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DYNAMICS OF INTELLECTUAL CAPITAL TOWARDS GREEN INNOVATION STRATEGY IN INDONESIA-MALAYSIA-THAILAND GROWTH TRIANGLE (IMT-GT)

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ABSTRACT

This study investigates the degree of intellectual capital needed to lower CO2 emissions in the atmosphere and how it affects the GDP growth in Indonesia, Malaysia, and Thailand. This study uses secondary data from World Bank and Global Carbon Atlas from 1998 until 2022. The extracted data are the level of industrialization and the CO2 emission in the three countries that form an economic growth triangle involving Indonesia, Malaysia, and Thailand. The data are analysed using the Hansen threshold model to assess intellectual capital and CO2 emission. Intellectual Capital (IC) comprises of knowledge, expertise, and innovation and it plays a pivotal role in reducing negative environmental impacts. When a company or country has an effective green innovation strategy, IC can help mitigate the negative influence of GDP and the level of Industrialization on CO2 emissions. Increasing the level of intellectual capital encourages the adoption of environmentally friendly technologies and sustainable practices. Innovations emerging from IC can also lead to more efficient energy uses and reduced waste. This study is limited to the observed period from 1998 through 2022 and only focuses on Indonesia, Malaysia, and Thailand. The observed variables include Intellectual Capital (IC), CO2 emissions, GDP growth, and the level of industrialization. It is important to note that the empirical findings from this study might not be generalizable to other regions. Future research should extend the study period, incorporate more countries and break down IC into its components for a better analysis and understanding. The differences in IC threshold values in Indonesia, Malaysia, and Thailand profoundly affect these countries' capabilities to mitigate the impact of GDP growth and industrialization on CO2 emissions. This study finds that increasing the level of intellectual capital is significantly important in an effort to reduce carbon emissions in those three countries.

KEYWORDS: Green Strategy Innovation, Intellectual Capital, Level Of Industrialization.

Paper Type Research Paper
JEL Classification: O11, P12, Q11, R11

1. INTRODUCTION

Intellectual capital can provide added value to the company and differentiate it from competitors (Fauziana et al., 2022). Apart from goodwill and patents, intellectual capital includes employee competence, customer relationships, innovation, computer systems, and the ability to master technology (Ryandono et al., 2022).

Intellectual capital consists of several components. First, there is knowledge owned by individuals and documented in company systems. Second, employee expertise plays an important role in creating value. Third, relationships with customers and the ability to establish meaningful interactions. All this together forms intellectual capital. Intellectual capital is the key to competitive advantage in a world driven by innovation and creativity (Cahyono and Ardianto, 2024).

Companies that manage and utilize their knowledge and intellectual assets will be better prepared to face change and win the competition. Intellectual assets are crucial in improving company performance and competitiveness in the era of knowledge-based companies.

These assets are not physically tangible but provide valuable knowledge-based resources (Mendo et al., 2023). Intellectual capital has unique characteristics. First, this resource is "non-rivalrous," meaning it can be used by many parties simultaneously. Second, intellectual capital can produce profits that increase proportionally to the investment.

Third, the value produced continues to grow without reducing the basic elements of these resources. Intellectual assets are the key to achieving competitive advantage in globalization and intense competition. Companies that understand the importance of intellectual assets and manage them wisely will have greater opportunities to achieve better performance (Alrowwad and Abualoush, 2020).

The World Bank compiles the Human Capital Index (HCI) annual measurement. HCI identifies the nations that mobilize human capital—that is, the potential of their people on the economic and professional fronts—as the best. This index calculates the amount of capital lost in each nation due to poor health and education (Ghifara et al., 2022).

With a value range of 0 to 1, HCI in this context calculates a child's productivity based on health and education variables; a greater number denotes higher human capital. Human capital contributes more to equity and economic prosperity the better it is developed. An indicator of the overall development of human capital is the human capital index, which is a human capital development index of intellectual capital in a country (Khan and Ahmed, 2022).

Green innovation is an increasingly relevant approach to facing modern environmental challenges. In the context of manufacturing companies in Indonesia, green innovation strategies have a positive impact that can indirectly strengthen green innovation (Qosim et al., 2023). In public awareness of environmental issues, managers must prioritize green innovation strategies.

