Sustainability of G20 Countries within Environmental and Energy Perspectives

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Abstract: Sustainability is one of the most significant aims strived to achieve. Energy and the environment are interrelated factors that contribute to sustainability. Measuring energy and environmental sustainability is of utmost importance. The paper's aim is to analyze the energy and environmental performance of the G20 members. An integrated approach with MCDM methods is proposed. First, we attribute criteria weight via the CRITIC method. Secondly, we evaluate the performance of the G20 countries via the VIKOR and CoCoSo methods. Our results show that Brazil is ranked as the G20 country with the best performance. We may conclude that performance evaluation via MCDM methods may give significant insight into the sustainable development of countries.

1. Introduction

Sustainable development is closely related to sustainable and environmentally friendly energy resources (Grigoroudis et al., 2021). Therefore, sustainability is one of the most significant aims for countries to attend. Recently, industrialization and increasing population have made countries act more cautiously (Ecer et al., 2019). In this regard, carbon dioxide (CO₂) emissions stemming from using fossil energy sources are a remarkable threat to sustainability. Renewable energy has been a pivotal alternative to provide sustainability for countries. Heavy industry-oriented sectors need a great amount of energy in developed countries (Bekun et al., 2019). A high share of the global energy supply belongs to fossil fuels, which are unsustainable and will deplete in the future. Fossil fuels are also drivers of other environmental problems namely acid rain, particulates, and aerosols (Michaelides, 2018). These problems have urged countries to be more cautious to maintain sustainability and the ecosystem of the environment (Wang and Zhan, 2019). The increasing fossil fuel prices have caused energy security problems, which sustain countries to sustainability problems. Renewable energy sources (RESs) are considered extremely efficient breakthroughs in challenging the aforementioned threats (Petinrin and Shaaban, 2015). Governments have focused more on sustainable development objectives in recent years. Sustainable development is defined as meeting present demands without compromising the capacity of future generations to meet their necessities (Phillis et al., 2021). Given the world's finite resources and catastrophic environmental consequences, living a more sustainable lifestyle is one of the most crucial solutions that must be seriously considered (Zolfani et al., 2018). When a choice addressing sustainability, issues needs to be taken, research-based information about sustainability is required. Providing open, logical, and consistent decision support for sustainable consumption and production patterns has been harder. Various concepts, such as ecological capacity, resources, and technological criticism, are the precursors of the concept of sustainability (Dong and Hauschild, 2017).
influence regulators to make decisions that will lead to a world that is habitable and sustainable for humans. Decarbonization is a critical solution to address the economic and environmental problems caused by climate change. Expanding the economy and reducing CO$_2$ emissions are crucial for low-carbon approaches in societies (Sun et al., 2020). Hence, it is very essential to evaluate sustainability levels by different MCDM methods as it sheds light on the performances of investigated countries and presents policy implications about energy and environmental sustainability.

The G20 is an international economic cooperation group made up of the world’s most developed nations (Wang et al., 2020). Energy necessity is excessive in G20, which comprises mostly industrialized countries. G20 accounts for over 70% of energy use and greenhouse gas (GHG) emissions in the world. G20 countries comprise the leading economies of the world. They constitute approximately 77% of the universal economy and emit 75% of CO$_2$ emissions (Valdez, 2021). Risk management is very crucial in financial markets; it is one of the most significant issues for countries to provide their sustainability (Gökgöz and Altıntaş, 2013). Therefore, energy and environmental sustainability should be at the forefront in order to maintain the sustainable development of countries. Increased economic operation and high energy consumption have hampered long-term planning and made it more challenging to maintain sustainability. In order to strike a balance between environment and economic development, the need to align the interests of the many parties involved in long-term planning strategies has grown. Sustainability evaluation models can be regarded as the fundamental part of sustainability performance measurement (Pérez-Gladish et al., 2021). However, with the decision-making process more difficult and complex in sustainability assessment, decision-makers have sought alternative techniques. To this end, Multi-Criteria Decision-Making (MCDM) methods, which are components of Operation Research, have been used in sustainability assessment. MCDM techniques serve as useful tools for organizing and analyzing complicated decision situations, enabling more informed and better conclusions. For this reason, a variety of evaluation standards and testing techniques have been developed. It quickly became apparent that no single strategy is superior to all other methods in every way. Therefore, the question of how to determine which approach is the best becomes necessary. However, in order to respond to the question of the best MCDM technique, one must first apply the best MCDM method. As a result, a decision paradox results. This is the key justification for using a comparative approach when dealing with MCDM techniques (Triantaphyllou, 2000). The best way to assess how well various countries have performed in achieving their sustainable energy development goals is to apply MCDM methods, which allow trade-offs between important components of sustainable development (Su et al. 2020).

