

Assessing the Impact of the Knowledge Economy on Sustainable Development : Evidence from Southeast Asian Countries.

تقييم تأثير اقتصاد المعرفة في تحقيق التنمية المستدامة : دراسة قياسية لدول جنوب شرق آسيا

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Abstract:

This study assesses the contribution of the knowledge economy to sustainable development in Southeast Asian economies. Covering Indonesia, Thailand, Bangladesh, the Philippines, Sri Lanka, and Vietnam from 1990 to 2024, the analysis evaluates the effects of human capital, R&D expenditures, resident patent applications, and GDP on Adjusted Net Savings (ANS), with using a dynamic panel model estimated (GMM). The results show that human capital, R&D investment, and resident patenting significantly enhance ANS, underscoring the pivotal role of intangible assets in sustaining long-term development. Conversely, GDP exerts a positive yet statistically insignificant effect, indicating that economic growth alone, when not coupled with human and technology-oriented capacity building, fails to strengthen sustainability. Overall, the study demonstrates that sustainability in these emerging Asian economies is driven primarily by advancements in human and technological capabilities. The findings emphasize the need for policies that prioritize education, research, innovation, and knowledge diffusion to support the transition toward a sustainable development trajectory.

Keywords: Sustainable Development, Knowledge Economy, Innovation, Southeast Asian Countries, Dynamic Panel Model.

JEL Classification Codes: O11, O30, O44, C33.

ملخص:

تهدف هذه الدراسة إلى تحليل إسهام اقتصاد المعرفة في دعم مسار التنمية المستدامة على مجموعة من اقتصادات دول جنوب شرق آسيا، وذلك خلال الفترة الممتدة من 1990 إلى 2024. وتعتمد الدراسة على نموذج ديناميكي لبيانات البائل مُقدَّر باستخدام طريقة العزوم المعممة (GMM)، من أجل تقييم أثر رأس المال البشري، والإنفاق على البحث والتطوير، وطلبات براءات الاختراع المقدمة من المقيمين، والنتائج المحلي الإجمالي على صافي الادخار المعدل. وتشير النتائج إلى أن رأس المال البشري، والاستثمار في البحث والتطوير، ونشاط الابتكار، تسهم إسهامًا إيجابيًا ومعنويًا في تعزيز صافي الادخار المعدل، بما يعكس الدور الجوهري للأصول غير الملموسة في تحقيق استدامة التنمية على المدى الطويل. في المقابل، يُظهر الناتج المحلي الإجمالي أثرًا إيجابيًا غير دال إحصائيًا، وهو ما يدل على أن النمو الاقتصادي، إذا لم يُدعم بتنمية القدرات البشرية والتكنولوجية، يظل غير كافٍ لتعزيز الاستدامة. وعليه، تخلص الدراسة إلى أن الاستدامة في هذه الاقتصادات الآسيوية الصاعدة تُقاد أساسًا بالتقدم في القدرات البشرية والتكنولوجية، لا بمجرد التوسع الاقتصادي الكمي. كما تؤكد النتائج على ضرورة تبني سياسات تنمية تُعطي الأولوية للاستثمار في التعليم، والبحث العلمي، والابتكار.

كلمات مفتاحية: التنمية المستدامة، اقتصاد المعرفة، الابتكار، دول جنوب شرق آسيا، نموذج بيانات البائل الديناميكي.

تصنيفات JEL : O11, O30, O44, C33.

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INTRODUCTION:

Over the past three decades, South and Southeast Asian economies have experienced profound and accelerated structural transformation, driven by sustained industrialization, deeper economic diversification, and increasing integration into global value chains. These dynamics have been accompanied by notable improvements in human capital formation, technological infrastructure, and national innovation systems. Nevertheless, this rapid growth has simultaneously intensified pressures on exhaustible natural resources, thereby raising fundamental concerns regarding the long-term sustainability of development trajectories.

Southeast Asia offers a particularly salient case, as several economies in the region remain structurally dependent on resource-intensive and energy-intensive production systems while also exhibiting an emergent momentum in innovation capacity. This duality is unfolding in a broader environment marked by acute ecological vulnerabilities, including deforestation, mineral resource depletion, and deteriorating air quality. These challenges underscore the imperative of reinforcing innovation policies and upgrading human capabilities to facilitate a transition toward a sustainable and resilience-oriented development paradigm. Ultimately, the overarching policy challenge is the establishment of a wealth-creation model that ensures intertemporal sustainability and safeguards aggregate national wealth.