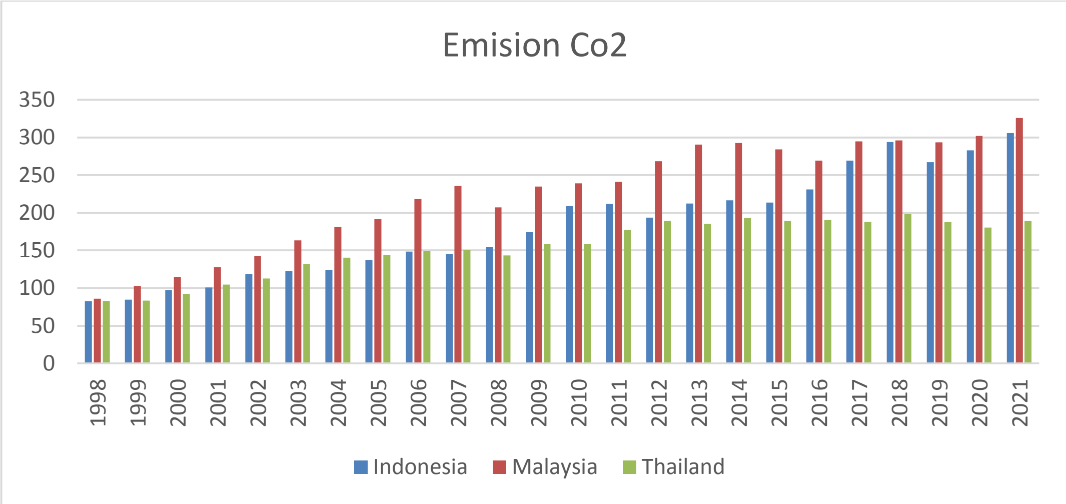
This strategy involves using environmentally friendly technology, processes, and products (Liu and Lai, 2021). However, more than just having a strategy is required. Managers must ensure that the strategy is well integrated into all aspects of the company's operations. Managers must ensure that the entire team understands the importance of green innovation (Sales, 2019).

Training and outreach regarding environmentally friendly practices can increase awareness and involvement. Thus, each team member can contribute actively to implementing the green innovation strategy. Managers need to measure green innovation performance regularly.

This involves collecting data regarding resource use, emissions, and other environmental impacts. By measuring performance, managers can identify areas that need improvement and take appropriate action (Winarsih et al., 2021).

Green innovation does not only apply internally to the company. Managers must also collaborate with suppliers and business partners. Together, they can develop innovative solutions that reduce environmental impacts, such as using more environmentally friendly raw materials or reducing waste (Febriyanti et al., 2022).

Graph 1 illustrates the steady increase in CO_2 emissions across the IMT region Indonesia, Malaysia, and Thailand from 1998 to 2021, measured in million metric tons. This upward trend reflects the region's rapid industrialization and economic growth, with Indonesia showing the highest rise, followed by Thailand and Malaysia. The data suggests that while development has accelerated, environmental pressures have intensified, highlighting the urgent need for sustainable strategies and the potential role of intellectual capital in mitigating emissions through innovation and green technology.



Graph 1: Increase In CO_2 Emissions In The IMT Region (Indonesia–Malaysia–Thailand), 1998–2021.
www.worldbank.org.

Green innovation can reduce CO2 growth so that CO2 emissions can be used as a measure of green innovation carried out by companies in a country. Graph 1 demonstrates the growth trajectory of CO2 emissions in the IMT region from 1998 through 2021. Among the three countries, Malaysia has recorded the highest CO2 emission since 1998. The lower the CO2 emissions, the higher the green innovation and the better the aggregate implementation of green strategies in a country (Wardhana and Ratnasari, 2022). Aggregate company performance can be measured using Gross Domestic Product (Pratiwi et al., 2022). GDP is the total worth of goods and services generated over a specific period by a nation's businesses and industries (Sasongko et al., 2021). GDP is a monetary indicator or market value of all products and services generated inside a nation's boundaries over a specific period. This covers all value added that arises during the creation of goods and services. GDP aids in the strategic decision-making of firms, investors, and governments (Triatmanto et al., 2023).

The level of industrialization is an important indicator in measuring industrial growth in a country. Industrialization is the process of developing and improving a country's industrial sector (Loestefani et al., 2022). This involves shifting from an economy based on agriculture or natural resources towards one based on mass manufacturing. The level of industrialization, as used in the context of industrial growth, is the degree to which a nation has embraced and advanced the industrial sector (Farooq and Ahmad, 2023). However, in developing nations like Indonesia, Malaysia, and Thailand, industrialization and gross domestic product have a beneficial effect on CO2 emissions (Soares et al., 2018).

Sustainable economic growth needs structural change from a low-productivity agricultural sector to a productive industrial sector. However, there are worries about how industrialization may affect the environment, particularly in light of climate change and carbon emissions (Liu and Lai, 2021). The ecology and human welfare may suffer from increased CO2 emissions. Countries need to take strategic steps to reduce emissions, such as reducing energy consumption and adopting environmentally friendly technology, so green innovation and green innovation strategies supported by intellectual capital are needed in developing aggregate company performance as indicated by economic growth and greater industrialization growth. Environmentally friendly so that it does not endanger environmental sustainability (Makhloufi et al., 2023).

The governments of Indonesia, Malaysia, and Thailand established Triangle Growth as a subregional cooperation program in 1993 (Nguyen, 2018). The goal is to accelerate social and economic change in provinces with lower levels of development. IMT-GT is a joint strategy to promote growth through greater regional economic integration and innovation. The focus is also on conservation and investment in IMT-GT's natural capital for the welfare of current and future generations (Viphindrartin & Bawono, 2023). Green innovation reflects a paradigm shift in business, driving the adoption of environmentally friendly technologies and practices. This is a trend and the foundation for building a sustainable future, combining economic growth with environmental protection (Iman et al., 2022).

