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Economic Development and Energy Transition Readiness Using Spline Approach: Evidence from Asia Region

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ABSTRACT

Purpose – This study examines the impact of energy transition readiness on economic development in Asian countries by analyzing five dimensions: regulation & political commitment, infrastructure, education & human capital, innovation, and finance & investments.
Design/Methodology/Approach – A spline regression approach was employed to capture the non-linear relationship between energy transition readiness and GDP per capita. Data from Asian countries were analyzed to identify threshold effects across readiness dimensions.
Findings – The results show heterogeneous non-linear effects of energy transition readiness on GDP. Regulation & political commitment and infrastructure have consistently significant impacts, while innovation and finance & investments become significant only after certain readiness thresholds. Education & human capital does not show a significant effect.
Originality/Value – This study extends the literature by demonstrating that the economic benefits of energy transition readiness are non-linear and vary across development stages. The findings provide policy guidance for Asian countries to adopt targeted, stage-specific strategies that strengthen energy transition readiness and promote sustainable economic development.

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1. Introduction

The notion of sustainable development has become increasingly pivotal in international discourse as nations strive to balance economic advancement, social equity, and environmental conservation. The objective is to meet contemporary requirements while preserving resources and opportunities for the prosperity of future generations (Pratiwi et al., 2024; Aye & Edoja, 2017). The economic crisis of 2008-2009 intensified the focus on green economic solutions designed to promote ecologically sustainable growth and address environmental deterioration (Mihai et al., 2021). Since the mid-20th century, swift globalization has presented considerable concerns for humanity, including intensified climate change and environmental degradation (Xue et al., 2022). Non-renewable energy has always been considered a vital element in fostering economic development in developing nations (Polat, 2021). The dependence on fossil fuels has generated considerable apprehension about energy supply security, price volatility, and the ecological consequences of energy production and consumption (Humbatova et al., 2024). These difficulties have necessitated that developing countries transition to renewable energy sources as substitutes for fossil fuels (Lin et al., 2024; Kassi & Li, 2025).

If timely action is not undertaken, future generations will confront severe repercussions of climate change. Scientists and policymakers have concluded that prioritizing sustainable development can alleviate climate change and its effects. Sustainable development pertains to the improvement of life while preserving the environment, making it a fundamental priority in policy formulation yet, it significantly relies on the substantial task of transforming energy systems (Gielen et al., 2019). In recent decades, reliance on fossil fuels and escalating energy demand have obstructed transitions to sustainable energy, despite global initiatives to decarbonize the energy sector, which constitutes the predominant source of greenhouse gas (GHG) emissions: approximately two-thirds of global GHG emissions originate from energy production and consumption, positioning the energy sector at the forefront of climate action (Pambudi et al., 2023; Michailidis et al., 2025; Dossou et al., 2023). Climate change and environmental degradation profoundly affect economic sustainability, impacting both financial and non-financial entities (Ozili, 2020; Miron et al., 2023). Climate hazards underscore the possible detrimental impacts of climate change on economic activity, threatening human livelihoods and overall well-being (Barati et al., 2023; Gkouliaveras et al., 2025). Mitigating these risks and costs necessitates societal decision-making, proactive management techniques, and the capacity to forecast climate trends associated with future greenhouse gas emissions, with larger socio-economic development and equity patterns (Chen et al., 2022). The energy transition is the primary goal of all decarbonisation policies and can be significantly accomplished through the expedited implementation of renewable energy technology and energy efficiency initiatives (Li & Strachan, 2019; Sovacool et al., 2018; Tagliapietra et al., 2019). Both major emitters and less developed nations want to reform their energy systems to guarantee a dependable, sustainable, and inexpensive energy supply, which is essential for economic activity, social development, and poverty alleviation (Bouzarovski, 2018; Nerini et al., 2018). The inquiry pertains to the extent to whether countries are capable of implementing necessary reforms to attain their particular objectives (Idris & Rahman Razak, 2025).

Countries globally are endeavoring to formulate effective accords to shift from fossil fuels to greener energy sources and improve energy efficiency to achieve carbon neutrality objectives (Wiseman, 2018). This change is notably complex. The demand for fossil fuels is anticipated to increase by 2030 compared to current levels, their overall share in the global energy mix is forecast to diminish (Rahman et al., 2025). World Economic Forum (2026) emphasizes the necessity for a "Effective Energy Transition," which involves a prompt transformation to tackle global energy issues while creating value for enterprises and communities. Realizing such a transition is a multifaceted endeavor, including extensive research to examine its diverse aspects and ramifications (Sabir et al., 2025). In the realm of national and international policy creation, policymakers typically establish priorities informed by various insights (Keenan & Meenar, 2025). Rankings serve as influential instruments that substantially impact policymakers by emphasizing success narratives and comparative benchmarks, ultimately aiding in the delineation of preferred trajectories.

Asia Region is area occupies a pivotal role on the world stage, especially with the imperative of expediting energy transitions. The region's substantial industrial production and considerable population render its energy transition crucial for fostering a cleaner planet in the future (Mohammad, 2019). Likewise, it was emphasized that the decreasing costs of clean energy and improvements in green energy efficiency present significant potential for Southeast Asian countries to execute their energy transition strategies (Qiao, 2019). UN Economic and Social Council (2018) has underscored the significance of energy transition in Asia, highlighting the increasing consumption of fossil fuels and the region's substantial industrial production capacity. In Asia, nations such as China and India lead in worldwide renewable energy production, experiencing concurrent energy transitions and economic transformations (Mamat et al., 2019). Multiple studies highlight the importance of analyzing energy transition dynamics in the Asia-Pacific area due to its relevance to both regional and global sustainability objectives (Jairah & Kumar, 2019; Al-Shamma's et al., 2020). Based on *Word Economic Forum*, there are five variables that build energy transition readiness, namely Regulation & Political Commitment; Infrastructre; Education & Human Capital; Innovation; Finance & Invesments.

This study employs the Spline approach to examine the prospects for economic development in Asia Nations, focusing on energy transition readiness indicators specific to each country. The spline approach is exceptionally proficient at modeling data exhibiting variable patterns over designated subintervals (Perperoglou et al., 2019). Spline is a regression method capable of interpreting data both statistically and visually, utilized for generalizing complex statistical modeling forms (Brugnano et al., 2024; Zhang & Goh, 2013; Lu & Loomis, 2013; Zhan & Yeung, 2011). The Asia Region is crucial for the decarbonization of the global energy industry and the transition to net zero emissions globally. Energy-related emissions in the region surged by 151% from 2000 to 2023, driven by vigorous economic development, population increase, and industrialization. Emissions must peak and rapidly decrease to achieve the goals of the Paris Agreement (BloombergNEF, 2024). Asia Region must substantially increase its investments in the energy sector, especially in renewable energy development. The government should reallocate funds towards renewable energy power facilities and offer financial incentives to foster advancements in energy storage technology, thereby accelerating the transition to a green economy in the Asia Region (Idris & Rahman Razak, 2025; Lin et al., 2024).