Against this backdrop, the present study addresses the following central research question: *to what extent do the core components of the knowledge economy, human capital, R&D expenditure, and inventive activity, contribute to enhancing sustainability in Southeast Asian economies?* In complement, the analysis examines the role of GDP, conventionally regarded as a primary engine of wealth accumulation, yet whose implication for sustainability remains theoretically ambiguous due to its potential disconnection from natural capital dynamics.

The inquiry is guided by two testable hypotheses:

H1: The knowledge economy, through human capital, R&D, and innovation, exerts a positive and significant influence on long-term capital sustainability.

H2: Extensive economic growth alone does not guarantee sustainability, as it may coincide with natural capital depletion when not supported by innovation-driven and human-capital-intensive development processes.

To empirically examine these hypotheses, the study employs a dynamic panel-data framework encompassing six South and Southeast Asian economies, Indonesia, Thailand, Bangladesh, the Philippines, Sri Lanka, and Vietnam, over the period 1990–2024. Considering the likely presence of endogeneity between sustainability and knowledge-economy variables, as well as the temporal persistence of the Adjusted Net Savings (ANS) indicator, the empirical strategy relies on the Generalized Method of Moments (GMM). This estimator provides robustness by controlling for unobserved heterogeneity, state dependence, and the simultaneity inherent in macroeconomic relationships. The dataset is constructed primarily from the World Bank and the World Intellectual Property Organization (WIPO, 2025), ensuring cross-country and intertemporal comparability.

1- Literature Review

The knowledge economy has emerged as a central paradigm for understanding contemporary dynamics of sustainable development. Rooted in the production, dissemination, and utilization of knowledge, it departs from traditional development models grounded in physical capital accumulation and intensive exploitation of natural resources (OECD, 1996). This conceptual shift aligns with sustainability theories that posit that long-term development hinges on the preservation of comprehensive wealth, encompassing natural, human, physical, and technological capital, to secure intergenerational well-being (Pearce & Atkinson, 1993; Dasgupta, 2001).

The notion of a knowledge-based economy is anchored in human capital theory (Schultz, 1961; Becker, 1964) and further expanded through endogenous growth models, in which human capital, knowledge accumulation, innovation, and technological spillovers exert persistent effects on economic trajectories (Romer, 1986; Aghion & Howitt, 1992).

World Bank's Adjusted Net Savings (ANS) indicator embodies this principle by integrating human capital formation, natural resource depletion, and environmental degradation into a comprehensive measure of sustainability (Hamilton & Clemens, 1999). Within this framework, the knowledge economy is understood to offset natural capital depletion through the accumulation of intangible capital, fostering innovation, energy efficiency, and long-run productivity gains (Romer, 1990; Aghion & Howitt, 1992).

Human capital forms a foundational pillar of both growth and sustainability theories. Lucas (1988), within an endogenous growth context, highlights the externalities generated by human capital accumulation, which can sustain long-term growth. From a strong-sustainability perspective, human capital supports transitions toward cleaner technologies, more rational natural resource management, and improved environmental governance.

Research and development (R&D) is widely recognized as a cornerstone of sustainable growth. Romer (1990) and Aghion & Howitt (1992) demonstrate that the creation of new knowledge generates increasing-returns innovations that drive productivity. R&D also underpins the development of cleaner technologies, improving energy efficiency and reducing negative environmental externalities (Popp, 2002). Hence, within a sustainability framework, R&D constitutes a strategic investment capable of compensating for natural capital depletion.

Building on Schumpeterian innovation theory, patent protection serves as a key incentive mechanism stimulating technological creativity (Schumpeter, 1934). Resident patent applications are commonly used to approximate national inventive activity (Griliches, 1990). From a sustainability standpoint, inventive activity promotes the development of green technologies, enhances resource productivity, and mitigates the environmental impacts of economic expansion.

However, the relationship between economic growth and sustainability remains conceptually ambiguous. Beckerman (1992) argues that rising national income provides the financial capacity necessary to improve environmental quality. Conversely, Dasgupta (2001) and Hamilton (2006) contend that GDP growth may conceal declines in natural capital when not accompanied by

investments in human and technological capital. In the ANS perspective, economic growth is sustainable only when driven by knowledge-based factors rather than resource-exhaustive expansion.

