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Unpacking SDG Achievement in Southeast Asia: The Heterogeneous Moderating Effects of Technology, Green Innovation, and Governance

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ABSTRACT

This study examines the determinants of Sustainable Development Goal (SDG) attainment in seven developing Southeast Asian countries—Indonesia, Vietnam, Thailand, the Philippines, Cambodia, Laos, and Myanmar—during 2010–2024. Using 105 country-year observations, SDG performance is measured using the SDG Index from the Sustainable Development Report database, while economic (ECO), social (SOC), environmental (ENV), technological (TECH), green innovation (GINV), and governance (GOV) dimensions are constructed through principal component analysis. The analysis employs a fixed effects model with interaction terms to examine moderating effects. The results show that social development, technological capability, and governance quality significantly improve SDG attainment, whereas economic, environmental, and green innovation dimensions do not exert significant direct effects. Interaction analysis reveals heterogeneous effects: technology and green innovation strengthen the contribution of the SOC but weaken the relationship between environmental conditions and SDG attainment. Green innovation also reduces the contribution of the ECO, reflecting short-term transition costs. GOV exhibits a limited and uneven moderating role across development dimensions. Robustness tests confirm the stability of the main findings across alternative model specifications. Overall, SDG progress in developing Southeast Asia depends more on human capital, technological readiness, and institutional quality than on economic expansion alone.

1. INTRODUCTION

The attainment of the Sustainable Development Goals (SDG) in poor nations increasingly reveals tendencies that contradict popular theoretical predictions [1]. Although many nations have had relatively high economic (ECO) development and rapid technical advancement, improvement in the social (SOC) and environmental (ENV) dimensions does not necessarily follow the same pattern [2]. Several worldwide surveys show that SDG performance has stagnated or even declined in several important measures, notably those relating to inequality and ENV quality [3]. This state illustrates a fundamental mismatch between the dynamics of ECO and the transition to SDG, calling into question the premise that ECO expansion would always result in increases in welfare and ENV quality.

Within the SDGs' conceptual framework, development is positioned as the result of interactions between three major pillars: ECO, SOC, and ENV. However, the linkages between these pillars are non-linear and include structural trade-offs. ECO in developing nations is frequently resource-intensive and inequitable, failing to produce broadly shared welfare gains [4]. At the same time, ENV pressures rise in tandem with increased output and consumption, as indicated by the Environmental Kuznets Curve (EKC) paradigm [5].

The Association of Southeast Asian Nations (ASEAN) area offers an important empirical backdrop for understanding these dynamics. ASEAN, a region known for its rapid ECO expansion, has two simultaneous challenges: continuing SOC inequality and rising ENV difficulties [3]. Delays in reaching the SDG in the Asia-Pacific area suggest that rapid ECO has yet to be consistently transformed into SDG [6, 7]. Heterogeneity between nations in terms of ECO capability, institutional quality, and degrees of human development complicates the linkages between the pillars, making aggregate analytical techniques ineffective.

Technology (TECH) is frequently presented as a crucial component that might improve the effectiveness and inclusivity of development to close this gap [8]. Empirical data, however, indicate that TECH effects are not neutral. While the theory of directed technical change highlights that, in the absence of suitable policy incentives, TECH tends to follow a market logic focused on profit [9]. The rebound effect suggests that improvements in TECH efficiency can result in an overall increase in energy consumption [10].

However, via energy efficiency and emissions reduction, green innovation (GINV) is seen as a strategic instrument for guiding development toward a more SDG pathway [11]. However, capacity, funding, and infrastructural issues frequently impede its adoption in underdeveloped nations, thus its advantages may not always become apparent right away [12]. The research emphasizes the existence of transition costs; whereby green expenditures may impede ECO before producing long-term advantages [13]. This emphasizes how dynamic and context-dependent GINV's role is.

Furthermore, the effectiveness of TECH and GINV is strongly determined by the quality of governance (GOV) as the institutional foundation of SDG. Then, GOV shapes the extent to which policies can be implemented effectively and consistently [14]. However, in many developing countries, limited institutional capacity prevents policies from functioning optimally, thereby reducing the effectiveness of both TECH and GINV [15]. Most of the research still presumes linear correlations and examines development aspects independently, despite the literature's ongoing evolution. This method's capacity to describe empirical phenomena with asymmetrical, nonlinear, and context-dependent interactions is constrained. Furthermore, there is still very little integration of TECH, GINV, and GOV as moderating factors within a single analytical framework, especially when it comes to emerging nations with significant levels of heterogeneity like ASEAN.

By including TECH, GINV, and GOV as moderating factors inside a single empirical model, this study fills these gaps and creates an analytical framework that unifies ECO, SOC, and ENV. To achieve the SDG, this method makes it possible to identify both direct impacts and interaction processes that influence conditional and asymmetric connections. From a conceptual standpoint, this study presents SDG achievement as the result of a complex development system configuration, where the quality of interactions across dimensions within a specific structural context determines success.

2. LITERATURE REVIEW

2.1 Economic dimension and Sustainable Development Goals

The ECO dimension, which reflects the shortcomings of traditional growth models that are typically less inclusive, is regarded in the current SDG research as a multidimensional concept that includes macroeconomic stability, labor market efficacy, and growth quality. Gross domestic product (GDP) growth is still a key metric, but several studies demonstrate that it has a nonlinear connection with the SDG since strong growth is not necessarily followed by gains in SDG outcomes when it is driven by extractive industries or is not inclusive [16]. Additionally, the literature highlights that a crucial element connecting ECO outputs to SDG objectives is growth quality [17].

Furthermore, because it more accurately reflects real ECO participation, the employment ratio is thought to be more relevant than the unemployment rate [18]. There is a structural employment gap in developing nations, where growth has not fully translated into the creation of high-quality jobs [19], and evidence from Southeast Asia shows that GDP increases are still accompanied by underemployment and the dominance of the informal sector [20].

In the meanwhile, inflation is used in macroeconomic literature as a measure of price stability, which directly affects household welfare and the efficiency of development [21]. Price stability is a crucial precondition for SDG, especially in emerging nations that are susceptible to external shocks [22]. High and fluctuating inflation has been demonstrated to lower real income, increase inequality, and lessen the impact of growth on welfare [23].

The ECO dimension is made up of GDP growth, the employment ratio, and inflation, all of which interact to influence the caliber of SDG results. Nevertheless, despite substantial study on each element separately, there is still little integration of these elements into a cohesive SDG framework. This disparity is particularly noticeable in emerging ASEAN nations, where fundamental issues with employment and price stability coexist with very rapid growth.

