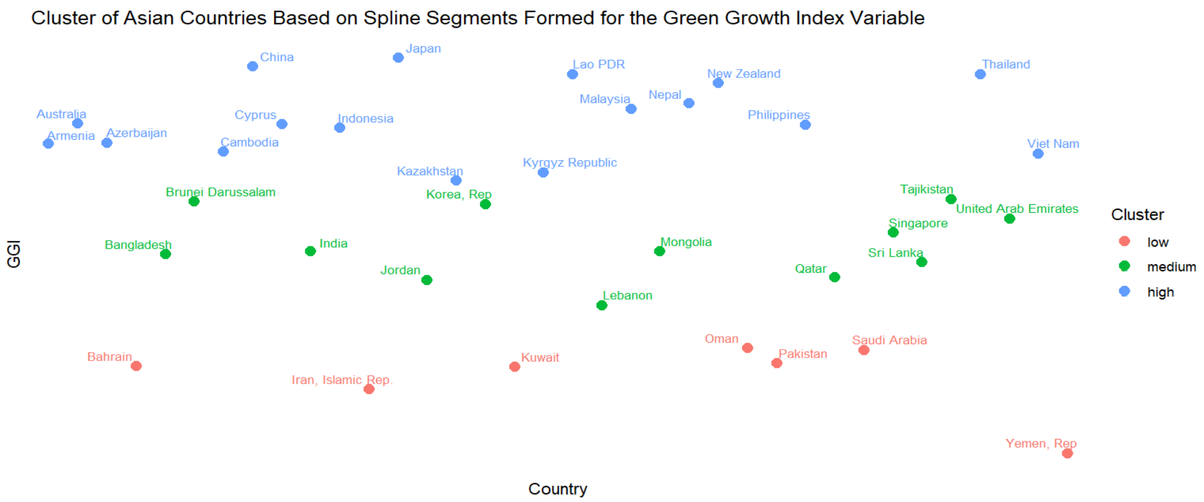
If energy transition and emissions are assumed constant, the influence of the green growth variable on the economic growth rate of Asia-Pacific countries is as follows.

$$\hat{y} = 0.16237GGI_1 - 0.23989(GGI_2 + 43.18959) + 0.06251(GGI_3 + 53.82918 + 0.11395(GGI_4 + 65.74796)$$

$$\hat{y} = \begin{cases} 0.16237; GGI < 43.18959 \\ -0.13653; 43.18959 \leq GGI > 53.82918 \\ -0.074279; 53.82918 \leq GGI > 65.74796 \\ 0.039671; GGI > 65.74796 \end{cases}$$

Based on the equation model, it is evident that four country clusters are formed based on the Green Growth indicator, which significantly affects the economic growth rate of Asia-Pacific countries according to the resulting Spline segments. The regional clusters formed can be seen in Figure 3 below.

Figure 3. Cluster of Asian-Pasific Countries based On Spline Segments Formed for Green Growth Index



Source: Processed Data by Author, 2024

Interpretation: If a country has a Green Growth Index scale of less than 43.18959, its potential economic growth is likely to increase by 0.16237 percent, placing it in the low category. If a country has a Green Growth Index scale between 43.18959 and 53.82918, its potential economic growth is likely to decrease by 0.13653 percent, placing it in the medium category. If a country has a Green Growth Index scale between 53.82918 and 65.74796, its potential economic growth is likely to decrease by 0.074279 percent, placing it in the high category. Finally, if a country has a Green Growth Index scale greater than 65.74796, its potential economic growth is likely to increase by 0.039671 percent, placing it in the very high category.

