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Prioritizing Climate Change Contributing Factors VIA the VIKOR Method under Q-Rung Orthopair Fuzzy Environment

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Abstract

Climate change, characterized by long-term shifts in temperature and weather patterns, is predominantly driven by human activities. Although numerous factors, such as carbon dioxide concentration, changes in the Earth's orbit, ocean currents, greenhouse gas emissions, and variations in solar energy reflection or absorption, are recognized as contributors, the degree of their individual impacts remains unclear and uncertain. This study aims to prioritize the contributing factors to climate change by employing the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method integrated with Q-Rung Orthopair Fuzzy Sets (Q-ROFS), a robust approach to handle vagueness and uncertainty in expert assessments. Five domain experts provided linguistic evaluations regarding the importance of each contributing factor. The aggregated linguistic data were analysed using the Q-ROFS-VIKOR model, revealing that two primary factors, identified as R1 and R2, are the most significant contributors to climate change. Interestingly, the factor 'carbon dioxide concentration' was ranked lowest, suggesting a relatively negative impact compared to other factors considered. The findings provide a clearer perspective on the relative significance of various climate change factors, offering valuable insights for policymakers and researchers in designing effective mitigation strategies.

Keywords: Decision making, Climate change, Q-Rung orthopair fuzzy sets, VlseKriterijumska optimizacija I kompromisno resenje method.

1 | Introduction

In the era of globalization and industrialization, many countries are increasingly vulnerable to natural disasters such as earthquakes, landslides, flash floods, tsunamis, and hurricanes. Human activities have been widely

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acknowledged as key contributors to the frequency and severity of these events [1]. For example, widespread deforestation contributes significantly to landslides, while the improper disposal of waste clogs drainage systems, leading to flash floods [2]. Similarly, anthropogenic activities are the primary drivers of climate change globally. From a scientific perspective, key contributing factors include global warming, depletion of the ozone layer, deforestation, the uncontrolled use of Chloro Fluoro Carbons (CFCs), industrial emissions, and other yet-to-be fully understood processes [3].

Today, climate change constitutes one of the most pressing global challenges, significantly affecting numerous regions around the world. According to Masson-Delmotte et al. [4], Europe and North America are among the areas most severely impacted by extreme weather events. The causes of climate change are often the subject of intense debate, as its origins can be attributed to natural processes, anthropogenic influences, and complex climate system interactions [5]. This ongoing discourse reflects the complexity and multifactorial nature of climate change, emphasizing the need for interdisciplinary approaches in understanding and addressing the issue.

Efforts to mitigate the risks of climate change have become increasingly critical. Numerous strategies have been developed to enhance community resilience and responsiveness to climate-related hazards. However, global climate sensitivity, the measure of how responsive the Earth's climate is to greenhouse gas emissions, remains uncertain [6]. Furthermore, the frequency and intensity of disasters have shown an upward trend globally [7]. Rising levels of carbon dioxide and greenhouse gases, largely from microbial decomposition, agricultural burning, and soil organic matter, exacerbate global warming [8], [9]. This warming, in turn, contributes to droughts and extreme precipitation events, increasing the likelihood of catastrophic climate-related disasters [1]. For instance, studies using NASA's [3] Goddard Institute for Space Studies (GISS) model predict that climate change could significantly impact rice production in Indonesia [10]. Given Malaysia's geographical proximity to Indonesia, similar impacts are plausible, warranting heightened vigilance.

Urban centers worldwide are actively implementing initiatives to curb the adverse effects of climate change. Measures such as establishing car-free days, promoting energy conservation during nighttime hours, and expanding green urban spaces represent proactive steps aimed at mitigating environmental degradation [11]. Flooding remains one of the most common and devastating natural disasters globally [12], [13]. Climate change has intensified the occurrence of heavy rainfall events, leading to more frequent and severe floods [14–16]. Floods inflict extensive damage on human settlements, disrupt socio-economic activities, and pose serious public health risks [17], [18]. Other climate-related impacts include rising temperatures, extreme weather variability, and imbalances in hydrological resources [19], [20]. Zhang et al. [21] observed that extreme warming trends in monsoon regions exhibit a significant nonlinear increase, further exacerbating risks to ecosystems, economies, and food production systems [22], [23].