MCDM methods are suitable techniques to determine the best option among a set of alternatives (Vinogradova et al., 2018). The MCDM framework starts with determining evaluation criteria and alternatives. Then, the weights attributed to the criteria are determined. To obtain a ranking, MCDM methods are applied and the final ranking is obtained (Barak and Mokfi, 2019). Practitioners have long implemented MCDM approaches to find a compromise solution (Abdelli et al., 2020). MCDM techniques are used in many different fields (Ren, 2020). Sustainability assessment is one of those fields, which necessitates considering different and conflicting criteria (Štirbanović et al., 2019). To this end, we evaluate the energy and environmental sustainability performance of the G20 countries via MCDM methods comparatively. Even if energy and environmental sustainability are key components of sustainability, the studies investigating the energy and environmental sustainability performance of countries via MCDM techniques are limited. These studies generally focus on either the energy or environment dimensions. We present these studies briefly.

Sun et al. (2020) assessed the environmental sustainability of South Asian region by a DEA-like technique. Their results point out the importance of RES for environmental sustainability. Using the Analytic Hierarchy Process, Cucchiella et al. (2017) evaluated the European countries’ sustainability performance regarding energy and environmental
indices. The countries which focus on RES and recycling wastes perform better. Su et al. (2020) used the TOPSIS and WASPAS methodologies to assess the energy sustainability of China and the European Union (EU). The reduction of energy import dependency and diversifying energy sources and RES generation are key policies for energy sustainability. Phillis et al. (2021) used the PROMETHEE approach to evaluate the energy sustainability of the European nations. The findings indicate a high correlation between geographic and socioeconomic groups and the efficiency of energy sustainability.

On the other hand, our analysis depends on both dimensions with an integrated framework. To our knowledge, this is a frontier study in energy and environmental sustainability of the G20 countries measured by MCDM techniques. We utilize different MCDM techniques to increase the robustness of our analysis. The main objective of our analysis is to assess and compare energy and environmental sustainability, which are pillars of sustainable development, in an integrated framework via MCDM approaches and present the best and worst-performing countries for policy implications. The main research gap our study aims to fill is to present an integrative performance assessment for the OECD countries, which accounts for around 80% of the Gross World Product and global energy demand. Energy and environment are two important pillars of sustainability, which are stressed in the 2030 Agenda for Sustainable Development. The available studies have focused on either energy or environmental aspects whereas our study depends on both aspects of energy and environmental aspects. Further, our empirical analysis brings a comparative assessment of the OECD countries by focusing on ingrained and novel approaches namely the VIKOR and CoCoSo methods respectively. The main aim of the study is to present the energy and environmental performance thereby putting forth the best and worst countries and determining policy implications for unsuccessful countries.

Our study continues in that way. Initially, we present sustainability studies about MCDM methods. Then, we introduce the MCDM methods used in our empirical analysis. Lastly, our study finishes with our conclusion and discussion.

2. Literature Review

Some studies exist about the energy and environmental sustainability performance of countries carried out via the DEA and MCDM methods in the literature. The DEA is an efficiency technique used to evaluate the relative performance of alternatives (Gökgöz, 2010; Gökgöz and Güvercin, 2018; Gökgöz and Yalçın, 2022). The following is a summary of these studies.

Phillis et al. (2021) assessed the energy sustainability of the European countries via the MCDM framework namely the PROMETHEE approach. They constitute three main dimensions namely environment, human system, and energy system. According to their analysis, Scandinavian countries outperform other nations in terms of energy sustainability.

Su et al. (2020) compared the energy sector sustainability of the EU and China via the TOPSIS and WASPAS approaches over ten years. They use economic, environmental, and social indicators to evaluate the energy sustainability of countries. They conclude that Romania, Czechia, and, Latvia performed better due to the high share of RES and increase in energy security.

Cucchiella et al. (2017) assessed the sustainability performance of the European countries comprising energy and environmental index via the AHP. They use GHG emissions, public spending for environmental preservation, recycled waste from electric and electronic equipment, recycled waste from extinct vehicles, recycled substances from municipal solid wastes, the share of RES in electricity and transport use. According to the analysis consequences, Sweden ranks as the top country in terms of sustainability.

Sun et al. (2020) assessed the environmental sustainability of South Asian countries via an index similar to DEA. They include economic, environmental, and energy
indicators in their model to evaluate the performance of countries. They conclude that Bhutan and Nepal are found to be relatively better countries in South Asian countries.

Guler et al. (2021) appraised the sustainable energy performance of the OECD countries via DEA and PROMETHEE approaches. They use RES consumption, energy intensity, and total electricity production as inputs while the output variable is determined as RES share of total electricity. Luxembourg and Norway are found best-performing countries according to the results of the DEA and PROMETHEE approaches.

3. MCDM Methods

Conventional single-criteria evaluation techniques fail to present a reliable solution in the presence of conflicting criteria. MCDM methods are suitable approaches for dealing with the evaluation of many criteria (Ishfaq et al., 2018). MCDM techniques are frequently used to rank, assess, and choose among several alternatives (Gökgöz and Yalçın, 2021). So far, various MCDM techniques have been introduced to solve problems comprising conflicting criteria and the number of these methods has grown year after year (Ren, 2020). Many different MCDM techniques exist to solve problems in decision-science literature. Each technique has its features, advantages, and disadvantages. Therefore, a systematic analysis needs to be carried out to shed light on performance measurement (Chowdhury and Paul, 2020).