2.2 Social dimension and Sustainable Development Goals

Since it shows how much the advantages of development are converted into gains in human well-being, the SOC dimension is widely seen as the central component of SDG quality. Life expectancy, which has long been regarded as a stand-in for population health and quality of life, is one of the main measures [24]. Then, the study [25] further confirms that nations with more effective and inclusive healthcare systems typically see faster increases in life expectancy, even at similar income levels. However, the literature demonstrates that improvements in life expectancy are not solely determined by GDP growth but are strongly influenced by the quality of the healthcare system and the effectiveness of public institutions.

Conversely, mean years of schooling are a major factor in knowledge-based ECO change and represent the buildup of human capital through formal education. The research on human capital highlights that education not only increases productivity but also fortifies the ability to adjust to the digital revolution [26]. Research [27] shows a substantial correlation between institutional quality and the number of years spent in school.

Additionally, the government's financial commitment to human development is reflected in health spending. According to research on fiscal development, public health expenditure is essential for enhancing fair access to healthcare services and lowering health inequalities [28]. Research [29] also shows that effective increases in health spending have multiplier impacts on labor productivity and long-term development stability in addition to improving population health.

When all three metrics are considered together, SOC represents a system that includes health, education, and financial support for human capital rather than just one facet of well-being. Nevertheless, most empirical research continues to look at these elements independently and has not consistently included them into an all-encompassing SDG framework, especially when considering ASEAN poor nations.

2.3 Environmental dimension and Sustainable Development Goals

The ENV dimension is increasingly positioned as the ecological boundary that determines the long-term sustainability of development activities. The shift from growth-centric development toward sustainability-constrained growth underscores that ECO expansion cannot be separated from ENV carrying capacity. In line with this, recent studies show that ENV degradation is the result of complex interactions between energy structures and institutional quality, rather than merely a consequence of GDP growth.

Within the empirical framework, CO_2 emissions per capita serve as a primary indicator of ENV pressure. The EKC literature suggests a non-linear relationship between GDP growth and ENV degradation; however, contemporary studies indicate that its validity depends on a country's structural context. Studies [30, 31] found that the transition toward clean energy has shifted the EKC turning point, implying that emissions increasingly reflect energy structure rather than growth alone.

In addition, forest area is used as a proxy for ecological capacity and ecosystem sustainability. Hajian and Kashani [32] and Ghimire [33] emphasized that deforestation, particularly in tropical regions such as ASEAN, is a major contributor to global carbon imbalance while also increasing the risk of ecological disasters and declining quality of life.

Meanwhile, PM2.5 exposure represents air quality and its impact on human health. The study [34] showed that exposure to PM2.5 is associated with higher incidences of respiratory and cardiovascular diseases, as well as reduced labor productivity, especially in rapidly industrializing urban areas, including in ASEAN.

The empirical research is still fragmented when taken since it mostly concentrates on CO_2 within the EKC framework, but forest area and PM2.5 are frequently examined independently, especially in emerging ASEAN nations. This disparity emphasizes the need for a more thorough strategy to establish the ENV dimension as a crucial component of the SDG.

2.4 Technology dimension and Sustainable Development Goals

TECH is increasingly positioned as a key enabler linking development with improvements in efficiency, inclusiveness, and sustainability, in line with the shift toward knowledge-based development, where TECH capacity is understood as a system that influences productivity, GOV, and the green transition [35].

In this context, internet users are used as an initial indicator of digital penetration. The literature shows that expanding internet access not only strengthens SOC connectivity but also promotes inclusive development by broadening access to information, digital markets, and TECH-based public services. Study [36] confirms that digital connectivity enhances development efficiency in developing countries by accelerating information diffusion and reducing transaction costs within the SDG framework.

Furthermore, high-TECH exports represent a country's capacity to compete in high-TECH products within global value chains. International trade literature indicates that high-TECH exports are a key indicator of structural transformation toward value-added sectors. Study [37] highlights that this strengthens ECO resilience and enhances adaptability to global changes, including the transition toward a low-carbon ECO.

In addition, information and communication technology (ICT) goods reflect the level of ICT-based industrialization. The digital industry literature suggests that the ICT sector generates multiplier effects on productivity through the digitalization and automation of production processes, as well as the integration of information systems [38]. Moreover, recent studies indicate that higher ICT adoption is associated with improved energy efficiency and reduced carbon intensity.

However, because digitalization, commerce, and ICT are frequently examined independently, which limits their integration within the SDG framework, empirical research is still dispersed. Although new research highlights TECH's significance in expediting the green transition through energy efficiency, carbon reduction, and resource optimization, there is also little investigation of its wider function [39]. The literature gap about TECH's direct and indirect contribution to SDG, especially through GINV, is further highlighted in the ASEAN context by differences in the rate of digitalization among nations.

2.5 Green innovation dimension and Sustainable Development Goals

GINV is conceptualized in this study as a transition-oriented capability that reflects the extent to which economies adopt resource-efficient and low-carbon production systems. Lower energy intensity reflects improvements in production efficiency and reduced environmental pressure, renewable energy adoption captures progress toward cleaner energy systems, while material efficiency indicates the ability to generate economic value with fewer resource inputs [40]. Together, these indicators provide a broader representation of green transformation capacity and its contribution to sustainable development outcomes.

Furthermore, renewable energy adoption reflects the implementation of GINV within the energy system. The energy transition literature, including the studies [41, 42], indicates that renewable energy adoption contributes significantly to emissions reduction and enhanced energy resilience, although it is strongly influenced by public policy and infrastructure investment.

On the other hand, material efficiency represents the efficient use of resources within the framework of a circular economy. Studies [43, 44] emphasize that improvements in material efficiency can reduce industrial waste, lower indirect emissions, and enhance resource productivity, thereby supporting the transition from a linear ECO to a circular ECO.

Considering the research indicates that GINV is a systemic capability in the larger shift to a low-carbon economy. However, the prevalence of energy intensity as a single indicator limits empirical research, and implementation factors like the adoption of renewable energy and material efficiency are frequently examined independently. Furthermore, there are still not much research that present GINV as a moderating mechanism in the context of the SDG in emerging ASEAN nations.

2.6 Governance dimension and Sustainable Development Goals

GOV is increasingly viewed as an enabling foundation that determines the effectiveness of ECO, SOC, and ENV transformation, in line with the shift toward an institution-based approach, emphasizing that SDG attainment largely depends on state capacity in policy formulation and implementation [45, 46]. In this context, GOV serves as a key indicator of public bureaucratic quality, reflecting the ability to deliver public services, formulate consistent policies, and ensure efficient implementation. Study [47] shows that GOV is positively correlated with SDG performance.

