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## RENEWABLE ENERGY, INTERNET PENETRATION, ECONOMIC GROWTH, AND ENVIRONMENTAL SUSTAINABILITY NEXUS IN ASEAN



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### Abstract

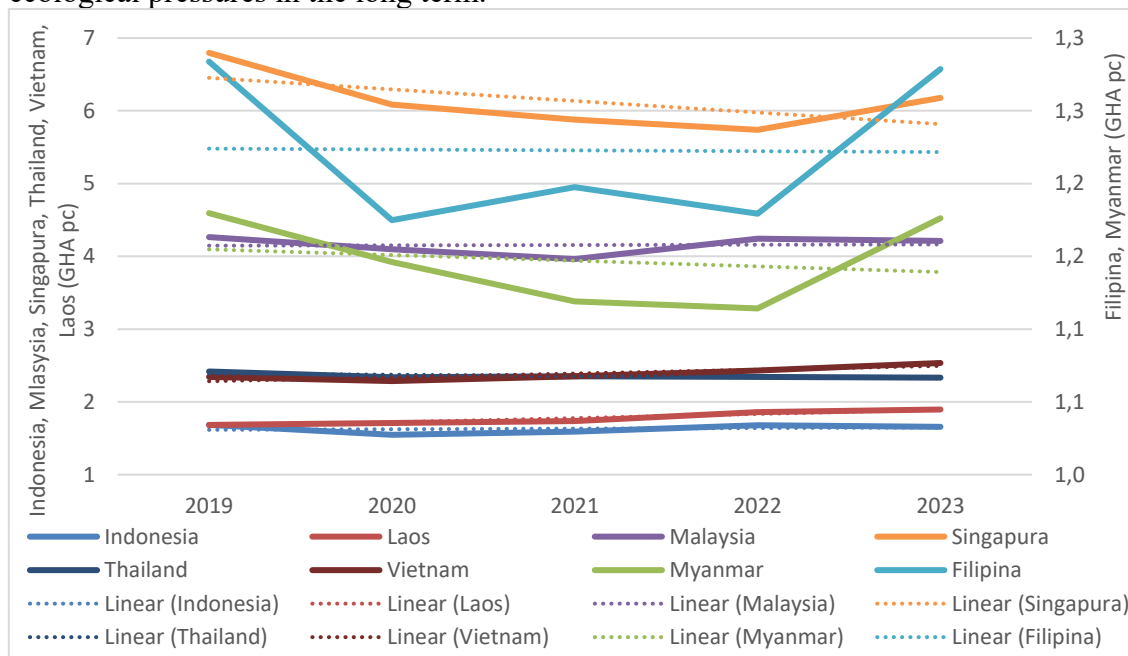
The study aims to examine the relationship between renewable energy consumption, internet penetration, and economic growth as independent variables, while ecological footprint as dependent variables. The sample of this study uses the ASEAN region, especially Indonesia, Malaysia, Singapore, Thailand, Vietnam, the Philippines, Laos, and Myanmar. These countries were chosen because of their rapid economic growth, large populations, rapid industrialization process, wealth of natural resources, significant foreign investment flows, ongoing economic reforms and more advanced infrastructure developments. Overall, these countries have an important role in the global economy despite still facing a number of challenges. The data used in this study are secondary data available from the World Bank and the Global Footprint Network. The analysis technique used in this study is panel data regression with the period 2011 – 2023. The results of this study found that renewable energy consumption and internet penetration contribute to reducing the ecological footprint in ASEAN while economic growth still contributes to increasing the ecological footprint.

**Keywords:** Renewable Energy Consumption, Internet Penetration, Economic Growth,  
JEL Classification : O11, P28, I86

## INTRODUCTION

In recent years, the issue of environmental sustainability has developed into one of the top priorities on the global development agenda (Udeagha & Ngepah, 2023). The increasing intensity of climate change, environmental degradation, and exploitation of natural resources have raised serious concerns about the earth's ability to sustain long-term human activity (Khurshid, 2022). The Southeast Asia Region (ASEAN) is an interesting region to study in this context, because on the one hand it shows an impressive economic growth trend. ASEAN member countries are in a vortex of development driven by industrialization, urbanization, and increased energy consumption (Minh Khuong et al., 2019). However, this growth is still largely driven by fossil-based energy, which has a major impact on increasing carbon emissions, air pollution, and deteriorating environmental quality (Nepal et al., 2021).

Based on Figure 1, Singapore with higher income levels record a much larger per capita ecological footprint, signaling patterns of consumption and resource utilization that exceed ecological carrying capacity, while developing countries, although still at a lower ecological footprint, are starting to show a consistent upward trend. This phenomenon indicates that there are structural problems in the ASEAN development model that is still oriented towards economic growth and consumption, without adequate transformation towards energy efficiency and sustainable development practices, thus potentially increasing ecological pressures in the long term.



**Figure 1.**  
**Ecological Footprint in ASEAN**  
 Source: Global Footprint Network, (2025)

The transition to renewable energy is seen as one of the strategic solutions to reduce the negative impact of development on the environment (Saleh & Hassan, 2024). Renewable energy consumption not only plays a role in reducing greenhouse gas emissions, but also

strengthens national energy security, creates green jobs, and supports low-carbon economic transformation (Kabeyi & Olanrewaju, 2022b). However, the level of renewable energy adoption in the ASEAN region is still relatively low and uneven between countries (Erdiwansyah et al., 2019). Some countries such as Thailand and the Philippines have shown greater commitment to clean energy investment, while others still rely on fossil energy subsidy policies (Aleluia et al., 2022). Differences in infrastructure readiness, policy support, and technological capacity are factors that affect the effectiveness of this energy transition (Singh, 2023).

