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Environmental Sustainability in Southeast Asia: Evidence from Linear and Nonlinear Unit Root Tests and Policy Implications

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Abstract

This study focuses on Southeast Asian countries that have attracted attention with their recent economic growth performance. The validity of environmental sustainability is investigated through data for the period 1973–2022. For this purpose, ecological footprint data from Indonesia, the Philippines, Cambodia, Malaysia, Singapore, Thailand and Vietnam are used. Unit root tests with various power properties are used in the study. Firstly, ADF and PP unit root tests based on the Dickey–Fuller unit root test procedure are used in the study. In addition, among the non-linear unit root tests, Leybourne *et al*. (1998) and Harvey and Mills (2002) unit root tests were used. On the other hand, Hepsağ (2021) unit root test, which includes gradual structural breaks and is among the current non-linear unit root tests, was performed. Results vary depending on unit root tests of different strengths. In general, the validity of environmental sustainability, in other words, convergence, is concluded. These results mostly show the effectiveness of regional and global policies. Some results have revealed that convergence is not valid in some countries, the invalidity of environmental sustainability, and emphasized the effectiveness of national policies.

Keywords: Environmental sustainability, convergence, nonlinear unit root, Southeast Asian countries

JEL Classification: Q53, Q56, C22

1. Introduction

Environmental degradation has become a global problem. Preventing environmental degradation and improving environmental quality are important research topics. In this context, how to ensure environmental sustainability is one of the main focal points. This issue, which has become a serious concern of both politicians and researchers, has increased its importance with the risks of global warming and climate crisis (Nguyen *et al*., 2023). Climate change has become a global problem. Many studies suggest that the main source of this problem is global warming (Ogunbode *et al*., 2020). Conferences and programs are being addressed on a global scale to solve the global warming problem. The most well-known of these are the Kyoto Protocol and the Paris Climate Agreement. The Kyoto Protocol, which aims to oblige industrialized countries to reduce greenhouse gases, was signed in 1997. The Paris Climate Agreement was signed in 2015 as part of the United Nations Framework Convention on Climate Change (UNFCCC). This agreement aims to limit global warming to well below 2 °C above pre-industrial levels. Thus, it aims to soften the effects of climate change. The search for solutions prioritizes the reduction of environmental degradation. In this context, sustainable development goals are put forward. In line with these goals, there is a global consensus on the urgency of changing the traditional "take-build-use-dispose" economic model. Despite these efforts and initiatives, 2016 was documented as the hottest year on record. The most important reason for this situation is considered to be increasing environmental degradation (D'Orazio *et al*., 2024).

Environmental degradation is caused by the accumulation of harmful greenhouse gas emissions that are trapped in the environment. These emissions are seen as a serious problem for the future use of fossil energy in general and coal in particular. Greenhouse gas emissions, which are a combination of various gases such as methane (CH_4), nitrous oxide (N_2O), carbon dioxide (CO_2) and sulfur hexafluoride (SF_6), have serious impacts on environmental quality (Smoot and Baxter, 2003). Among these gases, carbon, which accounts for about 81% of greenhouse gas emissions, stands out as the most important factor accelerating environmental degradation. Greenhouse gas emissions can increase as local vegetation is converted to agriculture and livestock farming. In this context, the increasing population and demand for land for agriculture, infrastructure development and urban expansion have led to significant changes in land use patterns, resulting in a decrease in forest cover and biodiversity (Kasahun, 2025). Deforestation, which started with the temperate regions of the world and reached high levels, has occurred to a lesser extent in tropical regions.

Deforestation rates have been on a decreasing trend in the 21st century. Vietnam, which is among the Southeast Asian countries, draws attention with its positive trend in terms of deforestation. Factors such as economic growth, population, energy consumption and industrializa-

tion can be effective in the decline of environmental quality (Özbek and Naimoğlu, 2022; Oğul, 2023). The main reason for this situation is the CO_2 emission increasing effects of the related increases. The process of negatively affecting the global biosphere in line with economic growth targets has reached very high levels today. So much so that 55% of the terrestrial biosphere comes under human use. of the 45%, 25% is left to the natural state and 20% to the semi-natural state (Ojogiwa, 2021). These developments reveal the necessity of reducing environmental degradation for the sustainability of economic growth.

The concept of convergence has gained importance with the globalization period. According to the neoclassical growth approach, convergence occurs when the difference in per capita income levels of countries that initially divided nations into different income groups disappears over time as these countries share the same rates in terms of savings, population growth and technical progress (Solarin *et al*., 2019). On the other hand, the recent increase in cryptocurrency production can cause serious impacts on the environment. Within the scope of cryptocurrency civilization, the amount of energy used by machines is increasing. With increasing energy consumption, it may cause environmental degradation, especially Bitcoin production (Erdogan *et al*., 2022). Thus, efforts to reduce pollution between countries/regions through convergence or divergence of pollution indicators can become an important policy. Convergence research, which can provide practical suggestions on how to achieve environmental sustainability, can provide regional/national policy recommendations against environmental problems. Environmental sustainability research is of great importance in revealing these solutions. In this context, it is seen that CO_2 emission convergence is included in the literature. However, there are limited number of studies on ecological footprint convergence. Ecological footprint helps to observe the impact of human activities on the environment. The ecological footprint, which stands out as an important indicator for a sustainable environment, can also be expressed as the rate of use of biological capacity. The ecological footprint stands out as a comprehensive indicator for sustainable development and natural capital use (Zhang *et al*., 2024).

In this study, the validity of environmental convergence is investigated in Southeast Asian countries. The relevant countries stand out on a global scale with their high growth performances. The 2024 IMF growth forecasts for Indonesia, Philippines, Cambodia, Malaysia, Singapore, Thailand and Vietnam are 4.96, 5.32, 5.65, 3.96, 1.04, 2.7 and 5.82, respectively. According to these data, Vietnam has the highest growth expectation. According to IMF-2024 estimates, the population data for Indonesia, Philippines, Cambodia, Malaysia, Singapore, Thailand and Vietnam are 279,965,000, 112,893,000, 16,153, 33,059,000, 5,659,000, 70,266,000 and 100,770,000, respectively. According to these data, it is understood that the Philippines and Vietnam are the countries with the highest population after Indonesia within the framework of the IMF forecast. Vietnam's increasing population and high growth rate expectation draws attention. Based on studies sug-

gesting that energy consumption and population used in the process of economic growth increase environmental pollution, it is evaluated that the projections for 2024 in Southeast Asian countries contain important information for environmental sustainability. Considering the IMF forecasts, it is understood that the relevant country group will have a significant population and will continue its high growth performance in the future perspective as well as its past performance.

