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RESEARCH ARTICLE

Is it worth polluting? A multimodal MCDM approach to understand the environmental harm done globally

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ABSTRACT

This study aims to determine whether environmental pollution caused by countries, their trade activities, and economic development is significant when considered collectively. Utilizing the most recent global data from (142) countries, six different Multi-Criteria Decision-Making methods were employed to assess which countries currently perform better. The correlations among the obtained scores were then analyzed to evaluate the robustness of the findings. The results revealed that the United States, Germany, and the Netherlands achieved the highest composite environmental–economic performance scores, while Burundi, Lesotho, and the Central African Republic ranked lowest. The Spearman correlation coefficients among the six methods exceeded 0.90, confirming the robustness of the rankings. The study's findings explore whether economic advancements justify environmental harm and whether the economic benefits are sufficient to offset environmental recovery efforts. Finally, it can be concluded that countries are willing to pollute the environment to gain more from the global economic system.

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INTRODUCTION

Since the adoption of the United Nations Sustainable Development Goals (SDGs), there has been an increasing emphasis on environmental research aimed at addressing a wide range of questions from diverse perspectives. Each year, thousands of studies investigate the sources of carbon emissions, which are commonly recognized as a form of environmental pollution. Conversely, many studies seek to explain the consequences of carbon emissions. A significant number of these investigations are linked to energy-related issues. However, when examining research that explores the intersection of social sciences and the environment, it becomes evident that the relationship between economic growth and carbon emissions is frequently analyzed. One of the primary reasons for this focus is the pollution generated by the production required to meet the demands of a growing global population. In this context, the SDGs play a crucial role in promoting a more sustainable future.

One of the greatest dilemmas facing the world today is balancing economic power derived from production with the environmental damage it causes. Without domestic production, global trade depends heavily on importing goods from other countries. The competitive nature of free trade underscores the importance of production, making it difficult to prioritize ecological sustainability over economic growth. As a result, countries are compelled to engage in fierce competition, leading to the normalization of environmental pollution. Export earnings are considered essential for economic growth, perpetuating a cycle of environmental degradation. However, scientific research provides opportunities for sustainable development by studying the impacts, outcomes, and consequences of production.

This study investigates the balance between the benefits derived from international trade and economic growth and the multidimensional environmental costs, such as carbon dioxide emissions and waste imports, within an analytical framework. It seeks to answer a fundamental research question: "Is the willingness of countries to incur environmental costs in exchange for economic gains sufficient to justify the resulting environmental damage? this question, the study assesses the multidimensional environmental impacts of global economic activities by incorporating the most up-to-date data from 142 countries. It explores whether the economic benefits justify the environmental damage from a Multi-Criteria Decision Making (MCDM) perspective.

Existing literature predominantly relies on econometric models (causality analysis) or single composite indices when

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examining the relationship between economic outcomes and environmental interactions. This approach creates a significant research gap in developing a practical, multi-criteria performance ranking that captures countries' simultaneous balancing of conflicting benefit-cost criteria. To address this gap, the study's primary contribution is its holistic evaluation of countries, moving beyond traditional one-dimensional analyses by integrating six distinct analytical methods. This approach is further enhanced by incorporating not only carbon emissions but also waste imports to explain environmental pollution, alongside the trade openness variable to assess global competition. The scope of economic benefits is broadened by considering multiple indicators of economic growth, including Gross Domestic Product (GDP), GDP per capita, and annual GDP growth. From a theoretical standpoint, the study offers a measurable and comparable framework for the environment-economy-trade interaction by simultaneously considering fundamental hypotheses such as the Environmental Kuznets Curve (EKC) and the Pollution Haven Hypothesis (PHH) within a unified model.

THEORETICAL FRAMEWORK

Although this study does not employ a method that directly tests theory, it is grounded in the assumption that the established models and variables have a theoretical basis. The Hollution Haven Hypothesis (PHH), proposed by Grossman and Krueger [1], serves as a significant starting point in this context. This hypothesis suggests that pollution-intensive sectors in international trade tend to relocate from developed countries to less developed or developing countries [2]. A key aspect of this concept is the assumption that environmental quality deteriorates as pollution shifts to these countries. From this perspective, underdeveloped and developing countries become pollution havens. Conversely, countries that export pollution away from their territories—referred to as pollution halos—are typically developed countries.

Given the environmental and economic context of this study, it is entirely appropriate to consider the Environmental Kuznets Curve (EKC) hypothesis as a key theoretical foundation frequently emphasized in the literature. Although this hypothesis originated from Kuznets's [3] study on income distribution and economic growth, it gained prominence through Grossman and Krueger's [1] work, which proposed a similar inverted U-shaped relationship between the environment and the economy. Subsequently, Grossman and Krueger [4] also introduced an N-shaped curve. Briefly, Stern [5] explains this inverted U-shape by suggesting that countries increase environmental pollution up to a certain level of economic growth, after which pollution begins to decline.

Both approaches focus on environmental pollution in various countries. One attributes pollution to commercial factors, while the other emphasizes economic growth. This study examines variables related to trade openness, waste imports, and economic growth to integrate both perspectives. The objective is to develop a comprehensive theoretical framework and model the relationships among these factors. Additionally, recent studies reviewed in the literature highlight the need to evaluate the research conducted in this study.

In this context, GDP and GDP growth represent the scale and income effects of the Environmental Kuznets Curve (EKC), illustrating how economic expansion initially increases but later reduces pollution after a certain income threshold is reached. Trade openness captures the composition and technique effects within the EKC mechanism, reflecting how integration into global markets affects production structures and emission intensities. Moreover, the inclusion of waste imports operationalizes the Pollution Haven Hypothesis (PHH) by indicating the extent to which pollution-intensive activities are relocated from developed to developing countries. Together, these variables enable a multidimensional evaluation of environmental degradation and economic performance, aligning with both EKC and PHH theoretical perspectives.

LITERATURE REVIEW

Given the variables of the research, it has been deemed appropriate to review scientific studies that consider economic growth as the dependent variable, including topics such as openness, carbon emissions, and waste import/trade. Additionally, studies examining the relationship between economic growth and the environment have been included in the literature review, with the belief that they will serve the purpose of the research. In this context, the focus is on relatively newer studies that encompass all the variables in the research model.

First, studies investigating the connection between openness and economic growth have been reviewed. Wang et al. [6], in their study examining 122 countries at different levels of development, revealed that trade openness has different effects on economic growth among countries with different income groups. Specifically, they found that the impact of trade openness on economic growth is positive in high and low-income countries, whereas, in middle-income countries, this effect is negative. Utilizing newly developed techniques, Jalil and Rauf [7] argued in their study covering 82 countries that trade openness supports the idea of triggering economic growth. Another study examining 29 middle-income countries that are net energy importers found a bidirectional causality relationship between trade openness and economic growth [8]. Ali et al. [9], in their empirical results, indicated widespread differences among the most open 20 Organization of Islamic Cooperation countries and across all percentiles of trade openness-economic growth. However, they found a positive relationship between trade openness and economic growth in 16 of these countries. Osei-Assibey Bonsu and Wang [10] examined the tripartite relationships among energy consumption, trade openness, and economic growth in 45 countries and found a bidirectional relationship between trade openness and income in the long run. In a study using panel data from 38 African countries, Kinfack and Bonga [11] found that the relationship between trade openness and economic growth varies according to a country's level of development. Specifically, they found a negative relationship between openness and growth in low-income countries in Africa, while the coefficients of trade indicators were positive and statistically significant in high-income countries. Kong et al. [12] examined 39 developing countries in Asia with different income levels and found that the overall trade of goods and services has a positive impact on economic growth. A study using the Generalized Method of Moments within the context of Sub-Saharan African countries showed that trade openness positively affects economic growth. However, it was found that if policies related to infrastructure, price stability, investment, financial development, and human capital development are inadequate, trade openness does not promote economic growth [13]. In a study using data from 39 Sub-Saharan African countries, Agyei and Idan [14] stated that institutions

have a positive effect on the relationship between trade openness and economic growth.

When examining studies focused on smaller groups of countries, similar results to those found in larger country groups are observed. In studies involving BRICS countries, Banday and Aneja [15] accepted that trade openness and economic growth have a long-term positive relationship, thus confirming the trade-led growth hypothesis for BRICS countries. Rani and Kumar [16] stated that trade openness is a significant determinant of economic growth in BRICS. Sriyana and Afandi [17], in their study examining some ASEAN countries (Indonesia, the Philippines, Thailand, and Singapore), found that trade openness has a clear positive effect on economic growth only in the Philippines and Singapore. Another study focusing on ASEAN countries concluded that, contrary to the common view in the literature, low trade barriers can lead to excessive trade openness, negatively impacting GDP in developing economies [18]. Meşter et al. [19] revealed that trade openness and CO2 emissions have a statistically significant effect on per capita GDP in the nine Eastern European countries they studied. Raghutla's [20] study, based on panel estimation methods, examined five developing countries and found that trade openness not only promotes economic growth but also plays a significant role in fostering economic development in these five emerging market economies. Another study using panel estimation methods, conducted by Jabuya et al. [21], focused on trade openness in agricultural products within the East African Community and found empirical results indicating that the impact of agricultural trade openness on economic growth is positive and significant in the long term. In a study using a panel of eight Mediterranean coastal countries, Bardi and Hfaiedh [22] noted that trade and financial openness variables support economic growth.

