Ecological Footprint Study as an Indicator of Sustainable Economic Development in ASEAN Countries

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Abstract. The ecological footprint is a metric that can be used to assess the state of environmental carrying capacity and the sustainability of economic development. The objective of this study is to examine the long-term impact of GDP per capita, trade openness, and energy use on the ecological footprint in ASEAN countries. The study utilizes panel data from 2000 to 2019 across eight ASEAN nations. Secondary data was gathered from authoritative sources such as the Global Footprint Network (GFN), the World Bank, and Our World in Data. The study employed the Fully Modified Ordinary Least Square (FMOLS) analysis approach. In this study, the ecological footprint serves as the dependent variable, while the independent variables include GDP per capita, trade openness, and energy use. The study's findings indicate that GDP per capita has a positive but statistically insignificant impact on the ecological footprint in high-income nations over the long term. Conversely, in middle-income countries, GDP per capita has a positive and statistically significant effect on the ecological footprint over the long term. In high-income nations, trade openness has a positive but statistically insignificant impact on the long-term ecological footprint. However, in middle-income countries, trade openness has a positive and statistically significant impact on the long-term ecological footprint. Energy usage in both high- and middle-income countries has a significant and positive effect on the long-term ecological footprint.

Keywords: Ecological Footprint, FMOLS, Sustainable Economic Development

1 Introduction

Climate A key concern in economic development is the choice between addressing development needs and prioritizing environmental sustainability. The carrying capacity of natural resources and the environment is inherently finite. Therefore, economic development that relies on natural resources without considering environmental sustainability has a detrimental effect on ecosystems. Sustainable economic growth emphasizes the optimal utilization of natural resources and the preservation of the environment. The long-term efficiency and effectiveness of economic development are contingent upon sustainability [1]. Sustainable economic development is achieved when the utilization of natural resources does not exceed the rate of natural replenishment and does not generate waste at a faster rate than the environment can absorb [2]. An essential factor in ensuring the long-term sustainability of economic development is the concept of environmental carrying capacity.

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Carrying capacity consists of two elements: supply capacity, which refers to the ability to support a certain population, and waste storage capacity, which refers to the ability to handle and process waste produced by that population. Supply capacity relates to the environment's ability to sustain biological life, while waste storage capacity, also known as holding capacity, refers to the environment's ability to absorb materials, energy, or other components introduced or deposited into it [3]. The ecological footprint is a useful indicator for evaluating the state of environmental carrying capacity.[1]

The ecological footprint concept was initially introduced by William Rees and Mathis Wackernagel in the 1990s. The ecological footprint is a quantitative method used to assess the quantity of natural resources required by a specific activity or behavior. The ecological footprint, as defined by the Global Footprint Network (GFN), quantifies the amount of biologically productive land and water needed by humans, populations, or activities to generate the natural resources they consume and to assimilate the waste they produce, particularly carbon emissions [4]. An ecological deficit occurs when the ecological footprint of a region surpasses its biological capacity, resulting in a shortfall of resources. Conversely, if the biological resources a region can produce exceed the resources it consumes, the area is said to have an ecological reserve [5].

The ecological footprint is included in Sustainable Development Goal No. 12, which pertains to promoting responsible consumption and production. To achieve economic growth and sustainable development, it is crucial to recognize the significance of altering how we produce and consume food and other resources to minimize our impact on the environment. Efficiently managing shared natural resources and properly disposing of toxic waste and pollutants are critical tasks to accomplish this goal [6].

The correlation between the rise in economic growth in the ASEAN region and its effect on the environment is undeniable. ASEAN countries account for 82% of global natural rubber production, as well as 70%, 56%, and 50% of global production of coconut, tin, palm oil, and hardwood products, respectively. Moreover, many countries in this region possess substantial reserves of environmentally harmful petroleum and coal [7]. According to GFN data from 2023, the ecological footprint in the ASEAN area has consistently exceeded its biocapacity since 1993.