Further research on the potential for economic development in Asian countries, based on indicators of energy transition readiness, is warranted. This prospective analysis will be examined more thoroughly based on the clustering of countries in the Asia Region generated by the utilized factors. No research has yet been undertaken on analyzing economic development potential using energy transition readiness indicators in Asian nations using the spline approach. A targeted study is required to evaluate differences in economic development across Asian countries based on energy transition readiness indicators. This analysis utilizes energy transition readiness indicators in the Asia Region, employing the spline method. This study seeks to articulate the findings of the analysis regarding the influence of energy transition readiness indicators on economic development across various Asian countries, then shown through visualizations. A strategy will be formulated to augment economic development potential and stabilize environmental factors in Asian countries based on these views.

Existing studies have largely relied on linear regression, panel estimation, or generalized econometric approaches. Consequently, little empirical evidence explains whether the contribution of energy transition readiness changes once countries reach different readiness levels. Understanding these threshold effects is particularly important for Asian countries because they display substantial heterogeneity in institutional quality, infrastructure, and innovation capacity.

This study presents a fresh methodology by offering a comprehensive analysis of economic development levels among Asian countries, utilizing indices of energy transition readiness. This study, in contrast to other research, not only examines the effects of these variables but also categorizes countries based on their economic performance, providing a more profound insight into the intricate interactions among these elements. This research employs spline regression models and country-specific data to deliver nuanced insights into the impact of varying levels of energy transition readiness on economic results, surpassing the broad trends identified in previous studies.

Unlike previous studies that mainly estimate average linear effects, this study identifies nonlinear threshold effects of energy transition readiness on GDP using spline regression. The analysis demonstrates that the economic contribution of each readiness dimension differs across readiness stages, allowing policy recommendations to be tailored for countries with low, medium, and high transition readiness.

2. Literature Review & Hypothesis Development

The pertinent literature can be categorized into concerns concerning energy transition readiness and economic development. All indicators utilized for countries in the Asia region. Additionally, it presents studies pertaining to the application of the spline approach.

The energy transition, emphasizing the transfer from fossil fuels to more sustainable energy sources, continues to be a significant subject of discussion among academics. A key inquiry is how macroeconomic variables affect the rate of energy transition in many regions, possibly resulting in common transition patterns. The research seeks to examine the relationship between energy transition patterns and economic variables in Asian economies, classified by income levels. The study analyzes data from 45 Asian countries spanning 1993 to 2018, utilizing the generalized method of moments (GMM). The results demonstrate that economic expansion facilitates energy transition, whereas CO_2 emissions hinder it. Moreover, population expansion impedes the energy transition process in both high and upper-middle-income categories as well as low and lower-middle-income categories. The report advises Asian economies to implement customized policies according to their income levels to improve and expedite energy transition initiatives. Governments in developing and growing countries, characterized by rapid economic development and increasing energy consumption, should enact supporting policies to enhance access to green energy sources, in accordance with sustainable development goals (SDGs). This is particularly crucial given the prevailing low oil price situation (Taghizadeh-Hesary & Rasoulinezhad, 2020).

A multitude of studies has investigated the impacts of energy transition by analyzing the correlations between renewable and non-renewable energy sources and diverse economic variables. Certain scholars propose that a relationship exists between economic development and energy consumption in both the short and long term (Carfora et al., 2019; Pandey & Rastogi, 2019; Saud et al., 2018; Kyophilavong et al., 2017; Niavand & Haghighat Nia, 2017). This signifies that energy consumption is crucial in industrial processes and either propels or sustains economic growth (Ram et al., 2020). Moreover, additional research indicates a bidirectional correlation between the utilization of renewable energy and economic growth (Shah et al., 2024; Azis & Jahan, 2023). Subsequent research underscores the beneficial effect of industrial production on energy usage (Raihan et al., 2023; Hanif & Zheng, 2025; Ahmad et al., 2022; Raihan et al., 2026).

The latest evaluation pertinent to energy transitions is the *World Economic Forum's Energy Transitions Index* (ETI), which assesses the performance of 120 countries in terms of their energy system efficacy and transition preparedness, thus aligning with the focus of this study. The ETI is founded on the normalization of diverse indicators spanning the economic (growth and development, capital and investment), environmental (sustainability), energy (access, security, mix), political (commitment and regulation), institutional (governance, infrastructure, innovation), and human (capital and participation) dimensions. Nonetheless, the substantial collection of 40 variables examined, while operational, does not, from a methodological perspective, form a coherent set of evaluation criteria, as there are functional relationships among the chosen criteria; specifically, a modification of one indicator cannot occur ceteris paribus (Neofytou et al., 2020). The family of 40 variables is neither readable nor minimum, which is essential for establishing a discussion framework that facilitates the examination of inter-criteria information and the execution of an aggregation technique.

The chosen computational strategy is an equal-weights average rather than a complex MCDA method, as the authors cite insufficient empirical information regarding the relative significance of variables within and across the ETI dimensions for the countries examined. The utilization of a considerable array of standardized indicators as evaluation criteria facilitates the standardization of rankings; however, it may complicate the alignment of input data across a wider spectrum of countries. This challenge is further illustrated by the political commitment to the COP21 Paris Agreement, which is contingent upon the Nationally Determined Contributions (NDCs) of the Parties involved. Consequently, assessing countries represented by a supranational entity and a collective commitment, such as EU member states, becomes problematic. Additionally, the Climate Action Tracker indicator employed to gauge this commitment evaluates only a limited number of countries. It should be emphasized that political commitment is essential for a transition, however it may signify aspiration rather than preparedness, as elucidated by Sachs et al. in the SDGI study (Sachs et al., 2020).

Several prior research have employed the Spline nonparametric regression method. Alwi et al., (2023) investigated the modeling of poverty levels in South Sulawesi using a Spline Nonparametric Regression Approach. In light of the lack of a clear pattern in the correlation between poverty levels in South Sulawesi and the influencing factors, the researchers utilized nonparametric regression modeling with a Spline approach. The results demonstrated that the ideal spline model included three knot points, achieving a minimum GCV value of 11.1155. The R^2 value is 79.75%. The factors of unemployment, population growth, and literacy rate

explain 79.75% of the variance in the poverty variable, whereas other factors account for the remaining 20.25%
The Asia Region has considerable variability in energy policy, economic frameworks, and developmental stages. The spline regression model is especially appropriate for this area, as it can adapt to these fluctuations and yield more accurate insights into the non-linear linkages among energy transition readiness and economic performance. This methodology facilitates a comprehensive understanding of how various nations with unique economic settings perceive the effects of energy transitions. While there is a paucity of studies utilizing spline regression for energy transition readiness in the Asiabregion, this methodology has been extensively employed in various domains of economic research, including income distribution analysis, growth trajectories, and environmental impact assessments, where non-linear relationships are common.

3. Methodology

This study employs Gross Domestic Product (GDP Total) at constant 2015 US dollars as a proxy for economic development. GDP Total reflects the aggregate value of goods and services produced within an economy and represents the overall scale of national economic activity. The data were obtained from the World Development Indicators (World Bank). Since this study uses cross-sectional data, GDP Total is employed to compare the level of economic development across Asian countries rather than annual economic growth (Jones, 2002). Economic development signifies an increase in a nation's production as reflected in real national income. Defines economic development as an increase in the inflated market value of commodities and services within an economy over a specified period (Thaddeus et al., 2020).
In addition, five indicators are used to measure energy transition readiness as an independent variable. The variables used in detail can be seen in Table 1. Because there are several countries in the Asia Region that do not have the necessary data, not all countries are the focus of the study. The data used is cross-section data which is secondary data for each country studied in 2023 consisting of 33 countries that are the research units.
The selection of countries included in this study is based on structural considerations that represent the diversity of economic development levels, institutional capacities, and sustainability transitions across Asia (Gurdgiev et al., 2025; Ţigănaşu et al., 2025). The sample includes both advanced and emerging economies to capture a wide range of variations in system performance, transition readiness, and green trade development.