Clearly, climate change is driven by multiple interrelated factors. These factors do not act independently; instead, they interact in complex ways, where one factor may amplify or mitigate the effects of another. Thus, the investigation of climate change drivers can be conceptualized as a multi-factorial decision-making problem. In this context, Multi-Criteria Decision-Making (MCDM) approaches offer a structured framework for systematically evaluating and prioritizing the factors contributing to climate change. Among various MCDM methods, the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method stands out for its ability to address decision problems involving conflicting and non-comparable criteria [24]. VIKOR, an acronym derived from the Serbian phrase "VIekriterijumsko KOmpromisno Rangiranje," focuses on ranking and selecting alternatives based on a compromise solution. Its relative simplicity and computational efficiency make it a widely preferred method in environmental decision-making contexts [25].

However, the inherent vagueness, uncertainty, and unpredictability of climate change factors necessitate the integration of fuzzy set theories. In this regard, Q-Rung Orthopair Fuzzy Sets (Q-ROFS) offer a robust mechanism for handling imprecise information. To this end, this study proposes the integration of the Q-ROFS with the VIKOR method, herein referred to as Q-ROFS-VIKOR. This novel approach combines the advantages of the two-tuple membership structure of Q-ROFS with the compromise-based decision-making framework of VIKOR. Consequently, this paper aims to identify and prioritize the most significant factors contributing to climate change using the proposed Q-ROFS-VIKOR method.

2|Materials and Methods

This section is divided into two subsections, where the first subsection describes linguistic labels, a group of experts, and criteria. The detailed proposed model Q-ROFS-VIKOR is described in Subsection 2.

2.1|Linguistic Labels, Criteria, and Experts

To meet the aforementioned objective, a group of five experts was invited and interviewed to obtain authentic data sources. In this study, a linguistic variable of 'influence' with ten labels is used as the evaluation scale given by experts. The linguistic labels with the respective Q-ROFS memberships are given in *Table 1*.

Table 1. Linguistic term of influence.

Linguistics Terms	Membership and Non-Membership Function
Exceptionally high (EXH)	(0.99, 0.01)
Extremely high (EH)	(0.90, 0.10)
Very high (VH)	(0.85, 0.15)
High (H)	(0.70, 0.30)
Medium high (MH)	(0.65, 0.35)
Medium (M)	(0.50, 0.50)
Medium low (ML)	(0.45, 0.55)
Low (L)	(0.35, 0.65)
Very low (VL)	(0.20, 0.80)
Extremely low (EL)	(0.10, 0.90)

Besides linguistic variables, this study also defines a list of criteria. In this study, the criteria, which represent the contributing factors of climate change, are considered key elements for analysis. The terms criteria and factors are used interchangeably throughout the paper. However, "criteria" aligns more closely with the modeling approach employed (i.e., the Q-ROFS-VIKOR method), whereas "factors" directly refer to the elements influencing climate change. A total of five criteria are identified, denoted as {C1, C2, C3, C4, C5}, and are defined as follows:

C1: Carbon dioxide concentrations,

C2: Changes in the Earth's orbit and axial tilt,

C3: Changes in ocean currents,

C4: Greenhouse gas emissions, and

C5: Reflection or absorption of solar energy.

These criteria were adapted from prior studies that investigated the causes and impacts of climate change, including [26–30]. Their findings provide a comprehensive basis for identifying critical factors influencing long-term climate variability and serve as a foundation for the current analysis. Not only are linguistic variables and criteria the main framework of this study, but a group of five experts is also vital in providing firsthand linguistic data. Five experts who are currently attached to a public university were invited to be interviewed and provide information about the influence of criteria on climate change. This group of experts is summarized in *Table 2*.

Table 2. A brief biographical information of experts.