It is known that Vietnam, one of the Southeast Asian countries, was one of the poorest countries in the world about 30 years ago. Currently ranked 38th in the world, Vietnam is projected to be among the top 20 economies by 2028 (IMF, 2024). It is argued that this dynamic process of Vietnam may lead to significant developments in other countries in the region. Malaysia, Vietnam, Indonesia and Thailand, which stand out with their high growth rates among Southeast Asian countries, account for approximately 80% of energy demand (IEA, 2024). These countries are dependent on fossil fuels such as coal and oil. This leads to an increase in energy consumption from fossil fuels in these countries. Energy is used intensively in economic growth activities. CO_2 is released with this use. CO_2 emissions increase with increasing economic activity. This situation is among the main reasons for the global climate crisis and environmental pollution (Aslan *et al*., 2025). ASEAN member countries, which stand out as a union of Southeast Asian countries, present important predictions for the coming periods. Medium-term targets have been updated in 2020-2021. Within the framework of updated national decisions, they are committed to reducing energy intensity by 30% by 2025. However, the current region's emission trajectory is not seen as compatible with a 1.5 or 2 degree scenario (Qiu *et al*., 2024). These measures, which are expected to reduce environmental degradation, are of serious importance. However, considering the dependence of the economic growth performance of these countries on energy consumption from fossil fuels, it is possible that some problems may occur in terms of macroeconomic indicators. The main motivation of the study is the high growth performance and environmental results in ASEAN countries, the distribution of environmental burdens in ASEAN countries and the course of developments within the countries and the group, whether ASEAN can act together as a country group in terms of environmental sustainability, the existence of environmental risks from a regional perspective and what the risks may be. Providing the correct answer to these questions is considered important both for ASEAN countries and the group. In this context, in-depth analyses should be made for countries. It is evaluated that the results to be obtained may have serious importance in taking important steps both nationally and globally for countries with significant potential in the future.

This study aims to determine the validity of environmental sustainability in Southeast Asian countries. For this purpose, the ecological footprint variable was used. Unit root tests with different power characteristics were used for this country group. It is aimed to provide both empirical and theoretical contributions to the study by using traditional and new generation tests

simultaneously. In addition, the idea of whether the common environmental policy can be effective in the relevant country group was investigated with the convergence approach. The fact that no study was used using the variables and methods used in this study on the country group used distinguishes the study from the literature. The first difference that distinguishes the study from similar studies is the use of a more comprehensive variable, the ecological footprint, instead of the CO_2 indicator frequently used in the literature. The use of current data sets belonging to ASEAN countries in the study constitutes another original aspect of the study. The most important contribution of the study is the use of traditional unit root tests, which tend not to reject the null hypothesis, together with the methods based on nonlinear and Fourier approaches, which are stronger tests in terms of power characteristics. It is evaluated that correct policy inferences will be made by comparing the results by considering the test findings together. The study aims to contribute to the relevant field with its specified characteristics. Following this section, the second section provides an extensive literature review and discusses previous studies comparatively. The third section first presents the empirical methodology. Then, the data set is introduced and empirical findings are presented. In the fourth section, empirical findings are discussed, general evaluations are made and policy recommendations are presented.

2. Literature Review

There has been a recent increase in the number of studies on environmental sustainability. Studies are generally analyzed in the context of environmental degradation or environmental quality. In this context, the Environmental Kuznets Curve hypothesis is frequently used. This hypothesis investigates the relationship between economic growth and environmental degradation. This hypothesis, which argues that this relationship is in the form of an inverted-u, suggests that economic growth will increase environmental pollution in the first stage, and after a certain point (turning point), economic growth has a decreasing effect on environmental pollution. Various forms of the Environmental Kuznets Curve hypothesis have been thoroughly analyzed in the literature. There are studies arguing that the hypothesis is valid (Guo *et al*., 2021; Alola and Ozturk, 2021; Naimoğlu and Özbek, 2022; Ullah and Lin, 2024; Özbek and Naimoğlu, 2025) as well as empirical results showing that the hypothesis is invalid (Ahmed and Pata, 2024; Makarov and Alataş, 2024; Pata *et al*., 2024; Güler *et al*., 2025).

Another important hypothesis in the context of environmental sustainability is the pollution refuge hypothesis. According to this hypothesis, it is argued that environmental pollution will increase in developing countries as a result of the fact that developing countries offer more profitable investment opportunities in terms of trade and finance compared to developed countries. The studies defending the validity of this hypothesis are Güzel and Okumuş (2020) and Balsalobre-

Lorente *et al*. (2022). On the other hand, Kearsley and Riddel (2010) and Mert and Bölük (2016) find that this hypothesis is invalid. Time series and panel data techniques are preferred in these hypotheses. Among these techniques, long-run relationships are investigated through cointegration tests. The other examination technique of environmental sustainability is conducted through unit root tests. For this purpose, the variable related to environmental sustainability is determined and many procedures, especially various time series and panel data methods, are applied.

The most frequently used environmental variable in studies is CO_2 emissions (Altintas and Kassouri, 2020; Ali *et al*., 2024). CO_2 emission can cause environmental destruction by increasing greenhouse gas emissions. This destruction can lead to global problems such as temperature increase and climate change. Another environmental variable used is sulfur dioxide and nitrogen oxides (Gil-Alana and Solarin, 2018). In these studies, although limited in number, environmental sustainability and convergence theories have been considered together and studies have been carried out in countries or country groups. In this context, Yurtkuran (2020) examined N11 economies. The study utilized the ecological footprint variable as an environmental variable and used the 1971–2016 sample period. Fourier stationarity tests were utilized as the empirical method in the study. The results differed according to the countries. According to the results obtained, it is emphasized that common environmental policies for the group of countries included in the analysis will be effective for some countries and ineffective for others.

