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Evaluation of ecological security for the Association of Southeast Asian Nations-5 countries: new evidence from the RALS unit root test

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Abstract
The present study seeks to determine the convergence of the ecological footprint pressure index for the Association of Southeast Asian Nations (ASEAN-5) countries over the period of 1961–2017. For this purpose, traditional unit root tests in conjunction with residual augmented least squares (RALS) type unit root tests have been applied to examine the convergence of all countries under investigation. RALS type tests were chosen due to showing a significantly improved power over conventional tests that do not use information on non-normal errors. The traditional unit root results do not show support for the ecological footprint pressure index convergence of the highlighted ASEAN-5 blocs. However, the RALS type and nonlinear unit root tests results reveal that the ecological footprint pressure index became convergent. Thus, governments and policymakers need to adopt stricter policies to protect the environment. These results have a more far-reaching effect on energy and environmental security for the study region.

Keywords ASEAN-5 countries · Convergence · Ecological sustainability · Energy security ecological footprint pressure index · Low-carbon economy · RALS unit root · SDGs

1 Introduction

For decades, one of the biggest problems faced by mankind is global warming and climate change (Rehman et al. 2021; Pata 2021; Adedoyin et al. 2020; United Nations

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2020). The greenhouse gas effect, which is due to carbon dioxide (CO2) emissions, is one of the major causes of environmental problems (Le and Ozturk 2020; Shahbaz et al. 2020). Increased use of non-renewable energy sources such as oil, coal, etc. and economic growth i.e. anthropogenic activities have led to an increase in greenhouse gas in the atmosphere. For this reason, the interest in economics and environmental topics has increased considerably with a focus on the nexus between increased economic activity and environmental quality. This relation has become popularized in the energy literature as the EKC phenomenon by Kuznets (1955) who asserted that there is an inverse relationship between income per capita and income inequality. He found there to be an inverted U-shape between the variables. This indicates that economic growth worsens the income inequality up to a certain threshold. It then improves it as the income increases over time. Environmental economists have adopted this phenomenon to examine the relationship between economic growth and environmental quality. There exists a flourishing literature on the theme for several blocs and country specific cases, including the works conducted by Alola et al. (2021a), Ahmed et al. (2021), Gyamfi et al. (2021; Umar et al. (2021), Ansari et al. (2020), Işık et al. (2019), Ozokcu and Ozdemir (2017), Apergis and Ozturk (2015), Farhani et al. (2014), and Kaika and Zervas (2013).

Several studies looking into the energy-environment-growth literature have tried to identify other factors that affect the environmental degradation drivers apart from economic growth. Many scholars have found that global climate change, energy consumption, population, tourism, the fertility rate, globalization, and foreign direct investment (FDI) can be factored into environmental degradation (Agboola et al. 2022; Adebayo et al. 2021; Alola et al. 2021b, c; Uzuner et al. 2020; Akadiri et al. 2020; Alola et al. 2019; Shahbaz et al. 2018). For instance, Akadiri et al. (2020) examined the effects of cooling degree days, heating degree days, and ecological footprint on environmental degradation in the USA over the period 1960 to 2016. Their results show that the cooling degree days, the heating degree days, and the ecological footprint accounting increased the country's environmental degradation. Specifically, FDI has been identified by authors who have argued in two ways (the Pollution Halo Hypothesis and the Pollution Haven Hypothesis) with respect of its impact on the environment. According to the Pollution Halo Hypothesis, FDI can provide a green technology transfer from developed to less developed countries (Hoffmann et al. 2005). This means that investing in developed countries contributes to the developing countries' reduction of emissions. On the contrary, the Pollution Haven Hypothesis claims that FDI leads to an increase in emissions in less developed and developing countries due to the disclaimer of environmental standards and taxes to produce more at a lesser cost and to attract more foreign investors (Mert and Caglar, 2020; Blanco et al. 2013; Kirkulak et al. 2011). The validity of the pollution hypothesis has been tested with the help of various modeling and cointegration tests in the literature (Liu and Xu 2021; Xu et al. 2021; Repkine and Min 2020; Huynh and Hoang 2019; Shahbaz et al. 2015; Zugravu-Soilita 2017; Solarin et al. 2017; Zhang and Zhou 2016; Kivyiro and Arminen 2014; Al-mulali and Foon Tang 2013).

On the other hand, environmental convergence is another issue related to environmental economics and energy security. There are many different types of convergence in the literature. They can be classified as beta-convergence, sigma-convergence, absolute (unconditional) convergence, conditional convergence, club convergence, and stochastic convergence. In this study, the stochastic convergence approach is used to determine environmental convergence. In this approach, stationary or unit root tests are used to scrutinize the existence of convergence. If the ecological indicator used is stationary, it can be said that the stochastic convergence is valid.

In the environmental economics literature, it is seen that CO_2 emissions are generally used as an ecological indicator. Carbon emissions and the emission of other greenhouse gasses into the atmosphere is a major cause of global warming and climate change (Luo and Wu 2016). CO_2 emissions, on the other hand, are just a small part of the overall impact of large-scale energy consumption (Al-Mulali et al. 2015). In addition to CO_2 emissions, resource supplies such as forestry land, mining, and oil reserves place a significant strain on the environment. Due to technical advancements and increasingly strict environmental regulations, many of the individual contaminants per unit of production have decreased in developed countries (Stern 2004). However, another reason for the decrease in contaminants may be the transfer of the wastewater mixture from sulfur and nitrogen oxides into solid waste. While the aggregate waste is still at a high level, the per capita waste may not decrease (Bello et al. 2018; Solarin 2019; Stern 2014; Ulucak and Lin 2017). For this reason, in addition to specific indicators such as CO_2, aggregate indicators should also be taken into account in studies on environmental pollution.

In this context, the ecological footprint (EF) has been established by Wackernagel and Rees (1996). The EF is divided into six sub-components: carbon footprint, cropland footprint, forest footprint, grazing land footprint, built-up land footprint, and fishing grounds footprint, taking into account the environmental pressures of human activities in all aspects (Ulucak and Lin 2017). The EF, defined as a combined index of pressures on the environment, is a ratio that intends to reveal the impact of human use on natural resources (Solarin 2019). For this reason, knowing the movement of the EF is critical for determining appropriate environmental policies and forecasting human pressure on the environment. In this context, the convergence of the EF means that there is no need for a precautionary change in policies, otherwise an intervention is needed. Furthermore, evaluating the convergence of EF is vital given that determining the environmental balance/security and taking precautions will also contribute to environmental development. There are various assessment criteria studied in the environmental literature (Gu et al. 2015; Huang et al. 2007; Wang et al. 2018; Yang and Cai 2020). Ecological deficit, the ecological footprint pressure index (EFPI), and the ecological and economic coordination coefficient are among these criteria, which are explained in Sect. 2.

This research makes three contributions. First, we used the EF per capita as it is a more comprehensive ecological indicator than carbon emissions in terms of energy security and sustainability. Second, to our knowledge, this is the first study to test the convergence of ecological pressure index instead of EF for the ASEAN-5 countries. The aims of ASEAN, referring to a group of five countries, are to increase economic growth, cultural development, and social progress in the region. To reach these aims, it is inevitable for the nations to face environmental pollution. The ecological footprint is increasing in these blocs. Furthermore, ASEAN-5 countries have had ecological deficits for the last 20 years. In this sense, the ASEAN-5 deserves increased attention when it comes to examining the ecological dynamics in the context of environmental sustainability. Third, we performed the analysis in three ways. We check whether the residuals obtained from the equation used in the classical unit root tests hold to the normality assumption. In addition, we examine the linearity property of the EF pressure index and structural break case. On account of these, we anticipate that this study will contribute to the existing literature in terms of policy formulation and serve as a blueprint for the investigated region.

The remaining parts of the paper are organized as follows. Section 2 describes in detail the ecological security criteria. Section 3 provides a summary of the empirical literature. Section 4 discusses the econometric methodology. Section 5 presents the data used for the empirical analysis and the discussion of the empirical results. Section 6 concludes the study with crucial policy implications and future research avenues.