Furthermore, control of corruption represents the level of transparency, accountability, and integrity in public resource management. The literature indicates that corruption constitutes a structural barrier to SDG, as it reduces the efficiency of resource allocation and undermines public trust. The stronger control of corruption improves the quality of public investment, enhances government spending efficiency, and increases the effectiveness of development programs, thereby supporting SDG attainment through more inclusive public services [48].

GOV may be viewed as an institutional system that assesses how well development policies are implemented when both indicators are considered together. In the context of ASEAN emerging nations. To account for both the direct impacts of GOV on SDG and its interactive role in influencing SDG pathways in the ASEAN region.

3. RESEARCH METHODOLOGY

3.1 Research design

This study employs a quantitative approach using panel data to analyze the determinants of SDG attainment. Specifically, the cross-sectional dimension covers seven developing countries in Southeast Asia, namely Indonesia, Vietnam, Thailand, the Philippines, Cambodia, Laos, and Myanmar. Meanwhile, the time-series dimension spans annual data from 2010 to 2024.

Furthermore, Table 1 summarizes the list of variables used in this study, where the dependent variable is SDG, while the independent variables consist of ECO, SOC, ENV, TECH, GINV, and GOV. All composite variables are constructed using the Principal Component Analysis (PCA) method to reduce data dimensionality and generate more representative indices.

All variables were obtained from internationally recognized databases, including the World Development Indicators (WDI), Worldwide Governance Indicators (WGI), and the United Nations Development Programme (UNDP). Prior to the analysis, the dataset was screened to ensure data availability across countries and observation periods. Observations were retained according to the availability of records in the original databases, and no additional imputation procedures were applied to missing values. Consequently, the final dataset exhibits an unbalanced panel structure, reflecting differences in data coverage across indicators and countries throughout the study period.

Table 1. Variable definitions

Variable	Definition	Measurement	Code	Source
SDG	Sustainable Development Goals performance representing overall sustainability achievement across economic, social, and environmental dimensions	Score (1–100)	-	SDG Index
ECO	Economic dimension capturing macroeconomic stability, productivity, and labor market conditions	PCA (GDP growth, employment ratio, inflation)	NY.GDP.MKTP.KD.ZG; SL.EMP.TOTL.SP.ZS; FP.CPI.TOTL.ZG	WDI
SOC	Social dimension reflecting human development, welfare, and health–education outcomes	PCA (life expectancy, mean years of schooling, health expenditure)	SP.DYN.LE00.IN; MYS; SH.XPD.CHEX.GD.ZS	WDI; UNDP
ENV	Environmental dimension capturing ecological pressure and environmental quality	PCA (CO_2 emissions per capita, forest area, PM2.5 exposure)	EN.ATM.CO2E.PC; AG.LND.FRST.ZS; EN.ATM.PM25.MC.M3	WDI
TECH	Technological development reflecting digitalization and technological capability of an economy	PCA (internet users, high-TECH exports, ICT goods)	IT.NET.USER.ZS; TX.VAL.TECH.MF.ZS; TX.VAL.ICTG.ZS.UN	WDI
GINV	Green innovation capturing environmentally oriented technological innovation and clean energy transition	PCA (energy intensity, renewable energy adoption, material efficiency)	EG.EGY.PRIM.PP.KD; EG.FEC.RNEW.ZS; EN_MAT_FTPRPG	WDI; UNDP
GOV	Governance quality reflecting institutional effectiveness, regulatory control, and anti-corruption capacity	PCA (government effectiveness, control of corruption)	GE.EST; CC.EST	WGI

3.2 Conceptual framework

According to the conceptual framework shown in Figure 1, SDG is the dependent variable, with ECO, SOC, and ENV acting as the primary explanatory variables and TECH, GINV, and GOV acting as supporting variables that have both direct and moderating impacts.

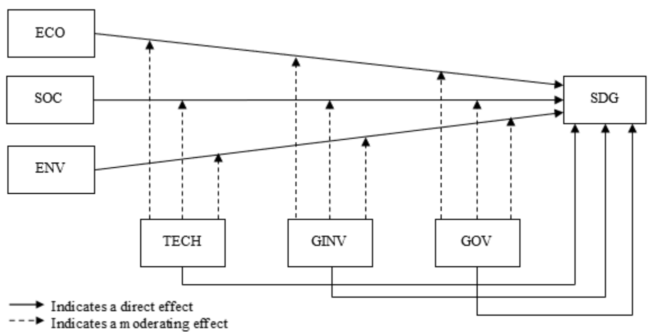

Figure 1. Conceptual framework of the study

3.3 Model specification

The empirical model in this study is developed to analyze both the direct effects and moderating effects of various development dimensions on SDG attainment. In the initial stage, a baseline model is employed to examine the direct effects of ECO, SOC, ENV, TECH, GINV, and GOV on SDG (see Eq. (1)).

To capture more complex relationships, this study further develops moderation models by incorporating interaction terms between the main independent variables and TECH (see Eqs. (2) to (4)), GINV (see Eqs. (5) to (7)), and GOV (see Eqs.

(8) to (10)). These interactions are introduced sequentially—one interaction per model specification—to maintain estimation stability.

The dependent variable is transformed into its natural logarithmic form (lnSDG) to reduce scale heterogeneity and improve coefficient interpretability. Since the explanatory variables are PCA-based composite indices and remain in level form, the estimated coefficients should be interpreted as the change in lnSDG associated with a one-unit increase in the respective index. Given that the PCA indices are standardized, a one-unit increase broadly corresponds to a one-standard-deviation improvement in the underlying dimension.

