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The Nexus between R&D, Financial Development and Sustainable Development

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ABSTRACT

The present study examines the connection among financial development, research and development expenditure and carbon dioxide emissions across seven Asian nations namely Japan, Korea, Singapore, Indonesia, Malaysia, Thailand and Vietnam. The author examined the years 1996–2021 using information from Global Financial Development and the World Bank Development Indicator. The author's research shows that R&D spending and financial development lower CO2 emissions in both developed and developing nations. Each country has a variety of estimation results. Furthermore, policies relating to sustainable development are discussed.

Keywords: *Financial Development, Sustainable Development, Sustainability, R&D, Seven Asian Nations*

1. INTRODUCTION

The correlation between R&D, financial innovation and economic growth especially sustainable development, has been a topic of interest for economists and policymakers alike. The importance of these factors in driving economic progress is well recognized. This relationship is crucial for understanding how economies can achieve long-term growth while maintaining environmental and social sustainability.

Financial development signifies the improvement in the financial institutions, markets and instruments that facilitate the efficient allocation of resources. It includes the expansion of banking services, stock markets, and other financial intermediaries. Financial development is essential for mobilizing savings, facilitating investments and promoting economic growth. It provides the necessary capital for businesses to invest in innovative projects and technologies which can lead to increased productivity and growth. Financial development can enhance the effectiveness of R&D investments by providing better access to capital and reducing financial constraints. This, in turn can lead to higher levels of innovation and productivity growth.

R&D expenditure is a critical driver of innovation and technological advancement. Investments in R&D lead to the development of new products, processes and services that can enhance productivity and economic growth. R&D activities are often associated with high levels of uncertainty and risk which makes access to financial resources crucial. Financial development can support R&D by providing the necessary funding and reducing the cost of capital for innovative projects.

Research by [1] found that R&D expenditure has been shown to have a positive impact on economic growth, mainly in high-income and upper-middle-income countries. The development of green technologies through R&D can also help mitigate environmental impacts and promote sustainable growth.

Understanding the correlation between financial development, R&D expenditure and sustainable economic growth is crucial for policymakers seeking to promote sustainable economic growth. By promoting financial development and supporting R&D investments, countries can achieve sustainable growth that benefits both current and future generations.

In the context of OECD countries, the study by [2] provides valuable insights into these relationships. Their research which spans the period from 2001 to 2016, reveals a unidirectional causality from economic growth to financial development. Interestingly, they found no evidence of causality from financial development to economic growth, between innovation and economic growth or between financial development and innovation. This neutrality hypothesis suggests that the relationships among these variables are complex and potentially influenced by country-specific characteristics. These findings underscore the need for further research to understand the nuanced dynamics among innovation, financial development and economic growth. In particular, the role of government in fostering innovation through legal frameworks and the impact of financial system regulation on economic development warrant further exploration. Moreover, the country-specific nature of these relationships suggests that a one-size-fits-all approach may not be effective, highlighting the need for tailored strategies that take into account the unique circumstances of each country.

This research aims to adjuncts on the work of [2] and [3] by delving deeper into these relationships, with a particular focus on the role of government policy. By doing so, it hopes to contribute to the body of knowledge in this field and provide actionable insights for policymakers towards sustainable development.

2. LITERATURE REVIEW

The intricate interplay between research and development (R&D) financial development, and economic growth has been the subject of extensive scholarly investigation. Recent studies on the origins of economic growth have underscored the pivotal role of innovation. A significant part of the growth observed in developed economies, such as those in the OECD, can be attributed to their innovative processes and the scale of their innovations. Tracing back to the influential work of [4], the literature by [5]–[8] has consistently highlighted that innovation and technological advancements have become a primary catalyst for economic growth. Innovation is seen as a crucial driver of economic growth with innovative activities forming the backbone of economic productivity and expansion.

The EKC concept was first proposed by the [9] and later developed by [10] describing an inverted U-shaped relationship between environmental degradation and economic growth. [10] argued that countries with lower income levels can draw lessons from the historical pattern illustrated by this curve and work to avoid repeating similar errors [10]. Furthermore, the quadratic link between pollution levels and income implies that environmental conditions may improve even without intervention. In general, numerous researchers have employed a variety of indicators [11], [12], various kinds of approaches [13]–[16], alo various explanatory factors [17]–[20] to asses air pollution levels.

[8] found that Technological advancements and all elements that promote the creation of new knowledge form the foundation of economic development [10]. [21] found that growth is exhibited through the spread of innovation in economic activities, facilitating a dynamic accumulation process of physical, human and technical capital. [22] stated that the process aids in enhancing labor productivity and total factor productivity (TFP), thereby propelling economic growth.

The study by [2] examines the causal links among innovation, financial sector development, and economic expansion. Using a panel vector autoregression (VAR) model, the researchers analyzed data from 27 Organisation for Economic Co-operation and Development member countries covering the years 2001–2016. The results indicate a one-way causal effect running from economic growth toward financial development. In addition, the findings support the neutrality hypothesis suggesting no direct causal influence from financial development to economic growth, nor between innovation and growth and likewise between financial development and innovation. The authors conclude by highlighting the importance of stronger financial system regulation and improved funding quality as key drivers of sustainable economic progress. Their work offers a useful framework for understanding the intricate interplay between innovation, finance and growth. Building on this perspective, the notion of digital inclusive finance becomes relevant, particularly in relation to R&D investment and green technological advancement. Digital inclusive finance involves leveraging digital technologies to provide financial services to individuals and enterprises, especially those excluded from conventional banking systems. This approach can stimulate economic development by encouraging innovation and expanding access to funding for R&D initiatives.