Table 1. Variable used.

Variable	Symbol	Definition of Variable	Source
Dependent variables			
GDP Total	GDP	Total Gross Domestic Product (constant 2015 US$), representing the aggregate value of goods and services produced within an economy and used as a proxy for economic development	World Development Indicator by World Bank
Independent variables			
Regulation & Political Commitment	RPC	The strength of regulatory frameworks and political commitment to managing and supporting sustainability transitions (Index)	World Economic Forum

Finance & Investment	FI	The availability of financial resources and investment mechanisms that support sustainable and green economic transformation (Index)	World Economic Forum
Infrastructure	INF	The quality and availability of infrastructure that supports sustainable economic activities and green innovation (Index)	World Economic Forum
Education & Human Capital	EHC	The capacity of human capital, education systems, and workforce skills to support sustainable economic transformation (Index)	World Economic Forum
Innovation	INV	The ability of an economy to generate, absorb, and scale innovation that supports green technologies and sustainable production (Index)	World Economic Forum

Source: Author`s Source, 2026

Data analysis uses a spline regression approach. A spline is termed as a subset of polynomials that is flexible and effectively adapts to the nature of the data being used. This part of the polynomial has an important role because it is very flexible and effective in processing attributes or data (Eubank, 1998). One of the most important polynomial pieces is the Spline based on an optimisation problem (Podgorski et al., 2024). Spline estimation depends on the Knot points. A knot point is a point where there is a change in the pattern of a function in different intervals (Fattah et al., 2025). Spline has the advantage of handling data patterns that have sharp fluctuations by using knot points and producing a curve fit. Spline estimators can automatically obtain their estimates so that a model can be obtained that fits the shape of the data, even if the data used is moving (Brugnano et al., 2024). For example, obtained data $(x_{1i}, x_{2i}, \dots, x_{pi}, y_i)$ that is interconnected with $(x_{1i}, x_{2i}, \dots, x_{pi})$ and y_i then the nonparametric regression model formed as follows.

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

where,

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

With its truncated function as follows.

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

with $k_{1j}, k_{2j}, \dots, k_{mj}$ knots as the points that show the change of the function in certain intervals, and q as the polynomial degree, the equation can be explained as follows (Perperoglou et al., 2019).

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

In this study, the method used for Spline Regression estimation is Ordinary Least Square (OLS). The form of the OLS model in this context can be explained as follows (Zhan & Yeung, 2011).

$$y = X\beta + \varepsilon \tag{5}$$

Knot points obtained have an important role in Nonparametric Spline Regression. Changes in data behaviour can occur in some parts of the interval. The selection of the best Spline estimator can be determined based on the minimum Generalised Cross Validation (GCV) value criteria. The GCV method can be written as follows (Zhang & Goh, 2013).

$$GCV\ (k_1, k_2, \dots, k_j) = \frac{MSE(k_1,k_2,\dots,k_j)}{\left(n^{-1}Trace[I-A(k_1,k_2,\dots,k_j)]\right)^2} \tag{6}$$

The coefficient of determination is an important measure of the quality of a model and indicates how well the model explains the data. The coefficient of determination is generally symbolised by R^2 and R^2_{adj} (corrected). The greater the value of R^2, the better the value of the independent variables in the model formed to describe the variability of the response variable. The formula for calculating the coefficient of determination can be seen as follows (Lu & Loomis, 2013).

$$R^2 = \frac{\hat{\beta}^T X^T y - n\bar{y}^2}{y^T y - n\bar{y}^2}\ x\ 100\% \tag{7}$$

The research step begins with descriptive statistical analysis for each variable used to determine the characteristics of the research unit. Next, modelling the economic development rate in Asian countries with predictor variables based on indicators from the Energy Transition Readiness Index for each country. Then select the optimal knot point by looking at the smallest GCV value generated and modelling the economic development rate in Asia countries with a spline approach with optimal knot points. Finally, test the significance of parameters in the spline model formed, calculate the results of the coefficient of determination of the model and interpret the results of the analysis and the spline model formed with visualisation in the form of a regional map. Statistical analysis was carried out with the help of R software.

4. Result and Discussion

4.1. Analysis Results

Table 2 presents descriptive statistics of Total GDP and the five Energy Transition Readiness indicators used in this study. Total GDP serves as the proxy for economic development across Asian countries.

Table 2. Descriptive statistics.

Variable	**Mean**	**Variance**	**Std. Dev**	**Skewness**	**Kurtosis**	**Minimum**	**Maximum**
GDP	61852362.	8.02892e	283353495	5.394924		3182,281	16323268
RPC	26	16	.5	71	32.2759	1	87
INF	55.1	168.4056	12.977119	0.107857	22	31.4	84
EHC	42.5545	25	3	6		16.1	70

INV	34.59091	184.958	13.5999	0.44534	-	16.8	71.9
FI	37.7455	195.6309	13.98681	0.719251	0.36332	18.6	83.7
	40.5424	226.488	15.0495	1.28664	6	18.4	76.5
		239.782	15.4849	0.77793	-0.3138		
					0.20521		
					1.64276		
					0.21853		

Source: Own Research, 2026

After seeing the descriptive analysis above, the correlation analysis between variables was then carried out. Correlation analysis is generally used to measure and determine the relationship between two or more variables used. Through correlation analysis, it can be seen how strong the relationship between the variables studied is. Based on the results of the correlation analysis shown in Table 3, it can be seen that along the diagonal displays variables that are highly correlated with themselves. In addition, the correlation shows the relationship between the independent variables and GDP as the dependent variable. There is a weak positive correlation between GDP and the regulation & political commitment variable, which suggests that its increase tends to be associated with higher Total GDP. GDP also has a moderate positive correlation with the Education & Human Capital variable, indicating that its increase may slightly boost GDP growth. The correlation with the Innovation variable and the Finance & Investments variable is also positive, indicating a more significant relationship, although still relatively weak. Meanwhile, the relationship between GDP and Infrastructure variable is very low and does not show a significant effect. Overall, the relationship between GDP and these independent variables tends to be positive, but with varying strengths from weak to moderate.

Table 3. Correlation matrix.

Variable	***GDP***	***RPC***	***Inf***	***EHC***	***Inn***	***FI***
GDP	1.000000					
RPC	0.109713	1.000000				
Inf	0.175130	0.578864	1.000000			
EHC	0.199233	0.236358	-0.028532	1.000000		
Inn	0.146368	-0.013278	0.165803	0.117162	1.000000	
FI	0.229186	0.455675	0.298658	0.226217	0.326707	1.000000

Source: Own Research, 2026

The first step to do in analysing potential economic development based on transition readiness indicators using the Spline approach is to select the most optimal knot point. The selection of optimal knot points is done by looking at the lowest GCV value produced by each knot.