Expert	Year of Experience	Academic	Field of Research
E1	3 years	Ph.D.	Climate and climate change
E2	3 years	Ph.D.	Environmental chemistry
E3	2 years 5 months	Ph.D.	Aquatic toxicology
E4	3 years	Ph.D.	Marine geophysics
E5	3 years	Ph.D	Physical oceanography

2.2 | Proposed Q-Rung Orthopair Fuzzy Sets Vlse Kriterijumsk Optimizacija Kompromisno Resenje

The following outlines the steps of the proposed method designed to determine the optimal solution for identifying the contributing factors of climate change using the Q-ROFS-VIKOR approach. The VIKOR method is employed to address decision-making problems involving conflicting and difficult-to-identify criteria by providing an acceptable compromise solution for conflict resolution. Meanwhile, the Q-ROFS framework utilizes membership and non-membership functions, along with hesitation margins, to effectively capture and represent expert opinions under uncertainty. The integration of Q-ROFS with the VIKOR method offers a robust strategy for identifying the fundamental contributing factors to climate change. Notably, fuzzy membership functions have been recognized as practical tools for enhancing decision-making processes and operational practices under uncertainty [31]. The computational procedures of the proposed method are detailed as follows.

Step 1 (Construct a normalized decision matrix). Normalizing the decision matrix can be done by utilizing the following equation with two types of attributes, A and B. Simplify the membership and non-membership functions of criteria from the expert's evaluation. The normalized element r_{cd} of the matrix is given as *Eq. (1)*.

$$r_{cd} = \begin{cases} f_{cd} & c \in A, \\ f_{cd} & c \in B. \end{cases} \tag{1}$$

Eq. (2) is used to find the average value of the criteria based on the expert's evaluation, and *Eq. (3)* is used to sum up the total average value of the data.

$$f_{cd} = \frac{\sum_{c,d=1}^{n,m} p_{cd}}{n}. \tag{2}$$

$$\text{Total } f_{cd} = \sum_{cd} f_{cd}. \tag{3}$$

Eq. (4) is used to find the exact data value from each criterion.

$$r_{cd} = \frac{f_{cd}}{\text{Total} f_{cd}}. \tag{4}$$

Eq. (5) is used to find the average value based on membership and non-membership values from each criterion to get the exact weight of each criterion.

$$r_{cd} = \frac{(r^u{}_{cd} + r^v{}_{cd})}{2}. \tag{5}$$

Step 2. Calculate the weight coefficients of experts. To obtain the weight coefficients of experts, the linguistic values are employed (*Table 3*). *Eq. (6)* is used to find Total E, where the total value of expert knowledge on each criterion is computed.

$$\text{Total E} = \sum_{c=1}^{n} b_{cd}. \tag{6}$$

Eq. (7) is used to find the exact data value from each expert's opinion.

$$E' = \frac{b_{cd}}{\text{Total E}}. \tag{7}$$

Eq. (8) is used to find the average value based on membership and non-membership values from each expert's opinion.

$$E_{cd} = \frac{E'^{u} + E'^{v}}{2}. \quad (8)$$

Entropy equation (*Eq. (9)*) with $c = 1,2,3, \dots, n$ is used to find entropy measures of each criterion.

$$e = \frac{-1}{\ln(D)} \sum_{c=1}^{n} E_{cd} \ln(E_{cd}). \quad (9)$$

The next step is to find the divergence value using *Eq. (10)*.

$$div_c = 1 - e. \quad (10)$$

Eq. (11) is used to get the exact value of the weight coefficient of experts.

$$w = \frac{div_c}{\sum_{c=1}^{n} div_c}. \quad (11)$$

Step 3. Compute the virtual positive ideal $x^{+}{}_{c}$ and the virtual negative ideal $x^{-}{}_{c}$ values under the attributes $\widehat{A}_{c}$. For these purposes, *Eqs. (12)* and *(13)* are utilized.

$$x_c^{+} = \max_{d}(x_{cd}). \quad (12)$$
$$x_c^{-} = \min_{d}(x_{cd}). \quad (13)$$

Step 4. Compute the values of group utility R_d and P_d. To obtain these values, *Eqs. (14)* and *(15)* are utilized.

