http://www.egejfas.org
Ege Journal of Fisheries and Aquatic Sciences, 42(2), 93-104 (2025)

Su Ürünleri Dergisi (2025)
DOI: 10.12714/egejfas.42.2.02

RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Economic growth and fisheries biocapacity in BRICS+T: An Environmental Kuznets Curve analysis

BRICS+T'de ekonomik büyüme ve balıkçılık biyokapasitesi: Çevresel Kuznets Eğrisi analizi

Şerif Canbay[1] ● Serkan Şengül[2*]

Department of Economics and Finance Faculty of Art and Social Sciences, Mudanya University, Bursa, Türkiye

*Corresponding author: serkan.sengul@mudanya.edu.tr

Received date: 18.10.2024 *Accepted date: 05.03.2025*

How to cite this paper:
Canbay, Ş., & Şengül, S. (2025). Economic growth and fisheries biocapacity in BRICS+T: An environmental Kuznets Curve analysis. *Ege Journal of Fisheries and Aquatic Sciences, 42*(2), 93-104. https://doi.org/10.12714/egejfas.42.2.02

Abstract: This study evaluates the robustness of the Environmental Kuznets Curve (EKC) hypothesis by examining the association between economic growth and fisheries biocapacity in BRICS+T countries, namely Brazil, Russia, India, China, South Africa, and Türkiye. Panel bootstrap causality test is utilized to evaluate the causal relationship between the variables using data covering the period 1992-2022. The results show that the EKC hypothesis is held for Russia, South Africa and Türkiye and that economic growth initially causes to a decrease in fisheries biocapacity, but after a certain threshold, biocapacity recovers. In contrast, the EKC hypothesis is not supported for Brazil, China and India. These findings necessitate governments to take policy measures to promote environmental sustainability.

Keywords: Fishing biocapacity, Environmental Kuznets Curve (EKC), economic growth, sustainability, environmental policy

Öz: Bu çalışma, Brezilya, Rusya, Hindistan, Çin, Güney Afrika ve Türkiye'den oluşan BRICS+T ülkelerinde ekonomik büyüme ve balıkçılık biyokapasitesi arasındaki ilişkiyi inceleyerek Çevresel Kuznets Eğrisi (EKC) hipotezinin sağlamlığını değerlendirmektedir. Panel bootstrap nedensellik testi, 1992-2022 dönemini kapsayan veriler kullanılarak değişkenler arasındaki nedensel ilişkiyi değerlendirmek için kullanılmıştır. Sonuçlar, EKC hipotezinin Rusya, Güney Afrika ve Türkiye için geçerli olduğunu ve ekonomik büyümenin başlangıçta balıkçılık biyokapasitesinde bir düşüşe neden olduğunu, ancak belirli bir eşikten sonra biyokapasitenin iyileştiğini göstermektedir. Buna karşılık, EKC hipotezi Brezilya, Çin ve Hindistan için desteklenmemektedir. Bu bulgular, hükümetlerin çevresel sürdürülebilirliği teşvik etmek için politika önlemleri almasını gerektirmektedir.

Anahtar kelimeler: Balıkçılık biyokapasitesi, Çevresel Kuznets Eğrisi (EKC), ekonomik büyüme, sürdürülebilirlik, çevre politikası

INTRODUCTION

The fisheries and aquaculture sector is crucial for maintaining food security and fostering economic growth, especially in developing countries where fish serves as a key source of both protein and income. Approximately 12% of the global population depends on fish for nutrition, with the global trade in fisheries surpassing $406 billion (UN, 2024). The sector supports the livelihoods of 3.3 billion people worldwide, making it a critical resource for both food and economic security (FAO, 2022). However, the rapid pace of industrialization, urbanization, and population growth over the last century has placed immense pressure on marine ecosystems. Economic activities have not only contributed to pollution and ocean warming but also posed severe threats to marine biodiversity and food security (Wei et al., 2023). Oceans, which absorb over 90% of the excess heat generated by greenhouse gas emissions, are undergoing notable temperature increases, particularly in the deeper ocean layers. These rising temperatures lead to oxygen depletion, causing behavioral changes, stunted growth, and increased mortality rates in marine species (Shi et al., 2022). The degradation of marine ecosystems, if left unchecked, could undermine global climate stability and disrupt ecological balance (Pata et al., 2023).

Industrial and commercial activities, particularly those centered around production in developed nations, are major contributors to greenhouse gas emissions and ocean pollution. In many cases, developed nations have shifted pollution-intensive production processes to developing countries to take advantage of lower labor costs, exacerbating global environmental inequality (Damirova and Yayla, 2021). This trend highlights the critical need for a comprehensive understanding of how economic growth interacts with environmental sustainability, a relationship encapsulated by the Environmental Kuznets Curve (EKC) hypothesis. Originally proposed by Grossman and Krueger (1995), the EKC hypothesis posits that environmental degradation intensifies during the early stages of economic growth but eventually decreases after reaching a specific income threshold. This reduction in environmental harm is attributed to greater investments in cleaner technologies, the implementation of stronger regulatory measures, and an increasing awareness of environmental issues.

The Environmental Kuznets Curve (EKC) hypothesis is an important theoretical framework that describes the relationship between economic growth and environmental degradation in an inverted-U shape. It is argued that economic growth increases environmental degradation in the first stage, but after a certain level of income is exceeded, environmental improvements are realized (Grossman and Krueger, 1995; Panayotou, 1993). The main mechanisms of this trend include technological advances, increased environmental awareness and tightening of regulatory policies (Pata, 2018; Farooq et al., 2022). The EKC hypothesis has often been tested on indicators such as carbon emissions and air pollution. However, such indicators mostly address terrestrial ecosystems and provide a limited perspective on the sustainability of marine ecosystems. Therefore, examining indicators for assessing sustainable marine resources in the context of the EKC hypothesis fills an important gap in the literature (Pata and Caglar, 2021).

The main objective of this study is to evaluate the soundness of the EKC hypothesis by investigating the link between economic growth and fisheries biocapacity in BRICS+T countries (Brazil, Russia, India, China, South Africa, and Türkiye). The EKC hypothesis posits that while economic growth initially leads to environmental degradation, a turning point occurs as income levels rise, after which improvements in environmental quality are expected. In this context, fisheries biocapacity, which measures the sustainable use of marine resources, serves as a critical yet underexplored indicator of environmental sustainability. Fisheries biocapacity refers to the biological production capacity that can be sustainably extracted from a region's marine ecosystems. Unlike traditional environmental indicators, this variable allows for a simultaneous assessment of both human pressure on ecosystems and nature's capacity to regenerate itself (Global Footprint Network, 2024c). Marine ecosystems play a critical role in the global carbon cycle and provide livelihoods for millions of people around the world (FAO, 2022). However, marine ecosystems are increasingly threatened by factors such as overfishing, pollution and climate change (Wei et al., 2023). This makes it necessary to consider fisheries biocapacity when analyzing the environmental impacts of economic growth. By focusing on BRICS+T countries—nations characterized by significant natural resources, biodiversity, and rapid economic growth—this study seeks to assess whether the inverted U-shaped relationship proposed by the EKC holds true for marine resource sustainability.

BRICS+T countries have seen their share of global GDP triple over the past 15 years (Wang et al., 2024), and Türkiye, though not a formal BRICS member, is frequently considered in analyses alongside these countries due to its similar economic structure and participation in BRICS meetings (Dogan et al., 2020). These countries also rank high in biocapacity, with Brazil, China, Russia, and India holding leading positions globally (Global Footprint Network, 2024a). China and India, in particular, are global leaders in aquaculture production, while Russia and Brazil also contribute significantly to global fisheries output (UN, 2024).