One of the most crucial steps in the MCDM method solution is to weigh criteria to establish the relative importance of indicators. Many weighting techniques exist in decision science literature. While some of these techniques are objective, others are subjectivity-based. Subjective approaches do not rely on initial data but rather on the knowledge of experts. Hence, these methods are considered biased. On the other hand, objective methods depend on original data and calculate criteria weights based on mathematical calculations. Some of these techniques are the entropy method, CRITIC method, Variance Coefficient Method (VCM). Each method has its features (Zafar et al., 2021).

Figure 1 illustrates the hierarchical structure of the energy and environmental sustainability assessment developed to evaluate the performance of the G20 countries.

Figure 1. The hierarchical structure of the empirical model and used methodologies.
3.1 The Criteria Importance through Inter-Criteria Correlation (CRITIC) Method

The CRITIC method, which focuses on the correlation among criteria, was first introduced by Diakoulaki et al. (1995) to establish and determine the relative significance of criteria based on the first decision matrix (Torkayesh et al., 2021a; Xu et al., 2020). Besides, it also considers standard deviation while attributing relative weight to criteria. The following list outlines the steps of the CRITIC technique (Peng et al., 2019):

**Step 1.** Decision Matrix Formation

The solution of MCDM techniques begins with the establishment of the decision matrix.

**Step 2.** Decision Matrix Normalization

Equations (1) and (2) are used to normalize the decision matrix for the benefit and cost criterion, respectively.

\[
\hat{r}_{ij} = \frac{x_{ij} - \text{min} x_{ij}}{\text{max} x_{ij} - \text{min} x_{ij}} \quad \text{for benefit criteria (1)}
\]

\[
\hat{r}_{ij} = \frac{\text{max} x_{ij} - x_{ij}}{\text{max} x_{ij} - \text{min} x_{ij}} \quad \text{for cost criteria (2)}
\]

where \( \hat{r}_{ij} \) denotes the normalized decision matrix values.

**Step 3.** Calculation of criteria standard deviations

Standard deviations of criteria are calculated as follows:

\[
\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}(\hat{r}_{ij} - \bar{r}_j)^2}{m}} \quad \text{(3)}
\]

where \( \bar{r}_j \) denotes the criteria standard deviations.

**Step 4.** Calculation of correlation between criteria

The correlation between the criteria investigated is calculated as follows:

\[
p_{jk} = \frac{\sum_{i=1}^{m}(\hat{r}_{ij} - \bar{r}_j)(\hat{r}_{ik} - \bar{r}_k)}{\sqrt{\sum_{i=1}^{m}(\hat{r}_{ij} - \bar{r}_j)^2(\hat{r}_{ik} - \bar{r}_k)^2}} \quad \text{(5)}
\]

where \( p_{jk} \) denotes the correlation coefficient between criteria.

**Step 5.** Calculation of information quantity for each criterion

\[
c_j = \sigma_j \sum_{k=1}^{n} p_{jk} \quad \text{(6)}
\]

\( c_j \) becomes larger when a specific criterion consists of more information, this increases the weight of this criterion relative to other criteria.

**Step 6.** Calculation of weight for each criterion

\[
w_j = \frac{c_j}{\sum_{i=1}^{n} c_j} \quad \text{(7)}
\]

where \( w_j \) is the weight.

3.2 The Combined Compromise Solution (CoCoSo) Method

The CoCoSo is a relatively novel MCDM approach introduced by (Yazdani et al., 2019). The CoCoSo method combines simple additive weighting (SAW) and exponentially weighted decision-making and, weighted aggregated sum product assessment (WASPAS) frameworks to acquire a compromise solution, which has been found consistent with other MCDM approaches. (Lahane and Kant, 2021). This approach has a high level of stability in determining the optimal solution and it is not affected by criteria weight changes (Khan and Haleem, 2021). The steps of the CoCoSo technique are presented as follows (Torkayesh et al., 2021b):

**Step 1.** The Establishment of the Initial Decision-Making Matrix
The solution of MCDM methods begins with the establishment of the decision matrix.

**Step 2.** The Normalization of the Initial Decision-Making Matrix

\[
x = \begin{bmatrix}
x_{11} & \cdots & x_{1n} \\
\vdots & \ddots & \vdots \\
x_{m1} & \cdots & x_{mn}
\end{bmatrix}
\]  

(8)

The solution of MCDM methods begins with the establishment of the decision matrix.

