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# EVALUATING ECONOMIC FREEDOM VIA A MULTI-CRITERIA MEREC-DNMA MODEL-BASED COMPOSITE SYSTEM: CASE OF OPEC COUNTRIES

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**Abstract.** Economic freedom indicators create a beneficial and suitable guide and a crucial reference for investors, policymakers, lenders, and market researchers worldwide. In light of these indicators, the economic freedom performances of countries can be determined. The Heritage Foundation annually releases a ranked list of the country based on their performance in terms of fourteen economic freedom criteria with equal weights through a simple aggregation approach. According to an average-based aggregator, equal weight of economic freedom criteria and calculating rank of countries cannot be a completely reliable approach. Thus, this work establishes a composite index system in the form of a decision support system that employs the method based on the removal effects of criteria (MEREC) and the double normalization-based multi-aggregation (DNMA) to specify the economic freedom levels of the OPEC countries. MEREC obtains the importance weights of indicators without the interference of any stakeholder or decision-makers. Afterward, DNMA, as a novel ranking multi-criteria method, is applied to sort countries based on their performance against all economic freedom criteria. This is the first attempt in the literature to calculate the index of economic freedom utilizing an integrated multi-criteria decision support model. Whereas "investment freedom" is the most significant indicator of economic freedom, the UAE is in the best position in terms of economic freedom among OPEC countries. A four-phased sensitivity control is also performed so as to verify the robustness and usefulness of the developed decision tool.

**Keywords:** economic freedom, OPEC, economic freedom index, sustainable development, MCDM, composite index system.

**JEL Classification:** C43, C61, D81.

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## Introduction

Sustainable development is one of the crucial issues that emerged due to social, technical, and political developments in the world to address current issues in the economy, environment, and society (Emas, 2015; Strezov et al., 2017; Ecer, 2021a). Economic development has been one of the important and highly attractive aspects among all three pillars of sustainable development (Sousa et al., 2021). Since economic growth is a pivot and driver of growth in environmental and social aspects, high attention has been paid to develop economies based on sustainability practices (Gropper et al., 2015; Graafland, 2019; Assi et al., 2020; Shahnazi & Shabani, 2021). Sustainability requires a continuously evaluative framework for countries to re-assess their performance in comparison to other countries in terms of achieving multiple economic indicators, criteria, or metrics. On the other hand, the measurement of the performance of a country based on economic metrics is a very complicated task. Index of economic freedom is one of the well-known indexes that annually determines the performance of countries in terms of several indicators/criteria. In simpler words, the index of economic freedom measures how far human beings can take economic actions in terms of free markets, free trade, and private property based on their fundamental rights. Thence, economic freedom plays a significant role in improving human development and achieving economic and social sustainability targets based on its fundamental goals (Gwartney, 2017; Ott, 2018).

Since 1995, The Heritage Foundation annually releases a report on the performance of countries based on several economic freedom criteria, called the index of economic freedom, through an exclusive index calculator which considers equal importance for all criteria. Index of economic freedom is based on four main aspects and 12 drivers as follows. The rule of law as the first main criterion includes three sub-criteria as property rights (C1), government integrity (C2), and judicial effectiveness (C3). The second main criterion, government size, includes three sub-criteria as government spending (C4), tax burden (C5), and fiscal health (C6). Regulatory efficiency as the third main criterion consists of three sub-criteria business freedom (C7), labor freedom (C8), and monetary freedom (C9). Finally, open markets' main criterion includes three sub-criteria as trade freedom (C10), investment freedom (C11), and financial freedom (C12). The Heritage Foundation utilizes a simple average weighting method to determine the index of economic freedom considering similar weight values of criteria.

A composite index can be expressed as the mathematical integration of many indicators for a purpose (Saisana & Tarantola, 2002). Constructing a composite index to compare performances of institutions, countries, or cities is not a simple task (El Gibari et al., 2019). Nardo et al. (2008) argue that efforts to produce composite indexes gradually increase to reduce complexity using information more effectively. The outcomes produced by the combined indexes are easier to interpret than to find a general trend by focusing on each indicator individually (Singh et al., 2009; Paruolo et al., 2013). As per El Gibari et al. (2019), forming a composite index includes three steps, which are normalization, weighting (Simic et al., 2021; Tutak & Brodny, 2022), and aggregation. Additionally, criteria with various characteristics are considered when forming a composite index (Asadzadeh et al., 2017). Thus, MCDM terminology offers appropriate approaches to aggregate single indicators into a combined system. Multi-criteria decision-making (MCDM) methods are well-known decision models that are applied for different purposes such as assessment, evaluation, periodization, or sorting a series of alternatives concerning a high number of decision criteria based on systematic and reliable soft computing calculations (Kumar et al., 2017; Zolfani et al., 2021; Torkayesh et al., 2021a). MCDM methods can be classified as weighting-based and ranking-based methods regarding the purpose of research and researcher (Gušavac & Savić, 2021). Analytical Hierarchy Process-AHP (Ecer, 2018), Criteria Importance Through Intercriteria Correlation-CRITIC (Simic et al., 2021), Full Consistency Method-FUCOM (Böyükaslan & Ecer, 2021), Best-Worst Method-BWM (Pamucar et al., 2020; Zolfani et al., 2020), and Entropy (Torkayesh et al., 2021b) are among the most known weighting methods preferred by the researchers in respectful papers. On the other hand, in literature, some effective weighting techniques have appeared recently such as Level Based Weight Assessment-LBWA (Torkayesh et al., 2021a), Simultaneous Evaluation of the criteria and Alternatives-SECA (Ecer, 2021b), and Vital-Immaterial-Mediocre Method-VIMM (Zakeri et al., 2021). Weighting methods are further classified into two types wherein the first type decision-makers and authorities can determine weight values based on their preferences while in the other type, real data is used to derive weight values without any interferences of outsiders such as decision-makers and authorities. Notwithstanding, the number of MCDM methods developed for ranking purposes is higher than the weighting methods (Yazdani et al., 2019; Ecer et al., 2019; Torkayesh et al., 2021a). This category includes, for example, Technique for Order Performance by Similarity to Ideal Solution-TOPSIS (Galik et al., 2022; Radovanović et al., 2021), Preference Ranking Organization Method for Enrichment Evaluations-PROMETHEE (Zu et al., 2022), Complex Proportional Assessment-COPRAS (Ecer, 2014), Visekriterijumska optimizacija i Kompromisno Resenje-VIKOR (Yalcin & Ünlü, 2018), Combined Compromise Solution-COCOSO (Ecer & Pamucar, 2020), and Measurement Alternatives and Ranking according to the Compromise Solution-MARCOS (Pamucar et al., 2021). Moreover, to build composite index, integrated MCDM approaches have also been conducted frequently in the literature. For instance, Simple Additive Weighting-SAW (Haider et al., 2018; Kropp & Lein, 2012; Arbolino et al., 2018), AHP (Krajnc & Glavič, 2005; Sibille et al., 2009; Li et al., 2017), Measuring Attractiveness by a Categorical-Based Evaluation Technique-MACBETH (Clivillé et al., 2007; Rodrigues et al., 2017), Elimination and Choice Expressing the Reality-ELECTRE (Petrović et al., 2014; Attardi et al., 2018), PROMETHEE (Antanasijević et al., 2017; Hernandez-Perdomo & Man, 2017), data envelopment analysis-DEA-based approaches (Dobos & Vörösmarty, 2014; Amado et al., 2016; Martí et al., 2017), TOPSIS (Wang et al., 2012, 2017; Boggia et al., 2018), and Decision-Making Trial and Evaluation Laboratory-DEMATEL (Zhang et al., 2017) with other MCDM methods.