Heil and Selden (1999) investigated whether convergence is valid in the relevant countries by using CO_2 emissions in 135 countries. The sample period is 1950–1992 and panel unit root method is utilized. The results of the analysis showed that the unit root process is not valid in 115 countries. A similar study was conducted by List and Strazicich (2003) using the sample period 1960–1997. Time series and horizontal cross-sectional analyses were used as empirical methods. Empirical findings revealed that CO_2 emissions in 21 industrialized countries did not contain a unit root process. In 97 countries, Stegman (2005), who investigated the stationarity of CO_2 emission with distributional analysis, examined the sample period 1950-1999. The results show that stationarity is valid only in 26 countries.

Panopoulou and Pantelidis (2007), who examined the 1960–2003 period in a large data set consisting of 128 countries, utilized panel data analysis as a method. The results proved the stationarity of CO_2 emissions. Lee and Chang (2009), who conducted research on 21 OECD countries, utilized CO_2 emission data for the sample period 1950–2002. Using panel unit root tests as an empirical method, the study concluded that stationarity is valid. Applying a similar study to 35 Sub-Saharan African countries, Tiwari *et al*. (2016) examined the sample period 1960–2009. The results revealed that CO_2 emission has a unit root process in 20 countries. Gil-Alana *et al*. (2017) also conducted research on G-7 and BRICS countries in different sample periods. Time

series techniques with different power characteristics are used. The study utilizes a long-run dataset and employs a long-memory approach with nonlinear trends and structural breaks. It is concluded that shocks to CO_2 emissions in Germany, the US and the UK are transitory. In other words, the existence of stationarity in the relevant countries is found. The empirical results emphasize that the developed and emerging market economies included in the analysis contain differences.

Ahmed *et al*. (2016), who studied 162 countries in the sample period 1960–2010, investigated the validity of CO_2 convergence through wavelet unit root tests. The results revealed that convergence is not valid in a significant portion of the countries in the sample. Bilgili and Ulucak (2018) tested ecological footprint convergence in the G-20 country group using the panel KPSS method. Using the sample period of 1961–2014, the results showed the existence of convergence. In a similar study, Erdoğan and Okumuş (2021) utilized the Fourier panel KPSS method as an empirical method. In general, the findings are similar to Bilgili and Ulucak (2018). Cai *et al*. (2018) examined the stationarity of 2 emissions with data for the sample period 1950–2014. In the study of 21 OECD countries, empirical results showed that convergence in CO_2 emissions was realized in Austria, Finland, Japan, the Netherlands, Norway, Norway, Sweden, Switzerland and the USA as a whole. In other words, the existence of a unit root process was not found in these countries. Ulucak (2017) investigated the validity of the environmental convergence hypothesis with ecological footprint data for the sample period of 1961–2009 in 120 economies. The empirical methodology utilizes the club convergence test proposed by Phillips and Sul (2007). The empirical findings show mixed results. More precisely, the hypothesis of environmental convergence as a whole is not valid, but there is evidence that there are clubs where convergence is valid.

Özcan *et al*. (2019) analyzed high-income countries for ecological footprint convergence and used panel unit root tests as an empirical method. The existence of convergence was found in the study utilizing the 1961–2013 sample period. Yılancı and Pata (2020a), who conducted a similar study for the ASEAN-5 country group for the sample period 1961–2016, used the panel TAR method and the findings showed the validity of absolute convergence in Indonesia, Malaysia, Philippines, Thailand and Vietnam. Yılancı and Pata (2020b) investigated the stationarity of ecological balance in E-7 and G-7 countries. Six different LM-type unit root tests were applied by taking the difference between ecological footprint and biocapacity. In the study, in which the period 1961–2016 was used, it was concluded that the ecological balance contains a unit root in five countries (France, Canada, United Kingdom, Brazil, Russia) according to linear and non-linear unit root tests. In other countries, stationarity is valid. According to the unit root tests with structural breaks, it is concluded that the number of countries with stationarity is higher. Applying a similar study to G10 and N11 country groups, Yılancı and Pata (2021) utilized conventional, quantile and quantile unit root tests with smooth breaks as empirical methods. Ecological balance data for the period 1961–2016 were used in the study. The results of the study generally show that

positive or negative shocks to the ecological balance have a more persistent effect in G10 countries compared to N11 countries.

Işık *et al*. (2021), who investigated the validity of ecological footprint convergence in the country group including the USA, Canada and Mexico for the period 1961–2016 by using a similar method, found evidence for the existence of convergence. Performing a similar study in G7 countries in the same sample period, Yılancı *et al*. (2021) utilized the Fourier Threshold unit root test as an empirical method. The results showed the existence of convergence. Ursavaş and Apaydın (2023) tested the hypothesis of environmental convergence in G-7 countries for the sample period 1997–2018. Using greenhouse gas emissions as an environmental proxy, the study utilized the club convergence test proposed by Phillips and Sul (2007). Econometric findings show that the environmental convergence hypothesis is invalid in the G-7 countries in the relevant sample period. Tatar (2022) selected ASEAN-5 as the country group and investigated the existence of environmental convergence. The sample period of the study, which utilizes ecological footprint as an environmental variable, is 1973–2017. In the study, SURADF and SURKSS unit root tests were utilized as empirical methods and it was concluded that the ecological footprint does not contain a unit root process. In other words, strong evidence for the validity of convergence is presented. Pata and Aydin (2023) investigated the stationarity of CO_2 emissions in G-7 countries. A large data set for the period 1868–2014 is used in the study. The authors applied eight different tests with different power properties. A new wavelet-based nonlinear unit root test is proposed in the study. The results are mixed. Accordingly, the findings of different linear tests show that CO_2 emissions are non-stationary in the frequency domain for all countries. In the United Kingdom, the non-linear unit root test results show that CO_2 emissions are stationary in the time domain. Considering the frequency domain test results in the G-7, it is generally stated that CO_2 emission policies have persistent effects.

As a result of the literature review, it has been observed that there is a limited number of studies that also take into account the convergence approach to environmental sustainability. On the other hand, it was determined that time series and panel data methods were frequently preferred in the studies. Other unit root or stationarity tests are found to have various power properties. It is understood that the empirical findings differ by country/country group, period and test. Therefore, in this study, it is evaluated that unit root tests with different power properties and test procedures will contribute to the related literature. On the other hand, no study on Southeast Asian countries based on this convergence approach to environmental sustainability has been identified in the literature. In this respect, the study differs from other studies.

