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FUAD AGHAMAMMADLI
Azerbaijan State University of Economics
ŞURA TOPTANCI
Eskisehir Technical University
ÇAĞLAR KARAMAŞA
ckaramasa@anadolu.edu.tr

Anadolu University

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ANALYZING THE ENERGY CONSUMPTION OF OECD COUNTRIES THROUGH AN INTERVAL-VALUED CIRCULAR INTUITIONISTIC FUZZY AHP-BASED CRADIS APPROACH

Fuad AGHAMAMMADLI

Turkic World of Economics Faculty, Azerbaijan State of Economics (UNEC), Baku, Azerbaijan; fuad_agamammadli@unec.edu.az, ORCID: 0000-0003-4671-7042

Department of Quantitative Methods, Institute of Social Sciences, Istanbul University, Istanbul, Türkiye; fuadaghamammadli@ogr.iu.edu.tr

Şura TOPTANCI

Eskişehir Technical University, Faculty of Engineering, Department of Industrial Engineering, Eskişehir, Türkiye. Email: sani@eskisehir.edu.tr
ORCID: 0000-0002-3612-2478

Çağlar KARAMAŞA*(corresponding author)

Faculty of Business Administration, Anadolu University, Eskişehir, Türkiye; ckaramasa@anadolu.edu.tr ORCID: 0000-0003-2454-1824

ABSTRACT

The complexity of energy management and policy development is increasing and it necessitates the use of multi-criteria decision-making (MCDM) approaches to offer solutions in concern to various energy sources and assessment criteria. In this context, an example is demonstrated, the interval-valued circular intuitionistic fuzzy (IVCIF) AHP-integrated CRADIS methodology, to evaluate the energy consumption performance of the OECD nations. This article discusses six basic criteria concerning primary energy consumption, hydroelectric consumption, wind consumption, coal consumption, gas consumption, and oil consumption. There is thus a variactivation analysis among the analyzed criteria; less critical criteria share the stage with the primary energy consumption criteria, including hydro and wind energy in the category of renewable energy sources. As discussed in the results, criterion weight increases for fossil fuels, whereas less weight is given to coal, gas, and oil compared to other categories.

There are distinct differences in the energy efficiency achieved by OECD countries. Among the countries, effective energy management strategies and their implications present significant positive results in the case of Canada, Germany, and Japan, while the United Kingdom and France have relatively robust energy programs fostering practices in sustainable living. In contrast, the dismally performing country must be Hungary, with the Czech Republic, Greece, and Slovakia also not too promising, given the general profile. The study underscores the influence of the IVCIF-AHP&CRADIS approach to offset the complexity of assessing energy and channel the data-oriented policymaking agenda. This systematic prioritizing of the various criteria, with respect to energy consumption, will permit a comprehensive understanding of the relative strengths and weaknesses in energy practices across OECD countries. The result will be a policy-effective outcome for the policymakers, as well as an incentive to further develop energy efficiency and renewable energy. It is one of the reasons certain strategies are focused on enhancing general sustainability within the OECD framework.

Keywords: Energy Consumption, Multi-criteria Decision-making, CRADIS, Circular Intuitionistic Fuzzy Sets, OECD Countries.

1. Introduction

World Population is increasing, and industrialization and technological advancements are pushing energy demand up. Energy, which is reflected in practically every dimension of human life associated with raising the welfare level of communities and economic development as well as social growth are among the fundamental byproducts of creation. At the same time, it is one of their most fundamental requirements and a primary element in production. In economic and social terms, energy is the single most important condition that must be met for a society to advance in national development or global living standards. As the population all over the world grows, it affects the energy requirements of every state and as well as due to industrial progressions a major change is observed.

It is imperative for both developed and emerging nations to consider the availability and usage of various energy sources. Knowing how important energy is prompts nations to continuously look for new sources while simultaneously raising concerns about some aspects of their consumption. Questions like which sources are better for consumption, or which sources contribute less to atmospheric pollution, for instance, are sought for answers. We refer to cost, increased efficiency, and simplicity of consumption when we discuss advantages in terms of use. Both rich and developing nations weigh these benefits against specific drawbacks when selecting which energy source to use. It should be emphasized at this point that selecting energy sources is a significant matter on both a national and global scale. In particular, a nation's energy strategy, energy security, economic expansion, environmental regulations, and competitiveness in the global market can all be directly impacted by the decisions made. For instance, the nation's economic activity will continue if renewable energy sources are chosen for independent and continuous energy use. As an additional illustration, the nation's production of products and services is offered at reduced costs due to the selection of a more cost-effective energy source, improving the competitive environment. This is by no means an exhaustive list of examples. In summary, therefore, achieving these benefits more readily depends in large part on the assessment of energy consumption levels. In this regard, it is critical that nations assess their current state of energy use and take appropriate actions considering these assessments. This significance necessitates careful handling of a delicate subject like energy use.

Almost all evaluations of a country's industrial, economic, and environmental health take its energy use into account. OECD industrialized nations consume a significant amount of energy worldwide. These countries' energy usage and policy choices have a significant impact on global energy markets, environmental sustainability programs, and future economic growth. Today's country administrations and policymakers that wish to assess their energy consumption status face a multi-criteria decision-making (MCDM) challenge due to the diversity of energy resources available and they must consider various criteria throughout the selection process. In this study, the OECD countries' energy consumption situation was examined via interval-valued circular intuitionistic fuzzy (IVCIF)-AHP-based CRADIS methodology. This review's primary goals are to provide a thorough analysis of the energy consumption conditions in OECD member countries and to assist the management of those nations in making decisions about their preferred energy usage.

The rest of the paper is arranged as follows. Section 2 reviews the related studies on energy consumption. Section 3 describes the methodology. Section 4 presents the case study and application. In section 5 we give validation studies on the results. Finally, section 6 concludes.

2. Literature Review

As civilization expands in terms of population and economics, our energy demand is increasing. Our previous ages and history books have also been rewritten by the epoch. New energy sources have been developed, fossil fuels have diversified, and new nuclear and hydroelectric technologies have been developed, enabling us to now create various amounts of energy; even other renewable energy alternatives. For these reasons, any approach or problem related to energy consumption is considered

very important worldwide. As a result, the number of studies conducted in this field in recent years is not small. A few of the studies conducted on this subject are mentioned in the following paragraphs.

Lee (2005) used data from 1975 to 2001 to examine the co-movement and causal link between GDP and energy consumption in 18 emerging nations. The study's findings led to the conclusion that energy conservation, whether it be long-term or short-term, can hinder emerging nations' ability to expand economically.

In order to assess how changes in energy consumption affect income and vice versa in the G-7 countries, Soytaş and Sarı (2006) employed multivariate cointegration, error correction models, and generalized variance decompositions. Based on the study's findings, it was determined that there is a long-term causal relationship between income and energy use in all seven G-7 nations.

The study by Martins et al. (2018) looked at the energy consumption of fossil fuels in European nations and how it related to other factors including energy reliance and the percentage of renewable energy in gross final energy consumption. Consequently, it was determined that a large number of European nations continue to rely significantly on fossil fuels.

Amri (2016) looked at the relationship between output, foreign direct investment inflows, and energy consumption in 75 industrialized and developing nations between 1990 and 2010. The investigations led to the conclusion that there was a one-way connection between foreign inputs and both forms of energy.

In his research, Wolde-Rufael (2009) looked at the relationship that exists between energy use and economic growth in seventeen African nations. Fifteen out of seventeen countries showed no neutrality for the energy-income link, based on the Granger causality results that were obtained. Eleven out of seventeen countries' output increase was determined to be attributed to factors other than energy, as per the findings of the variance decomposition analysis. Furthermore, the analysis's findings led to the conclusion that labor and capital were more significant than energy.

Yao et al.'s (2019) investigation looked at how human capital affects energy usage. This study indicated that a one standard deviation gain in human capital was linked to a 17.33% decrease in the consumption of dirty energy and an 85.54% rise in the use of clean energy, accounting for cross-sectional dependency and structural discontinuities.

In 2018, Gözgör et al. looked at the connection between OECD countries' economic development and energy use. This study's findings, which were based on panel data from 29 OECD member nations, showed that a faster rate of economic growth is positively correlated with both economic complexity and the consumption of both renewable and non-renewable energy sources.

Özcan et al. (2020) looked into how changes in energy consumption and economic growth affected the environmental performance levels of 35 OECD nations between 2000 and 2014. The results led to the conclusion that the countries' paths of economic development and patterns of energy use started to align with environmental policies.

3. Methodology

The methodology section consists of Circular ntuitionistic Fuzzy Sets (CIFS), Interval-Valued Circular Intuitionistic Fuzzy Sets (IVCIFS), IVCIF-AHP, and CRADIS, respectively. A flowchart related to the steps of the study is presented in Figure 1.

3.1. Preliminaries related to Circular Intuitionistic Fuzzy Sets

Atanassov (2020) proposed CIFS by including an uncertainty region of radius ″r‟ to single-valued intuitionistic fuzzy sets. CIFS considers the instability of membership and non-membership degrees

assigned by experts with a circular area and easily explains the magnitude of experts' hesitation and uncertainty (Otay et al., 2023).

A single-valued circular intuitionistic fuzzy (SVCIF) set $\tilde{G}$ that can be identified with a circle showing the ambiguity, vagueness and impreciseness in terms of membership $\left(\mu_{\tilde{G}}(x)\right)$ and non-membership $\left(v_{\tilde{G}}(x)\right)$ degrees, is stated as below (Atanassov, 2020; Otay et al., 2023):

A SVCIF set $\tilde{G}_r$ in D can be described as an object that has the form for a fixed universe D:

$$\tilde{G}_r = \{\langle x, \mu_{\tilde{G}}(x), v_{\tilde{G}}(x); r \rangle | x \in D\} \quad (1)$$

where $0 \leq \mu_{\tilde{G}}(x) + v_{\tilde{G}}(x) \leq 1, r \in [0,1], \mu_{\tilde{G}} : D \rightarrow [0,1]$ and $v_{\tilde{G}} : D \rightarrow [0,1]$.

According to Eq.(1), a radius of the circle around each component $x, x \in D$ to the set $G \subseteq D$, is identified by ″r ‟.

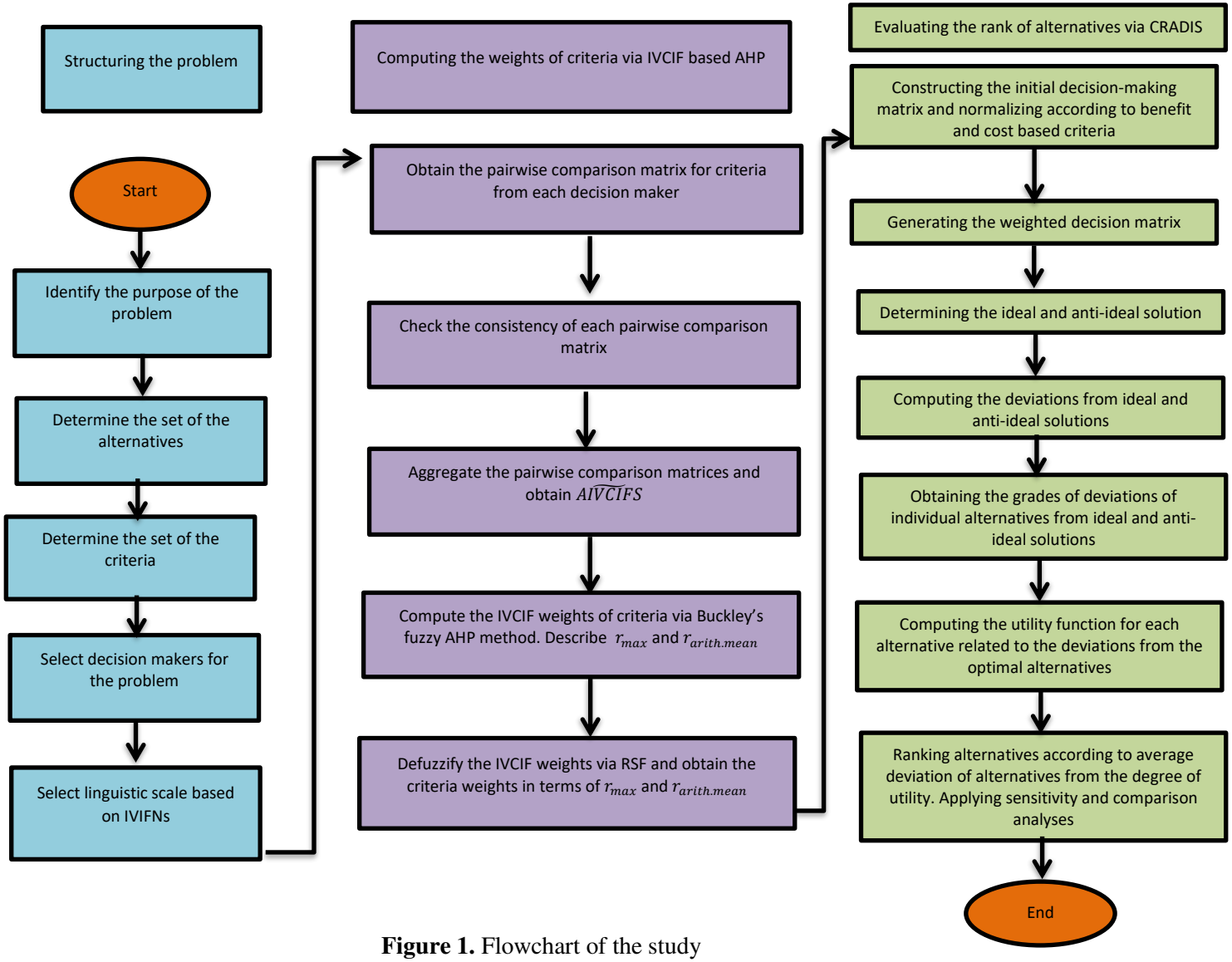


Figure 1. Flowchart of the study

Additionally, the degree of indeterminacy is calculated as below:

$$\pi_{\tilde{G}}(x) = 1 - \mu_{\tilde{G}}(x) - v_{\tilde{G}}(x) \tag{2}$$

Assume $\tilde{\beta}_i = \left(\mu_{\tilde{\beta}_i}, v_{\tilde{\beta}_i}\right)(i = 1,2,\cdots,n)$ as a set of intuitionistic fuzzy (IF) pairs. Besides, these IF pairs are aggregated via Intuitionistic Fuzzy Weighted Geometric (IFWG) operator as in Eq.(3), and the values of $\mu_{tpl} = \prod_{j=1}^{m} {\mu_{\tilde{\beta}_j}}^{w_j}$ and $v_{tpl} = \prod_{j=1}^{m} {v_{\tilde{\beta}_j}}^{w_j}$ related to the aggregated fuzzy numbers are obtained. Then, Euclidean distances between the views of each decision maker and the aggregated intuitionistic fuzzy sets are computed via Eq.(4), and the radius value related to each criterion can be found by handling maximum of these distances.