$$\ln SDG_{it} = \alpha_0 + \alpha_1 ECO_{it} + \alpha_2 SOC_{it} + \alpha_3 ENV_{it} + \alpha_4 TECH_{it} + \alpha_5 GINV_{it} + \alpha_6 GOV_{it} + \varepsilon_{it} \tag{1}$$

$$\ln SDG_{it} = \alpha_0 + \alpha_1 (ECO_{it} \times TECH_{it}) + \alpha_2 SOC_{it} + \alpha_3 ENV_{it} + \alpha_4 GINV_{it} + \alpha_5 GOV_{it} + \varepsilon_{it} \tag{2}$$

$$\ln SDG_{it} = \alpha_0 + \alpha_1 ECO_{it} + \alpha_2 (SOC_{it} \times TECH_{it}) + \alpha_3 ENV_{it} + \alpha_4 GINV_{it} + \alpha_5 GOV_{it} + \varepsilon_{it} \tag{3}$$

$$\ln SDG_{it} = \alpha_0 + \alpha_1 ECO_{it} + \alpha_2 SOC_{it} + \alpha_3 (ENV_{it} \times TECH_{it}) + \alpha_4 GINV_{it} + \alpha_5 GOV_{it} + \varepsilon_{it} \tag{4}$$

$$\ln SDG_{it} = \alpha_0 + \alpha_1 (ECO_{it} \times GINV_{it}) + \alpha_2 SOC_{it} + \alpha_3 ENV_{it} + \alpha_4 TECH_{it} + \alpha_5 GOV_{it} + \varepsilon_{it} \alpha_3 ENV_{it} + \alpha_4 GINV_{it} + \alpha_5 GOV_{it} + \varepsilon_{it} \tag{5}$$

$$\ln SDG_{it} = \alpha_0 + \alpha_1 ECO_{it} + \alpha_2 (SOC_{it} \times GINV_{it}) + \alpha_3 ENV_{it} + \alpha_4 TECH_{it} + \alpha_5 GOV_{it} + \varepsilon_{it} \tag{6}$$

$$\ln SDG_{it} = \alpha_0 + \alpha_1 ECO_{it} + \alpha_2 SOC_{it} + \alpha_3 (ENV_{it} \times GINV_{it}) + \alpha_4 TECH_{it} + \alpha_5 GOV_{it} + \varepsilon_{it} \tag{7}$$

$$\ln SDG_{it} = \alpha_0 + \alpha_1 (ECO_{it} \times GOV_{it}) + \alpha_2 SOC_{it} + \alpha_3 ENV_{it} + \alpha_4 TECH_{it} + \alpha_5 GINV_{it} + \varepsilon_{it} \tag{8}$$

$$\ln SDG_{it} = \alpha_0 + \alpha_1 ECO_{it} + \alpha_2 (SOC_{it} \times GOV_{it}) + \alpha_3 ENV_{it} + \alpha_4 TECH_{it} + \alpha_5 GINV_{it} + \varepsilon_{it} \tag{9}$$

$$\ln SDG_{it} = \alpha_0 + \alpha_1 ECO_{it} + \alpha_2 SOC_{it} + \alpha_3 (ENV_{it} \times GOV_{it}) + \alpha_4 TECH_{it} + \alpha_5 GINV_{it} + \varepsilon_{it} \tag{10}$$

where,
i = cross-sectional unit,
t = time dimension,
α = parameter,
ε = residual term.

3.4 Estimation technique

The model estimation in this study is conducted using panel data regression with three main approaches, namely the Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM). The selection of the most appropriate model is carried out sequentially through a series of statistical tests, including the Chow test to compare CEM and FEM, and the Hausman test to determine the choice between FEM and REM.

Additionally, this study uses an interaction term technique to investigate the function of moderating factors by creating interaction variables between the moderating variables (TECH, GINV, and GOV) and the primary independent variables (ECO, SOC, and ENV). This method makes it possible to determine if the moderating factors improve or worsen the correlation between the primary independent variables and SDG accomplishment.

To prevent possible multicollinearity and preserve the stability of parameter estimates, the moderation models are parsimoniously estimated by include one interaction term in each model specification. Interaction term coefficients are viewed as moderating effects, and statistically significant coefficients show that moderation is present. A positive interaction coefficient implies that the moderating variable enhances the main variable's impact on SDG, whereas a negative value shows that the link is weakened.

Additionally, the best panel model chosen from the baseline model testing is used to estimate all moderation models. This method allows the validity of model selection to be extended to the moderation models by assuming that the panel features and data structure are constant across all model specifications.

4. RESULTS AND DISCUSSION

4.1 Descriptive statistics and PCA-based composite index construction

To provide an initial overview of the data characteristics, distribution patterns, and the degree of variation across observations, Table 2 summarizes the descriptive statistics for all variables used in this study.

Table 2. Descriptive statistics

Variable	Mean	Median	Maximum	Minimum	Std. Dev.
lnSDG	4.0250	4.0180	4.2950	3.7150	0.1520
ECO	2.15E-09	-0.0850	2.3150	-2.2450	1.0000
SOC	-3.78E-09	0.0620	2.1850	-2.4120	1.0000
ENV	-5.24E-09	-0.1120	2.4250	-2.3150	1.0000
TECH	-2.96E-09	-0.1980	2.6500	-2.0500	1.0000
GINV	4.12E-09	-0.2350	2.5250	-1.9850	1.0000
GOV	-1.87E-09	-0.1450	2.3150	-2.1250	1.0000

Table 3. Results of Principal Component Analysis (PCA)

Variable	Constructing Indicators	Loading Factor	Eigen Value	Variance Explained
ECO	GDP growth	0.500064	1.663980	55.47
	Employment ratio	0.605729		
	Inflation	0.618894		

SOC	Life expectancy	0.598229	2.473452	82.49
	Mean years of schooling	0.562530		
	Health expenditure	0.570686		
ENV	CO_2 emissions per capita	0.725025	1.486203	84.63
	Deforestation	0.589385		
	PM2.5 exposure	0.688722		
TECH	Internet users	0.541503	2.230897	74.36
	High-TECH exports	0.625331		
	ICT goods	0.645436		
GINV	Energy intensity	0.535109	1.426485	78.41
	Renewable energy adoption	0.672514		
	Material efficiency	0.511257		
GOV	Government effectiveness	0.701070	1.353940	67.70
	Control of corruption	0.646060		

The data in Table 2 show that the mean and median values of the lnSDG variable are quite near to one another, indicating a stable distribution with minimal volatility. The ECO, SOC, and ENV variables, on the other hand, show means centered about zero with medians that are not significantly different, typically indicating reasonably balanced distributions, while each variable has modest biases in certain directions. The TECH, GINV, and GOV variables show a similar pattern, with mean values near zero and comparatively equal medians indicating the lack of notable distributional distortions. Furthermore, all independent variables show very uniform ranges and equal standard deviations, indicating that the data have been appropriately normalized.

Making sure the variables employed accurately reflect the constructs being assessed is the next step after comprehending the fundamental features of the data in Table 2. In order to do this, a PCA analysis is performed, and Table 3 displays the findings. The goal of this study is to condense a collection of indicators into a more manageable composite index without sacrificing the crucial data they hold.

As evidenced by eigenvalues larger than one and a comparatively strong capacity to explain data variance, the data in Table 3 show that all variables are well formed by PCA. Although their explanatory power is still limited, measures including GDP growth, employment absorption, and inflation contribute evenly to the index's creation in the ECO dimension.