2 Literature review

In recent years, the convergence of environmental pollution indicators is one of the most discussed topics in the current literature. The convergence of environmental pollution indicators has a critical role in constructing climate change policies at the international level. To improve the environmental quality, this approach can help policymakers to set better strategies and targets across the necessary countries (Ahmed et al. 2017; Yang et al. 2016). Several types of convergence (stochastic, beta, sigma, absolute, club etc.) have been studied in the literature so far. Tables 1 and 2 provide a comprehensive review of the literature on the convergence of EF and other pollutants (CO_2 and so on) respectively.

3 Assessment of ecological security

3.1 Ecological deficit

The difference between EF and biocapacity/carrying capacity (BC), defined as the ecosystems' capacity to reproduce what humans demand from these surfaces, is known as the ecological balance (EB). If the EB expressed by Eq. 1 is positive, there is an ecological deficit (ED). Vice versa indicates an ecological surplus (ES). The ED and the ES can be used to calculate a region's eco-security standard.

$$EB = EF - BC \tag{1}$$

The ED means that more ecological resources are used than natural sources, and that human actions cause an ecological imbalance (Wackernagel et al. 1999). ES means that although human activities consume ecological resources, they still remain within the BC (Chu et al. 2017).

Table 1 Literature of environmental convergence hypothesis (for other emissions)

Author	Time period	Country	Methodology	Variable	Results
List (1999)	1929–1994	U.S. regions	Beta-convergence, unit root tests	NO_x, SO_2	Convergence is valid
Strazicich and List (2003)	1960–1997	21 industrial countries	Cross section and IPS panel unit root test	CO_2	Stochastic and conditional convergence are valid
Lanne and Liski (2004)	1870–2028	16 countries	Unit root test with structural breaks	CO_2	Mix results
Aldy (2006)	1960–2000	23 OECD countries and 88 countries	Markow chain transition matrix	CO_2	Sigma convergence is valid for 23 OECD countries and mixed results for 88 countries
Westerlund and Basher (2008)	1870–2002	G28 countries	Panel unit root tests	CO_2	Convergence is valid
Herrerias (2013)	1980–2009	162 developed and developing countries	Phillips and Sul (2007) club convergence, pair-wise unit root, and log-*t* tests	CO_2 emissions from oil, coal, gas	Mix results
Yavuz and Yilanci (2013)	1960–2005	G7 countries	TAR panel uint root test	CO_2	Convergence is valid in the first regime
Payne et al. (2014)	1900–1998	U.S. states	LM and RALS-LM tests	SO_2	Convergence is valid
Acar and Lindmark (2016)		86 countries	Beta-convergence, growth regression	CO_2 emissions from oil	Unconditional beta-convergence
Acaravci and Erdogan (2016)	1960–2011	7 regions	CIPS and PANKPSS unit root tests	CO_2	Convergence is valid
Apergis and Payne (2017)	1980–2013	U.S. states	Phillips and Sul (2007) club convergence test	CO2 emissions from natural gas, electric power, and petroleum	Club convergence is valid
Solarin (2019)	1961–2013	27 OECD countries	Beta-convergence, sigma-convergence, RALS regression, RALS-LM test	CO_2, EF, Carbon footprint	Mix results
Churchill et al. (2020)	1921–2014	17 emerging economies	LM, RALS-LM, logit/probit estimations	CO_2	Mix results

Source Author's compilation

Table 2 Literature of environmental convergence hypothesis (for ecological footprint)

Author	Time period	Country	Methodology	Variable	Results
Ulucak and Lin (2017)	1961–2013	USA	Fourier unit root tests	EF, its components and deficit	Convergence is not valid
Ulucak ve Apergis (2018)	1961–2013	EU countries	Phillips and Sul (2007) club convergence	EF	Club convergence is valid
Bilgili and Ulucak (2018)	1961–2014	G20 countries	Bootstrap panel KPSS test	EF	Convergence is valid
Solarin and Bello (2018)	1961–2013	128 developed and developing countries	Narayan and Popp (2010), Kapetanios et al. (2003 and Kruse (2011) unit root tests	EF	Mix results
Bilgili et al. (2019)	1961–2014	15 countries	Bootstrap panel KPSS test	EF	Convergence is valid for Africa, America and Europe but not for Asia
Solarin (2019)	1961–2013	27 OECD countries	beta-convergence, sigma-convergence, RALS regression, RALS-LM	CO_2, EF, Carbon footprint	Convergence is valid for 13 countries
Solarin et al. (2019)	1961–2014	92 countries	Club convergence	EF and its components	Mix results
Yılancı et al. (2019)	1961–2013	25 OECD countries	Bahmani-Oskooee et al. (2014) panel stationary test	EF and its components	All components are stationary except fishing land
Haider and Akram (2019)	1961–2014	77 countries	Phillips and Sul (2007) club convergence test	EF, Carbon footprint	Countries with low PCEF and PCCF converge faster than others
Ozcan et al. (2019)	1961–2013	Low, middle and high income economies	Panel KSS unit root test	EF	Convergence is valid for high- income, half of the low-income, and upper-middle income countries
Yilanci ve Pata (2020)	1961–2016	ASEAN-5	non-linear panel threshold unit root	EF	Convergence is valid
Erdogan and Okumus (2021)	1961–2016	Countries by difference income groups	panel stationarity test with smooth shifts and log-t methods	EF	Convergence is not valid for high, middle, and low-income countries
Işık et al. (2021)	1961–2016	USMCA countries	TAR panel unit root test	EF	Convergence is valid in the second regime

PCEF Per capita ecological footprint, *PCCF* Per capita carbon footprint.

Table 3 Eco-security assessment based on ecological footprint pressure index

Level	EFPI	Characterization state
1	< 0.50	Pretty safe
2	0.50–0.80	Relatively safe
3	0.81–1.00	Relatively unsafe
4	1.01–1.50	Quite unsafe
5	1.51–2.00	Very unsafe
6	> 2.00	Completely unsafe

Source Wang et al. (2018)

3.2 Ecological footprint pressure index

The definition of the ecological footprint pressure index (EFPI) is the 'danger level' of ecological footprint compared to the bio-capacity. In other words, EFPI can also be defined as the degree of human intervention in the eco-environment and the level of eco-security (Yang et al. 2018). This indicator is defined in Eq. (2):

$$EFPI = \frac{EF}{BC} \tag{2}$$

If the EFPI is between 0 and 1, the ecological resource supply exceeds its demand. If EFPI is equal to 1, the ecological supply and demand are equal, and the eco-security is in a critical situation. Finally, if the EFPI is greater than 1, the ecological resource demand exceeds its supply and the eco-security is in a dangerous situation (Wang et al. 2018). The ecological security assessment index and classification standard developed by Yuan (2010) are given in Table 3.

3.3 Ecological and economic coordination index

The eco-economic coordination index (EECI), which shows the ecological sustainability, has been developed to overcome the deficiency of ED. The formula is shown in Eq. 3 (Chen 2017).

$$EECI = \frac{EF + BC}{\sqrt{EF^2 + BC^2}} \tag{3}$$

The criteria mentioned above are frequently used in the assessment of eco-security. In this study, the ecological footprint pressure index will be used.