Table 4. GCV value generated by each knot point.

Knot Point	**GCV Value**
Knot Point 1	$3.831976e^{16}$
Knot Point 2	$1.592465e^{15}$
Knot Point 2	$1.672359e^{14}$

Source: Own Research, 2026

Table 4 shows that the smallest GCV value is generated by knot point 3 with a resulting value of $1.672359e^{14}$. Therefore, the modelling for the economic development rate in the Asia Region will use knot point 3. The modelling is shown in the following model equation.

$$\begin{aligned}\hat{y} = 79396515 &+ 1036211476RPC_1 + 901132949(RPC_2 + 32.47347)\\ &+ 345426829(RPC_3 + 33.54694) + 210279312(RPC_4 + 80.77959)\\ &+ 104412386INF_1 + 604431201(INF_2 + 17.2) + 34990900(INF_3 + 18.3)\\ &+ 534449426(INF_4 + 66.7) + 12378774EHC_1 + 35291339(EHC_2 + 17.9244)\\ &+ 7270180(EHC_3 + 19.04898) + 16426566(EHC_4 + 68.52653)\\ &+ 1446517971INV_1 + 1745924887(INV_2 + 19.92857)\\ &+ 464101501\,(INV_3 + 21.25714) + 165186134\,(INV_4 + 79.71429)\\ &+ 411573919FI_1 + 2294681752\,(FI_2 + 19.58571)\\ &+ 1915819663\,(FI_3 + 20.77143) + 32884107\,(FI_4 + 72.94286)\end{aligned}$$

Furthermore, parameter tests are carried out using two types of tests, namely simultaneous parameter tests and individual tests.

Table 5. Simultaneous parameter test.

Source of Variance	Df	SS	MS	F	P-Value
Regression	20	$1.788715e^{18}$	$1.274722e^{17}$	77.21231	$9.910991e^{-10}$
Error	12	$7.805401e^{17}$	$1.650931e^{15}$		
Total	32	$2.569255e^{18}$			

Source: Own Research, 2026

The statistical value produces a p-value of $9.91099e^{-10}$. When compared to the significance level, the decision taken is Reject. This value gives the conclusion that there is at least one variable that has a significant influence on the model formed. The occurrence of reject indicates that it is necessary to test individually to find out which variables have a significant influence on the model formed.

Table 6. Individual test.

Variable	Parameter	Estimator	P-Value	Note
Constant	β_0	79396515	$9.861611e^{-05}$	Significant
RPC	β_1	1036211476	$9.473105e^{-05}$	Significant
	β_2	901132949	0.0001002684	Significant
	β_3	345426829	$9.373102e^{-05}$	Significant
	β_4	210279313	0.0001480459	Significant
INF	β_5	104412386	0.0001209449	Significant
	β_6	604431201	0.000101667	Significant
	β_7	34990900	0.0001206104	Significant
	β_8	534449426	0.0001116791	Significant
EHC	β_9	12378774	0.8887544	Not Significant
	β_{10}	35291339	0.9160334	Not Significant
	β_{11}	7270180	0.9863891	Not Significant
	β_{12}	16426566	0.9256281	Not Significant
INV	β_{13}	1446517971	$9.782129e^{-11}$	Significant
	β_{14}	1745924887	0.03107373	Significant
	β_{15}	464101501	0.6653222	Not Significant
	β_{16}	165186134	0.6419072	Not Significant
FI	β_{17}	411573919	0.2448023	Not Significant

β_{18}	2294681752	6.782125e-06	Significant
β_{19}	1915819663	9.919962e-09	Significant
β_{20}	32884107	9.029134e-09	Significant

Source: Own Research, 2025

The last step in this analysis is to determine the coefficient of determination to show how good the model is in explaining economic development in the Asia Region using variables in the Transition Readiness indicator.

$$R^2 = \frac{SS_{Regresi}}{SS_{Total}} x\ 100\% = \frac{1.788715e^{18}}{2.569255e^{18}} x100\% = 69.62\%$$

Based on the results of these calculations, a value R^2 is 66.62 percent is obtained, which means that the variables used are able to explain 66.62 Percent of the variation in the growth rate of countries in the Asia Region. While the rest is explained by other variables that have not been studied.

4.2. Spline Model Interpretation Results

After the results of the analysis have been carried out using the spline approach, and the residual assumptions have been met, the results show that the variables of the transition readiness indicator used have a significant influence on the rate of economic development value in Asian Region countries. Furthermore, it will be seen the potential for increasing the economic development of each Asian Region country based on the variables used.

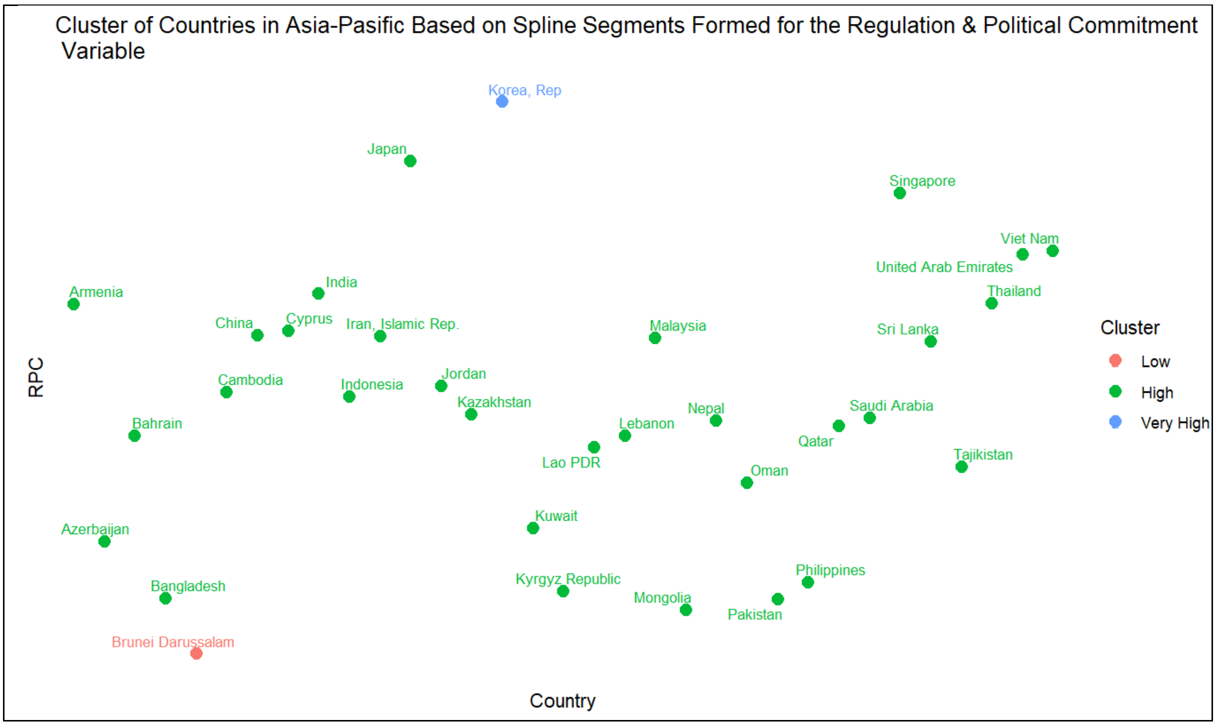
If the variables of Infrastructure; Education & Human Capital; Innovation; Finance & Investments are considered constant, the effect of the Regulation & Political Commitment variable on the rate of economic development in Asian Region countries is as follows.

