Journal of Turkish

Operations Management

Türkiye ve G7 ülkelerinin sürdürülebilirlik karşılaştırması: Yeni bir hibrit yöntem Entropi-ARTASI

Galip Cihan YALÇIN[1*], **Sercan EDİNSEL**[2]
[1] İktisadi ve İdari Bilimler Fakültesi, Ostim Teknik Üniversitesi, OSTİM, Ankara
e-mail: galipcihan.yalcin@ostimteknik.edu.tr, ORCID No: http://orcid.org/0000-0001-9348-0709
[2] İktisadi ve İdari Bilimler Fakültesi, Ostim Teknik Üniversitesi, OSTİM, Ankara,
e-mail: sedinsel@gmail.com, ORCID No: http://orcid.org/0000-0003-2831-7504
*Sorumlu Yazar

Makale Bilgisi

Makale Geçmişi:
Geliş: 10.12.2024
Revize: 11.07.2025
Kabul: 31.07.2025

Anahtar Kelimeler:

Sürdürülebilirlik
WEF Raporu
Entropi Yöntemi
ARTASI

Özet

Son yıllarda, sürdürülebilirliğin artan önemi, fosil yakıtlardan kaynaklanan hava kirliliği ve gelecek nesillere yaşanabilir bir dünya bırakma gerekliliğiyle daha belirgin hale gelmiştir. Bu zorlukların üstesinden gelmek, ülkelerin çevresel, sosyal ve ekonomik boyutlar açısından sürdürülebilirlik performanslarını sağlam bir şekilde anlamayı gerektirmektedir. Bu çalışma, Dünya Ekonomik Forumu'nun Geleceğin Büyüme Raporu 2024 verilerini kullanarak Türkiye ve G7 ülkelerini değerlendirmeyi ve karşılaştırmayı amaçlamaktadır. Çalışmada, çok kriterli karar verme (MCDM) çerçevesi uygulanmış ve Entropi ile ARTASI (Alternatiflerin uyarlanabilir standart aralıklara dayalı sıralama tekniği) yöntemleri birleştirilerek sistematik ve veri odaklı bir analiz gerçekleştirilmiştir. Entropi, sürdürülebilirlik kriterlerine objektif ağırlık atamak için kullanılırken, ARTASI bu kriterlere göre ülkeleri sıralamıştır. Analiz, Türkiye'nin G7 ülkelerine kıyasla konumunu vurgulamakta ve sürdürülebilir büyümeyi artırmaya yönelik olası politika düzenlemelerini önermektedir. Sonuç olarak, Türkiye G7 ülkeleri arasında yedinci sırada yer almaktadır. "Toplam Yeşil Patent" kriteri ise en önemli kriter olarak tespit edilmiştir. Ayrıca, duyarlılık analizi, yöntemin uygulanabilirliğini ve sağlamlığını ortaya koymaktadır.

Comparing sustainability in Türkiye and G7 countries: A novel hybrid method Entropy-ARTASI

Article Info

Article History:
Received:
Revised:
Accepted:

Keywords:

Sustainability
WEF Report
Entropy Method
ARTASI

Abstract

In recent years, the growing importance of sustainability has become increasingly apparent, driven by concerns over air pollution from fossil fuels and the need to leave a habitable world for future generations. Addressing these challenges requires a robust understanding of countries' sustainability performance across environmental, social, and economic dimensions. This study aims to evaluate and compare Türkiye and G7 countries using sustainability data from the World Economic Forum's The Future Growth Report 2024. Employing a multi-criteria decision-making (MCDM) framework, the Entropy and ARTASI (Alternative ranking technique based on adaptive standardized intervals) methods are combined to conduct a systematic and data-driven analysis. Entropy is used to objectively weigh sustainability criteria, ARTASI ranks the countries based on these criteria. This analysis highlights Türkiye's position compared to G7 countries and suggests potential policy adjustments for enhancing sustainable growth. In conclusion it's found that Türkiye ranked seventh among the G7 countries. And the "Green Patents Total" criterion is selected as the most important. And the sensitivity analysis shows applicability and robustness of the analysis.

1. Introduction

While sustainability has generally been interpreted as meaning the ability to meet current needs without compromising the ability of future generations to meet their needs, this concept has come to be regarded as a core issue for nations and institutions worldwide (Rees, 2021). Growing concern for sustainable development represents heightened awareness of environmental, social, and economic problems that threaten global stability and well-being (Hariram et al., 2023). Coupled with climate change, resource depletion, air and water pollution, and loss of biodiversity form other major areas of concern, adding to the challenges; all raise the need for the consideration of sustainability from the level of the individual life to government policy (Thiele, 2024). Whereas, especially, the consumption of fossil fuel and industrial activities are major contributors to increasing greenhouse gas emissions, air pollution, and all those environmental problems that urgently need to be tackled at the global level. In fact, this fact has been reflected in the growing efforts of countries to rise up to these challenges proactively (Wang and Azaam, 2024).

Now, the need for sustainable development-where there needs to be a paradigm shift toward sustainability for lasting economic stability, social equity, and protection of the environment-is already being echoed through governments, businesses, and international organizations (Chasek, 2018). Recognition ushers in actions in the form of concrete commitments and initiatives in renewable energy investments, sustainable resource management processes, and regulations on carbon emission minimization (Onwuka and Adu, 2024). Today, in most strategic frameworks of nations, sustainability is related not only to environmental protection but also as a core goal in itself, parallel to the big objectives of economic stability, job creation, and welfare policy (Häbel and Halaka, 2021). Within this framework, the World Economic Forum published a report at the end of this year entitled Future Growth Report 2024, ranking countries according to a variety of key parameters (World Economic Forum, 2024). This paper provides a balanced review of initiatives and success stories concerning the promotion of sustainable practices around the world.

This paper gives the basic data that will be used in the study to conduct the analysis and compare the sustainability performance of Türkiye with that of the G7 countries using Multi-Criteria Decision-Making methods, namely the Entropy and ARTASI methods. The mentioned methods support the structured analysis of the sustainability indicators. In the application of the Entropy method, each criterion would be given a neutral weight, while the ARTASI method allows the full ranking performance of each country.

Steps Türkiye will undertake toward sustainability, in that respect, show it is highly important, not only internally but also in view of standing shoulder-to-shoulder with powers such as the G7 countries (Eşiyok et al., 2023). The latter represent the most highly industrialized countries and play a key role in running global governance and influencing the processes of international decision-making. This comparison of sustainability performance for Türkiye with that of the G7 will be helpful in establishing the position of Türkiye within a competitive global framework and assessing its progress toward the sustainable development goals (Karahan et al, 2025). Such an analysis offers rich information regarding the domains within which Türkiye converges to or diverges from the sustainability standards posed by global leaders and thus informs policy recommendations toward better environmental, social, and economic outcomes.

2. Literature Review

In recent years, various Multi-Criteria Decision-Making (MCDM) methods have been employed to evaluate sustainability, energy, and environmental issues (Stojčić et al., 2019). These studies leverage comprehensive datasets from sources like the World Bank, United Nations, and Environmental Performance Index, providing insights into the complexities of sustainability. Siksnelyte et al. (2019) applied the MULTIMOORA method to sustainable energy development, utilizing data from United Nations, the International Atomic Energy Agency, International Energy Agency, European Environment Agency, and Eurostat. This study contributes significantly to the discourse on sustainable energy, particularly within international energy policy frameworks. Martin and Canero (2019) used AHP to analyze sustainable development based on Eurostat data, adding value to policy-driven sustainability research. This study illustrates the utility of AHP in aligning sustainable development goals with policy objectives in the European Union. Ecer et al. (2019) employed CoCoSo to examine sustainability issues, drawing from a range of global sources, including the World Bank, IMF, WHO, UN, and indices from organizations like the World Economic Forum and Boston Consulting Group. This comprehensive dataset underscores the complexity of sustainability assessment across multiple sectors and criteria. Giannetti et al. (2019) introduced the 5SEnSU model to assess the sustainability of production systems, relying on data from the Global Footprint Network, World Bank, United Nations, and Environmental Performance Index. Their work underscores the relevance of evaluating production systems within a global sustainability framework. Stecyk (2019) applied AHP and TOPSIS methodologies to assess sustainable development using data from the West Pomeranian Statistical Office. This study emphasized the applicability of MCDM methods in regional sustainability assessments, contributing to a deeper understanding of local development priorities. Alidrisi (2021) focused on sustainability assessment using TOPSIS and based the analysis on the World Energy Statistics Report and World Happiness Report from 2020. This study integrated both environmental and social metrics, providing a more holistic perspective on sustainability. Tutak (2021) employed the WASPAS method to evaluate energy sustainability with data sourced from Eurostat. This study contributes a focused analysis on energy-specific sustainability factors, enriching the literature with energy-centric sustainability metrics. Aytekin (2022) conducted an analysis using ARAT, CRITIC, SOWIA, CRADIS, and CODAS methods, concentrating on energy, environmental, and sustainability factors. The study utilized data from the World Bank, United Nations, and Environmental Performance Index, showcasing a detailed approach to understanding the multi-faceted aspects of sustainability. Gökgöz and Yalcin (2022) explored environmental and energy sustainability through CRITIC, VIKOR, and CoCoSo methodologies, using OECD data from 2012-2018. Their work provides insights into the comparative advantages of these methods in assessing environmental sustainability within developed economies. Senir (2024) employed ENTROPY, COPRAS, and WASPAS methods to evaluate environmental sustainability. Drawing from the Environmental Performance Index, this work highlighted the critical dimensions of sustainability, especially in relation to environmental metrics. Related literature for Sustainability of Countries shown in Table 1.