**Step 3.** Calculation of the Sum of Weighted Comparability \( (S_i) \) and Power-Weighted Comparability Sequences \( (P_i) \)

\[
S_i = \sum_{j=1}^{n} (w_j \cdot r_{ij})
\]  

(11)

\[
P_i = \sum_{j=1}^{n} (w_j)^{r_{ij}}
\]  

(12)

**Step 4.** Calculation of the Aggregation Evaluation

\[
M_{ia} = \frac{P_{i} + S_i}{\sum_{i=1}^{m} (S_i + P_i)}
\]  

(13)

\[
M_{ib} = \frac{S_i}{\max S_i} + \frac{P_i}{\min P_i}
\]  

(14)

\[
M_{ic} = \frac{\lambda(S_i) + (1-\lambda)P_i}{\max S_i + \min P_i}, \quad 0 \leq \lambda \leq 1
\]  

(15)

Equations (13) and (14) signify the sum of the weighted sum method (WSM) and weighted product method (WPM) scores respectively. Equation (15) denotes the comparative scores of WSM and WPM in comparison to the alternative with the highest score.

**Step 5.** Calculation of ultimate ranking of alternatives depending on the aggregated score \( (M_i) \)

\[
M_i = (M_{ia})^{1/3} + \frac{1}{3}(M_{ib} + M_{ic})
\]  

(16)

Lastly, Equation (16) calculates a compromise solution of WSM and WPM approaches. The value of \( \lambda \) varies from zero to one. This threshold value is generally considered as 0.5.

3.3 The Vise Kriterijumska Optimizacija I Kompromisno Resen (VIKOR) method

The VIKOR approach is a trade-off-based MCDM approach introduced by Opricovic and Tzeng, (2004). The trade-off solution is determined by how closely it resembles the best choice. The primary rationale of the VIKOR method is to establish positive and negative ideal solutions and then obtain an ideal solution. The VIKOR method's key value is that it can maximize group benefit while minimizing group regret (Zheng and Wang 2020).

The following are the steps of the VIKOR technique (Fallahpour and Moghassem, 2013; Nsafon et al., 2020).

**Step 1.** Calculation of the best \( f^*_i \) and worst \( f^-_i \) Values

If the \( i \)th criterion signifies a benefit indicator, then \( f^*_i = \max f_{ij}, f^-_i = \min f_{ij} \) if the \( i \)th criterion signifies a cost indicator, then \( f^*_i = \min f_{ij}, f^-_i = \max f_{ij} \)

**Step 2.** Calculation of \( S_i \) and \( R_i \) Values

\[
S_i = \sum_{j=1}^{m} (S_j - S^*) \quad (S^* - S_j)
\]  

(17)

\[
R_i = \max \left\{ w_j(f^*_i - f_{ij})/(f^-_i - f^-_i) \right\} \quad i = 1, 2, \ldots, m
\]  

(18)

where \( w_j \) is the weight of criteria; \( S_i \) and \( R_i \) signify the utility and regret measures respectively.

**Step 3.** Calculation of Index Values \( (Q_i) \)

\[
Q_i = \frac{(S_j - S^*)}{(S^* - S_j)} + \frac{(1-\nu)(R_i - R^*)}{(R^* - R_i)}
\]  

(19)
where $S^+ = \min_i S_i$, $S^- = \max_i S_i$, $R^+ = \min_i R_i$, $R^- = \max_i R_i$ and $v$ is the utility function coefficient and is generally considered 0.5.

**Step 4.** Ranking of Alternatives via $Q_j$ Values
The alternative having the lowest degree of $Q_j$ is regarded as the best option.

**Step 5.** Calculation of the Compromise Values

**C1.** Acceptable Advantage

$$Q(a^{(m)}) - Q(a^{(i)}) \geq DQ$$

$$DQ = 1/(M - 1)$$

where $(a^{(m)})$ and $(a^{(i)})$ are the second and first best alternatives in the ranking. $M$ signifies the number of alternatives.

**C2.** Acceptable Stability in Decision-making

Alternative $(a^{(i)})$ should be the best alternative in terms of $S$ or/and $R$.

### 4. Energy and Environmental Sustainability Figures of the G20 Countries

The G20 is an informal forum for discussing topics in relation to global economic stability. The G20 contains 19 major developed, developing countries, and European Union (EU), which are major actors in the world economy. These countries constitute two-thirds of the world’s population while they also represent around 80% of the world’s (Gross Domestic Product) GDP and CO$_2$ emissions. This emission mainly stems from fossil fuels, which are environmentally unsustainable and exhaustible. Today, most of the consumed energy belongs to G20 countries. As they are not fully able to adopt the usage of RES, they emit vast amounts of CO$_2$ emissions into the atmosphere mostly due to fossil energy consumption. Therefore, securing energy and environmental sustainability is very important for various reasons. Maintaining energy and environmental sustainability is a prerequisite for economic development, energy infrastructure, and affordable energy prices (Li et al., 2016). Environmental sustainability also enhances energy security (Sun et al., 2020). Energy and environmental sustainability are crucial to achieving the long-term goals of industrialized countries when all these aspects are taken into account. The G20 countries have initiated different initiatives to maintain their sustainability. In an action plan for sustainable development goals, which was implemented in 2016 and revised in April 2021, the G20 emphasized the significance of energy transitions to affordable, reliable, sustainable, and low-emissions systems. In this regard, the leaders of G20 countries have committed to transforming energy systems by increasing clean-based investments, deploying RES, and supporting energy innovation in accordance with the 2030 Sustainable Development Agenda. It consists of goals from different fields set by United Nations (UN). Significant energy and environmental sustainability goals are involved in this agenda namely climate action, clean and affordable energy, and land protection (Implementation of the 2030 Agenda, 2022).