Considering the complexity of interpreting yearly data and the relationship of economic freedom criteria, utilizing the average weighting method would not consider the relationship and differences between economic freedom criteria. In the real world, criteria considered for the index of economic freedom do not have a similar influence on the efficiency of economic freedom. Therefore, building a more reliable and robust composite index can take into account a systematic weighting structure to determine the relative importance of economic freedom criteria; then use weight values to determine the performance score of countries and their relative ranking order considering other countries. Although the studies mentioned above developed a composite index, none of them attempted to determine the economic freedom levels of countries. The authors of only a few studies have worked for this purpose. One of them, Erilli (2018) suggested using a fuzzy clustering algorithm to calculate the index of economic freedom for countries based on the membership degree of the proposed algorithm considering data of 2013–2016. The proposed algorithm showed a high similarity with the results of the technique utilized by The Heritage Foundation. In another paper, Cabello et al. (2021) highlight the applicability of the composite indicator framework for calculating the index of economic freedom for 44 European countries. To highlight the importance of calculating the index, they suggested using the multiple reference point method, which includes a systematic normalization and score aggregation operator. One of the main advantages of the multiple reference point method is representing the countries' overall strengths and weaknesses in terms of economic freedom. Although they used a new method to determine the index of economic freedom, their method was based on equal weight values and a single arithmetic average operator. These are the same issues that there exist in calculations of The Heritage Foundation.

Motivated by the above-mentioned matters, due to characteristics of MCDM methods in evaluation and assessment of several alternatives against a high number of criteria, this paper proposes a novel composite index system performing MEREC and DNMA decision-making methods to decide the economic freedom of OPEC countries (The Organization of the Petroleum Exporting Countries) based on the criteria introduced by The Heritage Foundation. The MEREC method objectively determines the different importance levels of the criteria and thus prevents the judgments of the decision-makers from being effective in the decision process. The DNMA method allows for more realistic normalization of raw data, thanks to its linear and vector normalization structure. It can be emphasized that the evaluations made with the MEREC-DNMA framework, which combines two methods with such unique advantages, will be more realistic and fill an important gap in the literature on the evaluation of the economic freedom of countries. This research contributes in several directions to the literature. First, this research is first in its kind to apply a combined MCDM framework as a composite index system to assess the economic freedom of countries. Within the MCDM framework, economic freedom scores are determined as utility or compromise scores, and countries are ranked with respect to these values. Also, unlike other works in the literature, this work uses a weighting method to determine the weight coefficients of criteria where are considered equal in most other studies. Another contribution of this study is related to its structure in which a data-driven weighting method is applied to highlight the weight of economic freedom criteria without interference from authorities or decision-makers. Another contribution of this study is to offer an integrated decision-making methodology based on MEREC and DNMA which are used together for the first time.

The rest of the research is formed as follows. Section 1 highlights preliminaries on the proposed methodology. Section 2 presents information about OPEC countries and the results of the introduced framework. Implications are given in Section 3. Finally, we conclude in last Section.

## 1. Research methodology

This section presents preliminaries and requirements regarding the proposed model for assessing the economic freedom of OPEC countries.

### 1.1. MEREC

The core principle of the MEREC method is that it considers the removal influences of each criterion on the aggregate performance of alternatives. Smaller weights are yielded to criteria that have a lower impact on performances. In other words, the criterion with a more significant weight causes a more considerable change when it is removed from the criterion set. This perspective in the MEREC method allows unimportant criteria to be left out of the evaluation process if necessary. When preparing this study, there were scarcely papers performing the MEREC method (Keshavarz-Ghorabaee, 2021; Trung & Thinh, 2021; Rani et al., 2022). MEREC has an easy computation process which is presented in Appendix A1 (Keshavarz-Ghorabaee et al., 2021).

### 1.2. DNMA

The basic principle of the DNMA technique is that the preferred alternative is very near to the desired solution. It concentrates on benefiting linear and vector normalization tools and three aggregation operators. DNMA can simultaneously cope with benefit and non-benefit criteria in a real-world problem for determining performance ranking. This technique has the superiorities of credibility, flexibility, and ease-of-use compared with some recent MCDM methods such as MACONT (Ecer & Torkayesh, 2022). To now, a scarce number of papers was performed using DNMA. With the help of hesitant fuzzy DNMA, Liao et al. (2019) solved the lung cancer screening problem. To select the most suitable internet financial investment product, Zhang et al. (2020) utilized Pythagorean fuzzy DNMA. Lai et al. (2020) performed a Z-number-based DNMA method to decide sustainable cloud service provider development. Very recently, Lai and Liao (2021) proposed a CRITIC objective weighting method based DNMA with D numbers to evaluate blockchain platforms. Besides, Wu et al. (2020), Nie et al. (2019), Liao et al. (2020), and Wang and Rani (2021) applied it successfully in different fields.

Appendix A.2 shows the steps of DNMA briefly (Wu & Liao, 2019; Liao & Wu, 2020).

## 2. Assessing economic freedom of OPEC countries

Released by the Heritage Foundation annually, the index of Economic Freedom (IEF) is a composite indicator. According to the Heritage Foundation, "economic freedom is the fundamental right of every human to control his or her own labor and property. Based on this, individuals are free to work, produce, consume, and invest in any way they please. Governments allow labor, capital, and goods to move freely, and refrain from the coercion of liberty beyond the extent necessary to protect and maintain liberty itself". This paper employs data from the 2021 IEF covering the second half of 2019 to the first half of 2020. Utilizing the IEF

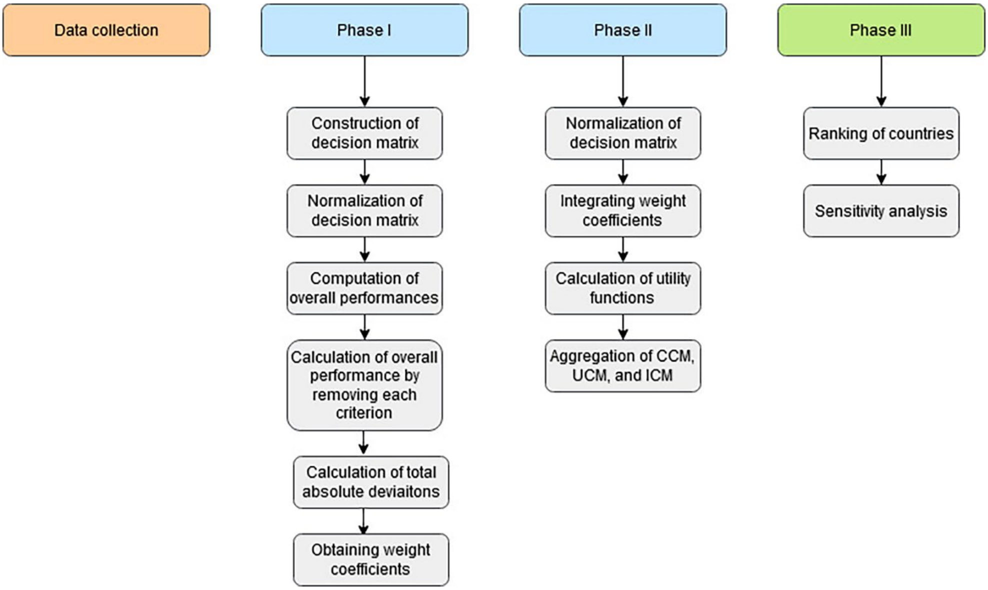


Figure 1. The procedure of the introduced MEREC-DNMA framework

data, therefore, this section depicts the application of the suggested methodology of MEREC and DNMA for ranking the OPEC countries in terms of their economic freedom. At first, to reach the desired goal, the calculation of the weights of the indicators is conducted by MEREC. Afterward, the DNMA technique is handled to determine the ranking orders of the 14 OPEC countries (Algeria (DZ), Angola (AO), Congo (CD), Ecuador (EC), Equatorial Guinea (GQ), Gabon (GA), Iran (IR), Iraq (IQ), Kuwait (KW), Libya (LY), Nigeria (NG), Saudi Arabia (SA), the United Arab Emirates (UAE) (AE), and Venezuela (VE)) according to their economic freedoms.

A summary of the proposed MEREC-DNMA model for economic freedom framework can be demonstrated in Figure 1.