There is a strong basis for considering Türkiye together with the BRICS countries in terms of both its economic structure and environmental dynamics. Türkiye is among the emerging market economies and exhibits similar development dynamics with BRICS countries in terms of industrialization and global trade (Dogan et al., 2020). Moreover, Türkiye's fisheries sector has significant potential, especially for ecosystems such as the Black Sea and the Mediterranean Sea and is directly related to sustainable resource management policies (Global Footprint Network, 2024b). In addition to having large biocapacity reserves on a global scale, BRICS countries are developing sustainability policies with different environmental governance models (Dogan and Pata, 2022). The inclusion of Türkiye in these countries is important both for understanding the economic growth-environment relationship and for comparing the effects of different development strategies on environmental sustainability.

The BRICS-T countries are becoming increasingly important actors in the global economy and have common dynamics in economic growth processes. Türkiye's inclusion in this group stems from the fact that it exhibits similar structures with BRICS countries in terms of economic, social and political globalization levels (Tekbaş, 2021). BRICS-T countries are among the countries that shape the global economy in terms of factors such as industrialization, trade volume and energy consumption and develop policies in line with sustainable development goals. Considering Türkiye together with BRICS countries provides an important framework for analyzing the effects of globalization on economic growth. In his study, Tekbaş (2021) reveals that globalization indicators are a determining factor in Türkiye's economic growth process and exhibit similar trends when compared to BRICS countries.

In terms of environmental sustainability, BRICS-T countries are among the highest carbon emitters in the world, and energy consumption and industrialization processes play a decisive role in environmental degradation (Samour et al., 2023). However, these countries also have large reserves of ecological capacity and have the potential to implement environmental sustainability policies. Türkiye's marine resource richness and sustainable fisheries policies necessitate comparative analysis with BRICS countries in terms of environmental sustainability. Fisheries biocapacity is not only a measure of human pressure on the ecosystem, but also a critical indicator for sustainable management of natural resources (Erdogan et al., 2020). Therefore, evaluating Türkiye together with the BRICS-T countries allows for a more holistic approach to the relationship between economic growth and environmental sustainability.

Previous research has mainly concentrated on the effects of economic growth on CO_2 emissions and deforestation, often neglecting its impact on marine resources such as fisheries biocapacity. This study addresses a significant gap in the literature by offering a detailed analysis of the relationship between economic growth and the sustainable management of marine resources. Given the increasing pressures global economic activities place on ocean ecosystems, understanding how economic growth affects fisheries biocapacity is crucial for the development of sustainable environmental policies.

To overcome the methodological limitations identified in previous studies, this study applies the panel bootstrap causality test developed by Kónya (2006). Although traditional methods are widely used in panel causality analyses in the literature, it is known that these methods usually ignore the dependence across countries (Dumitrescu and Hurlin, 2012). However, the method of Kónya (2006) takes into account the interconnectedness across countries and leads to a more robust analytical framework by providing a more reliable examination of the causal relationship between economic growth and fisheries biocapacity in BRICS+T countries. Similar methods have also been used in studies analyzing the relationship between environmental sustainability and economic growth and have been shown to yield effective results, especially in studies examining variables such as energy consumption, environmental degradation and biocapacity (Samour et al., 2023; Erdogan et al., 2020). Thus, this study not only tests the EKC hypothesis in a new context, but also provides policy recommendations to increase the sustainability of marine resources.

MATERIALS AND METHODS

Theoretical framework

Kuznets (1955)' foundational work explored the link between economic growth and income distribution, suggesting an inverted U-shaped relationship where inequality initially rises and later declines with development. Grossman and Krueger (1995) extended this concept to environmental degradation, proposing a similar inverted U-curve between economic growth and environmental impact, termed the Environmental Kuznets Curve (EKC) by Panayotou (1993).

The EKC theory posits that in the initial stages of economic growth, there is an increasing trend of environmental degradation and depletion of natural resources. However, once a certain threshold of economic development is surpassed, there tends to be a decrease in environmental degradation and resource depletion. In other words, economic development may have a detrimental short-term effect on the environment; however, it has a tendency to foster long-term environmental improvements. This is particularly feasible in advanced stages of development when governments and citizens allocate their increased incomes to initiatives that mitigate environmental contamination. It is imperative to implement environmental laws and technological advancements to enhance production methods in order to mitigate environmental pollution (Frodyma et al., 2022; Ayad, 2023). As explained, this relationship supports the inverted U-shaped hypothesis (Figure 1), where economic growth first worsens but later improves environmental outcomes (Uche et al., 2023; Wang et al., 2023).

Studies exploring the empirical validity of the EKC hypothesis have produced inconsistent results. While some findings support the EKC hypothesis (Chang, 2009; Kasman and Duman 2015; Pata, 2018; Farooq et al., 2022), others have disputed its validity (Abid, 2017; Allard et al., 2018; Shikwambana et al., 2021; Massagony and Budiono, 2022). These conflicting results stem from variations in country contexts, timeframes, environmental indicators, and methodologies used in the analyses. Most studies measure environmental pollution through CO2 emissions, with some also considering other greenhouse gases like methane and nitrogen oxides (Al-Mulali and Ozturk, 2015). However, these studies have faced criticism for focusing solely on air pollution, while neglecting more comprehensive environmental metrics such as soil and water pollution.

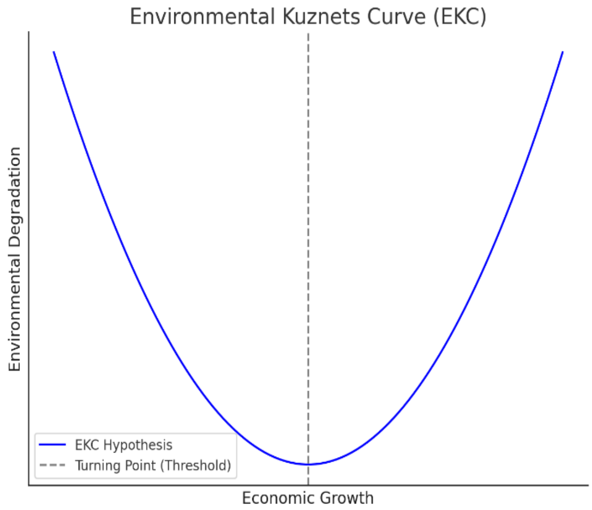

Figure 1. Enviromental Kuznets Curve (EKC)

In response to these limitations, scholars have called for broader indicators of environmental quality, such as the Ecological Footprint (EF). Developed by Wackernagel and Rees (1996), EF encompasses six components: agricultural land, pasture, fishing areas, forest land, built-up area, and carbon footprint (Kitzes et al., 2007). Integrating EF into EKC analyses provides a more holistic view of environmental quality (Yilanci et al., 2022). Nonetheless, studies examining the relationship between EF and the EKC hypothesis have also produced mixed outcomes. Some researchers affirm the EKC hypothesis (Saboori et al., 2016; Udemba, 2021), while others reject it (Hervieux and Darné, 2013; Dogan et al., 2020).

EF has faced criticism for concentrating on the demand side of environmental resources, while overlooking the supply side. To address this gap, Siche et al. (2010) launched the Load Capacity Factor (LCF) as an alternative measure. LCF represents the balance between nature's resource supply and human demand, calculated by dividing biocapacity by EF. This offers a more balanced assessment by considering both supply and demand in environmental quality (Pata and Isik, 2021). Building on this concept, Doğan and Pata (2022) introduced the Load Capacity Curve (LCC) hypothesis, which contrasts with the EKC by proposing a U-shaped relationship. According to the LCC, while economic growth initially depletes LCF, growth beyond a certain point leads to its recovery, reflecting improved environmental outcomes as economies develop (Figure 2).