When examining country-specific studies, it is observed that there are both similar results and different inferences regarding openness and economic growth. In a study using time series analysis on the Kingdom of Saudi Arabia, Islam [23] suggested that the Kingdom could increase its trade to gain more benefits and boost its income. Similarly, Islam et al. [24] argued that trade openness has a significant and positive impact on the Kingdom's economic growth in both the short and long term. Udeagha and Ngepah [25] concluded that trade openness has asymmetric effects on economic growth in South Africa in the short and long term.

Studies that examine African countries on a country-by-country basis using the ARDL technique reveal some notable findings. Esaku [26] examined Uganda and found a positive and significant relationship between trade openness and economic growth. In contrast, Malefane and Odhiambo [27] examined Lesotho and found that trade openness has no significant effect on economic growth in both the short and long term. In Botswana, when the ratio of total trade to GDP, the ratio of exports to GDP, and the trade openness index are used as representations of trade openness, it shows that trade openness has a significant and positive impact on economic growth in both the short and long term. However, when the ratio of imports to GDP is used as an indicator of openness, the study did not find significant effects of trade openness on economic growth in the short and long term [28]. In a study on Namibia, the results showed that economic growth has a negative relationship with imports and a positive relationship with exports [29].

When examining studies conducted in China, Kong et al. [30] concluded that trade openness can significantly enhance the quality of economic growth in both the short and long term. Ma et al. [31] suggested that increasing openness has a positive effect on the GDP of provinces and per capita GDP.

When examining the literature related to carbon emissions, which is another variable of the research, there are studies that include only carbon-economic growth variables [32-37]. However, it is mostly seen that variables such as energy consumption [38-43], renewable [44, 45] and non-renewable energy consumption [46], as well as fossil fuel consumption [47, 48] are also included in studies related to carbon and economic growth. Additionally, some studies have also attempted to test the EKC hypothesis.

When examining country-specific studies, Khan et al. [42] found that economic growth increases CO2 emissions in Pakistan in both the short and long term, while Wang et al. [49] similarly revealed a causality relationship between CO2 emissions and economic growth in Pakistan. Torun et al. [35] identified a bidirectional causality between GDP and CO2 in the US economy. Results from some studies conducted in China indicate that economic growth significantly increases carbon emissions [33, 37, 43, 50]. Li and Wei [51] found that carbon emissions hinder the positive effects of financial development and innovation on economic growth, and additionally, they revealed the existence of a significant nonlinear relationship between economic growth and carbon emissions. Sun et al. [44] investigated the relationship between economic growth, solar energy technology, and carbon emissions in China based on the Kuznets curve (EKC) and found that carbon emissions first increase with economic growth and then gradually decrease, forming an inverted “U” shape curve in the long term. Zou and Zhang [40] analyzed 30 regions in China and found that while economic growth can significantly improve carbon dioxide emissions, economic growth is not significantly affected by the reduction of carbon dioxide emissions.

Studies conducted on developing countries also reveal significant findings regarding the relationships between variables. Dimitriadis et al. [46] found a positive bidirectional causal relationship between economic growth and carbon dioxide emissions for 68 developing countries. In contrast, Hove and Tursoy [48] showed that a positive change in per capita real GDP reduces carbon dioxide emissions in their study of 24 developing countries. Wawrzyniak and Doryń [34] investigated the impact of economic growth on carbon dioxide emissions based on the quality of institutions in a sample of 93 emerging and developing countries. They revealed that an improvement in institutional quality can result in a decrease in CO2 emissions as GDP rises. Zhang et al. [38] found that the inverted U-shaped curve characteristics of the Environmental Kuznets Curve (EKC) theory emerged in several countries, including Mexico, Croatia, Kazakhstan, Iran, Algeria, Indonesia, and Thailand, among 50 typical developing countries. They also found that the negative impact of international trade was evident in developing countries benefiting from trade surpluses. Guo et al. [47] confirmed the Environmental Kuznets Curve hypothesis for 40 Asian countries only in the context of economic growth in the industrial and service sectors.

Khalfaouia et al. [36] revealed a bidirectional causality between carbon dioxide emissions and per capita GDP in G7 countries. Mujtaba et al. [41] demonstrated a negative and significant connection between economic growth and CO2 emissions in 25 upper-middle-income countries, suggesting that CO2 emissions decrease with increases in economic growth. Radmehr et al. [45] showed a bidirectional relationship between economic growth and carbon emissions in European Union countries. Singh et al. [52] found that in

the short term, CO2 emissions are positively affected by economic growth in all BRICS countries, but for Brazil, Russia, and China, this positive effect does not appear in the long term. The reason for this is that these countries can control CO2 emissions in the long term. In India and South Africa, economic growth has a significant negative impact on CO2 emissions in both the short and long term. González and Montañés [39] found that in the 31 countries they studied, most countries differentiate CO2 emission levels from economic growth. The study observed that this differentiation is higher in developed economies and lower in developing economies. Fávero et al. [32] identified a positive and statistically significant relationship between economic development and per-country carbon emissions in a model covering 187 countries worldwide.

Due to the limited number of studies on waste imports, the research was expanded to include waste trade and waste exports. Even with these topics included, it has been observed that previous studies examining the relationship between waste trade and economic growth are quite limited. Additionally, considering the variables of the research, reviewing previous studies that explore the relationship between the environment and economic growth was also deemed appropriate.

In studies examining environmental pollution and economic growth in China, Shi et al. [53] proposed that increased economic scale is a primary cause of environmental pollution, and Yan et al. [54] reached the same conclusion. Rao and Yan [55] found that environmental pollution restricts economic growth, while Yu et al. [56] discovered that economic growth targets exacerbate regional environmental pollution. Zhao et al. [57] identified a long-term balanced relationship between economic growth, environmental pollution, and public health. Chang et al. [58], based on panel data from 284 provinces, examined the Environmental Kuznets Curve (EKC) hypothesis and found that the relationship between environmental pollution and economic growth in China conforms to an inverted U-shaped curve. In another study testing the EKC hypothesis, Başar and Tosun [59] reached a similar conclusion for 28 OECD countries, while Wen et al. [60] validated the EKC hypothesis for South Asian economies. An additional study testing the EKC model in G20 countries initially confirmed the EKC hypothesis, but when per capita energy consumption was included in the analysis, the decreasing trajectory proposed by the inverted U-shaped hypothesis was found to be statistically insignificant [61]. Acheampong and Opoku [62] found that environmental degradation is significantly related to the deterioration of economic growth in a global panel of 140 countries, but nonlinear analysis revealed that environmental degradation variables have an inverted U-shaped relationship with economic growth.

In a study on waste trade, Barnes [63] highlights a different point, suggesting that the export of plastics from generally high-income countries to lower-income countries leads to a psychological detachment from plastic waste pollution. This perceived artificial cleanliness encourages the use of plastics. Abalansa et al. [64] evaluate the export of electronic waste to developing countries under the categories of good, bad, and ugly. The authors consider the increased production of plastics as a raw material source and its contribution to poverty reduction as "good," the worsening environmental conditions in developing countries, which are already poor, as "bad," and the negative health impacts on workers handling e-waste due to its diverse toxic components as "ugly." Additionally, empirical studies have revealed noteworthy findings. Martínez et al. [65] examined the global waste network and focused on 28 countries with a high risk of waste congestion and a low Environmental Performance Index (EPI). The study concluded that these countries face environmental pollution and hazards due to the improper handling and disposal of hazardous waste. Unfried and Wang [66] suggested that imported plastic waste in China polluted the local environment and that the import ban introduced in 2018 was effective in improving environmental conditions.

In this section, studies that combine environmental factors and MCDM methods are also briefly summarized in the below (Table 1). Table 1 provides a comprehensive overview of the authors of the studies, publication year, the methods, and context of the study.