Figure 1 shows the average ecological footprint and biocapacity per capita in eight ASEAN countries from 2000 to 2019. Singapore has the highest ecological deficit per capita at -6.87 gha, where the average ecological footprint is 6.96 gha and the biocapacity is only 0.09 gha. Brunei Darussalam follows in second place with an ecological deficit of -3.34 gha, where the ecological footprint is 6.40 gha and the biocapacity is 3.06 gha. Malaysia is next, with an ecological deficit of -1.70 gha, where the ecological footprint is 4.07 gha and the biocapacity is 2.37 gha. Among the eight ASEAN countries, Indonesia and Cambodia have the lowest ecological deficits at -0.14 gha and -0.16 gha, respectively.

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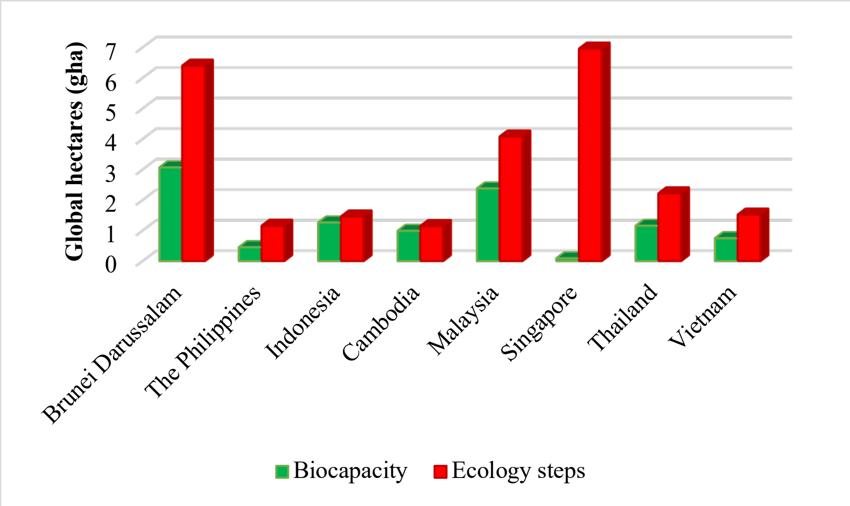

Fig. 1. Average Ecological Footprint and Biocapacity Per Capita in 8 ASEAN Countries 2000-2019

Source: Global Footprint Network, 2019

Research on ecological footprints is important because ecological footprint analysis is a useful indicator of sustainability. It provides insight into the carrying capacity and environmental capacity—or the Earth's biocapacity—by showing the consumption required by humans and the waste (emissions) produced. This analysis can reveal that the current rate of human exploitation of the environment exceeds the Earth's biocapacity to regenerate and assimilate waste. Magazzino states that GDP per capita can increase the ecological footprint. The relationship between GDP and the ecological footprint highlights that an increase in the ecological footprint accompanies higher consumption and production, which are closely related to the demand for natural resources and environmental use [5]. Several studies indicate a relationship between GDP per capita and the ecological footprint. The relationship between economic growth and the environment is also illustrated by the Environmental Kuznets Curve (EKC), which takes the shape of an inverted U [8]. Another variable thought to influence the ecological footprint is trade openness, measured by the ratio of imports and exports to GDP. Trade openness can drive economic growth but may also negatively impact the environment due to higher production levels and greater exploitation of natural resources [9].

Energy, economy, and the environment are closely interconnected. Energy serves as a basic input in the production process and is as fundamental as capital and labor. Given its extensive use, a sustainable energy supply is essential for maintaining and increasing production levels and living standards across countries [1]. Any reduction in energy supply can affect economic growth, making energy consumption and production processes crucial for sustainable economic development. The purpose of this study is to analyze the long-term influence of GDP per capita, trade openness, and energy consumption on the ecological footprint in ASEAN countries categorized as low-income and middle-income.

2 Literature Review

Ecological Footprint

William Rees first introduced the term "ecological footprint." The calculation of the ecological footprint is then compared to the available biocapacity. Both the ecological footprint and biocapacity are expressed in global hectares (gha). Biocapacity refers to the total biologically productive area in a region and is defined as the ability of an ecosystem to support biodiversity, produce energy and biological materials, and absorb and recycle waste from human activities, including carbon emissions. Comparing the ecological footprint and biocapacity indicates whether the ecological footprint is in deficit or surplus and shows how much land is available to support human consumption. Examples of ecological footprint and biocapacity values, expressed in units of area needed to provide an ecosystem, include agricultural land (arable land) for staple foods, pastures for livestock products, seas or fishing areas for seafood, forests for wood and other forest products, land to absorb carbon emissions, and urban areas for housing and infrastructure [4]. Moffat asserts that the ecological footprint contributes to achieving sustainable human development for present and future generations who live in harmony with nature [10].