4 Methodology

Dickey Fuller (DF) type unit root tests suffered from low power compared to recently developed methods. Generally, these types of test focus on autocorrelation in terms of the error of the DF model. Various parametric and nonparametric tests have been proposed to solve this issue (Said and Dickey 1984; Phillips and Perron 1988). It is a common mistake in the literature to assume that non-normal error terms have a normal distribution (Im et al. 2014). The ADF unit root test equation is shown as follows:

$$\Delta y_t = a_1 + \beta y_{t-1} + \sum\nolimits_{j=1}^{p} \delta_j \Delta y_{(t-j)} + e_t \tag{4}$$

where the corresponding test is $\beta = 0$ for the unit root test. The RALS version of the test is as follows:

$$\Delta y_t = a_1 + \beta y_{(t-1)} + \sum\nolimits_{(j=1)}^{p} \delta_j \Delta y_{(t-j)} + \hat{w}_t' + e_t, \quad \hat{w}_t = h(\hat{e}_t) - \underline{K} - \hat{e}_t D_2, \\ t = 1, 2, \ldots, T \tag{5}$$

where $\widehat{w}_t$ is the RALS term and $\underline{K} = (1/T)\sum_{t=1}^{T} h(\widehat{e}_t)$, $\widehat{D}_2 = (1/T)\sum_{t=1}^{T} h'(\widehat{e}_t)$. In this test, the used moment conditions make use of the knowledge in non-normal errors. The LM and RALS-LM unit root test procedures developed by Lee et al. (2011) and Meng et al. (2014) are then applied to our convergence analysis of EFPI.

$$y_t = z'_t \delta + x_t, \quad x_t = \beta x_{t-1} + e_t \tag{6}$$

where $z_t = [1, t, D_{1t}, D_{2t}, DT_{1t}^*, DT_{2t}^*]'$ includes exogenous components. $DT_{1t}^* = 1$ for $t \geq T_{B_i}+1$, $i = 1, 2$ and zero otherwise, and $DT_{it}^* = t - T_{B_i}$ for $t \geq T_{B_i}+1$, $i = 1, 2$ and zero otherwise. The LM unit root test statistic is as follows:

$$\Delta y_t = d' \Delta z_t + \phi \tilde{y}_{t-1} + \sum\nolimits_{j=1}^{p} c_j \Delta \tilde{y}_{t-j} + e_t \tag{7}$$

where $\widetilde{y}_{t-1} = y_t - \widetilde{\psi} - z_t \widetilde{\delta}$, $t = 2, \ldots, T$; $\widetilde{\delta}$ is the vector of the coefficients. Finally, under the null, the LM t-statistic is shown below:

$$\tau_{RLM} \to \rho \tau_{LM} + \sqrt{1 - \rho^2} N(0, 1) \tag{8}$$

The critical values of the RALS-LM statistics are given in Meng et al. (2014). On the other hand, the researcher should be attentive to possible nonlinearities in the macroeconomic time series. Otherwise, the unit root test can result in a tendency to not reject the null hypothesis (Cuestas and Garratt 2011). We have applied the linearity test of Harvey et al. (2008) to test the null hypothesis of linearity versus the alternative of a nonlinear model. Harvey et al.'s (2008) method differs from classical linearity tests in that it is a linearity test that can be applied to both I(0) and I(1) processes. The Wald test statistic to be calculated where the I(0) or I(1) property of the series is unknown:

$$W_\lambda = \{1 - \lambda\} W_0 + \lambda W_1, \quad \left(W_\lambda \sim \chi^2_{(2)}\right) \tag{9}$$

where the null hypothesis of the test indicates linearity, while the alternative hypothesis shows nonlinearity. We used the nonlinear unit root tests by Sollis (2009) and

Kruse (2011) based on the test results of Harvey et al. (2008). A simple unit root test against the alternative of symmetric or asymmetric ESTAR nonlinearity by Sollis was examined (2009). The asymmetric ESTAR (AESTAR) model is as follows:

$$\begin{aligned} &\Delta y_t = G_t(\gamma_1, y_{t-1})\{S_t(\gamma_2, y_{t-1})\rho_1 + (1 - S_t(\gamma_2, y_{t-1}))\rho_2\}y_{t-1} + \varepsilon_t \\ &G_t(\gamma_1, y_{t-1}) = 1 - exp\left(-\gamma_1\left(y_{t-1}^2\right)\right) \quad \gamma_1 \geq 0 \; S_t(\gamma_2, y_{t-1}) \\ &= \left[1 + exp(-\gamma_1(y_{t-1})\right]^{-1}\right] \quad \gamma_2 \geq 0 \end{aligned} \tag{10}$$

where $\varepsilon_t \sim iid(0, \sigma^2)$ and y_{t-1} is a transition variable. Due to the existence of undefined parameters under the null hypothesis, the model is restated using the Taylor expansion as follows:

$$\Delta y_t = \phi_1 y_{t-1}^3 + \phi_2 y_{t-1}^4 + \eta_t \tag{11}$$

where $H_0 : \phi_1 = \phi_2 = 0$ is non-stationarity, iif it is rejected, $H_0 : \phi_2 = 0$ hypothesis is tested. Kruse (2011) allowed the location parameter[1] to be different from zero. It is expressed as a Dickey-Fuller type regression model given by:

$$\Delta y_t = a y_{t-1} + \phi y_{t-1}\left(1 - exp\left\{-\gamma(y_{t-1} - c)^2\right\}\right) + \varepsilon_t \tag{12}$$

where $\varepsilon_t \sim iid(0, \sigma^2)$. Kruse (2011) constructed a first-order Taylor approximation to exponential part around $\gamma = 0$. Equation (12) can be written as follows:

$$\Delta y_t = a_1 y_{t-1}^3 + a_2 y_{t-1}^2 + \varepsilon_t \tag{13}$$

where the null hypothesis $H_0 : a_1 = a_2 = 0$ with the alternative hypothesis of $a_1 \leq 0; a_2 \neq 0$ to test unit root.

5 Data and findings

This study aims to determine the convergence of the EFPI defined as the per capita EF divided by the BC of the ASEAN-5 countries (except for Singapore as its period covers 1973–2017) over the period 1961 to 2017. The motivation behind the choice of this time period is to capture the breaks by including the longest data range available in which the time series analysis will be used. The dataset is taken from the Global Footprint Network (2021) in terms of the global hectare (gha) per person. The descriptive statistics for the dataset are given in Table 4. The graphs of EFPI are given in Fig. 1. It can be said that there is a clear trend in all countries except Singapore. In addition, structural breaks are clearly seen in the EFPI series of Thailand, Singapore, the Philippines, and Malaysia. However, the graphical analysis does not provide objective information about the stationarity of the series.

[1] As it is known, the location parameter is zero in Kapetanios et al. (2003).

Table 4 Descriptive statistics of ecological pressure index

Countries	Mean	Median	Deviation	Minimum	Maximum	Skewness	Kurtosis	JB
Indonesia	0.898	0.937	0.250	0.536	1.363	0.179	1.840	2.762
Malaysia	1.042	1.078	0.477	0.385	1.812	0.034	1.508	4.184
Philippines	1.895	1.923	0.269	1.467	2.511	0.197	2.108	1.785
Singapore	125.260	126.456	63.115	19.827	254.931	0.086	2.117	1.518
Thailand	1.580	1.726	0.481	0.878	2.209	– 0.290	1.416	5.336***