3. Empirical Methodology

This study investigates the validity of environmental sustainability and the validity of convergence in Southeast Asian countries with the help of ecological footprint data by using unit root tests with different power properties. The test procedures of the unit root tests used in this study will be briefly introduced. First, the extended DF unit root test and PP unit root test, which are among the traditional unit root tests, will be presented. Then, the methodology of the nonlinear unit root tests LNV and HM unit root tests, which are also included in the unit root literature with structural breaks, will be presented. Finally, the methodology of one of the most recent nonlinear unit tests, the Hepsağ (2021) nonlinear unit root test, will be presented. The DF unit root test implies that the relevant series adopts the first-order autoregressive AR (1) characteristic (Dickey and Fuller, 1979). In this test, the existence of a unit root is investigated by $Y_t = pY_{t-1} + e_t$. For this, the null hypothesis $H_0 = |p| \geq 1$ is tested. Failure to reject the null hypothesis indicates the presence of a unit root. Conversely, the rejection of the null hypothesis indicates the validity of stationarity. In order to solve the autocorrelation problem in this test, it has been suggested to add the dependent variable (Dickey and Fuller, 1981). Moreover, the test is extended by adding the mean and trend to the DF test and the model $\Delta Y_t = \beta_0 + \beta_1 t + \delta Y_{t-1} + \alpha \sum_{i=1}^{m} \Delta Y_{t-1} + \varepsilon_t$ is obtained. In the last equation, the presence of a unit root is investigated by setting a similar null hypothesis. The test statistics obtained in DF and ADF are compared with MacKinnon critical values. The PP unit root test, another conventional unit root test, was proposed by Phillips and Perron (1988). In this test, the Moving Averages (MA) process is taken into account instead of AR (1) specified in the DF. The null hypothesis and alternative hypothesis are formulated as in DF and ADF and the unit root process is investigated by comparing the test statistics with MacKinnon critical values. With the structural changes in countries, there are nonlinear approaches as well as linearity assumptions in time series. The tests to be used according to these approaches differ. In this case, it is important to determine which behavior the series exhibit. In this study, Harvey and Leybourne (2007) test is used to determine linearity or nonlinearity. This test conforms to the Chi-square distribution. Since 4 parameters are restricted, the calculated chi-square test statistic is compared with the chi-square table value with 4 degrees of freedom. Model (1) is used to test the null hypothesis of linearity:

$$y_t = a_0 + \beta_1 y_{t-1} + \beta_2 y_{t-1}^2 + \beta_3 y_{t-1}^3 + \beta_4 \Delta y_{t-1} + \beta_5 (y_{t-1})^2 + \beta_6 (y_{t-1})^3 + \varepsilon_t \quad (1)$$

In (1), the null hypothesis is set as H_0: $\beta_2 = \beta_3 = \beta_5 = \beta_6 = 0$. Based on the null hypothesis, the alternative hypothesis is formed as H_1: $\beta_2 \neq \beta_3 \neq \beta_5 \neq \beta_6 \neq 0$. In this test, failure to reject the null hypothesis indicates the presence of linearity. If the alternative hypothesis cannot be rejected, it is understood that the relevant series exhibits nonlinear behavior. In this test, no assumption is made regarding the stationarity of the series. There are three different nonlinear tests used in the study.

Leybourne *et al*. (LNV) (1998) unit root test gives a single break date. Due to this fact, it is also referred to as the test with structural break in the literature. In this test, the transition function is based on the logistic function. The unit root process is investigated with three different models. In these models, the unit root process is examined through three different models in LNV. A soft break in the constant with Model A; Model B indicates a soft break in the constant in the deterministic trend, and finally Model C indicates a soft break in both the constant and the trend. The models in question are given in (2), (3) and (4), respectively.

$$y_t = a_1 + a_2 S_t(\gamma, \tau) + v_t \tag{2}$$

$$y_t = a_1 + \beta_1 t + a_2 S_t(\gamma, \tau) + v_t \tag{3}$$

$$y_t = a_1 + \beta_1 t + a_2 S_t(\gamma, \tau) + \beta_2 t S_t(\gamma, \tau) + v_t \tag{4}$$

The term v_t in (2), (3) and (4) shows the zero-mean I(0) process. The number of samples is indicated by T. The parameter that controls the speed of transition between regimes is γ. This parameter takes values between 0 and 1. The situation in which the transition in question is rapid and sudden is indicated by the γ parameter being close to 1. The situation where the transition between regimes is slow and gradual is expressed by the γ parameter being close to 0. The logistics function specified in the above models is shown in (5).

$$S_t(\gamma, \tau) = [1 + \exp\{-\gamma(t - \tau T)\}]^{-1} \tag{5}$$

In LNV, which is a single structural break and non-linear unit root test, the null hypothesis indicates the existence of a unit root. Harvey and Mills (HM) (2002) non-linear unit root test stated that there may be more than one structural change in the series. Therefore, he expanded the LN test and proposed two soft transition versions. In other words, the HM test is obtained by adding another logistic function to all models containing LNV. (2002), in addition to LNV (1998), an additional soft transition function was added to all models. The situation in question is given in (6), (7) and (8).

$$y_t = a_1 + a_2 S_{1t}(\gamma_1, \tau_1) + a_3 S_{2t}(\gamma_2, \tau_2) + v_t \tag{6}$$

$$y_t = a_1 + \beta_1 t + a_2 S_{1t}(\gamma_1, \tau_1) + a_3 S_{2t}(\gamma_2, \tau_2) + v_t \tag{7}$$

$$y_t = a_1 + \beta_1 t + a_2 S_t(\gamma_1, \tau_1) + \beta_2 t S_t(\gamma_1, \tau_1) + a_3 S_{2t}(\gamma_2, \tau_2) + \beta_3 t S_{2t}(\gamma_2, \tau_2) + v_t \tag{8}$$

(6), (7) and (8) indicate soft breaks in constant, deterministic trend, constant and deterministic trend, respectively, as in LNV. In HM, unlike LNV, there are two soft breaks. Hepsağ (2021) unit root test, which is among the current non-linear unit root tests, is modeled with the soft structural break logistic soft transition function. Additionally, nonlinear form is included in this model with the ESTAR process. LNV (1998) procedure was followed in this test. There are three logistic smooth transition models in this test. These are stated in (9), (10) and (11), respectively, similar to LNV.