$$IFWG\left(\tilde{\beta}_1, \tilde{\beta}_2, \cdots, \tilde{\beta}_n\right) = \left(\prod_{j=1}^{m} {\mu_{\tilde{\beta}_j}}^{w_j}, \prod_{j=1}^{m} {v_{\tilde{\beta}_j}}^{w_j}\right) \tag{3}$$

where $w = (w_1, \cdots, w_n)^T$ can be considered as the weight vector for $\tilde{\beta}_i (i = 1,2,\cdots,n)$ with $w_j \in [0,1]$ and $\sum_{j=1}^{n} w_j = 1$.

$$r_i = \max_{1 \le j \le p_i} \sqrt{\left(\prod_{j=1}^{m} {\mu_{\tilde{\beta}_j}}^{w_j} - \mu_{\tilde{\beta}_i}\right)^2 + \left(\prod_{j=1}^{m} {v_{\tilde{\beta}_j}}^{w_j} - v_{\tilde{\beta}_i}\right)^2} \tag{4}$$

where experts are shown by p_i.

Assume $\widetilde{SVCIF}_1 = \langle \mu_1(x), v_1(x); r_1 \rangle$ and $\widetilde{SVCIF}_2 = \langle \mu_2(x), v_2(x); r_2 \rangle$ as two single-valued circular intuitionistic fuzzy numbers (SVCIFNs). Some arithmetic operations consisting of intersection, union, addition and multiplication related to these SVCIFNs are given in Eqs. (5)-(14) (Atanassov, 2020; Otay et al., 2023; Kahraman & Otay, 2022).

Intersection:

$$\widetilde{SVCIF}_1 \cap_{min} \widetilde{SVCIF}_2 = \left\{\langle x, min\left(\mu_1(x), \mu_2(x)\right), max\left(v_1(x), v_2(x)\right); min(r_1, r_2)\rangle | x \in X\right\} \tag{5}$$

$$\widetilde{SVCIF}_1 \cap_{max} \widetilde{SVCIF}_2 = \left\{\langle x, min\left(\mu_1(x), \mu_2(x)\right), max\left(v_1(x), v_2(x)\right); max(r_1, r_2)\rangle | x \in X\right\} \tag{6}$$

Union:

$$\widetilde{SVCIF}_1 \cup_{min} \widetilde{SVCIF}_2 = \left\{\langle x, max\left(\mu_1(x), \mu_2(x)\right), min\left(v_1(x), v_2(x)\right); min(r_1, r_2)\rangle | x \in X\right\} \tag{7}$$

$$\widetilde{SVCIF}_1 \cup_{max} \widetilde{SVCIF}_2 = \left\{\langle x, max\left(\mu_1(x), \mu_2(x)\right), min\left(v_1(x), v_2(x)\right); max(r_1, r_2)\rangle | x \in X\right\} \tag{8}$$

Addition:

$$\widetilde{SVCIF}_1 \oplus_{min} \widetilde{SVCIF}_2 = \{\langle x, \mu_1(x) + \mu_2(x) - \mu_1(x) * \mu_2(x), v_1(x) * v_2(x); min(r_1, r_2)\rangle | x \in X\} \tag{9}$$

$$\widetilde{SVCIF}_1 \oplus_{max} \widetilde{SVCIF}_2 = \{\langle x, \mu_1(x) + \mu_2(x) - \mu_1(x) * \mu_2(x), v_1(x) * v_2(x); max(r_1, r_2)\rangle | x \in X\} \tag{10}$$

Multiplication:

$$\widetilde{SVCIF}_1 \otimes_{min} \widetilde{SVCIF}_2 = \{\langle x, \mu_1(x) * \mu_2(x), v_1(x) + v_2(x) - v_1(x) * v_2(x); min(r_1, r_2)\rangle | x \in X\} \tag{11}$$

$$\widetilde{SVCIF}_1 \otimes_{max} \widetilde{SVCIF}_2 = \{\langle x, \mu_1(x) * \mu_2(x), v_1(x) + v_2(x) - v_1(x) * v_2(x); max(r_1, r_2)\rangle | x \in X\} \tag{12}$$

Multiplication by a scaler:

$$\lambda.\widetilde{SVCIF}_1 = \left\{\langle x, 1-\left(1-\mu_1(x)\right)^{\lambda}, \left(v_1(x)\right)^{\lambda}; r_1\rangle \,|x \in X\right\} \tag{13}$$

Power operation:

$$\widetilde{SVCIF}_1{}^{\lambda} = \left\{\langle x, \left(\mu_1(x)\right)^{\lambda}, 1-\left(1-v_1(x)\right)^{\lambda}; r_1\rangle \,|x \in X\right\} \tag{14}$$

3.2. Interval valued circular intuitionistic fuzzy sets

Preliminaries related to IVCIFS are given as follows (Otay et al., 2023):

An $\widetilde{IVCIFS}$ can be described as below:

$$\widetilde{IVCIFS} = ([\mu_1, \mu_2], [v_1, v_2]; r) \tag{15}$$

where membership interval is represented by $\mu_1 \, and \, \mu_2$, non-membership interval is shown by $v_1 \, and \, v_2$ $(\mu_1, \mu_2, v_1, v_2 \in [0,1])$, and the uncertainty related to membership and non-membership intervals is identified by radius r. Larger uncertainty requires larger radius.

The boundaries (bound) related to $\widetilde{IVCIFS}$ are presented as in Eq.(16).

$$bound\left(\widetilde{IVCIFS}\right) = \begin{cases} y = v_1 - r; x \in [\mu_1, \mu_2] \\ y = v_2 + r; x \in [\mu_1, \mu_2] \\ x = \mu_1 - r; y \in [v_1, v_2] \\ x = \mu_2 + r; y \in [v_1, v_2] \\ (x-\mu_1)^2 + (y-v_1)^2 = r^2; x \in [(\mu_1 - r), \mu_1], y \in [(v_1 - r), v_1] \\ (x-\mu_1)^2 + (y-v_2)^2 = r^2; x \in [(\mu_1 - r), \mu_1], y \in [v_2, (v_2 + r)] \\ (x-\mu_2)^2 + (y-v_1)^2 = r^2; x \in [\mu_2, (\mu_2 + r)], y \in [(v_1 - r), v_1] \\ (x-\mu_2)^2 + (y-v_2)^2 = r^2; x \in [\mu_2, (\mu_2 + r)], y \in [v_2, (v_2 + r)] \end{cases} \tag{16}$$

All the points in the area of $\widetilde{IVCIFS}$ are stated as below:

$$area\left(\widetilde{IVCIFS}\right) = (\mu_2 - \mu_1)(v_2 - v_1) + 2r(\mu_2 - \mu_1 + v_2 - v_1) + \pi r^2 \tag{17}$$

Interior (IRP) and exterior reference points (ERP) denoting an $\widetilde{IVCIFS}$ are given in Eq.(18) and Eq.(19), respectively.

$$IRP_1 = (\mu_1, v_1), IRP_2 = (\mu_1, v_2), IRP_3 = (\mu_2, v_1), IRP_4 = (\mu_2, v_2) \tag{18}$$

$$\begin{aligned} ERP_1 &= \left(\mu_1 - \tfrac{r}{\sqrt{2}}, v_1 - \tfrac{r}{\sqrt{2}}\right), ERP_2 = \left(\mu_1 - \tfrac{r}{\sqrt{2}}, v_2 + \tfrac{r}{\sqrt{2}}\right), \\ ERP_3 &= \left(\mu_2 + \tfrac{r}{\sqrt{2}}, v_1 - \tfrac{r}{\sqrt{2}}\right), ERP_4 = \left(\mu_2 + \tfrac{r}{\sqrt{2}}, v_2 + \tfrac{r}{\sqrt{2}}\right) \end{aligned} \tag{19}$$

Assume $A\widetilde{IVCIFS}$ as an aggregation of n $\widetilde{IVCIFSs}$ shown as $\widetilde{IVCIFS}_1, \widetilde{IVCIFS}_2, \cdots, \widetilde{IVCIFS}_n$. $A\widetilde{IVCIFS}$ can be described as in Eq.(20).

$$A\widetilde{IVCIFS} = ([\mu_{1A}, \mu_{2A}], [v_{1A}, v_{2A}]; r_A)$$

where

$$\begin{aligned} \mu_{1A} &= \textstyle\sum_{p=1}^{P} \mu_{1p} w_p \,, \mu_{2A} = \sum_{p=1}^{P} \mu_{2p} w_p \\ v_{1A} &= \textstyle\sum_{p=1}^{P} v_{1p} w_p \,, v_{2A} = \sum_{p=1}^{P} v_{2p} w_p \end{aligned} \tag{20}$$

According to Eq.(20) the weight of an expert is shown by w_p and number of experts is indicated via P, $p = 1,2, \ldots, P$.

ERP related to $A\widetilde{IVCIFS}$ are stated as below:

$$ERP_{1A} = \left(\mu_{1A} - \frac{r_p}{\sqrt{2}}, v_{1A} - \frac{r_p}{\sqrt{2}}\right), ERP_{2A} = \left(\mu_{1A} - \frac{r_p}{\sqrt{2}}, v_{2A} + \frac{r_p}{\sqrt{2}}\right),$$
$$ERP_{3A} = \left(\mu_{2A} + \frac{r_p}{\sqrt{2}}, v_{1A} - \frac{r_p}{\sqrt{2}}\right), ERP_{4A} = \left(\mu_{2A} + \frac{r_p}{\sqrt{2}}, v_{2A} + \frac{r_p}{\sqrt{2}}\right) \quad (21)$$

The radius values (r) are calculated via Eq.(22).

$$r = max\left(uz_{\forall p=1,\ldots,P}\left(IRP_1, ERP_{1Ap}\right), \left(IRP_2, ERP_{2Ap}\right), \left(IRP_3, ERP_{3Ap}\right), \left(IRP_4, ERP_{4Ap}\right)\right)$$

Where

$$uz\left(IRP_1, ERP_{1Ap}\right)_{p=1,\ldots,P} = \sqrt{\left(\mu_{1p} - \frac{r_p}{\sqrt{2}} - \mu_{1A}\right)^2 + \left(v_{1p} - \frac{r_p}{\sqrt{2}} - v_{1A}\right)^2}$$
$$uz\left(IRP_2, ERP_{2Ap}\right)_{p=1,\ldots,P} = \sqrt{\left(\mu_{1p} - \frac{r_p}{\sqrt{2}} - \mu_{1A}\right)^2 + \left(v_{2p} + \frac{r_p}{\sqrt{2}} - v_{2A}\right)^2}$$
$$uz\left(IRP_3, ERP_{3Ap}\right)_{p=1,\ldots,P} = \sqrt{\left(\mu_{2p} + \frac{r_p}{\sqrt{2}} - \mu_{2A}\right)^2 + \left(v_{1p} - \frac{r_p}{\sqrt{2}} - v_{1A}\right)^2} \quad (22)$$
$$uz\left(IRP_4, ERP_{4Ap}\right)_{p=1,\ldots,P} = \sqrt{\left(\mu_{2p} + \frac{r_p}{\sqrt{2}} - \mu_{2A}\right)^2 + \left(v_{2p} + \frac{r_p}{\sqrt{2}} - v_{2A}\right)^2}$$

Assume $\widetilde{IVCIFS_1} = ([\mu_{11}(x), \mu_{21}(x)], [v_{11}(x), v_{21}(x)]; r_1)$ and $\widetilde{IVCIFS_2} = ([\mu_{12}(x), \mu_{22}(x)], [v_{12}(x), v_{22}(x)]; r_2)$ as two IVCIF numbers. Some arithmetic operations consisting of intersection, union, addition and multiplication related to these numbers are given in Eqs. (23)-(34) (Otay et al., 2023).