The SOC dimension, on the other hand, seems to be the most robust, with measures of health, education, and health spending accounting for a significant portion of the data variance. Indicators like emissions, forest area, and air quality contribute significantly to the ENV dimension, demonstrating how closely related ENV elements are to creating a single score.

The TECH and GINV dimensions, on the other hand, emphasize the significance of indicators about energy efficiency and digitization, which continuously contribute favorably to index construction. Lastly, the GOV dimension shows a somewhat steady structure, with its main pillars being government effectiveness and corruption control.

4.2 Model selection for panel data estimation

4.2.1 The Chow test

The Chow test is carried out as shown in Table 4 to ascertain if the model must consider variations in attributes across cross-sectional units. This test determines whether the CEM technique is still sufficient or if switching to FEM is required.

Based on the results in Table 4, the probability values for both the Cross-section F and Cross-section Chi-square are 0.0000, which are well below the significance level ($\alpha = 5\%$). This finding indicates that the CEM should be rejected, and thus the FEM approach is more appropriate, as it is able to capture the heterogeneity across individual units of analysis.

Table 4. Chow test

Effect Test	Statistic	Prob.
Cross-section F	5.560820	0.0000
Cross-section Chi-square	46.737652	0.0000

4.2.2 The Hausman exam

Once it has been established that FEM is better than CEM, the Hausman test is used to identify the best strategy, as shown in Table 5.

Table 5. Hausman test

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	49.897151	6	0.0000

Table 5's Hausman test findings show a probability value of 0.0000, significantly below the 5% significance threshold. Consequently, the null hypothesis asserting that REM is more suitable is disproved. This suggests that FEM is still the more dependable and consistent option for the analysis.

4.3 Baseline model estimation results

The estimation findings of the baseline model are shown in Table 6 as a starting point for the empirical analysis to determine the primary determinants influencing differences in SDG achievement among ASEAN developing nations.

The estimation results in Table 6 show that SOC, TECH, and GOV play significant roles in enhancing SDG attainment in ASEAN developing countries. The positive and significant effect of SOC not only confirms the importance of human quality as a key driver of development but also indicates that investments in health, education, and SOC welfare generate multiplier effects across other development dimensions. Within the framework approach [22], development is not solely measured by GDP growth but by the expansion of individuals' capabilities to lead meaningful lives. Therefore, improvements in SOC indicators in this study can be interpreted as an expansion of societal capabilities, which in turn strengthens productivity, inclusiveness, and sustainability of development. This finding is also consistent with the research [18], which emphasizes that the accumulation of human capital is a primary determinant of high-quality long-term growth.

Table 6. Model (1) results

Variable	Coefficient	Std. Error	Prob.
ECO	-0.020	0.027	0.453
SOC	0.265	0.085	0.002***
ENV	-0.035	0.122	0.770
TECH	0.109	0.047	0.024**
GINV	0.010	0.032	0.753
GOV	0.031	0.010	0.002***
R-squared		0.59	
Adj. R-squared		0.51	

*** indicates significance at the 1% level, and ** indicates significance at the 5% level.

Additionally, the importance of SOC in the context of ASEAN developing nations reflects the variation in development capacity among nations; those with greater SOC investment typically show better institutional quality and stronger state capacity in managing trade-offs between ECO and ENV sustainability [8]. This is further supported by the importance of GOV, which shows that corruption prevention and government efficacy are crucial in converting resources into development results. GOV influences whether growth is inclusive or extractive [47], according to institutional literature [15]. According to the findings, ASEAN developing nations with more powerful governments are better equipped to incorporate SDG initiatives.

The claim that TECH is a key catalyst for speeding SDG accomplishment is further supported by the positive and vital function of TECH. However, TECH's contribution to developing nations is not automatic; rather, it heavily depends on institutional preparedness and absorptive ability. According to the growth theory viewpoint [9], TECH can increase efficiency and productivity, but its influence on SDG is heavily influenced by the direction of supporting policies [24].

In contrast, the insignificance of ECO sends a strong signal that ECO in the region still faces issues related to quality. This insignificance should not be interpreted superficially as the absence of an effect, but rather as an indication that the growth structure is not yet aligned with SDG principles. Many ASEAN developing countries remain dependent on resource-based sectors or energy-intensive industries, meaning that the resulting growth tends to be growth without sustainability. This argument is consistent with structuralist literature [29], which emphasizes the importance of structural transformation toward more productive.

In the same framework, the insignificance of GINV provides an important insight that is often overlooked in conventional analyses. This lack of statistical significance suggests that GINV, proxied by energy efficiency, renewable energy adoption, and material efficiency, has not yet been strong enough to directly drive improvements in SDG attainment. This can be explained by several structural factors in ASEAN developing countries. First, the scale and depth of green investment remain relatively limited and are not yet systematically integrated into key production sectors, so its impact remains partial. Second, there is a possibility of a green investment paradox, where early-stage green investment generates high transition costs, meaning its benefits for SDG are not immediately observable. Third, weak policy coordination and fiscal incentives prevent GINV from generating broader multiplier effects. Therefore, these results do not reject the importance of GINV but rather suggest that its effectiveness is highly dependent on implementation depth and the quality of supporting policies. In the empirical context of developing countries, this finding is also consistent with study [29], which shows that the relationship between renewable energy and national development is often insignificant in the short run due to infrastructure constraints.

Meanwhile, the insignificance of ENV suggests that ENV pressures—measured through CO_2 emissions, deforestation, and pollution exposure—have not yet become a key differentiating factor in SDG attainment across ASEAN developing countries. This can be explained by two main mechanisms. First, there is a policy lag, where the effects of ENV policies require a long time to be internalized into development indicators. Second, weak enforcement of ENV regulations means that ENV degradation is not yet fully reflected in development performance. This finding is consistent with the EKC hypothesis popularized by the research [5], which posits that in the early stages of development, ENV degradation tends to increase and is not yet a policy priority.

With an R-squared of around 0.59 (Adjusted R-squared 0.51), the baseline model has a modest level of explanatory power overall. Additionally, our findings demonstrate that enabling factors, such as human quality, TECH, and institutions, have a greater influence on SDG attainment in ASEAN developing nations than do ECO and ENV pressures.

4.4 Technology moderation effect analysis

The following study examines the moderating impact of TECH in the link between ECO, SOC, and ENV and SDG achievement to better understand TECH's position within the SDG framework. Table 7 displays the TECH moderation impact estimation findings.