$$R_d = \sum_{c=1}^{n} \frac{w_c\left(\left\|f_c^{b} - f_{cd}\right\|\right)}{\left(\left\|f_c^{b} - f_c^{w}\right\|\right)}. \quad (14)$$

$$P_d = \max_{c}\left[\frac{w_c\left(\left\|f_c^{b} - f_{cd}\right\|\right)}{\left(\left\|f_c^{b} - f_c^{w}\right\|\right)}\right], \quad (15)$$

Where $\|f_d, f_c\|$ represents the distance between two Q-ROFNs. The distance can be computed using *Eq. (16)*.

$$d(f_d, f_c) = \|f_d, f_c\| = \frac{1}{2}\sum_{d=1}^{D} \left(\left|n_d^{qr} - n_c^{qr}\right| + \left|m_d^{qr} - m_c^{qr}\right| + \left|W_{nd}^{qr} - W_{nc}^{qr}\right| + \left|W_{md}^{qr} - W_{mc}^{qr}\right|\right). \quad (16)$$

Step 5. Compute the values of $Q_d, d = 1,2, \dots, D$, *Eq. (17)* is utilized to compute Q_d.

$$Q_d = v\frac{(R_d - R^{w})}{(R^{w} - R^{b})} + (1 - v)\frac{\left(P_d - P^{b}\right)}{(P^{w} - P^{b})}, \quad (17)$$

Where $R^{b} = \min_{d}(R_d) R^{w} = \max_{d}(R_d) P^{b} = \min_{d}(P_d)$ and $P^{w} = \max_{d}(P_d)$. The symbol v is the balance parameter, which can balance the group of utility and individual regret. There are three possibilities:

I. If $v > 0.5$, it represents the maximum group utility being more than the minimum individual regret.

II. If $v < 0.5$, it represents the minimum individual regret being more than the maximum group utility.

III. If $v = 0.5$, it represents the maximum group utility, and the minimum individual remorse is constituted from a form of equal interest.

Step 6. Rank the alternatives. Using the values of R, P, and Q and comparison among fuzzy numbers, we will obtain compromise solutions. The method used for comparing fuzzy numbers is the fuzzy ranking method [32].

Step 7. When we get a compromise solution in *Step 6*, it needs to meet the following two conditions.

Condition 1: Acceptable advantages:

$$Q(A^{(2)}) - Q(A^{(1)}) \geq SQ, \quad (18)$$

where $A^{(2)}$ is the alternative with the second position in the ranking list by Q,

$$SQ = \frac{1}{(D-1)}. \quad (19)$$

Condition 2: Acceptable stability: Alternative $A^{(1)}$ must also be in the best position for R and P. The above computational procedures are implemented to find the compromised solution of contributing factors of climate change.

3 | Computation and Results

Q-ROF-VIKOR was calculated using a spreadsheet software, and some modifications were made to simplify the calculation method, and at the same time to achieve the research objectives. The following are the detailed computations based on the proposed method, where the input information is obtained from experts.

Step 1. Normalize the decision matrix. The $f^u{}_{cd}$ and $f^v{}_{cd}$ are a simplified version of the membership and non-membership function of criteria from experts' evaluation using *Eq. (1)*.

$$f^u_{cd} = \frac{0.10 + 0.45 + 0.85 + 0.70 + 0.20}{5} = 0.46,$$
$$f^v_{cd} = \frac{0.90 + 0.55 + 0.15 + 0.30 + 0.80}{5} = 0.54. \quad (19)$$

The total $f^u{}_{cd}$ and Total ${}^v{}_{cd}$ is the sum of the simplified data using *Eq. (2)*.

$$\text{Total } f^u{}_{cd} = 0 + 0.46 + 0.46 + 0.88 + 0.58 = 2.38.$$
$$\text{Total } f^v{}_{cd} = 0 + 0.54 + 0.54 + 0.12 + 0.42 = 1.62,$$

The $r^u{}_{cd}$ and $r^v{}_{cd}$ is the fraction of the simplified data to get $r^u{}_{cd} r^v{}_{cd} \leq 1$ *Eq. (3)*.

$$r^u{}_{cd} = \frac{0.46}{2.38} = 0.1933.$$
$$r^v{}_{cd} = \frac{0.54}{1.62} = 0.3333.$$

The ${}^r{}_{cd}$ is the combination of membership function $({}^{r^u}{}_{cd})$ and non-membership function $({}^{r^v}{}_{cd})$ *Eq. (4)*.

$$r_{cd} = \frac{0.1933 + 0.3333}{2} = 0.2633.$$

The rests of ${}^r{}_{cd}$ are calculated similarly. *Table 3* shows the simplified data for each criterion.