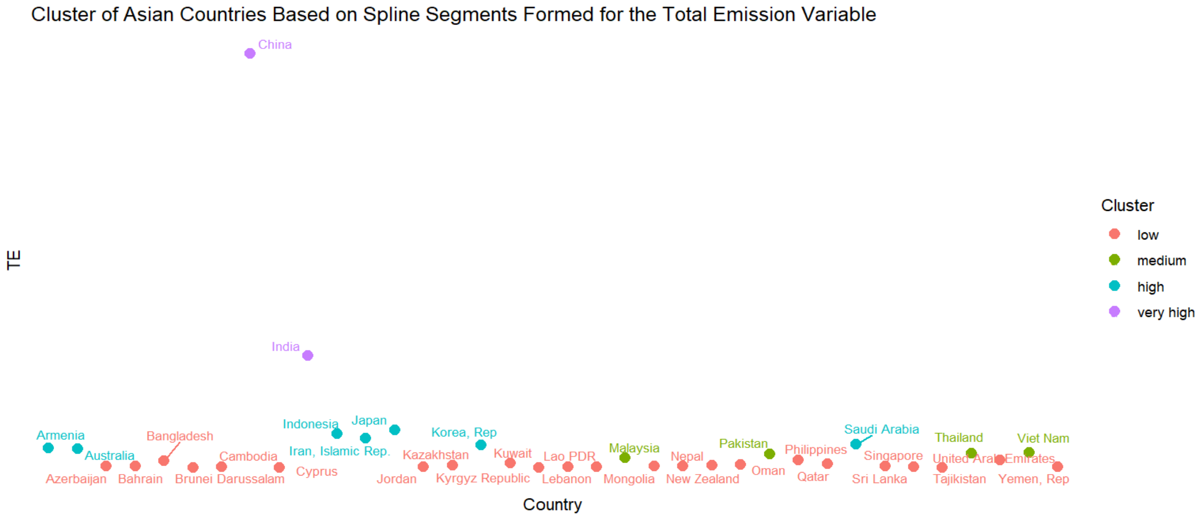
If energy transition and green growth are assumed constant, the influence of the emissions variable on the economic growth rate of Asia-Pacific countries is as follows.

$$\hat{y} = 0.01331TE_1 - 0.02064(TE_2 + 265.5263) - 0.01533(TE_3 + 522.5127) - 0.07826(TE_4 + 1293.472)$$

$$\hat{y} = \begin{cases} 0.01331; TE < 265.5263 \\ -0.000703; 265.5263 \leq TE > 522.5127 \\ -0.02236; 522.5127 \leq TE > 1293.472 \\ -0.10062; TE > 1293.472 \end{cases}$$

Based on the equation model, it is evident that four country clusters are formed based on the total emissions indicator, which significantly affects the economic growth rate of Asia-Pacific countries according to the resulting Spline segments. The regional clusters formed can be seen in Figure 4 below.

Figure 4. Cluster of Asian-Pasific Countries based On Spline Segments Formed for Total Emissions



Source: Processed Data by Author, 2024

Interpretation: If a country has total emissions of less than 265.5262 MtCO2e, its potential economic growth is likely to increase by 0.01331 percent, placing it in the low category. If a country has total emissions between 265.5262 and 522.5127 MtCO2e, its potential economic growth is likely to decrease by 0.000703 percent, placing it in the medium category. If a country has total emissions between 522.5127 and 1293.5127 MtCO2e, its potential economic growth is likely to decrease by 0.02236 percent, placing it in the high category. Finally, if a country has total emissions greater than 1293.472 MtCO2e, its potential economic growth is likely to decrease by 0.10062 percent, placing it in the very high category.

4. 3. DISCUSSION

The findings of this research provide valuable insights into the interplay between energy transition, green growth, and emissions on economic growth across Asia-Pacific countries. The high explanatory power of the model, suggests that these variables play a significant role in shaping economic performance in the region. This underscores the importance of incorporating sustainable practices into policy frameworks to ensure robust and inclusive growth in a rapidly evolving global economy.

The analysis of the Energy Transition Index reveals an intriguing pattern: while countries with low energy transition scores exhibit moderate growth potential, those in the middle and upper ranges demonstrate more nuanced outcomes. This suggests that transitioning economies may benefit significantly from scaling up their efforts, but diminishing returns could set in as countries reach higher thresholds of energy transition. Policymakers should therefore aim to strike a balance between advancing energy transitions and ensuring that such transitions do not inadvertently constrain economic activities, particularly in developing economies.

Regarding the Green Growth Index, the results illustrate a more complex relationship between green growth and economic performance. Countries in the lower and highest categories of green growth indices tend to exhibit positive economic trajectories, while those in the middle ranges face potential declines. This paradox highlights the challenges of green growth implementation: early adopters may struggle with transitional costs, while mature green economies reap long-term benefits. For many Asia-Pacific countries, which span a wide spectrum of development stages, this implies a need for tailored strategies to maximize the advantages of green growth without undermining short-term economic stability.

The findings related to emissions further underline the intricate dynamics at play. Low-emission countries tend to experience positive economic growth, which aligns with global narratives advocating for reduced carbon footprints. However, as emissions increase, economic growth begins to decelerate, particularly at high and very high levels of emissions. This emphasizes the pressing need for economies to decouple growth from carbon emissions by investing in cleaner technologies and more efficient production systems. For resource-dependent nations in the region, this transition may be particularly challenging but is nonetheless essential for sustainable development.