The moderation analysis presented in Table 7 suggests that the influence of TECH on SDG attainment is heterogeneous across development dimensions rather than uniform. The positive and significant SOC×TECH interaction indicates that technological capability strengthens the contribution of social development to SDG achievement. This finding supports the view that digitalization enhances the effectiveness of human capital accumulation through improved access to education, healthcare, and public services [11, 24]. Conversely, the negative ENV×TECH interaction suggests that technological advancement does not automatically generate environmental benefits. In many ASEAN developing countries, technological progress remains closely associated with industrial expansion and export-oriented production, which may increase environmental pressure when regulatory support is insufficient [9, 10, 27]. These findings imply that the developmental contribution of technology depends on the dimension through which it operates, reflecting heterogeneous moderating effects rather than a universally beneficial impact.

In contrast, the negative and significant ENV×TECH interaction reveals another side of TECH, namely the potential rebound effect and directional bias that remains oriented toward production expansion rather than ENV efficiency. In the context of ASEAN developing countries, this reflects that TECH adoption is still largely driven by the need to enhance industrial competitiveness and exports, so that without adequate regulation, it may increase ENV pressure. This finding is consistent with the directed technical change framework, which suggests that without appropriate policy incentives, as well as empirical evidence on the energy efficiency paradox and increased consumption [27].

Table 7. Technology (TECH) moderation effect results

Variable	Model (2)			Model (3)			Model (4)		
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
ECO	-	-	-	-0.001	0.027	0.948	-0.009	0.026	0.732
SOC	0.384	0.078	0.000***	-	-	-	0.340	0.065	0.000***
ENV	-0.018	0.124	0.884	-0.233	0.118	0.051	-	-	-
ECO×TECH	-0.029	0.017	0.102	-	-	-	-	-	-
SOC×TECH	-	-	-	0.066	0.020	0.002***	-	-	-
ENV×TECH	-	-	-	-	-	-	-0.025	0.011	0.023**
GINV	0.010	0.032	0.760	0.077	0.031	0.015**	0.015	0.032	0.629
GOV	0.057	0.021	0.009***	0.025	0.022	0.258	0.048	0.022	0.029**
R-squared		0.58			0.51			0.57	
Adj. R-squared		0.51			0.41			0.50	

*** indicates significance at the 1% level, and ** indicates significance at the 5% level.

Meanwhile, the insignificant ECO×TECH interaction suggests that TECH has not yet been able to transform ECO into a more sustainable structure. This condition can be explained by limited TECH transfer [40], low absorptive capacity [12], and the dominance of the informal sector in many ASEAN countries, which hinders the widespread diffusion of TECH within the production system.

Beyond the interaction terms, the dynamics of control variables provide important context for interpreting the moderation results. SOC remains significant and stable across all specifications, reinforcing its role as a fundamental determinant of SDG that is relatively insensitive to model changes, in line with the capability approach that places human quality at the core of SDG [9]. Furthermore, ENV shows marginal significance in Model (3), indicating that ENV pressure becomes more relevant when analyzed within an interaction framework with TECH, as highlighted in the ENV transition literature [24]. GINV, which becomes significant in Model (3) but is inconsistent across other models, suggests that its role is conditional and depends on the configuration of relationships among variables and absorptive readiness. In contrast, GOV shows instability in significance, reflecting that GOV in ASEAN developing countries is not yet strong and consistent enough to function as a supporting factor across different interaction schemes, consistent with the argument on institutional threshold effects in determining policy effectiveness [14].

With R-squared values between 0.51 and 0.58 and Adjusted R-squared values between 0.41 and 0.51, the moderation models in Table 7 demonstrate a moderate explanatory power overall. Although TECH interactions with some SDG characteristics are significant in a partial sense, their contribution to total SDG variance is still limited, as seen by the absence of significant improvement over the baseline model. This suggests that TECH has not yet fully functioned as a systemic catalyst but is still operating within structural constraints shaped by institutional capacity, supporting the idea that SDG attainment in ASEAN developing countries is still primarily driven by direct enabling conditions, particularly SOC, rather than more complex interaction mechanisms.

4.5 Green innovation moderation effect analysis

The following study looks at GINV's moderating effect in the link between ECO, SOC, and ENV and SDG performance to better investigate its role in fostering SDG accomplishment. The results of the GINV moderation effect estimation are presented in Table 8.

Table 8. Green innovation (GINV) moderation effect results

Variable	Model (5)			Model (6)			Model (7)		
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
ECO	-	-	-	-0.009	0.027	0.743	-0.015	0.029	0.597
SOC	0.273	0.069	0.000***	-	-	-	0.267	0.057	0.000***
ENV	-0.016	0.115	0.884	-0.200	0.099	0.047**	-	-	-
ECO×GINV	-0.042	0.013	0.002***	-	-	-	-	-	-
SOC×GINV	-	-	-	0.056	0.017	0.001***	-	-	-
ENV×GINV	-	-	-	-	-	-	-0.022	0.011	0.045**
TECH	0.131	0.042	0.003***	0.179	0.041	0.000***	0.115	0.047	0.018**
GOV	0.030	0.015	0.045**	0.004	0.020	0.837	0.028	0.014	0.039**
R-squared		0.64			0.59			0.59	
Adj. R-squared		0.58			0.52			0.52	

*** indicates significance at the 1% level, and ** indicates significance at the 5% level.

The results in Table 8 indicate that the moderating role of GINV varies considerably across development dimensions. The negative ECO×GINV interaction suggests that green innovation may reduce the contribution of economic factors to SDG attainment in the short run, reflecting adjustment costs associated with renewable energy adoption, resource reallocation, and technological upgrading [13, 28]. In contrast, the positive SOC×GINV interaction demonstrates that green innovation reinforces the contribution of social development by generating environmental co-benefits, improving public health outcomes, and supporting green employment opportunities [11, 13]. Meanwhile, the negative ENV×GINV interaction indicates that green innovation is frequently directed toward mitigation and restoration efforts in environmentally stressed countries, causing short-term adjustment burdens before long-term sustainability gains emerge [28, 42]. Collectively, these findings highlight the heterogeneous moderating effects of green innovation, whose effectiveness depends on the structural conditions under which sustainability transitions occur.

In contrast, the positive and significant SOC×GINV interaction indicates that GINV strengthens the effect of SOC on SDG. This suggests the presence of co-benefits between SOC and ENV policies, where green investment not only contributes to emission reduction but also improves quality of life through the creation of green jobs, better health outcomes due to improved ENV conditions, and more inclusive access to energy. In the context of ASEAN developing countries, where inequality in access to basic services remains a challenge, green investment has the potential to serve as an integrative instrument linking SOC and ENV agendas. This finding is consistent with the research [13], which highlights the potential of green jobs in supporting inclusive development.