### 2.1. Exploring the criteria weights by MEREC

As mentioned earlier, the economic freedom data shown in Table 1 is obtained from the Heritage Foundation web page (https://www.heritage.org/index/). The data set, which consists of 12 indicators (criteria) and 14 alternatives (OPEC countries), will hereafter be called the decision matrix. The first phase of the developed methodology is to derive the importance weights of criteria through MEREC.

By Eq. (1), as illustrated in Table 2, all criteria are normalized to convert different types into a standard unit of measure.

Afterward, $S_i$, $S'_{ij}$, and $E_j$ values are calculated via Eqs (2)–(4), respectively. Finally, weight values of criteria ($w_j$) are extracted by Eq. (5). These values are demonstrated in Table 3.

Table 1. Economic freedom indicators of OPEC countries by 2021 (source: Miller et al., 2021)

| | Criteria | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Optimization | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max |
| Countries | *C1* | *C2* | *C3* | *C4* | *C5* | *C6* | *C7* | *C8* | *C9* | *C10* | *C11* | *C12* |
| *DZ* | 34.00 | 41.60 | 32.70 | 67.20 | 55.40 | 49.10 | 63.50 | 51.30 | 84.30 | 57.40 | 30.00 | 30.00 |
| *AO* | 30.30 | 22.80 | 20.40 | 87.30 | 86.90 | 77.90 | 56.90 | 59.60 | 67.50 | 70.20 | 30.00 | 40.00 |
| *CD* | 32.20 | 25.70 | 23.50 | 80.40 | 84.00 | 81.80 | 36.60 | 36.60 | 86.50 | 56.40 | 35.00 | 30.00 |
| *EC* | 39.50 | 24.70 | 38.50 | 77.10 | 58.50 | 75.90 | 50.40 | 47.90 | 81.70 | 59.80 | 35.00 | 40.00 |
| *GQ* | 27.80 | 15.40 | 17.00 | 75.20 | 90.00 | 96.10 | 36.40 | 34.40 | 79.40 | 48.80 | 40.00 | 30.00 |
| *GA* | 24.20 | 25.50 | 36.40 | 77.70 | 90.80 | 93.70 | 54.70 | 52.90 | 84.50 | 56.80 | 60.00 | 40.00 |
| *IR* | 33.50 | 28.30 | 31.80 | 80.80 | 90.10 | 82.80 | 57.10 | 50.10 | 42.10 | 54.20 | 5.00 | 10.00 |
| *IQ* | 44.80 | 11.00 | 22.00 | 83.21 | 65.30 | 94.70 | 51.70 | 45.60 | 77.00 | 63.32 | 32.69 | 36.60 |
| *KW* | 57.40 | 52.60 | 47.50 | 97.70 | 21.40 | 99.70 | 66.00 | 62.20 | 73.60 | 75.80 | 55.00 | 60.00 |
| *LY* | 16.50 | 19.70 | 21.00 | 83.21 | 21.40 | 19.90 | 38.40 | 55.30 | 69.70 | 63.32 | 5.00 | 36.60 |
| *NG* | 36.80 | 38.70 | 23.50 | 84.90 | 95.30 | 59.90 | 60.00 | 84.40 | 68.00 | 68.40 | 45.00 | 40.00 |
| *SA* | 68.70 | 76.70 | 53.20 | 99.10 | 62.90 | 31.00 | 83.50 | 63.30 | 82.30 | 75.80 | 45.00 | 50.00 |
| *AE* | 80.80 | 81.10 | 66.00 | 100.00 | 73.00 | 98.50 | 80.00 | 81.60 | 80.60 | 81.40 | 40.00 | 60.00 |
| *VE* | 7.50 | 15.40 | 15.10 | 71.10 | 61.50 | 31.00 | 33.40 | 27.50 | 42.00 | 54.80 | 5.00 | 10.00 |

Table 2. Normalized decision matrix

| | Criteria | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *C1* | *C2* | *C3* | *C4* | *C5* | *C6* | *C7* | *C8* | *C9* | *C10* | *C11* | *C12* |
| *DZ* | 0.2206 | 0.2644 | 0.4618 | 1.0000 | 0.3863 | 0.4053 | 0.5260 | 0.5361 | 0.4982 | 0.8502 | 0.1667 | 0.3333 |
| *AO* | 0.2475 | 0.4825 | 0.7402 | 0.7698 | 0.2463 | 0.2555 | 0.5870 | 0.4614 | 0.6222 | 0.6952 | 0.1667 | 0.2500 |
| *CD* | 0.2329 | 0.4280 | 0.6426 | 0.8358 | 0.2548 | 0.2433 | 0.9126 | 0.7514 | 0.4855 | 0.8652 | 0.1429 | 0.3333 |
| *EC* | 0.1899 | 0.4453 | 0.3922 | 0.8716 | 0.3658 | 0.2622 | 0.6627 | 0.5741 | 0.5141 | 0.8161 | 0.1429 | 0.2500 |
| *GQ* | 0.2698 | 0.7143 | 0.8882 | 0.8936 | 0.2378 | 0.2071 | 0.9176 | 0.7994 | 0.5290 | 1.0000 | 0.1250 | 0.3333 |
| *GA* | 0.3099 | 0.4314 | 0.4148 | 0.8649 | 0.2357 | 0.2124 | 0.6106 | 0.5198 | 0.4970 | 0.8592 | 0.0833 | 0.2500 |
| *IR* | 0.2239 | 0.3887 | 0.4748 | 0.8317 | 0.2375 | 0.2403 | 0.5849 | 0.5489 | 0.9976 | 0.9004 | 1.0000 | 1.0000 |
| *IQ* | 0.1674 | 1.0000 | 0.6864 | 0.8076 | 0.3277 | 0.2101 | 0.6460 | 0.6031 | 0.5455 | 0.7707 | 0.1529 | 0.2732 |
| *KW* | 0.1307 | 0.2091 | 0.3179 | 0.6878 | 1.0000 | 0.1996 | 0.5061 | 0.4421 | 0.5707 | 0.6438 | 0.0909 | 0.1667 |
| *LY* | 0.4545 | 0.5584 | 0.7190 | 0.8076 | 1.0000 | 1.0000 | 0.8698 | 0.4973 | 0.6026 | 0.7707 | 1.0000 | 0.2732 |
| *NG* | 0.2038 | 0.2842 | 0.6426 | 0.7915 | 0.2246 | 0.3322 | 0.5567 | 0.3258 | 0.6176 | 0.7135 | 0.1111 | 0.2500 |
| *SA* | 0.1092 | 0.1434 | 0.2838 | 0.6781 | 0.3402 | 0.6419 | 0.4000 | 0.4344 | 0.5103 | 0.6438 | 0.1111 | 0.2000 |
| *AE* | 0.0928 | 0.1356 | 0.2288 | 0.6720 | 0.2932 | 0.2020 | 0.4175 | 0.3370 | 0.5211 | 0.5995 | 0.1250 | 0.1667 |
| *VE* | 1.0000 | 0.7143 | 1.0000 | 0.9451 | 0.3480 | 0.6419 | 1.0000 | 1.0000 | 1.0000 | 0.8905 | 1.0000 | 1.0000 |

Table 3. Results of the MEREC method

| Overall performance ($S_i$) | | Sum of absolute deviations ($E_j$) | | Relative weights ($w_j$) | |
|---|---|---|---|---|---|
| *S1* | 0.6279 | *E1* | 0.9322 | *w1* | 0.1457 |
| *S2* | 0.6408 | *E2* | 0.5982 | *w2* | 0.0935 |
| *S3* | 0.6060 | *E3* | 0.3974 | *w3* | 0.0621 |
| *S4* | 0.6530 | *E4* | 0.1271 | *w4* | 0.0199 |
| *S5* | 0.5603 | *E5* | 0.7063 | *w5* | 0.1104 |
| *S6* | 0.6890 | *E6* | 0.7434 | *w6* | 0.1162 |
| *S7* | 0.4843 | *E7* | 0.2752 | *w7* | 0.0430 |
| *S8* | 0.6078 | *E8* | 0.3876 | *w8* | 0.0606 |
| *S9* | 0.7506 | *E9* | 0.3264 | *w9* | 0.0510 |
| *S10* | 0.3375 | *E10* | 0.1534 | *w10* | 0.0240 |
| *S11* | 0.7027 | *E11* | 1.0082 | *w11* | 0.1576 |
| *S12* | 0.7730 | *E12* | 0.7424 | *w12* | 0.1160 |
| *S13* | 0.8498 | | | | |
| *S14* | 0.1547 | | | | |

Based on the results gathered from the MEREC technique, investment freedom (*C11*) is the most significant indicator, with 0.1576 among the economic freedom indicators. It is followed by property rights (*C1*) (0.1457), fiscal health (*C6*) (0.1162), and financial freedom (*C12*) (0.1160), respectively. However, trade freedom (*C10*) is discovered objectively as the least crucial indicator among 12 indicators.