In the context of environmentally friendly technological advancement, digital financial inclusion can serve a crucial function. A study by [23] demonstrates that green innovation is a key driver of high-quality economic growth. The researchers applied a threshold regression model alongside a panel fixed-effects approach utilizing provincial panel data from China spanning 2011 to 2020.Their results indicate a positive and direct relationship between digital financial inclusion and regional green technology innovation. The study also reveals that the effects vary depending on geographic location and the intensity of digital finance usage, highlighting the importance of targeted policy support. Government involvement is essential to enhance these aspects, particularly by improving information and communication infrastructure in less-developed regions. Additionally, enhance investment in R&D plays an indirect role in strengthening regional green innovation as it is influenced by the expansion of digital financial inclusion. Notably, the analysis identifies a threshold effect where the impact becomes more pronounced once digital financial inclusion surpasses a certain level. Therefore, encouraging the adoption of digital financial services is important for narrowing regional disparities in green technology innovation. In conclusion, digital inclusive finance can be a powerful tool for promoting R&D investment and fostering green technology innovation. However, the effectiveness of digital inclusive finance can vary depending on a variety of factors, including the level of financial development, the degree of innovation, and the specific characteristics of each country or region. Therefore, further research is needed to fully understand the potential of digital inclusive finance and to develop strategies for maximizing its benefits.

The research conducted by [24] examines the relationship between firms' R&D expenditures, their financing structure, and innovation outcomes. Using evidence from firms operating in the UK and EU, the study suggests that an anticipated rise in R&D investment in the subsequent year is associated with a decline in financial leverage during the current period. The authors further suggest that this negative relationship is strengthened or weakened depending on how effectively firms are able to produce innovations from their R&D activities that are both technically workable and commercially profitable. Based on existing theoretical frameworks, they propose an inverse relationship between anticipated changes in R&D spending for the next period and current changes in financial leverage. They further explain that successful R&D outcomes lower the perceived risk of such investments, both for company managers and for external lenders providing debt financing. Although there is typically an inverse relationship between R&D spending and current financial leverage, the authors argue that this link can be positively influenced by a firm's success in innovation activities. Specifically, when firms are highly effective in producing innovations that are both commercially practical and technically achievable, the negative effect of R&D investment on leverage becomes weaker. Put differently, strong innovation performance helps reduce the perceived risk associated with R&D expenditure.

The study adds to existing research by showing that the success of R&D outcomes affects how companies choose to finance future R&D activities. It further highlights that financial reporting and accounting disclosures can significantly support the functioning of open innovation systems by improving transparency and information flow.

Numerous studies lend credence to [25] proposition that banks foster innovative endeavors the studies include [6], [26]–[35]. These authors argue that banks stimulate technological innovation by channeling resources towards entrepreneurs who present the most favorable new chances such as novel products and production techniques. This implies that by modifying the process of resource allocation, a country's financial sector can positively impact innovation-related activities. They do this by offering crucial financial services, like information acquisition and risk management, which decrease transaction costs, mitigate risk, and consequently, promote investment in innovative entrepreneurial activities in the long term as [28] research.

The empirical findings presented by [3] indicate the existence of a stable long-term relationship among the variables under investigation. In particular, the EKC hypothesis is confirmed for the United Kingdom, suggesting that at early stages of development, economic expansion tends to deteriorate environmental conditions, but after reaching a certain income threshold, further growth is associated with environmental improvement. However, the period following the global financial crisis provides weaker evidence supporting this pattern. This suggests that the expected turning point of the EKC may not be as evident in recent years. Consequently, the study emphasizes that in the current economic context, environmental impacts of growth must be placed at the forefront of policy considerations in order to ensure long-term ecological sustainability. Based on the theoretical and empirical discussions, construct a general framework for carbon emissions by incorporating economic growth, financial development, energy use, and research and development spending as key drivers of environmental quality. The study relies on long historical data for the United Kingdom covering the period 1870–2017.

Using a bootstrapped bounds-testing method to assess both short-run and long-run dynamics, the results confirm the presence of a long-term equilibrium relationship between CO_2 emissions and their explanatory variables. The findings indicate that financial development and energy consumption contribute to higher emissions, thereby worsening environmental conditions, whereas R&D expenditure plays a mitigating role by helping to lower CO_2 output. The analysis also supports the EKC hypothesis in relation to economic growth, implying that emissions initially rise with income but decline after a certain development threshold is reached. In addition, a U-shaped relationship is identified between financial development and CO_2 emissions, while the association between R&D investment and emissions follows a pattern similar to the EKC framework. Overall, the study suggests that, in addressing climate change challenges, both financial sector development and investment in R&D should be considered important policy instruments for achieving emissions reduction targets.