$$\hat{y} = 1036211476RPC_1 + 901132949(RPC_2 + 32.47347) + 345426829(RPC_3 + 33.54694) \\ + 210279312(RPC_4 + 80.77959)$$

$$\hat{y} = \begin{cases} 1036211476;\ RPC_1 < 32.47347 \\ 1937344425;\ 32.47347\ \leq RPC_2 < 33.54694 \\ 2282771254; 33.54694\ \leq RPC_3 < 80.77959 \\ 2493050566;\ RPC_4 > 80.77949 \end{cases}$$

Based on the equation model, it is known that there are three country clusters formed based on the Regulation & Political Commitment variables that have an influence on the value of economic development in countries in the Asia Region according to the Spline cuts formed. The regional clusters formed can be seen in Figure 1.

Figure 1. Cluster of Asian Region Countries based On Spline Segments Formed for Regulation & Political Commitment Variable



Source: Own Research, 2026

Interpretation: If a country has a regulation & political commitment index scale of less than 32.47347, then the country's GDP has the potential to increase by 1036211476, which is a low category. If a country has a regulation & political commitment index scale between 33.54694 to 80.77959, then the country's GDP has the potential to increase by 2282771254, where this country is in the high category. And finally, if a country has a regulataion & political commitment index scale of more than 80.77959, then the country's GDP has the potential to increase by 2493050566, which is a very high category.

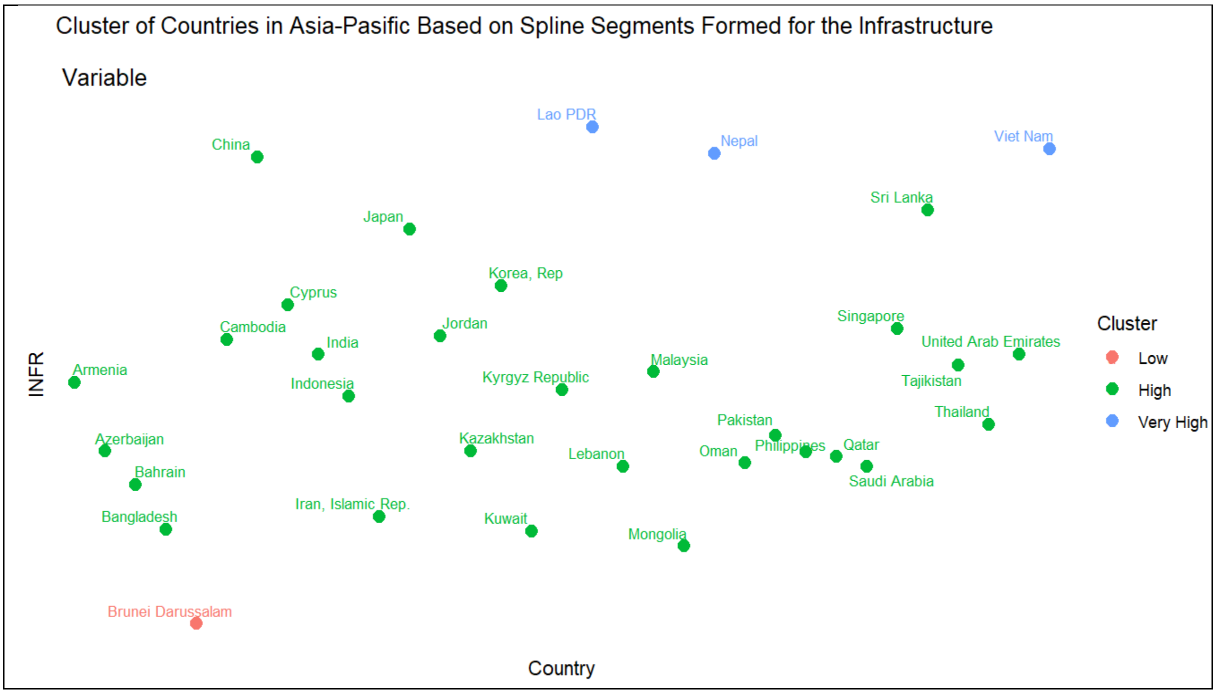
If the variables of Regulation & Political Commitment; Education & Human Capital; Innovation; Finance & Investments are considered constant, the effect of Infrastructure variables on the rate of economic development in Asian Region countries is as follows.

$$\hat{y} = 104412386 INF_1 + 604431201(INF_2 + 17.2) + 34990900(INF_3 + 18.3) + 534449426(INF_4 + 66.7)$$

$$\hat{y} = \begin{cases} 104412386; \ INF_1 < 17.2 \\ 708843587; \ 17.2 \le INF_2 < 18.3 \\ 743834487; 18.3 \le INF_3 < 66.7 \\ 1278283913; \ INF_4 > 66.7 \end{cases}$$

Based on the equation model, it is known that there are three clusters of countries formed based on Infrastructure variables that have an influence on the value of economic development in countries in the Asia Region according to the Spline cuts formed. The regional clusters formed can be seen in Figure 2.

Figure 2. Cluster of Asian Region Countries based On Spline Segments Formed for Infrastructure Variable



Source: Own Research, 2026

Interpretation: If a country has an infrastructure index scale of less than 17.2, then the country's GDP will potentially increase by 104412386, which is a low category. If a country has an infrastructure index scale between 18.3 and 66.7, then the country's GDP has the potential to increase by 743834487, which is in the high category. And finally, if a country has an infrastructure index scale of more than 66.7, then the country's GDP has the potential to increase by 1278283913, which is a very high category.