This research examines the intellectual capital threshold required to reduce CO2 levels in the air and its impact on aggregate company performance as measured by gross domestic product. Measure the level of industrialization, we use the level of industrialization as a measure of industrial growth in each country studied, namely the three countries that form a growth triangle in the collaboration of three countries in Southeast Asia (Indonesia, Malaysia, Thailand).

2. LITERATURE REVIEW

Achieving sustainable economic growth necessitates a structural shift from a low-productivity agricultural sector to a high-productivity industrial sector in developing nations like Indonesia, Malaysia, and Thailand.

However, there are significant concerns about how industrialization may affect the environment, particularly in light of climate change and carbon emissions (Sunarmin, 2020). Long-term CO2 emissions in these countries are significantly positively impacted by GDP, energy consumption, and carbon intensity (Khusna & Kusumawardani, 2021).

In this context, the IMT-GT (Indonesia-Malaysia-Thailand Growth Triangle), established in 1993, represents a sub-regional cooperation effort to expedite social and economic change in the less-developed provinces of these countries.

The initiative responds to the imbalance in development between more developed and less-developed regions (Sales, 2019). One critical aspect of IMT-GT is the investment in natural capital. This area, rich in natural resources such as forests, fisheries, and agriculture, aims to improve the welfare of current and future generations through sustainable management. Positive impacts of IMT-GT include increased investment, economic growth, and population mobility (Firdaus et al., 2023).

However, challenges such as regulatory differences, development inequality, and climate change remain focal points of this collaboration. Future success hinges on deeper integration, innovation, and environmental protection.

Intellectual capital, defined as the value a business creates through its knowledge, expertise, and inventiveness, plays a crucial role in organizational performance and environmental impact (Obeidat et al., 2021). Companies that manage intellectual capital effectively can improve their performance, and those that invest in green technology or reduce CO2 emissions can enhance their reputation and mitigate negative environmental impacts (Huang & Rust, 2021). Intellectual capital management focused on sustainability can help companies reduce their carbon footprint and strengthen stakeholder relationships.

The level of industrialization measures the extent to which a country relies on the industrial sector in its economy. Countries undergoing industrialization typically experience higher economic growth, enabled by economic diversification, increased productivity, and job creation. The interplay between intellectual capital and industrialization is significant; companies managing intellectual capital well can enhance their performance and contribute to economic growth, while countries promoting industrialization can achieve higher economic growth goals (Kruse et al., 2023; Rahman et al., 2022; Astuti & Suryani, 2024).

An organization's intellectual capital, encompassing its knowledge, skills, and inventiveness, is pivotal within a green innovation framework. Organizations with robust intellectual capital can develop innovative solutions to reduce environmental impacts, including CO2 emissions (Ali et al., 2021).

Research and development in environmentally friendly technologies, use of renewable energy, and resource management are critical strategies for reducing the carbon footprint. Moreover, intellectual capital enables organizations to adopt sustainable business practices and integrate environmental aspects throughout their value chains (Liu & Lai, 2021).

CO2 emissions serve as an indicator of the success of green innovation strategies. Organizations that reduce CO2 emissions through innovation and sustainable practices demonstrate the effectiveness of their strategies.

Measuring CO2 emissions can gauge the positive impact of green innovation initiatives. Additionally, the impact of industrialization on CO2 emissions may be mitigated by intellectual capital, making CO2 emissions measurements a barometer for the effectiveness of green innovation initiatives (Fang, 2023).

This study explores the environmental implications of economic growth and industrialization within the Indonesia–Malaysia Thailand Growth Triangle (IMT-GT), focusing on the role of intellectual capital in mitigating carbon dioxide (CO_2) emissions.

By analyzing panel data from 1998 to 2022, the research investigates how gross domestic product (GDP) and industrialization contribute to rising emissions, while intellectual capital serves as a moderating factor that may reduce environmental impact through innovation and sustainable practices.

The conceptual model developed highlights the dynamic interplay between these variables, offering insights into how strategic investments in intellectual capital can support low-carbon development across the IMT region. Figure 1 show that conceptual model figure.