METHODS

The present study encompasses data from 142 countries. This is because data for all six criteria employed can be sourced from the 142 countries in the analyses. The countries included in the analyses were evaluated in terms of several economic and environmental indicators, including trade openness (measured in thousands of dollars), plastic waste imports (also in thousands of dollars), CO_2 emissions, GDP, GDP per capita and GDP growth rate. The pertinent criteria were assigned weights using the entropy method, one of the objective criteria weighting methods. Subsequently, the decision alternatives were assessed using hybrid multi-criteria decision-making methods, including ARAS (Additive Ratio Assessment), MAUT (Multi-Attribute Utility Theory), GRA (Grey Relational Analysis), WASPAS (Weighted Aggregated Sum Product Assessment), TOPSIS (Technique for Order Preference by Similarity), and VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje). These methods have many advantages. For instance, the most critical advantages of the MAUT approach are that it enables the evaluation of potential uncertainties and risks. Besides, the most advantageous aspect of TOPSIS is its simplicity and ease of use [81]. Similarly, the ARAS method is also easy to comprehend, with a short calculation time and few mathematical calculations [111]. One of the most significant advantages of the WASPAS method is its use of a combination of the weighted sum model and weighted product model methods, thereby aiming for a high degree of accuracy in ranking decision alternatives [112]. One of the most essential advantages of the VIKOR method is its simplicity in terms of calculation. Another advantage is that the technique allows decision-makers to assess alternatives with conflicting criteria [108, 109, 110]. The GRA method is clearly superior to other methods in terms of being more effective in solving complex problems, having an extensive range of utilization, flexibility and shorter computational time [116]. Moreover, these methods also have different disadvantages, but the common ones are as follows: Different weighting [113] and normalization [114] methods have the potential to affect results and rankings.

Table 1. A brief summary of MCDM methods on environmental factors

Authors	Context	MCDM Methods
Jia et al., (2012) [121]	Determining the low-carbon level of countries	Fuzzy AHP, TOPSIS
Wang et al., (2019) [122]	Supplier selection for raw materials in the plastic industry	Fuzzy ANP, VIKOR
Sulistyoningarum et al., (2019) [123]	Supplier selection of recycled plastic materials	BWM, TOPSIS
Li et al., (2021) [124]	Development and usage of renewable energy based on carbon emission reduction	ANP, WSM, TOPSIS, PROMETHEE, ELECTRE, VIKOR
Arsu & Ayçin (2021) [125]	Evaluation of OECD countries by environmental, economic, and social factors	CRITIC, MARCOS
Tutak (2021) [126]	Renewable energy usage in European countries	WASPAS
Gököz & Yalçin (2021) [127]	Environmental and economic performances of the energy sector in OECD countries	CRITIC, GRA, MAUT
Thanh (2022) [128]	Sustainable supplier selection in the plastic industry	Fuzzy AHP, TOPSIS
Brodny & Tutak (2023) [129]	Evaluating the energy and climate sustainability of European countries	CODAS, EDAS, TOPSIS, VIKOR, WASPAS
Sengupta et al., (2023) [130]	Suitable warehouse selection for plastic solid waste	TOPSIS
Soni et al., (2023) [131]	Waste plastic selection	AHP, WASPAS
Jeon et al., (2023) [132]	Selecting flexible packaging bags	WASPAS, AHP
Suvitha et al., (2024) [133]	Ideal plastic waste management system selection	Fuzzy AHP, Fuzzy CODAS
Pelit & Avşar (2025) [134]	Evaluating Turkey's carbon emission profile	MAREC, PROMETHEE
Güler (2025) [135]	Assessment of the environmental sustainability of European Countries	AHP, TOPSIS

Table 2. A summary of data source, criteria, and analysis methods

Criteria	Data Source	Weighing Method	Analysis Methods	Normalization Procedures
Trade Openness[1], Plastic Waste Import[1], CO2 Emission[2], GDP[2], GDP/per capita[2], GDP Growth Rate[3]	[1]ITC (trademap), [2]Worldbank (data.world bank), [3]Calculated by authors using data from[2]	Entropy	MAUT, GRA, ARAS, WASPAS, TOPSIS, VIKOR	All employed MCDM methods have their own normalization procedure. Accordingly, the relevant normalization method has been used in each MCDM method.

Following the analyses the results are then subjected to comparison and discussion. The consistency and sensitivity of the results was evaluated using the Spearman rank correlation method. The correlation coefficients of the results obtained from six different methods were compared, and the similarity between the ranking results was examined [115]. A substantial literature exists on the hybrid use of multi-criteria decision-making methods. For example, Liu et al. [67], Lee and Chang [68], Mulliner et al. [69], Li et al. [70], Anojkumar et al. [71], and Ceballos et al. [72] employed multi-criteria decision-making methods in a hybrid approach and evaluated the outcomes. A comparative analysis is essential for ensuring the reliability and consistency of the findings. In this context, the data source, criteria, weighting method, normalization procedures, analysis methods, and decision alternatives are briefly summarized in Table 2.

The following section provides a concise overview of the methodology employed in the study.

Entropy Method

The concept of entropy was introduced in thermodynamics by the German physicist Clausiu in 1865. In 1948 Claude Shannon developed the entropy method and applied it to information theory [73]. In information theory, entropy measures the information content of a certain message [74]. This is called information entropy or Shannon entropy [75]. Entropy, known as the uncertainty measure of information and based on probability theory, is an objective weighting method used to determine the importance weights of criteria [75-77]. In the Entropy method, the solution is obtained independently of the decisions made by the decision-makers. One of the most significant advantages of the Entropy method is its objective weighting. In this method, the objective criteria weights are dependent on the measurement of uncertain information in the decision matrix [75, 76, 78, 79,]. The steps of entropy method are as follows [76-78,].

Step 1: Establish the decision matrix

Step 2: Normalization of decision matrix: The normalized values in the decision matrix are calculated using equation (1) as alternative value $\boldsymbol{i}$, criterion value $\boldsymbol{j}$, benefit value of alternative $\boldsymbol{i}$ in criterion $\boldsymbol{j}$, $\boldsymbol{x_{ij}}$ and normalized value $\boldsymbol{r_{ij}}$.

$$\mathbf{r_{ij}} = \frac{\mathbf{x_{ij}}}{\sum_1^I \mathbf{x_{ij}}} \quad (1)$$

Step 3: Calculate the entropy values: With the help of equation (2), the entropy values of all criteria are calculated as entropy coefficient $\boldsymbol{k}$, normalized values $\boldsymbol{r_{ij}}$, and entropy value $\boldsymbol{e_j}$.

$$\boldsymbol{e_j} = -\boldsymbol{k}.\sum_{j=1}^{m} \boldsymbol{r_{ij}}.\ln(\boldsymbol{r_{ij}}) \quad (2)$$

Step 4: Calculation of criterion weights: The weights (w_j) of all criteria are calculated using equation (3).

$$w_j = \frac{1-e_j}{\sum_1^m (1-e_j)} \qquad \sum_1^m w_j = 1 \tag{3}$$

MAUT Method

The MAUT method is employed to convert several interests into numerical values on a scale of 0-1, with 0 denoting the least favorable outcome and 1 indicating the most favorable outcome [80]. In the MAUT method, a utility value is assigned to each potential outcome to achieve the desired objective in decision-making processes. The most significant benefit of this approach is that it enables the assessment of potential risks and uncertainties [81, 82]. The steps of MAUT method are as follows [80 - 83]

Step 1: Determination of Criteria and Alternatives

Step 2: Calculation of Weight Values of Criteria: The criterion weights are calculated so that w_j is equal to 1 in total.

$$\sum_1^m w_j = 1 \tag{4}$$

Step 3: Establish the decision matrix

Step 4: Normalization of decision matrix: The normalized values in the decision matrix are calculated using equation (5). x_i^+ is the best value of alternatives and x_i^- is the worst value of alternatives.

$$u_i(x_i) = \frac{x-x_i^-}{x_i^+-x_i^-} \tag{5}$$

Step 5: Calculation of the total utility value: Total utilities are calculated using equation (6) as Ux: Utility of alternatives.

$$U_x = \sum_{j=1}^n u_i(x_i) * w_j \tag{6}$$

Step 6: Ranking of alternatives according to total utility values

Grey Relational Analysis

The Grey relational analysis method is founded upon the tenets of grey system theory, which posits that situations devoid of information are to be regarded as black, while those characterized by complete information are to be considered white [84 - 86]. In the real world, the majority of system parameters are neither perfectly known nor perfectly unknown, rendering them as such in a state of ambiguity. It is crucial to acknowledge that grey system theory is concerned with analyzing situations that are neither entirely known nor entirely unknown [87]. Following an observation and evaluation of the functioning of the systems, it can be concluded that in most cases, there is a grey system where information is incomplete and uncertain [88]. Therefore, Grey system theory is a commonly employed methodology for analyzing, predicting, and modeling relationships between uncertain systems [89]. In the context of grey relational analysis, the data are initially normalized within the range of 0–1. A grey relational coefficient is subsequently calculated from the normalized data, to express the link between the desired and actual data [90, 91]. The Grey relational analysis method steps are as follows [90, 92, 93].