Table 1. Related literature for sustainability of countries analysis using MCDM

Authors	***Methods***	***Sector***	***Years***	***Index***
Siksnelyte et al., 2019	MULTIMOORA	Sustainable Energy Development	2018	United Nations Department of Economic and Social Affairs, International Atomic Energy Agency, The International Energy Agency, European Environment Agency, Eurostat, European Commission
Martin and Canero, 2019	AHP	Sustainable Development	2015	Eurostat
Ecer et al, 2019	CoCoSo	Sustainability	2018	The World Bank, IMF, WHO, UN, Indices of social development, World Economic Forum, Boston Consulting Group
Giannetti et al., 2019	5SEnSU	Sustainability of Production Systems	2017	Global Footprint Network, World Bank, United Nations and Environmental Performance Index
Stecyk, 2019	AHP, TOPSIS	Sustainable Development	2017	West Pomeranian Statistical Office
Alidrisi, 2021	TOPSIS	Sustainability	2020	World Energy Statistics Report, World Happiness Report
Tutak, 2021	WASPAS	Energy Sustainability		Eurostat
Aytekin, 2022	ARAT, CRITIC, SOWIA, CRADIS, CODAS	Energy, Environment, and Sustainability	2022	World Bank, United Nations and Environmental Performance Index
Gökgöz and Yalcin, 2022	CRITIC, VIKOR, CoCoSo	Environmental and Energy Sustainability	2012-2018	OECD
Senir, 2024	ENTROPY, COPRAS, WASPAS	Environmental Sustainability	2022	Environmental Performance Index

3. Methodology

In this study, Entropy-ARTASI hybrid method has been developed and proposed for finding the situation and ranking of Türkiye in Sustainability among G7 countries. ARTASI method is preferred because it is a flexible, practical and effective multi-criteria decision-making method that ranks alternatives precisely according to positive and negative ideal solutions by taking into account the criteria weights, is sensitive to decision maker preferences, has high discrimination power and can be integrated with other methods. The methodological flow of the research is conducted in two phases. In *Phase 1*, the weights of the criteria are calculated using the Entropy method. *Phase*

2, the final utility function values of the countries are calculated using the ARTASI method and country rankings are obtained. The methodological flow is illustrated in Figure 1. In the application section of the research, the situation of Türkiye in Sustainability among G7 countries.

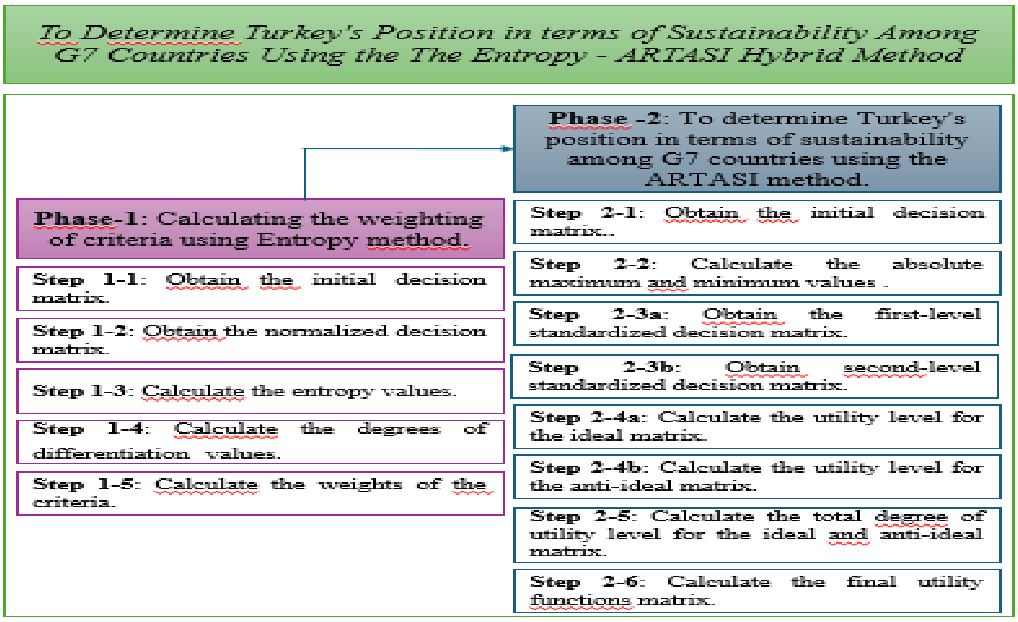

Figure 1. The Framework of The Methodology.

3.1 The Entropy - ARTASI Hybrid Method

A hybrid method called the Entropy - ARTASI hybrid method is proposed for determining Türkiye's status in terms of sustainability among G7 countries. The inputs of this method comprise a set of criteria $C = \{C_1, C_2, \dots, C_u, \dots, C_{\mathcal{u}}\}$ with $(u = 1,2,\dots,\mathcal{u})$, a set of alternatives $A = \{A_1, A_2, \dots, A_t, \dots, A_{\mathcal{t}}\}$ with $(t = 1,2,\dots,\mathcal{t})$. This hybrid method consists of two phases. In ***Phase-1***, the weights of criteria are calculated using the Entropy method. In ***Phase-2***, the ARTASI method is employed to obtain the final utility functions' values and rankings of the countries. The process steps of the Entropy - ARTASI hybrid method are as follows.

***Phase-1**: Calculating the weighting of criteria using Entropy method:*

Step 1: An initial decision matrix $(\mathfrak{D} = [\mathfrak{d}_{tu}]_{\mathcal{t}\mathcal{u}})$ consist of $\mathcal{t}$ alternatives and $\mathcal{u}$ criteria. This initial decision matrix is shown in Eq. (1).

$$\mathfrak{D} = [\mathfrak{d}_{tu}]_{\mathcal{t}\mathcal{u}} = \begin{bmatrix} \mathfrak{d}_{11} & \cdots & \mathfrak{d}_{1u} & \cdots & \mathfrak{d}_{1\mathcal{u}} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ \mathfrak{d}_{t1} & \cdots & \mathfrak{d}_{tu} & \dots & \mathfrak{d}_{t\mathcal{u}} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ \mathfrak{d}_{\mathcal{t}1} & \cdots & \mathfrak{d}_{\mathcal{t}u} & \dots & \mathfrak{d}_{\mathcal{t}\mathcal{u}} \end{bmatrix}; (t = 1,2,\dots,\mathcal{t}; u = 1,2,\dots,\mathcal{u}). \tag{1}$$

Step 2: The initial decision matrix is normalized by employing Eq. (2) (Çelen, 2014). Thus, normalized decision matrix $(\aleph = [\aleph_{tu}]_{\mathcal{t}\mathcal{u}})$ is obtained.

$$\daleth_{tu} = \frac{\mathfrak{d}_{tu}}{\sum_{t=1}^{\mathcal{t}} \mathfrak{d}_{tu}}; \; for\ benefit\ criteria \tag{2}$$

$$\daleth_{tu} = \frac{1/\mathfrak{d}_{tu}}{\sum_{t=1}^{\mathcal{t}} 1/\mathfrak{d}_{tu}}; \; for\ cost\ criteria$$

Step 3: The entropy values $(\mathcal{E}_u)$ are calculated by employing Eq. (3). Thus, the entropy value matrix $(\mathcal{E} = [\mathcal{E}_u]_{\mathcal{u}})$ is obtained.

$$\mathcal{E}_u = -\Bbbk \sum_{t=1}^{\mathcal{t}} \daleth_{tu} \ln(\daleth_{tu}) \tag{3}$$

herein, $\Bbbk = \frac{1}{\ln(\mathcal{t})}$.