Table 3. The simplified data for each criterion.

r_{cd}	C1	C2	C3	C4	C5
C1	0.0000	0.2450	0.2512	0.2422	0.2143
C2	0.2633	0.0000	0.2470	0.2523	0.2714
C3	0.2633	0.2570	0.0000	0.2560	0.2999
C4	0.2219	0.2490	0.2520	0.0000	0.2143
C5	0.2515	0.2490	0.2498	0.2496	0.0000

Step 2. Weight of the coefficients of experts. The significance of each expert using linguistic variables has been shown in *Table 4*. The weight of experts can be calculated using *Eq. (10),* and the results are shown in *Table 4*. First, calculate the total E, E', and E_{cd} using *Eqs. (5)-(7)*. Then, using the entropy formula *Eq. (8),* we find the divergence value of the intrinsic information of each criterion.

$\text{Total } E^u = 0.99 + 0.20 + 0.35 + 0.99 + 0.20 = 2.73.$
$\text{Total } E^v = 0.01 + 0.80 + 0.62 + 0.01 + 0.80 = 2.27.$

The E'^u and E'^v is the fraction of the function and the total function.

$$E'^u = \frac{0.99}{2.73} = 0.3626.$$
$$E'^v = \frac{0.01}{2.27} = 0.0044.$$

The E_{cd} is the simplified version of the function.

$$E_{cd} = \frac{0.3626 + 0.0044}{2} = 0.1835.$$

Using the entropy formula to get the entropy value, *Eq. (8)*.

$$e = \frac{-1}{\ln(5)}((0.1835 \times \ln(0.1835)) + (0.2128 \times \ln(0.2128)) + (0.2073 \times \ln(0.2073)) + (0.1835 \times \ln(0.1835)) + (0.2128 \times \ln(0.2128))) = 0.9986.$$

Then, calculate the degree of divergence ($^{div}{}_c$) of the intrinsic information of each criteria ($C1, C2, C3, C4, C5$) using formula from *Eq. (9)*.

$$div_c = 1 - 0.9986 = 0.0015.$$

The w is employed to calculate the weight of experts using *Eq. (10)*.

$$w = \frac{0.0015}{0.0601} = 0.0242.$$

Weights for all experts are given in *Table 4*.

Table 4. Weight coefficients of experts.

Experts	Weight
E1	0.0242
E2	0.2290
E3	0.2167
E4	0.2537
E5	0.2765

Step 3. Compute the virtual positive ideal, $(x^+{}_c f^b{}_c)$ and the virtual negative ideal, $(x^-{}_c f^w{}_c)$ values. The maximum and minimum values are obtained using *Eqs. (11)* and *(12)*. It is summarised in *Table 5*.

Table 5. Maximum and minimum value.

	C1	C2	C3	C4	C5
$x^+{}_c$	0.2633	0.2570	0.2520	0.2560	0.2999
$x^-{}_c$	0.0000	0.0000	0.0000	0.0000	0.0000

Step 4. Computing the values of group utility R_d Values of group utility R_d and P_d are computed using *Eq. (13)* and *Eq. (14)*, respectively, while the weight coefficients of experts are retrieved from *Table 4*. For example,

$$R_d = \frac{0.0242(0.2633 - 0)}{(0.2633 - 0)} = 0.0242.$$

Table 6 presents the R_d values using the weight coefficient of the expert.

Table 6. The R_d values.