In addition, internet penetration as a structural force in the world economy also has a significant influence on the dynamics of environmental sustainability (Vyshnevskaya et al., 2021). The penetration of the economic internet has opened up wider access to trade, foreign direct investment, and technology transfer (Obeng Amponsah & Owusu, 2025). Meanwhile, internet penetration can also be contrary to environmental issues (Obeng Amponsah & Owusu, 2025). On the one hand, trade liberalization has the potential to encourage the expansion of extractive and energy-intensive sectors of the economy, which in turn can weaken domestic environmental supervision and regulation due to the pressure of competition in production costs between countries (Ji et al., 2025).

Economic growth, which is often used as the main indicator of development success is also inseparable from its ecological dimension (Hirai & Comim, 2022). Although economic growth could theoretically provide resources for investment in clean technology and environmental management (Zhang et al., 2022). This phenomenon is known as the environmental kuznets curve (EKC), which states that in the early stages of development, economic growth tends to damage the environment, but after passing a certain turning point, more advanced economies will start investing in environmental protection (Ma et al., 2023). However, the validity of the EKC depends heavily on the policy context, economic structure, and environmental governance in each country (Ma et al., 2023).

The selection of the ASEAN region, especially Indonesia, Laos, Myanmar, Malaysia, Singapore, the Philippines, Thailand, and Vietnam is based on a diversity of economic characteristics, openness Internet penetration, and environmental policies that allow for comprehensive analysis. These countries represent different stages of development and levels of adoption of renewable energy, as well as face significant environmental challenges. This becomes relevant to examine the relationship between energy, internet penetration, economic growth, and environmental sustainability in the ASEAN region. This research offers novelty by integrating these three variables in influencing ecological footprints using panel data for the 2011-2023 period.

## REVIEW OF LITERATURE

Renewable energy consumption has become a key focus in global efforts to reduce dependence on fossil fuels and address climate change (Holechek et al., 2022). According to Paraschiv & Paraschiv, (2023) Renewables such as solar, wind, biomass, and hydro have experienced significant growth in the last two decades. Studies show that oil prices and economic growth are the main determinants in increasing renewable energy consumption, especially in developing countries (Deka et al., 2024). ASEAN countries are working to increase renewable energy consumption as part of a sustainable energy transition (Aleluia et al., 2022). According to Veng et al., (2020) ASEAN's renewable energy mix target reaches

23 percent of total primary energy consumption by 2025. Indonesia, Vietnam, and Thailand show significant growth in the solar and biomass sectors (Tun et al., 2019). However, limited infrastructure, financing, and regulatory frameworks remain major challenges (Ehlers, 2014). Hallelujah et al., (2022) emphasized that increased investment and technology transfer are needed to accelerate the energy transition and promote environmental sustainability in the ASEAN region.

Internet penetration refers to the use of information technology, internet, data centers, and automation, which has two sides to the environment (Kez et al., 2022). Internet penetration can reduce the ecological footprint through energy efficiency, reduced physical activity, and improved monitoring and management of natural resources by reducing the need for transportation, fuel consumption, and paper use, as well as supporting the implementation of renewable-based smart energy systems (Ni et al., 2022). However, on the other hand, internet penetration can increase the ecological footprint if not managed properly because digital infrastructure requires a lot of energy, especially in countries that are still dependent on fossil fuels, as well as causing e-waste problems and increased emissions due to the growth of e-commerce and logistics (Brenner & Hartl, 2021). In ASEAN, Singapore is leveraging internet penetration to develop a low-carbon economy while other countries are still relying on fossil energy to drive exports and industrial growth (Lau et al., 2021). In line with that, research (Akin & Ozgun, 2024) emphasized that internet penetration reduces the ecological footprint in Brazil, India, Indonesia, South Africa and Turkey in both the short and long term.

Economic growth is often the top priority for countries, especially developing countries. However, the relationship between economic growth and environmental sustainability is still a matter of debate. The Environmental Kuznets Curve (EKC) theory states that in the early stages of growth, environmental degradation increases, but decreases after reaching a certain level of income (Brands, 2022). However, the empirical evidence regarding the validity of EKC is mixed. Several studies show that economic growth that is not accompanied by a clean energy transition actually increases the ecological footprint (Li et al., 2022a). Economic growth in ASEAN in the last two decades has been very rapid, especially in Indonesia, Vietnam, and the Philippines (Le et al., 2022). However, this growth is largely supported by the exploitation of natural resources and the consumption of fossil energy (Wang & Azam, 2024). Inclusive and sustainable economic growth remains a challenge (Kamran et al., 2023). Nyuin et al., (2023) demonstrates that renewable energy can contribute to long-term economic growth in developing countries, including ASEAN if supported by appropriate fiscal policies and incentives.

Ecological footprints measure the impact of human activities on the capacity of the earth's ecosystems (Morufu et al., 2021). Fossil energy consumption is the largest contributor to the global ecological footprint (Çelekli & Zaric, 2023). Research Appiah et al., (2023) It shows that increased consumption of renewable energy can reduce the ecological footprint, but this effect depends on scale, efficiency, and integration of supportive environmental policies. The interaction between economic growth and internet penetration can enlarge or shrink the ecological footprint depending on the direction of development policies (Jahanger et al., 2022). The ecological footprint in ASEAN continues to increase along with urbanization, industrialization, and increased consumption (Ansari, 2022). Some ASEAN countries such as Indonesia and Malaysia are experiencing high ecological stress due to

deforestation and the use of fossil energy (Lau et al., 2022). Research Nepal et al., (2021) found that renewable energy consumption can significantly lower the ecological footprint in Southeast Asian countries, but a cross-sectoral approach and regional collaboration are needed for maximum results. This study hypothesizes that there is an influence between renewable energy consumption, internet penetration, and economic growth on the ecological footprint in ASEAN.

**RESEARCH METHOD**

This study examines renewable energy consumption, internet penetration, and economic growth as independent variables, while ecological footprint as dependent variables. The sample of this study uses the ASEAN region, especially Indonesia, Malaysia, Singapore, Thailand, Vietnam, the Philippines, Laos, and Myanmar. These countries were chosen because of their rapid economic growth, large populations, rapid industrialization process, wealth of natural resources, significant foreign investment flows, ongoing economic reforms and more advanced infrastructure developments. Overall, these countries have an important role in the global economy despite still facing a number of challenges. The operational description of the variables is described in Table 1. This study utilizes secondary data sourced from the World Bank and the Global Footprint Network covering the period 2011 – 2023. This study uses panel data regression analysis, which combines common, fixed, and random models.