## 2.2. Ranking the OPEC countries as per economic freedom using DNMA

Very recently, Liao and Wu (2020) developed the double normalization-based multiple aggregation (DNMA) technique which is designated by double target-based normalization techniques (linear and vector) and three types of aggregation operators. As in the second phase of the proposed model, below is the step-by-step solution to drive the DNMA method.

**Step 1.** The decision matrix, which is given in Table 1 above, consists of the economic freedom data of the OPEC countries. Based on this real data as well as Eqs (6) and (7), we get linear and vector normalized decision matrices as demonstrated in Tables 4 and 5, respectively.

**Step 2.** Considering weight values of criteria determined by MEREC above and employing the Eqs (8), (9), and (10), the adjusted criteria weights are derived as shown in Table 6.

Table 4. Linear normalization values

| | Criteria | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Optimization | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max |
| Countries | *C1* | *C2* | *C3* | *C4* | *C5* | *C6* | *C7* | *C8* | *C9* | *C10* | *C11* | *C12* |
| *DZ* | 0.3615 | 0.4365 | 0.3458 | 0.0000 | 0.4601 | 0.3659 | 0.6008 | 0.4183 | 0.9506 | 0.2638 | 0.4545 | 0.4000 |
| *AO* | 0.3111 | 0.1683 | 0.1041 | 0.6128 | 0.8863 | 0.7268 | 0.4691 | 0.5641 | 0.5730 | 0.6564 | 0.4545 | 0.6000 |
| *CD* | 0.3370 | 0.2097 | 0.1650 | 0.4024 | 0.8471 | 0.7757 | 0.0639 | 0.1599 | 1.0000 | 0.2331 | 0.5455 | 0.4000 |
| *EC* | 0.4366 | 0.1954 | 0.4597 | 0.3018 | 0.5020 | 0.7018 | 0.3393 | 0.3585 | 0.8921 | 0.3374 | 0.5455 | 0.6000 |
| *GQ* | 0.2769 | 0.0628 | 0.0373 | 0.2439 | 0.9283 | 0.9549 | 0.0599 | 0.1213 | 0.8404 | 0.0000 | 0.6364 | 0.4000 |
| *GA* | 0.2278 | 0.2068 | 0.4185 | 0.3201 | 0.9391 | 0.9248 | 0.4251 | 0.4464 | 0.9551 | 0.2454 | 1.0000 | 0.6000 |
| *IR* | 0.3547 | 0.2468 | 0.3281 | 0.4146 | 0.9296 | 0.7882 | 0.4731 | 0.3972 | 0.0022 | 0.1656 | 0.0000 | 0.0000 |
| *IQ* | 0.5089 | 0.0000 | 0.1356 | 0.4881 | 0.5940 | 0.9373 | 0.3653 | 0.3181 | 0.7865 | 0.4453 | 0.5035 | 0.5320 |
| *KW* | 0.6808 | 0.5934 | 0.6365 | 0.9299 | 0.0000 | 1.0000 | 0.6507 | 0.6098 | 0.7101 | 0.8282 | 0.9091 | 1.0000 |
| *LY* | 0.1228 | 0.1241 | 0.1159 | 0.4881 | 0.0000 | 0.0000 | 0.0998 | 0.4886 | 0.6225 | 0.4453 | 0.0000 | 0.5320 |
| *NG* | 0.3997 | 0.3951 | 0.1650 | 0.5396 | 1.0000 | 0.5013 | 0.5309 | 1.0000 | 0.5843 | 0.6012 | 0.7273 | 0.6000 |
| *SA* | 0.8349 | 0.9372 | 0.7485 | 0.9726 | 0.5616 | 0.1391 | 1.0000 | 0.6292 | 0.9056 | 0.8282 | 0.7273 | 0.8000 |
| *AE* | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.6982 | 0.9850 | 0.9301 | 0.9508 | 0.8674 | 1.0000 | 0.6364 | 1.0000 |
| *VE* | 0.0000 | 0.0628 | 0.0000 | 0.1189 | 0.5426 | 0.1391 | 0.0000 | 0.0000 | 0.0000 | 0.1840 | 0.0000 | 0.0000 |

Table 5. Vector normalization values

| | Optimization | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max |
| | *C1* | *C2* | *C3* | *C4* | *C5* | *C6* | *C7* | *C8* | *C9* | *C10* | *C11* | *C12* |
| *DZ* | 0.7380 | 0.7691 | 0.7737 | 0.9003 | 0.8606 | 0.8316 | 0.9125 | 0.8534 | 0.9924 | 0.9051 | 0.8016 | 0.8113 |
| *AO* | 0.7173 | 0.6592 | 0.6901 | 0.9614 | 0.9707 | 0.9274 | 0.8837 | 0.8902 | 0.9346 | 0.9557 | 0.8016 | 0.8742 |
| *CD* | 0.7279 | 0.6761 | 0.7112 | 0.9404 | 0.9605 | 0.9404 | 0.7949 | 0.7883 | 1.0000 | 0.9012 | 0.8347 | 0.8113 |
| *EC* | 0.7688 | 0.6703 | 0.8131 | 0.9304 | 0.8715 | 0.9208 | 0.8553 | 0.8384 | 0.9835 | 0.9146 | 0.8347 | 0.8742 |
| *GQ* | 0.7033 | 0.6159 | 0.6670 | 0.9246 | 0.9815 | 0.9880 | 0.7940 | 0.7786 | 0.9756 | 0.8711 | 0.8677 | 0.8113 |
| *GA* | 0.6832 | 0.6749 | 0.7988 | 0.9322 | 0.9843 | 0.9800 | 0.8741 | 0.8605 | 0.9931 | 0.9027 | 1.0000 | 0.8742 |
| *IR* | 0.7352 | 0.6913 | 0.7676 | 0.9416 | 0.9818 | 0.9437 | 0.8846 | 0.8481 | 0.8472 | 0.8925 | 0.6363 | 0.6855 |
| *IQ* | 0.7985 | 0.5902 | 0.7010 | 0.9490 | 0.8952 | 0.9834 | 0.8609 | 0.8282 | 0.9673 | 0.9285 | 0.8194 | 0.8528 |
| *KW* | 0.8690 | 0.8334 | 0.8743 | 0.9930 | 0.7419 | 1.0000 | 0.9235 | 0.9017 | 0.9556 | 0.9779 | 0.9669 | 1.0000 |
| *LY* | 0.6401 | 0.6410 | 0.6942 | 0.9490 | 0.7419 | 0.7344 | 0.8028 | 0.8711 | 0.9422 | 0.9285 | 0.6363 | 0.8528 |
| *NG* | 0.7537 | 0.7521 | 0.7112 | 0.9541 | 1.0000 | 0.8675 | 0.8972 | 1.0000 | 0.9363 | 0.9486 | 0.9008 | 0.8742 |
| *SA* | 0.9323 | 0.9743 | 0.9130 | 0.9973 | 0.8868 | 0.7713 | 1.0000 | 0.9066 | 0.9855 | 0.9779 | 0.9008 | 0.9371 |
| *AE* | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9221 | 0.9960 | 0.9847 | 0.9876 | 0.9797 | 1.0000 | 0.8677 | 1.0000 |
| *VE* | 0.5897 | 0.6159 | 0.6541 | 0.9122 | 0.8819 | 0.7713 | 0.7809 | 0.7480 | 0.8468 | 0.8948 | 0.6363 | 0.6855 |