The G20 Energy Sustainability Group assumes different sustainable development plans as well. In this regard, the energy and environmental sustainability of the G20 countries is attached of great importance. Therefore, we aim to evaluate the energy and environmental sustainability of G20 countries via MCDM methods comparatively. Initially, we provide some insight into energy and environmental sustainability figures. One of the most remarkable fields for sustainable development is RES usage. The G20 countries attach great importance to RES usage as it contributes to decreasing CO$_2$ emissions and enhances energy efficiency (Sikder et al., 2019).

The primary cause of CO$_2$ emissions, which are significant factors that should be minimized while enhancing energy and environmental sustainability, is energy consumption, primarily from fossil fuels. Additionally, energy intensity, which measures the amount of energy used to produce one unit of GDP, is a highly critical indication of environmental and energy sustainability (Sun et al., 2020).

As Figure 2 indicates, the average CO$_2$ emissions level was recorded as the lowest level in 2016. However, an upward trend was observed in 2017 and 2018 in CO$_2$
emissions. This trend shows that more attention should be paid to decreasing fossil fuel consumption in order to provide sustainability in the G20 countries. The proportion of forest area reveals emphasis placed by countries as the negative change in the rate of forest area signifies the demand for forest products. Forest area level seems to have remained constant in the G20 countries.

**Figure 2.** The Average CO$_2$ emissions and forest area levels in the G20 countries

Even if the average energy intensity in the G20 countries decreased by 1% in 2018 compared with 2012, it follows a fluctuating course over the investigated period (Figure 3). Likewise, the decline in average energy intensity shows that the G20 countries need less energy consumption to produce the same amount of GDP. Hence, they consume less energy and this consumption contributes to sustainability as well. Raising the proportion of RES generation in overall energy use is one of the most crucial ways to provide countries with sustainable energy and environmental practices. Besides, one of the most important components in addressing the energy crisis is RES (Murshed, 2021). The RES generation in the total energy mix has an upward trend in the G20 countries. They increased their RES generation by 10% over the investigated period. The increase in RES generation is both a contributor to climate change mitigation and environmental sustainability. The UN Sustainability Goals list it as one of the most significant markers for the ecosystem’s long-term viability (Sun et al., 2020). Lastly, we include energy consumption per capita in our model as one of our evaluation criteria. It can be regarded as a plausible criterion for evaluating environmental performance as this value differ considerably based on the development level of countries. Countries that heavily depend on fossil energy for economic growth while lacking RES demonstrate lower environmental performance as consumption of more fossil sources negatively affects the environment (Sun et al., 2020).

**Figure 3.** The average energy intensity, energy consumption, and RES share in the G20 countries
After introducing performance evaluation indicators, we proceed with empirical analysis to present insight into the sustainability of the G20 countries.

5. Data and Variables

We introduce the technical criteria determined to evaluate the energy and environmental performance of the G20 countries. In our empirical analysis, we analyze 19 member countries of the G20. We do not include the EU since its major countries are already on the G20 list. In further, we determine the technical criteria by considering available studies and data availability. We select CO\textsubscript{2} emissions, RES generation amount, energy consumption per capita, forest area, and energy intensity as performance evaluation criteria. We retrieve our criteria from the OECD database. We present the criteria and their units in Table 1.

Table 1. The unit of indicators for performance measurement model

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Consumption per capita</td>
<td>Million tonnes of oil equivalent/person</td>
</tr>
<tr>
<td>CO\textsubscript{2} Emissions</td>
<td>Thousand metric tons of CO\textsubscript{2}</td>
</tr>
<tr>
<td>Energy Intensity</td>
<td>Tonnes of oil equivalent (toe)</td>
</tr>
<tr>
<td>RES Generation</td>
<td>Million tonnes oil equivalent</td>
</tr>
<tr>
<td>Forest Area</td>
<td>Square kilometers</td>
</tr>
</tbody>
</table>

In this section, we explain the reasons why these criteria were selected for environmental sustainability performance measurement. The major sustainability parameters employed in earlier energy studies serve as the foundation for the framework of this research.

Energy Consumption per capita: Energy use is anticipated to have a favorable effect on the amount of environmental pollution since emissions and economic activity are closely related. Meanwhile, because of the vast industrial production and continued reliance on fossil fuels for energy, this relationship is responsible for the rise in environmental pollution (Saint Akadiri et al., 2019). An indicator of cumulative intensity, energy consumption per person can be evaluated to assess economic prosperity. The amount of energy utilized per person could also be used as a substitute for an indication of living quality. Importing large amounts of energy based on carbon constitutes a threat to environmental performance (Sun et al. 2020).