Recent empirical studies provide further insight into the links between knowledge-economy components and sustainable development. Han et al. (2023), using panel econometric techniques, show that R&D expenditures significantly reduce CO₂ emissions through improvements in technological efficiency. Their longitudinal analysis demonstrates that R&D intensity constitutes a robust determinant of environmental performance, particularly in developing economies. Similarly, Makeeva et al. (2024), employing firm-level microdata in the energy sector, find that patented green innovations enhance both profitability and environmental performance, underscoring the pivotal role of patent quality in energy-transition dynamics.

Ghodsi et al. (2023), analyzing global patent trends, identify sustained growth in green-technology patents, with emerging Asian regions, especially Southeast Asia, showing notable progress. Their findings build on systematic exploitation of WIPO and EPO datasets. Rouse (2020), in a patent-landscape study focusing on Vietnam, also documents a sharp rise in patent filings related to renewable energy and energy efficiency, although the domestic diffusion of these innovations remains limited. Collectively, these studies highlight that resident patents related to environmental technologies are positively associated with sustainability improvements.

At the macroeconomic level, institutional reports provide additional evidence on innovation capacity and sustainability in Southeast Asia. The KPMG (2021) report emphasizes that sustainable innovation capabilities in ASEAN countries critically depend on human capital levels and R&D incentive policies. Similarly, OECD (2014), whose findings frame the 2015-2025 development outlook, shows that the region's transition toward a knowledge-based economy requires strategic investments in education and technical training. These studies demonstrate that educational attainment plays a decisive role in innovation absorption and in transforming economic growth into durable wealth. The European Patent Office (EPO, 2022) notes steady growth in patent filings in Indonesia, Thailand, and Vietnam, largely driven by foreign investment, though domestic spillovers depend strongly on local human capital quality. WIPO (2022) further reports that the diffusion of green technologies in these countries is constrained by uneven applied-research capacity and limited university–industry integration.

Finally, the relationship between economic growth and sustainability, examined through the World Bank's ANS indicator, confirms that GDP alone is not a sufficient proxy for sustainability. These studies show that the composition of growth, particularly investments in human capital and innovation, is decisive. Data from the World Bank DataBank (2024) reveal that in several ASEAN countries, periods of high economic growth do not systematically translate into improvements in Adjusted Net Savings, owing to concurrent natural capital degradation.

2- Methodology and Data

In this section, we estimate a dynamic panel-data model using the Generalized Method of Moments (GMM) to assess the contribution of knowledge-economy variables to sustainable development in a panel of South and Southeast Asian countries over the period 1990–2024. The empirical analysis covers the following economies: Indonesia, Thailand, Bangladesh, the Philippines, Sri Lanka, and Vietnam.

2-1 Model variables

Adjusted Net Savings (ANS), the endogenous variable in our model, represents the World Bank’s sustainability indicator designed to capture changes in a country’s comprehensive wealth, including physical, human, and natural capital. The underlying premise is that long-term sustainability depends on an economy’s ability to maintain or increase its total wealth stock over time.

ANS adjusts gross national savings by subtracting physical capital depreciation, environmental degradation, and natural resource depletion, while adding investments in human capital, particularly expenditure on education. A positive ANS value indicates sustainable accumulation of total capital, whereas a negative value reflects erosion of national wealth and thus a non-sustainable development trajectory.

Human Capital (HC): Human capital encompasses the knowledge, skills, and health conditions acquired by individuals throughout their lives, enabling them to realize their potential and contribute productively to the economy. It is widely recognized as a key driver of economic development, promoting innovation, improving product and service quality, and enhancing labor productivity.

Research and Development Expenditures (R&DE): Measured as a percentage of GDP, R&D expenditures include both investment and current spending undertaken by firms, public-sector institutions, and higher-education systems. R&D is considered a critical input to innovation, technological upgrading, and long-run productivity growth.

Gross Domestic Product (GDP): GDP represents the total value of goods and services produced within a country over a given period. It also reflects the income generated by economic activity and is generally used as a standard indicator of economic growth.

Resident Patent Applications (RPA): Resident patent applications refer to filings submitted either through the Patent Cooperation Treaty (PCT) system or directly to a national patent office to obtain exclusive rights over an invention. Patents protect novel products or processes offering innovative technical solutions and generally provide protection for a period of 20 years. Resident patenting serves as a proxy for national inventive activity.