Table 6. Adjusted criteria weights

| $\tilde{\omega}_1$ | $\tilde{\omega}_2$ | $\tilde{\omega}_3$ | $\tilde{\omega}_4$ | $\tilde{\omega}_5$ | $\tilde{\omega}_6$ | $\tilde{\omega}_7$ | $\tilde{\omega}_8$ | $\tilde{\omega}_9$ | $\tilde{\omega}_{10}$ | $\tilde{\omega}_{11}$ | $\tilde{\omega}_{12}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1149 | 0.0963 | 0.0729 | 0.0351 | 0.1048 | 0.1118 | 0.0575 | 0.0688 | 0.0632 | 0.0390 | 0.1307 | 0.1051 |

**Steps 3 and 4.** To arrive at the final ranking, as mentioned above, the CCM, UCM, and ICM values need to compute firstly. To achieve this, Eqs (11), (12), and (13) are performed, respectively. Then, utilizing Eq. (14), the final ranking of alternatives is found. In calculations, it should be noted that the weights of CCM, UCM, and ICM are $w_1 = 0.6$, $w_2 = 0.1$, and $w_3 = 0.3$, respectively. All values calculated are presented in Table 7 below. Consequently, the rank order of alternatives is $AE \succ SA \succ KW \succ GA \succ NG \succ AO \succ EC \succ IQ \succ GQ \succ CD \succ DZ \succ IR \succ LY \succ VE$, which indicates that the UAE is the most economical freedom country. It is followed by Saudi Arabia and Kuwait, respectively. However, Iran, Libya, and Venezuela are the worst-performing OPEC countries in terms of economic freedom.

Table 7. The results obtained by DNMA

| | *CCM* | | *UCM* | | *ICM* | | Utility value | Rank order |
|---|---|---|---|---|---|---|---|---|
| | $u_1(a_i)$ | $r_1(a_i)$ | $u_2(a_i)$ | $r_2(a_i)$ | $u_3(a_i)$ | $r_3(a_i)$ | | |
| *DZ* | 0.4555 | 11 | 0.0878 | 8 | 0.8330 | 9 | 0.3087 | 11 |
| *AO* | 0.5700 | 6 | 0.1016 | 12 | 0.8584 | 6 | 0.4597 | 6 |
| *CD* | 0.4608 | 10 | 0.0867 | 7 | 0.8257 | 11 | 0.3218 | 10 |
| *EC* | 0.5517 | 7 | 0.0825 | 6 | 0.8549 | 7 | 0.4524 | 7 |
| *GQ* | 0.4642 | 9 | 0.0990 | 10 | 0.8281 | 10 | 0.3322 | 9 |
| *GA* | 0.6084 | 4 | 0.1009 | 11 | 0.8685 | 4 | 0.5534 | 4 |
| *IR* | 0.3762 | 12 | 0.0907 | 9 | 0.8070 | 12 | 0.2479 | 12 |
| *IQ* | 0.5165 | 8 | 0.0685 | 4 | 0.8433 | 8 | 0.4199 | 8 |
| *KW* | 0.7066 | 3 | 0.0417 | 3 | 0.9095 | 3 | 0.6689 | 3 |
| *LY* | 0.3270 | 13 | 0.1842 | 13 | 0.7862 | 14 | 0.1877 | 13 |
| *NG* | 0.5935 | 5 | 0.0784 | 5 | 0.8672 | 5 | 0.5439 | 5 |
| *SA* | 0.7187 | 2 | 0.0216 | 2 | 0.9158 | 2 | 0.7221 | 2 |
| *AE* | 0.9034 | 1 | 0.0000 | 1 | 0.9699 | 1 | 0.8137 | 1 |
| *VE* | 0.1655 | 14 | 0.2408 | 14 | 0.7870 | 13 | 0.1288 | 14 |

Figure 2 illustrates a heat map based on the score of countries in terms of economic freedom criteria in this work. In this figure, the green color shows the best performance and the red color shows the worst performance. That is, the country's performance improves as the color changes from red to green.

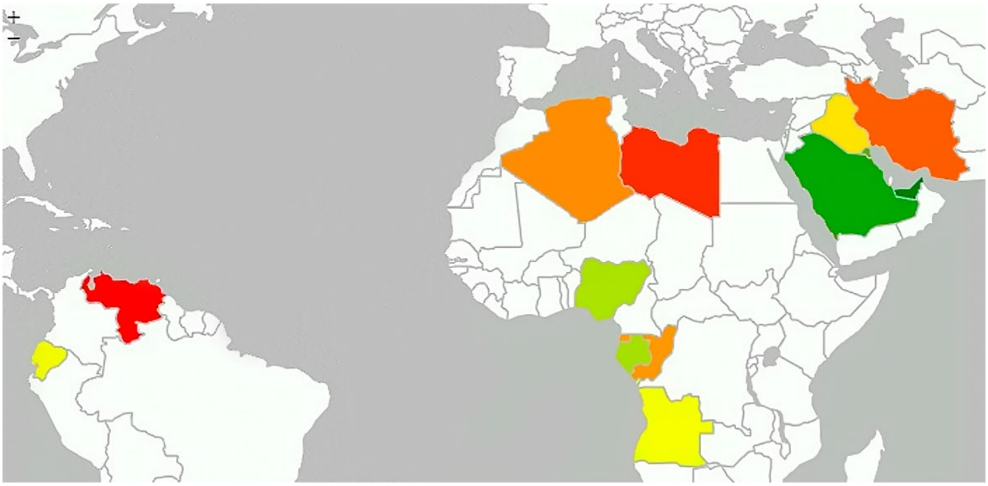

Figure 2. Heat map of OPEC countries based on results of MEREC-DNMA model

### 2.3. Sensitivity analysis

Although novel MCDM methods provide more reliable decision-making frameworks than traditional methods, there are still some important issues regarding such methods. In different cases, MCDM methods can become highly sensitive to parameters, experts' opinions, and other related values within the model. One of the effective computational analyses to verify the results of an MCDM method is to conduct sensitivity analysis on potential parts of the method where possible changes may bring up serious modification in results. This section presents several sensitivity analysis tests to validate the model for the considered problem.

#### 2.3.1. Effects of the criteria weights on the final ranking

Weight coefficients are crucial parts of any MCDM method, which have serious effects on the results of decision models. In general, decision models aim to determine weight coefficients using systematic MCDM weighting models such as MEREC, BWM, and AHP. However, any inconsistencies in the weight coefficient can dramatically affect the final ranking order of the model. Therefore, this section provides a simulated framework with five weight vectors to observe how the proposed model behaves under different weight values. These simulated weight vectors are named "Case #" in Table 8.

Case 1 represents the initial status of the model where results are obtained in the previous section. Case 2 assumes that all criteria should have the same weight value. This is the situation that is also considered in computations of The Heritage Foundation. According to the results of Table 8, UAE, Saudi Arabia, and Kuwait are the three top countries in Case 2; however, there are slight changes compared to Case 1. Nigeria is placed in 4$^{th}$ rank while it was in 5$^{th}$ (in Case 1). Similarly, the ranking order of Angola, Gabon, and Algeria are also changed.

Cases 3, 4, and 5 aim to observe the behavior of the proposed methodology where some of the criteria are highlighted, and some are given minor importance. Case 3 assign maximum possible weight importance to the first four criteria and minimum importance of the result of the criteria. In this situation, again, UAE, Saudi Arabia, and Kuwait are the three top countries. Changes in Case 3 are very similar to changes in Case 2 against Case 1. This situation also occurs for Case 4 and 5 as well. Based on indications of Table 8, results provide that the proposed approach is very robust to determine which countries perform well against economic freedom criteria even under different weight values.