Intersection:

$$\widetilde{IVCIFS_1} \cap_{min} \widetilde{IVCIFS_2} = \left\{\left\langle x, \begin{matrix}\left[min\left(\mu_{11}(x), \mu_{12}(x)\right), min\left(\mu_{21}(x), \mu_{22}(x)\right)\right], \\ \left[max\left(v_{11}(x), v_{12}(x)\right), max\left(v_{21}(x), v_{22}(x)\right)\right]; min(r_1, r_2)\end{matrix}\right\rangle | x \in X\right\} \quad (23)$$

$$\widetilde{IVCIFS_1} \cap_{max} \widetilde{IVCIFS_2} = \left\{\left\langle x, \begin{matrix}\left[min\left(\mu_{11}(x), \mu_{12}(x)\right), min\left(\mu_{21}(x), \mu_{22}(x)\right)\right], \\ \left[max\left(v_{11}(x), v_{12}(x)\right), max\left(v_{21}(x), v_{22}(x)\right)\right]; max(r_1, r_2)\end{matrix}\right\rangle | x \in X\right\} \quad (24)$$

Union:

$$\widetilde{IVCIFS_1} \cup_{min} \widetilde{IVCIFS_2} = \left\{\left\langle x, \begin{matrix}\left[max\left(\mu_{11}(x), \mu_{12}(x)\right), max\left(\mu_{21}(x), \mu_{22}(x)\right)\right], \\ \left[min\left(v_{11}(x), v_{12}(x)\right), min\left(v_{21}(x), v_{22}(x)\right)\right]; min(r_1, r_2)\end{matrix}\right\rangle | x \in X\right\} \quad (25)$$

$$\widetilde{IVCIFS_1} \cup_{max} \widetilde{IVCIFS_2} = \left\{\left\langle x, \begin{matrix}\left[max\left(\mu_{11}(x), \mu_{12}(x)\right), max\left(\mu_{21}(x), \mu_{22}(x)\right)\right], \\ \left[min\left(v_{11}(x), v_{12}(x)\right), min\left(v_{21}(x), v_{22}(x)\right)\right]; max(r_1, r_2)\end{matrix}\right\rangle | x \in X\right\} \quad (26)$$

Addition:

$$\widetilde{IVCIFS_1} \oplus_{min} \widetilde{IVCIFS_2} = \left\{\left\langle x, \begin{matrix}\left[\mu_{11}(x) + \mu_{12}(x) - \mu_{11}(x) * \mu_{12}(x), \mu_{21}(x) + \mu_{22}(x) - \mu_{21}(x) * \mu_{22}(x)\right], \\ \left[v_{11}(x) * v_{12}(x), v_{21}(x) * v_{22}(x)\right]; min(r_1, r_2)\end{matrix}\right\rangle | x \in X\right\} \quad (27)$$

$$\widetilde{IVCIFS}_1 \oplus_{max} \widetilde{IVCIFS}_2 = \left\{ \left\langle x, \begin{matrix} [\mu_{11}(x) + \mu_{12}(x) - \mu_{11}(x) * \mu_{12}(x), \mu_{21}(x) + \mu_{22}(x) - \mu_{21}(x) * \mu_{22}(x)\,], \\ [v_{11}(x) * v_{12}(x), v_{21}(x) * v_{22}(x)]; max(r_1, r_2) \end{matrix} \right\rangle | x \in X \right\} \quad (28)$$

$$\widetilde{IVCIFS}_1 \oplus_{arith.mean} \widetilde{IVCIFS}_2 = \left\{ \left\langle x, \begin{matrix} [\mu_{11}(x) + \mu_{12}(x) - \mu_{11}(x) * \mu_{12}(x), \mu_{21}(x) + \mu_{22}(x) - \mu_{21}(x) * \mu_{22}(x)\,], \\ [v_{11}(x) * v_{12}(x), v_{21}(x) * v_{22}(x)]; (r_1 + r_2)/2 \end{matrix} \right\rangle | x \in X \right\} \quad (29)$$

Multiplication:

$$\widetilde{IVCIFS}_1 \otimes_{min} \widetilde{IVCIFS}_2 = \left\{ \left\langle \begin{matrix} x, [\,\mu_{11}(x) * \mu_{12}(x), \mu_{21}(x) * \mu_{22}(x)], \\ [v_{11}(x) + v_{12}(x) - v_{11}(x) * v_{12}(x), v_{21}(x) + v_{22}(x) - v_{21}(x) * v_{22}(x)]; min(r_1, r_2) \end{matrix} \right\rangle | x \in X \right\} \quad (30)$$

$$\widetilde{IVCIFS}_1 \otimes_{max} \widetilde{IVCIFS}_2 = \left\{ \left\langle \begin{matrix} x, [\,\mu_{11}(x) * \mu_{12}(x), \mu_{21}(x) * \mu_{22}(x)], \\ [v_{11}(x) + v_{12}(x) - v_{11}(x) * v_{12}(x), v_{21}(x) + v_{22}(x) - v_{21}(x) * v_{22}(x)]; max(r_1, r_2) \end{matrix} \right\rangle | x \in X \right\} \quad (31)$$

$$\widetilde{IVCIFS}_1 \otimes_{arith.mean} \widetilde{IVCIFS}_2 = \left\{ \left\langle \begin{matrix} x, [\,\mu_{11}(x) * \mu_{12}(x), \mu_{21}(x) * \mu_{22}(x)], \\ [v_{11}(x) + v_{12}(x) - v_{11}(x) * v_{12}(x), v_{21}(x) + v_{22}(x) - v_{21}(x) * v_{22}(x)]; (r_1 + r_2)/2 \end{matrix} \right\rangle | x \in X \right\} \quad (32)$$

Multiplication by a scaler:

$$\lambda . \widetilde{IVCIFS}_1 = \left\{ \left\langle x, \left[1 - \left(1 - \mu_{11}(x)\right)^{\lambda}, 1 - \left(1 - \mu_{21}(x)\right)^{\lambda}\right], \left[\left(v_{11}(x)\right)^{\lambda}, \left(v_{21}(x)\right)^{\lambda}\right]; r_1 \right\rangle | x \in X \right\} \quad (33)$$

Power operation:

$$\widetilde{IVCIFS}_1{}^{\lambda} = \left\{ \left\langle x, \left[\left(\mu_{11}(x)\right)^{\lambda}, \left(\mu_{21}(x)\right)^{\lambda}\right], \left[1 - \left(1 - v_{11}(x)\right)^{\lambda}, 1 - \left(1 - v_{21}(x)\right)^{\lambda}\right]; r_1 \right\rangle | x \in X \right\} \quad (34)$$

3.3. Interval-valued circular intuitionistic fuzzy AHP

The steps of IVCIF-AHP can be summarized as follows (Otay et al., 2023):

Step 1. A hierarchical structure related to the problem is formed by taking experts' judgments and extensive literature review into account. Finite set of criteria $\left(C_j, j = 1,2, \dots, n\right)$ and alternatives $(A_i, i = 1,2, \dots, m)$ comprise this structure.

Step 2. Pairwise comparison matrices in terms of criteria that can be seen as Eq.(35), are obtained according to the experts' views via the linguistic scale given in Table 1.

$$\tilde{X} = \begin{bmatrix} 1 & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & 1 & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & 1 \end{bmatrix} \quad (35)$$

Table 1. Linguistic scale and related IVIFNs

Linguistic terms	IVIFNs
Absolutely Low (AL)	([0,0], [0.8,1])
Very Low (VL)	([0,0.1], [0.7,0.9])
Low (L)	([0,0.2], [0.6,0.8])
Medium Low (ML)	([0.1,0.3], [0.5,0.7])
Exactly Equal (EE)	([0.5,0.5], [0.5,0.5])
Medium High (MH)	([0.5,0.7], [0.1,0.3])
High (H)	([0.6,0.8], [0,0.2])
Very High (VH)	([0.7,0.9], [0,0.1])
Absolutely High (AH)	([0.8,1], [0,0])

Source: (Otay et al., 2023)

Step 3. Consistency ratios (CR) related to each pairwise comparison matrix are calculated for satisfying CR≤ 0.10. A new score index (SCI) is proposed by utilizing Eq. (36). Then Saaty's (1980) Classical Consistency Ratio is calculated via obtained SI values related to linguistic evaluations.

$$SI = 0.9905 + 3.174\left(\left(\frac{\mu_1+\mu_2}{2}\right)-\left(\frac{v_1+v_2}{2}\right)\right) + 4.458\left(\left(\frac{\mu_1+\mu_2}{2}\right)-\left(\frac{v_1+v_2}{2}\right)\right)^2 + 2.251\left(\left(\frac{\mu_1+\mu_2}{2}\right)-\left(\frac{v_1+v_2}{2}\right)\right)^3 \quad (36)$$

Step 4. If the satisfied CR are obtained, IVIF pairwise comparison matrices are aggregated and $\widetilde{AIVCIFS}$ is obtained via Eqs. (20-22). Besides, r values are computed in terms of Eq.(22) by taking the maximum distance between $\widetilde{AIVCIFS}$ (Eq.(20)) and ERP (Eq.(21)) into the account.

Step 5. Criteria weights are computed in terms of IVCIF numbers via Buckley's (1985) fuzzy AHP method (Eqs. (37-38)). Firstly related multiplication formula in Eqs. (30-32) is employed and following to that power operator in Eq. (34) is applied. Radius values are described according to maximum value (r_{max}) and arithmetic mean $(r_{arith.mean})$.

$$\tilde{k}_j = \left[\left(\widetilde{AIVCIFS}_1 \otimes \cdots \otimes \widetilde{AIVCIFS}_n\right)^{\frac{1}{n}}\right], j = 1,2,\dots,n \quad (37)$$

$$\widetilde{w}_{Cj} = \tilde{k}_j \otimes \left[\tilde{k}_1 \oplus \cdots \oplus \tilde{k}_n\right]^{-1}, j = 1,2,\dots,n \quad (38)$$

Step 6. Similar procedure is applied for obtaining the weights of sub-criteria in terms of IVCIF numbers $\left(\widetilde{w}_{subCj}, j = 1,2,\dots,n\right)$ if any.

Step 7. Weights in terms of IVCIF numbers are defuzzified via Relative Score Function (RSF) described as in Eq. (39).

$$RSF_i = \frac{\mu_1+\mu_2+(1-v_1)+(1-v_2)+\mu_1\mu_2-\sqrt{(1-v_1)(1-v_2)}}{4} x \left(\frac{1/r_i}{\sqrt{\sum_{i=1}^{m}\left(1/r_i^2\right)}}\right)^{\tau} \quad (39)$$

where τ showing the parameter related to the distinction among IVCIFS can be considered as a small number such as 0.1 or 0.01. Additionally the coefficient $\left(\frac{1/r_i}{\sqrt{\sum_{i=1}^{m}(1/r_i^2)}}\right)^{\tau}$ $(i = 1,2,\cdots,m)$ states the relative magnitude degree related to an $\widetilde{IVCIFS}$ in terms of the other $\widetilde{IVCIFSs}$.

Step 8. Final weights are obtained in terms of corresponding RSF_i values based on the r_{max} and $r_{arith.mean}$.

3.4. Compromise Ranking of Alternatives from Distance to Ideal Solution (CRADIS)

The CRADIS method which was proposed by Puška et al. (2022) was based on the utility function and designed to determine the deviation of certain alternatives from ideal and anti-ideal solutions. This method having the combination of steps from the ARAS (Additive Ratio ASsessment), MARCOS (Measurement of Alternatives and Ranking according to COmpromise Solution), and TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) methods relies on simple mathematical operations and has no restrictions related to alternatives and criteria. The CRADIS method is considered a new approach to utilizing steps from existing methods in a unique combination. According to this method, alternatives are examined across all criteria by considering both ideal solutions representing the maximum value for an ideal solution and the minimum value for an ideal solution (Puška et al., 2022; Altıntaş, 2023).

The steps of the CRADIS method can be summarized below (Puška et al., 2022):

Step 1. An initial decision matrix X_{mxn} is created by taking a set of "n" criteria and "m" alternatives into the account and can be seen as Eq. (40).

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad , \quad \begin{matrix} i = 1, \dots, m \\ j = 1, \dots, n \end{matrix} \tag{40}$$

Step 2. The decision matrix is normalized according to the following equations.