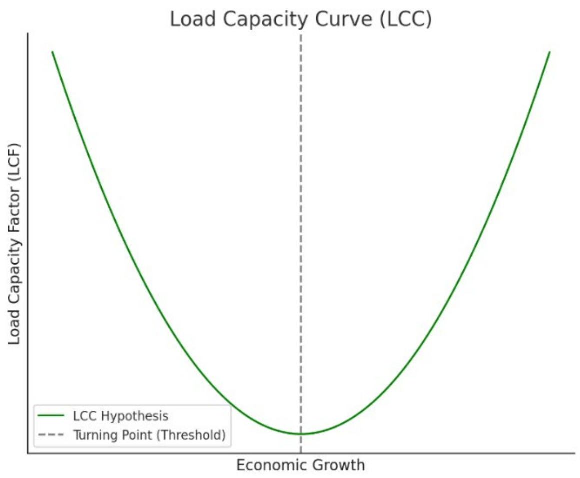

Figure 2. Load Capacity Curve (LCC)

LCF has become a powerful indicator of environmental conditions by providing the opportunity to simultaneously assess air, water, and soil quality. LCF values below 1 indicate that the ecosystem is unsustainable, while values above 1 indicate sustainable environmental conditions (Awosusi et al., 2022). Various studies using LCF, such as Awosusi et al. (2022) and Balsalobre-Lorente et al. (2019), have found that economic growth reduces LCF and thus contributes to environmental degradation. In contrast, studies by Doğan and Pata (2022), and Sun et al. (2024) support the LCC hypothesis. The theoretical framework presented above shows that the EKC hypothesis has been extended to the environmental quality domain, starting from Kuznets' initial findings on income inequality. This framework has been subjected to extensive empirical testing over the years in different geographical, temporal and methodological contexts. Despite strong support for the hypothesis, inconsistencies in the results suggest that the relationship between economic growth and environmental quality is more complex and may vary depending on a variety of factors, including the choice of environmental indicators used, policy interventions and the level of economic development. The ongoing debate around the use of alternative measures, particularly the Ecological Footprint and the Load Capacity Factor, highlights the need for more nuanced approaches to assessing environmental degradation.

In the literature, there are only a few studies that examine the validity of the EKC and LCC hypotheses in the context of marine pollution and biodiversity. One such study is conducted by De Leo et al. (2014), who investigate the EKC/LCC hypothesis alongside various variables related to marine pollution. The authors assert that fishing, storage, and international transportation negatively impact marine biodiversity. In contrast, Sebri (2016) and Paolo Miglietta et al. (2017), using the water footprint variable in different groups of countries, found the EKC hypothesis to be invalid. However, Clark et al. (2018) and Clark and Longo (2019) concluded that economic development is a significant determinant of the FF. Similarly, Kong et al. (2021), in their study on the marine fishery ecological footprint across 11 regions in China, found an inverted U-shaped relationship, supporting the EKC.

Karimi et al. (2022) and Amin et al. (2022), in separate studies conducted on Asia-Pacific countries, confirmed the validity of the EKC using the FF variable. Yıldırım et al. (2022), in their study of 10 Mediterranean countries, concluded that human capital plays a role in reducing FF. Testing the EKC hypothesis within the context of the Chinese economy, Yilanci et al. (2022) found it valid in the long term but not in the short term. In another study, Yilanci et al. (2023), analyzing Indonesian data from 1976 to 2018 using the Autoregressive Distributed Lag (ARDL) Bounds test, confirmed the validity of the EKC. Similarly, Sarkodie and Owusu (2023), conducting a study on over 200 economies using data from 1961 to 2021, also concluded that the EKC holds. Additionally, Pata et al. (2023a), testing both the EKC and Fishing Load Capacity Curve (FLCC) hypotheses with data from the top 20 fishing countries from 2000 to 2018, found both hypotheses to be valid. Lastly, Ayad (2023), focusing on G7 countries from 1970 to 2019, confirmed the validity of the Load Capacity Curve (LCC) hypothesis in the context of fishing grounds.

Data

This study utilizes data from BRICS+T countries to examine the relationship between economic growth and fisheries biocapacity within the Environmental Kuznets Curve (EKC) framework. The key variables used in the analysis are Gross Domestic Product (GDP) and Fisheries Biocapacity (FB), obtained from The World Bank (2024a) and Global Footprint Network (2024b), respectively. The study period is limited to 1992-2022 due to data availability constraints, particularly for Russia.

GDP is included in the model in logarithmic form and adjusted to constant 2015 US dollars to eliminate the effects of inflation and ensure comparability over time. Fisheries Biocapacity (FB) represents the sustainable fish stock that can be harvested from marine ecosystems without depleting future resources. It is calculated based on trophic levels and converted into primary production equivalents, a method widely accepted in ecological accounting (Global Footprint Network, 2024d). Biocapacity is measured in global hectares and serves as an indicator of an ecosystem's ability to regenerate resources relative to human consumption (Wackernagel et al., 2002; Lin et al., 2018). This metric is crucial for understanding whether economic expansion occurs within the limits of environmental sustainability.

The data descriptions of the key variables used in this study are presented in Table 1, while Figure 3 illustrates their trends over the study period.

When analyzing GDP and FB trends across BRICS+T countries, significant variations are observed. As shown in Figure 1, GDP has generally exhibited a continuous increase, particularly in China and India, where rapid economic expansion has been evident since the early 2000s. In contrast, Brazil, Russia, South Africa, and Türkiye have demonstrated a more moderate growth trajectory. This trend is consistent with previous findings in the literature, which highlight the role of industrialization and economic liberalization in fostering economic expansion in emerging economies (Tekbaş, 2021; Samour et al., 2023).

Table 1. Data description

Variable	Description	Source	Unit	Calculation Method
GDP	Gross Domestic Product	The World Bank (2024a)	Constant 2015 USD	Log-transformed
FB	Fisheries Biocapacity	Global Footprint Network (2024b)	Global hectares	Adjusted for trophic levels

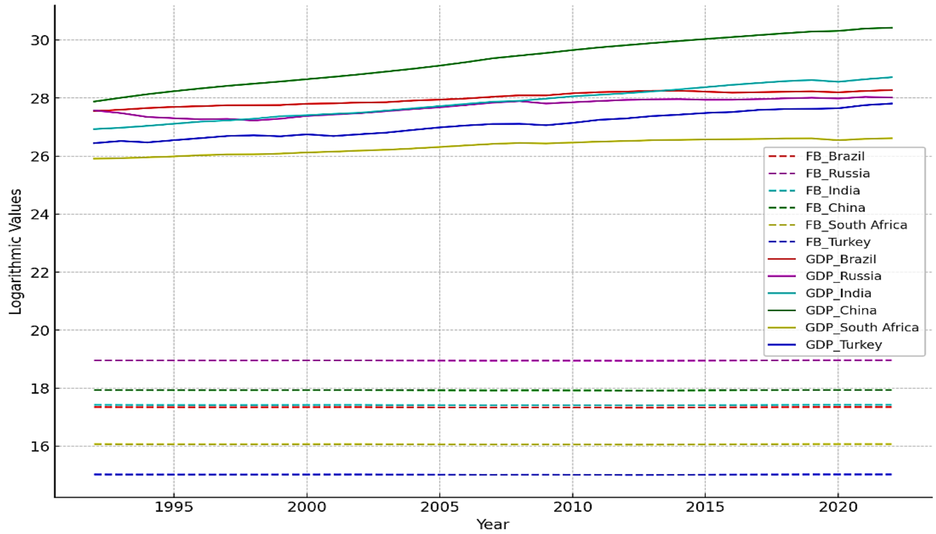

Figure 3. Graphs of FB and GDP variables

However, unlike GDP, fisheries biocapacity has remained relatively stable over time across all countries. This stagnation suggests that while economic output has grown substantially, the regenerative capacity of marine ecosystems has not exhibited a similar upward trend. This finding aligns with earlier studies emphasizing the limitations of biocapacity growth compared to economic expansion (Erdogan et al., 2020). Notably, the declining availability of fish stocks due to overfishing, climate change, and pollution may further constrain fisheries biocapacity in the coming decades (Pauly et al., 2005).