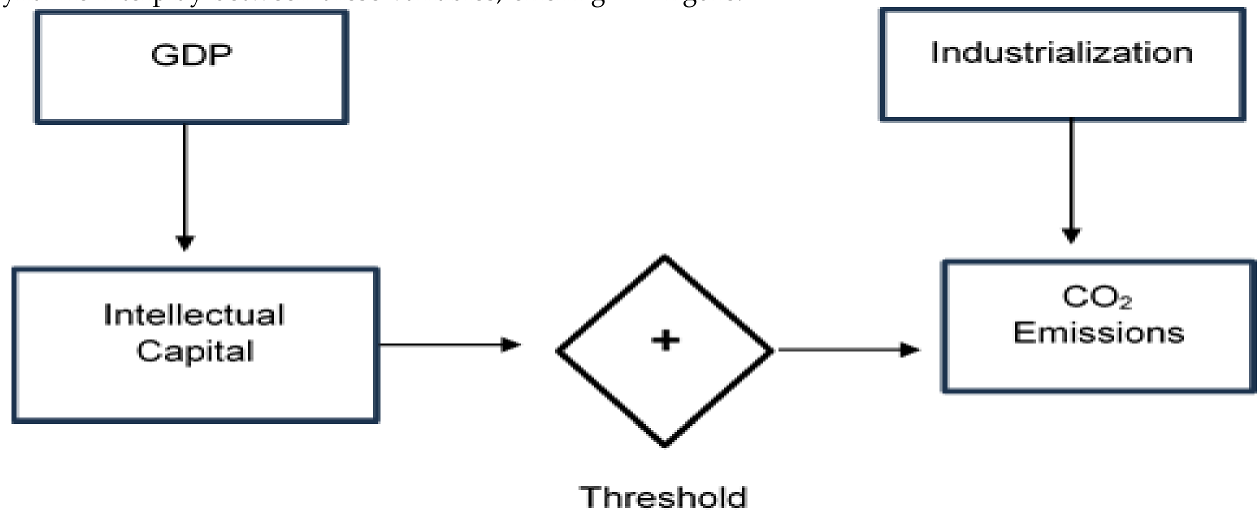


Figure 1: Conceptual Model Figure.

In the face of accelerating industrialization and economic growth, environmental sustainability has emerged as a critical global concern. One of the most pressing challenges is the rising level of carbon dioxide (CO_2) emissions, which are closely linked to gross domestic product (GDP) expansion and industrial activities. To address this issue, many countries have adopted green innovation strategies aimed at decoupling economic progress from environmental degradation. A key factor in the success of these strategies is intellectual capital, which encompasses human capital, structural capital, and relational capital. Intellectual capital plays a dynamic role in shaping how economies manage growth while minimizing ecological impact. In this context, the following hypotheses are proposed:

H1. Intellectual capital dynamically reduces the influence of gross domestic product and the level of industrialization in increasing CO2 emission levels in the atmosphere as a form indicator of the success of green innovation strategies

H2. Indonesia, Malaysia, and Thailand have different Intellectual Capital threshold values, which are indicated by the human capital index in reducing gross domestic product and the level of industrialization in increasing CO2 emissions in the atmosphere.

3. RESEARCH METHODS

This research examines the collaboration between Indonesia, Malaysia, and Thailand in the IMT-GT (Indonesia-Malaysia-Thailand Growth Triangle). By analyzing carbon dioxide emissions as the dependent variable, the study investigates the independent variables of industrialization levels and real sector performance, indicated by gross domestic product (GDP), and their environmental impact, measured using CO2 emissions. Additionally, the research emphasizes the role of intellectual capital in mitigating CO2 emissions resulting from GDP growth and industrialization levels. The study spans an annual period from 1998 to 2022 to identify trends and patterns in CO2 emissions, with relevant data carefully compiled and presented in Table 1, which describes the variables.

Table 1: Variable Description.

Variables	Description	Unit Analysis	Source
Green Innovation	Total CO_2 emissions in the atmosphere on a national scale divided by the population	$MtCO_2$ per capita	globalcarbonatlas.org
Gross domestic product	Gross domestic product growth every year	per cent	www.worldbank.org
Intellectual Capital	Human capital index by world bank	Index Scale	www.worldbank.org
Level Of Industrialization	National level of industrial activity	Percent of GDP	www.worldbank.org

3.1. Pesaran Cross-Sectional Dependence Test

To assess cross-sectional dependence in the panel data model, this study employs the Pesaran cross-sectional dependence test. This statistical method is crucial for identifying interdependence among cross-sectional units observed over time, which can arise from joint shocks, unobserved variables, or geographical effects. The test measures the average pairwise correlation coefficient of the least squares (OLS) residuals of each regression in the panel, providing insights into cross-sectional dependencies. This is essential for validating hypothesis tests and ensuring the efficiency of standard estimators. The test, also known as the CD(p) and CD test, can be used with a set order p and in situations where no specific order of cross-sectional units is assumed. Other frequently used tests include the Frees semi-parametric test and the Friedman statistic.

However, alternative models such as structural equation modeling (SEM) or multi-level modeling could provide different insights into the relationships between intellectual capital, GDP, industrialization, and CO2 emissions. The Hansen Threshold Model is particularly well-suited for this study because it allows for the identification of nonlinear relationships between Intellectual Capital (IC) and CO_2 emissions, which are likely to exhibit regime-dependent effects. Unlike linear models that assume constant marginal impacts, the threshold approach captures critical tipping points—levels of IC beyond which its influence on environmental outcomes changes significantly. This is especially relevant in the context of Indonesia, Malaysia, and Thailand, where the effectiveness of green innovation strategies may vary depending on the maturity of IC. Moreover, the Hansen model accommodates fixed effects and potential endogeneity in the threshold variable, ensuring more robust and consistent estimation in dynamic panel settings. Its ability to reveal structural shifts provides valuable insights for policymakers aiming to optimize IC investments for sustainable development. Therefore, the model enhances both the explanatory power and policy relevance of the study's findings (Hansen, 1999; Seo & Shin, 2016).