Figure 3 illustrates changes in the ranking order of countries under five defined cases in Table 8.

Table 8. The ranking order of alternatives concerning the changes of criteria weights

| Case | Weights | Final ranking |
|---|---|---|
| Case 1 | Current | $AE \succ SA \succ KW \succ GA \succ NG \succ AO \succ EC \succ IQ \succ GQ \succ CD \succ DZ \succ IR \succ LY \succ VE$ |
| Case 2 | All equal ($w_1 = w_2 = \ldots = w_{12}$) | $AE \succ SA \succ KW \succ NG \succ AO \succ GA \succ EC \succ IQ \succ DZ \succ CD \succ GQ \succ IR \succ LY \succ VE$ |
| Case 3 | $w_1 = w_2 = w_3 = w_4 = 0.10$, the rest 0.075 | $AE \succ SA \succ KW \succ NG \succ AO \succ GA \succ EC \succ IQ \succ DZ \succ CD \succ GQ \succ IR \succ LY \succ VE$ |
| Case 4 | $w_5 = w_6 = w_7 = w_8 = 0.10$, the rest 0.075 | $AE \succ SA \succ KW \succ NG \succ AO \succ GA \succ EC \succ IQ \succ DZ \succ CD \succ GQ \succ IR \succ LY \succ VE$ |
| Case 5 | $w_9 = w_{10} = w_{11} = w_{12} = 0.10$, the rest 0.075 | $AE \succ SA \succ KW \succ NG \succ AO \succ GA \succ EC \succ IQ \succ DZ \succ CD \succ GQ \succ IR \succ LY \succ VE$ |

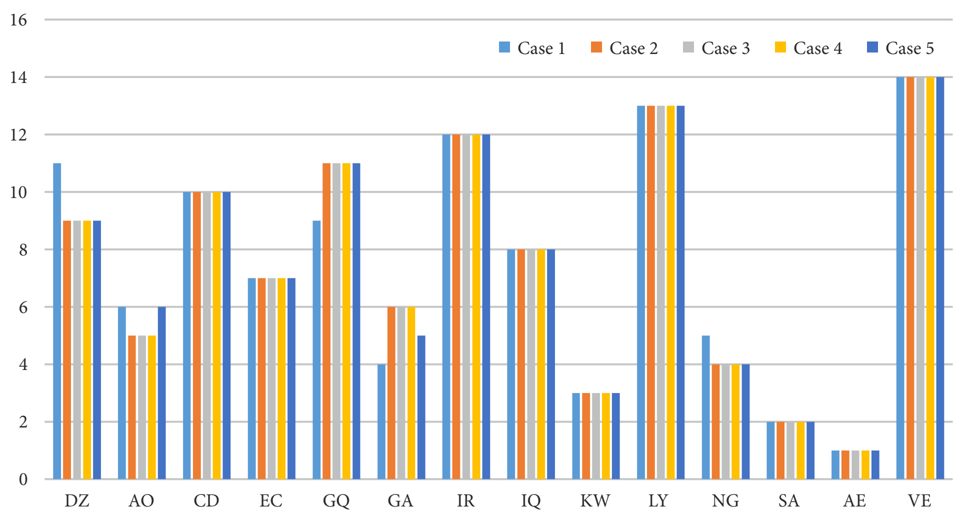


Figure 3. Ranking of alternatives under defined weight cases

#### 2.3.2. Impact of the weights of utility functions

Numerous MCDM techniques in the literature are based on compromise solution-based functions, utility functions, or distance functions. Within these functions that determine the final performance of alternatives, there are some intermediate parameters that are used as aggregators. DNMA model also consists of three parameters that integrate three utility functions CCM, UCM, and ICM. In the previous result section, the initial values for these parameters are considered as 0.6 for CCM, 0.1 for UCM, and 0.3 for ICM utility functions. This section aims to observe how the proposed model reacts to changes in the weight of utility functions in terms of the ranking order of countries. Seven scenarios are generated to simulate the model's performance under different weight values of utility functions.

Table 9 presents detailed information on weight scenarios and their impact on the final ranking order of OPEC countries. In all scenarios generated in this part, UAE, Saudi Arabia, and Kuwait are the top countries with the best performance against economic freedom criteria. To understand the results of this part, Figure 4 demonstrates how OPEC countries are ranked under each scenario.

Table 9. The ranking order of alternatives as per the changes of the weights of CCM, UCM, and ICM

| | Scenario 1 (Current) | Scenario 2 ($\varpi_1 = \varpi_2 = \varpi_3 = 0.333$) | Scenario 3 ($\varpi_1 = 0.5$, $\varpi_2 = \varpi_3 = 0.25$) | Scenario 4 ($\varpi_2 = 0.5$, $\varpi_1 = \varpi_3 = 0.25$) | Scenario 5 ($\varpi_3 = 0.5$, $\varpi_1 = \varpi_2 = 0.25$) | Scenario 6 ($\varpi_1 = 0.8$, $\varpi_2 = \varpi_3 = 0.1$) | Scenario 7 ($\varpi_2 = 0.8$, $\varpi_1 = \varpi_3 = 0.1$) | Scenario 8 ($\varpi_3 = 0.8$, $\varpi_1 = \varpi_2 = 0.1$) |
|---|---|---|---|---|---|---|---|---|
| *DZ* | 11th | 10th | 10th | 9th | 10th | 11th | 8th | 9th |
| *AO* | 6th | 8th | 8th | 10th | 8th | 6th | 12 | 7th |
| *CD* | 10th | 9th | 9th | 8th | 9th | 10th | 7th | 10th |
| *EC* | 7th | 6th | 6th | 6th | 6th | 7th | 6th | 6th |
| *GQ* | 9th | 11th | 11th | 11th | 11th | 9th | 11th | 11th |
| *GA* | 4th | 7th | 5th | 7th | 5th | 4th | 10th | 4th |
| *IR* | 12th | 12th | 12th | 12th | 12th | 12th | 9th | 12th |
| *IQ* | 8th | 5th | 7th | 5th | 7th | 8th | 4th | 8th |
| *KW* | 3rd | 3rd | 3rd | 3rd | 3rd | 3rd | 3rd | 3rd |
| *LY* | 13th | 13th | 13th | 13th | 13th | 13th | 13th | 13th |
| *NG* | 5th | 4th | 4th | 4th | 4th | 5th | 5th | 5th |
| *SA* | 2nd | 2nd | 2nd | 2nd | 2nd | 2nd | 2nd | 2nd |
| *AE* | 1st | 1st | 1st | 1st | 1st | 1st | 1st | 1st |
| *VE* | 14th | 14th | 14th | 14th | 14th | 14th | 14th | 14th |

#### 2.3.3. Multi-period analysis of OPEC countries

In a world full of dynamicity and fluctuations in events and systems, evaluations of countries regarding their performance against economic freedom criteria have become a complex task. Although The Heritage Foundation considers equal importance for the weight value of criteria, in real-life practices and conditions, the weight of criteria may change year by year due to a series of annual changes in the world's economy. Such changes also make a serious impact on how countries are ranked. In this regard, the proposed model is a reliable aggregation model to determine to what extent OPEC countries could achieve excellence in terms of annual weight of economic freedom criteria. Figure 5 illustrates ranking orders obtained through a multi-period assessment of OPEC countries against economic freedom criteria.