3 Research Methods

The data used in this study is secondary data in the form of a panel, which combines time series data and cross-sectional data. The time series data covers the years 2000 to 2019, while the cross-sectional data includes eight ASEAN member countries: high-income countries such as Brunei Darussalam and Singapore, and low-income countries such as the Philippines, Indonesia, Cambodia, Malaysia, and Thailand. The data was obtained from publications including the Global Footprint Network, the World Bank, and Our World in Data. The model used in the study refers to the model employed in the research of Usman & Makhdum [6]. Two equations are used in the study: one for high-income countries and one for middle-income countries.

$$\mathbf{lnEF_{it} = \beta_0 + \beta_1\, lnGDP_{it} + \beta_2\, lnTO_{it} + \beta_3\, lnKE_{\,it} + \varepsilon_{it}} \tag{1}$$

where:

EF_{it} = Ecological Footprint (gha)
GDP_{it} = GDP per capita (USD)
TO_{it} = Trade Openness (%)
$KE_{\,it}$ = Energy Consumption (KWh)
β_0 = Constant
$\beta_{1,2,3}$ = Coefficient
ε_{it} = *error term*
i = 2 high income countries, 6 middle income countries
t = Year
ln = Natural logarithm

3.1 Operational Definition of Variables

1. Ecological Footprint Per Capita

The ecological footprint used in this study is measured per capita in global hectares (gha). It consists of six sub-footprints: carbon footprint, fishing ground footprint, forest footprint, agricultural land footprint, built-up land footprint, and grazing land footprint.

2. Gross Domestic Product (GDP)
   The GDP per capita is calculated at constant 2015 prices and expressed in USD.
3. Trade Openness
   Trade openness is defined as the ratio of exports and imports to GDP, expressed as a percentage (%).
4. Energy Consumption
   Energy consumption is measured per capita in kilowatt-hours (kWh).

3.2 Data Analysis Procedure

1. Panel Unit Root Test
   To conduct a panel unit root test, Fishe's method is used to combine the p-values of individual unit root tests. The approach involves performing separate ADF regressions for each cross-section, following the Phillips-Perron (PP)-Fisher test.
2. Cointegration Test
   The cointegration test determines whether there is a long-term equilibrium among the variables (Sekaran, 2017). The Kao Residual Cointegration Test is used to assess long-term equilibrium between variables. This test follows the unit root test to evaluate whether the variables are integrated with each other. The hypotheses for the cointegration test are:
   - H_0: There is no cointegration between variables.
   - H_1: There is a cointegration between variables.
3. Fully Modified Ordinary Least Squares (FMOLS)
   After performing the cointegration test, the next step is to use the Fully Modified Ordinary Least Squares (FMOLS) method to analyze the long-term influence between the independent and dependent variables. Introduced by Phillips and Hansen in 1990, FMOLS is designed to provide optimal results for models with cointegration in regression. FMOLS modifies the Ordinary Least Squares (OLS) method by addressing issues such as serial correlation/autocorrelation and endogeneity due to the cointegration relationship between variables [11].

4 Discussion

High Income Countries

Table 1. Cointegration Test (Kao)

	t-Statistic	Prob.
ADF	-2.886605	0.0019
Residual variance	0.017715	
HAC variance	0.011473	

Source: data processed, 2024

The equation model has a probability value that is smaller than the α value of 5%, which is 0.0019. Therefore, it can be concluded based on this value that all variables used in this study are co-integrated or have a long-term relationship.