Methodology

In this study, the causal relationships between variables are analyzed using the panel bootstrap causality test developed by Kónya (2006). One of the key advantages of this test is that it does not require the presence of a cointegration relationship between variables and does not necessitate prior examination of their stationarity levels. However, before applying the test, it is essential to determine the existence of cross-sectional dependence in the models and assess whether the model coefficients are homogeneous or heterogeneous. Therefore, in the initial stage of the study, cross-sectional dependence and coefficient heterogeneity are analyzed to ensure the appropriate modeling approach. Only after these critical preliminary tests are completed can the second stage be passed and the Kónya (2006) panel bootstrap causality test be applied.

Disregarding cross-sectional dependence can result in misleading conclusions, as shocks impacting one country may influence others in the same panel (Pesaran, 2004). To account for this, cross-sectional dependence among countries in the sample is examined using specific statistical tests. These tests (Breusch and Pagan (1980)'s BP_{LM} test, Pesaran (2004)'s CD_{LM} test, Pesaran et al. (2008)'s LM_{adj} test and Baltagil et al. (2012)'s LM_{BC} test) ensure that the interdependence between countries is accurately measured, thus enhancing the robustness of the analysis and preventing erroneous interpretations of the relationships within the panel data.

The hypotheses formulated to test cross-sectional dependence are defined as follows:

H_0: The model does not exhibit cross-sectional dependency.

H_1: The model exhibits cross-sectional dependency.

If the probability values of the test statistics obtained from each test are smaller than the 10%, 5%, and 1% statistical significance levels, the H_0 hypothesis is rejected. This result indicates the presence of cross-sectional dependence in the model.

Another prerequisite for the Kónya (2006) panel bootstrap causality test is that the coefficients of the models should exhibit heterogeneity. If the slope coefficients of each country in the sample have the same value, the model is considered homogeneous. However, if the slope coefficients vary across countries, the model is assumed to have a heterogeneous structure.

This study assesses the homogeneity of coefficients using the delta (Δ and Δadj) test statistics developed by Pesaran and Yamagata (2008), which are based on Swamy (1970)'s Random Coefficients Model.

The hypotheses formulated to test the homogeneity of the Model are as follows:

H_0: The model exhibits homogeneity.

H_1: There exists a nation for which the coefficient is not the same. The model is heterogeneous.

If the probability values obtained from these test statistics are smaller than the 10%, 5%, or 1% statistical significance levels, the H_0 hypothesis is rejected. This result indicates that the slope coefficients of the model vary across countries, meaning that the model has a heterogeneous structure.

Kónya (2006) proposed a causality test that extends the Seemingly Unrelated Regressions (SUR) estimator, which was first formulated by Zellner (1962). Based on the Vector Autoregressive (VAR) framework, which Sims (1980) introduced, each equation in the SUR system is derived. The SUR system is used in this research to represent the structural connections among the variables being investigated, as explained by Kónya (2006).

$$\left.\begin{array}{l}
FB_{1,t} = \varphi_{1,1} + \sum_{l=1}^{ml_FB_1} \alpha_{1,1,l} FB_{1,t-1} + \sum_{l=1}^{ml_GDP_1} \beta_{1,1,l} GDP_{1,t-1} + \sum_{l=1}^{ml_GDP^2{}_1} \gamma_{1,1,l} GDP^2{}_{1,t-1} + \xi_{1,1,t} \\
FB_{2,t} = \varphi_{1,2} + \sum_{l=1}^{ml_FB_1} \alpha_{1,2,l} FB_{2,t-1} + \sum_{l=1}^{ml_GDP_1} \beta_{1,2,l} GDP_{2,t-1} + \sum_{l=1}^{ml_GDP^2{}_1} \gamma_{1,2,l} GDP^2{}_{2,t-1} + \xi_{1,2,t} \\
\vdots \\
FB_{N,t} = \varphi_{1,N} + \sum_{l=1}^{ml_FB_1} \alpha_{1,N,l} FB_{N,t-1} + \sum_{l=1}^{ml_GDP_1} \beta_{1,N,l} GDP + \sum_{l=1}^{ml_GDP^2{}_1} \gamma_{1,N,l} GDP^2{}_{2,t-1} + \xi_{1,N,t}
\end{array}\right\}$$

where N shows the number of countries, and t denotes the time interval (t=1992, 1993, 2022). Additionally, ml denotes the lag length, which is determined by employing configurations that reduce the Akaike and Schwartz Information Criterion values.

RESULTS

The cross-sectional dependence test results for the study are presented in detail in Table 2. This table evaluates the probability values of each test along with their statistical significance levels.

Table 2. Cross-sectional dependence test

Tests	Test-Stat.	Probability
BP_{LM}	369.209*	0.001
CD_{LM}	64.669*	0.001
LM_{BC}	64.569*	0.001
LM_{adj}	19.188*	0.001

*denotes the rejection of null hypothesis at 1%.

The analysis indicates the existence of horizontal cross-sectional dependence within the model. As seen in Table 2, the probability values are below 0.01, allowing us to confidently reject the null hypothesis of no horizontal cross-sectional dependence at the 1% significance level across all models. This confirms the presence of horizontal cross-sectional dependency among the variables. The test results related to homogeneity are presented in Table 3.

Table 3. Homogeneity test results

Test	Test-Stat.	Probability
Δ	-1.918*	0.055
Δadj	-3.322*	0.001

*denotes the rejection of null hypothesis at 1%.

According to the homogeneity test findings presented in Table 3, the test statistic for the Δ test is calculated as -1.918, with a p-value of 0.055. This result indicates that the null hypothesis is rejected at the 10% significance level, suggesting that the model coefficients exhibit a heterogeneous structure.

Similarly, for the Δadj test, the test statistic is -3.232, with a p-value of 0.001, leading to the rejection of the null hypothesis at the 1% significance level, further confirming the heterogeneous nature of the model coefficients. Based on the results of both the Δ and Δadj tests, the model is considered to be heterogeneous.

Since the Kónya (2006) panel bootstrap causality test requires model coefficients to be heterogeneous, these results confirm that the necessary methodological conditions for applying the test have been met.

According to Table 4, the analysis results indicate a causality relationship from GDP and GDP^2 to FB for all countries except India. Specifically, findings reveal a negative causality from GDP to FB in Russia, South Africa, and Türkiye, while a positive causality is observed from GDP^2 to FB in these countries. The findings from Russia, South Africa, and Türkiye are consistent with previous research supporting the EKC hypothesis. Studies by Pata (2018) and Farooq et al. (2022) have similarly demonstrated that in certain countries, economic growth initially leads to environmental degradation, but environmental quality improves once a specific income level is reached. This confirms the presence of an inverted U-shaped relationship between GDP growth and fishing biocapacity in these countries, showing that as GDP grows, fishing biocapacity initially decreases but begins to improve after reaching a certain threshold of economic development. In contrast, a positive causal relationship is observed from GDP and GDP^2 to FB in Brazil and China, indicating that while the EKC hypothesis is not valid in these countries, economic growth still exerts a beneficial effect on fishing biocapacity. Additionally, no significant causal relationship between the variables is detected in India, further underscoring the heterogeneity in environmental outcomes across the BRICS+T.

Table 4. Kónya panel bootstrap causality test results

	GDP	GDP^2	Wald	10%	5%	1%
Brazil	+	+	2.271**	0.710	1.145	2.798
China	+	+	2.994*	0.707	1.174	2.652
India	+	+	0.428	0.750	1.193	2.632
Russia	-	+	6.674*	2.233	3.374	6.626
South Africa	-	+	4.297*	0.762	1.116	2.875
Türkiye	-	+	4.003*	0.657	1.243	2.770

* and **denotes causality at 1%, and 5%, significance level, respectively. H_0: GDP, GDP^2 are not the Granger causality for FB.