Step 1: Normalization of decision matrix:

Step 2: Calculation of the weighted normalized decision matrix.

Step 3: Identification of the series to be compared.

Step 4: Determination of the Gray relational coefficient

Step 5: Determination of the Gray relational grade

Step 6: Ranking the alternatives

A decision matrix is formulated as $F = (f_{ij})_{n\times m}$ to accommodate "n" alternatives and m criteria. To obtain the requisite normalization values, one must first calculate the values represented by Equations (7) and (8) as follows:

$$x_i(k) = \frac{x_i^0(k)-\min x_i^0(k)}{\max x_i^0(k)-\min x_i^0(k)} \textit{ for benefit criteria} \tag{7}$$

$$x_i(k) = \frac{\max x_i^0(k)-x_i^0(k)}{\max x_i^0(k)-\min x_i^0(k)} \textit{ for cost criteria} \tag{8}$$

In this context, the variables i and j take on the values 1, 2, 3, …, n and 1, 2, 3, …, m, respectively. In this notation, m represents the number of experimental data points and n represents the number of parameters. The term $x_i^0(k)$ denotes the original data sequence, whereas $x_i(k)$ represents the sequence of data that has undergone preprocessing. The notation $x_i^0(k)$ signifies the maximum value of $x_i(k)$, while $x_i^0(k)$ indicates the minimum value of $x_i(k)$.

In grey relational analysis, the grey relational grade is employed to indicate the relevance between two systems or sequences. In the case of a single sequence $x_0(k)$, a local grey relation measurement is employed as the reference sequence, with all other sequences serving as comparison sequences. Once the data pre-processing has been completed, the grey relation coefficient ξ_k for the k_{th} performance characteristic in the i_{th} experiment can be expressed as;

$$\xi_i(k) = \frac{\Delta_{min}+\xi\,\Delta_{max}}{\Delta_{0i}(k)+\xi\Delta_{max}} \tag{9}$$

In the context of sequence analysis, the term "deviation sequence" is used to denote the discrepancy between a reference sequence and a comparability sequence. In such cases, the deviation sequence is represented by the symbol Δ_{0i}.

$$\Delta_{0i}(k) = |\,x_0(k) - x_j(k)| \tag{10}$$

$$\Delta_{min} = |x_0(k) - x_j(k)| \tag{11}$$

$$\Delta_{max} = |x_0(k) - x_j(k)| \tag{12}$$

In this study, the reference sequence is designated as $x_0(k)$, whereas the comparability sequence is denoted as $x_j(k)$. Furthermore, the identifying or distinguishing coefficient is represented by the variable ξ which takes values in the interval [0, 1]. t is possible to modify the value of ξ in accordance with the specific requirements of the system in question. In most cases, a value of 0.5 for the coefficient of ξ is employed. This study also utilized ξ = 0.5. Once the grey relational grade has been calculated, the average of the grey relational coefficients is determined and taken as the final grey relational grade. In consequence, the grey relational grade is defined as follows:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^n \xi_i(k) \tag{13}$$

ARAS Method

The ARAS method was initially employed by Zavadskas and Turksis [94] for the resolution and analysis of diverse multi-criteria decision-making problems. The method is founded upon the tenets of utility theory, whereby the relative merits of alternative courses of action are evaluated according to a utility function. When evaluating the performance of the alternatives in the ARAS method, the comparison ratios are calculated for each of them by the alternative that offers the optimal benefit (95 - 97). The steps of ARAS method are as follows [94, 95, 97 - 99].

Step 1: Establish the decision matrix:

$$X = [x_{01}\, x_{0j}\, \dots\, x_{0n}\, x_{i1}\, x_{ij}\, \dots\, x_{in}\, \dots\, \dots\, \dots\, \dots\, x_{m1}\, x_{mj}\, \dots\, x_{mn}]$$

$$i = 0, 1, \dots, m \;\; = 1, 2, \dots, n \tag{14}$$

For benefit criteria $x_{0j} = max x_{ij}$

For cost criteria

$$x_{0j} = min x_{ij} \tag{15}$$

Step 2: Normalization of decision matrix:

For benefit criteria

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{16}$$

For cost criteria

$$x_{ij}^{*} = \frac{1}{x_{ij}} \tag{17}$$

$$\bar{x}_{ij} = \frac{x_{ij}^{*}}{\sum_{i=0}^{m} x_{ij}^{*}} \tag{18}$$

Once the aforementioned equations have been applied, a normalized decision matrix, designated as $\bar{X}$, is generated. The normalized matrix is presented in Equation (19).

$$\bar{X} = \begin{bmatrix} \bar{x}_{01} & \bar{x}_{0j} & \dots & \bar{x}_{0n} \\ \bar{x}_{i1} & \bar{x}_{ij} & \dots & \bar{x}_{in} \\ \dots & \dots & \dots & \dots \\ \bar{x}_{m1} & \bar{x}_{mj} & \dots & \bar{x}_{mn} \end{bmatrix}$$

$$i = 0, 1, \dots, m \quad j = 1, 2, \dots, n \tag{19}$$

Step 3: Calculation of the weighted normalized decision matrix

The elements of the normalized decision matrix are multiplied by the criteria weights to determine the elements of the weighted normalized decision matrix $\hat{x}_{ij}$ Equation (20).

$$\hat{x}_{ij} = \bar{x}_{ij} \,.\, w_{ij} \tag{20}$$

In this study, the criterion weights (w_j) were calculated using the entropy method.

Step 4: Calculation of optimality function values (S_i) of decision alternatives: The optimal values of the decision alternatives are determined utilizing Equation (21).

$$S_i = \sum_{j=1}^{n} x_{ij}\,; i = 0, 1, \dots, m \tag{21}$$

The S_i value, as expressed in the equation, represents the optimal value of the i alternative. A larger S_i value indicates superior performance of the alternative. Subsequently, the S_i values of all alternatives are divided by the optimal value of S_0. The calculation of the K_i values is illustrated in Equation (22). The values of K_i are employed to assess the utility functions of the alternatives, thereby enabling decision-makers to readily ascertain which alternative is more advantageous and which is more costly.

$$K_i = \frac{S_i}{S_0}\,; i = 0, 1, \dots, m \tag{22}$$

WASPAS Method

The WASPAS method was initially proposed by Zavadskas et al. [100] and is one of the robust novel MCDM (Multiple Criteria Decision Making) approaches for determining utility [101]. In this method, the weighted sum model (WSM) and weighted product model (WPM) methods are used in an integrated form to rank alternatives [101,102,]. The steps of the WASPAS method are as follows [100 - 103].

Step 1: Establish the decision matrix

Step 2: Normalization of decision matrix:

For benefit criteria $\bar{x}_{ij} = \frac{x_{ij}}{Max x_{ij}}$ (23)

For cost criteri

$$\bar{x}_{ij} = \frac{Min x_{ij}}{x_{ij}} \tag{24}$$

Step 3: Calculation of WSM and WPM

for WSM method $Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} * w_{ij}$ (25)

for WPM method $Q_i^{(2)} = \prod_{j=1}^{n} (\bar{x}_{ij})^{w_j}$ (26)

Step 4: Ranking of the decision alternatives: Equation (27) is used to calculate the ranking values of the alternatives. The value of λ in the equation is the combined optimality coefficient. This coefficient is determined by the decision makers and takes a value between 0-1. The combined optimality coefficient is generally used as 0.5 in the literature. In this study it is assumed to be 0.5.

$$\lambda * Q_i^{(1)} + (1 - \lambda) Q_i^{(2)} \tag{27}$$

TOPSIS Method

The TOPSIS method was originally developed by Hwang and Yoon [104] as a multi-criteria decision-making technique. The TOPSIS method considers both the distance to the positive ideal solution and the distance to the negative ideal solution when determining the required proximity to the ideal solution. Decision alternatives are then ranked according to these distances [105, 106]. Nevertheless, the methodology does not incorporate an assessment of the relative significance of these distances [107]. The positive ideal solution is defined as a solution that strives to optimize the beneficial criterion and minimize the cost criterion. Conversely, the negative ideal solution is characterized by the maximization of the cost criterion and the minimization of the beneficial criterion [105]. The steps of TOPSIS method are as follows [104 - 107].