Table 2. Regression Test Results (FMOLS)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LN_GDPC	0.020664	0.130542	0.158297	0.8752
LN_KP	0.157141	0.211501	0.742982	0.4627
LN_KE	0.236994	0.108329	2.187722	0.0359
R-squared	0.247707	Mean dependent var		1.888524
Adjusted R-squared	0.156520	S.D. dependent var		0.115024
S.E. of regression	0.105640	Sum squared resid		0.368273
Long-run variance	0.009052			

Source: data processed, 2024

Middle Income Countries

Table 3. Cointegration Test (Kao)

	t-Statistic	Prob.
ADF	-1.845245	0.0325
Residual variance	0.002174	
HAC variance	0.001673	

Source: data processed, 2024

The equation model has a probability value that is smaller than the α value of 5%, namely 0.0325. Therefore, it can be concluded based on this value that all variables used in this study are co-integrated or have a long-term relationship.

Table 4. Regression Test Results (FMOLS)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LN_GDPC	0.298342	0.119380	2.499099	0.0140
LN_KP	0.306364	0.094563	3.239787	0.0016
LN_KE	0.180779	0.089620	2.017173	0.0462
R-squared	0.975739	Mean dependent var		0.544921
Adjusted R-squared	0.973891	S.D. dependent var		0.465743
S.E. of regression	0.075257	Sum squared resid		0.594673

Long-run variance	0.010465

Source: data processed, 2024

Based on the estimation results from the FMOLS model, GDP per capita has a positive but insignificant long-term effect on the ecological footprint in high-income countries and a positive and significant long-term effect in middle-income countries. As GDP per capita or welfare increases, people gain more purchasing power, which stimulates greater consumption and production activities. This leads to increased use of natural resources. Higher production of goods and services also drives industrialization, which can raise energy consumption as fuel is needed to operate industrial machinery. The combustion of this energy results in carbon emissions or a carbon footprint. Additionally, the limited availability of environmentally friendly production methods in the long term impacts the carbon footprint.

Trade openness has a positive but insignificant long-term effect on the ecological footprint in high-income countries, while it has a positive and significant long-term effect in middle-income countries. Trade has grown rapidly across ASEAN countries and between ASEAN and other countries worldwide. This trade integration has brought many benefits, particularly in technology, foreign investment, and international trade, leading to increased productivity, output, and growth. The region's economic growth rate has averaged 5.55% over the past three decades [7] .

The results of this study indicate that trade in ASEAN countries contributes to worsening environmental quality by increasing the ecological footprint in the long term. The positive effect of trade openness in the long term arises from increased economic activity, which drives industries to boost output and production to meet trade demands. This increased output leads to greater use of natural resources and, consequently, higher energy consumption and carbon emissions.

Energy consumption has a positive and significant long-term effect on the ecological footprint in both high- and middle-income countries. Energy is crucial for social and economic development and human activities. Energy consumption includes the industrial, household, commercial, transportation, agricultural, construction, and mining sectors, with oil, natural gas, and coal being the dominant sources [12]. Currently, the world's energy use is still largely dependent on these primary energy sources [13]. The positive impact of energy consumption on the long-term ecological footprint is due to the ASEAN region's heavy reliance on non-renewable energy sources, with some countries even importing these resources. This suggests that the region has not yet adopted environmentally friendly energy on a large scale. High costs associated with renewable energy, such as solar panels, continue to make petroleum, coal, and other fossil fuels the preferred energy sources [14]. The increased consumption of non-renewable energy leads directly to higher carbon emissions, which necessitates more land or areas for carbon absorption. Therefore, energy consumption positively impacts the long-term ecological footprint [15].

5 Conclusion

GDP per capita has a positive but insignificant long-term effect on the ecological footprint in high-income countries, and a positive and significant long-term effect in middle-income countries. Trade openness has a positive but insignificant long-term effect on the ecological footprint in high-income countries, while it has a positive and significant long-term effect in middle-income countries. Energy consumption has a positive and significant long-term effect on the ecological footprint in both high- and middle-income countries.

6 Suggestions

The government should continue to support and encourage the development of the energy sector, particularly by investing in renewable energy infrastructure to lower production costs for renewable energy. Additionally, programs should be introduced to transition from environmentally harmful energy sources to renewable energy. One approach could be to reduce subsidies for primary or fossil fuels and redirect those funds to support renewable energy initiatives, thereby reducing the carbon footprint.

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