Furthermore, the study treats intellectual capital as a homogeneous entity and does not disaggregate it into its components (e.g., human capital, structural capital, relational capital). Disaggregating intellectual capital could provide more granular insights into which aspects most influence green innovation and CO2 reduction. Addressing these methodological concerns would enhance the study's rigor and provide a more comprehensive understanding of the impact of intellectual capital on environmental sustainability. The following is the Pesaran cross-sectional dependence test statistic:

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

The correlation coefficient in this study, denoted by the symbol Û, evaluates the link between data series from nations i and k. The variables N and T represent the number of nations studied and the length of the time under investigation, respectively. The null hypothesis (H0) in the Pesaran CD test is the presumption that cross-sectional dependency across nations occurs independently of outside influences.

3.2. Hansen Threshold Model

Expanding the Hansen threshold model, we employ a dynamic threshold panel data model with endogenous threshold variables. The Hansen model permits exogenous variables to have asymmetric threshold effects based on whether the threshold variable is above or below an unknown threshold.

It is suggested that the following parameters be included in a dynamic threshold panel data model with endogenous threshold variables:

yit=Xit′β+(1,Xit′)γ1⋅I(qit≤τ)+(1,Xit′)γ2⋅I(qit>τ)+εit

Explanation of Each Component:

yit: Dependent variable (e.g., CO_2 emissions)

Xit: Vector of explanatory variables (e.g., GDP, industrialization level)

β: Coefficient vector for baseline effects

qit: Threshold variable (e.g., Intellectual Capital)

τ: Estimated threshold value

γ1,γ2: Coefficients for regimes below and above the threshold

I(⋅): Indicator function that equals 1 if the condition is true, 0 otherwise

εit\varepsilon_{it}: Error term

i = 1, …, n; t = 1, …, T

y_{it} is the dependent variable. This variable may be influenced by its past values, so we can enter X as a lagged dependent variable. It is a threshold variable that defines various regimes or conditions in the model. The threshold value τ and the vector of coefficients β' determine how the independent variable influences the dependent variable. The regime coefficients γ_1 and γ_2 measure the influence of the independent variable in two different situations or regimes. The indicator function I activate is the appropriate regime coefficient based on the value of the threshold variable. The country effect μi represents the unique characteristics of each country that do not change over time, while εit is a random error that can occur in each period. To eliminate country effects that can cause bias in the estimates, we can use a first-difference transformation, which reduces the data by previous values, thus eliminating components that are constant over time. As a result, the final model measures the impact of independent factors on the dependent variable more accurately and without the distortion caused by country-fixed effects. The error term is ε.

The following is a mathematical representation of the first difference transformation:

$\Delta yit=\Delta(\beta' Xit)+\Delta(\gamma 1Iqit\leq\tau)+\Delta(\gamma 2Iqit>\tau)+\Delta\varepsilon it$

With this approach, research can more accurately assess the impact of policy or economic changes on dependent variables, such as Green Innovation, in a more dynamic and realistic context. This approach combines econometric analysis with dynamic threshold panel data models, allowing researchers to account for threshold effects and cross-dependencies between observation units.

4. RESULTS

The cross-sectional dependency (CD) test, created by Pesaran, is crucial to threshold autoregression research. It is common for panel data models to demonstrate cross-sectional dependency on the error term. This can happen because of unobserved components that eventually become a part of the fault, common shocks (common disturbances), and idiosyncratic pairwise dependence in disturbances that do not follow a specific pattern of common components or spatial dependence. Strong dependency between cross-sectoral units can develop from cross-sectional dependence caused by the economic and financial integration that has occurred over the past several decades between nations and financial organizations.

Table 2: Pesaran's CD Test.

Variables	CD test	p-value
Green Innovation	9.86	0,000
Gross domestic product	10.21	0,000
Intellectual Capital	9.82	0,000
Level Of Industrialization	8.12	0,000

Pesaran's CD test is one technique for determining if the data panel exhibits cross-sectional dependency. The cross-sectional dependency of errors in panel data models is tested in this test. Several variables, such as the strength of the cross-sector correlation and the kind of cross-sectional dependency, affect how cross-sectional dependence affects estimates. Assuming that cross-sectional dependency exists, the calculated standard errors are biased, and the traditional fixed-effects (FE) and random-effects (RE) estimators remain consistent, although inefficient, due to the presence of unobserved common factors (whose impacts are perceived through noise terms). The Pesaran CD test is displayed in Table 2.

The Cross-Sectional Dependency test, sometimes called Pesaran's CD test, determines if variables in a panel data model have a cross-sectional dependency. The variable in question, Green Innovation, has a CD test statistic of 9.86 and a corresponding p-value of 0.000. The null hypothesis of no cross-sectional dependency is rejected since the p-value is smaller than a typical significance level (like 0.05). This shows that the "Green Innovation" variable may have a cross-sectional dependency.

Table 3: Unit Root Test Panel.