***Show the significance levels at the 10%. JB indicates Jarque–Bera normality test statistics

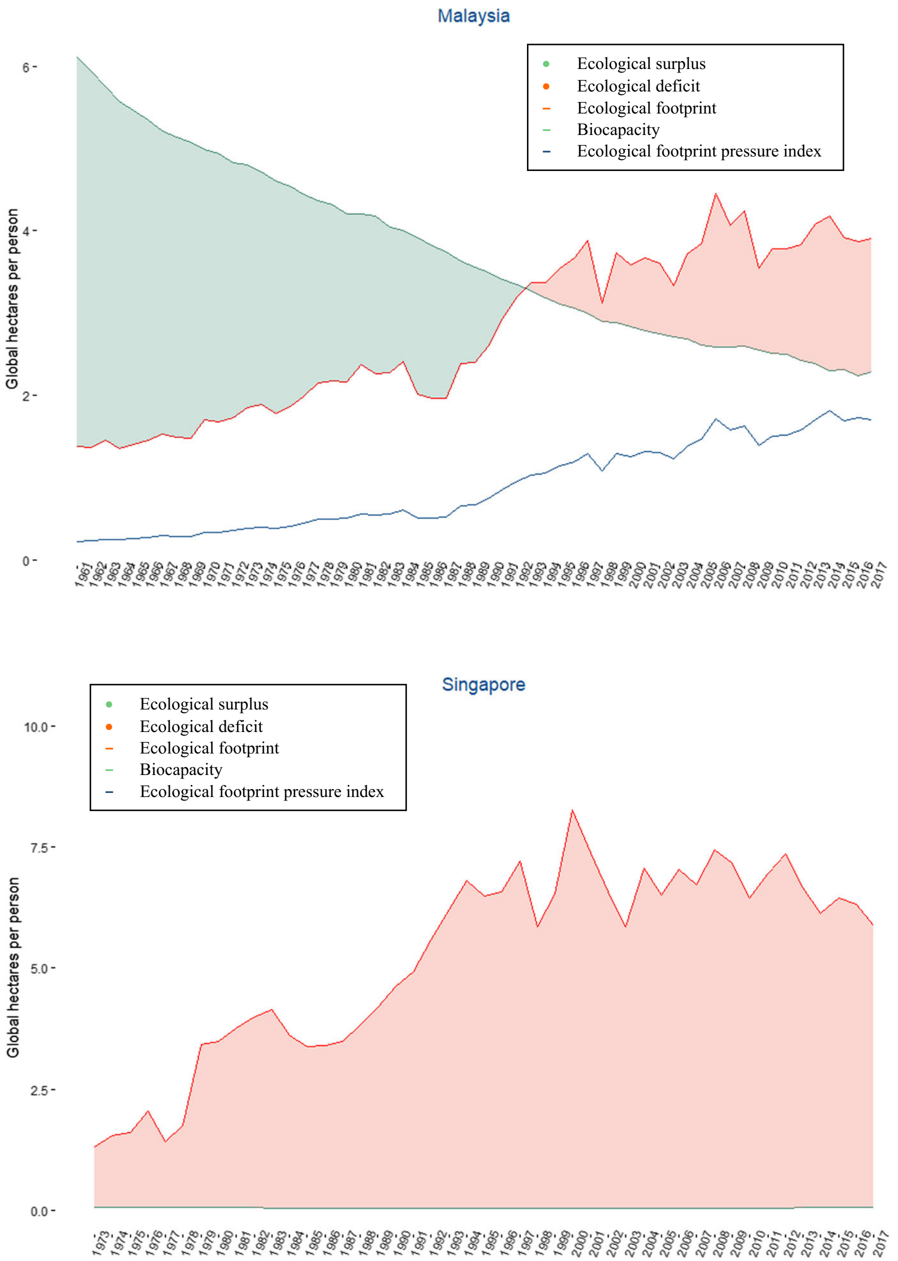
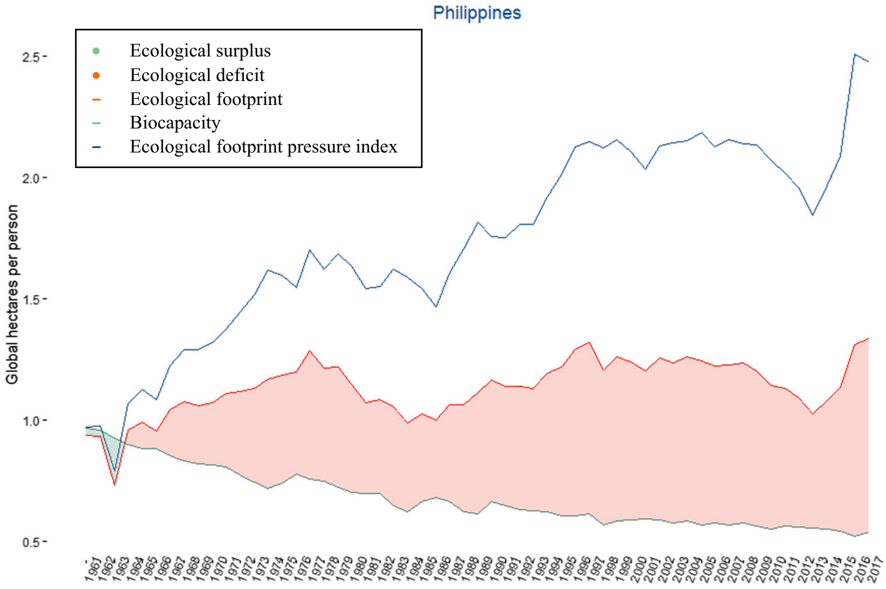


Fig. 1 Ecological footprint and biocapacity for ASEAN-5 countries. *Source* https://data.footprintnetwork.org/



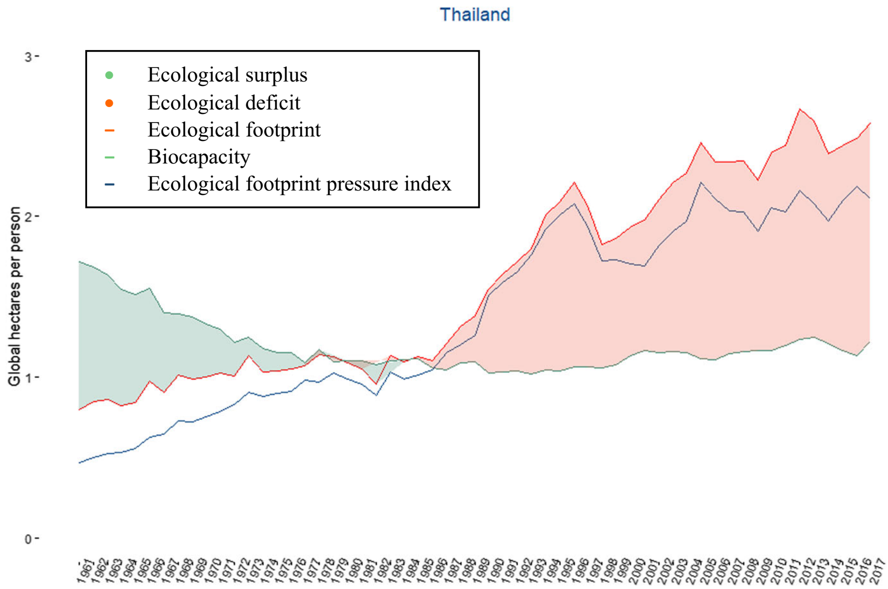


Fig. 1 continued

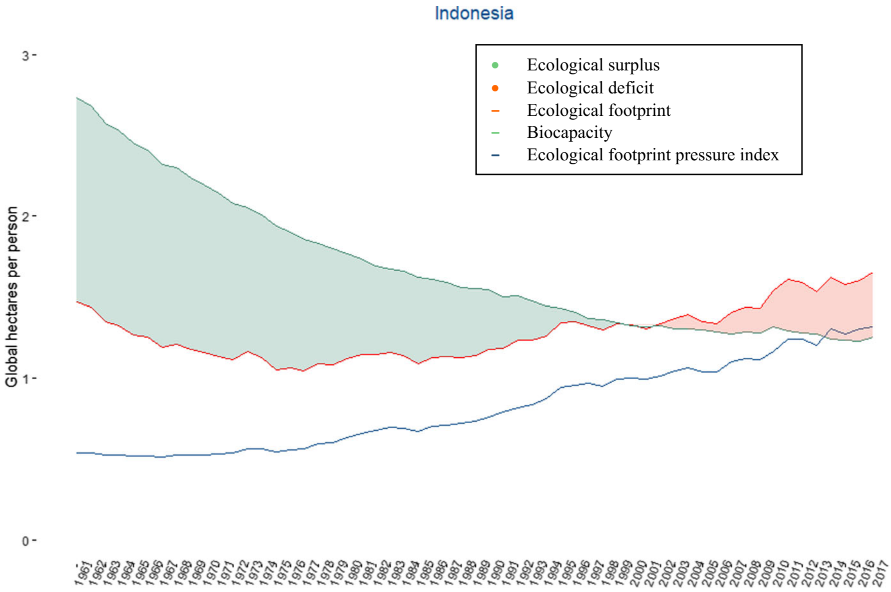


Fig. 1 continued

In many Asian countries, the total ecological footprint is much higher than its biocapacity. This means that the country's natural capital is degraded, or it produces more carbon emissions than the country's ecological system could handle (Ecological Footprint Atlas 2010). For instance, Indonesia is one of the countries with the lowest pressure index among the ASEAN-5 countries. Before the 1990s, Indonesia was a relatively safe country but since the 1990s, it has become a relatively unsafe country. Since the 2000s, the pressure index has been constantly above 1. It reached its highest value in 2017. Malaysia is the second highest on average for the pressure index. While it was in the pretty safe category for about 20 years from 1961, the environmental pressure started to increase from the 1980s onwards.