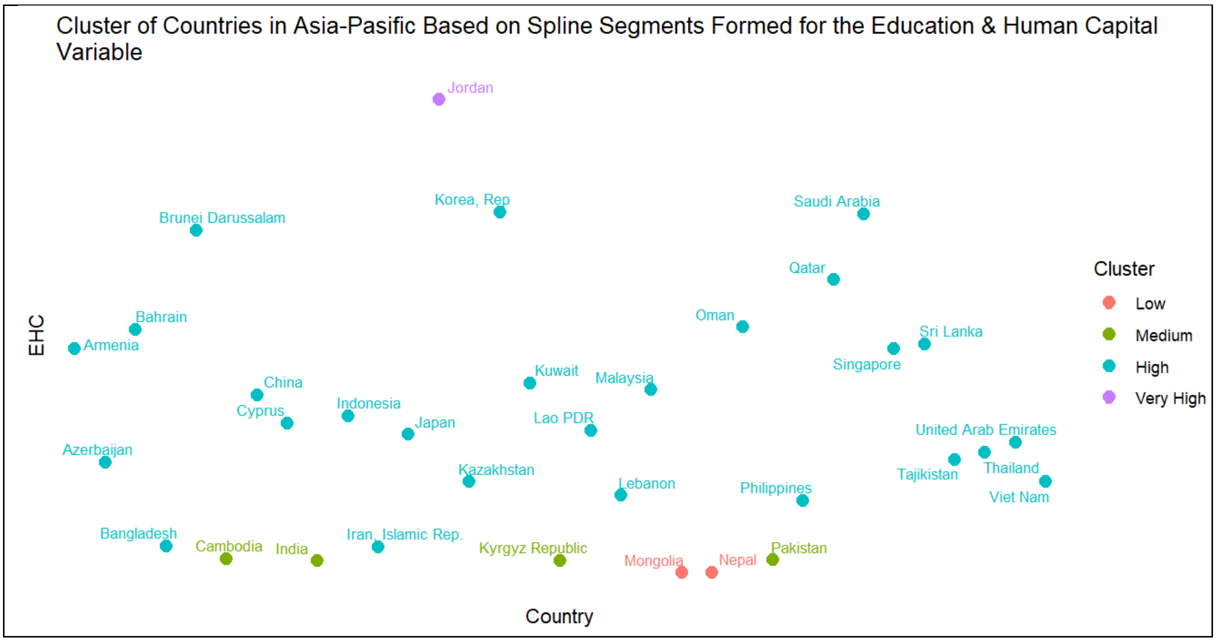
If the variables Regulation & Political Commitment; Infrastructure; Innovation; Finance & Investments are considered constant, then the effect of the variable Education & Human Capital on the rate of economic development in Asian Region countries is as follows.

$$\hat{y} = 12378774EHC_1 + 35291339(EHC_2 + 17.9244) + 7270180(EHC_3 + 19.04898) + 16426566(EHC_4 + 68.52653)$$

$$\hat{y} = \begin{cases} 12378774;\ EHC_1 < 17.9244 \\ 47670112;\ 17.9244 \le EHC_2 < 19.04898 \\ 540940293; 19.04898 \le EHC_3 < 68.52653 \\ 71366859;\ EHC_4 > 68.52653 \end{cases}$$

Based on the equation model, it is known that there are four country clusters formed based on the Education & Human Capital variables that have an influence on the value of economic development in countries in the Asia Region according to the Spline cuts formed. The regional clusters formed can be seen in Figure 3.

Figure 3. Cluster of Asian Region Countries based On Spline Segments Formed for Education & Human Capital Variable



Source: Own Research, 2026

Interpretation: If a country has an education & human capital index scale of less than 17.9244, then the country's GDP will potentially increase by 12378774, which is a low category. If a country has an education & human capital index scale between 17.9244 and 19.04898, then the country's GDP has the potential to increase by 47670112, which is a medium category. If a country has an education & human capital index scale between 19.04898 and 68.52653, then the country's GDP has the potential to increase by 540940293, which is a high category. And finally, if a country has an education & human capital index scale of more than 68.52653, then the country's GDP has the potential to increase by 71366859, which is a very high category.

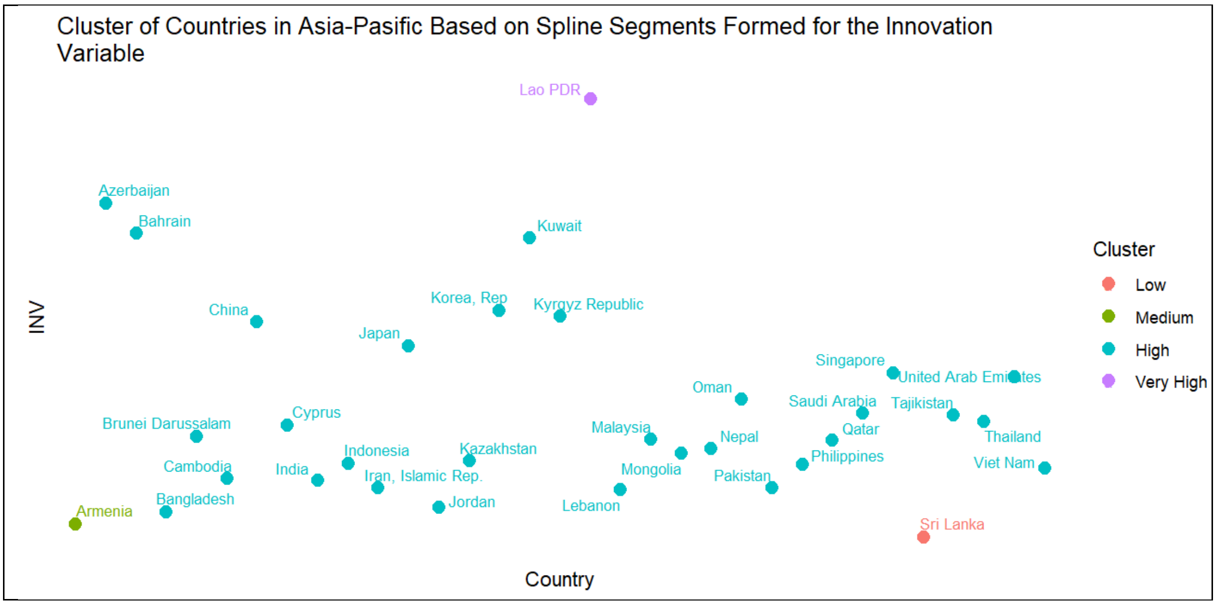
If the variables Regulation & Political Commitment; Infrastructure; Education & Human Capital; Finance & Investments are considered constant, then the effect of the Innovation variable on the rate of economic development in Asian Region countries is as follows.

$$\hat{y} = 1446517971 INV_1 + 1745924887(INV_2 + 19.92857) + 464101501\,(INV_3 + 21.25714) + 165186134\,(INV_4 + 79.71429)$$

$$\hat{y} = \begin{cases} 1446517971;\ INV_1 < 19.92857 \\ 3192442858;\ 19.92857 \le INV_2 < 21.25714 \\ 3656544359; 21.25714 \le INV_3 < 79.71329 \\ 3821730493;\ INV_4 > 79.71329 \end{cases}$$

Based on the equation model, it is known that there are four country clusters formed based on Innovation variables that have an influence on the value of economic development in countries in the Asia Region according to the Spline cuts formed. The regional clusters formed can be seen in Figure 4.

Figure 4. Cluster of Asian Region Countries based On Spline Segments Formed for Innovation Variable



Source: Own Research, 2026

Interpretation: If a country has an innovation index scale of less than 19.92857, then the country's GDP has the potential to increase by 1446517971, which is a low category. If a country has an innovation index scale between 19.92857 and 21.25714, then the country's GDP has the potential to increase by 3192442858, where this country is in the medium category. If a country has an innovation index scale between 21.25714 to 79.71329, then the country's GDP has the potential to increase by 3656544359, where this country is in the high category. And finally, if a country has an innovation index scale of more than 79.71329, then the country's GDP has the potential to increase by 3821730493, where this country is in the very high category.