Step 1: Normalization of decision matrix:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^{\,2}}}\,, \text{ j = 1, 2, n} \quad \text{i = 1, 2, ...m} \tag{28}$$

Step 2: Calculation of the weighted normalized decision matrix: In this study, the criterion weights (w_j) were calculated using the entropy method.

$$\hat{x}_{ij} = \bar{x}_{ij} \,.\, w_{ij} \tag{29}$$

Step 3: Finding positive and negative ideal solutions: In this context, the symbols A^* and A^- are used to denote positive and negative ideal solutions, respectively.

$$A^{*} = [v_1^{*}, v_2^{*}, \dots, v_j^{*}] \tag{30}$$

$$A^{-} = [v_1^{-}, v_2^{-}, \dots, v_j^{-}] \tag{31}$$

where,

v_j^{*} = {max v_{ij}, if j is a benefit attribute

{min v_{ij}, if j is a cost attribute

v_j^{-} = {min v_{ij}, if j is a benefit attribute

{max v_{ij}, if j is a cost attribute

Step 4: Calculation of distance values: The distance of alternative j from the ideal solution, the positive ideal distance S_i^{*} and the negative ideal solution S_i^{-} are calculated using Equations (32) and (33).

$$S_i^{*} = \sqrt{\sum_{j=1}^{j} (v_{ij} - v_j^{*})^2} \tag{32}$$

$$S_i^- = \sqrt{\sum_{j=1}^{j}(v_{ij} - v_j^-)^2} \quad (33)$$

Step 5: Calculation of relative proximity to the ideal solution: In order to ascertain the proximity of the alternatives to the ideal solution, C_i^*, Equation (34) is employed.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad 0 \le C_i^* \le 1 \quad (34)$$

Step 5: Ranking of the alternatives according to their proximity to the ideal solution C_i^*.

VIKOR Method

VIKOR, which means multi-criteria optimization and compromise solution in Serbian [108], was conceived as a means of addressing the challenges inherent in MCDM problems characterized by conflicting or irreconcilable criteria. The underlying assumption of this method is that a compromise is an acceptable solution in cases of conflicting criteria [109]. The method is widely used due to its simplicity in calculation and solution [108]. The VIKOR method provides a framework for decision-makers to evaluate and select between alternatives that present conflicting criteria. If each alternative is evaluated in accordance with multiple criterion functions, the compromise ranking is conducted by means of a comparison of the degree of proximity to the ideal alternative [109, 110]. The steps of the VIKOR method are as follows [108 - 110].

Step 1: Identification of the best and worst values for each criterion

for beneficial criteria

$$f_i^* = max_i f_{ij} \quad i = 1,2,3,\ldots, n \quad (35)$$

$$f_i^- = min_i f_{ij}$$

for cost criteria

$$f_i^* = min_i f_{ij} \quad i = 1,2,3,\ldots, n \quad (36)$$

$$f_i^- = max_i f_{ij}$$

Step 2: Calculation of S_j *and* R_j values of each decision alternatives. The symbols S_j and R_j represent the distance of alternative j from the positive ideal (best) solution and the distance from the negative ideal (worst) solution, respectively. (w_j) represents criterion weights. In this study, the criterion weights (w_j) were calculated using the entropy method.

$$S_j = \sum_{i=1}^{n} w_j(f_i^* - f_{ij}) / (f_i^* - f_i^-) \quad j = 1,2,\ldots m \quad (37)$$

$$R_j = max\,[w_j(f_i^* - f_{ij}) / (f_i^* - f_i^-) \quad (38)$$

Step 3: Calculation of Q_j value for each decision alternatives:

$$Q_j = v(S_j - S^*)/(S^- - S^*) + (1 - v)(R_j - R^*)/(R^- - R^*), \quad (39)$$

$$S^* = min_j S_j \qquad S^- = max_j S_j$$

$$R^* = min_j R_j \qquad R^- = max_j R_j$$

v = The weight of the strategy that optimises group utility

$(1 - v)$ = The weight of the individual regret.

A value of v greater than 0.5 is indicative of a predominantly positive attitude, whereas a value of v less than 0.5 is suggestive of a predominantly negative attitude. In the existing literature, it is typically assumed that the evaluation expert groups (positive and negative) exhibit a consensus attitude by selecting a value v of 0.5. In this study, the value of v was set to 0.5, and the requisite calculations were performed.

Step 4: The ranking of the decision alternatives is presented in descending order of their respective Q_j values.

FINDINGS

In this section, 142 countries are assessed by environmental and economic criteria, employing six multi-criteria decision-making methods. The relevant decision matrix is presented in Table S1.

Table 3 illustrates the criteria and target values employed in the assessment of countries with regard to environmental and economic outcomes.

Before the commencement of the analysis, the environmental and economic criteria are subjected to a weighting process, whereby the entropy method is employed.

The results of the Entropy method indicate that GDP (0.2601) has the highest criterion weight. The following criteria are of relatively lesser importance. The following criteria were found to have relatively low importance weights: Plastic Waste Import (in thousand $), CO2 Emission, Trade Openness (in thousand $), GDP/per capita, and GDP Growth Rate.

The results of the assessment conducted using the ARAS, MAUT, GRA, WASPAS, TOPSIS, and VIKOR methods are presented in Table 5 and Table 6.

Table 3. Criteria for countries assessment

Criteria Code	Criteria	Target
C1	Trade Openness (thousand $)	Maximum
C2	Plastic Waste Import (thousand $)	Maximum
C3	CO2 Emission	Maximum
C4	GDP	Maximum
C5	GDP/per capita	Maximum
C6	GDP Growth Rate	Maximum

Table 4. Criterion weights

Criterion/Criterion Weight	C1	C2	C3	C4	C5	C6
wj	0.1796	0.2383	0.1949	0.2601	0.1017	0.0254

Table 5. Ranging of countries

ARAS		MAUT		GRA	
Ranking	**Performance Scores**	**Ranking**	**Performance Scores**	**Ranking**	**Performance Scores**
USA	0.00000000000002660	**USA**	0.9175	**USA**	0.8612
Germany	0.00000000000000822	**Germany**	0.3844	**Netherlands**	0.6338
India	0.00000000000000677	**Netherlands**	0.3545	**Germany**	0.6179
Netherlands	0.00000000000000607	**India**	0.2411	**Ireland**	0.5933
Japan	0.00000000000000466	**Türkiye**	0.2390	**Luxembourg**	0.5873
Türkiye	0.00000000000000452	**France**	0.2059	**Fiji**	0.5851
France	0.00000000000000442	**Belgium**	0.2004	**Bermuda**	0.5818
Canada	0.00000000000000401	**Canada**	0.1974	**India**	0.5811
Italy	0.00000000000000395	**Italy**	0.1921	**Norway**	0.5754
UK	0.00000000000000393	**Spain**	0.1854	**Türkiye**	0.5753
Suriname	0.00000000000000005	**Congo**	0.0051	**Morocco**	0.5061
Liberia	0.00000000000000004	**Guinea-Bissau**	0.0049	**Comoros**	0.5055
Malawi	0.00000000000000004	**Sierra Leone**	0.0049	**Burkina Faso**	0.5043
Eswatini	0.00000000000000003	**Burkina Faso**	0.0043	**Congo**	0.5041
Sierra Leone	0.00000000000000003	**Comoros**	0.0040	**Burundi**	0.5039
Guinea-Bissau	0.00000000000000003	**Eswatini**	0.0038	**Paraguay**	0.5027
Comoros	0.00000000000000002	**Burundi**	0.0026	**Lesotho**	0.5025
Burundi	0.00000000000000002	**Malawi**	0.0024	**Eswatini**	0.5022
Central African Republic	0.00000000000000002	**Lesotho**	0.0021	**Malawi**	0.5021
Lesotho	0.00000000000000002	**Central African Republic**	0.0011	**Central African Republic**	0.5011

Table 6. Ranging of countries

WASPAS		TOPSIS		VIKOR	
Ranking	**Performance Scores**	**Ranking**	**Performance Scores**	**Ranking**	**Performance Scores**
USA	0.0154	**USA**	-1.0548	**USA**	0.0000
Germany	0.0097	**Germany**	-0.8969	**Germany**	0.6962
Netherlands	0.0142	**Netherlands**	-0.7207	**Netherlands**	0.7838
India	0.0276	**India**	-0.6908	**India**	0.7899
France	0.0120	**Türkiye**	-0.4167	**France**	0.8238
Türkiye	0.0203	**Japan**	-0.2948	**United Kingdom**	0.8330
Canada	0.0953	**France**	-0.2614	**Canada**	0.8428
Italy	0.1021	**Belgium**	-0.2466	**Italy**	0.8483
United Kingdom	0.0159	**Viet Nam**	-0.2448	**Türkiye**	0.8492
Spain	0.0226	**Italy**	-0.2331	**Japan**	0.8575
Congo	0.1845	**Guinea-Bissau**	-0.0038	**Congo**	0.9975
Burkina Faso	0.0067	**Sierra Leone**	-0.0038	**Burkina Faso**	0.9978
Sierra Leone	0.0680	**Burkina Faso**	-0.0034	**Sierra Leone**	0.9979
Guinea-Bissau	0.1658	**Congo**	-0.0032	**Guinea-Bissau**	0.9979
Eswatini	0.8978	**Eswatini**	-0.0029	**Eswatini**	0.9984
Comoros	0.0142	**Comoros**	-0.0027	**Comoros**	0.9985
Malawi	0.0165	**Burundi**	-0.0020	**Malawi**	0.9990
Burundi	0.1290	**Malawi**	-0.0019	**Burundi**	0.9992
Lesotho	0.0057	**Lesotho**	-0.0013	**Lesotho**	0.9995
Central African Republic	0.0077	**Central African Republic**	-0.0011	**Central African Republic**	1.0000