Variables	CIPS test	Hadri and Rao's test
Green Innovation	1.65	0.101***
Gross domestic product	1.72	0.103***
Intellectual Capital	1.11**	0.102***
Level Of Industrialization	1.14**	0.105**

The Gross Domestic Product (GDP) has a p-value of 0.000 and a CD test statistic of 10.21. Once more, we reject the null hypothesis, which contends that GDP has a cross-sectional dependency. The p-value for intellectual capital is still 0.000, and the CD test statistic is 9.82. As in the last instance, we reject the null hypothesis, suggesting that "Intellectual Capital" depends on several sectors. The CD test statistic for the variable at the industrialization level is 8.12, with a p-value of 0.000, leading to the rejection of the null hypothesis and suggesting cross-sector dependency for the "Level of Industrialization." Evidence of cross-sector reliance is found in all four variables. The Panel Unit Root Test may be shown in Table 3. According to the Panel Unit Root Test findings, there is insufficient evidence for a unit root for any variables (Level of Industrialization and Green et al.), indicating that the data is stationary. Stationarity implies that the descriptive statistics of a variable do not change significantly over time, meaning the data does not show significant trends or continuous fluctuations. Consequently, models assuming stationarity can be used for this data. Table 4 shows the Dumitrescu-Hurlin Panel Causality Test.

Table 4: Dumitrescu-Hurlin Panel Causality Test.

Hypothesis	W-stat	Zbar-stat	Conclusion
Gross Domestic Product →Green Innovation	1.72	1.54	Gross Domestic Product ←→Green Innovation
Green Innovation →Gross domestic product	1.31	1.78	
Green Innovation Level of Industrialization	1.67	1.32	Green Innovation ←→Level of industrialization
Level Of Industrialization: →Green Innovation	1.56	1.34	
Green Innovation →Intellectual Capital	1.66	1.42	Green Innovation ←→Intellectual Capital
Intellectual Capital →Green Innovation	1.72	1.47	
Intellectual Capital Level of Industrialization	1.31	1.21	Intellectual Capital Level of Industrialization
Level Of Industrialization →Intellectual Capital	1.44	1.12	
Intellectual Capital →Gross domestic product	1.77	1.34	Intellectual Capital ←→Gross domestic product
Gross Domestic Product →Intellectual Capital	1.69	1.46	

The Dumitrescu-Hurlin Panel Causality Test results indicate a correlation between Green Innovation, GDP, Industrialization Level, and Intellectual Capital. Green innovation influences the degree of industrialization, and GDP is directly impacted by it. A causal connection between GDP and Intellectual Capital exists, suggesting that increasing Intellectual Capital can contribute to economic growth (GDP). The level of industrialization influences Green Innovation, demonstrating that the four variables have a causal relationship that influences each other. The Dynamic Threshold Panel Data Model estimation is illustrated in Table 5. Model 1 shows a connection between intellectual capital and green innovation. At the *** level of significance, the threshold value of the intellectual capital coefficient is -0.322. Additionally, the variables gross domestic product (GDP) (0.133, significant at the *** level) and green innovation (0.125, significant at the ** level) both positively relate to green innovation. The degree of industrialization, with a coefficient of 0.182 (significant at the *** level), and intellectual capital, with a coefficient of -0.198 (significant at the *** level), are two additional contributing factors. The model constant's value of 0.113 is noteworthy at the *** level, and the Wald test yields a significant result with a statistic of 42.23 (significant at the *** level).

Model 2 has an adjusted coefficient similar to Model 1, with a threshold value of -0.333 (significant at the *** level) and a Wald test statistic of 62.26 (significant at the *** level). Model 3 shows further customization with a threshold value of -0.272 (significant at the ** level) and a Wald test statistic of 61.12 (significant at the *** level). Lastly, Model 4 has additional customization with a threshold value of -0.223 (significant at the ** level) and a Wald test statistic of 62.11 (significant at the *** level). The coefficients AR (1) and AR (2) are insignificant in all models. However, the SupWald statistic shows significant results in all models, ranging from 18.32 to 19.01, significant at the *** level.

Table 5: Dynamic Threshold Panel Data Model Estimation.

	IMT-GT	Indonesia	Malaysia	Thailand
	Model 1	Model 2	Model 3	Model 4
Dependent variable	Green Innovation	Green Innovation	Green Innovation	Green Innovation
Variable Thresholds	Intellectual Capital	Intellectual Capital	Intellectual Capital	Intellectual Capital
Threshold Estimate	-0.322***	-0.333***	-0.272**	-0.223**
Green Innovation	0.125**	0.122***	0.131**	0.126**
Gross domestic product	0.133***	0.121**	0.122**	0.129**
Intellectual Capital	-0.198***	-0.271***	-0.132***	-0.122***
Level Of Industrialization	0.182***	0.141***	0.177**	0.188**
Constant	0.113***	0.091***	0.095***	0.089***
Wald test	42.23***	62.26***	61.12***	62.11***
Sargan teat	21.01	19.22	9.42	9.61
AR(1)	-1,008***	-1,004**	-1,009**	-1,001**
AR(2)	-0.812	-0.883	-0.871	-0.811
SupWald Statistics	18.32***	17.01**	19.01***	18.09***

These findings underscore the connections between green innovation, GDP, industrialization level, and intellectual capital in IMT-GT nations. Further analysis and policy implications can be drawn from these findings. Based on the estimation results, Hypothesis 1 is confirmed: Intellectual Capital dynamically reduces the influence of GDP and the level of industrialization in increasing CO2 emission levels in the atmosphere, serving as an indicator of the success of green innovation strategies. Hypothesis 2 is also confirmed: Indonesia, Malaysia, and Thailand have different threshold values for Intellectual Capital, as indicated by the human capital index, in reducing GDP and the level of industrialization in increasing CO2 emissions in the atmosphere.