Beginning from the 1990s, the pressure index has exceeded one and reached its maximum value in 2014. The pressure index of the Philippines has been greater than 1 since 1960 and reached its maximum value in 2016. The pressure index of Thailand has risen above 1 in the late 1970s. The pressure index has increased continuously since 1985 and reached its maximum value in 2005. From this point of view, Singapore differs from other countries. The footprint production of Singapore has the greatest percentage overshot in Asia, and it is more than 195 times greater than the existing biocapacity (Ecological Footprint Atlas 2010). The pressure index reached its maximum value in 2000 and then trended downward. According to Table 3, the Philippines, Thailand, and Singapore are completely unsafe, while Indonesia and Malaysia are in the quite and very unsafe categories respectively in 2017.

As shown in Table 4, Singapore has the highest mean value of the EFPI, while Indonesia has the lowest value. Indonesia had an ecological surplus until 2000. Indonesia relies largely on agriculture and as a result, it exports more agricultural products

(Nathaniel 2020). However, this situation has been reversed in recent years and it now has an ecological deficit. Some countries—like Singapore—have a high population density in low-productive areas which leads to a low biocapacity per capita and ecological deficit (Syrovátka 2020). The standard deviation suggests that Singapore has the most volatile EFPI. The series has a normal distribution, except for Thailand. The plots of EF and BC of the ASEAN-5 countries are given in Fig. 1. Here, the red and green areas show the ecological deficit and ecological surplus, respectively. As seen in Fig. 1, the ecological deficits of Singapore and the Philippines are higher compared to the other countries.

We examine, using unit root tests, whether there is the existence of stochastic convergence in EFPI. Initially, we used the ADF unit root test. As shown in Table 5, the null hypothesis that means the variable has a unit root was not rejected for ASEAN-5. As is already known, the RALS unit root tests exhibit more power than traditional unit root tests. Therefore, we employed the Jarque–Bera test to determine whether the residuals were normally distributed. The results show that the normality of the residuals for Indonesia, Malaysia and the Philippines is not provided. Next, we applied the RALS version of the ADF to these countries. For Indonesia, Malaysia and the Philippines, the results found in ADF were exactly the opposite. In the test using the information that the residuals were non-normal, EFPI is stationary for these countries. Correspondingly, any shocks will be temporary; these results are evidence for stochastic convergence in Indonesia, Malaysia, and the Philippines. Im et al. (2014) stated that the ADF and RALS-ADF tests are expected to have a similar performance under the assumption of normality. As shown in Table 5, the ADF test results for Singapore and Thailand are where the normality assumption is held. As expected, the null hypothesis is not rejected according to both ADF and RALS-ADF tests.

The results of employing traditional LM (for one break and two breaks) and one break RALS-LM are shown in Table 6. According to the traditional LM test results, it can be seen that Thailand and Singapore are stationary with two breaks, while Malaysia is stationary with one break. However, Indonesia and the Philippines have a unit root with one break. In addition, considering the non-normal residual information, Indonesia and the Philippines are stationary according to the one-break RALS unit root test results. Therefore, it can be said that the EFPI is stationary for all countries, taking into account the non-normal residual information and structural break. This

Table 5 Traditional ADF and RALS-ADF unit root test results

Countries	ADF	Jarque–Bera	RALS-ADF	ρ^2
Indonesia	– 2.242 (0)	17.593*	– 2.578 (0)***	0.3
Malaysia	– 2.957 (0)	9.167**	– 3.158 (1)**	0.2
Philippines	– 2.511 (0)	24.364*	– 3.175 (0)**	0.4
Singapore	– 1.728 (0)	2.749	– 1.486 (4)	0.1
Thailand	– 0.983 (0)	0.616	– 2.192 (0)	0.3

ρ^2 represents the correlation coefficient and the brackets are shown at optimal lag length
*, **, and *** show the significance at the 1%, 5%, and 10% levels, respectively

Table 6 Traditional LM and RALS-LM unit root test results

Countries	LM	$T_{B\text{-}LM}$	Jarque–Bera	RALS-LM	$T_{B\text{-}RLM}$	ρ^2
Indonesia	− 4.094 (10)	1990	3.590	− 3.475 (10)***	1990	0.9
Malaysia	− 5.774 (2)*	1990	6.379**	− 5.207 (2)*	1990	0.8
Philippines	− 3.637 (1)	1976	32.214*	− 3.544 (1)**	1976	0.7
Singapore	− 5.570 (6)***	1998,2001	3.264	− 5.300 (6)*	1998,2001	0.9
Thailand	− 5.629 (6)***	1988,2004	0.048	− 5.516 (6)*	1988,2004	1

ρ^2 represents correlation coefficient and k and T_B show optimal lag length and structural break date, respectively

*, **, and *** show the significance at the 1%, 5%, and 10% levels, respectively

result shows that ignoring structural breaks and nor-normal residuals does not result in a rejection of the false unit root null hypothesis. The structural break dates for each country show the crucial turning points. The fall in oil prices in the 1980s was one of the factors that led to the recession in Indonesia in 1982 and 1983. However, this negative situation contributed to the rebuilding of the country's economy. The structural reforms induced in the late 1980s made the country's economy more resilient.

The agricultural sector provides the livelihood of a significant portion of the workforce in Malaysia. While 40% of the 4.8 million people employed in 1980 were engaged in agriculture, by 1990, 20% of the 9.4 million total employment was dependent on agriculture for their livelihood. Therefore while the total number of employed people has more than doubled, the rate of employment in agriculture has remained almost the same and even decreased (Rahman 1998). In the second half of 1998, the Singapore economy entered a recession due to the impact of the Asian financial crisis. Singapore's economy declined to 1.5% in 1998 after an 8% growth in 1997. Despite its rapid recovery from the recession, the country had a difficult time in 2001 due to the 3 main factors driving the Singapore economy (US economic growth, world semiconductor sales, and the weakness of the regional economies) (Huxley 2002, p. 156). A magnitude-7.9 earthquake in 1976 in the Philippines generated a tsunami in the Moro Gulf. A tsunami was generated in the Moro Gulf causing considerable damage to the economy and a loss of life (U.S. Geological Survey 2022). The Food and Agricultural Organization (FAO) reported that "The December 2004 tsunami-ravaged coastal communities off the Indian Ocean, claiming nearly a quarter of a million lives in 12 countries. India, Indonesia, Sri Lanka, and Thailand were among the hardest hit."

Similar to the case of a structural break, ignoring nonlinearity does not reject the false unit root null hypothesis. Table 7 presents Harvey et al. (2008) nonlinearity test results. According to the results, the null hypothesis shows that the linearity is rejected for all countries. This means that the linear unit root tests are unreliable. The nonlinear unit root test results for EFPI are shown in Table 8. According to these results, the EFPI in all countries does converge.