CO\textsubscript{2} Emissions: Energy is required to maintain economic growth, but it also has a negative impact on the environment by releasing pollutants like CO\textsubscript{2} (Sun et al., 2020). The energy sector and excessive energy use, which is primarily supported by the burning of fossil fuels, are accelerating GHG emissions, which are the primary contributor to climate change. The energy industry is at the top of the list for deforestation, air pollution, and land degradation (Philips et al., 2021). CO\textsubscript{2} emissions have increased significantly worldwide as a result of the industrial progress seen over the past century. These environmental degradations include decreasing air quality, an increase in global temperatures, and climate change (Ponce and Khan, 2021).

Energy Intensity: Energy intensity is a highly significant indicator of environmental and energy sustainability, which indicates the amount of energy required to generate a unit of GDP. As the value of energy intensity falls, lower environmental pressure undergoes developed countries. Energy intensity is a concept that includes energy consumption and GDP. As a result of increased energy consumption and production, there is increased pressure on the environment. In the long run, lower energy intensity reduces carbon emissions (Khan et al., 2022).

RES Generation: Currently, RES is viewed as a crucial option for lowering greenhouse gas emissions and as a crucial replacement for fossil fuels. Increasing the use of RES can also help reduce reliance on imported energy, provide energy security,
and encourage the sustainable growth of the economy. RES is thought to be able to alleviate energy poverty in underdeveloped countries (Wang and Zhan, 2019).

**Forest Area:** Multiple ecosystem services can be provided by forests, including raw materials for goods, controlling regional and global temperatures, insulating meteorological conditions, controlling the hydrological cycle, and safeguarding watersheds (Martire et al., 2015). By reducing carbon emissions, forest area contributes to environmental sustainability (Raihan et al., 2022).

The descriptive statistics of criteria regarding the G20 countries is given below in Table 2.

<table>
<thead>
<tr>
<th>Years</th>
<th>Criteria</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Energy Consumption per capita</td>
<td>0.47</td>
<td>9.38</td>
<td>3.69</td>
<td>2.43</td>
</tr>
<tr>
<td></td>
<td>CO₂ Emissions</td>
<td>178350</td>
<td>9533210</td>
<td>1348695</td>
<td>2199354</td>
</tr>
<tr>
<td></td>
<td>Energy Intensity</td>
<td>0.60</td>
<td>7.69</td>
<td>3.49</td>
<td>2.06</td>
</tr>
<tr>
<td></td>
<td>RES Share</td>
<td>0.004</td>
<td>40.9</td>
<td>11.1</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td>Forest Area</td>
<td>9770</td>
<td>8150536</td>
<td>141631</td>
<td>210964</td>
</tr>
<tr>
<td>2013</td>
<td>Energy Consumption per capita</td>
<td>0.48</td>
<td>9.59</td>
<td>3.69</td>
<td>2.44</td>
</tr>
<tr>
<td></td>
<td>CO₂ Emissions</td>
<td>184000</td>
<td>9936810</td>
<td>1377389</td>
<td>2291620</td>
</tr>
<tr>
<td></td>
<td>Energy Intensity</td>
<td>0.60</td>
<td>7.76</td>
<td>3.47</td>
<td>2.06</td>
</tr>
<tr>
<td></td>
<td>RES Share</td>
<td>0.005</td>
<td>39.6</td>
<td>11.4</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Forest Area</td>
<td>9770</td>
<td>8150125</td>
<td>1416580</td>
<td>2099941</td>
</tr>
<tr>
<td>2014</td>
<td>Energy Consumption per capita</td>
<td>0.51</td>
<td>9.61</td>
<td>3.67</td>
<td>2.46</td>
</tr>
<tr>
<td></td>
<td>CO₂ Emissions</td>
<td>179910</td>
<td>9894940</td>
<td>1380612</td>
<td>2287630</td>
</tr>
<tr>
<td></td>
<td>Energy Intensity</td>
<td>0.63</td>
<td>7.88</td>
<td>3.47</td>
<td>2.10</td>
</tr>
<tr>
<td></td>
<td>RES Share</td>
<td>0.004</td>
<td>38.8</td>
<td>11.4</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>Forest Area</td>
<td>9770</td>
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<td>Energy Consumption per capita</td>
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<td>9.32</td>
<td>3.66</td>
<td>2.43</td>
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<td>7.84</td>
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<tr>
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<td>0.008</td>
<td>42.7</td>
<td>11.8</td>
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### 6. Empirical Analysis

In our empirical analysis, we analyze the energy and environmental sustainability of the G20 countries via an MCDM framework. To this end, we determine the criteria weight...
via the CRITIC technique, which is an objective weighting approach. In the second stage, we assess the energy and environmental sustainability performance via VIKOR and CoCoSo approaches over the 2012-2018 period. In our empirical analysis, we use an ingrained and novel MCDM technique VIKOR and CoCoSo to render results more reliable. Initially, we present the criteria weight calculated via the CRITIC method in Table 3.

Table 3. The objective criteria weight calculated by the CRITIC method

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<th>Years</th>
<th>Energy Consumption per capita</th>
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<th>Energy Intensity</th>
<th>RES Generation</th>
<th>Forest Area</th>
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</table>

We rank and evaluate the energy and environmental sustainability of the G20 countries via VIKOR and CoCoSo methods over the 2012-2018 period. Initially, we present the analysis results of the VIKOR method in Table 4 as follows.