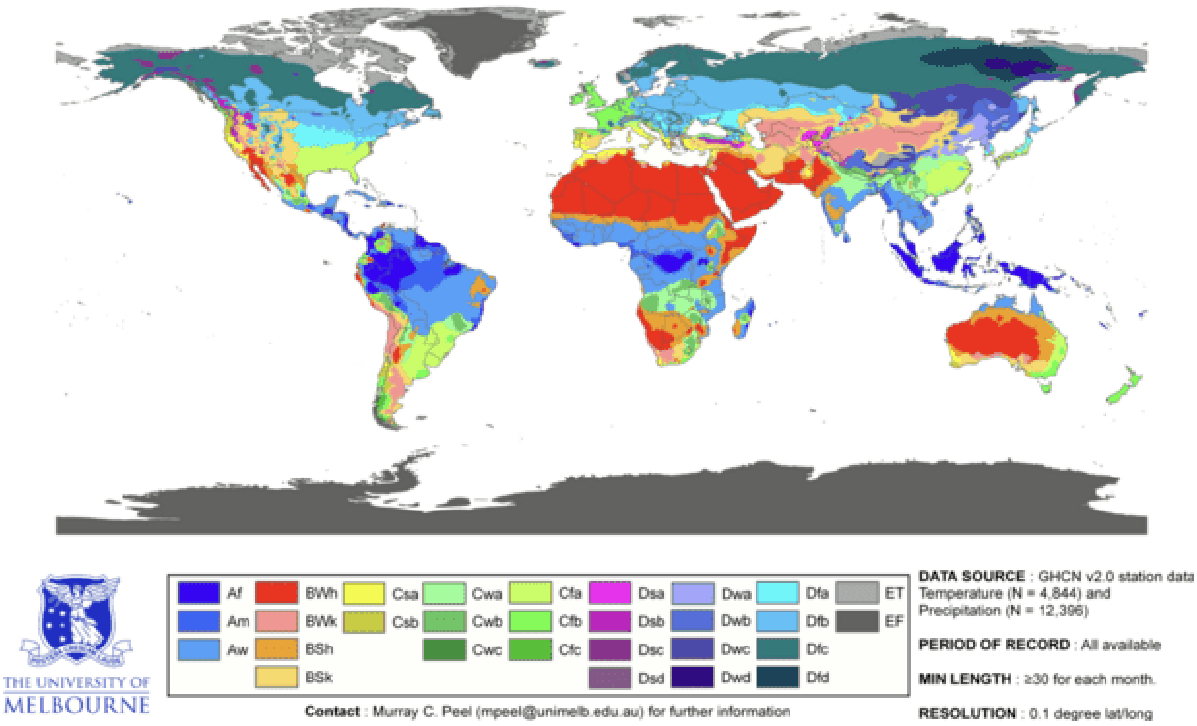


Figure 1. Worl Map of Koppen-Geiger Classification

Based on the Köppen climate classification, Japan and Korea fall into temperate and continental zones due to their higher latitudes. Southern Japan is largely humid subtropical (Cfa), while northern Japan and much of Korea experience humid continental climates (Dfa/Dfb, Dwa/Dwb), marked by cold winters with snow and hot, humid summers influenced by the East Asian monsoon. In contrast, Indonesia, Singapore, Malaysia, Thailand, and Brunei Darussalam are situated near the equator, dominated by tropical climates. Indonesia, Malaysia, and Brunei mostly exhibit tropical rainforest (Af) and monsoon (Am) climates, with consistently high temperatures and rainfall. Singapore is almost entirely Af, hot and humid year-round without a distinct dry season. Thailand is more varied, with tropical savanna (Aw) in the central and northern regions and monsoon (Am) in the south. This contrast highlights how latitude and monsoon systems shape regional climates: East Asia experiences four distinct seasons with sharp temperature variations, while Southeast Asia remains warm and humid throughout the year, with rainfall patterns dictated by monsoon cycles [36].

Based on the Low Carbon Development Indonesia report written by Bappenas in the Executive Summary, climate change is driven by increasing global temperatures around 0.45–0.75°C which is triggered by greenhouse gases, one of which is CO_2. This temperature rise leads to changes in the frequency of daily and seasonal temperatures, resulting in changes in the intensity of global rainfall patterns, the rainy and dry season periods, as well as affecting marine ecosystems. Such conditions are highly vulnerable to increasing the intensity of hydro-meteorological disasters such as floods, droughts, forest fires, landslides, and sea level rise. The temperature increase caused by CO_2 emissions generates potential economic losses of Rp115,53 trillion in 2024. As a result, recently the government of Indonesia has increasingly adopted the Green Economy approach as a strategy to curb emissions while maintaining economic growth. The Green Economy can be described as a sustainable global economic system that encompasses both land-based (terrestrial) and ocean-based (blue economy) sectors. Under this model, all economic activities, investment decisions, and infrastructure development are structured in a way that contrasts with the conventional brown economy, which is dependent on high-carbon and environmentally damaging practices.

Indonesia has set a target to shift all activities towards achieving Net Zero Emission by 2060. This transition is projected to increase Indonesia's GDP by up to 6.5% in 2050. The study estimates that nearly 100 billion ton of CO_2 emissions could be avoided between 2021 and 2060, with emission intensity projected to decline by around 68% by 2045 and ultimately reaching net zero by 2060. In addition, the Green Economy is expected to generate approximately 1.8 million new green employment opportunities. Based on Green Economy initiatives, the transition toward low-carbon development and climate resilience is projected to deliver substantial benefits for Indonesia. These include a reduction in emission intensity of about 68% by 2045, average annual GDP growth of 6.1–6.5% up to 2050, and a total decrease of roughly 87–96 billion tonnes of greenhouse gas emissions over 2021–2060. Furthermore, gross national income (GNI) is expected to be 25–34% higher by 2045. The shift is also anticipated to create around 1.8 million additional green jobs by 2030 across sectors such as energy, land rehabilitation, and waste management. Ecosystem services are projected to deliver economic value of about US$ 4.75 trillion per year by 2060. Public health improvements are also expected, with more than 40,000 lives potentially saved in 2045 due to reduced air pollution. In terms of environmental conservation, approximately 3.2 million hectares of primary forest are expected to be protected by 2060, while mangrove coverage is projected to expand to 3.6 million hectares by the same year [37].

The research conducted by [38] examines the evolving links among economic growth, energy use, financial sector development, trade openness, and CO_2 emissions in Indonesia over the period 1975Q1–2011Q4.To analyze these relationships, the authors employed the Autoregressive Distributed Lag (ARDL) bounds testing technique for cointegration, allowing them to capture long-run associations even in the presence of structural breaks in the data series. In addition, they used a Vector Error Correction Model (VECM) Granger causality framework to identify the direction of causality among the variables, and further validated the robustness of the results through an Innovative Accounting Approach (IAA). The findings confirm the existence of a long-term equilibrium relationship among the variables despite structural changes in the dataset. Empirical results also show that higher energy consumption leads to increased CO_2 emissions, while economic growth is identified as a key driver of environmental degradation through rising emissions. Financial development is found to reduce carbon emissions, and the results also confirm an inverted U-shaped relationship between financial development and CO_2 emissions. This supports the idea that the financial sector can contribute positively to environmental improvement. In addition, greater trade openness is associated with lower levels of energy-related pollution. The causality analysis reveals a two-way relationship between energy consumption and carbon emissions, indicating that each influences the other. Economic growth and CO_2 emissions are also mutually connected. The feedback hypothesis is further supported between trade openness and emissions, suggesting reciprocal effects between the two. Moreover, energy use and economic growth are shown to Granger-cause each other. Financial development is found to Granger-cause energy consumption, pollution levels, economic growth, and trade openness. These findings imply that reducing emissions may come with trade-offs in terms of economic growth, unless cleaner and more energy-efficient technologies are adopted. It is therefore important to promote technological upgrades that improve production efficiency while also encouraging the import of environmentally friendly technologies from more advanced economies. Since financial development influences energy consumption, it suggests that implementing energy-saving policies does not necessarily hinder economic performance. Consequently, financial institutions should prioritize funding for firms that adopt green technologies and support businesses in shifting toward more energy-efficient production methods, thereby helping to reduce environmental degradation.