The findings for Brazil and China align with the assertion by Balsalobre-Lorente et al. (2019) that GDP growth contributes to environmental quality. Brazil, which boasts the longest coastline in Latin America, harbors coastal ecosystems that host a great diversity of species (Miloslavich et al., 2011). Moreover, Brazil ranks first globally in total biocapacity (Global Footprint Network, 2024a). Despite significant CO^2 emissions growth in BRICS countries since 1990, emissions in Brazil lag behind other countries after India, primarily due to Brazil's industrial structure. Brazil's economic development focuses more on the service sector than industrialization, facilitating a reduction in carbon emissions (Zhang, 2021). This observation aligns with the study of Wu et al. (2015), who demonstrated that in Brazil, CO2 emissions decrease as economic growth progresses, consistent with the results of this study regarding environmental improvements alongside GDP growth among BRICS nations.

The findings for China indicate that economic growth has a positive impact on fishing biocapacity. Pata and Caglar (2021) support this study's findings by asserting that in China, while the EKC may not be applicable, economic growth reduces CO^2 emissions. Conversely, research by Pal and Mitra (2017) and Hussain et al. (2022) found that the Environmental Kuznets Curve (EKC) hypothesis does not hold true for China. Despite being a developing country, China ranks as the world's second-largest economy, following the U.S., and has shifted its focus towards high-quality economic growth (Jiang and Wang, 2019). Over the past 40 years, China has implemented strategic policies, such as the creation of the Ministry of Natural Resources in 2018, to ensure the stability and resilience of its marine ecosystems. This includes the introduction of Special Marine Protected Areas and consolidating all conservation efforts, both marine and terrestrial, under a unified management system (Hu et al., 2020). The study's findings specific to China can be attributed to its recent shift from rapid growth to higher-quality development, coupled with proactive policies towards marine and aquatic life, which are integral to its economy.

The results of the study suggest that there is no causal relationship between fishing biocapacity and growth in India. This is consistent with the conclusions of Alam and Adil (2019), who hypothesize that India's growth momentum may have been influenced by its acceleration after approximately the year 2000. Furthermore, India's economic growth heavily relies on the service sector, which accounted for 44% of its GDP between 1992 and 2022 (The World Bank, 2024b). The predominant role of the service sector within its growth trajectory may have affected the expected relationship between growth and environmental pollution differently than anticipated. In this regard, India's per capita carbon emissions are relatively low compared to other BRICS countries (Zhang, 2021). On the other hand, India ranks sixth globally in total biocapacity (Global Footprint Network, 2024a).

DISCUSSION

The objective of this study is to evaluate the validity of the EKC hypothesis across BRICS+T countries from 1992 to 2022, with a particular emphasis on the fisheries biocapacity variable. In Russia, South Africa, and Türkiye, evidence has been discovered that supports the validity of the EKC hypothesis through the panel bootstrap causality test. Furthermore, the results of the study imply that the EKC hypothesis may not be valid in Brazil and China. However, they also suggest that economic growth has a beneficial impact on the biocapacity of the fishing industry in these countries. Nevertheless, no causal relationship was identified between fishing biocapacity and growth in India. The results from the other countries, with the exception of India, consistently indicate that sustained economic growth has a positive impact on fisheries biocapacity.

Oceans and seas, which play a central role in stabilizing the world's climate system and providing regulation and livelihood for other dependent species (Pata et al., 2023), are experiencing significant biodiversity loss due to global warming caused by greenhouse gas emissions. This impact is particularly felt in less developed and developing countries, where oceans and seas are crucial sources of income and food. In 2019 alone, air pollution cost the world $8.1 trillion, equivalent to 6.1% of global GDP. This economic burden disproportionately affects less developed and developing countries, where environmental pollution costs range from an estimated 5% to 14% of their GDPs, hindering economic growth and exacerbating poverty and inequality in urban and rural areas (The World Bank, 2024c). Therefore, addressing the warming and pollution observed in oceans and seas, which are crucial for environmental sustainability, should be treated as a global issue. Integrating this critical topic into basic education curricula and raising public awareness through public service announcements can serve as significant initial steps toward addressing these vital concerns.

The research findings indicate that prolonged economic growth can result in a decrease in environmental pollution, supporting the idea that, over time, development can foster environmental improvements through cleaner technologies and stronger regulations. Therefore, especially in sectors driving economic growth in developing countries, it is essential to employ environmentally friendly production techniques while prioritizing conservation and even enhancement of natural habitats. On the other hand, for developed countries aiming at sustainable development goals, shifting pollution-generating production activities to less developed and developing countries, often driven by lower labor costs, poses a significant challenge. To mitigate this issue, multinational corporations engaging in activities that may lead to environmental pollution should be mandated to adopt clean energy sources and environmentally sustainable technologies. Production processes should undergo stricter scrutiny by local and central authorities, ensuring compliance with these requirements.

In order to strengthen the alignment between economic growth and environmental sustainability, several policy recommendations can be developed for BRICS+T countries. First of all, sustainable fisheries management policies need to be supported by more concrete steps. In this context, measures such as determining Total Allowable Catch (TAC), allocating fishing quotas in line with scientific data and increasing Marine Protected Areas (MPAs) should be taken. Long-term sustainability of fish stocks can be ensured by utilizing the practices of countries that are successful in fisheries management, such as the Norwegian model.

In addition, fiscal and legal regulations should be introduced to promote environmentally friendly technologies. Production processes based on renewable energy should be supported through green tax reductions and subsidies, and fossil fuel subsidies should be gradually removed. For example, the special incentive models implemented in China for low carbon technologies can be a guiding light for BRICS+T countries. Making cleaner production techniques mandatory in the industrial sector and expanding environmental taxation mechanisms will also support environmental sustainability.

The activities of multinational companies should be supervised by strict environmental regulations and legislation should be implemented to mandate the use of clean energy. For example, carbon pricing mechanisms such as the European Union Emissions Trading System (EU ETS) could be implemented in BRICS+T countries. In countries like Russia, where there is a lack of environmental data, environmental data collection systems should be strengthened to increase transparency.

Transfer of clean technologies should be encouraged by increasing international cooperation. Especially among BRICS+T countries, joint funds should be established to combat climate change and regional initiatives based on technology sharing should be implemented. Experiences from international cooperation to protect Brazil's Amazon rainforest could be similarly adapted to initiatives to protect marine ecosystems.

Finally, it is crucial to integrate the concept of sustainability into education systems to raise environmental awareness. In particular, more attention should be given to environmental awareness and ecological footprinting in primary and secondary education curricula to encourage individuals to develop attitudes and behaviors that contribute to environmental sustainability in the long term. Governments should also establish regular monitoring and evaluation systems to analyze the effectiveness of implemented environmental policies and make adjustments when necessary. When these policies are considered holistically, it will be possible to harmonize economic growth with the principles of environmental sustainability.

CONCLUSION

This study examined the relationship between economic growth and fisheries biocapacity in BRICS+T countries within the context of the Environmental Kuznets Curve (EKC) hypothesis. The results were mixed: the EKC hypothesis holds true for Russia, South Africa, and Türkiye, where economic growth initially leads to a decline in fisheries biocapacity but eventually improves it. However, the hypothesis was not supported for Brazil, China, and India, where the relationship between economic growth and fisheries biocapacity did not align with the EKC pattern. In Brazil and China, economic growth positively influences fisheries biocapacity, contrary to the EKC hypothesis. The absence of significant relationships in India suggests different dynamics. These variations can be attributed to differences in economic structures, environmental regulations, and fisheries management policies across countries. In Russia, South Africa, and Türkiye, the initial decline in fisheries biocapacity may be linked to rapid industrialization and weak early-stage environmental policies, whereas the eventual improvement could be driven by strengthened regulatory frameworks and technological advancements in marine resource management. Conversely, in Brazil and China, the positive impact of economic growth on fisheries biocapacity might stem from proactive environmental policies, sustainable fisheries initiatives, and investments in marine conservation. The lack of a significant relationship in India suggests that factors such as inconsistent policy enforcement, data limitations, and differing levels of economic dependence on fisheries may play a role.