Table 4. The VIKOR analysis results for the energy and environmental sustainability performance in the G20 countries

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</tbody>
</table>

*R = rank

Energy and environmental aspects of sustainability consist of different criteria, which can be handled better with MCDM techniques. To this end, we adopt a hybrid and holistic approach to assessing the energy and environmental performance of the G20 countries over the 2014-2018 period. Performance rankings of successful countries set a benchmarking point for low-performing countries. As per VIKOR method results, Brazil
and United States are found to be relatively better countries in terms of energy and environmental performance. Three out of five BRICS countries namely Brazil, Russia, and India performed relatively better in G20. In general, the nations with a relatively low industrial operation concentrate at the top of the table mostly due to the lower energy consumption. The countries with relatively high GDP per capita levels such as Canada, Australia, Korea, and the UK remained far from sufficient performance. On the other hand, Germany and Italy are found to be the best European Union (EU) members in G20 whereas Saudi Arabia is found to be relatively lower mostly due to the lowest share of RES among G20. Our analysis results fulfill acceptable advantage and acceptable stability in decision-making requirements, which provide the robustness of VIKOR results. We also proceed with our empirical analysis with the CoCoSo method to provide the robustness of the analysis. We present the sustainability analysis results of the CoCoSo technique in Table 5 to compare the results with the VIKOR method as follows.

### Table 5. The CoCoSo analysis results for the energy and environmental sustainability performance.

<table>
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<tr>
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</tbody>
</table>

*R = rank

As per CoCoSo technique results, Brazil and India are found to be the best-performing countries in terms of energy and environmental performance over the investigated period. Besides, most countries retained their place in the ranking, although with minor changes over the 2012-2018 period. As can be observed from Table 5, three BRICS countries take place in the top four ranking. These countries possess relatively lower energy consumption. High energy consumption because of rapid industrialization brings about critical problems in the atmosphere and society. In this regard, we observe that the countries with lower energy consumption per capita perform better in decreasing their energy intensity, which enables countries to use less energy consumption for production. Canada is the country that is affected negatively by the highest energy intensity. On the other hand, despite having a high amount of energy consumption due...
to industrialization, the USA performs above the G20 mostly thanks to the high RES share.

7. Discussion

A country’s sustainable development depends heavily on the creation and application by the government of a set of well-designed policies. Several tools such as financial or tax incentives, obligation plans, and minimum energy performance requirements for machinery used in industry, can help the industrial sector reduce emissions. For the agriculture industry to reduce emissions, standards, and support for sustainable agricultural practices and the usage of agricultural goods are required. Incentives to lessen deforestation, encouragement of excellent forestry management, enhancement of livestock production, land-use management, and food security practices are possible policy options. Implementing transportation policies like increased energy efficiency, advancements in vehicle technology, the use of electric vehicles, improvements to public transportation, increased vehicle fuel efficiency, and emission standards are all ways to implement urban planning strategies that support the reduction of emissions from the transportation sector. The most crucial objective to be met in a sustainable system is the decrease in pollutant emissions (Codal et al., 2021). In this regard, an increase in RES investments is one of the most crucial targets for long-term sustainability. Besides, reducing waste and adopting circular economy is one of the most critical breakthroughs in enhancing the sustainability of countries. A circular economy, in which wastes are reused as sources, may increase the performance of countries (Cucchiella et al., 2017). Reducing reliance on energy imports, enhancing supply security, and achieving environmental protection and GHG emission reduction targets are key strategies for enhancing the sustainability of countries. Besides, our analysis results indicate the performance ratings of the OECD countries differ considerably. This outcome may be attributed to the highly varying scales of sustainability policies in the OECD countries. Focusing on renewable energy instead of fossil sources, and lowering energy intensity may be regarded as the most influential strategies for long-term success in sustainability performance. Low-performing countries must make significant progress in several important areas if they are to reach sustainable goals.

Significant policies exist to maintain energy and environmental performance in developed countries. One of the most remarkable breakthroughs for sustainability is reducing energy intensity by conserving energy sources (Sun et al., 2020). Reducing energy intensity is a contributor to both economic growth and environmental sustainability. To this end, policymakers should adopt novel investments such as smart energy systems and energy conversion technologies. Besides, increasing RES share in the total energy mix is a sine qua non for energy and environmental sustainability. Thereby, countries can reduce oil dependence as well. In this regard, countries should stimulate renewable foreign direct investments. Moreover, there should be carbon quotas to reduce CO₂ emissions implemented by countries. Lastly, countries should adopt environmentally friendly natural resource management for energy and environmental sustainability (Lin and Abudu, 2019).