**Table 1.**  
**Variable Operational Definition**

<b>Variabel</b>	<b>Definition</b>	<b>Source</b>
Renewable energy consumption	(% of total final energy consumption)	World Bank
Internet penetration	(Individuals using the internet, % of total POP)	World Bank
Economic Growth	(Annual percentage growth rate of GDP at market prices based on constant local currency.	World Bank
Ecological footprint	(Global hectares per person (GHA pc))	Global Footprint Network

The selection of the most suitable model is determined through a chow test and a thurst test. The regression equation model used in this study is described as follows:

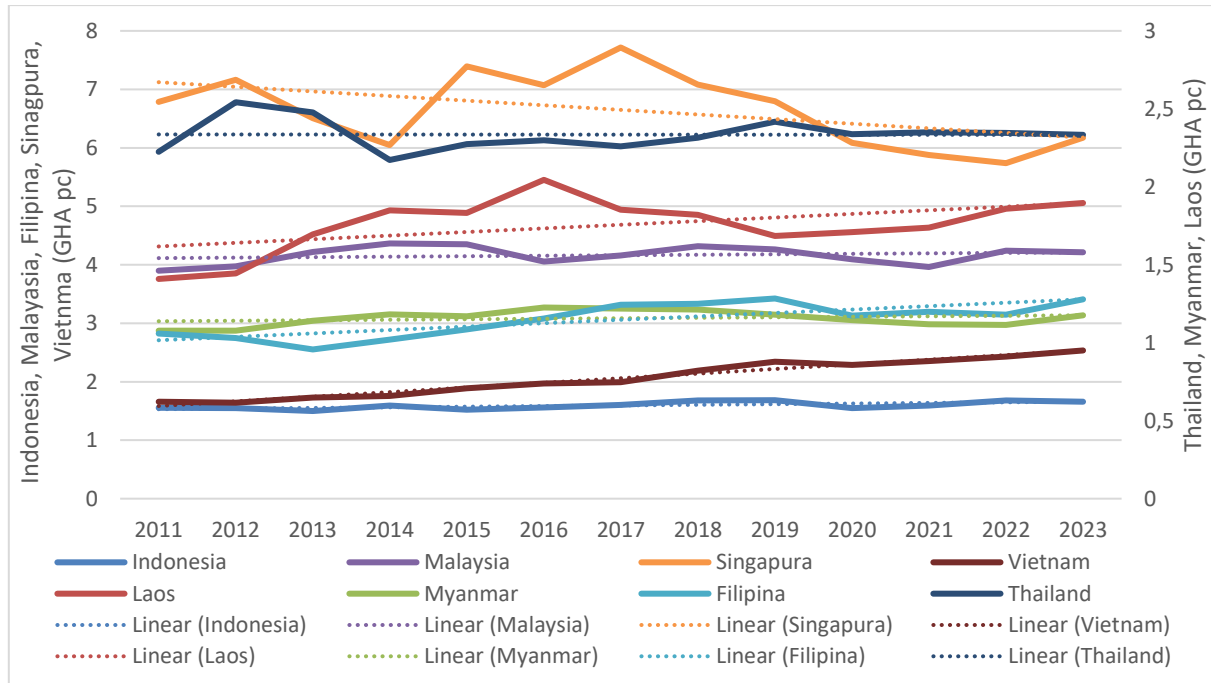
$$LNEFP_{it} = \beta_0 + \beta_1 REC_{it} + \beta_2 DIG_{it} + \beta_3 GROWTH_{it} + e_{it} \dots \dots \dots (1)$$

Where: is a constant; LNEFP is an ecological footprint; REC is the consumption of renewable energy; DIG is internet penetration; GROWTH is economic growth; i is cross section; t is a time series; and e is the error term.  $\beta$

**RESULTS AND DISCUSSION**

Ecological footprint is one of the main indicators in measuring environmental sustainability (Rafique et al., 2022). Ecological footprint describes the large human demand for natural resources and the earth's ecological capacity to restore environmental impacts, the greater the ecological footprint of a country, the greater the pressure placed on the

environment, both through energy consumption, land use, and carbon emissions (Wiedmann & Barrett, 2010). In the context of sustainable development, ecological footprint analysis is important to assess whether economic growth and improvement of people's well-being go hand in hand with efforts to preserve the environment (Udemba, 2020).



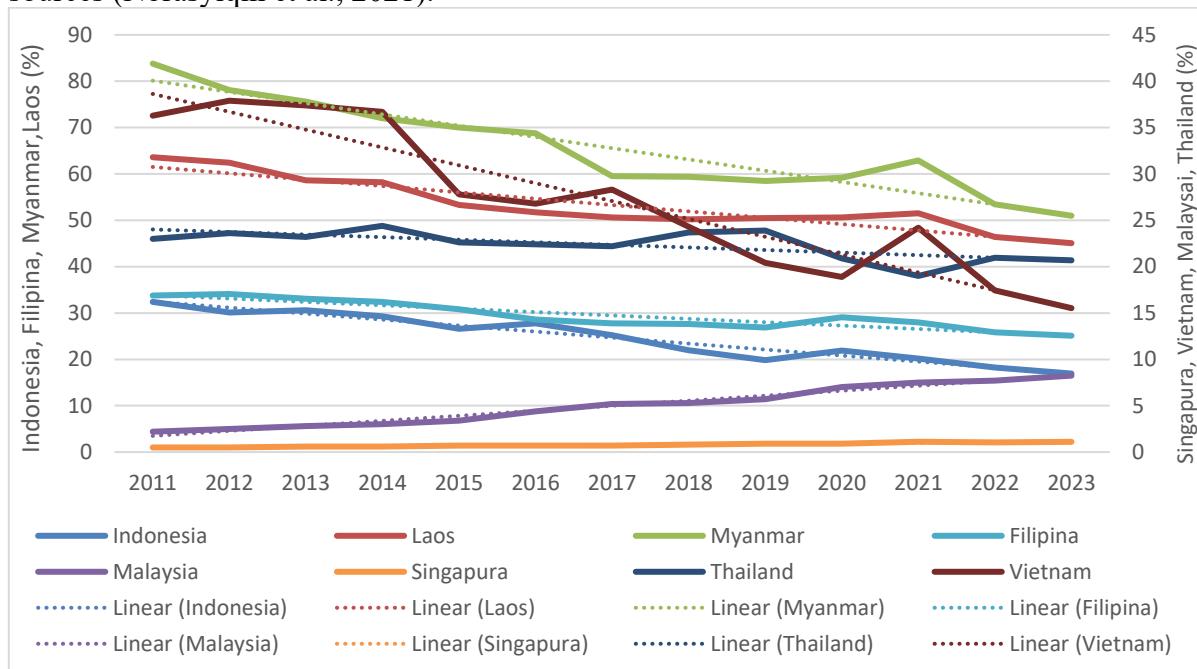
**Figure 2.**  
**Ecological Footprint in ASEAN**  
 Source: GFN, (2025)