$$y_t = a_1 + a_2 S_t(\gamma, \tau) + v_t \tag{9}$$

$$y_t = a_1 + \beta_1 t + a_2 S_t(\gamma, \tau) + v_t \tag{10}$$

$$y_t = a_1 + \beta_1 t + a_2 S_t(\gamma, \tau) + \beta_2 t S_t(\gamma, \tau) + v_t \tag{11}$$

Models (9), (10) and (11) constitute Model A, Model B and Model C, respectively. These models respectively express the situations in which the soft break is allowed to occur in the constant term, in the presence of a deterministic trend, and in both the constant term and the deterministic trend (Yavuz, 2023). The logistic smooth transition function in the above models is denoted by S_t (γ, τ) and this function is seen in (12).

$$S_t(\gamma, \tau) = [1 + \exp\{-\gamma(t - \tau T)\}]^{-1} \tag{12}$$

In the model (12), the breaking point is expressed as τ and it is assumed that $\gamma > 0$. The parameter that determines the speed of transition between regimes is γ. In Hepsağ (2021), where a two-stage estimation procedure is followed, the non-linear least squares method is applied in three models (Model A, B and C) in the first step. The assumption that the error terms obtained as a result of the relevant method follow the ESTAR process constitutes the second stage. Under these assumptions, a first-order Taylor expansion is applied to the model. The test regression is re-estimated using the least squares method. Here, the null hypothesis states the validity of the unit root process. The alternative hypothesis, which is valid when the null hypothesis is rejected, shows the existence of ESTAR stationarity with soft breaks. The validity of the null hypothesis is decided by comparing the obtained test statistics with the critical values in Hepsağ (2021). In this context, the fact that the test statistic is greater than the critical value indicates that the null hypothesis is rejected.

4. Dataset and Empirical Findings

In the study, ecological footprint (EF) data of Southeast Asian countries consisting of the economies of Indonesia, the Philippines, Cambodia, Malaysia, Singapore, Thailand and Vietnam were used. The data in question was accessed from the Global Footprint Network database. Five count-

ries in Southeast Asia (Indonesia, Malaysia, Thailand, Philippines and Singapore) are founding members of ASEAN. ASEAN was established in 1967. Cambodia and Vietnam joined the union in the following years. On the other hand, the oil crisis occurred in 1973 and the countries included in the analysis were affected socio-economically. When these developments are considered together, the period 1973–2022 is determined as a sample period to design environmental policies and demonstrate environmental sustainability within ASEAN. Table 1 shows the descriptive statistics of the EF variable in the countries in question.

Table 1: Descriptive Statistics of EF Variable

	Indonesia	Philippines	Cambodia	Malaysia	Singapore	Thailand	Vietnam
Mean	1.314519	1.137043	1.180747	3.506471	5.262721	1.764873	1.106662
Median	1.299696	1.163069	1.165395	3.711429	5.977602	1.948945	0.766241
Maximum	1.683977	1.283765	1.821802	5.046304	8.346918	2.542514	2.432274
Minimum	1.078336	0.957054	0.890776	2.162471	1.326016	0.917276	0.594999
Std. Dev.	0.183651	0.085892	0.191881	0.754232	1.955974	0.525145	0.590992
Skewness	0.581883	−0.401340	0.442206	−0.279114	−0.600651	−0.279013	0.945866
Kurtosis	2.064328	2.123120	2.712676	1.878403	2.175219	1.495529	2.469979
Jarque–Bera	4.645483	2.944196	3.603081	3.270000	4.423728	5.364221	8.040779
Probability	0.098005	0.229444	0.165044	0.194952	0.109496	0.068419	0.017946
Sum	65.72594	56.85214	118.0747	175.3235	263.1361	88.24364	55.33311
Sum Sq. Dev.	1.652662	0.361490	3.645002	27.87446	187.4659	13.51307	17.11430
Observations	50	50	50	50	50	50	50

Source: Authors' own calculations

According to the descriptive statistics in Table 1, it can be seen that the country with the lowest and highest EF average is Vietnam. All countries included in the analysis of the EF series were measured according to the Jarque–Bera statistic. At the 5% significance level, the existence of a normal distribution according to Jarque–Bera could not be rejected in all countries except Vietnam. This result shows that the EF series has a normal distribution in other countries except Vietnam.

Some regulations are being made for the series to be used to measure environmental sustainability for Southeast Asian countries. The natural logarithm of the series in question was taken by

dividing it by the group average. This resulting series is called LEF. The fact that this series contains a unit root process indicates environmental sustainability. In other words, it reveals the existence of convergence. Before determining the unit root process of the LEF series, it is determined whether the LEF follows a linear course. For this purpose, Harvey and Leybourne (2007) linearity test was used. Relevant findings are included in Table 2.

Table 2: LEF Linearity Test Results

	Indonesia	Philippines	Cambodia	Malaysia	Singapore	Thailand	Vietnam
***F*-statistics**	6.24	13.39	18.81	6.94	23.03	11.20	16.87

Note: In the Harvey and Leybourne (2007) test, the critical value calculated at the 5% significance level is calculated with 2 degrees of freedom. In this test, the critical values at 1%, 5% and 10% significance levels are 9.21, respectively; 5.99 and 4.60.

Source: Authors' own calculations

Harvey and Leybourne (2007) *F*-statistics given in Table 2 were calculated at 5% significance level. In other words, the validity of the null hypothesis of the relevant linearity test should be compared with the critical value calculated at the 5% significance level with the *F*-statistic in Table 2. When the findings are examined in Table 2, it is seen that the *F*-statistics in all countries are greater than 5.99, which is the critical value at the 5% significance level. This shows that the null hypothesis is rejected. In other words, the LEF variable follows a non-linear course in all countries included in the analysis. This result shows that nonlinear unit root tests can be used. First, traditional unit root tests will be applied to the LEF series. ADF and PP results are given in Table 3.