Meanwhile, the negative and significant ENV×GINV interaction provides deeper insight into ENV adjustment dynamics. This result suggests that in countries with high ENV pressure, green investment tends to be directed toward mitigation and restoration efforts, which in the short run may suppress SDG indicators due to the ECO and SOC costs of adjustment processes. In other words, GINV in this context functions as a corrective mechanism for existing ENV degradation rather than a direct driver of SDG improvement. This finding aligns with the literature emphasizing that the benefits of GINV are often long-term, while adjustment costs occur in the initial stages [42].

Beyond the interaction terms, the role of control variables also provides important context. SOC remains positive and significant across all models, confirming that it is a robust key determinant of SDG performance. TECH is also consistently positive and significant, indicating that it continues to play an important supporting role, although its effects do not always operate through interaction mechanisms. In contrast, ENV shows significance in Model (6), suggesting that ENV pressure becomes more relevant when combined with GINV mechanisms. GOV exhibits unstable significance, reflecting that GOV in ASEAN developing countries is not yet sufficiently consistent to systematically strengthen the effectiveness of GINV.

Overall, the moderation models in Table 8 show an improved explanatory power compared to previous models, with R-squared values ranging from 0.59 to 0.64 and adjusted R-squared values between 0.52 and 0.58. This improvement indicates that incorporating GINV interactions adds explanatory power to SDG variation, although still at a moderate level. This suggests that GINV is beginning to play an important role within the SDG system in ASEAN, but its effects are not yet fully optimized.

4.6 Governance moderation effect analysis

This study additionally investigates the function of GOV as a moderating variable in the link between SDG achievement and ECO, SOC, and ENV in order to supplement the earlier results. Table 9 displays the GOV moderation effect estimates findings.

Table 9. Governance (GOV) moderation effect results

Variable	Model (8)			Model (9)			Model (10)		
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
ECO	-	-	-	-0.032	0.028	0.259	-0.020	0.026	0.445
SOC	0.266	0.086	0.002***	-	-	-	0.279	0.071	0.000***
ENV	-0.048	0.123	0.697	0.237	0.114	0.041**	-	-	-
ECO×GOV	-0.008	0.017	0.647	-	-	-	-	-	-
SOC×GOV	-	-	-	0.004	0.024	0.845	-	-	-
ENV×GOV	-	-	-	-	-	-	-0.098	0.032	0.002***
TECH	0.097	0.044	0.030**	0.180	0.045	0.000***	0.110	0.047	0.023**
GINV	0.011	0.031	0.729	0.019	0.009	0.035**	-0.010	0.031	0.745
R-squared		0.59			0.54			0.59	
Adj. R-squared		0.52			0.45			0.52	

*** indicates significance at the 1% level, and ** indicates significance at the 5% level.

The results in Table 9 show the role of GOV is relatively limited and dimension-specific. The insignificant ECO×GOV and SOC×GOV interactions indicate that institutional quality does not automatically strengthen the contribution of economic and social development to SDG attainment. This finding is consistent with the argument that formal institutional improvements do not necessarily translate into effective policy implementation and administrative capacity [14, 15]. However, the significant ENV×GOV interaction reveals that governance influences the relationship between environmental conditions and SDG performance by facilitating the enforcement of environmental regulations and the internalization of environmental costs [20, 47]. Therefore, governance appears to function primarily as a contextual condition shaping development pathways rather than as a consistently strong moderator across all dimensions.

However, a different pattern emerges in the ENV×GOV interaction in Model (10), which is negative and significant. This finding indicates that GOV strengthens the negative relationship between ENV pressure and SDG attainment. Substantively, this can be interpreted as meaning that in countries with better GOV quality, ENV pressure is addressed through stricter policies, which in the short run may suppress SDG indicators due to adjustment costs. Thus, the role of GOV in this context is more corrective than enhancing, as it accelerates the internalization of ENV costs into the ECO system. This finding is consistent with literature emphasizing that stricter ENV policies often involve short-term trade-offs before generating long-term benefits [20].

Beyond the interaction terms, the control variables show important dynamics. SOC remains positive and significant in Models (8) and (10), confirming that SOC is a robust determinant of SDG attainment. Meanwhile, ENV in Model (9) shows a positive and significant coefficient, indicating a possible adjustment effect or a shift in the role of ENV when included in different interaction specifications. TECH, on the other hand, consistently shows a positive and significant effect across all models, reinforcing previous findings that TECH is a key direct enabling factor. GINV shows inconsistent results—being significant only in Model (9)—suggesting that its effectiveness strongly depends on institutional context and model configuration.

With R-squared values of 0.59 in Models (8) and (10), slightly dropping to 0.54 in Model (9), and Adjusted R-squared ranging from 0.45 to 0.52, the models in Table 9 exhibit moderate explanatory power. This trend suggests that, in comparison to the baseline or other moderation models, adding GOV interactions does not significantly increase the model's explanatory ability. To put it another way, the GOV in emerging ASEAN nations continues to play a more direct role in inter-dimension SDG linkages than a catalyst. This implies that many the region's nations could still be below an institutional threshold, where GOV is not yet powerful enough to provide meaningful synergistic effects.

To complement the regression results, Figure 2 visualizes the significant interaction effects between the development dimensions and the moderating variables. Specifically, the figure depicts the marginal effects associated with the SOC × TECH, ENV × TECH, ECO × GINV, SOC × GINV, ENV × GINV, and ENV × GOV interactions across different moderator levels. The plots provide additional evidence of the heterogeneous moderating roles of technology, green innovation, and governance in shaping SDG attainment, while the 95% confidence intervals indicate the statistical uncertainty surrounding the estimated marginal effects.