The results for the ten countries with the most and least optimal performance scores are presented. The results of the analysis indicate that the United States of America is the country with the highest performance rating according to all six MCDM methods utilized. The United States is followed by Germany, which has the highest performance score. Germany is positioned second in the performance ranking across all five methods, except GRA. In the GRA method, the Netherlands achieves the second-highest ranking. Furthermore, the Netherlands is positioned third in the performance rankings for the MAUT, WASPAS, TOPSIS, and VIKOR methods, except for the ARAS method. Concerning the ARAS method, India achieves the third-highest ranking. Furthermore, India, France, the United Kingdom, Canada, Turkey, Japan, and Italy are at the forefront of all the methods employed. Countries with relatively underdeveloped economies, including the Democratic Republic of Congo, Malawi, Burkina Faso, Sierra Leone, Guinea-Bissau, Eswatini, Lesotho, Burundi, Central African Republic, and Comoros, are positioned at the lowest levels of performance across all MCDM methods.

Sensitivity Analysis

Sensitivity analysis in the MCDM method is required to determine the compatibility, reliability and consistency of the problem solutions [117, 120]. There is no consensus in the literature regarding sensitivity analysis. Sensitivity analysis can be performed by employing different methods. One of the most commonly utilized sensitivity analysis methods for solving complex decision-making problems is to compare the results of a model with those of other existing and well-structured methods. This enables the examination of the robustness, reliability, and consistency of the ranking scores for the alternatives. The results are validated by comparing the high correlation coefficients between the ranking scores of the decision alternatives. Comparing the correlations of the results obtained from different MCDM methods is a global approach to sensitivity analysis [118, 119, 117]. In this context, we analyzed and compared the decision alternatives results obtained from different MCDM methods using the Spearman correlation. Table 7 presents the results of the Spearman correlation analysis, which was conducted to assess the consistency and sensitivity of the analysis results across the various methods employed.

Table 7. Spearman ranking correlation

		ARAS	MAUT	GRA	WASPAS	TOPSIS	VIKOR
ARAS	Correlation Coefficient	1.000	.948**	.725**	.979**	.958**	.970**
	Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
MAUT	Correlation Coefficient	.948**	1.000	.881**	.989**	.991**	.993**
	Sig. (2-tailed)	0.000		0.000	0.000	0.000	0.000
GRA	Correlation Coefficient	.725**	.881**	1.000	.825**	.863**	.851**
	Sig. (2-tailed)	0.000	0.000		0.000	0.000	0.000
WASPAS	Correlation Coefficient	.979**	.989**	.825**	1.000	.986**	.995**
	Sig. (2-tailed)	0.000	0.000	0.000		0.000	0.000
TOPSIS	Correlation Coefficient	.958**	.991**	.863**	.986**	1.000	.992**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000		0.000
VIKOR	Correlation Coefficient	.970**	.993**	.851**	.995**	.992**	1.000
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	

Note: **. Correlation is significant at the 0.01 level (2-tailed)

The results of both the analysis and the Spearman correlation demonstrate that all six methods are consistent and yield comparable and relatively similar results. This phenomenon can be attributed to the observation that countries with a comparable level of development consistently occupy the top positions in performance rankings, whereas countries with a similar level of underdevelopment tend to be at the lower end of the spectrum. In addition, Figure 1 presents a network diagram of the correlation results. As can be easily seen from the diagram, the correlations between the results obtained from the six methods are significant. The thickness of the lines in the diagram is directly proportional to the magnitude of the correlation coefficient. Methods with high correlations are more closely connected to each other within the network.

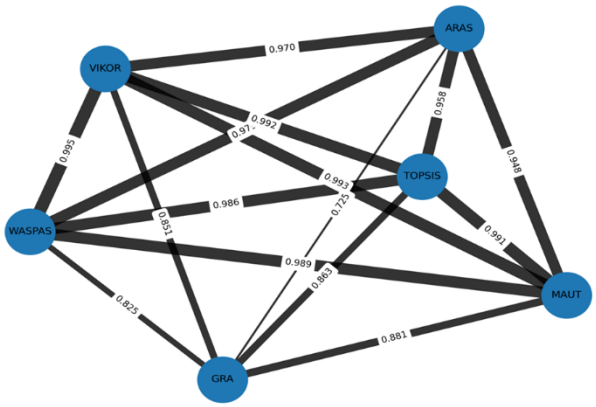

Figure 1. Network diagram of MCDM methods (r>0.70, p<0.01, 2-tailed) (Source: Created by authors)

The Spearman rank correlation coefficients among the six MCDM methods exceeded 0.90 in all pairwise comparisons, confirming the robustness and consistency of the ranking results.

Minor variations between the ARAS and GRA methods stem from their distinct normalization and distance-measurement procedures rather than conceptual discrepancies. These differences, however, do not alter the overall ranking pattern, which remains in line with theoretical expectations: developed economies perform better due to technological efficiency and environmental regulation, while developing countries bear higher environmental costs consistent with the PHH and EKC frameworks.

LIMITATIONS

While offering a holistic perspective, as with every academic study, this study's approach inherently has some inherent limitations. The main limitation of the study is its reliance on a static analysis; MCDM methods assess country performance at a specific point in time using the most recent data. This limits the ability to examine the long-term dynamics and causal direction of the relationship between economic growth and environmental degradation. Second, while the selection of environmental variables is critical, the model focuses only on carbon emissions and waste imports. The failure to include other vital environmental costs, such as air and water quality, biodiversity loss, or forest cover change, makes it difficult to provide a comprehensive picture of environmental performance. These limitations do not diminish the value of the study's findings, but they do provide an important guide for future research.

DISCUSSION AND CONCLUSION

The research findings do not definitively confirm or refute either the pollution haven hypothesis or the Environmental Kuznets Curve (EKC) hypothesis. It is observed that countries with the highest criteria weights for GDP, waste imports, carbon emissions, and international trade have the highest rankings. This suggests that countries are willing to tolerate more environmental pollution to achieve greater economic gains. Developed countries, such as the USA, Germany, the Netherlands, and India, are seen to maintain their economic gains while causing environmental damage. In other words, the findings indicate that developed countries, despite producing high levels of environmental emissions due to their economic size and trade openness, rank high in overall performance. This can be explained by technological innovation, energy efficiency, and the effectiveness of environmental policies. Developed economies are able to limit environmental damage per unit of economic activity through technological transformations that reduce emissions intensity (e.g., renewable energy use, carbon capture systems, circular production processes). Furthermore, these countries minimize environmental impacts by strengthening waste management and recycling infrastructures. Therefore, while developed countries produce high absolute emissions, they are more efficient in terms of environmental damage per unit of production or income. Therefore, technological innovation and structural change are believed to be the primary reasons behind this high performance of developed economies. Thanks to strict environmental regulations and high R&D investments, these countries are able to use significantly less energy and pollution per unit of economic growth. From this perspective, developed countries are believed to be able to successfully offset the environmental costs with the significant economic benefits derived from their high GDP and trade volume, as their technological advantages offset the emission intensity they produce.

The absence of data on China in the study is a limitation. However, based on the available countries, it is possible to state that a global environment-economy dilemma is occurring. This dilemma significantly impacts the incomplete validation of the pollution haven and EKC hypotheses.

The observed country rankings are also theoretically consistent with the joint interpretation of the EKC and PHH. According to the EKC, developed countries that have reached higher income levels tend to experience lower marginal emissions due to technological innovation and stricter environmental regulations. In contrast, the PHH suggests that developing economies increasingly host pollution-intensive industries displaced from advanced economies. Therefore, the MCDM results—where countries such as the United States, Germany, and the Netherlands rank at the top while low-income economies appear at the bottom—empirically support the complementary implications of these two hypotheses.

Studies in the literature examining the relationship between economic growth and trade openness often conclude that trade openness has a positive effect on economic growth (see 6 - 9]. These findings can be used to support the explanation of the GDP and trade openness variables and their impact on rankings in this study, which emerged with high criterion weights. The fact that the criterion weights for trade openness and GDP have reached approximately 44% is also quite normal in the context of environmental studies with regard to the PH and EKC hypotheses. Indeed, there are studies in the literature examining the relationship between economic growth and carbon emissions (see 34 - 37] Additionally, most research [42, 49, 35, 51] has empirically proven the relationship between economic growth and the environment. In this context, the criterion weight of approximately 43% for carbon emissions and waste imports is also highly explainable.