Table 3 findings contain different results specific to countries. The fact that the ADF and PP test statistics are greater than the critical values (compared by taking their absolute values) shows that the LEF series does not have a unit root process at the relevant significance level. In this context, Indonesia is stationary at the 1% significance level according to both ADF and PP according to the constant and trend model. Philippines is stable at 5% significance level according to ADF unit root test and stationary according to constant & trend model. According to the Malaysian PP unit root test, it is stationary at the 10% significance level only according to the constant & trend model. According to the Singapore PP unit root test, it is stationary at the 5% significance level only compared to the constant model. The mentioned countries have a unit root process in other cases. The other three countries analyzed (Cambodia, Thailand, Vietnam) have both unit root tests and unit root processes at each significance level according to the model.

Table 3: Traditional Unit Root Test Findings

LEF	ADF		PP	
	SM	STM	SM	STM
Indonesia	0.633202	−4.237958	1.012742	−4.188330
Philippines	−3.128041	−3.351439	−2.429453	−2.485190
Cambodia	−2.739124	−0.564035	−1.862272	−1.663795
Malaysia	−1.850996	−1.916224	−1.959584	−3.377341
Singapore	−2.779833	−2.090958	−3.410544	−1.836713
Thailand	−0.846160	−2.019750	−0.846160	−2.060755
Vietnam	2.365365	−2.674972	1.613273	−2.535520

Note: SM: Model with constant, STM: Model with constant and trend. For the ADF unit root test, the critical values at the 1%, 5% and 10% significance level in the constant model are −3.577723, respectively; They are −2.925169 and −2.600658. In the constant and trend model, this ranking is −4.161144; They are −3.506374 and −3.183002. Schwarz information criterion was used in the ADF unit root test. For the PP unit root test, the critical values at the 1%, 5% and 10% significance level in the constant model are −3.571310, respectively; They are −2.922449 and −2.599224. In the constant and trend model, this ranking is −4.156734; −3.504330 and −3.181826.

Source: Authors' own calculations

Table 4, Table 5, Table 6, Table 7, Table 8, Table 9 and Table 10 shows the nonlinear unit root test findings. Table 4 presents the unit root test findings for Indonesia.

Table 4: Nonlinear Unit Root Test Results for Indonesia

One Break		**LNV (1998)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	−5.31514	0	2008	−4.009; −4.363; −5.095	LEF is stationary.
Model B	50	−4.72553	0	2009	−4.636; −5.053; −5.770	LEF is stationary.
Model C	50	−5.35596	0	2011	−4.990; −5.395; −6.135	LEF is stationary.
Two Break		**HM (2002)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	−3.47949	1	1996-2004	−5.33; −5.73; −6.49	LEF has Unit Root.
Model B	50	−5.40918	1	1983-1994	−6.07; −6.48; −7.37	LEF has Unit Root.
Model C	50	−5.49967	1	2011-1997	−6.74; −7.16; −8.14	LEF has Unit Root.
		Hepsağ (2021)				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	8.33137	0	2008	8.014; 9.662; 13.390	LEF is ESTAR stationary with soft break.
Model B	50	14.60768	0	2009	10.897; 15.619; 27.252	LEF is ESTAR stationary with soft break.
Model C	50	9.15130	0	1997	10.409; 12.404; 17.315	LEF has Unit Root.

Note: T stands for the number of observations, TI stands for the test statistic and CV stands for the critical value.
Source: Authors' own calculations

According to the LNV results presented in Table 4, LEF in Indonesia is stationary according to all models. According to HM results, there is a unit root process according to all models. According to the findings of Hepsağ (2021), LEF is ESTAR stationary with soft break in all models except Model C. Table 5 presents the unit root test findings for Philippines.

Table 5: Nonlinear Unit Root Test Results for Philippines

One Break		**LNV (1998)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	–2.23192	0	1994	–4.009; –4.363; –5.095	LEF has Unit Root.
Model B	50	–2.28989	0	1994	–4.636; –5.053; –5.770	LEF has Unit Root.
Model C	50	–2.90740	0	1989	–4.990; –5.395; –6.135	LEF has Unit Root.
Two Break		**HM (2002)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	–2.74747	0	1981-1982	–5.33; –5.73; –6.49	LEF has Unit Root.
Model B	50	–2.26491	0	1994-1997	–6.07; –6.48; –7.37	LEF has Unit Root.
Model C	50	–3.62972	0	1979-2009	–6.74; –7.16; –8.14	LEF has Unit Root.
Hepsağ (2021)						
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	7.97696	0	1994	8.014; 9.662; 13.390	LEF has Unit Root.
Model B	50	8.83532	0	1994	10.897; 15.619; 27.252	LEF has Unit Root.
Model C	50	8.53477	0	1989	10.409; 12.404; 17.315	LEF has Unit Root.

Note: T stands for the number of observations, TI stands for the test statistic and CV stands for the critical value.
Source: Authors' own calculations

According to all unit root tests presented in Table 5, LEF in the Philippines is found to contain a unit root process. Table 6 presents the unit root test findings for Cambodia.

Table 6: Nonlinear Unit Root Test Results for Cambodia

One Break		**LNV (1998)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	−1.63152	1	1983	−4.009; −4.363; −5.095	LEF has Unit Root.
Model B	50	−6.14530	1	1988	−4.636; −5.053; −5.770	LEF is stationary.
Model C	50	−6.18086	1	1987	−4.990; −5.395; −6.135	LEF is stationary.
Two Break		**HM (2002)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	−6.52437	1	1987-2012	−5.33; −5.73; −6.49	LEF is stationary.
Model B	50	−6.59803	1	1987-2002	−6.07; −6.48; −7.37	LEF is stationary.
Model C	50	−6.59080	1	1981-1992	−6.74; −7.16; −8.14	LEF has Unit Root.
		Hepsağ (2021)				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	5.53853	1	1983	8.014; 9.662; 13.390	LEF has Unit Root.
Model B	50	19.07357	1	1988	10.897; 15.619; 27.252	LEF is ESTAR stationary with soft break.
Model C	50	19.91839	1	1987	10.409; 12.404; 17.315	LEF is ESTAR stationary with soft break.

Note: T stands for the number of observations, TI stands for the test statistic and CV stands for the critical value.
Source: Authors' own calculations

According to the results for Cambodia in Table 6, LEF shows mixed unit root process or stationarity results in all unit root tests according to different models. Table 7 presents the unit root test findings for Malaysia.