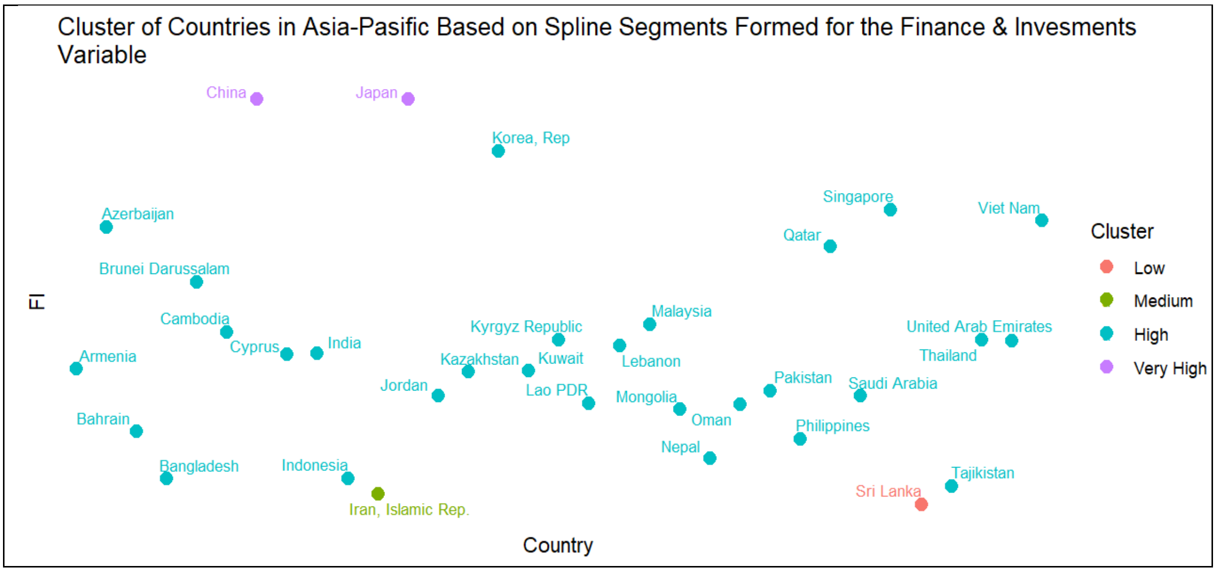
If the variables Regulation & Political Commitment; Infrastructure; Education & Human Capital; Innovation are considered constant, then the influence of the variable Finance & Investments on the rate of economic development in Asian Region countries is as follows.

$$\hat{y} = 411573919FI_1 + 2294681752\,(FI_2 + 19.58571) + 1915819663\,(FI_3 + 20.77143) + 32884107\,(FI_4 + 72.94286)$$

$$\hat{y} = \begin{cases} 411573919;\ FI_1 < 19.58571 \\ 2706255671;\ 19.58571 \le FI_2 < 20.77143 \\ 4662075334;\ 20.77143 \le FI_3 < 72.94286 \\ 4654959441;\ FI_4 > 72.94286 \end{cases}$$

Based on the equation model, it is known that there are four country clusters formed based on the Finance & Investments variable that has an influence on the value of economic development in countries in the Asia Region according to the Spline cuts formed. The regional clusters formed can be seen in Figure 5.

Figure 5. Cluster of Asian Region Countries based On Spline Segments Formed for Finance & Invesments Variable



Source: Own Research, 2026

Interpretation: If a country has a finance & investments index scale of less than 19.58571, then the country's GDP will potentially increase by 411573919, which is in the low category. If a country has a finance & investments index scale between 19.58571 and 20.77143, then the country's GDP has the potential to increase by 2706255671, which is a medium category. If a country has a finance & investments index scale between 20.77143 and 72.94286, then the country's GDP has the potential to increase by 4662075334, which is a high category. And finally, if a country has a finance & investment index scale of more than 72.94286, then the country's GDP has the potential to increase by 465495441, which is a very high category.

4.3. Discussion

This study examines the relationship between energy transition readiness and economic development, proxied by GDP total, across Asian countries using a spline regression approach. The findings indicate that regulation and political commitment, infrastructure, education and human capital, innovation, and finance and investment are all positively associated with GDP, albeit with varying intensities across different readiness levels. These results reinforce and extend previous empirical findings in the energy–growth literature, while also providing new evidence on the non-linear nature of the transition–growth nexus in Asia.

The positive association between transition readiness and GDP aligns with the macro-level evidence presented by (Idris & Rahman Razak, 2025), who find that economic expansion facilitates the energy transition process in Asian economies. While their study emphasizes how growth drives transition, our results complement this perspective by demonstrating the reverse channel: stronger transition readiness—particularly through regulatory quality and political commitment—contributes to higher income levels. This bidirectional dynamic is consistent with earlier findings on the interdependence between energy systems and economic performance (Carfora et al., 2019; Saud et al., 2018; Kyophilavong et al., 2017), suggesting that energy transition and economic development reinforce one another in a cumulative process.

The significance of the regulation and political commitment index confirms the institutional argument embedded in the World Economic Forum's ETI framework (Singh et al., 2019), which positions governance quality and policy credibility as central pillars of transition preparedness. However, our findings also respond to the critique raised by Neofytou et al. (2020), who argue that ETI indicators are functionally interrelated and cannot be interpreted ceteris paribus. The spline results show that improvements in regulation generate stronger marginal effects on GDP after countries surpass certain readiness thresholds. This suggests that institutional reforms may exhibit increasing returns once foundational governance standards are met, supporting the view that political commitment must move beyond aspirational targets—such as NDC pledges discussed by Sachs et al. (2019)—and translate into effective policy implementation.

Infrastructure also emerges as a key determinant of GDP. This result is consistent with the broader literature linking energy systems, industrial activity, and economic output (Shahbaz & Lean, 2012; Keho, 2016; Adom et al., 2012). Energy infrastructure—such as grid reliability, renewable integration capacity, and transport systems—reduces transaction costs and enhances production efficiency, thereby stimulating growth. In the Asian context, where developmental stages differ widely, the spline model reveals that infrastructure investment yields particularly strong growth effects among middle-readiness countries. This finding supports Taghizadeh-Hesary and Rasoulinezhad's (2020) recommendation that developing and rapidly growing economies implement tailored policies to accelerate green energy access in line with the SDGs. Education and human capital significantly influence GDP, reinforcing the argument that transition readiness is not solely a technological issue but also a human-capacity challenge. The literature on energy–growth linkages (Ram et al., 2020; Pandey & Rastogi, 2019) emphasizes the role of energy in sustaining production; however, our findings highlight that the ability to adopt and manage advanced energy systems depends heavily on workforce skills and institutional learning capacity. Countries with stronger human capital appear better positioned to transform energy transition efforts into tangible economic gains, especially after crossing critical spline knot points. This supports the notion that transition policies must be integrated with long-term investments in education and vocational training.

Innovation shows a robust and nonlinear association with GDP, consistent with the ETI's institutional and technological dimensions (Singh et al., 2019). Prior studies demonstrate bidirectional relationships between renewable energy use and economic development (Shah et al., 2024; Azis & Jahan, 2023). Our findings extend this evidence by showing that innovation readiness amplifies the growth dividend of transition policies. In countries with low innovation capacity, improvements generate modest economic effects; however, once R&D ecosystems mature, the economic payoff becomes substantially larger. This threshold effect helps explain why some Asian economies experience rapid green-growth acceleration while others remain in transition stagnation. The finance and investment index further supports the established view that capital formation and financial development are crucial for both energy transition and growth (Carfora et al., 2019). Access to credit, green financing instruments, and transparent investment environments facilitate renewable energy deployment and industrial modernization. The spline estimation reveals that financial readiness becomes particularly decisive at higher development levels, indicating that sophisticated financial systems magnify the economic returns of transition policies.