In the ASEAN region, the ever-evolving social and economic dynamics affect the level of ecological footprint in each country (Halkos & Tsrivis, 2025). Figure 2 presents the trend of ecological footprints in ASEAN countries which shows quite striking variations between countries. Singapore is recorded as the country with the highest level of ecological footprint, although in the long term it shows a downward trend. This can reflect the existence of a policy of resource efficiency or the absorption of environmentally friendly technology (Wang et al., 2024).

Malaysia and Thailand are in the middle category with patterns that tend to be stable throughout the observation period. The changes in these two countries are not very noticeable, indicating the stability in their ecological consumption. Indonesia, Myanmar, Laos, and Vietnam have lower ecological levels however, Vietnam shows a gradual increasing trend indicating increased economic activity and resource consumption. On the other hand, Indonesia and the Philippines tend to show a stable pattern, while Myanmar and Laos have seen a slight increase.

Renewable energy plays a crucial role in realizing sustainable development, especially in reducing dependence on fossil fuels and lowering greenhouse gas emissions (Wang & Azam, 2024). In the ASEAN region, the energy transition is one of the strategic

issues given the high economic growth and increasing energy needs (Safrina & Utama, 2023). The consumption of renewable energy reflects the extent to which countries in the region have successfully integrated environmentally friendly energy sources into the national energy system (Hassan et al., 2024). Based on Figure 3, renewable energy consumption in ASEAN countries tends to decrease. Myanmar is recorded as the country with the highest renewable energy consumption but with a downward trend. This is due to the increasing use of fossil energy as a result of the expansion of national development and electrification (Rehman et al., 2019). A similar downward trend also occurred from Laos and the Philippines which at the beginning of the decade showed a fairly high proportion of renewable energy consumption. Although both countries have great hydro energy potential, the downward trend shows that the country's energy mix is increasingly dominated by conventional energy sources (Norasyiqin et al., 2021).



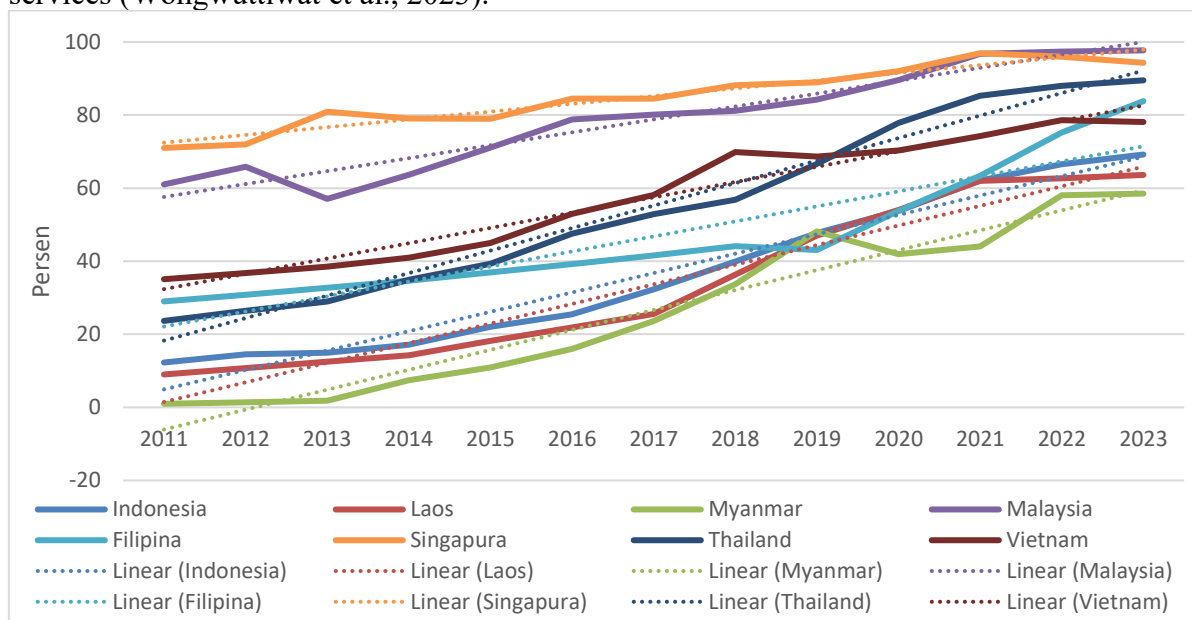
**Figure 3.**  
**Renewable Energy in ASEAN**  
 Source: Worldbank, (2025)

Vietnam, Thailand, and Indonesia showed a more moderate downward trend. Nevertheless, the decline still reflects the challenges in maintaining or increasing the portion of renewable energy amid increasing domestic energy demand. In contrast, Malaysia and Singapore showed very low levels of renewable energy consumption during the observation period. The changes that occurred in both countries were relatively stagnant, although there was a slight improvement in Malaysia. The low consumption of renewable energy in these countries is likely due to the limited potential of renewable natural resources as well as the dominance of fossil energy-based infrastructure (Holechek et al., 2022).