For benefit-based criteria:

$$n_{ij} = \frac{x_{ij}}{x_{jmax}} \tag{41}$$

For cost-based criteria:

$$n_{ij} = \frac{x_{jmin}}{x_{ij}} \tag{42}$$

Step 3. The weighted decision matrix is generated by multiplying the normalized decision matrix by the corresponding weights based on Eq. (43).

$$v_{ij} = n_{ij}.w_j \tag{43}$$

Step 4. The ideal and anti-ideal solution is determined. The calculation related to the ideal solution (t_i) is made by determining the largest value of v_{ij} in the weighted decision matrix. On the other hand, the calculation related to anti-ideal solution (t_{ai}) is identified by finding the smallest value of v_{ij} in the weighted decision matrix.

$$t_i = max v_{ij} \tag{44}$$

$$t_{ai} = min v_{ij} \tag{45}$$

Step 5. Deviations from ideal (d^+) and anti-ideal (d^-) solutions are computed according to Eqs. (46) and (47) respectively.

$$d^+ = t_i - v_{ij} \tag{46}$$

$$d^- = v_{ij} - t_{ai} \tag{47}$$

Step 6. The grades of deviation of individual alternatives from ideal (s_i^+) and anti-ideal (s_i^-) solutions are obtained via Eqs.(48) and (49) respectively.

$$s_i^+ = \sum_{j=1}^{n} d^+ \tag{48}$$

$$s_i^- = \sum_{j=1}^{n} d^- \tag{49}$$

Step 7. The utility function for each alternative related to the deviations from the optimal alternatives is computed according to the following equations.

For the ideal solution

$$K_i^+ = \frac{s_0^+}{s_i^+} \tag{50}$$

For the anti-ideal solution

$$K_i^- = \frac{s_i^-}{s_0^-} \tag{51}$$

where s_0^+ shows the optimal alternative having the smallest distance from the ideal solution and s_0^- represents the optimal alternative having the greatest distance from the anti-ideal solution.

Step 8. Alternatives are ranked according to the average deviation of the alternatives from the degree of utility (Q_i) as seen in Eq. (52).

$$Q_i = \frac{K_i^+ + K_i^-}{2} \tag{52}$$

The alternative with the highest Q_i value is considered as the best one.

4. Data and Application

Criteria, definitions, and related references are presented in Table 2.

Table 2. Criteria of the study

Criteria (code)	Definitions	Reference
Primary energy consumption **(C1)**	It is, before conversion to secondary forms-such as electricity or refined fuels-the total amount of energy directly obtained or extracted by humans from all natural resources, including nuclear, renewable energy resources such as solar, wind, and hydro, and fossil fuels like coal, oil, and natural gas.	Şahin (2022)
Oil consumption **(C2)**	This can be defined as the total amount of crude and various petroleum products that are consumed within an area in a given period of time, whether for the industries, transportations, or power-generating sectors.	Usman et al. (2024)

Table 2 (Cont.). Criteria of the study

Criteria (code)	Definitions	Reference
Gas consumption **(C3)**	The term "gas consumption" means the total volume of natural gas consumed in an area for any given time or period by production, heating, electricity generation, industry, and others.	Adebayo et al. (2023)
Coal consumption **(C4)**	Consumption of coal means the amount of coal burned to generate energy, various industrial uses, and other forms within a certain region or period.	Jiang and Sun (2023)
Hydroelectricity consumption **(C5)**	Hydroelectricity consumption refers to the total amount of electric energy generated in hydro plants using energy obtained by falling water and by moving downstream of the plant for electric power.	Adebayo et al. (2021)
Wind consumption **(C6)**	Wind consumption is the summation of all the electricity generated from the harnessed energy of the wind, using wind turbines to produce the power.	Pata and Kartal (2024)

Alternatives as OECD countries are shown in Table 3.

Table 3. Alternatives of the study

Code	Alternatives	Code	Alternatives
A1	Austria	A18	Latvia
A2	Australia	A19	Lithuania
A3	Belgium	A20	Luxembourg
A4	Canada	A21	Mexico
A5	Chile	A22	Netherlands
A6	Colombia	A23	New Zealand
A7	Czech Republic	A24	Norway
A8	Denmark	A25	Poland
A9	Estonia	A26	Portugal
A10	Finland	A27	Slovakia
A11	France	A28	Slovenia
A12	Germany	A29	Spain
A13	Greece	A30	Sweden
A14	Hungary	A31	Switzerland
A15	Ireland	A32	Turkey
A16	Italy	A33	United Kingdom
A17	Japan		

Iceland and Israel as two OECD countries are excluded from the analysis due to missing data related to the criteria. Additionally due to the availability only data related to 2021 are taken into the account. After determining criteria and alternatives via depth literature review and experts' views, a questionnaire is designed for obtaining criteria weights via IVCIF AHP based on the r_{max} and $r_{arith.mean}$. Three decision makers are selected from academicians and energy professionals. Pairwise comparison of criteria for all DMs with their CR values are given in Tables 4-6.

Table 4. Pairwise comparison of criteria for DM1

DM1	C1	C2	C3	C4	C5	C6
C1	EE	VH	H	H	EE	MH
C2	VL	EE	EE	ML	AL	EE
C3	L	EE	EE	ML	AL	EE
C4	L	MH	MH	EE	EE	EE
C5	EE	AH	AH	EE	EE	EE
C6	ML	EE	EE	EE	EE	EE

CR=0.095

Table 5. Pairwise comparison of criteria for DM2

DM2	C1	C2	C3	C4	C5	C6
C1	EE	EE	EE	ML	EE	EE
C2	EE	EE	EE	ML	EE	ML
C3	EE	EE	EE	EE	MH	EE
C4	MH	MH	EE	EE	EE	EE
C5	EE	EE	ML	EE	EE	EE
C6	EE	MH	EE	EE	EE	EE

CR=0.058

Table 6. Pairwise comparison of criteria for DM3

DM3	C1	C2	C3	C4	C5	C6
C1	EE	H	AH	AH	EE	EE
C2	L	EE	EE	H	ML	AL
C3	AL	EE	EE	VH	ML	L
C4	AL	L	VL	EE	VL	L
C5	EE	MH	MH	VH	EE	EE
C6	EE	AH	H	H	EE	EE

CR=0.098

All CR values are smaller than the threshold value, so pairwise comparisons related to criteria are found to be consistent. Following to that, IVIF pairwise evaluation matrices are formed for all DMs according to the linguistic terms given in Table 1. The priority weight of each DM is set to 0.333. Then IVIFNs-based judgements of three DMs are aggregated via Eqs. (20-22) and obtained $A\widetilde{IVCIFS}$ is presented in Table 7.

Criteria weights are computed in terms of IVCIF numbers by using Eqs. (37) and (38) for both r_{max} and $r_{arith.mean}$. IVCIF numbers-based weights are defuzzified via RSF as in Eq. (39) by taking $\tau = 0.1$ into account. Obtained IVCIF criteria weights and final weights are given in Table 8.

Table 7. Aggregated pairwise comparison matrix related to criteria $\left(A\widetilde{IVCIFS}\right)$

Criteria	C1	C2	C3	C4	C5	C6
C1	$\left(\begin{matrix}[0.5,0.5],\\ [0.5,0.5];\\ 0\end{matrix}\right)$	$\left(\begin{matrix}[0.60,0.73],\\ [0.16,0.26];\\ 0.40\end{matrix}\right)$	$\left(\begin{matrix}[0.63,0.76],\\ [0.16,0.23];\\ 0.42\end{matrix}\right)$	$\left(\begin{matrix}[0.50,0.70],\\ [0.16,0.30];\\ 0.56\end{matrix}\right)$	$\left(\begin{matrix}[0.5,0.5],\\ [0.5,0.5];\\ 0\end{matrix}\right)$	$\left(\begin{matrix}[0.50,0.56],\\ [0.36,0.43];\\ 0.29\end{matrix}\right)$
C2	$\left(\begin{matrix}[0.16,0.26],\\ [0.60,0.73];\\ 0.40\end{matrix}\right)$	$\left(\begin{matrix}[0.5,0.5],\\ [0.5,0.5];\\ 0\end{matrix}\right)$	$\left(\begin{matrix}[0.5,0.5],\\ [0.5,0.5];\\ 0\end{matrix}\right)$	$\left(\begin{matrix}[0.26,0.46],\\ [0.33,0.53];\\ 0.47\end{matrix}\right)$	$\left(\begin{matrix}[0.20,0.26],\\ [0.60,0.73];\\ 0.38\end{matrix}\right)$	$\left(\begin{matrix}[0.20,0.26],\\ [0.60,0.73];\\ 0.38\end{matrix}\right)$
C3	$\left(\begin{matrix}[0.16,0.23],\\ [0.63,0.76];\\ 0.42\end{matrix}\right)$	$\left(\begin{matrix}[0.5,0.5],\\ [0.5,0.5];\\ 0\end{matrix}\right)$	$\left(\begin{matrix}[0.5,0.5],\\ [0.5,0.5];\\ 0\end{matrix}\right)$	$\left(\begin{matrix}[0.43,0.56],\\ [0.33,0.43];\\ 0.47\end{matrix}\right)$	$\left(\begin{matrix}[0.20,0.33],\\ [0.46,0.66];\\ 0.51\end{matrix}\right)$	$\left(\begin{matrix}[0.33,0.40],\\ [0.53,0.60];\\ 0.38\end{matrix}\right)$

C4	([0.16,0.30], [0.50,0.70]; 0.56)	([0.33,0.53], [0.26,0.46]; 0.47)	([0.33,0.43], [0.43,0.56]; 0.47)	([0.5,0.5], [0.5,0.5]; 0)	([0.33,0.36], [0.56,0.63]; 0.42)	([0.33,0.40], [0.53,0.60]; 0.38)
C5	([0.5,0.5], [0.5,0.5]; 0)	([0.60,0.73], [0.20,0.26]; 0.38)	([0.46,0.66], [0.20,0.33]; 0.51)	([0.56,0.63], [0.33,0.36]; 0.42)	([0.5,0.5], [0.5,0.5]; 0)	([0.5,0.5], [0.5,0.5]; 0)
C6	([0.36,0.43], [0.50,0.56]; 0.29)	([0.60,0.73], [0.20,0.26]; 0.38)	([0.53,0.60], [0.33,0.40]; 0.38)	([0.53,0.60], [0.33,0.40]; 0.38)	([0.5,0.5], [0.5,0.5]; 0)	([0.5,0.5], [0.5,0.5]; 0)

Table 8. IVCIF criteria weights and final weights

Criteria	$\widetilde{IVCIF}$ weights $(\widetilde{w}_{Cj})$	r_{max}	$RSF_{i,m}$	w_{max}	$r_{arith.mean}$	$RSF_{i,a}$	$w_{arith.mean}$	Rank
C1	([0.55,0.62], [0.32,0.37];	0.56)	0.49	0.216	0.21)	0.49	0.214	1
C2	([0.28,0.36], [0.52,0.63];	0.56)	0.26	0.116	0.25)	0.25	0.113	6
C3	([0.33,0.41], [0.49,0.58];	0.56)	0.30	0.133	0.27)	0.29	0.128	5
C4	([0.32,0.42], [0.47,0.57];	0.56)	0.31	0.135	0.26)	0.30	0.131	4
C5	([0.53,0.59], [0.38,0.40];	0.56)	0.46	0.203	0.12)	0.48	0.211	2
C6	([0.51,0.56], [0.40,0.43];	0.56)	0.44	0.193	0.12)	0.46	0.201	3

According to Table 8, primary energy consumption (C1) was found to be the most important criterion with the values of 0.216 and 0.214 for both r_{max} and $r_{arith.mean}$, and oil consumption (C2) was obtained as the least essential one with the values of 0.116 and 0.113 for r_{max} and $r_{arith.mean}$, respectively. The ranking of criteria in terms of r_{max} and $r_{arith.mean}$ is stated as C1>C5>C6>C4>C3>C2. As can be seen from the results of r_{max} and $r_{arith.mean}$, the order of criteria is the same.

After obtaining criteria weights for both r_{max} and $r_{arith.mean}$, OECD countries as alternatives are ranked via CRADIS method. For that purpose firstly initial decision making matrix for r_{max} is formed as Eq. (40) and presented in Table 9.