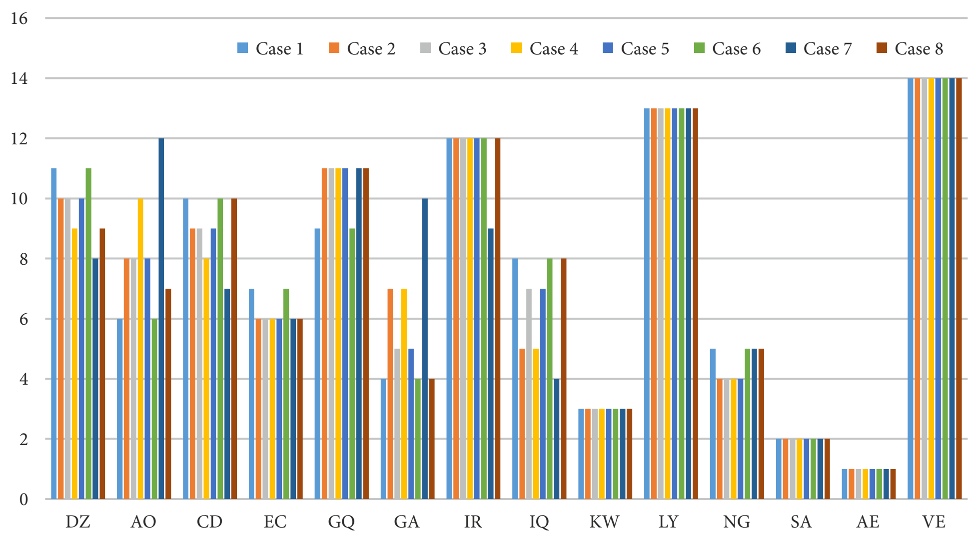


Figure 4. Ranking of alternatives based on various scenarios

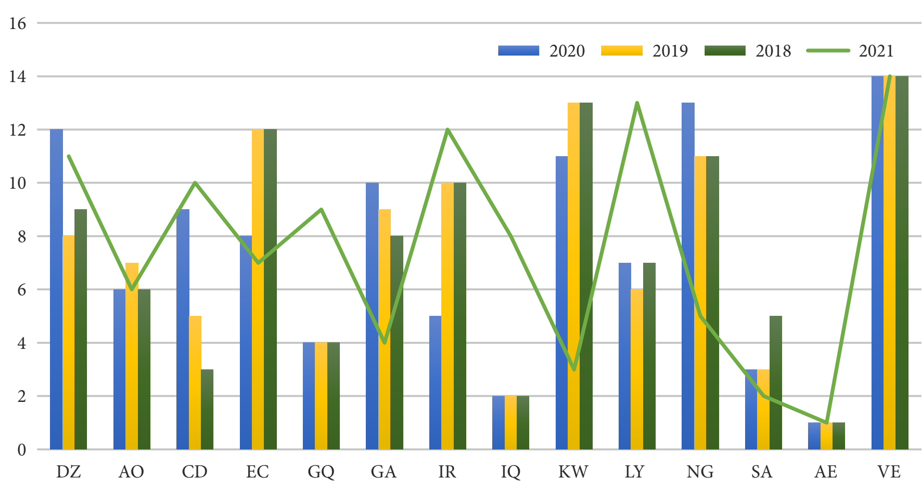


Figure 5. Multi-period assessment of OPEC countries

According to Figure 5, UAE and Saudi Arabia have shown robust performance over the last three years in which they ranked as the top two countries with the highest performance. Saudi Arabia has shown noticeable improvement in its economic freedom performance since 2018 where it was ranked as 5th country, but now in 2021 is ranked as 2nd country. Kuwait also showed similar performance and highly maximized its performance through the last three years (3rd). Some countries, such as Venezuela, have not improved through the last years, and they are ranked in the same place as 2021. On the other hand, some countries could not improve their performance due, and their performance deteriorated year by year. Iraq is one of these countries ranked as 2nd country during last years, but its performance in 2021 has dramatically decreased. The same has happened to countries such as Equatorial Guinea, Libya, Algeria, and Iran.

#### 2.3.4. Comparison of other MCDM methods

To confirm the quality of the solution obtained, the results found with some powerful MCDM methods can also be utilized. Thus, the reliability of the outcomes is evaluated concerning the other MCDM methods such as ARAS, COCOSO, MAIRCA, and MARCOS. Spearman's analysis is therefore employed to compare the final rankings of the methods. Comparison of the outcomes gathered by performing Spearman's analysis is depicted in Table 10.

Table 10. Spearman's rho values of the techniques compared.

| | | ARAS | COCOSO | MAIRCA | MARCOS |
|---|---|---|---|---|---|
| DNMA | Spearman's rho value | 0.982 | 0.987 | 0.991 | 0.991 |
| | Significance | 0.000** | 0.000** | 0.000** | 0.000** |

*Note*: **. Significant at the 1% level (two-tailed).

The results of Spearman's analysis address a very high correlation between the rankings of the various MCDM techniques. As per the recommendations of many authors (Rani et al., 2022; Pamucar et al., 2021), all Spearman's rho values higher than 0.80 emphasize a remarkably strong correlation. Based on Table 10, therefore, it is possible to deduce that the framework proposed has sufficient reliability.

## 3. Managerial and theoretical implications

Economic freedom is considered one of the important drivers for economic growth and achieving sustainable development goals. The proposed multi-criteria model generates useful results that can be used as insights within economic plans and strategies. This section discusses insights into the findings gathered conducting the introduced approach for countries with best and worst performances.

UAE is selected as the best country among all OPEC members based on its outstanding performance in economic freedom. UAE has shown the best performance over the last three years and none of the OPEC members could challenge the country in this regard. Considering the nature of OPEC countries and their organizational systems, corruption has always been a threat. However, UAE has made specific efforts to minimize corruption within its organizational systems. On the other hand, UAE has shown high performance in terms of high capital income and trade, mostly oil and gas. Besides its energy trade, tourism, and manufacturing centers with modern technologies have been great drivers to UAE's high GDP per capita during the last years. Comparing the results of previous years with those of 2021, it is understood that UAE has made great improvements in government size and regulatory efficiency criteria.

As one of the biggest countries in the Middle East and OPEC, Saudi Arabia is thought one of the prominent countries with free economic. Based on the results, Saudi Arabia has improved its economic freedom performance over the last years and is now ranked as 2nd country after UAE. Saudi Arabia's improvement in terms of economic freedom goals is mostly because of structural changes in its organizational systems, which have facilitated business freedom compared to recent decades. The oil industry contributes highly to Saudi Arabia's economy and GDP. Maybe one of the possible ways to improve its economic freedom is to stop relying on the oil industry and make investments in green energy generation.

Our results indicate that Venezuela has been a country with the worst economic freedom over the last years. Based on the original data, Venezuela only showed improvements in judicial effectiveness, government integrity, and business freedom while other criteria were worsened compared to 2020. One of the main reasons behind Venezuela's weak performance is corruption spread in all organizations and sectors. Outside OPEC countries, Venezuela is also selected as the worst country among all Americas region by The Heritage Foundation. Although Venezuela has high fossil fuel reservoirs, its weak market democracy, high inflation, and public debt have ended this country with the weakest performance among all OPEC countries. Great structural changes in the governmental system and related sectors are considered possible ways to improve the economic freedom of Venezuela.

Composite index systems based on MCDM play an essential role in picturing the overall economic freedom performance of countries. Thence, the theoretical implications of this paper are twofold. First, in the study, the MEREC technique is employed to observe the criteria weights. With the technique, criteria weights are determined objectively. Besides, importance weights are decided by taking into account the effect of the criterion left out of the criterion set. Thus, more realistic evaluations can be made by ignoring criteria that have little impact on performance. Second, to find the overall prioritization of the countries, this research utilizes the DNMA method. Since the normalization is done simultaneously with two different techniques, the shortcomings and disadvantages of each technique are compensated by the other. Thus, more successful evaluations can be made by preventing information loss. Further, the method achieves final sequence ordering using three different aggregation functions. The MEREC-DNMA framework proposed could be employed by researchers and authorities for managing a more detailing investigation of factors affecting economic freedom and evaluation of other countries in the world. The study result can as well be exploited to identify and recognize the critical factors for achieving economic freedom.