Internet penetration is one of the important indicators in measuring a country's readiness to face technology-based economic and social transformation (Yoo et al., 2020). In the ASEAN region, the process of internet penetration plays a strategic role in encouraging

economic growth, expanding access to information, and improving the efficiency of public services. Increasing the use of digital technology is also key in accelerating the achievement of sustainable development, especially in the context of regional economic integration and readiness to face the Industrial Revolution 4.0 (Zhang et al., 2025).

Based on Figure 4, several ASEAN countries show an increasing trend in internet penetration rates. Singapore has consistently been the country with the highest internet penetration rate since the beginning of the observation period. Its stable and ever-improving position reflects the readiness of its excellent technology infrastructure, high level of digital literacy, and strong policy support from the government (Wang & Si, 2024). Malaysia and Thailand also show significant upward trends, placing them in the group of countries with the most advanced internet penetration in the region. This increase shows the success of investment in the information technology sector as well as the widespread adoption of digital services (Wongwuttivat et al., 2023).



**Figure 4.**  
**Internet penetration in ASEAN**  
Source: Worldbank, (2025)

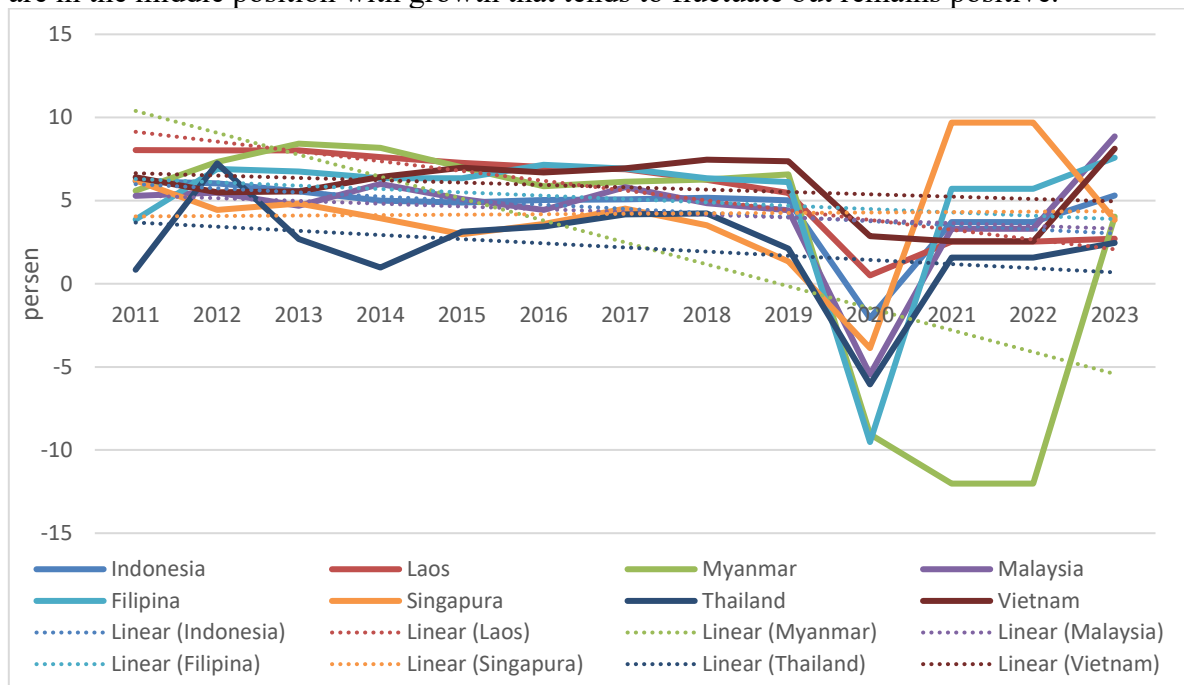
Developing countries such as Indonesia, Vietnam, and the Philippines have experienced significant spikes in internet penetration, despite starting from a lower point. This growth is likely driven by the widespread penetration of the internet, the increase in the use of smartphones, and the emergence of dynamic digital economy sectors, such as e-commerce and digital financial services (M et al., 2022). Meanwhile, based on Figure 5, Laos and Myanmar, which were previously at the lowest position, also increased, albeit at a slower pace. Limited infrastructure and inequality of digital access in rural areas are likely to be factors that hinder the acceleration of internet penetration in both countries (Simpson, 2024).

Small fluctuations are seen in some countries such as Malaysia and Singapore in certain years. These changes can be caused by the COVID-19 pandemic which had disrupted economic activities and slowed down the development of digital infrastructure in several

sectors (McKibbin & Fernando, 2023). Overall, however, the upward trend remains consistent and shows a positive direction.

Economic growth is the main indicator that reflects the performance of a country and is a benchmark for development success in the short and long term (Mohamed et al., 2022). In the ASEAN region, stable and inclusive economic growth is essential to maintain regional competitiveness and improve people's welfare. Figure 5 shows the dynamics of annual economic growth in the ASEAN region over a period of more than a decade by showing complex and diverse patterns in each country.

In the early period, most countries showed stable economic growth with little difference in the speed of their development. Vietnam and Laos appear to be consistent in maintaining relatively high growth rates, while countries such as Thailand and Singapore show a more moderate pattern. On the other hand, Indonesia, the Philippines, and Malaysia are in the middle position with growth that tends to fluctuate but remains positive.