Another valuable discussion of the research in terms of criterion weights can be made through GDP per capita and GDP growth. The objective criterion weights for these two variables are around 12%. One significant reason for this is the similarity in growth rates across the world and the relatively similar levels of GDP per capita among countries, leading to the formation of groups. However, an important point here is that, particularly for GDP per capita, personal income is less significant in terms of environmental impact. In other words, when total incomes are divided by the population, the resulting values are very small. Moreover, the fairness of income distribution is a separate topic of discussion. Indeed, when considering individual income, a crucial question arises: does an individual really harm the environment to the extent caused by their income?

The research indicates that, according to its results, polluting the environment leads to commercial and economic leadership for countries. Economically, countries can interpret the research findings to argue that the environmental damage they cause is worth it. However, considering how challenging it is to reverse environmental damage, the findings suggest that countries may not take this issue as seriously as they should.

THEORETICAL IMPLICATIONS

The results obtained from the research provide evidence for why the Environmental Kuznets Curve (EKC) and Pollution Haven (PH) approaches continue to be debated and tested theoretically. The data show that, regardless of their level of economic development, countries continue to pollute the environment and import waste that contributes to pollution. Thus, this assessment explains why empirical studies are still ongoing. Additionally, the findings suggest the need for further development of the theoretical models being tested. If the theories commonly used to explain the relationship between the environment and economy still indicate differing results, it might indicate that we have reached a stage of historical development. One of the theoretical contributions of this study is the conclusion that, due to the nature of scientific inquiry—testing, discussion, and subsequent development—there is a need to explore new environmental theories. The ongoing discussions and varying results in the literature further support this research's findings.

Future research is expected to build on theoretical frameworks from past studies and propose new theoretical models. The findings of this study also have the potential to pave the way for models to be presented in the future. Certainly, similar evaluation studies can be conducted using different variables. In fact, it is recommended that such studies be carried out more frequently. This study has addressed a significant gap in the literature by providing a ranking in a manner that econometric studies in the environmental field have not extensively examined.

PRACTICAL IMPLICATIONS

The study's findings have significant implications for practical concerns. The results raise questions about the fairness of the global economic system. It is not acceptable for the most developed countries to be the biggest polluters. The purchase of rights to pollute the environment in carbon markets and the associated fees seem unfair. The ability of countries to pollute the environment presents a major threat. The rankings provided by this study are essential for ongoing discussions on how commercial interests or economic objectives pose significant risks to the future of the world.

Countries that rank highly in the assessments are strongly advised to focus more diligently on environmental issues and to find solutions to the dilemma between the economy and the environment from an environmental perspective. Additionally, it is recommended that international economic organizations, environmental organizations, and the United Nations impose stricter sanctions on these countries. While a country may use its economic prosperity for its own interests, the entire world suffers from pollution. Therefore, steps should be taken to make initiatives on carbon emissions stricter and fairer. In this context, the ranking provided by the study addresses a significant gap.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest with any individual, institution, or organization in the preparation, evaluation, or publication of this study.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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Table S1. Decision matrix

		C1	C2	C3	C4	C5	C6
1	**Algeria**	102068612,000	215,000	284,445	194998449769,085	4342,638	3,200
2	**Angola**	68979312,000	982,000	66,480	106782770714,619	3000,444	3,045
3	**Antigua and Barbuda**	644799,000	9,000	0,360	1867733333,333	19919,727	9,516
4	**Argentina**	164430777,000	129,000	382,992	631133384439,944	13650,605	4,956
5	**Armenia**	13942527,000	60,000	9,377	19513474648,243	7018,052	12,600
6	**Aruba**	1579648,000	3,000	0,497	3544707788,057	33300,839	10,458
7	**Australia**	692279853,000	5799,000	571,382	1692956646855,700	65099,846	4,269
8	**Austria**	430228656,000	122377,000	76,743	470941926750,741	52084,681	4,806
9	**Azerbaijan**	52686489,000	6624,000	68,877	78721058823,529	7762,074	4,617
10	**Bahamas**	4332205,000	101,000	1,882	12897400000,000	31458,301	14,368
11	**Bahrain**	37786686,000	703,000	69,976	44383297872,340	30146,925	4,861
12	**Bangladesh**	156554458,000	4574,000	281,082	460201265527,977	2688,306	7,100
13	**Barbados**	2645183,000	23,000	0,928	5699950000,000	20238,784	11,334
14	**Belgium**	1260713873,000	181495,000	114,032	583435595579,963	49926,825	3,010
15	**Benin**	4177585,000	2,000	20,685	17396792699,549	1302,851	6,253
16	**Bermuda**	1225785,000	2,000	0,354	7546000000,000	118774,791	2,927
17	**Bolivia, Plurinational State of**	26702219,000	837,000	58,463	44008282877,961	3600,122	3,606
18	**Bosnia and Herzegovina**	25060577,000	921,000	29,324	24473906673,709	7568,798	4,106
19	**Botswana**	16404808,000	57,000	12,607	20355541962,851	7738,879	5,788
20	**Brazil**	607164813,000	3126,000	1310,499	1920095779022,730	8917,675	2,901
21	**Bulgaria**	108341950,000	23492,000	68,414	90346169914,935	13974,449	3,926
22	**Burkina Faso**	10180558,000	46,000	36,497	18820064797,838	830,037	1,780
23	**Burundi**	1392531,000	1,000	7,480	3338722827,662	259,025	1,849
24	**Cabo Verde**	874274,000	2,000	1,303	2226862134,088	3754,305	17,117
25	**Cambodia**	50517375,000	60,000	50,016	29504829319,317	1759,608	5,240
26	**Cameroon**	16254145,000	4,000	43,171	43644068310,851	1563,489	3,583
27	**Canada**	1168772625,000	108023,000	756,810	2161483369422,010	55522,446	3,820
28	**Cayman Islands**	6743758,000	40,000	0,345	6844827379,310	99624,885	3,675
29	**Central African Republic**	747349,000	2,000	13,448	2382618615,017	427,058	0,502
30	**Chile**	211891652,000	900,000	137,011	301024724911,923	15355,480	2,440
31	**Colombia**	134672681,000	2151,000	215,537	343622114560,409	6624,165	7,257
32	**Comoros**	430788,000	1,000	0,922	1242519407,278	1484,892	2,388
33	**Congo**	12548931,000	2,000	25,962	15816996654,579	2649,225	1,475
34	**Costa Rica**	36463708,000	2458,000	16,861	69243626028,670	13365,356	4,551
35	**Côte d'Ivoire**	34367441,000	3,000	36,177	70018715016,829	2486,412	6,741
36	**Croatia**	69497975,000	9490,000	24,178	71600049650,195	18570,404	6,347
37	**Curaçao**	2727134,000	12,000	2,154	3075180834,724	20501,752	7,890
38	**Cyprus**	16299925,000	2490,000	10,630	29250524418,086	32048,240	5,058
39	**Czech Republic**	478009142,000	34621,000	124,495	290565654835,809	27226,616	2,351
40	**Denmark**	256889448,000	24254,000	45,795	400167196948,707	67790,054	2,731
41	**Djibouti**	11802888,000	3544,000	2,232	3515108859,955	3136,113	3,124
42	**Dominican Republic**	42380321,000	1374,000	41,858	113537368176,130	10111,246	4,858
43	**Ecuador**	68429286,000	2376,000	76,944	115049476000,000	6391,282	2,948
44	**Egypt**	127860797,000	7908,000	377,780	476747720364,742	4295,407	6,588
45	**El Salvador**	24223115,000	8104,000	13,074	32488720000,000	5127,322	2,600
46	**Eswatini**	4547354,000	29,000	3,387	4790922065,610	3986,887	0,476
47	**Ethiopia**	19628271,000	4528,000	192,474	126783471597,671	1027,586	5,317
48	**Fiji**	4086212,000	2,000	2,982	4979979546,012	5356,164	20,016