The research conducted by [1] aims to analyze policy frameworks across Asian countries and assess their initiatives toward environmentally sustainable development. In particular, the study focuses on strategies related to green growth, green financing mechanisms, and programs designed to reduce carbon dioxide (CO_2) emissions. The study analyzes the impact of GDP expansion, various energy consumption sources, and other relevant explanatory factors on carbon dioxide emissions, using panel data from selected Asian economies covering the period 1980–2015. The FMOLS estimation results for the full sample confirm the presence of the EKC relationship, where GDP growth exerts a positive influence on CO_2 emissions, while the squared GDP term shows a negative effect. This pattern implies that environmental degradation increases at early stages of economic development but eventually decreases after income surpasses a certain threshold. In addition, the results indicate an inverted U-shaped association between CO_2 emissions and key determinants such as energy usage, economic performance, and additional control variables. This relationship is consistently validated across high-income countries, upper-middle-income economies, and the overall Asian panel, reinforcing the robustness of the findings. The FMOLS results for lower-middle-income countries do not provide evidence supporting the EKC hypothesis. The analysis shows that renewable energy, when used as a replacement for non-renewable sources, plays a statistically significant role in influencing emissions. In particular, the responsiveness of CO_2 emissions to renewable energy consumption is negative across the upper-middle-income, lower-middle-income, and full-panel FMOLS estimations. Moreover, the impact of renewable energy usage on reducing CO_2 emissions is more pronounced in upper-middle-income economies compared to other Asian country groups included in the study.

The research conducted by [39] investigates the connections between financial development, research and development, energy intensity, income levels, and carbon dioxide (CO_2) emissions. The analysis is based on panel data from selected West Asia and Middle East (WAME) countries covering the period 1990–2017. The results indicate that financial development in West Asia and Middle East (WAME) countries contributes to greater environmental degradation, largely because financial resources are often directed toward energy-intensive projects. In addition, higher energy intensity is associated with increased CO_2 emissions. Conversely, research and development play a positive role by promoting innovative techniques and more efficient energy alternatives, which in turn help improve environmental conditions across the region. The results further indicate the existence of bidirectional causality between CO_2 emissions and financial development, between R&D and emissions, income level and emissions, energy intensity and income level, R&D and income level, energy intensity and squared income, R&D and energy intensity, as well as between energy intensity and financial development.

More importantly, the analysis shows that once GDP surpasses a specific threshold, environmental degradation begins to decline, thereby confirming the validity of the EKC hypothesis.

This pattern is also observed in the WAME economies when considering both R&D activity and financial sector development.

Based on these empirical outcomes, several policy recommendations are proposed to help decision-makers address the negative environmental effects associated with income growth and energy intensity. In particular, the financial sector is identified as a contributor to environmental harm, suggesting the need for stricter regulatory oversight on lending practices. Financial institutions should be required to carefully assess the environmental impact and sustainability of projects before providing funding, ensuring that investment decisions align with environmental protection goals. Policy frameworks should be structured to simplify and streamline the procedures involved in financing green energy initiatives. Enhancing investment in research and development is expected to foster the emergence of innovative technologies as well as improve their effective application. The main objective of increasing R&D expenditure is to generate new production techniques and promote the adoption of advanced industrial technologies. Therefore, the selected WAME countries are encouraged to raise their R&D spending in order to stimulate economic growth given the observed causal relationship between R&D and GDP while also contributing to the reduction of CO_2 emissions.

Recognizing how innovation and the development of the financial sector can influence environmental outcomes, a growing number of countries have sought strategies to strengthen environmental performance. However, empirical literature examining the combined relationships among innovation, financial development, and pollution has not reached a consistent consensus, with findings often varying across studies. Against this background, [40] analyze data from 27 industrialized economies to explore the connections between innovation, financial development, and environmental degradation, using ecological footprint and CO_2 emissions as indicators of environmental impact. The empirical evidence suggests that increases in innovation are generally associated with reductions in environmental pollution, with the effect being more pronounced for ecological footprint than for CO_2 emissions. At the same time, the study detects non-linear dynamics, specifically a threshold-driven U-shaped pattern, indicating that after innovation surpasses a certain level, it may begin to contribute to higher environmental degradation instead of reducing it. The results also show that financial development is typically linked with worsening environmental quality; however, advancements in innovation can help offset or weaken the adverse environmental impact generated by financial sector growth. This relationship is robust across different indicators of environmental pollution. From the causality perspective, the findings point to a feedback relationship between innovation and ecological footprint, whereas CO_2 emissions are found to influence innovation in a one-directional manner. Meanwhile, financial development does not exhibit a clear causal connection with environmental degradation at the aggregate level, although country-specific differences reveal varying causal patterns among innovation, finance, and pollution.

3. METHODS

The author primarily used data from the World Bank Development Indicator and Global Financial Development. The author adjusted the Cointegrating Regression FMOLS from the [1], [37], [39] model. The author selected samples from several nations, including Japan, Korea, Singapore, Malaysia, Vietnam, Indonesia, and Thailand, and the sample data covered the years 1996–2021. The following equation was used by the author:

$$Ct= f(Yt, Yt^2, Rt, Ft)$$
$$dCt= d\ Yt+ d\ Yt^2 +dRt+ dFt+ ei$$

where, Ct, Yt, Yt^2, Rt, Ft, and ei are carbon emissions per capita, GDP per capita (constant 2015 US$), square of GDP per capita, R&D expenditures(%gdp), liquid liabilities (%gdp), and domestic private credit(%gdp) as the proxy for financial development adjusted based on [41]–[43] and the residual term.

The ratio of liquid liabilities to GDP measures the size of an economy's broad money supply (M3) relative to its total output. Liquid liabilities, commonly referred to as M3, represent a comprehensive money aggregate that includes several layers of monetary assets. It consists of currency in circulation and central bank deposits (M0), along with transferable deposits and electronic money (M1). It further expands to include time and savings deposits, transferable foreign currency deposits, certificates of deposit, and repurchase agreements (M2). On top of these, it also covers travelers' checks, foreign currency time deposits, commercial paper, and residents' holdings in mutual fund or money market fund shares.