These findings underscore the importance of tailoring environmental policies to the unique economic structures and growth patterns of each country. For nations experiencing positive biocapacity trends, such as Brazil and China, policies should focus on maintaining and reinforcing sustainable growth patterns. This can be achieved by promoting responsible fisheries management, strengthening conservation incentives, and implementing stricter monitoring mechanisms to ensure continued biocapacity improvement. This trend may be driven by the integration of environmental policies with economic growth strategies, as seen in Brazil's expansion of marine protected areas and China's government-led initiatives to limit overfishing and promote aquaculture sustainability. Strengthening these regulatory frameworks and ensuring long-term policy stability will be crucial for sustaining the positive trajectory of fisheries biocapacity in these countries.

In contrast, for Russia, South Africa, and Türkiye-where the EKC hypothesis holds-policymakers should prioritize the transition to a sustainable phase by integrating stronger environmental regulations, investing in eco-friendly marine technologies, and encouraging public-private partnerships to foster sustainable fisheries management. These countries can also benefit from targeted subsidies for sustainable fishing practices and stricter enforcement of marine protection laws to accelerate the recovery of fisheries biocapacity.

For India, where no significant relationship was found, future policies should focus on improving fisheries data collection and identifying underlying socio-economic and institutional factors affecting biocapacity. Investing in sustainable aquaculture, enhancing marine resource governance, and promoting community-based fisheries management could help establish a clearer link between economic growth and biocapacity changes.

Future research can address in more detail the determinants of the relationship between economic growth and fisheries biocapacity across countries. In particular, by examining the impact of factors such as the level of industrialization, environmental policies, natural resource management strategies and renewable energy use rates on this relationship, sustainable development policies can be developed in line with the unique socio-economic and environmental dynamics of each country. In addition to the panel bootstrap causality test used in this study, the robustness of the findings can be tested by using different methodological approaches and the reasons for cross-country differences can be analyzed in more depth through time series analysis. In addition, issues such as the long-term effects of climate change on fisheries biocapacity and how ecological carrying capacity is shaped by economic growth provide an important basis for future research. Such expanded analyses would make a more comprehensive contribution to efforts to balance economic development and environmental sustainability on a global scale.

ACKNOWLEDGEMENTS AND FUNDING

This research has not received any specific grant, funding or other support from any funding organization in the public, commercial or non-profit sectors.

AUTHOR CONTRIBUTIONS

All authors contributed to the idea and design of the study. Material preparation, research and part of writing was carried out by Şerif Canbay. The rest of writing and editing of the manuscript was done by Serkan Şengül and all authors have read and approved the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest or competing interests.

ETHICAL APPROVAL

Ethical approval is not required for this study.

DATA AVAILABILITY

All relevant data is inside the article. Additional data sets of the current study will be provided by the corresponding author upon request.

REFERENCES

Abid, M. (2017). Does economic, financial and institutional developments matter for environmental quality? a comparative analysis of EU and MEA countries. *Journal of Environmental Management*, *188*, 183-194. https://doi.org/10.1016/j.jenvman.2016.12.007

Alam, R., & Adil, M.H. (2019). Validating the environmental Kuznets curve in India: ARDL bounds testing framework. *OPEC Energy Review, 43*(3), 277-300. https://doi.org/10.1111/opec.12156

Allard, A., Takman, J., Uddin, G.S., & Ahmed, A. (2018). The N-shaped environmental Kuznets curve: An empirical evaluation using a panel quantile regression approach. *Environmental Science and Pollution Research, 25*(6), 5848-5861. https://doi.org/10.1007/s11356-017-0907-0

Al-Mulali, U., & Ozturk, I. (2015). The effect of energy consumption, urbanization, trade openness, industrial output, and political stability on environmental degradation in the MENA region. *Energy, 84*, 382-389. https://doi.org/10.1016/j.energy.2015.03.004

Amin, S., Li, C., Khan, Y. A., & Bibi, A. (2022). Fishing grounds footprint and economic freedom indexes: evidence from Asia-Pacific. *PLoS One, 17*(4), e0263872. https://doi.org/10.1371/journal.pone.0263872

Awosusi, A. A., Kutlay, K., Altuntaş, M., Khodjiev, B., Agyekum, E. B., Shouran, M., & Kamel, S. (2022). A roadmap toward achieving a sustainable environment: Evaluating the impact of technological innovation and globalization on the load capacity factor. *International Journal of Environmental Research and Public Health, 19*(6), 3288. https://doi.org/10.3390/ijerph19063288

Ayad, H. (2023). Investigating the fishing grounds load capacity curve in G7 nations: Evaluating the influence of human capital and renewable energy use. *Marine Pollution Bulletin, 194*, 115413. https://doi.org/10.1016/j.marpolbul.2023.115413

Balsalobre-Lorente, D., Álvarez-Herranz, A., & Shahbaz, M. (2019). The long-term effect of economic growth, energy innovation, and energy use on environmental quality. In: Shahbaz, M., Balsalobre, D. (Eds.) *Energy and Environmental Strategies in the Era of Globalization.* Green Energy and Technology. Springer, Cham. https://doi.org/10.1007/978-3-030-06001-5_1

Baltagi, B.H., Feng, Q, & Kao, C. (2012). A lagrange multiplier test for cross-sectional dependence in a fixed effects panel data model. *Journal of Econometrics*, *170*(1), 164-177. https://doi.org/10.1016/j.jeconom.2012.04.004

Breusch, T.S., & Pagan, A.R. (1980). The lagrange multiplier test and its applications to model specification in econometrics. *The Review of Economic Studies*, *47*(1), 239-253. https://doi.org/10.2307/2297111

Chang, C.C. (2009). A multivariate causality test of carbon dioxide emissions, energy consumption and economic growth in China. *Applied Energy, 87*(11), 3533–3537. https:// doi.org/10.1016/j.apenergy.2010.05.004

Clark, T.P., & Longo, S.B. (2019). Examining the effect of economic development, region, and time period on the fisheries footprints of nations (1961-2010). *International Journal of Comparative Sociology, 60*(4), 225-248. https://doi.org/10.1177/0020715219869976

Clark, T.P., Longo, S.B., Clark, B., & Jorgenson A.K. (2018). Socio-structural drivers, fisheries footprints, and seafood consumption: a comparative international study, 1961-2012. *Journal of Rural Studies, 57*, 140-146. https://doi.org/10.1016/j. jrurstud.2017.12.008

Damirova, S., & Yayla, N. (2021). The relationship between environmental pollution and its macroeconomic determinants: A panel data analysis for selected countries. *International Journal of Economics and Administrative Studies, 30*, 107-126. https://doi.org/10.18092/ulikidince.804787

De Leo, F., Miglietta, P.P., & Pavlinović, S. (2014). Marine ecological footprint of Italian mediterranean fisheries. *Sustainability, 6*(11), 7482-7495. https://doi.org/10.3390/su6117482

Dogan, E., Ulucak, R., Kocak, E., & Isik, C. (2020). The use of ecological footprint in estimating the environmental Kuznets curve hypothesis for BRICS+T by considering cross-section dependence and heterogeneity. *Science of the Total Environment, 723*, 138063. https://doi.org/10.1016/j.scitotenv.2020.138063

Dogan, A., & Pata, U.K. (2022). The role of ICT, R&D spending, and renewable energy consumption on environmental quality: Testing the LCC hypothesis for G7 countries. *Journal of Cleaner Production, 380*, 135038. https://doi.org/10.1016/j.jclepro.2022.135038