Step 4: The degrees of differentiation values are calculated by employing Eq. (4). Thus, the degree of differentiation value matrix $(\mathfrak{q} = [\mathfrak{q}_u]_{\mathcal{u}})$ is obtained.

$$\mathfrak{q}_u = 1 - \mathcal{E}_u \tag{4}$$

Step 5: The weights of the criteria are calculated by employing Eq. (5). Thus, the criteria weighting matrix $(\text{ꞷ} = [\text{ꞷ}_u]_u)$ is obtained.

$$\text{ꞷ}_u = \frac{\text{ꝗ}_u}{\sum_{u=1}^{\mathscr{u}} \text{ꝗ}_u} \tag{5}$$

***Phase -2**: Ranking the alternatives using ARTASI method:*

Step 1: An initial decision matrix $(\mathfrak{D} = [\text{ꝺ}_{tu}]_{\mathscr{t}\mathscr{u}})$ consist of $\mathscr{t}$ alternatives and $\mathscr{u}$ criteria. This initial decision matrix $(\mathfrak{D} = [\text{ꝺ}_{tu}]_{\mathscr{t}\mathscr{u}})$ is shown in Eq. (1).

Step 2: Calculate the absolute maximum values $(\text{Ⱥ}^{max} = [\text{Ⱥ}_u^{max}]_{\mathscr{u}})$ and absolute minimum values $(\text{Ⱥ}^{min} = [\text{Ⱥ}_u^{min}]_{\mathscr{u}})$ matrix using Eq. (6) and Eq. (7), use this initial decision matrix, respectively:

$$\text{Ⱥ}_u^{max} = (\max_{1\le t\le \mathscr{t}}(\text{ꝺ}_{tu})) + (\max_{1\le t\le \mathscr{t}}(\text{ꝺ}_{tu}))^{1/\mathscr{t}} \tag{6}$$

$$\text{Ⱥ}_u^{min} = (\min_{1\le t\le \mathscr{t}}(\text{ꝺ}_{tu})) - (\min_{1\le t\le \mathscr{t}}(\text{ꝺ}_{tu}))^{1/\mathscr{t}} \tag{7}$$

Step 3: This step involves the calculation of the standardized decision matrix through the application of two sub-steps.

Step 3a: The first-level standardized decision matrix $\left(\text{Ꝑ}^1 = [\text{Ꝑ}^1{}_{tu}]_{\mathscr{t}\mathscr{u}}\right)$ is calculated as:

$$\text{Ꝑ}^1{}_{tu} = \left(\left(\frac{\gamma^{(u)}-\gamma^{(l)}}{\text{Ⱥ}_u^{max}-\text{Ⱥ}_u^{min}}\right)\text{ꝺ}_{tu}\right) + \left(\left(\frac{(\text{Ⱥ}_u^{max})(\gamma^{(l)})-(\text{Ⱥ}_u^{min})(\gamma^{(u)})}{\text{Ⱥ}_u^{max}-\text{Ⱥ}_u^{min}}\right)\right) \tag{8}$$

where the standardized interval $[\gamma^{(u)}, \gamma^{(l)}]$ is set to values [1,100] [21].

Step 3b: The second-level standardized decision matrix $\left(\text{Ꝑ}^2 = [\text{Ꝑ}^2{}_{tu}]_{\mathscr{t}\mathscr{u}}\right)$ is calculated as:

$$\text{Ꝑ}^2{}_{tu} = \begin{pmatrix} (-\text{Ꝑ}^1{}_{tu} + max_{1\le t\le \mathscr{t}}(\text{Ꝑ}^1{}_{tu}) + min_{1\le t\le \mathscr{t}}(\text{Ꝑ}^1{}_{tu}))\ for\ \ cost\ criteria \\ \text{Ꝑ}^1{}_{tu}\ for\ \ benefit\ criteria \end{pmatrix} \tag{9}$$

Step 4: The calculation of the utility level of alternatives with respect to ideal and anti-ideal values involves the implementation of two sub-steps.

Step 4a: The calculation of the utility level for the ideal matrix $(\text{ȽȺ}^{max} = [\text{ȽȺ}_{tu}^{max}]_{\mathscr{t}\mathscr{u}})$ is performed by applying Eq (10) as:

$$\text{ȽȺ}_{tu}^{max} = \left(\left(\frac{\text{Ꝑ}^2{}_{tu}}{max_{1\le t\le \mathscr{t}}(\text{Ꝑ}^2{}_{tu})}\right)(\text{ꞷ}_u)(\gamma^{(u)})\right) \tag{10}$$

where $\gamma^{(u)} = 100$.

Step 4b: The calculation of the utility level for the anti-ideal matrix $\left(\text{ȽȺ}^{min} = [\text{ȽȺ}_{tu}^{min}]_{\mathscr{t}\mathscr{u}}\right)$ is performed by applying Eq (11) as:

$$\text{ȽȺ}_{tu}^{min} = (-\mathbb{U}_{tu} + \max_{1\le t\le \mathscr{t}}(\mathbb{U}_{tu}) + \min_{1\le t\le \mathscr{t}}(\mathbb{U}_{tu})) \tag{11}$$

herein $\mathbb{U}_{tu}$ is the degree of usefulness. It is computed as:

$$\mathbb{U}_{tu} = \left(\left(\frac{min_{1\le t\le \mathscr{t}}(\text{Ꝑ}^2{}_{tu})}{\text{Ꝑ}^2{}_{tu}}\right)(\text{ꞷ}_u)(\gamma^{(u)})\right) \tag{12}$$

Step 5: The evaluation of the utility levels of the alternatives involves the calculation of the total degree of utility for the ideal value matrix $(\Lambda^{max} = [\Lambda_t^{max}]_{\mathscr{t}})$ and the anti-ideal value matrix $\left(\Lambda^{min} = [\Lambda_t^{min}]_{\mathscr{t}}\right)$ using Eq. (13) and Eq. (14), respectively:

$$\Lambda_t^{max} = \sum_{u=1}^{\mathscr{u}} \text{ȽȺ}_{tu}^{max} \tag{13}$$

$$\Lambda_t^{min} = \sum_{u=1}^{\mathscr{u}} \text{ȽȺ}_{tu}^{min} \tag{14}$$

Step 6: The calculation of the final utility functions matrix $(\text{Ƒ} = [\text{Ƒ}_t]_{\mathscr{t}})$ is performed through Eq. (15) as follows:

$$\text{Ƒ}_t = (\Lambda_t^{max} + \Lambda_t^{min})\left(\left((\Psi)\left(f(\Lambda_t^{max})\right)^{\xi}\right) + \left((1-\Psi)\left(f(\Lambda_t^{min})\right)^{\xi}\right)\right)^{1/\xi}; \tag{15}$$

$(t = 1,2,\ldots,\mathscr{t}) \mid \xi \in [1,+\infty);\ \Psi \in [0,1],$

where $f(\Lambda_t^{max})$ and $f(\Lambda_t^{min})$ denote additive functions, computed as $\left(f(\Lambda_t^{max}) = \frac{\Lambda_t^{max}}{\Lambda_t^{max}+\Lambda_t^{min}}\right)$ and $\left(f(\Lambda_t^{min}) = \frac{\Lambda_t^{min}}{\Lambda_t^{max}+\Lambda_t^{min}}\right)$, respectively. Finally, the best alternative is identified by determining the highest value in the final utility function matrix. Table 2 delineates the Algorithmic stages of the Entropy - ARTASI hybrid method.