R_d	C1	C2	C3	C4	C5
R1	0.0242	0.0107	0.0007	0.0137	0.0789
R2	0.0000	0.2290	0.4290	0.0037	0.0263
R3	0.0000	0.0000	0.2167	0.0000	0.0000
R4	0.0038	0.0071	0.0000	0.2537	0.0789
R5	0.0011	0.0071	0.0019	0.0063	0.2765

Then, compute the maximum ($^{P}{}_{d}$) value of R_d *Eq. (14)*. *Table 7* shows the sum up (R) of R_d, the maximum values of R_d, and the best and worst value of R and P_d.

Table 7. The values of R, $^{P}{}_{d}, R^{+}, R^{-}, P^{+}$, and P^{-}.

R_d	R	P_d
R1	0.1281	0.0789
R2	0.6880	0.4290
R3	0.2167	0.2167
R4	0.3435	0.2537
R5	0.2929	0.2765
R^{+}, P^{+}	0.6880	0.4290
R^{-}, P^{-}	0.1281	0.0789

Step 5. Compute the values of Q_d. The values of Q_d are computed using *Eq. (16)*, where $v = 0.5$ represents the maximum group utility, and the minimum individual remorse is constituted from a form of equal interest.

$$Q_d = 0.5\frac{(0.1281-0.6880)}{(0.12809-0.6880)} + (1-0.5)\frac{(0.0789-0.42903)}{(0.0789-0.42903)} = 1.$$

Calculate all the values of Q_d to evaluate the compromise solution and the result, *Table 8*.

Table 8. The values of group utility R_d, P_d, Q_d and the rank of the compromise solution.

R_d	R	P_d	Q_d
R1	0.1281	0.0789	1.000
R2	0.6880	0.4290	0.000
R3	0.2167	0.2167	0.7242
R4	0.3435	0.2537	0.5581
R5	0.2929	0.2765	0.5706
Ranking	$R_{R1} \succ R_{R3} \succ {}_{R5} \succ R4 \succ R2$	$R_{R1} \succ_{R3} \succ_{R4} \succ R5 \succ R2$	$R_{R2} \succ {}_{R4} \succ {}_{R5} \succ R3 \succ R1$
Compromise solution	R1	R1	R2

Figs. 1-3 shows the different rankings of group utility, maximum, maximum value of R, and the values of Q for each criterion.

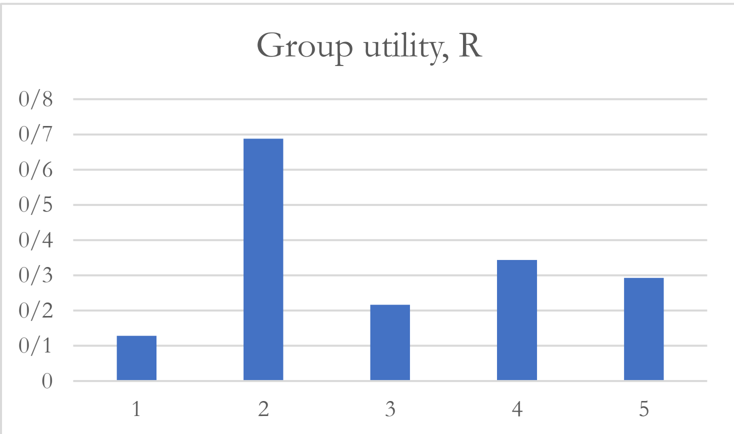

Fig. 1. The graph of group utility values, R.

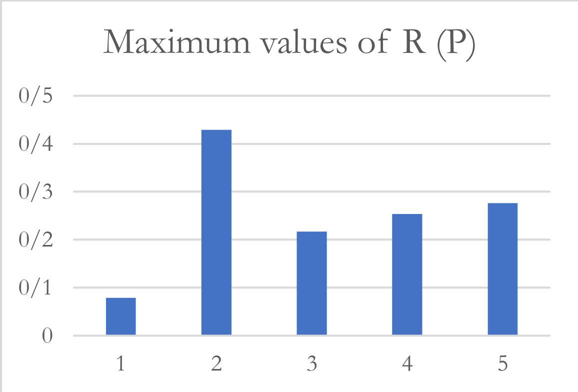

Fig. 2. The graph of the maximum values of R.