Table 9. Initial decision making matrix

Countries	C1	C2	C3	C4	C5	C6
A1	1.4827	235.8143	9.0138	0.1123	0.4036	0.0636
A2	5.7200	943.0813	39.4073	1.6306	0.1506	0.2524
A3	2.7261	638.1303	16.9606	0.1034	0.0035	0.1118
A4	13.9361	2228.6590	119.1679	0.4798	3.5875	0.3308
A5	1.6638	364.7633	6.2724	0.2646	0.1557	0.0893
A6	1.9235	349.0902	12.6266	0.1327	0.5638	0.0005
A7	1.6776	200.1532	9.0694	0.5435	0.0226	0.0056
A8	0.6715	128.1271	2.3159	0.0462	0.0001	0.1510
A9	0.2371	28.6787	0.4858	0.1228	0.0002	0.0069
A10	1.1587	177.6104	2.0423	0.1183	0.1479	0.0773
A11	9.4060	1424.1210	43.0413	0.2327	0.5460	0.3482
A12	12.6417	2045.1800	90.5303	2.1156	0.1799	1.1087
A13	1.0531	249.4458	6.9803	0.0739	0.0548	0.0986
A14	1.0158	171.2889	10.7865	0.0605	0.0019	0.0061
A15	0.6271	132.6408	5.0898	0.0523	0.0070	0.0914
A16	6.3552	1155.8720	72.5025	0.2298	0.4055	0.1942
A17	17.7402	3341.3210	103.6224	4.7975	0.7313	0.0777
A18	0.1519	33.8274	1.1588	0.0013	0.0255	0.0013
A19	0.2526	64.3396	2.2281	0.0076	0.0036	0.0128
A20	0.1515	50.8041	0.7727	0.0014	0.0009	0.0031
A21	6.7889	1350.4300	88.2260	0.2315	0.3270	0.1968
A22	3.4745	741.7149	35.0666	0.2345	0.0008	0.1685
A23	0.8414	143.7424	3.8814	0.0721	0.2281	0.0248
A24	2.0452	199.1447	4.2837	0.0329	1.3479	0.1108

A25	4.4420	686.8009	23.2454	1.8823	0.0220	0.1526
A26	0.9565	208.3370	5.8635	0.0107	0.1116	0.1245
A27	0.7098	86.3635	5.3210	0.1225	0.0398	0.0000
A28	0.2699	46.5665	0.9007	0.0347	0.0443	0.0000
A29	5.5916	1169.4080	33.8986	0.1608	0.2785	0.5873
A30	2.2838	269.6448	1.3047	0.0566	0.6731	0.2572
A31	1.0739	180.9752	3.6041	0.0036	0.3424	0.0013
A32	6.8272	939.2193	57.3234	1.7426	0.5246	0.2933
A33	7.1794	1236.2820	76.9475	0.2103	0.0472	0.6072

After constructing the initial decision-making matrix the normalization procedure is executed for benefit (C1, C3, C5, and C6) and cost (C2 and C4) based criteria in terms of Eqs. (41) and (42). Obtained normalized decision matrix for r_{max} is given in Table 10.

Table 10. Normalized decision matrix

Countries	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
A1	0.0835	0.1216	0.0756	0.0119	0.1125	0.0573
A2	0.3224	0.0304	0.3306	0.0008	0.0420	0.2276
A3	0.1536	0.0449	0.1423	0.0129	0.0009	0.1009
A4	0.7855	0.0128	1.0000	0.0027	1.0000	0.2983
A5	0.0937	0.0786	0.0526	0.0050	0.0434	0.0805
A6	0.1084	0.0821	0.1059	0.0100	0.1571	0.0005
A7	0.0945	0.1432	0.0761	0.0024	0.0063	0.0051
A8	0.0378	0.2238	0.0194	0.0289	0.0000	0.1362
A9	0.0133	1.0000	0.0040	0.0109	0.0000	0.0063
A10	0.0653	0.1614	0.0171	0.0113	0.0412	0.0697
A11	0.5302	0.0201	0.3611	0.0057	0.1522	0.3140
A12	0.7126	0.0140	0.7596	0.0006	0.0501	1.0000
A13	0.0593	0.1149	0.0585	0.0181	0.0152	0.0889
A14	0.0572	0.1674	0.0905	0.0221	0.0005	0.0055
A15	0.0353	0.2162	0.0427	0.0255	0.0019	0.0825
A16	0.3582	0.0248	0.6084	0.0058	0.1130	0.1751
A17	1.0000	0.0085	0.8695	0.0002	0.2038	0.0700
A18	0.0085	0.8477	0.0097	1.0000	0.0071	0.0011
A19	0.0142	0.4457	0.0186	0.1755	0.0010	0.0115
A20	0.0085	0.5644	0.0064	0.9450	0.0002	0.0028
A21	0.3826	0.0212	0.7403	0.0057	0.0911	0.1775
A22	0.1958	0.0386	0.2942	0.0057	0.0002	0.1520
A23	0.0474	0.1995	0.0325	0.0185	0.0636	0.0224
A24	0.1152	0.1440	0.0359	0.0406	0.3757	0.0999
A25	0.2503	0.0417	0.1950	0.0007	0.0061	0.1376
A26	0.0539	0.1376	0.0492	0.1248	0.0311	0.1123
A27	0.0400	0.3320	0.0446	0.0109	0.0111	0.0000
A28	0.0152	0.6158	0.0075	0.0385	0.0123	0.0000
A29	0.3151	0.0245	0.2844	0.0083	0.0776	0.5297
A30	0.1287	0.1063	0.0109	0.0236	0.1876	0.2320
A31	0.0605	0.1584	0.0302	0.3670	0.0954	0.0012
A32	0.3848	0.0305	0.4810	0.0007	0.1462	0.2645
A33	0.4046	0.0231	0.6457	0.0063	0.0131	0.5476

In the third and fourth steps of the CRADIS method, the weighted decision matrix is genarated via Eq. (43), and the ideal and anti-ideal solutions are determined by using Eqs.(44) and (45) respectively. These values are presented in Table 11.

Table 11. Weighted decision matrix

Countries	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
A1	0.0181	0.0142	0.0100	0.0016	0.0229	0.0111

A2	0.0698	0.0035	0.0441	0.0001	0.0085	0.0440
A3	0.0333	0.0052	0.0189	0.0017	0.0002	0.0195
A4	0.1702	0.0015	0.1334	0.0003	0.2036	0.0577
A5	0.0203	0.0091	0.0070	0.0006	0.0088	0.0155
A6	0.0235	0.0096	0.0141	0.0013	0.0320	0.0000
A7	0.0204	0.0167	0.0101	0.0003	0.0012	0.0009
A8	0.0082	0.0261	0.0025	0.0039	0.0000	0.0263
A9	0.0028	0.1169	0.0005	0.0014	0.0000	0.0012
A10	0.0141	0.0188	0.0022	0.0015	0.0083	0.0135
A11	0.1149	0.0023	0.0482	0.0007	0.0309	0.0608
A12	0.1544	0.0016	0.1014	0.0000	0.0102	0.1936
A13	0.0128	0.0134	0.0078	0.0024	0.0031	0.0172
A14	0.0124	0.0195	0.0120	0.0029	0.0001	0.0010
A15	0.0076	0.0252	0.0057	0.0034	0.0004	0.0159
A16	0.0776	0.0029	0.0812	0.0007	0.0230	0.0339
A17	0.2167	0.0010	0.1160	0.0000	0.0415	0.0135
A18	0.0018	0.0991	0.0012	0.1355	0.0014	0.0002
A19	0.0030	0.0521	0.0024	0.0237	0.0002	0.0022
A20	0.0018	0.0660	0.0008	0.1280	0.0000	0.0005
A21	0.0829	0.0024	0.0988	0.0007	0.0185	0.0343
A22	0.0424	0.0045	0.0392	0.0007	0.0000	0.0294
A23	0.0102	0.0233	0.0043	0.0025	0.0129	0.0043
A24	0.0249	0.0168	0.0047	0.0055	0.0765	0.0193
A25	0.0542	0.0048	0.0260	0.0000	0.0012	0.0266
A26	0.0116	0.0161	0.0065	0.0169	0.0063	0.0217
A27	0.0086	0.0388	0.0059	0.0014	0.0022	0.0000
A28	0.0032	0.0720	0.0010	0.0052	0.0025	0.0000
A29	0.0683	0.0028	0.0379	0.0011	0.0158	0.1025
A30	0.0279	0.0124	0.0014	0.0032	0.0382	0.0449
A31	0.0131	0.0185	0.0040	0.0497	0.0194	0.0002
A32	0.0834	0.0035	0.0642	0.0001	0.0297	0.0512
A33	0.0877	0.0027	0.0861	0.0008	0.0026	0.1060
max-ti	0.2167	0.1169	0.1334	0.1355	0.2036	0.1936
min-tai	0.0018	0.0010	0.0005	0.0000	0.0000	0.0000

Deviations of alternatives from the ideal solution are computed via Eq. (46) and shown in Table 12.

Table 12. Deviation values for the ideal solution

Countries	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
A1	0.1986	0.2025	0.2066	0.2151	0.1938	0.2056
A2	0.1468	0.2131	0.1726	0.2166	0.2081	0.1726
A3	0.1834	0.2114	0.1977	0.2149	0.2165	0.1972
A4	0.0464	0.2152	0.0832	0.2163	0.0130	0.1589
A5	0.1964	0.2075	0.2097	0.2160	0.2079	0.2011
A6	0.1932	0.2071	0.2026	0.2153	0.1847	0.2166
A7	0.1962	0.1999	0.2065	0.2164	0.2154	0.2157
A8	0.2085	0.1905	0.2141	0.2128	0.2167	0.1903
A9	0.2138	0.0997	0.2162	0.2152	0.2167	0.2155
A10	0.2025	0.1978	0.2144	0.2152	0.2083	0.2032
A11	0.1018	0.2143	0.1685	0.2159	0.1857	0.1559
A12	0.0622	0.2151	0.1153	0.2166	0.2065	0.0231
A13	0.2038	0.2032	0.2089	0.2142	0.2136	0.1995
A14	0.2043	0.1971	0.2046	0.2137	0.2166	0.2156
A15	0.2090	0.1914	0.2110	0.2132	0.2163	0.2007
A16	0.1390	0.2138	0.1355	0.2159	0.1937	0.1828
A17	0.0000	0.2157	0.1006	0.2167	0.1752	0.2031
A18	0.2148	0.1175	0.2154	0.0812	0.2152	0.2165
A19	0.2136	0.1645	0.2142	0.1929	0.2165	0.2145
A20	0.2148	0.1507	0.2158	0.0886	0.2166	0.2161

A21	0.1338	0.2142	0.1179	0.2159	0.1981	0.1823
A22	0.1742	0.2122	0.1774	0.2159	0.2166	0.1873
A23	0.2064	0.1934	0.2123	0.2142	0.2037	0.2124
A24	0.1917	0.1998	0.2119	0.2112	0.1402	0.1973
A25	0.1624	0.2118	0.1907	0.2166	0.2154	0.1900
A26	0.2050	0.2006	0.2101	0.1998	0.2104	0.1949
A27	0.2080	0.1778	0.2107	0.2152	0.2144	0.2167
A28	0.2134	0.1446	0.2157	0.2115	0.2142	0.2167
A29	0.1484	0.2138	0.1787	0.2156	0.2009	0.1141
A30	0.1888	0.2043	0.2152	0.2135	0.1785	0.1718
A31	0.2036	0.1982	0.2127	0.1670	0.1973	0.2165
A32	0.1333	0.2131	0.1525	0.2166	0.1869	0.1655
A33	0.1290	0.2140	0.1305	0.2158	0.2140	0.1107
min	0.0000	0.0997	0.0832	0.0812	0.0130	0.0231

Similarly deviations of alternatives from the anti-ideal solution are computed via Eq.(47) and shown in Table 13.

Table 13. Deviation values for the anti-ideal solution

Countries	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
A1	0.0181	0.0142	0.0100	0.0016	0.0229	0.0111
A2	0.0698	0.0035	0.0441	0.0001	0.0085	0.0440
A3	0.0333	0.0052	0.0189	0.0017	0.0001	0.0195
A4	0.1702	0.0014	0.1334	0.0003	0.2036	0.0577
A5	0.0203	0.0091	0.0070	0.0006	0.0088	0.0155
A6	0.0234	0.0096	0.0141	0.0013	0.0320	0.0000
A7	0.0204	0.0167	0.0101	0.0003	0.0012	0.0009
A8	0.0081	0.0261	0.0025	0.0039	0.0000	0.0263
A9	0.0028	0.1169	0.0005	0.0014	0.0000	0.0012
A10	0.0141	0.0188	0.0022	0.0015	0.0083	0.0135
A11	0.1149	0.0023	0.0482	0.0007	0.0309	0.0608
A12	0.1544	0.0016	0.1013	0.0000	0.0102	0.1936
A13	0.0128	0.0134	0.0078	0.0024	0.0031	0.0172
A14	0.0124	0.0195	0.0120	0.0029	0.0001	0.0010
A15	0.0076	0.0252	0.0056	0.0034	0.0003	0.0159
A16	0.0776	0.0028	0.0812	0.0007	0.0230	0.0339
A17	0.2167	0.0009	0.1160	0.0000	0.0415	0.0135
A18	0.0018	0.0991	0.0012	0.1355	0.0014	0.0002
A19	0.0030	0.0521	0.0024	0.0237	0.0001	0.0022
A20	0.0018	0.0660	0.0008	0.1280	0.0000	0.0005
A21	0.0829	0.0024	0.0988	0.0007	0.0185	0.0343
A22	0.0424	0.0045	0.0392	0.0007	0.0000	0.0294
A23	0.0102	0.0233	0.0043	0.0025	0.0129	0.0043
A24	0.0249	0.0168	0.0047	0.0055	0.0765	0.0193
A25	0.0542	0.0048	0.0260	0.0000	0.0012	0.0266
A26	0.0116	0.0160	0.0065	0.0169	0.0063	0.0217
A27	0.0086	0.0388	0.0059	0.0014	0.0022	0.0000
A28	0.0032	0.0720	0.0010	0.0052	0.0025	0.0000
A29	0.0683	0.0028	0.0379	0.0011	0.0158	0.1025
A30	0.0278	0.0124	0.0014	0.0031	0.0382	0.0449
A31	0.0131	0.0185	0.0040	0.0497	0.0194	0.0002
A32	0.0834	0.0035	0.0642	0.0000	0.0297	0.0512
A33	0.0877	0.0027	0.0861	0.0008	0.0026	0.1060
max	0.2167	0.1169	0.1334	0.1355	0.2036	0.1936

The grades of deviation of alternatives from ideal and anti-ideal solutions are computed via Eqs. (48) and (49) respectively. Then while utility function for each alternative related to ideal solution is obtained

by using Eq. (50), the utility function for each alternative related to anti-ideal solution is calculated via Eq.(51). Finally alternatives are ranked according to the average deviation of the alternatives from the degree of utility by utilizing Eq.(52). Final calculations and ranking of alternatives for r_{max} is exhibited in Table 14.