The empirical model to be estimated is specified as follows:

$$ANS_t = C + \alpha_1 GDP_t + \alpha_2 R\&DE_t + \alpha_3 RPA_t + \alpha_4 HC_t + \varepsilon_t$$

With ε_t denoting the residual term, assumed to follow a standard normal distribution.

The data are primarily sourced from the World Bank (World Bank, 2025) and the World Intellectual Property Organization (WIPO, 2025).

2-2 Stationarity Analysis of the Series

For the stationarity assessment, we employ first-generation panel unit root tests, namely the Levin, Lin and Chu test (2002), the Im, Pesaran and Shin test (2003), the Fisher–Augmented Dickey–Fuller test (1979), the Fisher–Phillips–Perron test, and the Hadri test (2000), as these procedures are well suited to unbalanced panel datasets (Hurlin & Mignon, 2005).

The stationarity tests were conducted on specifications including a constant term. The optimal lag length was selected based on the Schwarz Information Criterion.

Table 1. Results of Panel Unit Root Tests at Level

	LLC	IPS	ADF-F	PP-F	Hadri-Z stat
ANS	-0.4210 (0.3369)	-0.2123 (0.4159)	10.9121 (0.5361)	9.4038 (0.6681)	4.6102 (0.0000)
GDP	-3.4953 (0.0002)*	-3.9759 (0.0017)*	41.9660 (0.0000)*	65.7677 (0.0000)*	2.3313 (0.0099)
R&DE	0.5419 (0.7061)	1.3588 (0.9129)	0.1539 (0.9259)	0.0416 (0.9794)	6.0690 (0.0000)
RPA	3.2486 (0.9994)	1.7517 (0.9601)	22.8219 (0.0293)**	23.6290 (0.0228)**	6.8883 (0.0000)
HC	-3.5789 (0.0002)*	-0.3445 (0.3652)	9.2686 (0.6798)	8.5442 (0.7413)	7.9203 (0.0000)

() Indicates the p-value associated with the parameter.

*Denotes that the parameter is statistically significant at the 1% level.

** Indicates rejection of the null hypothesis of non-stationarity at the 5% significance level.

Source: Computed using EViews 13.

The stationarity tests indicate that only the GDP variable is stationary at level, whereas the variables ANS, R&DE, RPA, and HC exhibit unit roots.

Table 2. Results of Panel Unit Root Tests at First Difference

	LLC	IPS	ADF-F	PP-F	Hadri Z-stat
D(ANS)	-3.1584 (0.0008)*	-6.2142 (0.0000)*	58.4152 (0.0000)*	75.9089 (0.0000)*	0.0789 (0.4685)**
D(R&DE)	-1.9581 (0.0251)*	-1.9742 (0.0470)**	70.7651 (0.0255)**	70.6959 (0.0261)**	0.9429 (0.1728)**
D(RPA)	2.0864 (0.9815)	-8.5533 (0.0000)*	94.6712 (0.0000)*	142.536 (0.0000)*	4.0214 (0.0000)
D(HC)	-15.2577 (0.0000)*	-32.6490 (0.0000)*	163.606 (0.0000)*	110.527 (0.0000)*	-2.1752 (0.2852)**

() Indicates the p-value associated with the parameter.

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*Denotes that the parameter is statistically significant at the 1% level.

** Indicates rejection of the null hypothesis of non-stationarity at the 5% significance level.

Source: Computed using EViews 13.

The variables ANS, R&D, RPA, and HC are stationary at first difference. The presence of four non-stationary variables integrated of the same order suggests the existence of a cointegrating relationship among the variables.

2-3 Cointegration Analysis

To test for the presence of long-run relationships among the variables, we apply the Pedroni and Kao cointegration tests.

Table 3. Pedroni Cointegration Test

Alternative Hypothesis	Test	Statistic (p-value)	Weighted Statistic (p-value)
Common AR Coefficients (Within-Dimension)	Panel v-Statistic	-1.0590 (0.8552)	-0.0701 (0.5279)
	Panel rho-Statistic	0.7393 (0.7701)	0.7393 (0.7701)
	Panel PP-Statistic	0.4886 (0.6874)	0.4886 (0.6874)
	Panel ADF-Statistic	-0.8478 (0.1983)	-0.8478 (0.1983)
Individual AR Coefficients (Between-Dimension)	Group rho-Statistic	1.2211 (0.8890)	–
	Group PP-Statistic	0.9028 (0.8167)	–
	Group ADF-Statistic	-0.7369 (0.2306)	–

Source: Computed using EViews 13.