**Figure 5.**  
**Economic Growth in ASEAN**  
Source: Worldbank, (2025)

Based on Figure 5, the turning point occurred when ASEAN was affected by the global crisis due to the COVID-19 pandemic. Almost all countries are experiencing severe economic pressure, reflected in the sharp decline in the graph. Some countries experienced a very deep contraction, while others were still able to withstand the pace of slowdown despite the difficulties. However, this condition did not last long. In the post-pandemic period, the majority of countries showed a fairly strong recovery, although the pace and stability were not uniform. Singapore, for example, recovered quickly and recorded impressive growth, while Myanmar was still held back by complex internal pressures.

If the trend line is drawn, it can be seen that some countries are starting to experience a long-term decline in growth rate. This can reflect structural challenges such as productivity stagnation, dependence on certain sectors, or political uncertainty (Nikiforos, 2022). However, some countries such as Vietnam and Malaysia are showing a steady growth direction, showing the potential to continue an inclusive and dynamic economic transformation.

**Statistics Descriptive**

Based on the results of descriptive statistics, the ecological footprint variable had an average value of 2.61 and a median of 1.85, indicating that the data distribution tended to be skewed to the right. The maximum value of the ecological footprint reaches 7.72, while the minimum value is 0.96, with a standard deviation of 1.80. This shows that EFP data has a fairly wide distribution and high variability.

For the renewable energy variable, the average was recorded at 28.53, slightly higher than the median of 25.15, which indicates a rather symmetrical distribution. The maximum value is 83.80, while the minimum is only 0.50, with a standard deviation of 21.27. This shows that REC has a very wide range of values and large data variations.

**Table 2.**  
**Descriptive Statistics**

	<b>EFP</b>	<b>REC</b>	<b>YOU</b>	<b>GROWTH</b>
Mean	2.607715	28.52614	52.56432	4.275056
Median	1.851444	25.14818	53.74570	5.234102
Maximum	7.715935	83.80000	97.70000	9.690767
Minimum	0.957054	0.500000	0.980000	-12.01637
Std. Dev.	1.798990	21.26657	26.81826	4.051685
Skewness	1.436867	0.570727	-0.099161	-2.258349
Kurtosis	3.893819	2.563938	1.933683	8.753312
Jarque-Bera	39.24814	6.469951	5.097578	231.8383
Probability	0.000000	0.039361	0.078176	0.000000
Sum	271.2023	2966.718	5466.689	444.6058
Sum Sq. Dev.	333.3455	46583.50	74079.54	1690.864
Observations	104	104	104	104

Source: Eviews, (2025)

The internet penetration variables showed an average of 52.56 and 53.75, indicating an almost symmetrical distribution of data. The maximum values of 97.70 and the minimum of 0.98, as well as the standard deviation of 26.82, show a high variation, although the distribution of data appears to be more balanced than the other variables.

Meanwhile, economic growth has an average of 4.28 which is lower than the average of 5.23, indicating a left-skewed distribution. The maximum value was recorded at 9.69, while the minimum value was very low which was -12.02, with a standard deviation of 4.05. This shows that economic growth has large fluctuations, including the possibility of negative extreme values.

**Heterokedasticity Test**

Based on the results of the heterocedasticity test in Table 3, it can be concluded that the regression model does not show any indication of heteroscedasticity. This can be seen from the probability values for all independent variables, namely REC of 0.4410, DIG of 0.4961, and GROWTH of 0.5492, all of which are above the significance level of 5 percent. That is, there is not enough evidence to reject the null hypothesis that the variance of the residual is constant (homoskedasticity).

**Table 3.**  
**Heterokedasticity Test**

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.000621	4.30E-05	14.44792	0.0000
REC	-8.44E-07	1.09E-06	-0.773811	0.4410
YOU	-2.00E-07	2.93E-07	-0.683405	0.4961
GROWTH	8.15E-07	1.36E-06	0.601185	0.5492

Source: Eviews, (2025)

**Multicollinearity Test**

Based on Table 3, no serious indication of multicollinearity was found between independent variables. Although the correlation between renewable energy and internet penetration of -0.7629 and ecological footprint and renewable energy of -0.7329 is quite high, both are still below the threshold of 0.80. The economic growth variable also showed a low correlation with other variables. Thus, the model is declared free of multicollinearity problems and is worthy of further analysis.

**Table 4.**  
**Multicollinearity Test**

	EFP	REC	YOU	GROWTH
EFP	1.000000	-0.732874	0.660555	-0.014120
REC	-0.732874	1.000000	-0.762900	0.040049
YOU	0.660555	-0.762900	1.000000	-0.232015
GROWTH	-0.014120	0.040049	-0.232015	1.000000

Source: Eviews, (2025)

**Model Estimation Results**

The result of the chow test was 0.0000 and the thirist test result was 0.0470 showed that the Fixed Effect Model (FEM) was selected as the best model in the study. The regression results show that renewable energy consumption, internet penetration, and economic growth have a significant influence on the ecological footprint. The interception coefficient of 3.369 shows that when renewable energy consumption, internet penetration, and economic growth are both zero, then the average ecological footprint is predicted to be worth 3.369419 GHA per person. Renewable energy consumption shows a coefficient of -0.022 with a very high significance, which means that a one percent increase in renewable energy consumption will reduce the ecological footprint by 0.022 GHA per person. This underscores the great potential of renewable energy in reducing the ecological footprint.

**Table 5.**  
**Fixed Effect Model Estimation Results**

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3,369419	0,053309	63,20568	0,0000***
REC	-0,022428	0,001324	-16,94013	0,0000***
YOU	-0,002464	0,000316	-7,788641	0,0000***
GROWTH	0,001777	0,000883	2,013283	0,0470**
R-squared	0,992699	Mean dependent var		30,85941
F-statistic	1264,572	Durbin-Watson stat		1,867943
Chow Test				0,0000***
Hausman Test				0,0165**
Normality Test				0,343654
<b>Cross Section Effect</b>				
Indonesia	-1.138270			
Laos	-0.344781			
Myanmar	-0.680896			
Malaysia	1.091951			
Philippines	-1.454935			
Singapore	3.499476			
Thailand	-0.401425			
Vietnam	-0.571119			

Sumber : Author Compilation, (2025)

Note : \*,\*\*,\*\*\* is the Significance level of 10%, 5%, and 1%Source : Eviews, (2025)

On the other hand, internet penetration has a coefficient of -0.002 with very high significance, which means that a one percent increase in internet penetration will reduce the ecological footprint by 0.002 GHA per person. This means that internet penetration also supports reducing the ecological footprint in the ASEAN Region. On the other hand, economic growth has a coefficient of 0.001 and is significant at the level of 5 percent, which indicates that an increase of one percent in economic growth will add to the ecological footprint. This means highlighting the role of economic growth in contributing to the ecological footprint in the ASEAN region.