The diversity of countries analyzed in this study, ranging from highly industrialized economies like Japan and Australia to emerging markets such as Bangladesh and Cambodia, provides a rich basis for comparative analysis. Countries with strong institutional frameworks, advanced technologies, and supportive policy environments are better positioned to benefit from energy transitions and green growth initiatives. In contrast, developing economies may face barriers such as limited access to capital, inadequate infrastructure, and lack of technical expertise, which could hinder their progress.

Given the regional variations, the Asia-Pacific countries must adopt differentiated approaches to sustainability. For example, resource-rich nations like Indonesia and Kazakhstan might prioritize managing emissions while gradually transitioning to cleaner energy sources. Meanwhile, economies like Singapore and New Zealand, which are already leaders in green initiatives, could focus on refining their strategies to maintain competitive advantages. This differentiated approach would allow countries to capitalize on their unique strengths while addressing specific challenges.

The study's findings emphasize the interconnected nature of energy transition, green growth, and emissions in influencing economic growth. Policymakers in the Asia-Pacific region should consider these relationships when designing policies, ensuring that economic growth remains compatible with environmental sustainability. The results also suggest that while there are broad trends applicable across the region, tailored strategies based on individual country contexts will be critical for maximizing the potential benefits of sustainable development initiatives.

5. CONCLUSION

This study makes a significant contribution to science by providing a deeper understanding of the non-linear relationship between energy transition, green growth, emissions, and economic growth in the Asia-Pacific region. Through the application of spline regression models and clustering analysis, this research offers new insights into the impact of energy transition policies and green growth on the economies of developing countries in the region, helping policymakers design more targeted and data-driven strategies. Additionally, these findings contribute to the existing literature by introducing a more detailed and country-specific analysis, which will serve as an important reference for future research and provide practical insights for decision-making in the sustainable energy and economic sectors.

This study sheds light on the dynamic relationships between energy transition, green growth, emissions, and economic growth across 36 Asia-Pacific countries using a spline approach. The results demonstrate that energy transition and emissions exhibit nonlinear impacts on economic performance, with growth potential varying across different levels of these indicators. The findings reveal that energy transitions and green growth can promote economic growth, but the outcomes depend on the development stage and thresholds of each variable. Furthermore, emissions are shown to have a negative effect on growth as their levels increase, underscoring the need for sustainable practices to mitigate environmental harm while fostering economic progress.

Overall, the high explanatory power of the model highlights the importance of integrating sustainable policies into the economic development strategies of Asia-Pacific countries. These results emphasize that achieving sustainable development goals requires a nuanced understanding of how green policies interact with economic dynamics across varying national contexts.

Countries in the Asia-Pacific region should prioritize investments in renewable energy infrastructure to enhance their Energy Transition Index scores. Policymakers must create enabling environments through fiscal incentives, subsidies for clean energy technologies, and public-private partnerships to accelerate the shift from fossil fuels to renewables. Emerging economies, in particular, should adopt phased approaches to ensure a balance between transitioning to greener energy systems and maintaining economic stability.

Governments should develop tailored green growth strategies that reflect their unique developmental stages. Low- and middle-income countries should focus on minimizing the transitional costs of adopting green policies by leveraging international financing mechanisms such as green bonds or climate funds. Meanwhile, advanced economies should invest in technological innovation to maximize the long-term benefits of green growth while supporting developing nations through technology transfers and capacity-building programs.

Reducing emissions should remain a core focus across the region. Policymakers need to strengthen environmental regulations, incentivize carbon-efficient production methods, and encourage businesses to adopt circular economy practices. Additionally, countries with high emissions should commit to international agreements and establish carbon trading systems to ensure accountability and progress in reducing their environmental footprints. Collaboration among Asia-Pacific countries through regional initiatives can also foster knowledge-sharing and collective action in addressing climate change challenges.

Despite its robust findings, this study has certain limitations. The analysis relies on cross-sectional data from 2022 and 2023, which may not capture long-term trends or the impact of lagged variables. Additionally, the study focuses solely on three independent variables—energy transition, green growth, and emissions—leaving out other critical factors such as institutional quality, trade openness, and technological innovation that may influence economic growth. Future research could address these limitations by employing longitudinal data and expanding the scope of variables to offer a more comprehensive understanding of sustainable economic development in the Asia-Pacific region.

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