4. RESULTS AND DISCUSSION

All Countries

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(RD)	-0.00381	0.241629	-0.01575	0.9875
D(LL)	-0.00238	0.003154	-0.75378	0.4523
D(FDI)	0.002656	7.64E-03	0.347535	0.7287
D(PRIVATE_CREDIT)	-0.00146	0.004114	-0.35576	0.7226
D(GDP2)	-3.61E-09	1.22E-09	-2.95565	0.0037**
D(GDP_PER_CAP)	4.34E-04	1.07E-04	4.047175	0.0001**

Selected Countries

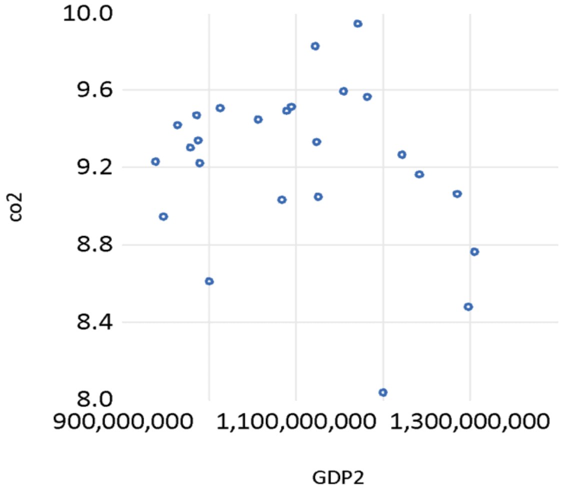
Countries	Variable	Coefficient	Std. Error	t-Statistic	Prob.
JAPAN	D(RD)	0.295855	0.598931	0.493972	0.628
	D(LL)	0.021535	8.52E-03	2.526546	0.0224**
	D(FDI)	1.258607	0.183009	6.877307	0.00**
	D(PRIVATE_CREDIT)	-3.99E-02	1.40E-02	-2.83931	0.0118**
	D(GDP2)	6.21E-08	2.47E-08	2.514852	0.023**
	D(GDP_PER_CAP)	-3.84E-03	1.65E-03	-2.32569	0.0335**
KOREA	D(RD)	0.602338	0.551125	1.092925	0.2906
	D(LL)	-7.61E-04	4.99E-03	-0.15266	0.8806
	D(FDI)	-0.05844	0.178549	-0.32732	0.7477
	D(PRIVATE_CREDIT)	-1.69E-02	8.98E-03	-1.88332	0.078*
	D(GDP2)	-9.24E-09	7.85E-09	-1.17719	0.2563
	D(GDP_PER_CAP)	1.08E-03	3.08E-04	3.514839	0.0029**
SINGAPORE	D(RD)	-0.11591	0.436507	-0.26553	0.794
	D(LL)	-0.03608	0.010733	-3.36144	0.004**
	D(FDI)	8.61E-02	0.009626	8.944435	0.00**
	D(PRIVATE_CREDIT)	3.97E-02	1.09E-02	3.628175	0.0023**

	D(GDP2)	-4.64E-09	2.02E-09	-2.29158	0.0358**
	D(GDP_PER_CAP)	1.99E-05	1.99E-04	0.100358	0.9213
INDONESIA	D(RD)	-1.55653	0.525843	-2.96007	0.0119**
	D(LL)	0.002531	0.005577	0.453776	0.6581
	D(FDI)	-0.00999	0.011125	-0.89795	0.3869
	D(PRIVATE_CREDIT)	-1.88E-02	8.76E-03	-2.14831	0.0528*
	D(GDP2)	1.30E-07	1.17E-07	1.109493	0.289
	D(GDP_PER_CAP)	1.39E-04	9.21E-04	0.150685	0.8827
MALAYSIA	D(RD)	-0.41286	0.373294	-1.10598	0.2904
	D(LL)	-0.00739	0.011242	-0.65722	0.5234
	D(FDI)	0.000856	0.029849	0.02867	0.9776
	D(PRIVATE_CREDIT)	4.33E-03	1.42E-02	0.305649	0.7651
	D(GDP2)	-2.08E-07	6.48E-08	-3.2057	0.0076**
	D(GDP_PER_CAP)	4.48E-03	1.41E-03	3.168954	0.0081**
THAILAND	D(RD)	-0.32175	0.149362	-2.15414	0.0506*
	D(LL)	0.001377	0.002538	0.542395	0.5967
	D(FDI)	0.012443	0.007727	1.610243	0.1313
	D(PRIVATE_CREDIT)	4.84E-03	3.01E-03	1.607261	0.132
	D(GDP2)	-6.80E-08	3.82E-08	-1.78114	0.0983*
	D(GDP_PER_CAP)	1.22E-03	4.37E-04	2.792749	0.0152**
VIETNAM	D(RD)	-1.11114	0.49708	-2.23534	0.0452**
	D(LL)	0.000558	0.003195	0.174574	0.8643
	D(FDI)	-0.00687	0.014558	-0.47219	0.6453
	D(PRIVATE_CREDIT)	2.46E-03	3.01E-03	0.817182	0.4298
	D(GDP2)	3.63E-07	2.39E-07	1.517866	0.1549
	D(GDP_PER_CAP)	-2.55E-05	1.91E-03	-0.01338	0.9895

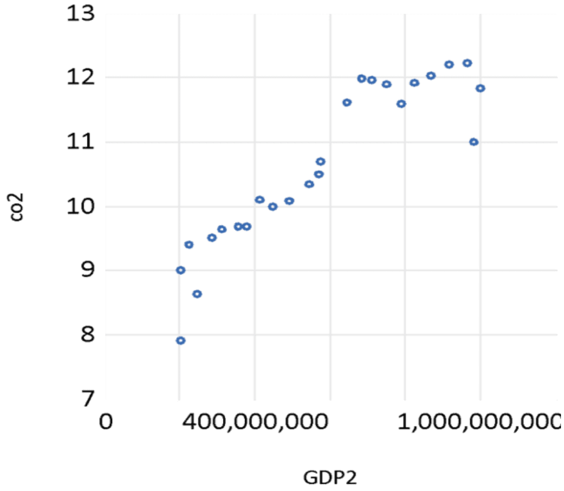
** sig at .05,* sig at.1

Graphic Kuznet EKC

JAPAN



KOREA



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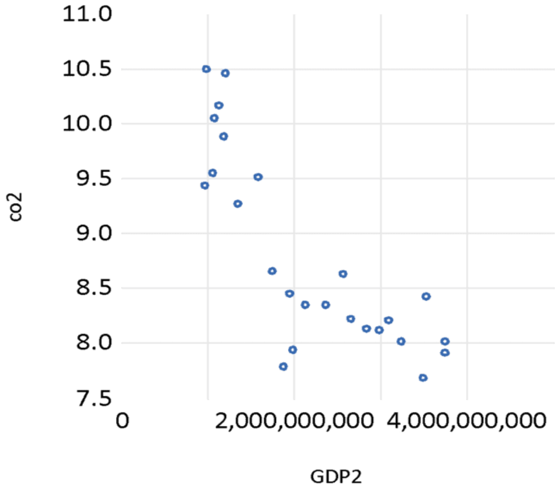