Dumitrescu, E.I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling*, *29*(4), 1450-1460. https://doi.org/10.1016/j.econmod.2012.02.014

Erdogan, S., Kirca, M., & Gedikli, A. (2020). Is there a relationship between CO2 emissions and health expenditures? Evidence from BRICS-T countries. *Business and Economics Research Journal*, *11*(2), 293-305. https://doi.org/10.20409/berj.2019.231

FAO. (2022). The state of world fisheries and aquaculture 2022: Towards blue transformation. *Food and Agriculture Organization of the United Nations*. https://www.fao.org/3/cc0461en/cc0461en.pdf

Farooq, S., Ozturk, I., Majeed, M.T., & Akram, R. (2022). Globalization and CO2 emissions in the presence of EKC: A global panel data analysis. *Gondwana Research, 106*, 367-378. https://doi.org/10.1016/j.gr.2022.02.002

Frodyma, K., Papież, M., & Śmiech, S. (2022). Revisiting the environmental Kuznets curve in the European Union countries. *Energy, 241*, 122899. https://doi.org/10.1016/j. energy.2021.122899

Global Footprint Network. (2024a). Total biocapacity. *Global Footprint Network*. https://data.footprintnetwork.org/?_ga=2.229406620.1234288758.1719733753-1485324782.1719733753#/ (Accessed January 2024)

Global Footprint Network. (2024b). Open data platform. *Global Footprint Network*. https://data.footprintnetwork.org/?_ga=2.187868973.486531688.1720198163-1485324782.1719733753#/countryTrends?cn=5001&type=BCtot,EFCtot (Accessed January 2024)

Global Footprint Network. (2024c). What biocapacity measures. *Global Footprint Network*. https://www.footprintnetwork.org/what-biocapacity-measures/ (Accessed January 2024)

Global Footprint Network. (2024d). Glossary. *Global Footprint Network*. https://www.footprintnetwork.org/resources/glossary/ (Accessed January 2024)

Grossman, G.M., & Krueger, A.B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics, 110*(2), 353-377. https://doi.org/10.2307/2118443

Hervieux, M.S., & Darné, O. (2013). Environmental Kuznets curve and ecological footprint: A time series analysis. *HAL Archives Ouvertes*. https://hal.archives-ouvertes.fr/hal-00781958

Hu, W., Liu, J., Ma, Z., Wang, Y., Zhang, D., Yu, W., & Chen, B. (2020). China's marine protected area system: Evolution, challenges, and new prospects. *Marine Policy, 115*, 103780. https://doi.org/10.1016/j.marpol.2019.103780

Hussain, M., Wang, W., & Wang, Y. (2022). Natural resources, consumer prices and financial development in China: Measures to control carbon emissions and ecological footprints. *Resources Policy, 78*, 102880. https://doi.org/10.1016/j.resourpol.2022.102880

Jiang, L., & Wang, X.J. (2019). EKC hypothesis verification between rural environmental quality and agricultural economic growth in China: An empirical analysis based on panel data of 31 provinces. *Issues in Agricultural Economy, 12*, 43-51.

Karimi, M. S., Khezri, M., Khan, Y. A., & Razzaghi, S. (2022). Exploring the influence of economic freedom index on fishing grounds footprint in environmental Kuznets curve framework through spatial econometrics technique: evidence from Asia- Pacific countries. *Environmental Science and Pollution Research, 29*(4), 6251-6266. https://doi.org/10.1007/s11356-021-16110-8

Kasman, A., & Duman, Y.S. (2015). CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis. *Economic Modelling, 44*, 97-103. https://doi.org/10.1016/j. econmod.2014.10.022

Kitzes, J., Audrey, P., Goldfinger, S., & Wackernagel, M. (2007). Current methods for calculating national ecological footprint accounts. *Science for Environment & Sustainable Society, 4*(1), 1-9.

Kong, F., Cui, W., & Xi, H. (2021). Spatial-temporal variation, decoupling effects and prediction of marine fishery based on modified ecological footprint model: case study of 11 coastal provinces in China. *Ecological Indicators, 132*, 108271. https://doi.org/10.1016/j.ecolind.2021.108271

Kónya, L. (2006). Exports and growth: Granger causality analysis on OECD countries with a panel data approach. *Economic Modelling, 23*(6), 978-992. https://doi.org/10.1016/j.econmod.2006.04.008

Kuznets, S. (1955). Economic growth and income inequality. *The American Economic Review, 45*(1), 1-28.

Lin, D., Hanscom, L., Murthy, A., Galli, A., Evans, M., Neill, E., Serena Mancini, M., Martindill, J., Medouar, F.-Z., Huang, S., & Wackernagel, M. (2018). Ecological footprint accounting for countries: updates and results of the National Footprint Accounts, 2012–2018. *Resources*, *7*(3), 58. https://doi.org/10.3390/resources7030058

Massagony, A., & Budiono. (2022). Is the environmental Kuznets curve (EKC) hypothesis valid on CO_2 emissions in Indonesia? *International Journal of Environmental Studies, 80*(1), 20-31. https://doi.org/10.1080/00207233.2022.2029097

Miloslavich, P., Klein, E., Díaz, J.M., Hernández, C. E., Bigatti, G., Campos, L., Artigas, F., Castillo, J., Penchaszadeh, P.E., Neill, P.E., Carranza, A., Retana, M.V., de Astarloa, J.M.D., Lewis, M., Yorio, P., Piriz, M.L., Rodríguez, D., Yoneshigue-Valentin, Y., Gamboa, L., & Martín, A. (2011). Marine biodiversity in the Atlantic and Pacific coasts of South America: Knowledge and gaps. *PLOS ONE, 6*(1), e14631. https://doi.org/10.1371/journal.pone.0014631

Pal, D., & Mitra, S. K. (2017). The environmental Kuznets curve for carbon dioxide in India and China: Growth and pollution at crossroad. *Journal of Policy Modeling, 39*(2), 371-385. https://doi.org/10.1016/j.jpolmod.2017.03.005

Panayotou, T. (1993). Empirical tests and policy analysis of environmental degradation at different stages of economic development. *International Labour Organization*. https://www.ilo.org/public/libdoc/ilo/1993/93B09_31_engl.pdf

Paolo Miglietta, P., De Leo, F., & Toma, P. (2017). Environmental Kuznets curve and the water footprint: an empirical analysis. *Water and Environment Journal, 31*(1), 20-30. https://doi.org/10.1111/wej.12211

Pata, U.K. (2018). Renewable energy consumption, urbanization, financial development, income, and CO2 emissions in Turkey: Testing the EKC hypothesis with structural breaks. *Journal of Cleaner Production, 187*, 770-779. https://doi.org/10.1016/j.jclepro.2018.03.236

Pata, U.K., & Caglar, A.E. (2021). Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization, and trade openness for China: Evidence from augmented ARDL approach with a structural break. *Energy, 216*, 119220. https://doi.org/10.1016/j.energy.2020.119220

Pata, U.K., Dam, M.M., & Kaya, F. (2023). How effective are renewable energy, tourism, trade openness, and foreign direct investment on CO2 emissions? An EKC analysis for ASEAN countries. *Environmental Science and Pollution Research, 30*(6), 14821-14837. https://doi.org/10.1007/s11356-022-23160-z

Pata, U.K., & Ertugrul, H.M. (2023a). Do the Kyoto protocol, geopolitical risks, human capital and natural resources affect the sustainability limit? A new environmental approach based on the LCC hypothesis. *Resources Policy, 81*, 103352. https://doi.org/10.1016/j.resourpol.2023.103352

Pata, U.K., & Isik, C. (2021). Determinants of the load capacity factor in China: A novel dynamic ARDL approach for ecological footprint accounting. *Resources Policy, 74*, 102313. https://doi.org/10.1016/j.resourpol.2021.102313