Table 7: Nonlinear Unit Root Test Results for Malaysia

One Break		**LNV (1998)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	−5.67828	0	1991	−4.009; −4.363; −5.095	LEF is stationary.
Model B	50	−6.00842	0	1991	−4.636; −5.053; −5.770	LEF is stationary.
Model C	50	−6.23522	0	1992	−4.990; −5.395; −6.135	LEF is stationary.
Two Break		**HM (2002)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	−5.25046	1	1991-1992	−5.33; −5.73; −6.49	LEF has Unit Root.
Model B	50	−5.15398	1	1992-1993	−6.07; −6.48; −7.37	LEF has Unit Root.
Model C	50	−8.76401	1	1985-1993	−6.74; −7.16; −8.14	LEF is stationary.
		Hepsağ (2021)				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	43.72181	0	1991	8.014; 9.662; 13.390	LEF is ESTAR stationary with soft break.
Model B	50	31.38383	0	1991	10.897; 15.619; 27.252	LEF is ESTAR stationary with soft break.
Model C	50	40.90581	0	1992	10.409; 12.404; 17.315	LEF is ESTAR stationary with soft break.

Note: T stands for the number of observations, TI stands for the test statistic and CV stands for the critical value.
Source: Authors' own calculations

According to the results in Table 7, it is concluded that the LEF in Malaysia is generally stationary or ESTAR stationary with soft break. Table 8 presents the unit root test findings for Singapore.

Table 8: Nonlinear Unit Root Test Results for Singapore

One Break		**LNV (1998)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	−3.91017	1	1995	−4.009; −4.363; −5.095	LEF has Unit Root.
Model B	50	−2.02440	1	1996	−4.636; −5.053; −5.770	LEF has Unit Root.
Model C	50	−3.92334	1	1995	−4.990; −5.395; −6.135	LEF has Unit Root.
Two Break		**HM (2002)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	−5.72546	0	1978-1991	−5.33; −5.73; −6.49	LEF is stationary.
Model B	50	−3.80052	1	1979-1988	−6.07; −6.48; −7.37	LEF has Unit Root.
Model C	50	−6.09365	0	1979-1991	−6.74; −7.16; −8.14	LEF has Unit Root.
		Hepsağ (2021)				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	6.65824	1	1996	8.014; 9.662; 13.390	LEF has Unit Root.
Model B	50	8.01616	1	1996	10.897; 15.619; 27.252	LEF has Unit Root.
Model C	50	7.71472	1	1995	10.409; 12.404; 17.315	LEF has Unit Root.

Note: T stands for the number of observations, TI stands for the test statistic and CV stands for the critical value.
Source: Authors' own calculations

According to the results in Table 8, it is concluded that the LEF variable in Singapore contains a unit root process according to all tests and models. Table 9 presents the unit root test findings for Thailand.

Table 9: Nonlinear Unit Root Test Results for Thailand

One Break		**LNV (1998)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	−3.80439	0	1991	−4.009; −4.363; −5.095	LEF has Unit Root.
Model B	50	−4.64584	0	1990	−4.636; −5.053; −5.770	LEF is stationary.
Model C	50	−5.21124	0	1989	−4.990; −5.395; −6.135	LEF is stationary.
Two Break		HM (2002)				
LEF	T	Tİ	Appropriate Lag Length	Break Dates	KD (%10; %5; %1)	Results
Model A	50	−5.43394	0	1990-2003	−5.33; −5.73; −6.49	LEF is stationary.
Model B	50	−5.49418	0	1989-2005	−6.07; −6.48; −7.37	LEF has Unit Root.
Model C	50	−5.24542	0	1987-1997	−6.74; −7.16; −8.14	LEF has Unit Root.
		Hepsağ (2021)				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	8.87386	0	1991	8.014; 9.662; 13.390	LEF is ESTAR stationary with soft break.
Model B	50	15.33141	0	1990	10.897; 15.619; 27.252	LEF is ESTAR stationary with soft break.
Model C	50	10.62154	0	1989	10.409; 12.404; 17.315	LEF is ESTAR stationary with soft break.

Note: T stands for the number of observations, TI stands for the test statistic and CV stands for the critical value.
Source: Authors' own calculations

According to the results in Table 9, in all unit root tests of LEF in Thailand, the unit root process or stationarity results are mixed according to different models. Table 10 presents the unit root test findings for Vietnam.

Table 10: Nonlinear Unit Root Test Results for Vietnam

One Break		**LNV (1998)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	−3.20825	0	2006	−4.009; −4.363; −5.095	LEF has Unit Root.
Model B	50	−3.09030	0	2006	−4.636; −5.053; −5.770	LEF has Unit Root.
Model C	50	−4.15467	0	1999	−4.990; −5.395; −6.135	LEF has Unit Root.
Two Break		**HM (2002)**				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	−4.26760	0	2016-2002	−5.33; −5.73; −6.49	LEF has Unit Root.
Model B	50	−3.67236	0	1985-2001	−6.07; −6.48; −7.37	LEF has Unit Root.
Model C	50	−5.55535	0	1989-1992	−6.74; −7.16; −8.14	LEF has Unit Root.
		Hepsağ (2021)				
LEF	**T**	**Tİ**	**Appropriate Lag Length**	**Break Dates**	**KD (%10; %5; %1)**	**Results**
Model A	50	5.55194	0	2006	8.014; 9.662; 13.390	LEF has Unit Root.
Model B	50	5.12244	0	2006	10.897; 15.619; 27.252	LEF has Unit Root.
Model C	50	9.50622	0	1999	10.409; 12.404; 17.315	LEF has Unit Root.

Note: T stands for the number of observations, TI stands for the test statistic and CV stands for the critical value.
Source: Authors' own calculations

According to the results in Table 10, it is concluded that the LEF variable in Vietnam contains a unit root process according to all tests and models.

The tables above include the results of LNV and HM tests, which are nonlinear and structural break tests, and Hepsağ (2021) unit root tests, which take into account the nonlinear process and gradual break. According to the tables, it has been concluded that the LEF series does not generally contain a unit root process. In other words, the validity of different types of stationarity was obtained. Among these tests, it is known that HM is stronger than LNV and Hepsağ (2021) is stronger than HM in terms of power. Considering these situations, it has been concluded that LEF does not contain a unit root process in the economies of other countries except the Philippines,

Singapore and Vietnam. In other words, considering Hepsağ (2021), it was found that the LEF series has ESTAR stationarity with soft breaks in other countries except the Philippines, Singapore and Vietnam. These results are generally valid for all models. Therefore, both conventional and non-linear unit root tests from the countries included in the analysis show the presence of mixed results in Southeast Asian countries. Considering all the tests, it is noteworthy that only Vietnam has a unit root process in all cases. The general validity of environmental sustainability in the relevant country group, in other words, the validity of convergence, has been concluded.