Based on the cross-section effect between individuals, the country with the largest negative effect value was the Philippines (-1.454935), followed by Indonesia (-1.138270) and Myanmar (-0.680896). This negative value indicates that these countries have fixed structural factors or characteristics that tend to worsen environmental conditions, even though they have taken into account renewable energy consumption, internet penetration, and economic growth. This can reflect internal challenges such as high dependence on fossil energy, weak environmental policies, or less sustainable industrialization practices.

Meanwhile, Vietnam, Thailand, and Laos also had negative effects, but on a more moderate scale, indicating that the influence of their internal characteristics on environmental sustainability was not as bad as previous countries. On the other hand, Malaysia and Singapore showed positive effect values, amounting to 1.091951 and 3.499476, respectively. This means that both countries have structural conditions that consistently support

environmental sustainability, likely due to the implementation of green policies, higher energy efficiency, and the development of clean technologies. Singapore, with the highest positive scores, stands out as the country that most strongly supports environmental sustainability in the ASEAN region.

### **The Relationship between Renewable Energy Consumption and Ecological Footprint**

The renewable energy transition has an important role in efforts to mitigate the ecological footprint, especially in the ASEAN region, which has been experiencing environmental pressure due to rapid economic growth, urbanization and high dependence on fossil-based energy. The substitution of fossil energy sources to renewable energy will directly reduce greenhouse gas emissions, especially carbon dioxide, which is a major component of the ecological footprint. The results of this study answer the research hypothesis and are in line with previous research (Amin et al., 2024; Rehman et al., 2019). In the ASEAN region, the energy sector is a major contributor to the ecological footprint through greenhouse gas emissions from coal- and oil-fired power plants (Oanh & Huy, 2024). The consumption of solar, wind, hydro and bioenergy energy lowers carbon intensity and reduces the inequality between human demand for nature and the regenerative capabilities of the biosphere (Paraschiv & Paraschiv, 2023).

Renewable energy produces much lower emissions with fossil energy not only releasing large amounts of CO<sub>2</sub> but also polluting the air with harmful particles and toxic gases (Holeczek et al., 2022). Based on Figure 3, Indonesia and Thailand have increased the capacity of solar power plants and wind has begun to replace coal-fired steam power plants, helping to reduce carbon intensity in the national energy system (Clark et al., 2020). In addition to reducing emissions, the process of consuming renewable energy also minimizes pressure on terrestrial and marine ecosystems. Fossil energy infrastructure such as coal mines or oil refineries often leads to deforestation, land degradation, and water pollution (Kabeyi & Olanrewaju, 2022b).

In contrast, solar panel installations or wind turbines can be placed on unproductive land or roofed buildings so that they do not require large-scale land conversion (Dhar et al., 2020). This is especially important for the ASEAN region which has tropical ecosystems with a high level of biodiversity and crucial ecological functions such as rainforests and peatlands (Mishra et al., 2021). ASEAN countries help maintain local and global climate stability by avoiding the opening of new land for energy infrastructure. In addition, the integration of renewable energy is accompanied by the application of energy efficiency technology and intelligent power grid systems that reduce energy wastage and strengthen the reliability of distribution systems. This efficiency also reduces the need for infrastructure expansion that can damage the environment. In addition, renewable energy consumption also supports a circular economy and sustainable waste management (Tan et al., 2021). Biomass and biogas produced from agricultural or organic waste can be converted into clean energy sources so that it can reduce dependence on fossil fuels while solving waste problems (Kabeyi & Olanrewaju, 2022a).

Malaysia and Vietnam, palm oil waste and agricultural residues have been utilized as biomass power generation fuel, which not only reduces the environmental burden but also increases the economic value of waste (Kaniapan et al., 2021). Not only that, renewable energy opens up opportunities for decentralized and community-based energy systems, especially in remote areas. This reduces the need for major infrastructure development such

as long-distance power grids that often damage landscapes and trigger land-use conflicts (Ahmad et al., 2022). Thus, the process of energy consumption in the ASEAN region has made a significant contribution to reducing the ecological footprint through emission reduction, ecosystem conservation, resource efficiency, and energy system transformation towards a more sustainable and inclusive direction.

### **The Relationship of Internet Penetration and Ecological Footprint**

The results of the model estimation (Table 4) show that internet penetration has a negative and significant effect on the ecological footprint. This means that the spread of internet penetration will reduce the ecological footprint, especially in ASEAN countries. Increased internet access in Singapore, Malaysia, Thailand, Indonesia, Vietnam, and the Philippines has changed people's lifestyles, ways of working, and production systems from conventional resource-intensive methods to more efficient and low-emission digital systems. Through digital connectivity, various economic and social activities can now be carried out without the need for high physical mobility. Digital connectivity has a direct impact on reducing the use of fossil fuels, decreasing air pollution, and reducing carbon emissions from the transportation and industrial sectors. The implementation of e-commerce, e-banking, and e-government also reduces the consumption of paper, ink, and operational energy in government and private offices. In addition, the increasingly widespread trend of teleworking and e-learning allows people to work and study from home, thereby saving transportation energy and reducing the daily carbon footprint of urban communities (Mouratidis & Papagiannakis, 2021).