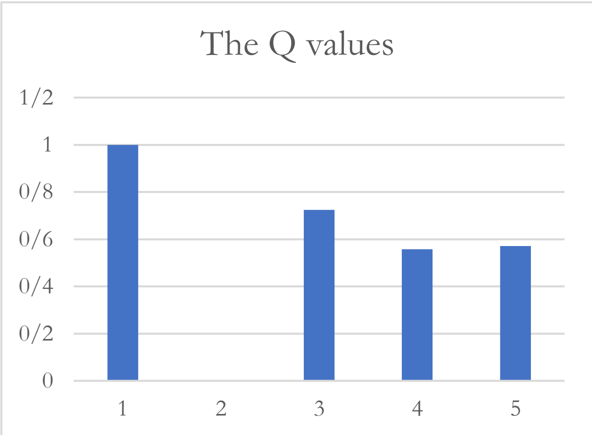

Fig. 3. The graph of Q values.

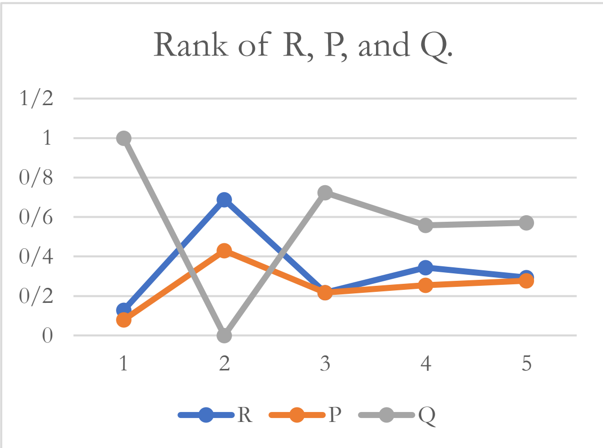

Fig. 4. The rank graph of R, P, and Q.

Using the value of R_d, P_d, and Q_d, their ranking in *Table 9* and *Fig. 4*, we can obtain the compromise solution as R1 and R2. The solution closest to the feasible ideal is a compromise solution [24]. The determination of fuzzy compromise solutions for various criteria for VIKOR connections is presented in the following step.

Step 6 (Checking the compromise solution). Check if the compromise solution follows the conditions.

Condition 1: Acceptable advantages: Using *Eq. (17)* to calculate SQ, where (A^2) is the criterion with the second position in the ranking list by Q_d and SQ formula can be obtained from *Eq. (18)*.

$$SQ = \frac{1}{5-1} = 0.25.$$

$0.5581 - 0 \geq 0.25.$

So, condition 1 holds accurately; therefore, by condition 1, R2 is the compromise solution with the lowest cause of climate change. We are accepted under Condition 1.

Condition 2: Acceptable stability: Criteria (A^1) must also be in the best position in R_d and P_d.

So, from the results, it is sure that Condition 2 does not hold accurately; therefore, we reject Condition 2.

From the result using Condition 1, we can conclude that changes in the Earth's orbit and axial tilt (R2) received the highest rank. In other words, R2 is one of the lowest contributing factors to climate change. Contrarily, the concentration of carbon dioxide (R1) is the lowest rank, which means it is the highest contributing factor to climate change.

4 | Discussion

The main objective of this study was to identify climate change risk factors that can affect human daily activities using Q-ROF VIKOR. Through this method, the diagram of the contributing factors of climate change and the network relationship between criteria and other criteria can be described. Based on the results in Table 8, the highest rank of the contributing factors of climate change has been listed. Contributing factors of climate change are carbon dioxide concentrations (C1), changes in the Earth's orbit and axial tilt (C2), changes in ocean currents (C3), greenhouse gas emissions (C4), and reflection or absorption of solar energy (C5).

Based on the result obtained in *Table 8*, the carbon dioxide concentrations (C1) gain the lowest rank, which provides a high risk to Malaysia if these contributing factors are not curbed. While changes in the Earth's orbit and axial tilt (C2) gain the highest rank using the VIKOR method. *Figs. 4-6* presents the graph of the criteria that are influenced by other criteria.