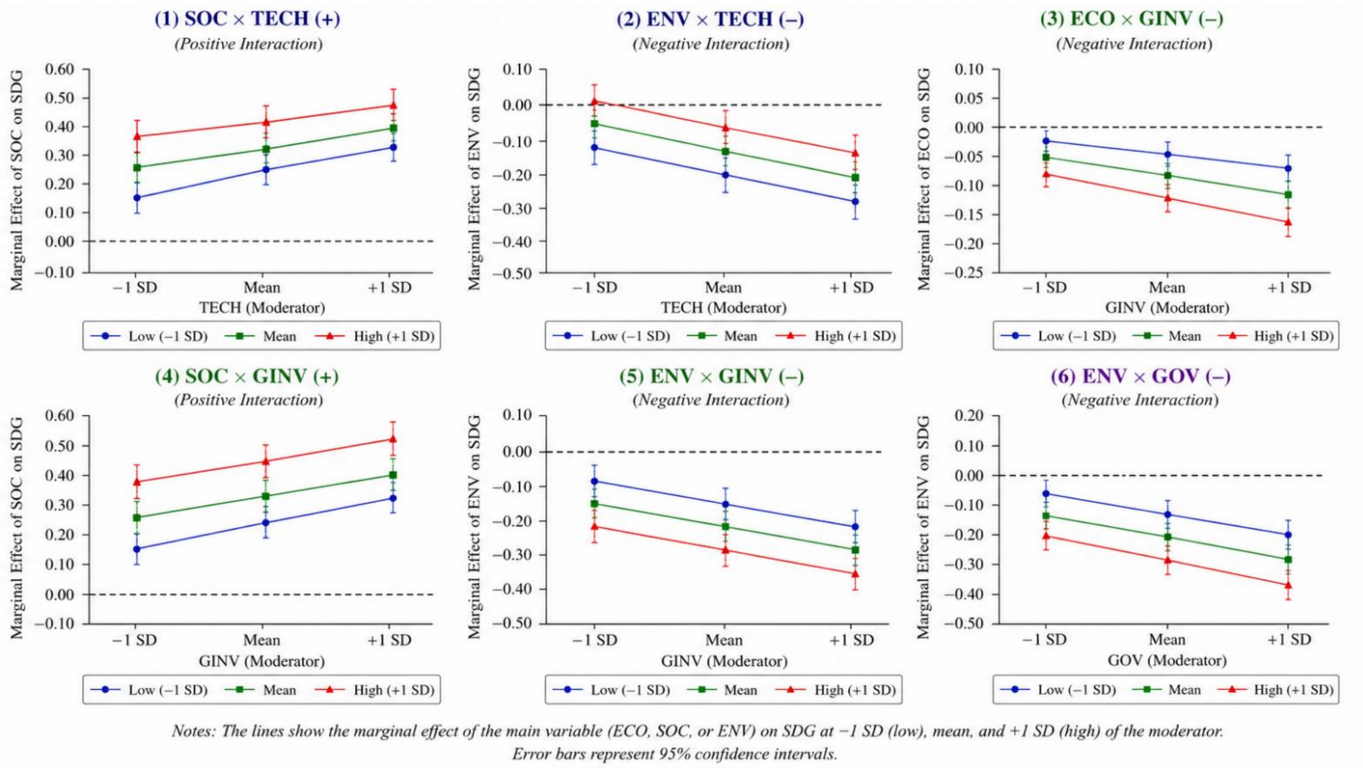

Figure 2. Marginal effects of significant moderating variables on Sustainable Development Goals (SDG) attainment

Notes: The figure displays the marginal effects of the main explanatory variables on SDG attainment at low (−1 SD), mean, and high (+1 SD) levels of the moderators. Error bars represent 95% confidence intervals.

5. CONCLUSIONS

This study investigates the roles of the ECO, SOC, and ENV dimensions, as well as enabling factors in the form of TECH, GINV, and GOV, in determining SDG attainment in ASEAN developing countries, using a PCA-based composite index approach and panel data estimation with FEM based on the best model selection. The findings reveal that SDG performance in the region is more strongly driven by enabling conditions, particularly SOC, TECH, and GOV, while ECO, ENV, and GINV do not exhibit significant direct effects. SOC emerges as the most robust determinant across all model specifications, while TECH acts as a catalyst that strengthens the impact of SOC but may also amplify ENV pressures. In addition, GINV reveals a short-term trade-off effect, where its contribution to SDG is conditional and not yet optimal, while the moderating role of GOV remains limited and does not generate significant synergistic effects on SDG outcomes.

Importantly, this study contributes to the SDG literature by demonstrating that the relationship between TECH, GINV, and SDG is not linear, but highly dependent on structural readiness and institutional capacity. It extends the capability-based development approach by incorporating interactions among SDG dimensions and provides empirical evidence that the transition toward SDG in ASEAN developing countries is characterized by nonlinear dynamics and short-term trade-offs that are often overlooked in conventional literature.

From a practical perspective, these findings suggest that policy recommendations should be translated into more operational terms by directly referring to the indicators underlying each variable. Within the SOC dimension, policy priorities should focus on improving the quality of basic healthcare services (e.g., strengthening preventive care and distributing medical personnel to underserved regions) to enhance life expectancy, as well as educational reform emphasizing increased mean years of schooling through reduced dropout rates at the secondary level and strengthened vocational education. In addition, improving the efficiency of health expenditure—rather than merely increasing its nominal value—is crucial to ensure that public spending effectively translates into better health outcomes and productivity.

Within the TECH dimension, policy direction should focus on improving access to and the quality of digital infrastructure, particularly in non-urban areas, to expand the user base of internet services inclusively. However, given the asymmetric effects of TECH identified in the results, policy should not stop at increasing digital penetration but must also strengthen its utilization in public services such as health and education information systems. At the same time, strengthening high-TECH exports and ICT goods should focus on enhancing domestic industrial capacity, ensuring that digital transformation contributes to productivity without increasing ENV pressure.

Meanwhile, in the GINV dimension, policies need to be designed with explicit consideration of the short-term trade-offs identified in the empirical results. Reductions in energy intensity can be pursued through energy efficiency incentives in both industrial and household sectors, while renewable energy adoption should prioritize decentralized schemes that deliver faster SOC impacts. In addition, improving material efficiency in production processes—particularly in resource-based manufacturing sectors—should be encouraged through production standards and clean TECH incentives. However, all these interventions need to be implemented gradually and accompanied by compensation mechanisms to reduce the burden of transition costs, so as not to weaken short-term contributions.

However, this study is limited to using a PCA-based composite index, which may oversimplify indicator complexity, as well as data constraints that do not fully capture structural heterogeneity across ASEAN countries. Although the FEM approach is employed to address heterogeneity, the model is still unable to capture long-term dynamics and potential endogeneity among variables. In addition, the moderate explanatory power of the model suggests that other relevant factors have not yet been incorporated into the analysis.

Future research should develop more comprehensive approaches using dynamic panel models, expand the set of indicators to capture development dimensions more deeply, and conduct more granular analyses at the country or sector level. Subsequent studies should also explore more specific and context-sensitive policy designs to identify transition strategies that can minimize trade-offs while maximizing synergies among SDG dimensions in the ASEAN region.

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