5. DISCUSSION

In the context of sustainable development across ASEAN, intellectual capital (IC) has emerged as a strategic asset capable of reconciling the demands of economic growth with the imperatives of environmental preservation. Countries such as Indonesia, Malaysia, and Thailand face complex challenges as they navigate rapid industrialization, where rising gross domestic product (GDP) and expanding industrial sectors often coincide with increased carbon dioxide (CO_2) emissions. Therefore, the discussion surrounding IC must be deepened by explicitly linking it to prior studies that have examined its role in green innovation and environmental sustainability within the region.

Ali, Rahman, and Ismail (2021) emphasize that intellectual capital plays a central role in driving green innovation strategies. The knowledge, skills, and competencies embedded within individuals and organizations can be mobilized to develop environmentally friendly technologies and processes. In the ASEAN context, this insight is particularly relevant as member countries strive to meet global climate commitments while maintaining economic competitiveness. Green innovation strategies rooted in IC enable the creation of energy-efficient systems, improved waste management practices, and renewable energy solutions that help mitigate environmental degradation.

Asiaei et al. (2022) reinforce this perspective by demonstrating that green intellectual capital, when integrated with environmental management accounting, can significantly enhance organizational environmental performance. Their study highlights the importance of orchestrating natural resources through knowledge-based approaches to achieve efficiency and effectiveness in environmental management. This orchestration is especially critical in ASEAN, where resource constraints and vulnerability to climate change necessitate innovative and sustainable solutions. By strategically leveraging IC, organizations and governments can develop context-specific responses to environmental challenges.

Chen (2008) further supports the argument by showing that green intellectual capital contributes not only to sustainability but also to competitive advantage. In a global market increasingly driven by transparency and environmental accountability, firms that integrate IC into their core strategies are better positioned to thrive. This is particularly relevant for ASEAN economies seeking to strengthen their global economic standing while adhering to sustainable development goals. Intellectual capital, in this sense, becomes a dual-purpose asset—enhancing both environmental outcomes and economic resilience.

From a theoretical standpoint, Bontis (1998) and Bayraktaroglu et al. (2019) have developed foundational models for measuring IC and linking it to organizational performance. Their work identifies three key components of IC: human capital, structural capital, and relational capital. These components interact to create economic and social value. In ASEAN, where small and medium enterprises (SMEs) dominate the economic landscape, understanding how IC influences performance and sustainability is crucial. Utami et al. (2020) demonstrate that IC also contributes to financial performance in the banking sector, particularly through green product innovation, which aligns with broader environmental objectives.

Khusna and Kusumawardani (2021) highlight that economic growth in ASEAN is often accompanied by rising carbon emissions. This finding underscores the urgency of developing growth strategies that are not only economically viable but also environmentally responsible. Intellectual capital offers a pathway to shift development paradigms from extractive models to knowledge-driven, sustainable frameworks. In this regard, IC functions as a catalyst for structural transformation that prioritizes long-term ecological balance.

Firdaus, Putri, and Wulandari (2023), in their study of the Indonesia-Malaysia-Thailand Growth Triangle (IMT-GT), emphasize that the success of regional cooperation in promoting sustainable development depends heavily on the quality of human resources and institutional capacity. Intellectual capital forms the foundation for building institutional and social capacity that supports the implementation of green policies. This suggests that IC is not only relevant at the organizational level but also at the regional and national levels, serving as a determinant of successful sustainable development strategies.

Methodologically, Hansen (1999) and Seo and Shin (2016) offer a threshold panel model approach that allows for the identification of nonlinear effects of IC on CO_2 emissions. Their models reveal that the impact of IC on sustainability is not uniform but depends on reaching certain maturity thresholds. In ASEAN, where disparities in IC development exist among countries, this approach is particularly useful for designing targeted policy interventions. Nations with lower human capital indices may require foundational investments in education and training, while those with more advanced IC can focus on scaling green innovations and embedding sustainability into strategic planning.

Alrowwad and Abualoush (2020) contribute to this discourse by illustrating that IC serves as a mediating variable between transformational leadership and organizational performance. In the ASEAN context, this implies that the development of IC must be supported by visionary and inclusive leadership styles that foster innovation and cultural shifts toward sustainability. Leadership, therefore, becomes a critical enabler of IC's potential to drive environmental transformation.