The Pedroni test indicates that the parameters, Panel V statistic, Panel rho, Panel PP statistic, Panel ADF statistic, Group PP statistic, Group rho statistic, and Group ADF statistic, fail to reject the null hypothesis of no cointegration among the parameters. To enhance accuracy, we also applied the Kao cointegration test.

Table 4. Kao Cointegration Test

	t-Statistic	Prob
ADF	-0.7217	0.2353
Residual variance	2.0455	
HAC Variance	1.9632	

Source: Computed using EViews 13.

The p-value associated with the ADF statistic is substantially higher than the 5% significance level, which supports the acceptance of the null hypothesis of no cointegration.

Accordingly, based on the results of the Pedroni and Kao tests, we can confirm the absence of a cointegrating relationship among the model variables. Therefore, we proceed to estimate the model parameters using the Generalized Method of Moments (GMM) for a dynamic panel framework.

2-4 Model Estimation

Table 4. The results of estimation

	GMM/Dynamic Panel
<i>GDP</i>	0.12501 [0.6626] (0.5105)
R&DE	4.6529 [-2.0116] (0.0494)**
<i>RPA</i>	0.0046 [-4.1965] (0.0001)*
HC	1.3935 [3.7848] (0.0004)*
C	9.2753 [2.7171] (0.0089)*
$R^2 = 0,58$ $J - stat = 22,000$ $P - value = 0,1920$	

() Indicates the p-value associated with the parameter.

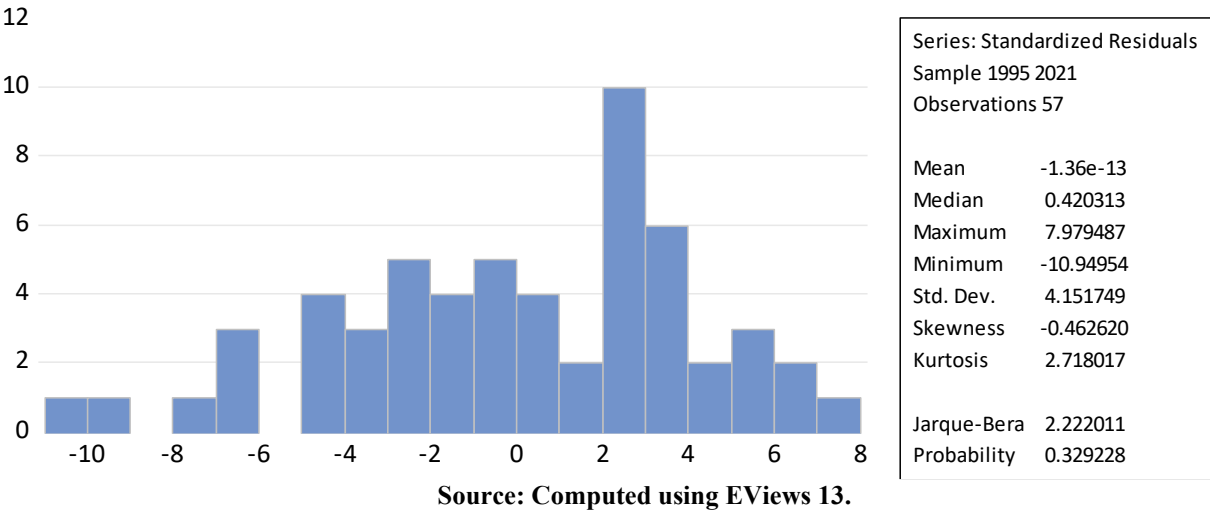
[] Indicates the t-statistic associated with each parameter.

*Denotes that the parameter is statistically significant at the 1% level.

** Indicates rejection of the null hypothesis of non-stationarity at the 5% significance level.

Source: Computed using EViews 13.

Figure 1: Normality Test of the Residuals



The p-value associated with the Jarque-Bera statistic exceeds the 5% significance level, which supports the acceptance of the null hypothesis that the residuals are normally distributed.