Table 14. s_i^+, s_i^-, K_i^+, K_i^-, and Q_i and ranking of alternatives according to max

Countries	s_i^+	s_i^-	K_i^+	K_i^-	Q_i	Rank
A1	1.2223	0.0780	0.2458	0.0780	0.1619	24
A2	1.1301	0.1702	0.2658	0.1702	0.2180	12
A3	1.2214	0.0790	0.2460	0.0790	0.1625	23
A4	0.7334	0.5670	0.4096	0.5670	0.4883	1
A5	1.2387	0.0616	0.2425	0.0616	0.1520	26
A6	1.2197	0.0806	0.2463	0.0806	0.1635	21
A7	1.2504	0.0499	0.2402	0.0499	0.1451	32
A8	1.2331	0.0672	0.2436	0.0672	0.1554	25
A9	1.1773	0.1231	0.2552	0.1231	0.1891	15
A10	1.2416	0.0587	0.2419	0.0587	0.1503	27
A11	1.0424	0.2580	0.2882	0.2580	0.2731	5
A12	0.8390	0.4613	0.3581	0.4613	0.4097	2
A13	1.2435	0.0568	0.2416	0.0568	0.1492	31
A14	1.2522	0.0482	0.2399	0.0482	0.1440	33
A15	1.2419	0.0584	0.2419	0.0584	0.1502	28
A16	1.0809	0.2194	0.2779	0.2194	0.2487	10
A17	0.9115	0.3889	0.3296	0.3889	0.3592	3
A18	1.0609	0.2395	0.2832	0.2395	0.2613	6
A19	1.2165	0.0839	0.2469	0.0839	0.1654	20
A20	1.1030	0.1974	0.2724	0.1974	0.2349	11
A21	1.0624	0.2379	0.2828	0.2379	0.2603	7
A22	1.1839	0.1164	0.2537	0.1164	0.1851	16
A23	1.2426	0.0577	0.2417	0.0577	0.1497	29
A24	1.1524	0.1479	0.2607	0.1479	0.2043	13
A25	1.1872	0.1131	0.2530	0.1131	0.1831	17
A26	1.2211	0.0793	0.2460	0.0793	0.1626	22
A27	1.2432	0.0571	0.2416	0.0571	0.1494	30
A28	1.2163	0.0840	0.2470	0.0840	0.1655	19
A29	1.0718	0.2286	0.2803	0.2286	0.2544	9
A30	1.1723	0.1281	0.2563	0.1281	0.1922	14
A31	1.1953	0.1050	0.2513	0.1050	0.1782	18
A32	1.0681	0.2322	0.2812	0.2322	0.2567	8
A33	1.0142	0.2861	0.2962	0.2861	0.2912	4
s_0^+	0.3004	s_0^-	0.9999			

Table 14 shows that Canada (A4) is the best-performing OECD country according to the ranking of alternatives in terms of r_{max}. This country is followed by Germany (A12). Japan (A17) is the third highest-ranked OECD country in terms of energy consumption. On the contrary, Hungary (A14) appears to be the worst-performing OECD country concerning energy consumption. Similar calculations are made for $r_{arith.mean}$ and ranking of alternatives are shown in Table 15.

Table 15. s_i^+, s_i^-, K_i^+, K_i^-, and Q_i and ranking of alternatives according to arith. mean

Countries	s_i^+	s_i^-	K_i^+	K_i^-	Q_i	Rank
A1	1.2080	0.0782	0.2370	0.0782	0.1576	24
A2	1.1165	0.1698	0.2564	0.1698	0.2131	12
A3	1.2078	0.0784	0.2371	0.0784	0.1578	23
A4	0.7162	0.5700	0.3998	0.5701	0.4849	1
A5	1.2245	0.0617	0.2338	0.0617	0.1478	26
A6	1.2055	0.0807	0.2375	0.0807	0.1591	21
A7	1.2374	0.0489	0.2314	0.0489	0.1401	32
A8	1.2191	0.0671	0.2349	0.0671	0.1510	25
A9	1.1669	0.1194	0.2454	0.1194	0.1824	15

A10	1.2276	0.0587	0.2332	0.0587	0.1460	27
A11	1.0278	0.2584	0.2786	0.2584	0.2685	5
A12	0.8224	0.4638	0.3481	0.4638	0.4060	2
A13	1.2295	0.0567	0.2329	0.0567	0.1448	30
A14	1.2393	0.0469	0.2310	0.0469	0.1390	33
A15	1.2284	0.0579	0.2331	0.0579	0.1455	28
A16	1.0687	0.2176	0.2679	0.2176	0.2427	10
A17	0.9021	0.3841	0.3174	0.3842	0.3508	3
A18	1.0543	0.2319	0.2716	0.2320	0.2518	7
A19	1.2048	0.0814	0.2376	0.0814	0.1595	20
A20	1.0951	0.1911	0.2614	0.1911	0.2263	11
A21	1.0511	0.2352	0.2724	0.2352	0.2538	6
A22	1.1708	0.1155	0.2446	0.1155	0.1800	16
A23	1.2290	0.0573	0.2330	0.0573	0.1451	29
A24	1.1358	0.1505	0.2521	0.1505	0.2013	13
A25	1.1738	0.1125	0.2439	0.1125	0.1782	17
A26	1.2073	0.0790	0.2372	0.0790	0.1581	22
A27	1.2306	0.0556	0.2327	0.0556	0.1442	31
A28	1.2046	0.0816	0.2377	0.0816	0.1597	19
A29	1.0553	0.2309	0.2713	0.2310	0.2511	9
A30	1.1558	0.1305	0.2477	0.1305	0.1891	14
A31	1.1830	0.1033	0.2420	0.1033	0.1727	18
A32	1.0543	0.2319	0.2716	0.2319	0.2517	8
A33	1.0002	0.2861	0.2863	0.2861	0.2862	4
$\boldsymbol{s_0^+}$	0.2863	$\boldsymbol{s_0^-}$	0.9999			

r_{max} and $r_{arith.mean}$ showed similar ranking results. OECD country with the best performance is Canada (A4). The second highest performer is Germany (A12) and the third best performance is displayed by Japan (A17). Hungary (A14) again, found itself in the last place according to the ranking of alternatives in terms of $r_{arith.mean}$.

In general, Canada (A4), Germany (A12), and Japan (A17) are among the top three OECD countries in both r_{max} and $r_{arith.mean}$ related to energy consumption. Along with this, the United Kingdom (A33) and France (A11) also performed well. On the other hand, Hungary (A14) is by far the worst performer while the Czech Republic (A7), Greece (A13), and Slovakia (A27) had poor performances as well.

5. Validation studies on the results

This subsection presents some validation studies to test the applicability of the proposed model. This study performs validation studies as comparative, sensitivity, and rank reversal analyses. In addition, the outcomes of the validation tests are assessed using Pearson's correlation coefficient and Spearman's rank correlation coefficient, which are widely used in the literature. Pearson's correlation is calculated to compare the criteria weights, while Spearman's rank correlation coefficient is calculated to validate the ranking results of different approaches.

As a first validation study, a comparative analysis is performed to compare the criteria weights based on RSF_{max} and $RSF_{arith.mean}$ values obtained using the IVCIF-AHP method. The result of this comparative analysis is shown in Table 16.

Table 16. IVCIF-AHP criteria weights based on RSF_{max} and $RSF_{arith.mean}$

Criteria	Criteria weights	
	RSF_{max}	$RSF_{arith.mean}$
C1	0.2167	0.2144
C2	0.1170	0.1133
C3	0.1335	0.1284

C4	0.1355	0.1311
C5	0.2036	0.2115
C6	0.1936	0.2013
Pearson correlation coefficient: 0.995		

According to the Pearson correlation coefficient result, these two proposed approaches correlate highly. Therefore, it can be claimed that both RSF_{max} and $RSF_{arith.mean}$ approach in the IVCIF-AHP method is applicable to weigh the criteria.

As a second validation study, a sensitivity analysis is conducted to examine the impact of criteria weights on the ranking result of the IVCIF AHP-CRADIS method. Accordingly, 30 different weight scenarios are generated and evaluated under the RSF_{max} and $RSF_{arith.mean}$ approaches. These scenarios are presented in Appendixes A and B. The first scenarios (Set 0) under both approaches are the current ranking results computed using the proposed IVCIF AHP-CRADIS method. In the other scenarios (Set 1-Set 30), the relevant criteria weights are reduced by 10%, 30%, 50%, 70% and 90%. The sensitivity results are depicted in Figures 2 and 3.

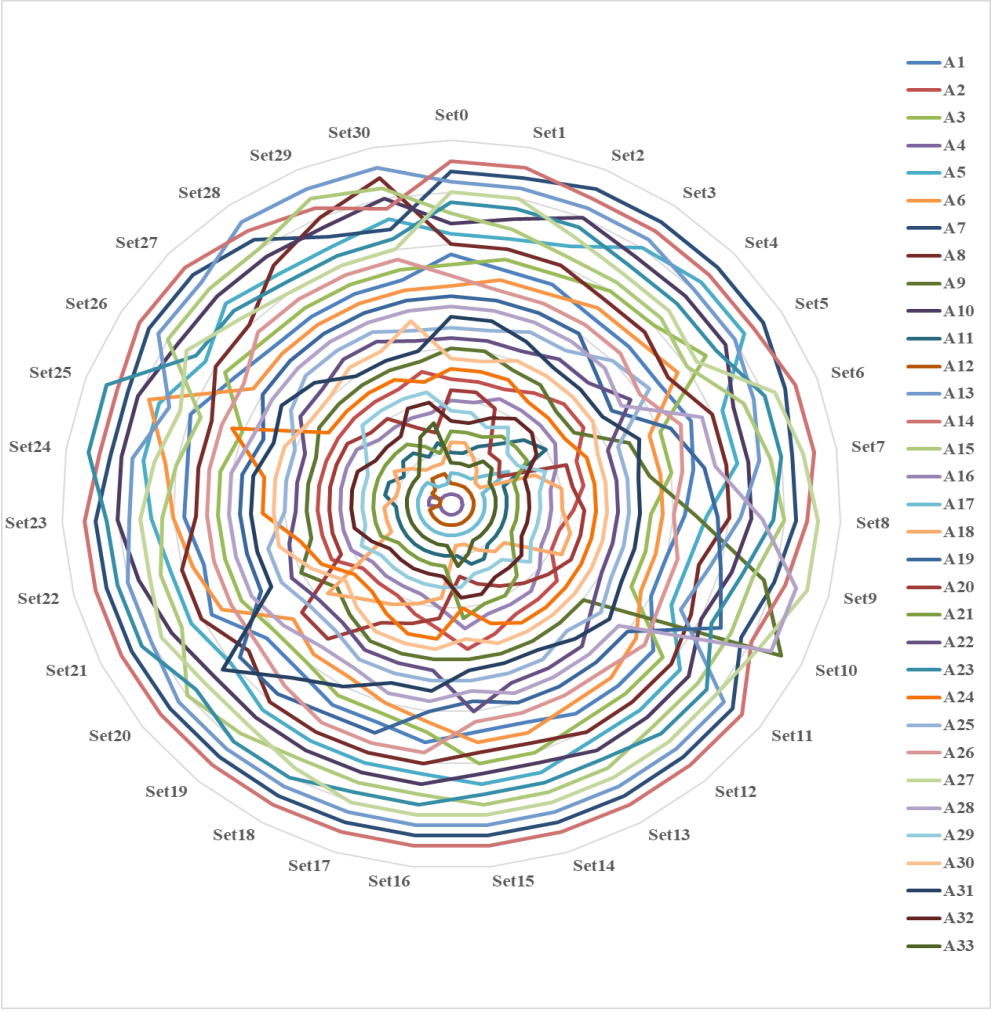


Figure 2. Ranking changes for alternatives by changing criteria weights based on RSF_{max}.