ASEAN shows that the implementation of internet penetration has a positive impact on energy efficiency and resource management. Singapore is a pioneer with the Smart Nation concept that integrates digital technology in transportation, energy, and waste management, thereby significantly reducing carbon emissions. Malaysia is implementing smart city systems in Kuala Lumpur and Putrajaya that utilize sensors and the Internet of Things (IoT) to monitor energy and water consumption in real time, while improving the efficiency of resource distribution. Thailand 4.0 policy emphasizes digital innovation in the industrial and agricultural sectors to optimize energy use and reduce waste. Vietnam is also undergoing a major transformation through the penetration of the internet, economy, and government with the use of digital technology to support energy efficiency and minimize industrial waste. Meanwhile, the Philippines and Indonesia are experiencing rapid growth in internet usage, which has prompted people to switch to digital transactions, remote work, and online services that reduce mobility and fossil fuel use. Laos and Myanmar, while still lagging behind in digital penetration, are starting to show progress with the application of renewable energy-based technologies to expand internet access in remote areas, which indirectly supports environmental efficiency through reduced physical travel and fuel consumption (Akin & Ozgun, 2024).

Furthermore, internet penetration also opens up wider access to environmental information and innovations throughout the ASEAN region. Through digital platforms and social media, the public can participate in campaigns regarding renewable energy, waste management, and environmentally friendly lifestyles. Internet access strengthens public participation in the digital circular economy, such as the use of used goods buying and selling applications, ride-sharing services, and household waste management applications. This not only reduces the consumption of new resources, but also extends the product life cycle and

reduces waste accumulation (Kwilinski & Lyulyov, 2023). The role of internet penetration in education and environmental awareness is also increasingly prominent, where people in rural and urban areas can gain knowledge about sustainability through online platforms without geographical boundaries.

However, advances in internet penetration also pose new challenges to the environment. The rapid growth of the use of the internet and digital technology has led to increased energy consumption by data centers and the production of electronic waste (e-waste) which has the potential to pollute the environment if not managed properly (Georgiana et al., 2024). Countries such as Indonesia and Vietnam are starting to face increasing electricity needs to support the ever-growing digital infrastructure. Therefore, it is important for ASEAN countries to adopt green digital infrastructure, expand the use of renewable energy in data centers, and implement electronic recycling policies comprehensively. Such measures can ensure that the benefits of internet penetration to the reduction of ecological footprint are not masked by their negative impacts.

### **The Relationship between Economic Growth and Ecological Footprint**

Economic growth contributes to increasing the ecological footprint, especially in the ASEAN region, because the development process is still dependent on the exploitation of natural resources and fossil energy. As gross domestic product increases (Figure 4), the demand for energy, land, water, and raw materials has also increased sharply. Indonesia, Malaysia, Thailand, and Vietnam experienced economic growth driven by the expansion of the industrial, mining, oil palm and rubber agriculture sectors, as well as rapid urbanization (Samphantharak, 2019). These activities increase the pressure on the carrying capacity of the environment which leads to deforestation, land degradation, air and water pollution, and increased carbon emissions, all of which contribute directly to the increase in ecological footprint (Kumar et al., 2022).

The ASEAN region also faces major challenges in terms of energy divestment. The majority of countries in the ASEAN region are still highly dependent on fossil energy such as coal and petroleum, which have high carbon emission intensities (Lau et al., 2022). Despite efforts to adopt renewable energy, the energy transition is still very slow and has not been able to significantly reduce the ecological footprint (Li et al., 2022b). Based on the environmental kuznets curve (EKC) theory in the early stages of economic growth, environmental damage will increase but after reaching a certain level of income the state begins to allocate resources for clean technology and effective environmental regulations (Prasetyanto et al., 2021). However, in ASEAN countries, not all countries have reached this turning point.

In addition, this increase in ecological footprint is due to changes in people's consumption patterns that are increasingly consumptive (Ashery, 2022). When people begin to have higher purchasing power, there will be an increase in demand for consumer products, especially products that are not environmentally friendly (Mahaputra & Saputra, 2022). This consumption pattern increases carbon emissions and solid waste and increases the need for energy (Razzaq et al., 2021). Not only from the domestic side, ASEAN's ecological footprint is also influenced by the region's role as a global production center and international supply chain (Ashari et al., 2024). Environmental and institutional governance also plays an important role in controlling the ecological footprint in the midst of economic growth (Ahmed et al., 2022). As well as weak environmental law enforcement, low transparency in

resource management, and limited capacity of public institutions in some ASEAN countries are often obstacles to implementing sustainable development policies (Dwi & Margaretha, 2024).

## CONCLUSION

The transition to renewable energy can reduce the ecological footprint in the ASEAN region, which has been heavily dependent on fossil energy and faces environmental pressures due to rapid economic growth and urbanization. Renewables such as solar, wind, hydro, and bioenergy not only significantly reduce greenhouse gas emissions, but also minimize ecosystem damage and extensive land conversion needs. In addition, internet penetration also contributes to reducing the ecological footprint through clean technology transfer, environmental market integration, and the implementation of global sustainability standards that encourage resource efficiency and better environmental regulation in ASEAN countries. However, economic growth, which is still highly dependent on the exploitation of natural resources and fossil energy, coupled with increasingly consumptive consumption patterns, continues to increase pressure on the environment and enlarge the ecological footprint. Despite efforts to transition energy and the adoption of clean technologies, the pace of change is still slow and institutional challenges and weak law enforcement are obstacles to the implementation of sustainable development.

To effectively reduce the ecological footprint, ASEAN governments need to accelerate the transition to renewable energy by strengthening policies and incentives, as well as increasing public education on clean energy. In addition, the utilization of internet penetration should be optimized through the adoption of green technologies, international environmental standards, and sustainable business practices supported by the integration of carbon market policies and green certification. The management of economic growth should be directed at diversification into the low-carbon sector, with better law enforcement and natural resource governance to minimize environmental impacts. The development of community-based decentralized energy systems also needs to be encouraged to reduce dependence on large infrastructure that damages the environment. Finally, increasing public awareness and participation in energy and natural resource management is essential to encourage changes in consumption patterns towards a more environmentally friendly and sustainable one.

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