Pauly, D., Watson, R., & Alder, J. (2005). Global trends in world fisheries: impacts on marine ecosystems and food security. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1453), 5-12. https://doi.org/10.1098/rstb.2004.1574

Pesaran, M.H. (2004). General diagnostic tests for cross section dependence in panels. *Cambridge Working Papers in Economics, 0435,* IZA Discussion Paper No. 1240. https://doi.org/10.17863/CAM.5113

Pesaran, M.H., Ullah, A., & Yamagata, T. (2008). A bias-adjusted LM test of error cross-section independence. *The Econometrics Journal*, *11*(1), 105-127. https://doi.org/10.1111/j.1368-423X.2007.00227.x

Pesaran, M.H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics 142*(1), 50-93. https://doi.org/10.1016/j.jeconom.2007.05.010

Saboori, B., Al-Mulali, U., Bin Baba, M., & Mohammed, A. H. (2016). Oil-induced environmental Kuznets curve in OPEC. *International Journal of Green Energy, 13*(4), 408-416. https://doi.org/10.1080/15435075.2014.961468

Samour, A., Adebayo, T.S., Agyekum, E.B., Khan, B., & Kamel, S. (2023). Insights from BRICS-T economies on the impact of human capital and renewable electricity consumption on environmental quality. *Scientific Reports, 13*, 5245. https://doi.org/10.1038/s41598-023-32134-1

Sarkodie, S.A., Owusu, P.A. (2023). Assessment of global fish footprint reveals growing challenges for sustainable production and consumption. *Marine Pollution Bulletin, 194*, 115369. https://doi.org/10.1016/j.marpolbul.2023.115369

Sebri, M. (2016). Testing the environmental Kuznets curve hypothesis for water footprint indicator: a cross-sectional study. *Journal of Environmental Planning and Management, 59*(11), 1933-1956. https://doi.org/10.1080/09640568.2015.1100983

Shi, Z., Assis, J., & Costello, M.J. (2022). Vulnerability of marine species to low oxygen under climate change. Imperiled: *The Encyclopedia of Conservation*, 887-894. https://doi.org/10.1016/B978-0-12-821139-7.00203-8

Siche, R., Pereira, L., Agostinho, F., & Ortega, E. (2010). Convergence of ecological footprint and energy analysis as a sustainability indicator of countries: Peru as case study. *Communications in Nonlinear Science and Numerical Simulation, 15*(10), 3182-3192. https://doi.org/10.1016/j.cnsns.2009.10.027

Shikwambana, L., Mhangara, P., & Kganyago, M. (2021). Assessing The relationship between economic growth and emissions levels in South Africa between 1994 and 2019. *Sustainability, 13*(5), 2645. https://doi.org/10.3390/su13052645

Sims, C.A. (1980). Macroeconomics and reality. *Econometrica*, *48*(1), 1-48. https://doi.org/10.2307/1912017

Sun, A., Bao, K., Aslam, M., Gu, X., Khan, Z., & Uktamov, K. F. (2024). Testing load capacity and environmental Kuznets curve hypothesis for China: Evidence from novel dynamic autoregressive distributed lags model. *Gondwana Research, 129*, 476-489. https://doi.org/10.1016/j.gr.2023.07.018

Swamy, P.A.V.B. (1970). Efficient inference in a random coefficient regression model. *Econometrica*, *38*(2), 311-323. https://doi.org/10.2307/1913012

Tekbaş, M. (2021). The Impact of economic, social and political globalization on economic growth: Evidence from BRICS-T countries. Gaziantep University Journal of Social Sciences, 20(1), 57-71. https://doi.org/10.21547/jss.796472

The World Bank. (2024a). GDP (constant 2015 US$). https://data.worldbank.org/indicator/NY.GDP.MKTP.KD (Accessed January 2024)

The World Bank. (2024b). Services, value added (% of GDP). https://data.worldbank.org/indicator/NV.SRV.TOTL.ZS (Accessed January 2024)

The World Bank. (2024c). Pollution. https://www.worldbank.org/en/topic/pollution (Accessed January 2024)

Uche, E., Das, N., & Bera, P. (2023). Re-examining the environmental Kuznets curve (EKC) for India via the multiple threshold NARDL procedure. *Environmental Science and Pollution Research*, *30*(5), 11913-11925. https://doi.org/10.1007/s11356-022-22912-1

Udemba, E.N. (2021). Ascertainment of ecological footprint and environmental Kuznets in China. In: Muthu, S.S. (Ed.). *Assessment of Ecological Footprints*. Springer, Singapore. https://doi.org/10.1007/978-981-16-0096-8_3

UN. (2024). Sustainable development goal, goal 14: Conserve and sustainably use the oceans, seas and marine resources. *United Nations*. https://www.un.org/sustainabledevelopment/oceans (Accessed June 2024)

Wackernagel, M., & Rees, W. (1996). *Our ecological footprint: reducing human impact on the earth.* New Society Publishers, Gabriola Island.

Wackernagel, M., Schulz, N.B., Deumling, D., Linares, A.C., Jenkins, M., Kapos, V., Monfreda, C., Loh, J., Myers, N., Norgaard, R., & Randers, J. (2002). Tracking the ecological overshoot of the human economy. *Proceedings of the National Academy of Sciences*, *99*(14), 9266-9271. https://doi.org/10.1073/pnas.142033699

Wang, K., Rehman, M.A., Fahad, S., & Linzhao, Z. (2023). Unleashing the influence of natural resources, sustainable energy and human capital on consumption-based carbon emissions in G7 countries. *Resources Policy, 81*, 103384. https://doi.org/10.1016/j.resourpol.2023.103384

Wang, S., Zafar, M.W., Vasbieva, D.G., & Yurtkuran, S. (2024). Economic growth, nuclear energy, renewable energy, and environmental quality: Investigating the environmental Kuznets curve and load capacity curve hypothesis. *Gondwana Research, 129*, 490-504. https://doi.org/10.1016/j.gr.2023.06.009

Wei, Y., Ding, D., Gu, T., Xu, Y., Sun, X., Qu, K., & Cui, Z. (2023). Ocean acidification and warming significantly affect coastal eutrophication and organic pollution: A case study in the Bohai Sea. *Marine Pollution Bulletin, 186*, 114380. https://doi.org/10.1016/j.marpolbul.2022.114380

Wu, L., Liu, S., Liu, D., Fang, Z., & Xu, H. (2015). Modelling and forecasting CO2 emissions in the BRICS countries using a novel multi-variable grey model. *Energy, 79*, 489-495. https://doi.org/10.1016/j.energy.2014.11.052

Yilanci, V., Cutcu, I., & Cayir, B. (2022). Is the environmental Kuznets curve related to the fishing footprint? Evidence from China. *Fisheries Research, 254*, 106392. https://doi.org/10.1016/j.fishres.2022.106392

Yilanci, V., Cutcu, I., Cayir, B., & Saglam, M.S. (2023). Pollution haven or pollution halo in the fishing footprint: evidence from Indonesia. *Marine Pollution Bulletin, 188*, 114626. https://doi.org/10.1016/j.marpolbul.2023.114626

Yildirim, D.C., Yildirim, S., Bostancı, S.H., & Turan, T. (2022). The nexus between human development and fishing footprint among Mediterranean countries. *Marine Pollution Bulletin*, *176*, 113426. https://doi.org/10.1016/j.marpolbul.2022.113426

Zellner, A. (1962). An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. *Journal of the American Statistical Association*, *57*(298), 348-68. https://doi.org/10.1080/01621459.1962.10480664

Zhang, H. (2021). Technology innovation, economic growth and carbon emissions in the context of carbon neutrality: Evidence from BRICS. *Sustainability, 13*(20), 11138. https://doi.org/10.3390/su132011138