This study contributes to the literature by applying spline nonparametric regression to capture nonlinearities in the transition–growth nexus. Previous applications of spline regression in economic contexts, such as Alwi et al. (2023), demonstrate its ability to model relationships without assuming a fixed functional form. Similar to their findings—where multiple knot points improved explanatory power—our spline specification identifies threshold effects across readiness levels. This confirms that the relationship between energy transition readiness and GDP is not purely linear, particularly in a heterogeneous region such as Asia. Given the diversity in income levels, policy frameworks, and energy structures, a flexible approach like spline regression is especially appropriate.

The policy implications of these findings are substantial. Governments should adopt differentiated strategies according to their readiness stage. For low-readiness countries, priority should be given to strengthening regulatory credibility, improving governance quality, and expanding basic infrastructure. For middle-readiness countries, accelerating human capital development and innovation ecosystems becomes critical. High-readiness countries should focus on deepening financial markets and scaling advanced green technologies to maximize growth benefits. Consistent with Lin et al., (2024), policies must be tailored to income levels. Rapidly growing developing economies in Asia should integrate green energy access policies with industrial and demographic strategies to avoid the growth–emission trade-off. Given the evidence that CO_2 emissions hinder transition progress, aligning environmental and economic objectives is essential.

Regional cooperation mechanisms in Asia can facilitate knowledge-sharing on regulatory reforms, renewable integration, green finance, and innovation policy. Since ETI indicators are interrelated (Neofytou et al., 2020), coordinated reforms across multiple dimensions are more effective than isolated interventions. Multilateral institutions can support capacity-building initiatives to enhance institutional quality and technological diffusion across countries. This study strengthens the existing literature by empirically demonstrating that energy transition readiness is not only associated with economic development but does so in a nonlinear and stage-dependent manner. By integrating institutional, infrastructural, human capital, innovation, and financial dimensions within a spline framework, the analysis provides a more nuanced understanding of the transition–growth nexus in Asia. Sustainable economic prosperity in the region requires integrated policy frameworks, income-sensitive strategies, and sustained investments across multiple readiness dimensions to unlock the full economic potential of energy transition.

5. Conclusion and Suggestion

This study has demonstrated a significant relationship between transition readiness indicators and economic development across Asian countries. The findings indicate that improvements in regulation and political commitment, infrastructure, education and human capital, innovation, and finance and investments have a direct and positive impact on a country's GDP total. These results highlight the critical role of transition readiness in fostering economic development, as each of the examined indicators contributes differently to economic outcomes. Countries with higher scores in these indices generally experience greater economic development, while those with lower scores have limited potential for GDP increase. The analysis reveals that regulation and political commitment are key drivers of economic performance, with countries achieving higher GDP when their indices surpass certain thresholds. Similarly, infrastructure development, education and human capital, and innovation capacity play vital roles in shaping a country's economic trajectory. The findings further underline the importance of financial systems and investment environments in boosting a nation's economic development potential.

Moreover, the study shows that countries with moderate to high levels of transition readiness indices experience greater economic gains. These results suggest that investing in transition readiness indicators is a viable strategy for countries aiming to enhance their economic development. The varying impacts across different thresholds emphasize the need for tailored policies that address specific areas of improvement in each country. This research confirms that transition readiness is essential for economic development in the Asia region. Policymakers should prioritize reforms and investments in these key areas to ensure sustained and inclusive economic development. The study's insights provide valuable guidance for governments to craft strategies that boost transition readiness and, consequently, GDP total.

Based on the findings of this study, governments across Asia should consider implementing targeted policies that improve transition readiness indicators. Enhancing regulation and political commitment through governance reforms, transparency measures, and anti-corruption efforts can foster a stable environment for economic development. Governments should ensure that regulatory frameworks are conducive to business operations, which can attract both domestic and foreign investments.

Substantial investments in infrastructure are crucial to improve connectivity, logistics, and service delivery. Governments should prioritize projects that enhance transportation networks, digital infrastructure, and public utilities to support economic activities. Public-private partnerships can be leveraged to finance these projects efficiently and reduce the financial burden on governments.

Education and human capital development policies should be at the core of national strategies. Investing in education systems that equip citizens with relevant skills and competencies is essential for boosting productivity and innovation. Governments should also promote lifelong learning and vocational training programs to ensure that the workforce remains competitive in the global market. Fostering innovation and improving the financial and investment climate are necessary steps to stimulate economic development. Policymakers should support research and development initiatives, create incentives for entrepreneurship, and ensure access to finance for businesses. By improving the overall business environment and encouraging innovation, countries can achieve sustainable economic development and resilience in the face of global challenges.

6. Limitations and Future Research

Despite its contributions, this study has several limitations. The primary limitation is the reliance on secondary data sources, which may introduce biases due to discrepancies in data collection methods across different countries. Additionally, the study focuses solely on Asian countries, which may limit the generalizability of the findings to other regions. Furthermore, the model used in this study does not account for external shocks such as geopolitical conflicts or global economic downturns that could impact transition readiness and economic development. Future research could address these limitations by incorporating real-time data and expanding the analysis to include countries from other regions to enhance the generalizability of the findings. Additionally, future studies could explore the impact of external factors, such as technological advancements or environmental policies, on transition readiness and economic development. Researchers may also consider utilizing more advanced econometric models to capture the dynamic relationships between various indicators and economic outcomes over time, providing a more comprehensive understanding of the factors driving economic development in different contexts.

Declaration of AI and AI-assisted technologies in the writing process (if author[s] utilize AI)

The authors did not use artificial intelligence tools for data analysis, interpretation of results, or generation of original scientific content in the manuscript. The use of digital tools was limited solely to language-related assistance. Specifically, we used eepl.com/en/translator to translate the original text from Indonesian into English, and Chat GPT to improve grammar, sentence structure, and linguistic clarity. These tools were applied only at the editing stage to enhance readability and ensure compliance with academic English standards. All ideas, analyses, interpretations, and conclusions presented in the article are entirely the authors' own work. The use of these tools did not influence the scientific content, originality, or integrity of the manuscript, and we believe this complies fully with the journal's policies on the responsible use of AI-assisted tools

Appendix

Tabel A. Countries Included in the Study Sample (n = 33)

No.	Country	No.	Country
1	Armenia	18	Lao PDR
2	Azerbaijan	19	Lebanon
3	Bahrain	20	Malaysia
4	Bangladesh	21	Mongolia
5	Brunei Darussalam	22	Nepal
6	Cambodia	23	Oman
7	China	24	Pakistan
8	Cyprus	25	Philippines
9	India	26	Qatar
10	Indonesia	27	Saudi Arabia
11	Iran, Islamic Rep.	28	Singapore
12	Japan	29	Sri Lanka
13	Jordan	30	Tajikistan
14	Kazakhstan	31	Thailand
15	Korea, Rep.	32	United Arab Emirates
16	Kuwait	33	Viet Nam
17	Kyrgyz Republic		

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