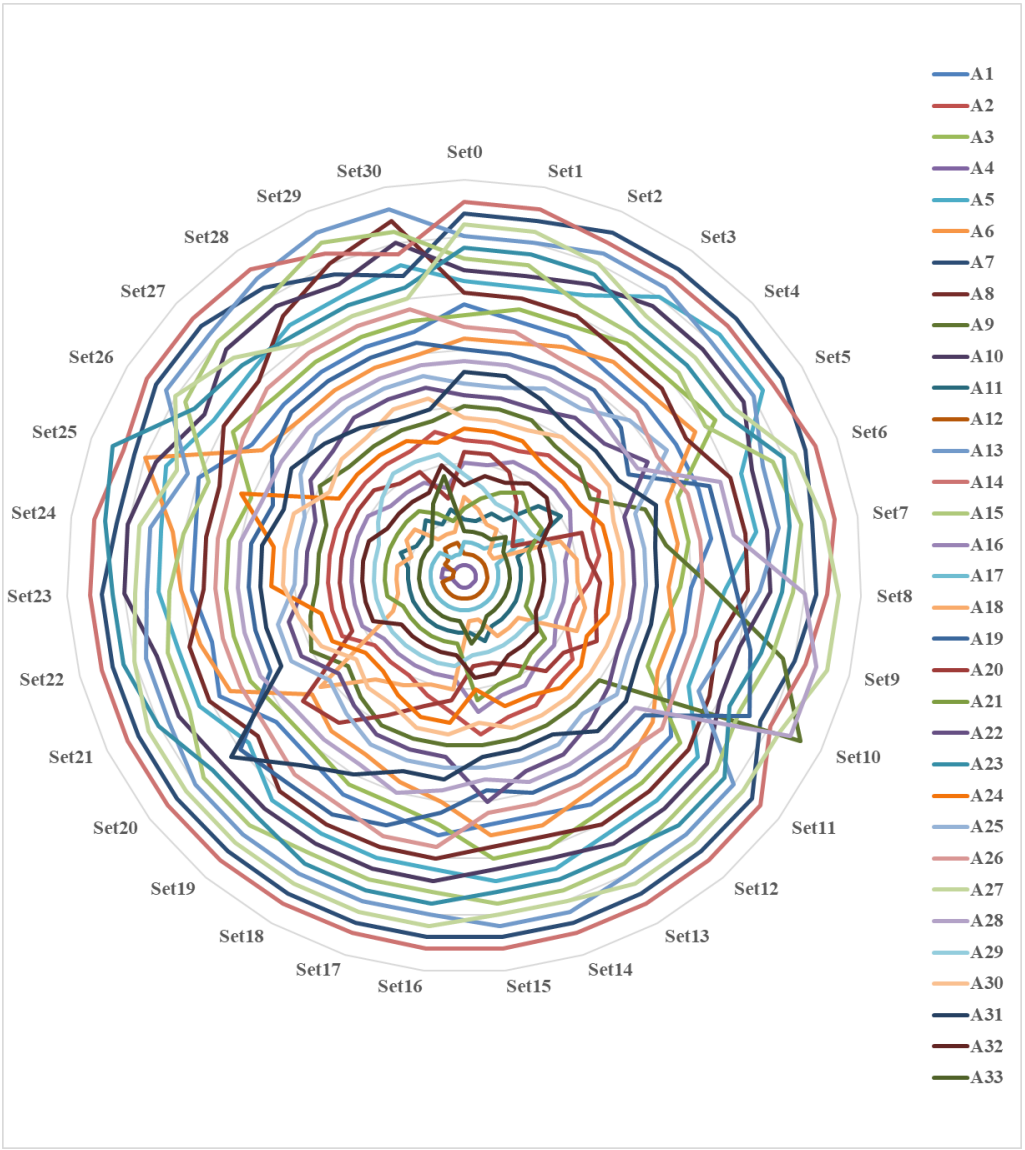


Figure 3. Ranking changes for alternatives by changing criteria weights based on $RSF_{arith.mean}$.

As can be seen from Figures 2 and 3, there are variations in the ranking orders of alternatives as the weight scenarios change. Therefore, the proposed IVCIF-AHP method is sensitive to the criteria weights. However, under different weighting scenarios, it is observed that the rankings of alternatives obtained from both RSF_{max} and $RSF_{arith.mean}$ approaches in IVCIF-AHP give mostly similar results. In both approaches, A4 is mostly ranked as having the best performance on energy consumption. However, it has the second ranking according to weights scenarios Set 23-25. In addition, A14 is mostly ranked as having the worst performance on energy consumption in both approaches. The results indicate that it is important to determine the level of importance of the criteria.

As a third validation study, the proposed IVCIF AHP-CRADIS method is compared with other MCDM techniques such as WEDBA, COPRAS, WASPAS, MARCOS, and ARAS to check the reliability of the ranking result obtained from the existing model. The results of comparative analyses among various MCDM techniques are shown in Tables 17 and 18.

Table 17. Results of Spearman's rank correlation based on RSF_{max} for comparative analysis.

	CRADIS	WEDBA	COPRAS	WASPAS	MARCOS	ARAS
IVCIF-CRADIS	1					
IVCIF-WEDBA	0.982	1				
IVCIF-COPRAS	0.917	0.901	1			
IVCIF-WASPAS	0.940	0.892	0.873	1		
IVCIF-MARCOS	1.000	0.982	0.917	0.940	1	
IVCIF-ARAS	0.982	0.969	0.920	0.934	0.982	1

Table 18. Results of Spearman's rank correlation based on $RSF_{arith.mean}$ for comparative analysis.

	CRADIS	WEDBA	COPRAS	WASPAS	MARCOS	ARAS
IVCIF-CRADIS	1					
IVCIF-WEDBA	0.981	1				
IVCIF-COPRAS	0.914	0.904	1			
IVCIF-WASPAS	0.933	0.892	0.867	1		
IVCIF-MARCOS	1.000	0.981	0.914	0.933	1	
IVCIF-ARAS	0.980	0.969	0.918	0.928	0.980	1

Tables 17 and 18 reveal that the result obtained using the IVCIF AHP-CRADIS method is comparable and provides a statistically significant and strong correlation with other MCDM methods. Therefore, IVCIF AHP-CRADIS can be considered to provide a reliable result.

As a fourth validation study, a rank reversal test is performed to investigate whether the ranking results obtained with the existing model give a stable response to sudden changes. The rank reversal test conducted in this study is based on the progressive deletion of sub-optimal alternatives and checking the ranking of the remaining ones. The results of rank reversal tests are presented in Figures 4 and 5. The first scenarios (Scenario 0) are the initial ranking orders obtained using the proposed IVCIF AHP-CRADIS model. The other scenarios (Scenario 1-32) are generated by progressively removing the alternatives ranked last in the previous rankings from the model one by one.

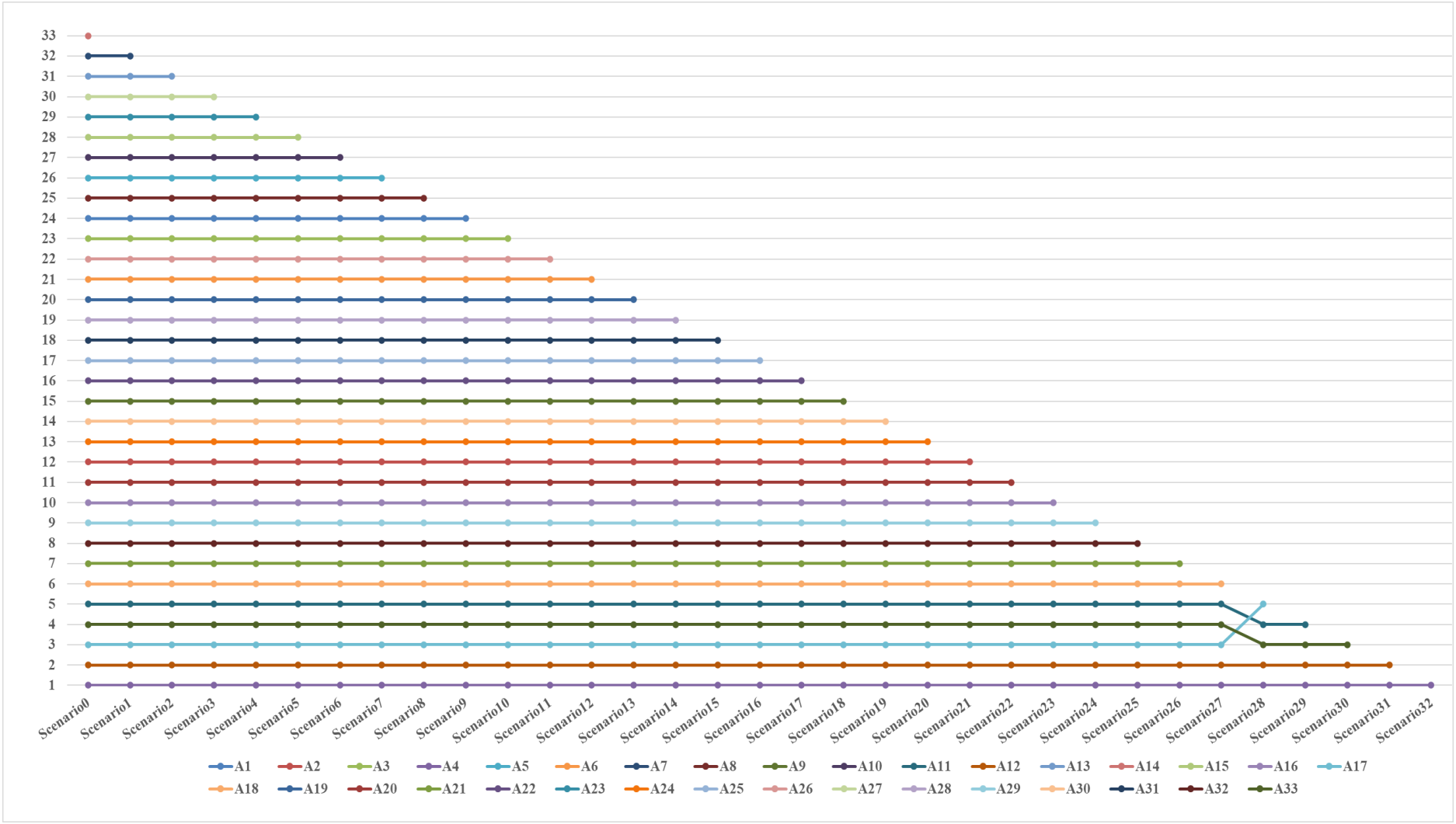


Figure 4. Results of rank reversal test based on RSF_{max} .

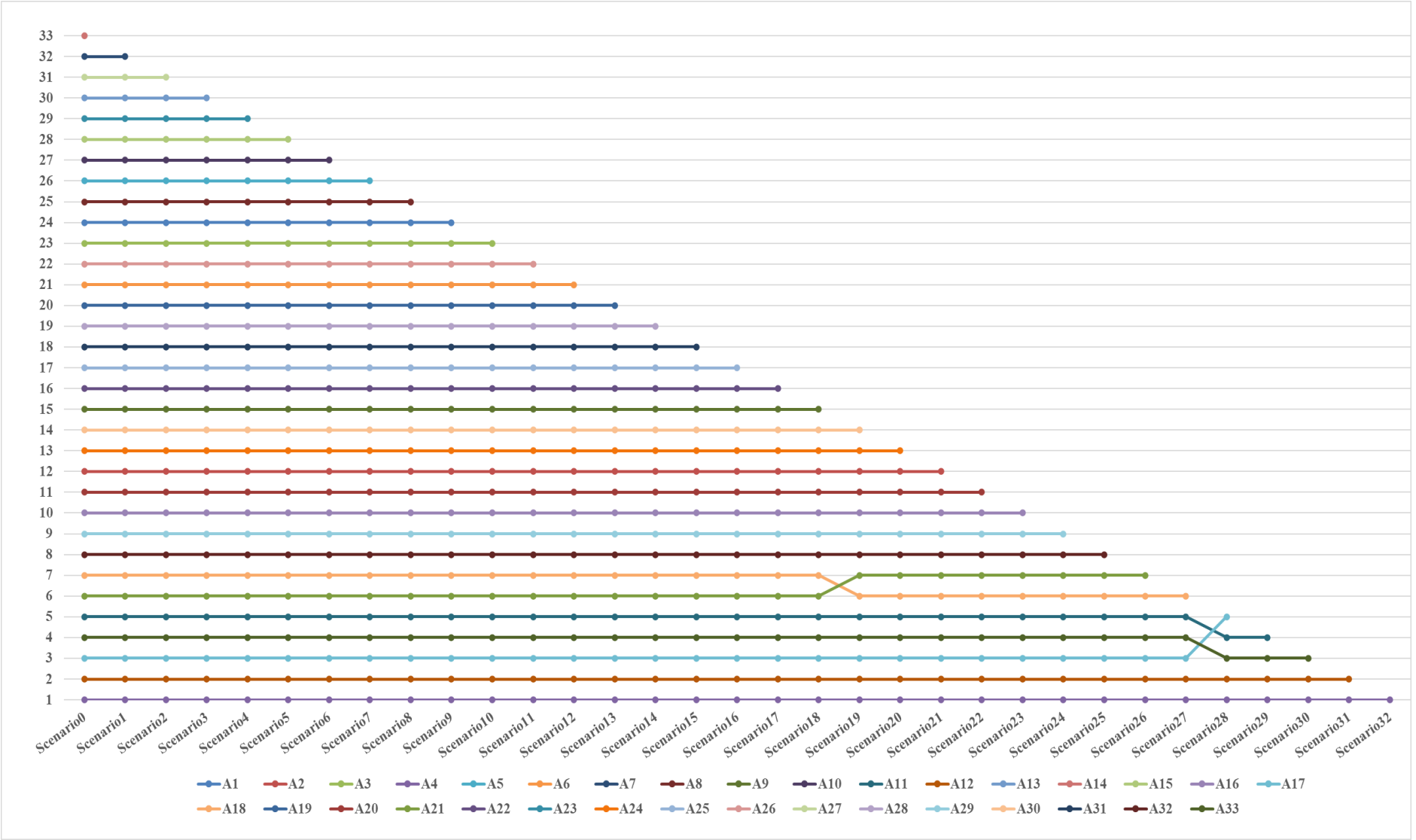


Figure 5. Results of rank reversal test based on $RSF_{arith.mean}$.