3-Discussion of Results

The results indicate that the variables representing the knowledge economy, namely research and development (R&D) expenditures, resident patent applications, and human capital, exert a positive and statistically significant effect on sustainable development, as measured by Adjusted Net Savings (ANS).

These findings are consistent with the majority of studies reviewed in the literature, which emphasize the contribution of intangible investments to the structural transformation of developing economies (Aghion & Howitt, 1998; Romer, 1990). They also corroborate recent empirical evidence from Asia highlighting the favorable effects of technological innovation and human capital accumulation on environmental performance and sustainable growth (Lee & Min, 2015; Chen & Chen, 2021).

The significant impact of R&D expenditures confirms the importance of innovation-oriented policies implemented in several countries within the sample. Indonesia and Thailand, for instance, have strengthened national research-support programs through fiscal incentives and public-private partnerships, particularly in the energy, agri-industrial, and digital sectors. These policy orientations are consistent with transformations observed in East Asian emerging economies, where increased R&D investment has accelerated the adoption of low-carbon technologies and improved energy efficiency (Wie, 2020). The observed empirical relationship suggests that the countries under study benefit from technological diffusion and institutional learning effects similar to those characterizing convergence trajectories in more advanced regional economies.

Resident patent applications also display a positive and significant relationship with sustainability, indicating that indigenous innovation actively contributes to the transition toward a more sustainable growth model. This result supports the findings of Crespi et al. (2020), who show that local innovation is a critical determinant of environmental performance in developing economies, particularly because

it enables the adaptation of technologies to local socio-economic and ecological conditions. In countries such as Vietnam and the Philippines, the recent emergence of technology clusters, supported by industrial development policies and targeted foreign direct investment in innovative sectors, has led to a marked increase in domestic inventive activity. The empirical results suggest that these dynamics translate into measurable improvements in adjusted natural capital indicators.

Human capital constitutes another crucial channel through which the knowledge economy positively influences sustainable development. Its significant effect aligns with the conclusions of Barro (2001) and Pelinescu (2015), who argue that workforce education and continuous skill development enhance overall productivity, facilitate the adoption of clean technologies, and strengthen innovation absorption capacity. This observation is consistent with ongoing reforms in the sampled countries. Bangladesh and Sri Lanka, for example, have implemented policies aimed at strengthening higher education, technical and vocational education and training (TVET), and digital skills. These institutional investments appear to support a gradual transition toward less resource-intensive economies increasingly oriented toward high value-added services.

By contrast, the effect of GDP is positive but statistically insignificant, suggesting that aggregate economic growth does not exert an autonomous influence on environmental sustainability. This finding aligns with empirical studies that challenge the assumption of a systematic link between growth and environmental performance, particularly in economies dominated by extractive activities or energy-intensive industries (Grossman & Krueger, 1995; Cole, 2004). In Southeast Asian countries, recent growth has largely been driven by manufacturing industrialization, rapid urbanization, and energy consumption heavily reliant on fossil fuels. These structural characteristics may offset the potential sustainability benefits of growth unless accompanied by a strategic shift toward low-carbon and knowledge-intensive sectors.

Overall, the findings underscore the relevance of public policies oriented toward the knowledge economy as a key driver of sustainable development. The gradual integration of national innovation strategies, such as *Thailand 4.0*, *Indonesia Vision 2045*, and the *Vietnam Science and Technology Strategy*, appears particularly pertinent as these countries seek to reduce their dependence on traditional industries and align with global ecological transition imperatives. The study confirms that innovation-led structural transformation, human capital accumulation, and technological upgrading constitute more effective levers for improving natural capital management and environmental resilience than GDP expansion alone.

From a policy perspective, the findings suggest that ;

The results highlight the strategic importance of strengthening the knowledge economy as a sustainability lever in Southeast Asian countries. A first policy recommendation is to intensify public and private investment in research and development. Governments should consolidate fiscal incentive schemes, promote university-industry partnerships, and reinforce national technological infrastructures. The objective is to enhance endogenous innovation capacity, which is essential for supporting growth that is less resource-intensive and more oriented toward clean technologies. Regional coordination, particularly within the Association of Southeast Asian Nations (ASEAN), could further facilitate skill-sharing and technological diffusion.