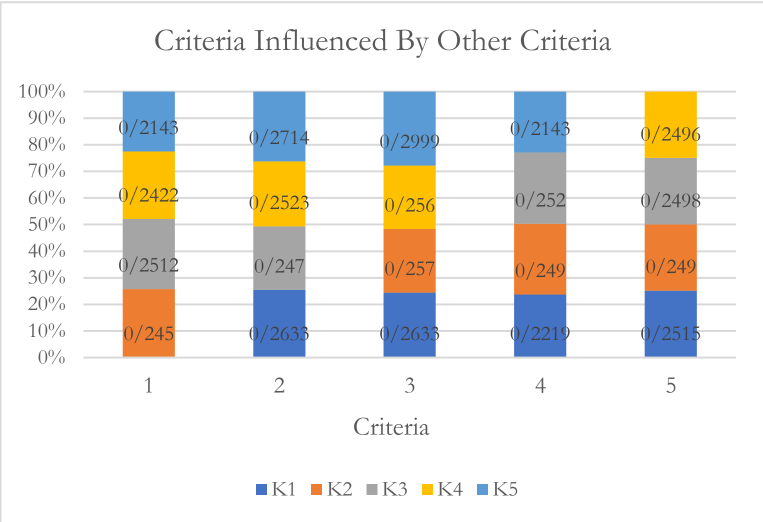

Fig. 6. The summarized data of the criteria that influenced by other criteria.

The network relationship between criteria and other criteria (*Fig. 1*) provides a more detailed understanding of how degree criteria can be generated. Each criterion may affect the other criteria, but it will not affect its own criteria. This research shows that carbon dioxide concentrations (C1) have the worst impact on the occurrence of climate change, while the changes in the Earth's orbit and axial tilt (C2) give the lowest risk of climate change.

5 | Conclusion

Climate change refers to the alteration of temperature and weather patterns over extended periods, a phenomenon largely driven by human activities. Numerous factors contribute to climate change, including the concentration of carbon dioxide, variations in the Earth's orbital patterns, changes in ocean currents, greenhouse gas emissions, and the reflection or absorption of solar energy. Nevertheless, the relative impact of these contributing factors remains uncertain and often ambiguous. The primary objective of this study was to assess and rank the contributing factors to climate change by applying a compromise solution approach using the VIKOR method integrated with Q-ROFS. This integrated method is particularly suitable for addressing decision-making problems under uncertainty, such as evaluating the complex and interrelated causes of climate change. In this study, five domain experts were engaged to provide assessments regarding the degree of importance of various contributing factors. Their linguistic evaluations were systematically analyzed through the proposed Q-ROFS-VIKOR approach. The results reveal that, based on group utility values, two contributing factors, labelled R1 and R2, were identified as the primary causes of climate change. Interestingly, the factor associated with 'carbon dioxide concentration' was ranked the lowest, suggesting that, relative to other factors, its impact was assessed as less significant in the present analysis. This finding challenges common perceptions in the climate change discourse and highlights the necessity of adopting multidimensional evaluation techniques in understanding such complex phenomena.

Overall, this study demonstrates that the integration of Q-ROFS with the VIKOR method offers a robust framework for prioritizing contributing factors to climate change under conditions of vagueness and uncertainty. Future research could extend this approach by involving a larger and more diverse group of experts or by integrating additional multicriteria decision-making methods to validate and further refine the findings. Additionally, dynamic assessments over time could provide deeper insights into how the perceived importance of various contributing factors evolves in response to ongoing environmental changes and new scientific discoveries. Future research could further enhance the proposed framework by incorporating a larger panel of interdisciplinary experts to capture broader perspectives on the contributing factors to climate change. Moreover, extending the model to dynamically account for temporal changes in environmental conditions and policy interventions would allow for a more comprehensive understanding of evolving risk factors. Comparative studies employing alternative MCDM methods, such as TOPSIS, DEMATEL, or PROMETHEE, in combination with advanced fuzzy set theories (e.g., Spherical or Picture Fuzzy Sets), could also be explored to validate the robustness and sensitivity of the results. Finally, applying the proposed methodology to case studies at regional or sectoral levels would offer valuable insights for policymakers in tailoring mitigation and adaptation strategies.

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