Figures 4 and 5 indicate that the proposed model does not show a significant sensitivity to rank reversal cases. In the proposed model with RSF_{max} approach, the ranking of only three alternatives (A11, A17 and A33) changed, while with the $RSF_{arith.mean}$ approach, the ranking of five alternatives (A11, A17, A18, A21, and A33) changed during the process of progressive deletion of sub-optimal alternatives. Moreover, when the rank reversal results of both approaches are compared, it is understood that only four alternatives (A13, A18, A21, and A27) have different order numbers. These changes identified in the rank reversal test are minimal.

6. Conclusion

Energy management and consumption have emerged as a multidimensional challenge of our time, bringing with it the need to simultaneously realize the goals of economic development, environmental sustainability, and social welfare. Especially in energy-intensive economies such as OECD countries, it is critical that energy policies support not only the efficient use of existing resources but also the transition to renewable energy and the reduction of carbon emissions. However, this process turns into a complex decision-making problem that requires a combination of diversity of energy sources, economic factors, and environmental impacts. In this context, our study aims to systematically assess the energy consumption performance of OECD countries using CRADIS methodology based on IVCIF-AHP to overcome this challenge.

In our analysis, six key criteria affecting energy management are considered: primary energy consumption, hydropower consumption, wind consumption, coal consumption, gas consumption, and oil consumption. The study findings reveal the centrality of primary energy consumption in shaping energy policies while highlighting the growing strategic importance of renewable energy sources (hydropower and wind). In contrast, fossil fuels (coal, gas, and oil) have lower priorities in terms of energy management. This clearly shows that investments in renewable energy sources should be encouraged. Moreover, this criteria-based assessment provided by our methodology provides an important roadmap for decision-makers who want to design energy policies more effectively.

Assessments of countries' energy consumption performance reveal that Canada, Germany, and Japan are among the leading countries in terms of energy efficiency and sustainability. These countries stand out with their policies promoting the efficient use of renewable energy sources and technology-based solutions. The United Kingdom and France stand out as other countries that have made significant progress in energy management. However, Hungary has the lowest energy consumption performance, while the Czech Republic, Greece, and Slovakia have similarly low performance. This suggests that energy policies need to be restructured to take into account country-specific dynamics.

An important aspect of the study is the four different validation exercises carried out to test the reliability and validity of the methodology used. First, a comparative analysis of the criteria weights based on the RSF_{max} and $RSF_{arith.mean}$ approaches used in the IVCIF-AHP method. The results indicate a high consistency between these two approaches, and both methods can be effectively used to determine the criteria weights. It proves that the IVCIF-AHP method has a solid theoretical and practical foundation. The second validation study focused on sensitivity analysis. In this analysis, the impact of the variation of the criteria weights on the ranking results of the alternatives was examined. For this purpose, 30 different weight scenarios based on RSF_{max} and $RSF_{arith.mean}$ approaches were created, and the rankings under these scenarios were evaluated. The findings show that changes in the weighting scenarios affect the ranking of the alternatives; thus, the IVCIF-AHP-based CRADIS methodology is sensitive to the criteria weights. This increases the applicability of the methodology in areas with dynamic and variable criteria, such as energy management. In the third validation study, the results of the proposed methodology were compared with other widely used CRADIS methods in the literature (WEDBA, COPRAS, WASPAS, MARCOS, and ARAS). The analysis revealed that the ranking results obtained by the IVCIF-AHP-based CRADIS methodology exhibit a strong correlation with the other methods, and the results are statistically significant. This confirms the proposed methodology as a valid tool for

accident assessment. The rank reversal test was applied for the final validation study. The test was conducted to assess whether the proposed methodology provides a robust response in the presence of abrupt changes in ranking results. The test results indicated that ranking results by means of the RSF_{max} and $RSF_{arith.mean}$ approaches differ only marginally, and the methodology is basically stable. It indicates that the methodology has provided a reliable framework for the long-term sustainability of energy policies.

This wide-ranging study deals with the analyses related to the energy consumption performance of OECD countries from a multidimensional perspective. Energy consumption is considered a strategic area that has to be kept in fine balance with the three pillars, namely economic growth, environmental sustainability, and social welfare. In this respect, the application in our work of the IVCIF-AHP-based CRADIS methodology addresses the intricate nature of energy management, setting the route towards a systematic benchmarking analysis in terms of energy consumption both at the benchmark and country level.

These results have fundamental implications for the drafting of sustainable energy policy. Besides the fact that it clearly proves the need to give more importance to renewable sources-the actual hydropower and wind-one can draw from it that dependence on fossil fuels must step by step go down. The positive consequence brought about is not environmental but most important for reaching energy security and economic sustainability. Especially, successful performances by countries like Canada, Germany, and Japan show the part that innovative policies and technology-based solutions have played in energy management. Such models are also supporting other OECD countries and indicate something of how the restructuring of energy policy has occurred or is underway. Our research offers concrete recommendations for policymakers and researchers in the field of energy management. The basic orientation in energy policy formulation must be towards more investment in renewable resources and their expanded share in energy production. In addition, comprehensive datasets regarding energy consumption and management should be generated to support scientific studies in the same area. Above all, it should promote the adaptation of renewable energy technologies to local conditions and improve the incentive mechanisms for their dissemination.

In this light, the proposed IVCIF-AHP-based CRADIS methodology can be integrated into energy management-related multi-criteria decision-making and considered an effective tool in solving current challenges. This methodology contributes not only to assessing the current state of energy consumption but also to the development of viable strategies concerning a more sustainable future. Our study provides concrete guidance on how OECD countries can define more effective policies in energy management.

AUTHOR DECLARATIONS

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ETHICAL APPROVAL

Not Applicable.

INFORMED CONSENT

Informed consent was obtained from all participants in the study.

CONSENT FOR PUBLICATION

Informed consent related to publication was obtained from all authors.

AUTHOR'S CONTRIBUTION

Conceptualization, F.A.; Methodology, Ş.T. and Ç.K.; Software, Ş.T. and Ç.K.; Validation, Ş.T.; formal analysis, F.A., Ş.T. and Ç.K.; investigation, F.A., Ş.T. and Ç.K.; resources, F.A., Ş.T. and Ç.K. ; data maintenance, Ş.T. and Ç.K.; writing-creating the initial design, F.A., Ş.T. and Ç.K.; writing-reviewing and editing, Ş.T. and Ç.K.; visualization, Ş.T.

CONFLICT OF INTEREST

The authors have no competing interests to declare that are relevant to the content of this article.

DATA AVAILABILITY STATEMENT

Data cannot be shared openly but are available on request from authors.

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Not Applicable.

CODE AVAILABILITY

MS Excel was utilized for analyzing the data.

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Appendix A. The weight scenarios designed based on RSF_{max} for sensitivity analysis

Scenarios	C1	C2	C3	C4	C5	C6
Set 0	0.2167	0.1170	0.1335	0.1355	0.2036	0.1936
Set 1	0.1951	0.1202	0.1372	0.1393	0.2093	0.1990
Set 2	0.1517	0.1267	0.1446	0.1468	0.2206	0.2097
Set 3	0.1084	0.1332	0.1519	0.1543	0.2318	0.2204
Set 4	0.0650	0.1397	0.1593	0.1618	0.2431	0.2311
Set 5	0.0217	0.1461	0.1667	0.1693	0.2544	0.2418
Set 6	0.2196	0.1053	0.1352	0.1373	0.2063	0.1962
Set 7	0.2254	0.0819	0.1388	0.1409	0.2117	0.2013
Set 8	0.2311	0.0585	0.1423	0.1445	0.2171	0.2064
Set 9	0.2368	0.0351	0.1459	0.1481	0.2225	0.2116
Set 10	0.2426	0.0117	0.1494	0.1517	0.2279	0.2167
Set 11	0.2201	0.1188	0.1201	0.1376	0.2068	0.1966
Set 12	0.2268	0.1224	0.0934	0.1418	0.2131	0.2026
Set 13	0.2334	0.1260	0.0667	0.1460	0.2193	0.2085
Set 14	0.2401	0.1296	0.0400	0.1501	0.2256	0.2145
Set 15	0.2201	0.1332	0.0133	0.1543	0.2319	0.2205

Set 16	0.2201	0.1188	0.1356	0.1220	0.2068	0.1966
Set 17	0.2269	0.1225	0.1398	0.0949	0.2132	0.2027
Set 18	0.2337	0.1262	0.1439	0.0678	0.2196	0.2088
Set 19	0.2405	0.1298	0.1481	0.0407	0.2260	0.2149
Set 20	0.2473	0.1335	0.1523	0.0136	0.2324	0.2209
Set 21	0.2223	0.1200	0.1369	0.1390	0.1833	0.1986
Set 22	0.2334	0.1260	0.1437	0.1459	0.1426	0.2085
Set 23	0.2445	0.1320	0.1505	0.1528	0.1018	0.2184
Set 24	0.2555	0.1379	0.1574	0.1598	0.0611	0.2283
Set 25	0.2666	0.1439	0.1642	0.1667	0.0204	0.2382
Set 26	0.2219	0.1198	0.1367	0.1388	0.2085	0.1743
Set 27	0.2324	0.1254	0.1431	0.1453	0.2183	0.1355
Set 28	0.2428	0.1310	0.1495	0.1518	0.2281	0.0968
Set 29	0.2532	0.1367	0.1559	0.1583	0.2379	0.0581
Set 30	0.2636	0.1423	0.1623	0.1648	0.2477	0.0194

Appendix B. The weight scenarios designed based on $RSF_{arith.mean}$ for sensitivity analysis

Scenarios	C1	C2	C3	C4	C5	C6
Set 0	0,2144	0,1133	0,1284	0,1311	0,2115	0,2013
Set 1	0,1930	0,1164	0,1319	0,1347	0,2172	0,2068
Set 2	0,1501	0,1226	0,1389	0,1419	0,2288	0,2178
Set 3	0,1072	0,1288	0,1459	0,1490	0,2403	0,2288
Set 4	0,0643	0,1350	0,1529	0,1562	0,2519	0,2398
Set 5	0,0214	0,1412	0,1599	0,1633	0,2634	0,2508
Set 6	0,2171	0,1020	0,1300	0,1328	0,2142	0,2039
Set 7	0,2226	0,0793	0,1333	0,1361	0,2196	0,2090
Set 8	0,2281	0,0567	0,1366	0,1395	0,2250	0,2142
Set 9	0,2336	0,0340	0,1398	0,1429	0,2304	0,2193
Set 10	0,2391	0,0113	0,1431	0,1462	0,2358	0,2245
Set 11	0,2176	0,1150	0,1155	0,1331	0,2146	0,2043
Set 12	0,2239	0,1183	0,0899	0,1369	0,2208	0,2102
Set 13	0,2302	0,1217	0,0642	0,1408	0,2270	0,2161
Set 14	0,2365	0,1250	0,0385	0,1446	0,2333	0,2221
Set 15	0,2176	0,1284	0,0128	0,1485	0,2395	0,2280
Set 16	0,2176	0,1150	0,1303	0,1180	0,2147	0,2044
Set 17	0,2241	0,1185	0,1342	0,0918	0,2210	0,2104
Set 18	0,2306	0,1219	0,1380	0,0656	0,2274	0,2165
Set 19	0,2370	0,1253	0,1419	0,0393	0,2338	0,2226
Set 20	0,2435	0,1287	0,1458	0,0131	0,2402	0,2287
Set 21	0,2201	0,1164	0,1318	0,1346	0,1903	0,2067
Set 22	0,2316	0,1225	0,1387	0,1417	0,1480	0,2175
Set 23	0,2431	0,1285	0,1456	0,1487	0,1057	0,2283
Set 24	0,2546	0,1346	0,1525	0,1557	0,0634	0,2391
Set 25	0,2661	0,1407	0,1593	0,1628	0,0211	0,2499
Set 26	0,2198	0,1162	0,1316	0,1344	0,2168	0,1812
Set 27	0,2306	0,1219	0,1381	0,1410	0,2275	0,1409
Set 28	0,2414	0,1276	0,1445	0,1476	0,2381	0,1007

Set 29	0,2522	0,1333	0,1510	0,1543	0,2488	0,0604
Set 30	0,2630	0,1391	0,1575	0,1609	0,2594	0,0201