## Conclusions

To assess the overall performance of countries effectively and efficiently in terms of economic freedom, this paper constitutes an integrated MEREC and DNMA multi-criteria decision support system. Utilizing the Heritage Foundation economic freedom data for 2021, we employ the MEREC objective weighting method for calculating the weight values of 12 economic freedom indicators, whereas the DNMA technique for determining the ranking of countries according to economic freedom. Based on the results obtained, investment freedom, property rights, and fiscal health are the key indicators to decide countries' economic freedom levels. Additionally, in light of weights of indicators, the UAE has the highest position country among 14 OPEC countries in terms of economic freedom. Moreover, Saudi Arabia, Kuwait, and Gabon are countries with satisfactory economic freedom, among others. Nevertheless, it has been determined that the economic freedoms of Iran, Libya, and Venezuela are not at a good level. The sanctions imposed on these countries worldwide and their domestic instability problems may have caused this outcome. Naturally, this study has some limitations. In the DNMA method, the weights of CCM, UCM, and ICM values are determined by the decision-maker. It should be noted that changing these values may affect the results.

There are some suggestions for future work. In the future, through the proposed model, economic freedom analyzes can be conducted within the consideration of developed and developing countries as well as countries in Asia, Europe, Africa, and other continents. Future work may address diverse MCDM methods such as MABAC, MAIRCA, MARCOS, and MACONT with fuzzy, rough, and soft sets for specifying economic freedom ranking to handle vagueness in expert preferences to bring the matter closer to the real world. Other suitable methods can be integrated into MCDM models to develop a more reliable aggregation model or score calculators to determine the overall performance of countries.

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# APPENDIX

## The preliminaries

### A.1. MEREC

**Step 1.** *Form the decision matrix.* First, a decision matrix ($X$) consisting of $n$ alternatives and $m$ criteria is built. It is stated that its elements ($x_{ij}$) should be positive.

**Step 2.** *Built the normalized decision matrix.* In the second step of the method, all elements of the decision matrix are normalized by Eq. (1).

$$n_{ij} = \begin{cases} \dfrac{\min\limits_k x_{kj}}{x_{ij}}, \ j \text{ is a benefit criterion} \\ \dfrac{x_{ij}}{\max\limits_k x_{kj}}, j \text{ is a cost criterion} \end{cases}. \tag{1}$$

**Step 3.** *Compute the overall performance of the alternatives.* Eq. (2) is employed for this calculation.

$$S_i = ln\left(1 + \left(\frac{1}{m}\sum_j \left|\ln\left(n_{ij}\right)\right|\right)\right). \tag{2}$$

**Step 4.** *Compute the performance of the alternatives by removing each criterion.* By removing each criterion from the whole criteria set, $m$ sets of performances are obtained as per m criteria. Thus, Eq. (3) is handled for computations.

$$S'_{ij} = \ln\left(1 + \left(\frac{1}{m}\sum_{k,k\neq j} \left|\ln\left(n_{ij}\right)\right|\right)\right). \tag{3}$$

**Step 5.** *Calculate the summation of absolute deviations.* Should $E_j$ represents the effect of removing the $j$th criterion, it can be calculated the values of $E_j$ by Eq. (4).

$$E_j = \sum_i \left|S'_{ij} - S_i\right|. \tag{4}$$

**Step 6.** *Decide the importance weights of the criteria.* Using Eq. (4), finally, we obtain the relative weights of the criteria.

$$w_j = \frac{E_j}{\sum_k E_k}. \tag{5}$$

## A.2. DNMA

**Step 1.** *Normalization.* First, the normalization process is applied for raw data via Eqs (6) and (7). More clearly, Eq. (6) is utilized for target-based linear normalization, whilst Eq. (7) is employed for target-based vector normalization.

$$\tilde{x}_{ij}^{1N} = 1 - \frac{\left|x^{ij} - r_j\right|}{\max\left\{\max_i x^{ij}, r_j\right\} - \min\left\{\min_i x^{ij}, r_j\right\}}; \tag{6}$$

$$\tilde{x}_{ij}^{2N} = 1 - \frac{\left|x^{ij} - r_j\right|}{\sqrt{\sum_{i=1}^{m}\left(x^{ij}\right)^2 + \left(r_j\right)^2}}, \tag{7}$$

where $r_j = \begin{cases} \max_i x_{ij}, \text{ if } c_j \in B \\ \min_i x_{ij}, \text{ if } c_j \in C \end{cases}.$

**Step 2.** *Adjusting.* To realize a trade-off between the evaluation criteria, in this step of the method, the weight values of criteria are adjusted by Eq. (8).

$$\omega_j^{\sigma} = \frac{\sigma_j}{\sum_{j=1}^{n} \sigma_j}. \tag{8}$$

In Eq. (8), $\sigma_j$ denotes the standard deviation of criterion $c_j$ and is calculated by Eq. (9).

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}\left(\frac{x^{ij}}{\max_i x^{ij}} - \frac{1}{m}\sum_{i=1}^{m}\left(\frac{x^{ij}}{\max_i x^{ij}}\right)\right)^2}{m}}. \tag{9}$$

Last but not least, with the help of Eq. (10), weights are adjusted as below.

$$\tilde{\omega}_j = \frac{\sqrt{\omega_j^{\sigma}.\omega_j}}{\sum_{j=1}^{n}\sqrt{\omega_j^{\sigma}.\omega_j}}. \tag{10}$$

**Step 3.** *Aggregation.* Considering three aggregation operators, the complete compensatory model (*CCM*), un-compensatory model (*UCM*), and incomplete compensatory model (*ICM*), we compute three types of utility values by Eqs (11), (12), and (13).

$$u_1\left(a_i\right)=\sum_{j=1}^{n}\tilde{\omega}_j.\tilde{x}_{ij}^{1N} / \max_i \tilde{x}_{ij}^{1N}; \tag{11}$$

$$u_2\left(a_i\right)=\max_j \tilde{\omega}_j(1-\tilde{x}_{ij}^{1N} / \max_i \tilde{x}_{ij}^{1N}); \tag{12}$$

$$u_3\left(a_i\right)=\prod_j\left(\tilde{x}_{ij}^{2N} / \max_i \tilde{x}_{ij}^{2N}\right)^{\omega_j}. \tag{13}$$

Thus, three subordinate ranks of $a_i$ are found, in descending, ascending, and descending orders of $u_1(a_i)$, $u_2(a_i)$, and $u_3(a_i)$, respectively.

**Step 4.** *Synthesizing and ranking*. In the last step, by Eq. (14), the comprehensive utility values are calculated by aggregating the utility values of *CCM*, *UCM*, and *ICM* and the subordinate ranks of alternatives.

$$S_i=\varpi_1 \cdot \sqrt{\varphi.\left(u_1\left(a_i\right)/\max_i u_1\left(a_i\right)\right)^2+\left(1-\varphi\right).\left(\frac{m-r_1\left(a_i\right)+1}{m}\right)^2}-$$
$$\varpi_2 \cdot \sqrt{\varphi.\left(u_2\left(a_i\right)/\max_i u_2\left(a_i\right)\right)^2+\left(1-\varphi\right).\left(\frac{r_2\left(a_i\right)}{m}\right)^2}+$$
$$\varpi_3 \cdot \sqrt{\varphi.\left(u_3\left(a_i\right)/\max_i u_3\left(a_i\right)\right)^2+\left(1-\varphi\right).\left(\frac{m-r_3\left(a_i\right)+1}{m}\right)^2}, \tag{14}$$

where the parameter $\varphi\left(\varphi\in\left[0,1\right]\right)$ is the relative importance of the utility value and can be taken as 0.5. Besides, $\varpi_1$, $\varpi_2$, and $\varpi_3$ and are the weights of CCM, UCM, and ICM, respectively, which satisfies $\varpi_1 + \varpi_2 + \varpi_3 = 1$. According to Wu and Liao (2019), higher weight can be allocated to the CCM if the decision-maker is willing to survey the comprehensive performances of the alternatives. Should s/he does not want to take a risk, a large weight value could be assigned to the UCM. Last, a large weight value may be assigned to the ICM if s/he is optimal about comprehensive performance and taking risks. Ultimately, alternatives are ranked in descending order, which means the alternative with the highest $S_i$ value is finest.