Table 2. Algorithm for Entropy - ARTASI hybrid method

Algorithm	*The purpose of this Algorithm is to determine Türkiye's position in terms of sustainability among G7 countries according to the criteria included in the "Sustainability" Index of the World Economic Forum 2024 Report using the Entropy - ARTASI hybrid method.*
Input	The inputs of this method comprise a set of criteria $C = \{C_1, C_2, \dots, C_u, \dots, C_u\}$, a set of alternatives $A = \{A_1, A_2, \dots, A_t, \dots, A_t\}$.
Phase-1	*Calculating the weighting of criteria using Entropy Method:*
Step 1	The initial decision matrix ($\text{Ꝺ} = [\text{ꝺ}_{tu}]_{tu}$) is expressed as shown in Eq. (1).
Step 2	Calculate the normalized decision matrix ($\aleph = [\aleph_{tu}]_{tu}$) using Eq. (2).
Step 3	Calculate the entropy value matrix ($\mathcal{E} = [\mathcal{E}_u]_u$) by employing Eq. (3).
Step 4	Calculate the degree of differentiation value matrix ($\text{Ɋ} = [\text{Ɋ}_u]_u$) by employing Eq. (4).
Step 5	Calculate the criteria weighting matrix ($\text{Ꞷ} = [\text{Ꞷ}_u]_u$) by employing Eq. (5).
Phase -2	*Ranking the alternatives using ARTASI method:*
Step 1	The initial decision matrix ($\text{Ꝺ} = [\text{ꝺ}_{tu}]_{tu}$) is expressed as shown in Eq. (1).
Step 2	Calculate the absolute maximum values matrix ($\text{Ⱥ}^{max} = [\text{Ⱥ}_u^{max}]_u$) and the absolute minimum values matrix ($\text{Ⱥ}^{min} = [\text{Ⱥ}_u^{min}]_u$) by employing Eq. (6) and Eq. (7), respectively.
Step 3a	Calculate the first-level standardized decision matrix $\left(\text{Ꞩ}^1 = [\text{Ꞩ}^1{}_{tu}]_{tu}\right)$ by employing Eq. (8).
Step 3b	Calculate the second-level standardized decision matrix $\left(\text{Ꞩ}^2 = [\text{Ꞩ}^2{}_{tu}]_{tu}\right)$ by employing Eq. (9).
Step 4a	Calculate the utility level for the ideal matrix ($\text{ꟺ}^{max} = [\text{ꟺ}_{tu}^{max}]_{tu}$) by employing Eq (10).
Step 4b	Calculate the utility level for the anti-ideal matrix $\left(\text{ꟺ}^{min} = [\text{ꟺ}_{tu}^{min}]_{tu}\right)$ by employing Eq (11) and Eq (12).
Step 5	Calculate the aggregate degree of utility for the ideal value matrix ($\Lambda^{max} = [\Lambda_t^{max}]_t$) and the anti-ideal value matrix $\left(\Lambda^{min} = [\Lambda_t^{min}]_t\right)$ by employing Eq. (13) and Eq. (14), respectively.
Step 6	Calculate the final utility functions matrix ($\text{Ꞙ} = [\text{Ꞙ}_t]_t$) by employing the Eq. (15) (($\Psi \in [0,1]$) and ($\xi \in [1, +\infty)$)).
Output	The weighting of criteria ($\text{Ꞷ} = [\text{Ꞷ}_u]_u$) and the final utility functions matrix ($\text{Ꞙ} = [\text{Ꞙ}_t]_t$) of countries.
End.	

4. Application

Sustainability has gained importance for Türkiye, motivated by strategic objectives put in place to increase resilience to economic shock and also to address environmental and social concerns (Özkan et al., 2024). Considering that Türkiye is interested in setting sustainable development within the scope of its national policies, a comparative examination against the G7 nations-who are leading in methods of sustainability-offers crucial insight. The present study has taken into consideration the value of sustainability performance of Türkiye in comparison to G7 countries, based on data gathered from the World Economic Forum's The Future Growth Report 2024. The Sustainability Index, presented in this report from the World Economic Forum, is adopted for application in this work because it allows holistic and harmonized measurement across the key dimensions:

environmental impact, economic stability, and social inclusivity (World Economic Forum, 2024). It is even more relevant to the comparison between Türkiye and the G7 nations, since this index represents worldwide accepted standards and measures of performance that capture the complex characteristics of sustainable development.

4.1 Criteria and Alternatives

The selection of sustainability criteria in this study was guided by both empirical relevance and theoretical support from existing literature. Specifically, the indicators used, such as total green patents, CO_2 emissions per capita, renewable energy share, environmental R&D expenditure, and water stress levels, have been widely recognized in previous sustainability performance assessments (e.g., OECD, 2023; UNDP, 2022; WEF, 2024). These criteria reflect the three fundamental pillars of sustainability: environmental (e.g., emissions, water use), economic (e.g., innovation, green investment), and social (e.g., long-term resource efficiency). Moreover, indicator selection aligns with the frameworks of widely accepted indices, including the Environmental Performance Index (EPI), Sustainable Development Goals (SDGs), and the Global Green Growth Index (GGGI), ensuring both comparability and relevance. While the Entropy method objectively determined the weights, the initial inclusion of indicators was validated through convergence with best practices in recent comparative sustainability studies (Senir, 2024; Gökgöz & Yalçın, 2022). Through this approach, arbitrariness in the selection of criteria is sought to be avoided, and the transparency and scientific credibility of the evaluation framework are intended to be improved.

Criteria are taken from World Economic Forum the Future of Growth 2024 Report’s “Sustainability” index and sub criteria. These ratio values are as follows (World Economic Forum, 2024):

Talent for green and energy transition (C_1): It is defined as the consumer's demand for the environmental sustainability of products and services, showing the degree of social consciousness and preference. Green-competent human resources will become indispensable to enable structural change in energy carriers from fossil fuels to renewables.

Buyers’ sophistication on environment and nature (C_2): The preserved amount of a country's ecosystem serves as a yardstick for measuring the richness and strength of biodiversity. With higher degrees of sophistication, people are more like to focus on those companies and products that contribute to ecological awareness for the instigation of such sustainability out of companies and the marketplace.

Biodiversity intactness (C_3): It concerns individual carbon footprint contribution by each country to the overall global emission. High levels of biodiversity intactness would indicate that natural ecosystems and their constituent species are sufficiently well-protected to maintain ecosystem resilience and promote ongoing ecosystem health.

Renewable energy consumption % total (C_4): This measures the negative impact of agriculture on the environment due to soil degradation and water pollution. A higher percentage means the greater share of clean energy sources against the fossil fuel sources of all renewable energy sources and corresponds to low GHG emissions and clean energy sector.

Investment in renewable energy %GDP (C_5): This is indicative of financial commitment towards renewable sources in relation to GDP and is thus an indicator of stress on clean alternatives. A higher investment in renewable energy thus furthers the shift towards sustainable energy systems and therefore reduces dependency on non-renewable resources.

Green patents total (C_6): It measures the number of patents dealing with environmental issues and therefore tracks inventions in green technologies. A high number of green patents simply indicates a good research and innovative climate for sustainability technologies.

Energy efficiency regulation (C_7): This specification provides the policy to be laid down to reduce energy usage and develop resources for better use. Good regulation contributes much to get the most from energy conversion with minimum wastage.

Renewable energy regulation (C_8): It assess policy frameworks supportive of the dissemination of renewable energy sources. Good renewable energy regulation creates an enabling environment for the adoption and investment in clean energy projects, hence transitioning into sustainable energy systems in a country.

Annual greenhouse gas emissions tons CO2 equiv.per.cap (C_9): This criterion will give a relation to the functioning of renewable energy in all consumption and hence the progress toward sustainable energy mix. This should be reduced for fighting climate change and global goals on carbon reduction.

Agricultural environmental damage (C_{10}): This criterion presents freshwater use and emphasizes the pressure on water resources concerning their availability. Therefore, sustainable agriculture contributes to minimizing environmental damage by preserving natural resources and ensuring food security.

Total water withdrawal m3 per capita/year (C_{11}): This represents the waste of an individual, describing countries' problems with waste management. Water should be managed sustainably to ensure availability for generations to come, especially in countries most affected by water scarcity.

Total waste tons per capita/year (C_{12}): This is an indicator of the financial commitment toward renewable energy sources regarding the percentage of GDP. It shows the priority given to renewable energy projects. Waste reduction is of considerable importance for preventing environmental contamination; however, significant generation of waste can lead to disproportionate pressure on landfills or other facilities for waste management.

Fossil-fuel subsidies USD per capita (C_{13}): Financial incentives for fossil fuel that may act as an obstacle to transition to green. A high subsidy for fossil fuel is causing damage to the transition of sustainable energy due to very cheap fossil fuel and deterrents to invest in much cleaner alternatives.

Alternatives are **Türkiye (A_1), Germany (A_2), USA (A_3), UK (A_4), Italy (A_5), France (A_6), Spain (A_7) and Canada (A_8).**

4.2 Calculating the weighting of criteria using Entropy Method

Entropy - ARTASI hybrid method was applied to calculate Türkiye's sustainability status among G7 countries. The application steps are as follows:

***Phase-1**: Calculating the weighting of criteria using Entropy method* (Wang et al., 2009; Durmaz and Gölcük, 2023)*:*

Step 1: An initial decision matrix ($\mathfrak{D} = [\mathfrak{d}_{tu}]_{tu}$) consist of t alternatives and u criteria. The initial decision matrix is shown in Table 3.