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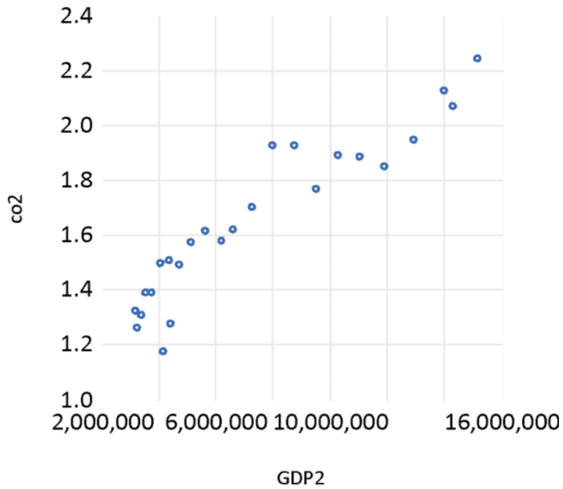
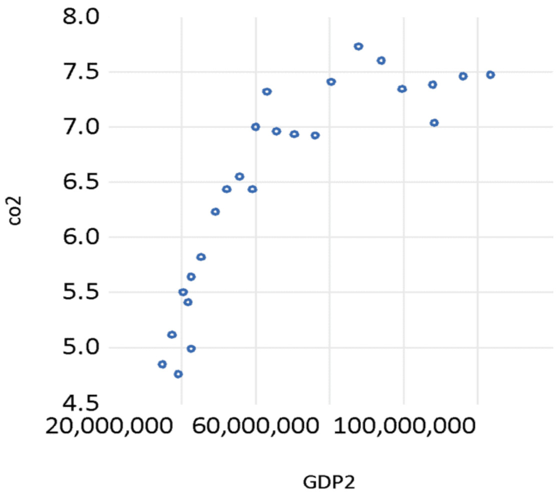
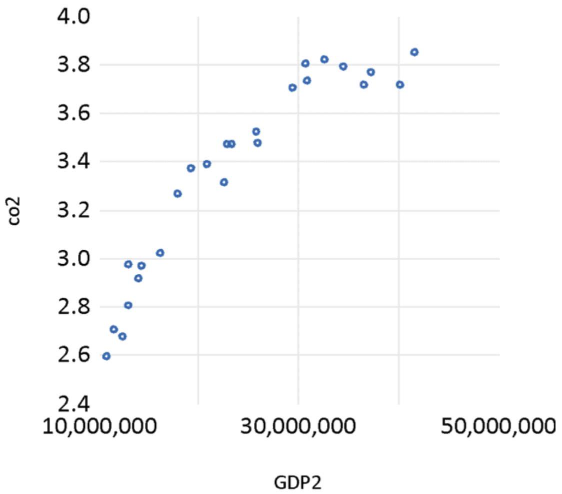


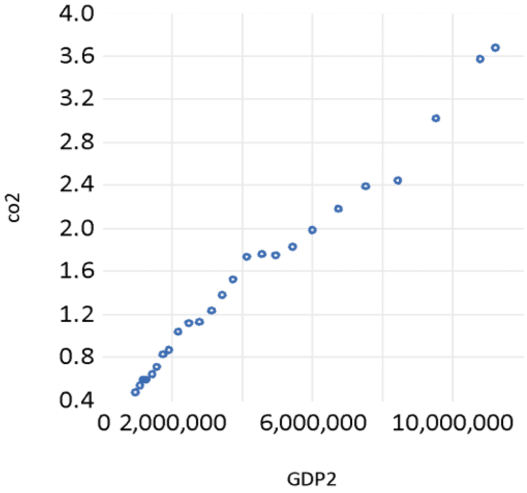
MALAYSIA



THAILAND



VIETNAM



Panel Cointegration Framework

Series: FDI GDP2 GDP_PER_CAP LL PRIVATE_CREDIT RD CO_2_PER_CAPITA

Alternative hypothesis: common AR coefs. (within-dimension)

	Prob.
Panel v-Statistic	0.9893
Panel rho-Statistic	0.9660
Panel PP-Statistic	0.0838*
Panel ADF-Statistic	0.0320**

Alternative hypothesis: individual AR coefs. (between-dimension)

	Prob.
Group rho-Statistic	0.9995
Group PP-Statistic	0.0000**
Group ADF-Statistic	0.0043**

The results from the panel cointegration analysis using the Pedroni Residual Cointegration Test show that four of the within-dimension statistics and two of the between-dimension statistics are statistically significant out of the seven total test measures. This indicates the presence of a strong long-term equilibrium relationship among the variables included in the study.