Table 7 Harvey et al. (2008) nonlinearity test results

Countries	W_λ
Indonesia	63.83*
Malaysia	7.54**
Philippines	13.67*
Singapore	9.25*
Thailand	5.23***

W_λ test critical value is distributed $\chi^2_{(2)}$ *, **, and ***show the significance at the 1%, 5%, and 10% levels, respectively

Table 8 Nonlinear unit root test results

Countries	Sollis	Kruse
Indonesia	15.336 (0)*	29.861 (0)*
Malaysia	7.500 (1)*	17.605 (1)*
Philippines	6.962 (2)**	12.060 (2)**
Singapore	7.374 (9)*	11.279 (9)**
Thailand	9.872 (0)*	15.584 (0)*

*, **, and ***Show the significance at the 1%, 5%, and 10% levels, respectively

6 Conclusion

The ecological footprint pressure index is an important index used for assessing a country's eco-security. The demand for ecological resources exceeding their supply is not sustainable for the country in the long run. A country's ecological surplus is in favor of the country's ecological security. However, most countries have an ecological deficit which plagues their ecological security. The ASEAN-5 countries have also had an ecological deficit for about 20 years. As is known, the EFPI is a ratio obtained by dividing EF into BC. An EFPI of less than one indicates that the country has an ecological reserve. However, this ratio may change over time. In this study, we are more concerned with the stability of this ratio rather than the low or high EFPI.

To the best of our knowledge, unlike the existing studies on the convergence of the ecological footprint, we used the ecological footprint pressure index relative to the previous studies that considered convergence with the use of EF, CO_2 emissions, and so on respectively. The aim of this paper is to examine the convergence of the EFPI in ASEAN-5 countries for the period 1961–2017. Firstly, we examine the convergence of all the countries under investigation using traditional unit root tests. When applying traditional unit root tests (such as ADF and LM tests), the error terms in the equation are assumed to be normally distributed. However, when the assumption of normal distribution in the error terms is not satisfied, the power of traditional tests is significantly reduced. Based on this, the tests proposed by Im et al. (2014) and Meng et al. (2014, 2016) show significantly improved power over traditional tests that do not use information about non-normal errors. Therefore, we also utilized RALS type unit tests. The traditional unit root results show that EFPI is not convergent in ASEAN-5 countries. It is worth mentioning that a failure to account for structural break(s) and nonlinearity can lead to spurious analysis and by extension, misleading inferences. Our study therefore concludes that the EFPI is stationary where there exists a possibility of structural break(s) and nonlinearity, and where the non-normal distribution of the residuals is taken into account.

Subsequently, the empirical results obtained in this study provide evidence that EFPI is stationary. The stationarity of the EFPI means that even if the EFPI deviates from the equilibrium, it tends to return to its mean again. Due to the characteristic nature of EFPI, it is possible to predict the future values of EFPI. Therefore, the decisions and environmental policies to reduce the pressure index will be ineffective. The decision makers are advised to consider this situation and take precautions accordingly.

From a policy perspective, given the results of this study, a policy direction exists for the investigated ASEAN countries and the region at large to consolidate the already existing environmental strides towards a sustainability path as it concerns ecological balance. The following guidance is suggested, namely that the current study validates the convergence of ASEAN ecological security over the ecological footprint, which means that there is convergence. This implies that the three core moments of its ecological footprint such as its average, variance and covariance are stationary over the considered time horizon. This indicates that the policy inferences drawn from these data generating processes are rendered ineffective. This has drawn attention from environmental and energy economists regarding more caution when it comes to understanding the key environmental indicator dynamics for robust policy decisions which in our case focus on the ecological footprint for the ASEAN blocs. As a direction for future research, other studies can be conducted for other blocs such as SSA, OECD, MENA, and MINT to either validate or refute the current study preposition. The present study can also be extended by investigation using disaggregated data for the ecological footprint.

References

Acar S, Lindmark M (2016) Periods of converging carbon dioxide emissions from oil combustion in a pre-Kyoto context. Environ Dev 19:1–9. https://doi.org/10.1016/j.envdev.2016.06.005

Acaravci A, Erdogan S (2016) The convergence behavior of CO_2 emissions in seven regions under multiple structural breaks. Int J Energy Econ Policy 6(3):575–580

Adedoyin F, Ozturk I, Abubakar I, Kumeka T, Folarin O, Bekun FV (2020) Structural breaks in CO_2 emissions: are they caused by climate change protests or other factors? J Environ Manag 266:110628

Adebayo TS, Udemba EN, Ahmed Z, Kirikkaleli D (2021) Determinants of consumption-based carbon emissions in Chile: an application of non-linear ARDL. Environ Sci Pollut Res 28(32):43908–43922

Agboola PO, Hossain ME, Gyamfi BA et al (2022) Environmental consequences of foreign direct investment influx and conventional energy consumption: evidence from dynamic ARDL simulation for Turkey. Environ Sci Pollut Res

Ahmed M, Khan AM, Bibi S, Zakaria M (2017) Convergence of per capita CO_2 emissions across the globe: insights via wavelet analysis. Renew Sustain Energy Rev 75:86–97

Ahmed Z, Zhang B, Cary M (2021) Linking economic globalization, economic growth, financial development, and ecological footprint: evidence from symmetric and asymmetric ARDL. Ecol Ind 121:107060

Akadiri SS, Alola AA, Alola UV, Nwambe CS (2020) The role of ecological footprint and the changes in degree days on environmental sustainability in the USA. Environ Sci Pollut Res 27(20):24929–24938
Aldy JE (2006) Per capita carbon dioxide emissions: convergence or divergence? Environ Resource Econ 33(4):533–555. https://doi.org/10.1007/s10640-005-6160-x
Al-mulali U, Foon Tang C (2013) Investigating the validity of pollution haven hypothesis in the gulf cooperation council (GCC) countries. Energy Policy 60:813–819. https://doi.org/10.1016/j.enpol.2013.05.055
Al-Mulali U, Weng-Wai C, Sheau-Ting L, Mohammed AH (2015) Investigating the environmental Kuznets curve (EKC) hypothesis by utilizing the ecological footprint as an indicator of environmental degradation. Ecol Ind 48:315–323
Alola AA, Bekun FV, Sarkodie SA (2019) Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. Sci Total Environ 685:702–709
Alola AA, Adebayo TS, Onifade ST (2021a) Examining the dynamics of ecological footprint in China with spectral Granger causality and quantile-on-quantile approaches. Int J Sustain Dev World Ecol 1–14.
Alola AA, Lasisi TT, Eluwole KK, Alola UV (2021b) Pollutant emission effect of tourism, real income, energy utilization, and urbanization in OECD countries: a panel quantile approach. Environ Sci Pollut Res 28(2):1752–1761
Alola AA, Eluwole KK, Lasisi TT, Alola UV (2021c) Perspectives of globalization and tourism as drivers of ecological footprint in top 10 destination economies. Environ Sci Pollut Res 28(24):31607–31617
Ansari MA, Haider S, Khan NA (2020) Environmental Kuznets curve revisited: an analysis using ecological and material footprint. Ecol Ind 115:106416
Apergis N, Ozturk I (2015) Testing environmental Kuznets curve hypothesis in Asian countries. Ecol Ind 52:16–22. https://doi.org/10.1016/j.ecolind.2014.11.026
Apergis N, Payne JE (2017) Per capita carbon dioxide emissions across U.S. states by sector and fossil fuel source: evidence from club convergence tests. Energy Econ 63:365–372. https://doi.org/10.1016/j.eneco.2016.11.027
Bahmani-Oskooee M, Chang T, Wu T (2014) Revisiting purchasing power parity in African countries: panel stationary test with sharp and smooth breaks. Appl Financial Econ 24(22):1429–1438
Bello MO, Solarin SA, Yen YY (2018) The impact of electricity consumption on CO2 emission, carbon footprint, water footprint and ecological footprint: the role of hydropower in an emerging economy. J Environ Manag 219:218–230
Bilgili F, Ulucak R (2018) Is there deterministic, stochastic, and/or club convergence in ecological footprint indicator among G20 countries? Environ Sci Pollut Res 25(35):35404–35419. https://doi.org/10.1007/s11356-018-3457-1
Bilgili F, Ulucak R, Koçak E (2019) Implications of environmental convergence: continental evidence based on ecological footprint. In: Shahbaz M, Balsalobre D (eds) Energy and environmental strategies in the era of globalization. Green Energy and Technology. Springer, Cham, pp 133–165
Blanco L, Gonzalez F, Ruiz I (2013) The Impact of FDI on CO2 emissions in Latin America. Oxf Dev Stud 41(1):104–121. https://doi.org/10.1080/13600818.2012.732055
Chen H-S (2017) Evaluation and analysis of eco-security in environmentally sensitive areas using an emergy ecological footprint. Int J Environ Res Public Health 14(2):136
Chu X, Deng X, Jin G, Wang Z, Li Z (2017) Ecological security assessment based on ecological footprint approach in Beijing-Tianjin-Hebei region, China. Phys Chem Earth Parts a/b/c 101:43–51
Churchill SA, Inekwe J, Ivanovski K (2020) Stochastic convergence in per capita CO2 emissions: evidence from emerging economies, 1921–2014. Energy Econ 86:104659. https://doi.org/10.1016/j.eneco.2019.104659
Cuestas JC, Garratt D (2011) Is real GDP per capita a stationary process? Smooth transitions, nonlinear trends and unit root testing. Empir Econ 41(3):555–563
Ecological Footprint Atlas (2010) Global footprint network. https://www.footprintnetwork.org/content/images/uploads/Ecological_Footprint_Atlas_2010.pdf
Erdogan S, Okumus I (2021) Stochastic and club convergence of ecological footprint: an empirical analysis for different income group of countries. Ecol Ind 121:107123. https://doi.org/10.1016/j.ecolind.2020.107123
Farhani S, Mrizak S, Chaibi A, Rault C (2014) The environmental Kuznets curve and sustainability: a panel data analysis. Energy Policy 71:189–198. https://doi.org/10.1016/j.enpol.2014.04.030