Table 3. The initial decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
A_1	3.30	2.90	75.20	13.70	0.50	45.00	57.20	78.00	7.10	0.60	742.00	0.40	1289.00
A_2	4.10	4.40	67.30	18.60	0.30	2984.00	82.90	91.90	9.00	0.50	341.00	0.60	1364.00
A_3	5.10	4.80	69.30	11.20	0.20	4859.00	83.50	63.30	17.80	0.40	1350.00	0.80	2329.00
A_4	4.60	4.50	42.20	13.50	0.40	717.00	82.50	91.90	6.30	0.60	125.00	0.50	857.00
A_5	4.40	4.60	66.30	18.70	0.10	395.00	80.00	82.50	6.30	0.60	565.00	0.50	783.00
A_6	4.50	4.00	62.00	16.90	0.20	1137.00	69.40	87.60	6.00	0.50	412.00	0.60	682.00
A_7	2.90	4.40	88.40	8.50	0.40	6883.00	68.30	78.40	8.80	0.60	624.00	0.30	2172.00
A_8	5.10	4.80	90.50	23.90	0.20	411.00	79.00	83.70	20.30	0.50	968.00	0.70	1010.00

Step 2: The initial decision matrix is normalized by employing Eq. (2). The normalized decision matrix ($\aleph = [\aleph_{tu}]_{tu}$) is shown in Table 4.

Table 4. The normalized decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
A_1	0.0971	0.0843	0.1340	0.1096	0.2174	0.0026	0.0949	0.1187	0.1475	0.1099	0.0679	0.1578	0.1063
A_2	0.1206	0.1279	0.1199	0.1488	0.1304	0.1712	0.1375	0.1398	0.1163	0.1319	0.1477	0.1052	0.1004
A_3	0.1500	0.1395	0.1235	0.0896	0.0870	0.2788	0.1385	0.0963	0.0588	0.1648	0.0373	0.0789	0.0588
A_4	0.1353	0.1308	0.0752	0.1080	0.1739	0.0411	0.1369	0.1398	0.1662	0.1099	0.4029	0.1262	0.1599
A_5	0.1294	0.1337	0.1181	0.1496	0.0435	0.0227	0.1327	0.1255	0.1662	0.1099	0.0891	0.1262	0.1750

A_6	0.1324	0.1163	0.1105	0.1352	0.0870	0.0652	0.1151	0.1333	0.1745	0.1319	0.1223	0.1052	0.2009
A_7	0.0853	0.1279	0.1575	0.0680	0.1739	0.3949	0.1133	0.1193	0.1190	0.1099	0.0807	0.2104	0.0631
A_8	0.1500	0.1395	0.1613	0.1912	0.0870	0.0236	0.1311	0.1273	0.0516	0.1319	0.0520	0.0902	0.1356

Step 3: The entropy values (u^{th}) are calculated by employing Eq. (3). The entropy value matrix $(\mathcal{E} = [\mathcal{E}_u]_u)$ is shown in Table 5.

Table 5. The entropy value matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
$\mathcal{E}_u$	0.2579	0.2587	0.2572	0.2545	0.2474	0.1905	0.2590	0.2592	0.2508	0.2587	0.2229	0.2541	0.2502

Step 4: The degrees of differentiation values are calculated by employing Eq. (4). The degree of diversification value matrix $(\text{Ɋ} = [\text{Ɋ}_u]_u)$ is shown in Table 6.

Table 6. The degree of differentiation value matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
Ɋ_u	0.7421	0.7413	0.7428	0.7455	0.7526	0.8095	0.7410	0.7408	0.7492	0.7413	0.7771	0.7459	0.7498

Step 5: The weights of the criteria are calculated by employing Eq. (5). The criteria weighting matrix $(\text{ꞷ} = [\text{ꞷ}_u]_u)$ is shown in Table 7.

Table 7. The criteria weighting matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
ꞷ_u	0.07589	0.07581	0.07596	0.07623	0.07696	0.08278	0.07577	0.07576	0.07661	0.07581	0.07946	0.07628	0.07668
Ranking	**9**	**11**	**8**	**7**	**3**	**1**	**12**	**13**	**5**	**10**	**2**	**6**	**4**

It has been determined that "Green patents total (C_6)" is the most important criterion and "Total water withdrawal m3 per capita/year (C_{11})"is the second important criterion while "Renewable energy regulation (C_8)" and "Energy efficiency regulation (C_7)" criteria are the two criteria with the lowest importance level, respectively.

***<u>Phase -2</u>**<u>: Ranking the alternatives using ARTASI method</u>* <u>(Pamucar et al., 2024)</u>*<u>:</u>*

Step 1: An initial decision matrix $(\mathfrak{D} = [\mathfrak{d}_{tu}]_{tu})$ consist of t alternatives and u criteria. The initial decision matrix is shown in Table 1.

Step 2: Calculate the absolute maximum values $(\text{Ⱥ}^{max} = [\text{Ⱥ}_u^{max}]_u)$ and absolute minimum values $(\text{Ⱥ}^{min} = [\text{Ⱥ}_u^{min}]_u)$ matrix using Eq. (6) and Eq. (7). The absolute maximum and minimum values matrix are shown in Table 8.

Table 8. The absolute maximum and minimum values matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
Ⱥ^{max}	6.3259	6.0166	92.2562	25.3870	1.4170	6886.0180	85.2386	93.6596	21.7569	1.5381	1352.4620	1.7725	2331.6357

$₳^{min}$	1.7576	1.7576	40.6035	7.1933	-0.6499	43.3906	55.5417	61.6205	4.7490	-0.4918	123.1714	-0.5603	679.7394

Step 3: This step involves the calculation of the standardized decision matrix through the application of two sub-steps.

Step 3a: Calculate the first-level standardized decision matrix $\left(Ɉ^1 = \left[Ɉ^1{}_{tu}\right]_{tu}\right)$ using Eq. (8). The first-level standardized decision matrix is shown in Table 9.

Table 9. The first-level standardized decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
A_1	34.425	27.554	67.309	36.406	56.077	1.023	6.528	51.612	14.685	54.246	50.837	41.753	37.514
A_2	51.762	62.422	52.168	63.069	46.498	43.545	92.204	94.563	25.744	49.369	18.543	50.241	42.009
A_3	73.434	71.720	56.001	22.802	41.708	70.673	94.204	6.190	76.968	44.492	99.802	58.729	99.842
A_4	62.598	64.746	4.060	35.318	51.288	10.746	90.870	94.563	10.028	54.246	1.147	45.997	11.623
A_5	58.264	67.071	50.251	63.613	36.918	6.087	82.536	65.517	10.028	54.246	36.582	45.997	7.189
A_6	60.431	53.124	42.009	53.819	41.708	16.822	47.199	81.276	8.282	49.369	24.261	50.241	1.135
A_7	25.756	62.422	92.609	8.110	51.288	99.956	43.532	52.848	24.580	54.246	41.334	37.509	90.433
A_8	73.434	71.720	96.634	91.909	41.708	6.319	79.202	69.225	91.520	49.369	69.038	54.485	20.793

Step 3b: Calculate the second-level standardized decision matrix $\left(Ɉ^2 = \left[Ɉ^2{}_{tu}\right]_{tu}\right)$ using Eq. (9). The second -level standardized decision matrix is shown in Table 10.

Table 10. The second-level standardized decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
A_1	34.425	27.554	67.309	36.406	56.077	1.023	6.528	51.612	85.117	44.492	50.112	54.485	63.464
A_2	51.762	62.422	52.168	63.069	46.498	43.545	92.204	94.563	74.057	49.369	82.406	45.997	58.969
A_3	73.434	71.720	56.001	22.802	41.708	70.673	94.204	6.190	22.834	54.246	1.147	37.509	1.135
A_4	62.598	64.746	4.060	35.318	51.288	10.746	90.870	94.563	89.773	44.492	99.802	50.241	89.354
A_5	58.264	67.071	50.251	63.613	36.918	6.087	82.536	65.517	89.773	44.492	64.367	50.241	93.789
A_6	60.431	53.124	42.009	53.819	41.708	16.822	47.199	81.276	91.520	49.369	76.688	45.997	99.842
A_7	25.756	62.422	92.609	8.110	51.288	99.956	43.532	52.848	75.221	44.492	59.615	58.729	10.545
A_8	73.434	71.720	96.634	91.909	41.708	6.319	79.202	69.225	8.282	49.369	31.911	41.753	80.185

Step 4: The calculation of the utility level of alternatives with respect to ideal and anti-ideal values involves the implementation of two sub-steps.

Step 4a: Calculate the utility level for the ideal matrix ($ĦA^{max} = [ĦA_{tu}^{max}]_{tu}$) using Eq (10). The utility level for the ideal matrix is shown in Table 11.