49	**Finland**	183602693,000	5967,000	54,805	282649838009,729	50871,930	1,634
50	**France**	1422621418,000	139246,000	430,363	2779092236505,850	40886,253	2,455
51	**Gabon**	11856270,000	18,000	18,627	21071739224,892	8820,347	2,908
52	**Georgia**	13925675,000	198,000	18,046	24780791063,713	6674,957	10,393
53	**Germany**	3259508832,000	290585,000	784,005	4082469490797,680	48717,991	1,806
54	**Ghana**	41684236,000	862,000	53,007	73766052451,526	2203,559	3,078
55	**Greece**	155538321,000	16219,000	76,031	217581324512,059	20867,269	5,557
56	**Guatemala**	47905215,000	9840,000	45,018	95003330315,875	5473,209	4,118
57	**Guinea**	17821170,000	87,000	29,280	20999229260,496	1515,168	4,700
58	**Guinea-Bissau**	645406,000	31,000	3,243	1633559092,089	775,829	3,500
59	**Honduras**	31109251,000	17904,000	23,745	31717699764,362	3040,173	3,998
60	**Hungary**	309268677,000	11961,000	66,208	177337436677,365	18390,185	4,555
61	**Iceland**	17188152,000	2,000	4,768	28064529851,310	73466,779	7,238
62	**India**	1185250207,000	49176,000	3943,265	3416645826052,870	2410,888	7,240
63	**Indonesia**	529426160,000	103414,000	1240,833	1319100220407,720	4787,999	5,309
64	**Iran, Islamic Republic of**	139626578,000	740,000	951,984	413493207349,265	4669,571	3,777
65	**Iraq**	210177339,000	727,000	367,941	264182173793,103	5937,195	7,009
66	**Ireland**	368121057,000	39432,000	62,419	533140011838,276	103983,291	9,433
67	**Israel**	180326667,000	3168,000	87,754	525002447652,773	54930,939	6,833
68	**Italy**	1354623052,000	139970,000	394,748	2049737165407,980	34776,423	3,725
69	**Jamaica**	9632630,000	141,000	7,707	17097760723,920	6047,216	5,222
70	**Japan**	1657170531,000	2078,000	1182,770	4256410760723,750	34017,272	0,955
71	**Jordan**	40143864,000	347,000	34,539	48653381780,640	4311,000	2,428
72	**Kazakhstan**	134435258,000	236,000	331,530	225496328925,494	11492,032	3,200
73	**Kenya**	28518544,000	3554,000	117,895	113420008178,793	2099,302	4,847
74	**Kuwait**	135701185,000	145,000	167,862	175363265306,122	41079,523	8,861
75	**Kyrgyzstan**	12057661,000	53,000	21,940	11543966558,842	1655,073	6,332
76	**Lao People's Democratic Republic**	18527244,000	437,000	36,862	15468785203,753	2054,431	2,707
77	**Latvia**	50395215,000	19949,000	11,108	40932030049,564	21779,504	3,358
78	**Lesotho**	2798583,000	3,000	3,023	2236502124,170	969,936	1,115
79	**Liberia**	2123542,000	95,000	5,311	4001046970,000	754,533	4,808
80	**Lithuania**	101612047,000	27095,000	20,847	70974490450,494	25064,809	2,440
81	**Luxembourg**	42877361,000	6454,000	8,476	81641807865,759	125006,022	1,380
82	**Madagascar**	8987217,000	12,000	34,980	15297192798,977	516,593	3,796
83	**Malawi**	2493891,000	213,000	20,919	13164667626,936	645,159	0,923
84	**Malaysia**	648242463,000	173550,000	353,917	407027451714,616	11993,188	8,650
85	**Mali**	10358140,000	126,000	49,383	18827176529,698	833,297	3,727
86	**Malta**	11839719,000	208,000	2,178	18125564514,266	34127,511	6,916
87	**Mauritania**	8897830,000	63,000	16,670	9780863578,977	2065,156	6,376
88	**Mauritius**	7997901,000	1,000	6,409	12948726653,811	10256,230	8,881
89	**Mexico**	1182345329,000	58664,000	819,873	1465854089286,470	11496,523	3,898
90	**Morocco**	115164122,000	5805,000	114,771	130912558829,840	3441,991	1,259
91	**Mozambique**	22711213,000	729,000	40,072	18406835954,670	558,299	4,360
92	**Myanmar**	34487872,000	2452,000	169,387	62263466263,738	1149,211	4,037
93	**Namibia**	13962571,000	88,000	13,103	12914932655,685	5031,115	7,563
94	**Nepal**	15016012,000	3,000	56,735	40828247303,534	1336,546	5,613
95	**Netherlands**	1479031142,000	412274,000	167,847	1009398719033,080	57025,012	4,329
96	**New Zealand**	98672411,000	3554,000	82,720	248101705541,399	48418,592	2,851
97	**Nicaragua**	18606656,000	1571,000	21,025	15671583939,989	2255,426	3,751
98	**Niger**	4233361,000	1,000	43,240	15342278919,401	585,405	11,490

99	**Nigeria**	123826120,000	4340,000	407,690	472624597402,898	2162,634	3,252
100	**Norway**	378935795,000	1562,000	69,965	593348981537,661	108729,187	3,016
101	**Oman**	104636355,000	1904,000	137,244	114667360208,062	25056,795	4,311
102	**Pakistan**	102280609,000	26935,000	546,099	374697366359,244	1588,880	4,706
103	**Panama**	44716150,000	365,000	18,478	76522511800,000	17357,629	10,809
104	**Paraguay**	25827921,000	1415,000	45,565	41722295229,228	6153,056	0,075
105	**Peru**	118418915,000	4172,000	105,139	242631573320,790	7125,830	2,684
106	**Philippines**	224819536,000	2638,000	265,296	404284326110,463	3498,510	7,570
107	**Poland**	701437255,000	102569,000	400,824	688125010520,520	18688,004	5,260
108	**Portugal**	197850564,000	59756,000	59,713	255196660987,427	24515,266	6,828
109	**Qatar**	164443485,000	1937,000	194,652	236258302839,653	87661,450	4,209
110	**Romania**	229529165,000	46059,000	117,061	300691354864,855	15786,802	4,595
111	**Rwanda**	4803502,000	422,000	9,032	13311487445,069	966,232	8,160
112	**Saudi Arabia**	601061979,000	12685,000	810,512	1108571517285,380	30447,884	8,681
113	**Senegal**	17854444,000	403,000	30,615	27684264748,232	1598,726	4,154
114	**Serbia**	68322313,000	7340,000	69,945	63563401043,504	9537,683	2,550
115	**Seychelles**	1593393,000	29,000	1,199	1588438144,377	13250,456	9,000
116	**Sierra Leone**	3198256,000	42,000	7,123	4094563859,436	475,796	3,458
117	**Singapore**	990593952,000	434,000	70,470	466788426791,966	82807,629	3,647
118	**Slovakia**	224022861,000	23061,000	45,564	115461711688,965	21256,808	1,750
119	**Slovenia**	114882326,000	54959,000	18,276	60063475466,345	28439,334	2,461
120	**South Africa**	235493027,000	4576,000	534,532	405270850099,387	6766,481	1,910
121	**Spain**	923341124,000	170501,000	328,591	1417800466262,650	29674,544	5,771
122	**Suriname**	4639482,000	24,000	4,500	3620987993,326	5858,825	2,434
123	**Sweden**	399744850,000	28027,000	60,637	591718144602,141	56424,285	2,912
124	**Switzerland**	758875207,000	10912,000	45,564	818426550206,450	93259,906	2,568
125	**Tajikistan**	7512907,000	815,000	22,834	10492123387,793	1054,189	8,000
126	**Tanzania, United Republic of**	22479293,000	332,000	89,378	75732311666,039	1192,766	4,558
127	**Thailand**	590367615,000	47455,000	463,875	495423343049,622	6909,956	2,598
128	**Togo**	4148751,000	184,000	11,088	8341225241,457	942,650	5,811
129	**Trinidad and Tobago**	19423242,000	119,000	45,911	30053575132,142	19629,465	1,482
130	**Tunisia**	45218052,000	214,000	49,820	46303552449,354	3747,419	2,438
131	**Turkmenistan**	19334722,000	10,000	128,919	56542857142,857	8792,549	1,700
132	**Turks and Caicos Islands**	736293,000	18,000	0,101	1138808881,100	24917,596	6,200
133	**Türkiye**	617882886,000	296944,000	687,526	907118435952,688	10674,504	5,533
134	**Uganda**	13325213,000	910,000	56,490	45567304608,476	964,396	4,588
135	**United Arab Emirates**	936114387,000	1753,000	295,110	507063968273,313	53707,980	7,850
136	**United Kingdom**	1346781429,000	74927,000	426,562	3089072722400,140	46125,256	4,347
137	**United States of America**	5438885447,000	378052,000	6017,443	25439700000000,000	76329,582	1,936
138	**Uruguay**	24163497,000	17,000	41,908	71177146197,495	20795,042	4,922
139	**Uzbekistan**	43550928,000	5241,000	227,207	80391853887,405	2255,151	5,669
140	**Viet Nam**	729697972,000	199617,000	489,159	408802378904,838	4163,514	8,020
141	**Zambia**	20738109,000	42,000	30,331	29163782138,342	1456,902	5,250
142	**Zimbabwe**	15185924,000	1209,000	30,190	27366627153,085	1676,821	6,522