The positive dynamics associated with resident patent applications suggest the need to strengthen institutional environments conducive to innovation. It is recommended to reinforce national intellectual property systems, improve legal protection for inventions, and reduce administrative costs related to patent filing. Such a framework would not only stimulate domestic innovation but also attract greater foreign investment in high-technology sectors. More broadly, countries should implement targeted industrial policies focusing on strategic domains such as renewable energy, smart agriculture, and green digital technologies.

The pivotal role of human capital in sustaining development calls for intensified efforts in education, vocational training, and the enhancement of digital and technical skills. Public authorities are encouraged to increase investment in education systems, particularly in higher education, STEM programs (science, technology, engineering, and mathematics), and technical and vocational training pathways. In addition, active labor market policies should be implemented to promote lifelong learning within firms and institutions and to strengthen the workforce's technological absorption capacity. Better alignment between available skills and the needs of an innovation-driven economy would durably enhance total factor productivity and support the transition toward greener growth.

The absence of a significant GDP effect on sustainability highlights the need to rethink growth strategies still heavily centered on quantitative expansion. It is increasingly essential to prioritize higher-quality growth that is less dependent on polluting sectors and more aligned with environmental objectives. In this regard, the countries studied should strengthen climate policies, improve energy efficiency, diversify energy sources, and integrate environmental considerations into industrial development planning. The adoption of natural capital assessment mechanisms, such as the Adjusted Net Savings indicator used in this study, could further guide public decision-making toward more efficient resource allocation.

Finally, an integrated and multisectoral approach is required to ensure a sustainable transition. Governments should coordinate innovation, education, environmental, and industrial policies to create a coherent ecosystem capable of maximizing the positive spillovers of the knowledge economy. The findings of this study clearly demonstrate that development sustainability depends not solely on economic growth, but on countries' capacity to invest in the knowledge, technologies, and skills necessary to address contemporary environmental challenges.

Conclusion

This study provides an empirical assessment of the contribution of the knowledge economy to sustainable development in a panel of South and Southeast Asian countries over the period 1990–2024. The use of a dynamic panel-data framework estimated through the Generalized Method of Moments (GMM), which is well suited to the structure of the empirical model, allows for the correction of potential endogeneity, unobserved heterogeneity, and autocorrelation issues, thereby ensuring the robustness of the estimated coefficients.

The empirical findings indicate that human capital, R&D expenditures, and resident patent applications exert a positive and statistically significant effect on Adjusted Net Savings. These results

confirm the critical role of intangible investments in consolidating sustainable growth trajectories. They further suggest that efforts aimed at enhancing skills, expanding innovation capacity, and strengthening national research systems actively contribute to the preservation of comprehensive wealth and the mitigation of long-term negative externalities.

By contrast, GDP exhibits a positive but statistically insignificant effect on Adjusted Net Savings. This lack of significance suggests that economic growth per se, when not accompanied by productive investments in knowledge and innovation, does not necessarily translate into improved sustainability outcomes. It underscores the need to move beyond a purely quantitative interpretation of growth and to prioritize qualitative approaches centered on intangible capital accumulation and the transition toward a knowledge-based economy.

Overall, the results highlight that development sustainability in the Southeast Asian economies examined depends more on the strengthening of human and technological capabilities than on GDP expansion alone. These conclusions call on policymakers to reinforce education, research, and innovation policies, while fostering an institutional environment conducive to knowledge creation and diffusion. Such strategies appear essential for supporting durable, resilient growth grounded in the long-term preservation of both natural and human capital.

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Appendice

Dependent Variable: ENA
 Method: Panel Generalized Method of Moments
 Date: 11/09/25 Time: 14:48
 Sample (adjusted): 1995 2024
 Periods included: 28
 Cross-sections included: 5
 Total panel (unbalanced) observations: 237
 2SLS instrument weighting matrix
 Instrument specification: ENA PIB DRD DBR CH C

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PIB	0.125014	0.188672	0.662601	0.5105
DRD	-4.652998	2.312987	-2.011684	0.0494
DBR	-0.004661	0.001111	-4.196561	0.0001
CH	1.393520	0.368184	3.784843	0.0004
C	9.275395	3.413606	2.717184	0.0089
R-squared	0.582176	Mean dependent var	16.91297	
Adjusted R-squared	0.542344	S.D. dependent var	5.769526	
S.E. of regression	4.308474	Sum squared resid	965.2732	
Durbin-Watson stat	2.068489	J-statistic	22.00000	
Instrument rank	6	Prob(J-statistic)	0.192000	