Table 11. The utility level for the ideal matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
A_1	3.557	2.912	5.291	3.020	7.696	0.085	0.525	4.135	7.125	6.218	3.990	7.077	4.874
A_2	5.349	6.598	4.101	5.231	6.381	3.606	7.416	7.576	6.200	6.899	6.561	5.974	4.529
A_3	7.589	7.581	4.402	1.891	5.724	5.853	7.577	0.496	1.912	7.581	0.091	4.872	0.087
A_4	6.469	6.844	0.319	2.929	7.039	0.890	7.309	7.576	7.515	6.218	7.946	6.525	6.862
A_5	6.021	7.089	3.950	5.276	5.067	0.504	6.639	5.249	7.515	6.218	5.125	6.525	7.203
A_6	6.245	5.615	3.302	4.464	5.724	1.393	3.796	6.511	7.661	6.899	6.106	5.974	7.668
A_7	2.662	6.598	7.280	0.673	7.039	8.278	3.501	4.234	6.297	6.218	4.747	7.628	0.810
A_8	7.589	7.581	7.596	7.623	5.724	0.523	6.371	5.546	0.693	6.899	2.541	5.423	6.158

Step 4b: Calculate the utility level for the anti-ideal matrix $\left(Ѩ^{min} = \left[Ѩ^{min}_{tu}\right]_{tu}\right)$ using Eq (11). The utility level for the anti-ideal matrix is shown in Table 12.

Table 12. The utility level for the anti-ideal matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
A_1	4.573	2.912	7.457	6.598	7.696	0.085	0.525	7.163	7.609	6.218	7.856	7.248	7.618
A_2	6.474	7.147	7.324	7.316	6.652	8.168	7.566	7.576	7.498	6.967	7.927	6.279	7.607
A_3	7.589	7.581	7.364	5.585	5.951	8.243	7.577	0.496	5.576	7.581	0.091	4.872	0.087
A_4	7.128	7.267	0.319	6.545	7.223	7.575	7.558	7.576	7.648	6.218	7.946	6.805	7.657
A_5	6.896	7.379	7.301	7.324	5.067	6.971	7.503	7.356	7.648	6.218	7.896	6.805	7.662
A_6	7.016	6.561	7.181	7.147	5.951	7.859	7.054	7.495	7.661	6.967	7.919	6.279	7.668
A_7	2.662	7.147	7.582	0.673	7.223	8.278	6.966	7.184	7.511	6.218	7.885	7.628	6.929
A_8	7.589	7.581	7.596	7.623	5.951	7.022	7.478	7.394	0.693	6.967	7.752	5.647	7.646

Step 5: Calculate the total degree of utility for the ideal value matrix $(\Lambda^{max} = [\Lambda^{max}_{t}]_{t})$ and the anti-ideal value matrix $\left(\Lambda^{min} = \left[\Lambda^{min}_{t}\right]_{t}\right)$ using Eq. (13) and Eq. (14), respectively. The total degree of utility for the ideal and the anti-ideal value matrix are shown in Table 13.

Table 13. The total degree of utility for the ideal and the anti-ideal value matrix

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
Λ^{max}	56.50	76.42	55.66	74.44	72.38	71.36	65.96	70.27
Λ^{min}	73.56	94.50	68.59	87.46	92.03	92.76	83.89	86.94

Step 6: Calculate the final utility functions matrix $(Ƒ = [Ƒ_t]_t)$ using Eq. (15). The total degree of utility for the ideal and the anti-ideal value matrix are shown in Table 14. $(\Psi = 1, \xi = 0{,}5)$

Table 14. The final utility functions matrix

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
Ƒ	65.031	85.462	62.124	80.953	82.203	82.059	74.924	78.603
Ranking	**7**	**1**	**8**	**4**	**2**	**3**	**6**	**5**

According to data taken from World Economic Forum the Future of Growth 2024 Report's "Sustainability" Index and sub criteria the sustainability performance ranking of the countries is as follows: Germany>Italy>France>United Kingdom>Canada>Spain>Türkiye>USA. The result of the study is shown in Figure 2.

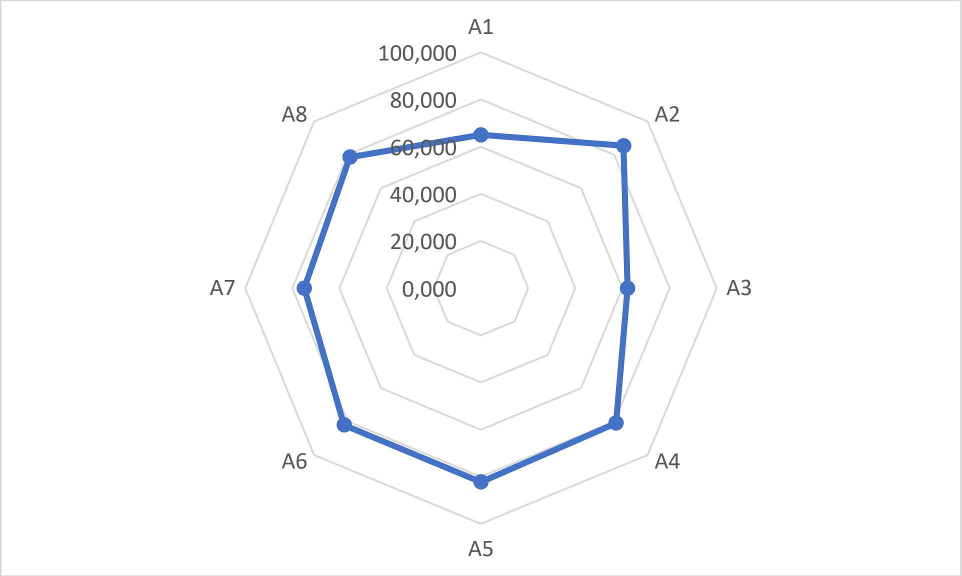

Figure 2. Results

5. Results and Implications

In this study, the Entropy-ARTASI hybrid method was proposed to find the situation and the ranking of Türkiye among G7 countries. The algorithmic steps of the Entropy- ARTASI hybrid method were applied sequentially to obtain the results. As a result of the implementation the rankings of the countries about sustainability were determined. The findings support the successful application of the Entropy- ARTASI hybrid method. The results obtained are as follows:

In the decision model, a total of thirteen criteria which were taken fromm World Economic Forum 2024 Report's "Sustainability" Index. The importance weights of the criteria were determined using the Entropy method as follows: Green patents total (C_6), Total water withdrawal m3 per capita/year (C_{11}), Investment in renewable energy %GDP (C_5), Fossil-fuel subsidies USD per capita (C_{13}), Annual greenhouse gas emissions tons CO2 equiv.per.cap (C_9), Total waste tons per capita/year (C_{12}), Renewable energy consumption % total (C_4), Biodiversity intactness (C_3), Talent for green and energy transition (C_1), Agricultural environmental damage (C_{10}), Buyers' sophistication on environment and nature (C_2), Energy efficiency regulation (C_7), Renewable energy regulation (C_8).

The ranking of the eight countries including Türkiye in terms of sustainability was calculated using the Entropy-ARTASI hybrid method. The final ranking of the countries is as follows: "Germany>Italy>France>United Kingdom>Canada>Spain>Türkiye>USA". According to this ranking, Germany was determined as the leading country in terms of sustainability according to the World Economic Forum 2024 Report Sustainability Index, with Italy identified as the second-best country. The position in the ranking can primarily be explained by the following structural and policy-related issues:

Germany's first position in the sustainability rankings mainly reflects its inclusive and extensive environmental policy. The country has continuously focused on ecological modernization, evident in its Energy Transition policy framework enabling the systematic shift from fossil fuels to renewable sources of energy (Krüger, 2022). Germany's strong regulatory system, high capacity for green technology innovations, and high spending in environment-related R&D have generated high scores in areas like green patents and the use of renewable energies. Additionally, high public support for the uptake of sustainable practices and relatively moderate per capita emissions has further established Germany's first position (Pata et al., 2023). Italy's second rank reflects its consistent but progressive improvements in the adoption of renewable energy and water resource management. In spite of regional deviations in policy enforcement and infrastructure development, Italy has registered high gains in investments in photovoltaic and wind energies, mainly by EU funding and local incentive packages. The country's achievement in terms of total per capita water withdrawal and renewable energy spending highlights the effective coordination of the sustainability goals with the EU policy architecture and local government measures (Raihan et al, 2024). France and the United Kingdom, in third and fourth places respectively, also enjoy the presence of proactive environmental institutions and strong climate policy legislation. Centralized environment planning makes it easier to integrate initiatives like the carbon taxes and states' investments in nuclear power and clean alternate sources of energy. The United Kingdom, despite policy reversals in the last couple of years due to Brexit, maintains the noble track record in sustainability governance, especially in terms of emissions mitigation and biodiversity management. Both countries have high scores in regulatory and efficiency dimensions; nevertheless, lower grades in garbage generation and fossil fuel subsidies might have influenced minor downgrades in the general standings (Chilvers et al, 2017; Ridwan et al., 2023). Canada, although highly developed, ranks in the middle of the group. This is primarily due to its relatively high per capita greenhouse gas emissions and fossil fuel subsidies, particularly in provinces reliant on extractive industries. While Canada has advanced green innovation policies and a strong emphasis on clean tech, the environmental externalities from oil sands and limited water usage controls have negatively influenced criteria such as annual greenhouse gas emissions and total water withdrawal (Harrison and Bang, 2022). Spain, included in this study for comparative breadth, presents a mixed performance. While Spain has achieved notable success in renewable energy deployment—especially in solar and wind—its overall sustainability score is moderated by economic fluctuations and inconsistencies in environmental enforcement across regions. Nevertheless, Spain scores reasonably well in green energy investment and regulatory frameworks, placing it above Türkiye and the USA in this evaluation (Fernandez, 2018). The United States ranks lowest among the countries analyzed, which may appear counterintuitive given its technological and financial capacity. This outcome is primarily driven by high per capita emissions, significant fossil fuel subsidies, and a historically fragmented environmental policy landscape. While the Inflation Reduction Act (IRA) of 2022 marks a major shift toward clean energy investment, its full impact may not yet be reflected in the current data. Moreover, inconsistent federal and state-level environmental regulations contribute to a lack of cohesive national performance in key sustainability metrics (Frank, 2015).