Food and Agriculture Organization of the United Nations, FAO in emergencies, in Tsunami. https://www.fao.org/emergencies/emergency-types/tsunami/en/?page=5&ipp=10&no_cache=1&tx_dynalist_pi1[par]=YToxOntzOjE6IkwiO3M6MToiMCI7fQ==

Gu Q, Wang H, Zheng Y, Zhu J, Li X (2015) Ecological footprint analysis for urban agglomeration sustainability in the middle stream of the Yangtze River. Ecol Model 318:86–99. https://doi.org/10.1016/j.ecolmodel.2015.07.022

Global Fotprint Network (2021) https://data.footprintnetwork.org/?_ga=2.186800940.501782068.1650449731-83225532.1649673624#/

Gyamfi BA, Ozturk I, Bein MA, Bekun FV (2021) An investigation into the anthropogenic effect of biomass energy utilization and economic sustainability on environmental degradation in E7 economies. Biofuels, Bioprod Biorefin 15(3):840–851

Haider S, Akram V (2019) Club convergence analysis of ecological and carbon footprint: evidence from a cross-country analysis. Carbon Manag 10(5):451–463

Harvey, D. I., Leybourne, S. J., & Xiao, B. (2008). A powerful test for linearity when the order of integration is unknown. Stud Nonlinear Dyn Econom 12(3).

Herrerias MJ (2013) The environmental convergence hypothesis: carbon dioxide emissions according to the source of energy. Energy Policy 61:1140–1150. https://doi.org/10.1016/j.enpol.2013.06.120

Hoffmann R, Lee CG, Ramasamy B, Yeung M (2005) FDI and pollution: a granger causality test using panel data. J Int Dev 17(3):311–317

Huang Q, Wang R, Ren Z, Li J, Zhang H (2007) Regional ecological security assessment based on long periods of ecological footprint analysis. Resour Conserv Recycl 51(1):24–41. https://doi.org/10.1016/j.resconrec.2006.07.004

Huynh CM, Hoang HH (2019) Foreign direct investment and air pollution in Asian countries: does institutional quality matter? Appl Econ Lett 26(17):1388–1392. https://doi.org/10.1080/13504851.2018.1563668

Huxley T (2002) Singapore in 2001: political continuity despite deepening recession. Asian Surv 42(1):156–164. https://doi.org/10.1525/as.2002.42.1.156

Im KS, Lee J, Tieslau MA (2014) More powerful unit root tests with non-normal errors. Festschrift in Honor of Peter Schmidt. Springer, New York, pp 315–342

Işık C, Ongan S, Özdemir D (2019) Testing the EKC hypothesis for ten US states: an application of heterogeneous panel estimation method. Environ Sci Pollut Res 26(11):10846–10853. https://doi.org/10.1007/s11356-019-04514-6

Işık C, Ahmad M, Ongan S, Ozdemir D, Irfan M, Alvarado R (2021) Convergence analysis of the ecological footprint: theory and empirical evidence from the USMCA countries. Environ Sci Pollut Res 28(25):32648–32659

Kaika D, Zervas E (2013) The environmental Kuznets Curve (EKC) theory-Part A: concept, causes and the CO2 emissions case. Energy Policy 62:1392–1402. https://doi.org/10.1016/j.enpol.2013.07.131

Kapetanios G, Shin Y, Snell A (2003) Testing for a unit root in the nonlinear STAR framework. J Econom 112(2):359–379

Kirkulak B, Qiu B, Yin W (2011) The impact of FDI on air quality: Evidence from China. J Chin Econ Foreign Trade Stud 4(2):81–98. https://doi.org/10.1108/17544401111143436

Kivyiro P, Arminen H (2014) Carbon dioxide emissions, energy consumption, economic growth, and foreign direct investment: Causality analysis for Sub-Saharan Africa. Energy 74(C):595–606. https://doi.org/10.1016/j.energy.2014.07.025

Kruse R (2011) A new unit root test against ESTAR based on a class of modified statistics. Stat Pap 52(1):71–85

Kuznets S (1955) Economic growth and income inequality. Am Econ Rev 45(1):1–28

Lanne M, Liski M (2004) Trends and breaks in per-capita carbon dioxide emissions, 1870–2028. Energy J 25(4).

Le HP, Ozturk I (2020) The impacts of globalization, financial development, government expenditures, and institutional quality on CO 2 emissions in the presence of environmental Kuznets curve. Environ Sci Pollut Res 27(18):22680–22697

Lee H, Meng M, Lee J (2011) How do nonlinear unit root tests perform with non normal errors? Commun Stat Simul Comput 40(8):1182–1191

List JA (1999) Have air pollutant emissions converged among US Regions? Evidence from unit root tests. South Econ J 66(1):144. https://doi.org/10.2307/1060840