5. Conclusion and Policy Recommendations

Liberalization steps accelerated in the world economies in the 1980s, and these steps accelerated in the 1990s, deepening the new era of globalization. These practices, which remain valid today, prioritize economic growth and financial development. In this process, Asian countries also came to the fore. High economic growth rates have been achieved, especially in China. Today, China has become the second largest economy after the USA. It has been observed that India achieved significant economic growth rates after China. Recently, the performances of Southeast Asian countries have attracted attention.

In this study, the validity of environmental sustainability was tested in Southeast Asian countries that have experienced serious developments and/or have potential as a result of policies that prioritize economic growth. In the study covering the 1973–2022 sample period, the existence of convergence was examined by using ecological footprint data. Unit root tests with various power characteristics were used in the seven countries included in the analysis. In this context, ADF and PP unit root tests, unit root tests with structural breaks and nonlinear unit root tests were used. Econometric results revealed that environmental sustainability was invalid in Cambodia, Thailand and Vietnam according to traditional unit root tests, ADF and PP. In other words, it has been found that convergence is invalid in the relevant countries. These results are similar to the studies of Ahmed *et al*. (2016) and Ulucak (2017). In the other four countries, stationarity was generally found to be valid and convergence was achieved. Harvey and Leybourne (2007) linearity test results for the countries included in the analysis showed the existence of a non-linear course of the LEF series. This result showed that nonlinear unit root tests can be performed. LNV and HM unit root test results, which are among both structural break and nonlinear tests, revealed that the LEF series generally does not contain a unit root process. According to Hepsağ (2021) unit root test, which is among the most recent tests among non-linear unit root tests, it has been revealed that LEF does not have a unit root process except for the Philippines, Singapore and Vietnam, and the existence of ESTAR stationarity with soft breaks. When the results of structural break and non-linear unit root tests, which are considered to be stronger than traditional unit root tests, are evaluated, it is understood that environmental sustainability is generally valid in Southe-

ast Asian countries. This result showed the existence of convergence in the relevant country group. This result is similar to the studies of Özcan *et al*. (2019), Yılancı *et al*. (2021) and Tatar (2022). In this study, which investigated the stability of the ecological footprint regarding environmental sustainability, it was determined that although it was generally found that there was no unit root process, mixed results were obtained according to some countries/models and empirical methods. This situation revealed that convergence is partially valid in Southeast Asian countries. These results also reveal similar findings to the studies of Yurtkuran (2020), Pata and Aydın (2023).

Accurately determining whether a shock to the ecological footprint is permanent or temporary is considered important in the context of environmental sustainability in terms of sustainable development goals. The fact that the relevant series contains a unit root process reveals that the shocks to the series are not temporary. In other words, this permanent effect reveals the importance of environmental policies in the long term. On the other hand, it has been concluded that convergence within the country group is invalid in countries where the existence of a unit root process has been achieved. This result shows that it will be effective to make policies for environmental sustainability on a national scale. In this context, the concepts of quality, sustainability and social responsibility awareness should be integrated into the policies followed by institutions. It is considered important that the policies to be implemented should prioritize clean energy. The lack of convergence can be explained by the fact that some countries in ASEAN have a high ecological footprint while others have a relatively low ecological footprint. In this context, it is considered to be related to the lack of coordination in regional environmental policies.

It is understood that global and regional policies will be effective in countries where convergence is valid. This result shows that ASEAN countries have reached similar levels of environmental sustainability in a coordinated manner. In other words, environmental pressures act together in ASEAN countries. This situation reveals that the relevant countries are approaching similar levels of environmental responsibility. This situation can occur with regional environmental policies and cooperations carried out in ASEAN countries. It is evaluated that the technology transfer and green production techniques coming to the forefront between the countries in question are effective in the existence of convergence. In addition, it is seen that there are serious positive developments in the economies of Vietnam and Indonesia, especially in ASEAN countries, and stable economic developments in Singapore. This situation reveals the existence of balancing in industrialization throughout ASEAN and is evaluated as important indicators showing the existence of convergence. On the other hand, the existence of convergence can also be explained by the significant developments in commercial and financial terms of ASEAN countries and the adaptation processes towards sustainable development goals. Therefore, in order to ensure the sustainability of the economic growth processes of these countries and to deepen their global integration, they should be supported with incentives and subsidies that increase environmental

quality. Relatively more developed countries such as Singapore, Thailand and Malaysia, which are among the ASEAN countries, support environmental policies. It will be important for other ASEAN countries, such as Vietnam, the Philippines and Indonesia, to prioritize policies that prioritize the environment in their economic growth processes. Therefore, it is important to remain loyal to the environmental agreements signed between ASEAN countries.

The Paris Climate Agreement and the Kyoto Protocol are considered important to expand global agreements. Sanctions need to be added to increase the effectiveness of these agreements. Regionally, monetary funds consisting of Southeast Asian countries can be established and measures and incentive mechanisms to prevent environmental degradation can be implemented. There is an ASEAN energy center and Kuala Lumpur transportation strategic plan established by the ASEAN countries within the country group in question. It is evaluated that it will be effective to contribute to environmental sustainability by expanding the scope of the relevant center and plans. Additionally, steps need to be taken on a global scale. In this context, practices aimed at reducing energy intensity and increasing economic efficiency are considered important.

In studies that follow this study, empirical predictions can be made regarding the determinants of environmental sustainability in Southeast Asian countries. By determining the importance of the determinants of sustainability for the relevant countries, more effective policy recommendations can be made. Moreover, the research question in this study can be investigated with unit root and stationarity tests extended with Fourier functions. Thus, mixed findings according to power characteristics can be supported and contribute to the literature. Policy recommendations can be deepened by comparing the findings obtained in this study with tests with different characteristics in terms of power. Finally, in addition to the ecological footprint variable regarding environmental sustainability, the load capacity factor and inverse load capacity factor variables can be used to compare the results and provide more comprehensive recommendations.

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