As for Türkiye, the country ranks in a fairly modest position amongst analyzed nations. While policy pledges by Türkiye have been quite significant in recent decades, concrete advancement in the majority of core environment and innovation indicators has been restricted, revealing the gap between planning in policy and implementation in practice (Öztürk and Durak, 2024). One of the root causes behind Türkyie's modest rank is its ongoing over-reliance on fossil fuels for generating energy (Yeldan, 2023). In 2022, Türkiye heavily depended on coal and natural gas (%85), even though the capacity for solar and wind has been expanding in the recent past. The generation mix causes fairly high per capita emissions of greenhouse gasses, remaining over the average global mark (Climate Transparancy, 2022). Secondly, Türkiye has hefty fossil fuel subsidies in place, especially for coal-powered electricity generation, which sets back the creation of the low-carbon regime (Karagöz, 2019). For green innovation, Türkiye lags behind by a long distance. The environment-related patents per capita continue to rank amongst the lowest in the OECD (OECD, 2025), indicating negligible spending on environmental R&D and poor connectivity in academia, industry, and the government in green technology creation. Innovation capacity deficiencies pose a negative impact on Türkiye's competitiveness in the global sustainability transition. Türkyie has effected symbolic policy changes nonetheless (Duru, 2024). In 2021, Türkiye ratified the Paris Agreement and launched its Green Deal Action Plan (T.C. Ticaret Bakanlığı, 2021), with the objective to align the national development with EU environment objectives. Nevertheless, the majority of them remain at the strategic developmental level or legislation. Enforcing regulatory action, specifically in the industries, construction, and transport sectors, is in patches and lacks sufficient resources (Aydın, 2019). Therefore, Türkye scores poorly on environmental regulatory quality and governance metrics. Water stress and mismanagement additionally hinder Türkye's poor performance. The per capita freshwater availability in the country has fallen below 1,500 m³/year to near-water stress conditions (TÜİK, 2023). Irkes water irrigation systems in the agricultural sector and limited capacity for urban wastewater treatment also derail performance in water-related sustainability indicators. And Also Türkiye's base water stress is in high level. (Kuzma et al., 2023). Widespread and frequently spontaneous urbanization adds to these pressures, generating habitat loss, air and noise pollution, and exposure to climate risk. Türkiye's strategic position, young urbanizing population, and growing concern for the environment, mainly from the private sector stakeholders and the youth, point to high hidden potential. The spread of more frequent corporate sustainability reporting and interest in green finance products (e.g., green bond and ESG investing) reflect bottom-up attitude change (Sancar, 2017). Türkiye's sustainability performance at the moment embodies internal shortcomings and implementation opportunities missed. Yet, high-level commitments in place along with emerging public and private impetus promise Türkiye the potential to greatly enhance its sustainability trend in the near term with strategic investment, enhanced governance, and policy coherence.

5.1 Sensitivity Analysis for Entropy-ARTASI Method

The result obtained as a result of comparing Türkiye with G7 countries in terms of sustainability, using the Entropy-ARTASI hybrid method, is as follows: Germany>Italy>France>United Kingdom>Canada>Spain>Türkiye>USA. To measure the robustness of the study, sensitivity analysis was conducted with two different scenarios: In the first scenario, the robustness of the method is tested with changes made to the Ψ and ξ parameters in the 6th step of the ARTASI method. In all results obtained from the sensitivity analysis, Germany was calculated as the country with the highest degree. Alternative rankings obtained according to changes in *Ψ* and *ξ* parameters are shown in Table 15 and Table 16.

Table 15. Alternative rankings obtained according to changes in *Ψ* parameters

	ξ=1								ξ=2							
	A1	A2	A3	A4	A5	A6	A7	A8	A1	A2	A3	A4	A5	A6	A7	A8
Ψ=0,0	7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5
Ψ=0,1	7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5
Ψ=0,2	7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5
Ψ=0,3	7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5
Ψ=0,4	7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5
Ψ=0,5	7	1	8	4	2	3	6	5	7	1	8	4	2	3	6	5
Ψ=0,6	7	1	8	4	2	3	6	5	7	1	8	4	2	3	6	5
Ψ=0,7	7	1	8	2	3	4	6	5	7	1	8	3	2	4	6	5
Ψ=0,8	7	1	8	2	3	4	6	5	7	1	8	2	3	4	6	5
Ψ=0,9	7	1	8	2	3	4	6	5	7	1	8	2	3	4	6	5
Ψ=1	7	1	8	2	3	4	6	5	7	1	8	2	3	4	6	5

Table 16. Alternative rankings obtained according to changes in *ξ* parameters

ξ=3								ξ=5								ξ=10							
A1	A2	A3	A4	A5	A6	A7	A8	A1	A2	A3	A4	A5	A6	A7	A8	A1	A2	A3	A4	A5	A6	A7	A8
7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5
7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5
7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5
7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5
7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5
7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5
7	1	8	4	2	3	6	5	7	1	8	4	3	2	6	5	7	1	8	4	3	2	6	5
7	1	8	4	2	3	6	5	7	1	8	4	2	3	6	5	7	1	8	4	3	2	6	5
7	1	8	2	3	4	6	5	7	1	8	4	2	3	6	5	7	1	8	4	3	2	6	5
7	1	8	2	3	4	6	5	7	1	8	2	3	4	6	5	7	1	8	4	2	3	6	5
7	1	8	2	3	4	6	5	7	1	8	2	3	4	6	5	7	1	8	2	3	4	6	5

In addition, the graph obtained according to the results is shown in Figure 3.

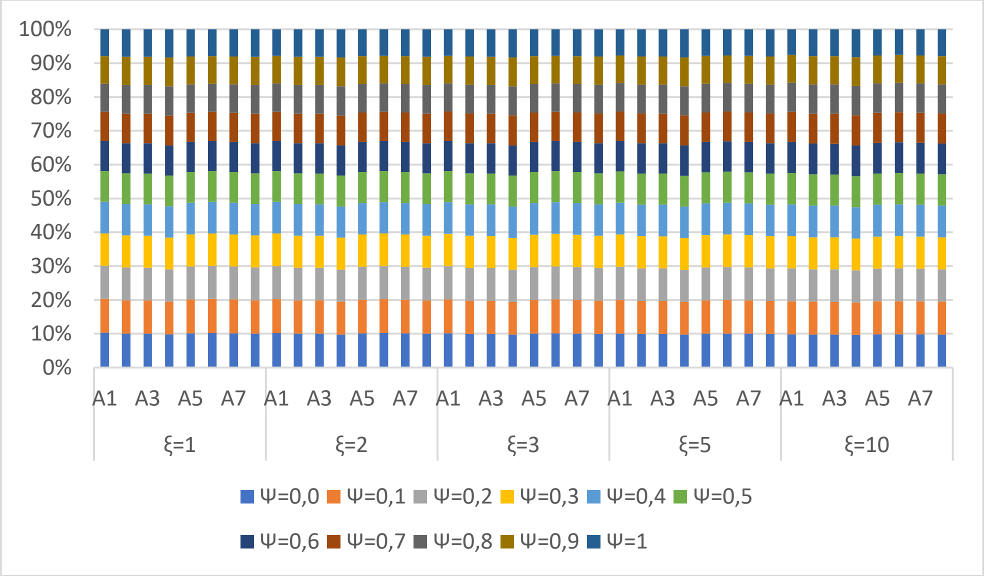

Figure 3. Results Graph

In the second scenario, all alternatives were removed from the study one by one, starting with the last alternative. Thus, the rankings were obtained again. According to the results obtained in the study, the ranking of Germany>Italy>France>United Kingdom>Canada>Spain>Türkiye>USA was obtained. According to the scenario, new rankings were obtained by removing the last alternative from the study each time. In all rankings obtained, Germany was determined as the alternative with the best degree. The ranking obtained as a result of the scenario is shown in Table 17.