Cahyono and Ardianto (2024) add a localized perspective by examining the relationship between IC, political connections, and firm performance in Indonesia. Their findings suggest that IC can strengthen a firm's position in navigating political and economic dynamics while enhancing its contribution to sustainable development. This indicates that IC possesses strategic dimensions that extend beyond internal organizational capabilities to include external socio-political interactions.

The systemic nature of IC is further illuminated by Bertalanffy's (1968) General System Theory and Burns and Stalker's (1961) work on innovation management. These theoretical frameworks position IC as an integral part of complex organizational systems that evolve through dynamic interactions. IC does not operate in isolation but interacts with various elements of the system to generate innovation and sustainability. In ASEAN, where environmental challenges are multifaceted and interconnected, a systemic approach to IC development is essential for crafting holistic and adaptive policies.

By integrating insights from these prior studies, the discussion affirms that intellectual capital is a strategic resource for achieving sustainable development in ASEAN. IC is not merely an internal organizational asset but a policy instrument and developmental tool that can redirect industrialization toward greener and more inclusive pathways. Therefore, the cultivation and strategic deployment of IC should be prioritized in national and regional development agendas, supported by policies that promote education, research, and cross-sector collaboration.

6. CONCLUSION

Intellectual Capital (IC) includes elements such as knowledge, expertise, and innovation owned by an entity. Within the framework of a green innovation plan, Intellectual Capital is the key to reducing negative environmental impacts. When a company or country has an effective green innovation strategy, Intellectual Capital can help reduce the negative influence of GDP and the level of Industrialization on CO2 emissions. The dynamic nature of intellectual capital contributes to the reduction of CO2 emissions.

Increasing intellectual capital can promote adopting sustainable practices and eco-friendly technologies in Indonesia, Malaysia, and Thailand. In addition, innovations emerging from Intellectual Capital can lead to more efficient energy use and reduced waste. Indonesia, Malaysia, and Thailand: These three countries have differences in Intellectual Capital threshold values. The human capital index, which reflects Intellectual Capital, can differentiate the quality of human resources in each country in Indonesia, Malaysia, and Thailand. Thus, the difference in intellectual capital thresholds influences the ability of Indonesia, Malaysia, and Thailand to reduce the impact of GDP and Industrialization on CO2 emissions.

The success of a green innovation strategy can be measured by looking at the reduction in CO2 emissions relative to economic growth. If countries succeed in reducing CO2 emissions despite increasing GDP and Industrialization. This demonstrates the value of IC and the efficacy of green innovation initiatives. These results suggest that investing in creating IC and green innovation initiatives is crucial. To reach targets for sustainable CO2 emission reduction, Indonesia, Malaysia, and Thailand must improve research, education, and public-private sector cooperation. Additionally, comparisons between countries can provide insight into more effective policies in addressing climate change.

6.1. Policy Advice

Indonesia, Malaysia, and Thailand need to increase their investment in education and research to strengthen their intellectual capital (IC). Quality education and research focused on green innovation will help reduce CO2 emissions. Collaboration between the public and private sectors is very important. Indonesia, Malaysia, and Thailand must encourage collaboration in developing green innovation strategies and reducing the negative impacts of industrialization. The government can provide incentives for companies to adopt environmentally friendly technologies. This will encourage more efficient energy use and reduce waste. Indonesia, Malaysia, and Thailand can measure the success of green innovation strategies by considering the reduction in CO2 emissions relative to economic growth. Company performance can also be assessed based on environmental impact. Companies must invest in human capital development and innovation. Skilled and knowledgeable employees will strengthen the company's capacity to reduce CO_2 emissions. All these suggestions aim to achieve sustainable reductions in CO_2 emissions and support balanced economic growth.

6.2. Suggestions For Further Research

This research can deepen the comparative analysis between Indonesia, Malaysia, and Thailand regarding Intellectual Capital (IC), green innovation strategies, and their impact on CO_2 emissions. Focus on the differences in IC threshold values in the three countries and how this affects firm performance and economic growth. Further research could examine the influence of green innovation strategies on specific industrial sectors, like how IC impacts the energy, manufacturing, or transportation sectors in reducing CO_2 emissions.

6.3. Research Limitations/Implications

This study is limited to the period from 1998 to 2022 and focuses specifically on three Southeast Asian countries: Indonesia, Malaysia, and Thailand. The observed variables include Intellectual Capital (IC), CO_2 emissions, GDP, and the level of industrialization. The dynamic threshold panel data method was employed to understand the relationships between these variables. While this methodology provides valuable insights, it also comes with certain limitations. The time frame of the study may not capture long-term trends or the impacts of very recent policies and technological advancements. Focusing only on Indonesia, Malaysia, and Thailand means the findings may not be generalizable to other regions with different economic structures or environmental policies. Additionally, treating Intellectual Capital as a homogeneous variable without breaking it down into its components (human capital, structural capital, relational capital) may obscure specific pathways through which intellectual capital influences CO_2 emissions. Future research could address these limitations by extending the study period, including a more diverse range of countries, and disaggregating Intellectual Capital into its key components to provide a more nuanced understanding. Sensitivity analyses could also be performed to test the robustness of the findings under different model specifications and assumptions.

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