Our analysis results indicate that the countries with the lower energy intensity level, high level of RES, and green areas demonstrate better performance. Therefore, decreasing energy necessity through innovative technologies, and replacing fossil sources with RES can be regarded as significant breakthroughs in the environmental and energy sustainability of countries. For instance, investing in technology for the use of renewable energy sources involves large financial resources; but, afterward, the operational costs are reduced and these technologies permit the production of clean energy. This lessens the demand for nonrenewable resources, lowers GHG emissions, and advances sustainability goals. Hence, our analysis results point out improvement strategies for low-performing countries. Only by solving all the issues indicated and raising all the standards taken into account would the investigated countries be able to
improve upon their current situation and compete with top-ranked nations. Low-performing countries will not be able to achieve this unless their current situation is improved and the predetermined Sustainable Development Goals are met.

Table 6 summarizes the comparative results of other performance studies analyzed by MCDM studies.

Table 6. The comparison of our results with other performance studies.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Analysis Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mavi and Mavi (2019)</td>
<td>The authors evaluate the energy and environmental performance of the OECD countries by the Malmquist index. As per the analysis results, the USA is found to be one of the best performance-improving countries in G20. Besides, the countries which improve their productivity significantly overlap with our sample.</td>
</tr>
<tr>
<td>Dang (2019)</td>
<td>The author appraises the environmental performance of the OECD countries by the entropy-weighted VIKOR method. The best and worst-performing countries overlap. For instance, the USA and Canada are found to be the best and worst-performing countries, which is parallel with our findings.</td>
</tr>
<tr>
<td>Vavrek and Chovancová (2019)</td>
<td>The authors evaluate the energy and environmental performance of the EU countries via the TOPSIS method. They conclude that countries with lower emission intensity and more renewable energy use perform better. This finding may be observed in our results as well.</td>
</tr>
<tr>
<td>Stanujkic et al. (2020)</td>
<td>The authors analyze the sustainable development of the EU countries by the entropy-integrated CoCoSo method. Although a country's higher GDP indicates that its economy is stable and prosperous, this does not automatically imply that the nation is devoted to sustainability goals.</td>
</tr>
<tr>
<td>Wang and Zhan (2019)</td>
<td>The authors evaluate the renewable energy sustainability of some European countries. As per their results, Germany is found to be the best-performing country among selected countries thanks to renewable and alternative energy use despite geographical disadvantages. Our results point out that Germany is found to be the best-performing European country in our sample as well.</td>
</tr>
</tbody>
</table>

8. Conclusion

Enhancing energy and environmental sustainability is a sine qua non for developed countries. We adopt an integrated approach to evaluate the G20 countries. We analyze the energy and environmental sustainability of the G20 countries via the VIKOR and CoCoSo methods. Both methods display harmony in terms of performance figures. This reveals the robustness of our analysis results.

As per the analysis results, Brazil is a remarkable country with its low energy consumption and CO$_2$ emissions per capita level and its high renewable generation level. Besides, low energy intensity contributes to energy and environmental sustainability performance in Brazil (Baloch et al., 2020). India has expanded its RES generation recently mainly from wind and solar energy (Sen et al., 2016). Although India is one of the most energy-consuming countries, its energy intensity namely energy efficiency has made it advantageous in comparison to other countries. Besides, the Indian energy sector is one of the most diversified ones with its gradually increasing RES share (Tripathi et al., 2016). Although the United States has a high level of energy consumption per capita, it adopts RES generation strategies to provide sustainability. Natural gas production and tax incentives for RES generation have shaped the energy transition of the United States (Gielen et al., 2019). The Chinese economy, which emits the most CO$_2$ emissions, has been compelled to utilize more energy resources due to its rapid
development. The high dependence on fossil fuels harms sustainability in China, which has led to environmental degradation (Zhang et al., 2017).

The sustainability performance of the investigated countries differs remarkably mostly due to their RES generation and energy intensity levels. The countries focusing on RES generation perform better as it helps secure energy security and decreases CO₂ emissions. Saudi Arabia is found to be the worst country among G20 mostly due to the lowest level of RES generation. Further, Canada is one of the countries that display lower performance in comparison to most G20 countries. More than 80% of Canada's GHG emissions per person are linked to energy use, making it one of the countries with the greatest GHG emissions overall (Torrie et al., 2016). The highest level of energy intensity level affects negatively its performance. Canada has a high energy intensity because of its dispersed population, cold environment, and high level of life (Riva et al., 2021). We observe that lower energy intensity and higher RES share contribute to energy and environmental sustainability. Enhancing energy efficiency lowers energy expenses while also lowering GHG emissions (Chang, 2019). Modernizing enterprises, utilizing more technology-oriented efficient systems, and raising electricity prices are the key ways to reduce energy intensity (Kriegler et al., 2014; Verbič et al., 2017). Low-performing countries should review their environmental policies in order to maximize their performance from sustainable development. We may also conclude that strong policies and long-term, strict adherence are essential to a nation's ability to maintain its energy and environmental sustainability. As can be observed in Table 6, there are some similarities between the results for the countries that rank first and last.

We may conclude that this study may provide significant insights into the energy and environmental performance of the G20 countries. Our analysis results may indicate remarkable implications for officials and decision-makers in this field.

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