In-depth Analysis: Interaction Variables Analysis

countries	Variable	Coefficient	Std. Error	t-Statistic	Prob.
JP	RD	10.26631	4.814722	2.132274	0.0456**
	PRIVATE_CREDIT	0.176971	0.07965	2.221847	0.0380**
	RD_PRIVATE_CREDIT	-0.06462	0.026623	-2.42706	0.0248**
KR	RD	4.471989	0.573247	7.801161	0.0000**
	PRIVATE_CREDIT	0.062491	0.009213	6.782678	0.0000**
	RD_PRIVATE_CREDIT	-0.0243	0.003872	-6.27594	0.0000**
KR	RD	2.977362	0.192701	15.45066	0.0000**
	LL	0.078398	0.010226	7.666124	0.0000**
	RD_LL	-0.02132	0.00236	-9.03489	0.0000**

MY	RD	-10.9759	5.526348	-1.9861	0.0644*
	LL	-0.12207	0.038479	-3.17235	0.0059**
	RD_LL	0.104407	0.042884	2.434659	0.0270**
MY	RD	-12.8563	4.031013	-3.18936	0.0057**
	PRIVATE_CREDIT	-0.11055	0.027643	-3.99905	0.0010**
	RD_PRIVATE_CREDIT	0.123327	0.033969	3.63054	0.0022**
ID	RD	20.04568	3.805374	5.267728	0.0001**
	PRIVATE_CREDIT	0.044336	0.009577	4.629292	0.0003**
	RD_PRIVATE_CREDIT	-0.46244	0.097789	-4.72892	0.0002**

In-depth Analysis

The author examined and further analysed each country's pattern. The author found that there are some paired variable patterns in some countries. The pattern we saw in Japan, Korea, Malaysia, and Indonesia. The author tested R&D expenditure of GDP, private credit of GDP, and liquid liabilities of GDP. Based on the results of the in-depth analysis, the author concluded that Japan and Indonesia had a similar pattern in which private credit of GDP was paired with R&D expenditure of GDP to reduce carbon emissions.

Meanwhile, the other pattern we saw was that Korea and Malaysia had similar patterns. Korea and Malaysia had private credit of GDP, and the liquid liabilities of GDP were paired with the R&D expenditure of GDP to reduce carbon emissions.

5. CONCLUSION

Based on the results, only Japan and Singapore had reached the reverse U-curve Kuznet EKC. That means Japan and Singapore have reached post-industrialized or knowledge-based economies. The Korean curve exhibited an incomplete of the reverse U curve. That means Korea is going into the post-industrialized, or knowledge economy phase. Meanwhile, the other countries don't show the reverse U curve as still in progress in the industrial phase.

In all selected Asia countries, the proxies of financial development variables, which are liquid liabilities to GDP and private credit of GDP, had a negative coefficient even that was not significant. GDP per capita and GDP per capita squared significantly impacted CO_2 emissions. That means that in all selected countries, there is a pattern of sustainable development that reduces CO_2 emissions.

The author was concerned with the financial development proxy in this research. The author saw that Japan, Korea, and Singapore as the high-income countries had promising results patterns. The private credit coefficients in Japan and Korea had negative results and were significant. That means the private credit of GDP had a significant effect on reducing carbon emissions. The Singapore results had a negative and significant coefficient at liquid liabilities of GDP. That means the Singapore liquid liabilities of GDP significant effect on reducing carbon emissions.

The other countries also had promising patterns. Indonesia had negative and significant R&D and private credit of GDP. That means the R&D expenditure paired with private credit had a significant effect on reducing carbon emissions.

Thailand and Vietnam had similar patterns. Thailand and Vietnam have negative and significant coefficients in R&D expenditure. In that case, Thailand and Vietnam had significant R&D expenditure of GDP on reducing carbon emissions.

Malaysia exhibited also promising variable patterns. Malaysia had negative and significant GDP per capita and GDP per capita squared. That means Malaysia's GDP per capita had a significant effect on reducing carbon emissions. It means Malaysia's growth also had a sustainable development pattern proven by its pattern in carbon emissions reduction.

In conclusion, in all selected Asia countries, there are some promising results patterns. In each country, we found the proven sustainable development pattern at some proxy variables. The selected Asia countries could manage this to a sustainable future.

REFERENCES

[1] H. Saleem, M. B. Khan, and M. S. Shabbir, "The role of financial development, energy demand, and technological change in environmental sustainability agenda: evidence from selected Asian countries," *Environ. Sci. Pollut. Res.*, vol. 27, no. 5, pp. 5266–5280, 2020.

[2] K. Mtar and W. Belazreg, "Causal nexus between innovation, financial development, and economic growth: The case of OECD countries," *J. Knowl. Econ.*, vol. 12, no. 1, pp. 310–341, 2021.

[3] M. Shahbaz, M. A. Nasir, E. Hille, and M. K. Mahalik, "UK's net-zero carbon emissions target: Investigating the potential role of economic growth, financial development, and R&D expenditures based on historical data (1870–2017)," *Technol. Forecast. Soc. Change*, vol. 161, p. 120255, 2020.

[4] J. A. Schumpeter, "The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle," 1934. [Online]. Available: https://api.semanticscholar.org/CorpusID:152358274

[5] P. M. Romer, "Endogenous technological change," *J. Polit. Econ.*, vol. 98, no. 5, Part 2, pp. S71–S102, 1990.

[6] P. Aghion, N. Bloom, R. Blundell, R. Griffith, and P. Howitt, "Competition and innovation: An inverted-U relationship," *Q. J. Econ.*, vol. 120, no. 2, pp. 701–728, 2005.

[7] G. M. Grossman and E. Helpman, "Endogenous innovation in the theory of growth," *J. Econ. Perspect.*, vol. 8, no. 1, pp. 23–44, 1994.

[8] P. Aghion and P. Howitt, "The Economics of Growth Cambridge." MA: MIT Press, 2009.

[9] World Bank, "World Bank Development Report 1992. New York, NY, USA," *Oxford University Press*, 1992.

[10] G. M. Grossman and A. B. Krueger, "Economic growth and the environment," *Q. J. Econ.*, vol. 110, no. 2, pp. 353–377, 1995.

[11] W. M. Huang, G. W. M. Lee, and C. C. Wu, "GHG emissions, GDP growth and the Kyoto Protocol: A revisit of Environmental Kuznets Curve hypothesis," *Energy Policy*, vol. 36, no. 1, pp. 239–247, 2008.

[12] E. Akbostancı, S. Türüt-Aşık, and G. İ. Tunç, "The relationship between income and environment in Turkey: is there an environmental Kuznets curve?," *Energy Policy*, vol. 37, no. 3, pp. 861–867, 2009.

[13] G. E. Halkos and E. G. Tsionas, "Environmental Kuznets curves: Bayesian evidence from switching regime models," *Energy Econ.*, vol. 23, no. 2, pp. 191–210, 2001.