Table 17. Scenario ranking results

	Ranking	Out of 3rd Alt.	Out of 1st Alt.	Out of 7th Alt.	Out of 8th Alt.	Out of 5th Alt.	Out of 6th Alt.
A1	7	7	-	-	-	-	-
A2	1	1	1	1	1	1	1
A3	8	-	-	-	-	-	-
A4	4	2	2	2	2	2	2
A5	2	4	4	4	4	-	-
A6	3	3	3	3	3	3	-
A7	6	6	6	-	-	-	-
A8	5	5	5	5	-	-	-

5.2 Comparative Analysis

It is compared with other methods to show that the study is reliable and robust. The results obtained are shown in Table 18. ARTASI, MARCOS (Stević, 2020) and AROMAN (Boskovic et al., 2023) methods were used in the comparative analysis. As a result of the analysis, the best alternative in all methods was determined as alternative A2. The results of the comparative analysis are shown in Figure 4.

Table 18. Scenario ranking results

	ARTASI		MABAC		AROMAN	
	Values	Ranking	Values	Ranking	Values	Ranking
A1	0.1246	7	0.0000	8	0.1582	7
A2	1.0000	1	1.0000	1	1.0000	1
A3	0.0000	8	0.1024	7	0.0000	8
A4	0.8068	4	0.8969	2	0.9328	2
A5	0.8604	2	0.6410	5	0.6669	4
A6	0.8542	3	0.7023	3	0.7475	3
A7	0.5485	6	0.4862	6	0.6537	5
A8	0.7061	5	0.6909	4	0.5530	6

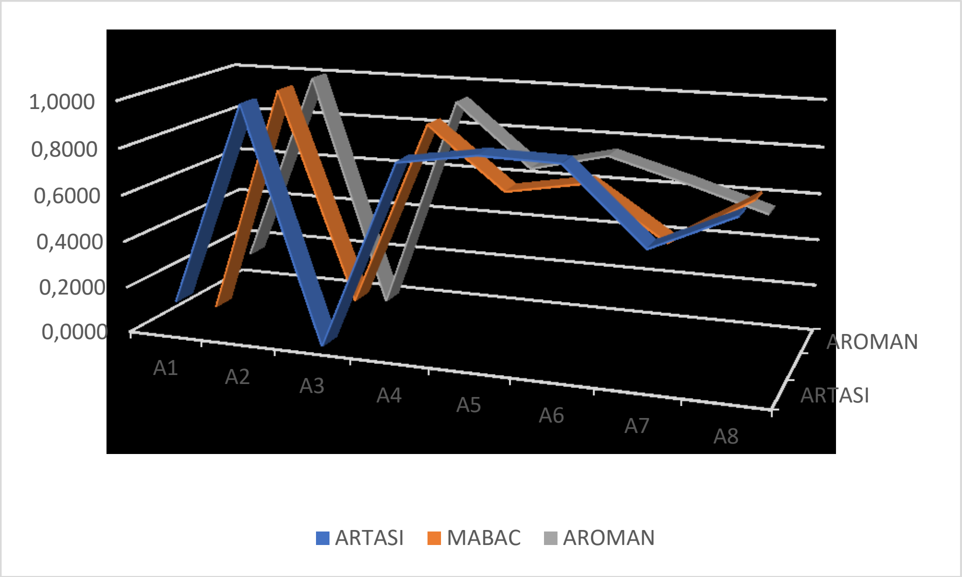

Figure 4. Results of Comparative Analysis

6. Conclusions

This study set up a decision support system intended to compare Türkiye against the G7 countries in line with the Sustainability Index as per The World Economic Forum 2024 Report. Generally, sustainability is the overarching concern for Türkiye in ensuring the security of natural resources and consolidating its economic resilience to climate change. Being a country with variable ecosystems, there is an urgent need for the augmentation of attention towards sustainability practice so that no environmental or economic interests are harmed. The Sustainability Index developed in the World Economic Forum 2024 Report outlines an overall framework through which the sustainability performance of a country may be gauged concerning all key indicators and thus helps Türkiye benchmark its progress against global standards and come into the realization of areas that need improvement with regard to sustainable development practices. The investigation develops the Entropy-ARTASI Hybrid Model-a new hybrid MCDM technique that enhances the accuracy of decision-making. It is a two-step model that, first, calculates the weightings of the decision criteria using Entropy method, while afterward it ranks the G7 countries and Türkiye concerning their sustainability performance based on the Sustainability Index developed in The World Economic Forum's 2024 Report with the use of ARTASI method. Moreover, sensitivity analyses have confirmed its practical applicability and the robustness of this hybrid model. In the final analysis, the proposed hybrid model of Entropy-ARTASI method advances the sustainable area by important steps because it applies a systematic multi-criteria methodology. It will be effective to provide solutions for both general organizational contexts and specific intra-organizational scenarios by enhancing the accurateness of decision-making and therefore making it more attractive to practitioners and decision-makers alike.

As a result of the study Green patents total, Total water withdrawal m3 per capita/year, Investment in renewable energy %GDP are the most important criteria, respectively. In this context; implications have been made for government, business and researchers. These are as follows:

For governments there is a need to increase monetary commitments towards renewable energies' technologies and infrastructure, developing energy efficiency, and moving away from reliance on non-renewable resources. Encourage innovation in green technologies and patents through policies that should be further strengthened by incentives for research and development. Similarly, it is also necessary that the regulations and mechanisms for monitoring water resources are strengthened to ensure sustainable use and equitable sharing of the resource. And, fostering international cooperation and incorporating exemplary practices in sustainability-oriented governance from G7 nations can significantly bolster Türkiye's initiatives in this domain.

For businesses, attention and investment should be given to research and development in all types of green technologies, including academia, to better apply water-saving practices and technologies at the level of the industrial process, which contributes to overall reduction in extraction. Also, integrating renewable sources of energy across operations and supply chains, using government incentives and subsidies, can provide added sustainability to operations. Finally, businesses should enhance their corporate social responsibility practices related to ecological sustainability by implementing organizational goals in compliance with international ecological standards.

Researchers should focus their efforts on developing scalable and affordable renewable energy solutions tailored to Türkiye's unique ecosystem. Interdisciplinary research on sustainable water management strategies and their socio-economic impacts is equally important. Collaborating with policymakers and commercial operators can help bridge the gap between research outcomes and practical applications. Ecological accountability for the next generation is to be cultivated through education, from school up to college. Further research is needed toward applications with more diversified fields in conjunction with real-time data, including dynamic decision-making strategies.

Limitations

While this study provides valuable insights into the sustainability performance of Türkiye in comparison to G7 countries using an objective and structured MCDM framework, several limitations must be acknowledged. Firstly, the analysis relies exclusively on the data provided by the World Economic Forum's Future of Growth Report 2024, which, although reputable, may not cover the full spectrum of sustainability indicators relevant for all countries equally. For instance, certain qualitative aspects, such as the effectiveness of governance mechanisms or cultural attitudes towards sustainability, are not captured by the selected quantitative criteria.

The criteria were ranked utilizing the Entropy technique, distinguished by its data-oriented approach that avoids dependence on expertise judgment. While this assists in enhancing objectivity, it has the tendency to ignore some contextually important features with insufficient variation in the dataset. In the same way, the ARTASI methodology being technically sound and suitable for the kind of comparative judgments, due to its relatively recent development, has lacked extensive acceptance in the field of sustainability research, and this might affect the generalizability and uptake of the study findings. Furthermore, the study is defined by its cross-sectional nature, with the study solely based on data from one year (2024), hence excluding the possibility of analyzing trends or variations over more than one time period. This time limitation delimits the study's ability to evaluate the changing advancement or regression of nations in terms of sustainability performance. Inasmuch as the sensitivity analysis determines the internal validity of the approach, the study neglects potential errors in the data used or the impacts of missing values in the effective application of the rankings.

Future studies might overcome these limitations by longitudinally summing datasets over prolonged periods of time, using objective and subjective approaches for weight measurement, and diversifying the scope of sustainability measures to include qualitative dimensions, including the quality of governance, citizen participation, and regulatory compliance.

Contribution of Researchers

Both authors have contributed equally to the work.

Conflicts of Interest

The authors declared that there is no conflict of interest.

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