Liu SJ, Xu XL (2021) The pollution halo effect of technology spillover and pollution haven effect of economic growth in agricultural foreign trade: two sides of the same coin? Environ Sci Pollut Res 28(16):20157–20173
Luo C, Wu D (2016) Environment and economic risk: an analysis of carbon emission market and portfolio management. Environ Res 149:297–301
Meng M, Im KS, Lee J, Tieslau MA (2014) More powerful LM unit root tests with non-normal errors. Festschrift in honor of peter schmidt. Springer, New York, pp 343–357
Meng M, Lee J, Payne JE (2016) RALS-LM unit root test with trend breaks and non-normal errors: application to the Prebisch-Singer hypothesis. Stud Nonlinear Dyn Econom 21(1):31–45
Mert M, Caglar AE (2020) Testing pollution haven and pollution halo hypotheses for Turkey: a new perspective. Environ Sci Pollut Res 27(26):32933–32943. https://doi.org/10.1007/s11356-020-09469-7
Narayan PK, Popp S (2010) A new unit root test with two structural breaks in level and slope at unknown time. J Appl Stat 37(9):1425–1438
Nathaniel SP (2020) Ecological footprint, energy use, trade, and urbanization linkage in Indonesia. GeoJournal 1–14.
Ozcan B, Ulucak R, Dogan E (2019) Analyzing long lasting effects of environmental policies: evidence from low, middle and high income economies. Sustain Cities Soc 44:130–143
Ozokcu S, Ozdemir O (2017) Economic growth, energy, and environmental Kuznets curve. Renew Sustain Energy Rev 72:639–647
Pata UK (2021) Linking renewable energy, globalization, agriculture, CO2 emissions and ecological footprint in BRIC countries: a sustainability perspective. Renew Energy 173:197–208
Payne JE, Miller S, Lee J, Cho MH (2014) Convergence of per capita sulphur dioxide emissions across US states. Appl Econ 46(11):1202–1211. https://doi.org/10.1080/00036846.2013.868588
Phillips PC, Perron P (1988) Testing for a unit root in time series regression. Biometrika 75(2):335–346
Phillips PC, Sul D (2007) Transition modeling and econometric convergence tests. Econometrica 75(6):1771–1855
Rahman AAA (1998) Economic reforms and agricultural development in Malaysia. ASEAN Econ Bull 15(1):59–76
Rehman A, Ma H, Ahmad M, Irfan M, Traore O, Chandio AA (2021) Towards environmental sustainability: devolving the influence of carbon dioxide emission to population growth, climate change, Forestry, livestock and crops production in Pakistan. Ecol Ind 125:107460
Repkine A, Min D (2020) Foreign-funded enterprises and pollution halo hypothesis: a spatial econometric analysis of thirty Chinese regions. Sustainability (switzerland). https://doi.org/10.3390/su12125048
Said SE, Dickey DA (1984) Testing for unit roots in autoregressive-moving average models of unknown order. Biometrika 71(3):599–607
Shahbaz M, Nasreen S, Abbas F, Anis O (2015) Does foreign direct investment impede environmental quality in high-, middle-, and low-income countries? Energy Econ 51:275–287. https://doi.org/10.1016/j.eneco.2015.06.014
Shahbaz M, Nasir MA, Roubaud D (2018) Environmental degradation in France: the effects of FDI, financial development, and energy innovations. Energy Econ 74:843–857
Shahbaz M, Shafiullah M, Khalid U, Song M (2020) A nonparametric analysis of energy environmental Kuznets Curve in Chinese Provinces. Energy Econ 89:104814
Solarin SA (2019) Convergence in CO2 emissions, carbon footprint and ecological footprint: evidence from OECD countries. Environ Sci Pollut Res 26(6):6167–6181. https://doi.org/10.1007/s11356-018-3993-8
Solarin SA, Bello MO (2018) Persistence of policy shocks to an environmental degradation index: the case of ecological footprint in 128 developed and developing countries. Ecol Indic 89:35–44. https://doi.org/10.1016/j.ecolind.2018.01.064
Solarin SA, Al-Mulali U, Musah I, Ozturk I (2017) Investigating the pollution haven hypothesis in Ghana: an empirical investigation. Energy 124:706–719. https://doi.org/10.1016/j.energy.2017.02.089
Solarin SA, Tiwari AK, Bello MO (2019) A multi-country convergence analysis of ecological footprint and its components. Sustain Cities Soc 46(January):101422. https://doi.org/10.1016/j.scs.2019.101422
Sollis R (2009) A simple unit root test against asymmetric STAR nonlinearity with an application to real exchange rates in Nordic countries. Econ Model 26(1):118–125
Stern DI (2004) The rise and fall of the environmental Kuznets curve. World Dev 32(8):1419–1439
Strazicich MC, List JA (2003) Are CO2 emission levels converging among industrial countries? Environ Resour Econ 24(3):263–271. https://doi.org/10.1023/A:1022910701857

Syrovátka M (2020) On sustainability interpretations of the Ecological Footprint. Ecol Econ 169:106543

Ulucak R, Apergis N (2018) Does convergence really matter for the environment? An application based on club convergence and on the ecological footprint concept for the EU countries. Environ Sci Policy 80:21–27. https://doi.org/10.1016/j.envsci.2017.11.002

Ulucak R, Lin D (2017) Persistence of policy shocks to Ecological Footprint of the USA. Ecol Ind 80(May):337–343. https://doi.org/10.1016/j.ecolind.2017.05.020

Umar M, Ji X, Kirikkaleli D, Alola AA (2021) The imperativeness of environmental quality in the United States transportation sector amidst biomass-fossil energy consumption and growth. J Clean Prod 285:124863

Uzuner G, Akadiri SS, Lasisi TT (2020) The asymmetric relationship between globalization, tourism, CO2 emissions, and economic growth in Turkey: implications for environmental policy making. Environ Sci Pollut Res 27(26):32742–32753

United Nations (2020) Climate change. https://www.un.org/en/global-issues/climate-change.

U.S. Geological Survey (2022) Today in earthquake history. https://earthquake.usgs.gov/learn/today/index.php?month=8&day=16&submit=View+Date#:~:text=M7.,9%20%2D%20Mindanao%2C%20Philippines%2C%201976&text=It%20is%20estimated%20that%20the,magnitude%206.0%20and%20lower%20range.

Wackernagel M, Rees W (1996) Our ecological footprint: reducing human impact on the earth. New Society Publishers, BC, Canada

Wackernagel M, Onisto L, Bello P, Linares AC, Falfán ISL, Garc\ía, J. M., Guerrero, A. I. S., & Guerrero, M. G. S. (1999) National natural capital accounting with the ecological footprint concept. Ecol Econ 29(3):375–390

Wang Z, Yang L, Yin J, Zhang B (2018) Assessment and prediction of environmental sustainability in China based on a modified ecological footprint model. Resour Conserv Recycl 132:301–313. https://doi.org/10.1016/j.resconrec.2017.05.003

Westerlund J, Basher SA (2008) Testing for convergence in carbon dioxide emissions using a century of panel data. Environ Resour Econ 40(1):109–120. https://doi.org/10.1007/s10640-007-9143-2

Xu C, Zhao W, Zhang M, Cheng B (2021) Pollution haven or halo? The role of the energy transition in the impact of FDI on SO2 emissions. Sci Total Environ 763:143002. https://doi.org/10.1016/j.scitotenv.2020.143002

Yang Y, Cai Z (2020) Ecological security assessment of the Guanzhong Plain urban agglomeration based on an adapted ecological footprint model. J Clean Prod 260:120973. https://doi.org/10.1016/j.jclepro.2020.120973

Yang J, Zhang T, Sheng P, Shackman JD (2016) Carbon dioxide emissions and interregional economic convergence in China. Econ Model 52:672–680

Yang Q, Liu G, Hao Y, Coscieme L, Zhang J, Jiang N, Casazza M, Giannetti BF (2018) Quantitative analysis of the dynamic changes of ecological security in the provinces of China through emergy-ecological footprint hybrid indicators. J Clean Prod 184:678–695

Yavuz NC, Yilanci V (2013) Convergence in per capita carbon dioxide emissions among G7 countries: a TAR panel unit root approach. Environ Resour Econ 54(2):283–291. https://doi.org/10.1007/s10640-012-9595-x

Yilanci V, Korkut Pata U (2020) Convergence of per capita ecological footprint among the ASEAN-5 countries: evidence from a non-linear panel unit root test. Ecol Ind 113(February):106178. https://doi.org/10.1016/j.ecolind.2020.106178

Yilanci V, Gorus MS, Aydin M (2019) Are shocks to ecological footprint in OECD countries permanent or temporary? J Clean Prod 212:270–301

Yuan WB (2010) Ecological security evaluation based on the ecological footprint in Nanning City. Jilin University, China (in Chinese)

Zhang C, Zhou X (2016) Does foreign direct investment lead to lower CO2 emissions? Evidence from a regional analysis in China. Renew Sustain Energy Rev 58:943–951. https://doi.org/10.1016/j.rser.2015.12.226

Zugravu-Soilita N (2017) How does foreign direct investment affect pollution? Toward a better understanding of the direct and conditional effects. Environmental and resource economics, vol 66, issue 2. Springer, Netherlands.