[14] T. Luzzati and M. Orsini, "Investigating the energy-environmental Kuznets curve," *Energy*, vol. 34, no. 3, pp. 291–300, 2009.

[15] W. Lise, "Decomposition of CO2 emissions over 1980–2003 in Turkey," *Energy Policy*, vol. 34, no. 14, pp. 1841–1852, 2006.

[16] I. Martınez-Zarzoso and A. Bengochea-Morancho, "Pooled mean group estimation of an environmental Kuznets curve for CO2," *Econ. Lett.*, vol. 82, no. 1, pp. 121–126, 2004.

[17] N. Heerink, A. Mulatu, and E. Bulte, "Income inequality and the environment: aggregation bias in environmental Kuznets curves," *Ecol. Econ.*, vol. 38, no. 3, pp. 359–367, 2001.

[18] M. A. Cole, "Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages," *Ecol. Econ.*, vol. 48, no. 1, pp. 71–81, 2004.

[19] A. Tamazian and B. B. Rao, "Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies," *Energy Econ.*, vol. 32, no. 1, pp. 137–145, 2010.

[20] M. Galeotti, A. Lanza, and F. Pauli, "Reassessing the environmental Kuznets curve for CO2 emissions: A robustness exercise," *Ecol. Econ.*, vol. 57, no. 1, pp. 152–163, 2006.

[21] L. Belze and O. Gauthier, "Innovation et croissance économique: rôle et enjeux du financement des PME," *Rev. Int. PME*, vol. 13, no. 1, pp. 65–86, 2000.

[22] B. Crépon, E. Duguet, and J. Mairesse, "Research, innovation, and productivity," *NBER. Work. Pap. Ser.*, 1998.

[23] H. Sun, Y. Luo, J. Liu, Z. Lin, and M. A. Bhuiyan, "Does the digital finance promote technological innovation? Evidence from Chinese cities," *J. Knowl. Econ.*, vol. 16, no. 2, pp. 8037–8059, 2025.

[24] V. O'Connell, N. AbuGhazaleh, Y. Tahat, and G. Whelan, "The impact of R&D innovation success on the relationship between R&D investment and financial leverage," *J. Open Innov. Technol. Mark. Complex.*, vol. 8, no. 3, p. 129, 2022.

[25] J. A. Schumpeter and R. Swedberg, *The theory of economic development*. Routledge, 2021.

[26] R. G. King and R. Levine, "Finance and growth: Schumpeter might be right," *Q. J. Econ.*, vol. 108, no. 3, pp. 717–737, 1993.

[27] H. Zang and Y. C. Kim, "Does financial development precede growth? Robinson and Lucas might be right," *Appl. Econ. Lett.*, vol. 14, no. 1, pp. 15–19, 2007.

[28] R. Levine, "Financial development and economic growth: views and agenda," *J. Econ. Lit.*, vol. 35, no. 2, pp. 688–726, 1997.

[29] R. Rajan and L. Zingales, "Financial dependence and growth," National bureau of economic research Cambridge, Mass., USA, 1996.

[30] F. Allen and D. Gale, "Innovations in financial services, relationships, and risk sharing," *Manage. Sci.*, vol. 45, no. 9, pp. 1239–1253, 1999.
[31] M. F. Morales, "Financial intermediation in a model of growth through creative destruction," *Macroecon. Dyn.*, vol. 7, no. 3, pp. 363–393, 2003.
[32] M. F. Morales Illán, "Financial intermediation in a model of growth through creative destruction," 2006.
[33] L. M. B. Cabral and J. Mata, "On the evolution of the firm size distribution: Facts and theory," *Am. Econ. Rev.*, vol. 93, no. 4, pp. 1075–1090, 2003.
[34] A. Hyytinen and O. Toivanen, "Do financial constraints hold back innovation and growth?: Evidence on the role of public policy," *Res. Policy*, vol. 34, no. 9, pp. 1385–1403, 2005.
[35] D. Acemoglu and J. A. Robinson, "De facto political power and institutional persistence," *Am. Econ. Rev.*, vol. 96, no. 2, pp. 325–330, 2006.
[36] H. E. Beck, N. E. Zimmermann, T. R. McVicar, N. Vergopolan, A. Berg, and E. F. Wood, "Present and future Köppen-Geiger climate classification maps at 1-km resolution," *Sci. data*, vol. 5, no. 1, p. 180214, 2018.
[37] J.-M. Lee, K.-H. Chen, and C.-H. Cho, "The relationship between CO2 emissions and financial development: evidence from OECD countries," *Singapore Econ. Rev.*, vol. 60, no. 05, p. 1550117, 2015.
[38] M. Shahbaz, Q. M. A. Hye, A. K. Tiwari, and N. C. Leitão, "Economic growth, energy consumption, financial development, international trade and CO2 emissions in Indonesia," *Renew. Sustain. energy Rev.*, vol. 25, pp. 109–121, 2013.
[39] S. Kihombo, S. Saud, Z. Ahmed, and S. Chen, "The effects of research and development and financial development on CO2 emissions: evidence from selected WAME economies," *Environ. Sci. Pollut. Res.*, vol. 28, no. 37, pp. 51149–51159, 2021.
[40] M. Ibrahim and X. V. Vo, "Exploring the relationships among innovation, financial sector development and environmental pollution in selected industrialized countries," *J. Environ. Manage.*, vol. 284, p. 112057, 2021.
[41] R. P. Pradhan, M. B. Arvin, M. Nair, S. E. Bennett, S. Bahmani, and J. H. Hall, "Endogenous dynamics between innovation, financial markets, venture capital and economic growth: Evidence from Europe," *J. Multinatl. Financ. Manag.*, vol. 45, pp. 15–34, 2018.
[42] M. Qamruzzaman, W. Jianguo, S. Jahan, and Z. Yingjun, "Financial innovation, human capital development, and economic growth of selected South Asian countries: An application of ARDL approach," *Int. J. Financ. Econ.*, vol. 26, no. 3, pp. 4032–4053, 2021.
[43] M. Qamruzzaman and W. Jianguo, "Financial innovation and economic growth in Bangladesh," *Financ. Innov.*, vol. 3, no. 1, p. 19, 2017.