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Optimized Climate Change Management: Integrating Fuzzy CRITIC-TOPSIS Approach with Continuous Function-Valued Fuzzy Sets

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Abstract

Climate change is a worldwide issue that affects the entire planet, necessitating comprehensive management planning and the development of effective solutions. Given the subject's worldwide relevance, the procedures should produce fast and accurate findings. Given all of these issues, effective climate change management plans and assessment criteria should be developed, backed up by the appropriate theoretical components, and finished with analysis methods. This study is based on genuine facts. Expert opinions inform the development of climate change evaluation criteria and strategies for climate change management. Each alternative is assessed using all criteria, and a multi-criteria group decision-making problem is created. In the theoretical dimension, the decision problem is helped by continuous function-valued q-rung orthopair fuzzy sets (CFV-q-ROFSs) and a novel cosine-based distance measure. The use of CFV-q-ROFSs and the new distance measure across these fuzzy sets leads to a more accurate evaluation. Criteria Importance The Intercriteria Correlation (CRITIC) approach and the approach for Order of Preference by Similarity to Ideal Solution (TOPSIS) are then united to propose an extended and combined fuzzy method. The criteria are weighted using the CRITIC method, and the alternatives are prioritized using TOPSIS. TOPSIS employs the approved innovative distance measure to calculate the distance between alternatives. A comparison of six techniques is performed to ensure that the results are consistent.

Keywords: Climate change management strategies, Continuous function-valued Pythagorean fuzzy set, Distance measure, CRITIC, TOPSIS.

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1|Introduction

Climate change is defined as a long-term shift in a region's typical weather patterns caused by the rapid accumulation of greenhouse gases in the Earth's atmosphere. The phenomenon encompasses both an increase in the Earth's average surface temperature and climatic alterations. These changes have a significant influence on many elements of life on Earth. Over ages, the Earth's climate has changed dramatically, owing primarily to human activity. Examples of such activities include the use of fossil fuels, changes in land use, deforestation, and industrial operations. These events cause an increase in the Earth's temperature and greenhouse gas concentrations. In particular, the composition of Europe's atmosphere has changed significantly as a result of the Industrial Revolution, with human activity boosting greenhouse gas emissions. The increase in atmospheric carbon dioxide (CO_2), the major greenhouse gas, is due to the usage of fossil fuels. In addition to the greenhouse effect, deforestation has been identified as a significant contributor to climate change. The indiscriminate use of land, the release of dangerous and hazardous compounds, the unregulated production of CO_2 by companies, the growth of motor vehicles, and a slew of other causes contribute to climate change. To analyze these changes from the past to the present, a variety of approaches are used, including satellite photos, aerial and ground observations, and computer systems to generate climate data records. Climate data records provide signs of climate change, such as glacier melt, rising ocean temperatures, floods, storms, and an increase in greenhouse gas concentrations in the atmosphere. Climate change statistics and proof are shown below.

- The mean global surface temperature has increased by approximately 2 degrees Fahrenheit (1,11 degrees Celsius) since the late eighteenth century. The principal causes of this phenomenon are the activities of humans and the increase in atmospheric emissions of CO_2 [30, 31, 32]. The previous forty years have seen the most warming, with the last seven years being the warmest on record. The two hottest years on record are 2020 and 2016 [33]. Figure 1, generated using data from [29], shows statistics on the observed rise in global temperature. This figure depicts the dramatic transformation that occurred from 1980 and 2020.

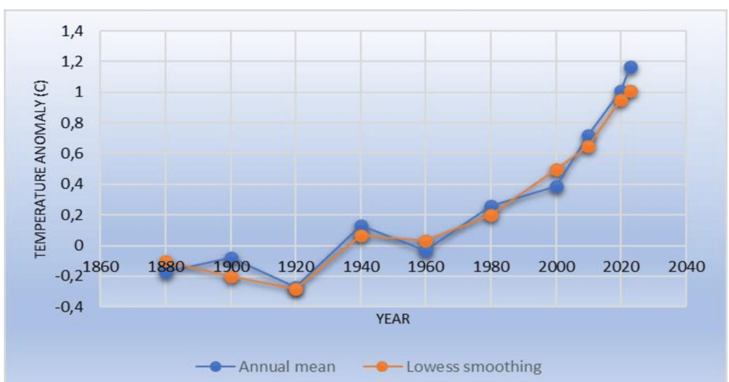

Figure 1. The Global Surface Temperature Change.

- The seas have taken up a large amount of the extra heat generated by the planet's recent warming phase. Since 1969, there has been an increase in temperature of 0.67 degree Fahrenheit (0.37 degree Celsius) in the upper 100 meters (about 328 feet) of the ocean[53, 34, 95]. Figure 2 shows the present state of this scenario, as referenced from [29].

- The collective mass of the Antarctic and Greenland ice sheets has diminished in conjunction with the observed increase in global temperature. The mean annual loss of ice from Greenland was 279 billion tonnes between 1993 and 2019, while Antarctica lost approximately 148 billion tonnes annually, according to data from NASA's Gravity Recovery and Climate Experiment [94]. Almost everywhere in the world, including the Alps, Himalayas, Andes, Rockies, Alaska, and Africa, glaciers are retreating [35]. A review of satellite data indicates a reduction in the extent of spring snow cover in the Northern Hemisphere over the past five decades, accompanied by an earlier onset of melting [36, 79, 37, 38]. In recent decades,

FIGURE 2. Changes in The Ocean's Heat Content Since 1957.

both the amount and thickness of Arctic sea ice have dropped quickly [39, 68, 40, 41]. As seen in Figure 3 [29], the Arctic sea ice area is disappearing by 12.2 percent every decade as temperatures rise.

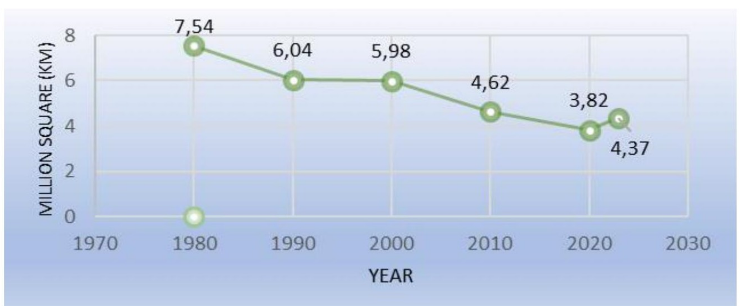

FIGURE 3. Minimum Extent of Arctic Sea Ice.

- The melting of glaciers in response to rising temperatures is a primary driver of sea level rise. Over the past century, global sea levels have risen by approximately 20 centimeters (7.87 inches). However, over the past two decades, the rate has increased nearly twofold in comparison to the preceding century, with a slight annual increase [62]. Figure 4[29] provides striking statistics on this subject.
- Man-made developments, such as industrial expansion, have contributed an essential component to climate change. Human activities have raised the quantity of CO_2 in the atmosphere by 50% in less than 200 years. CO_2 is a significant heat-trapping gas created by natural processes such as fossil fuel extraction and combustion, forest fires, and volcanic eruptions. The phenomenon of climate change and global warming can be attributed, at least in part, to the presence of atmospheric CO_2. Figure 5[29] shows the CO_2 change table.
- Human activity causes the release of methane (CH_4). CH_4 is a potent heat-trapping gas, with human activity accounting for 60% of its emissions. Agriculture, fossil fuels, and landfill waste decomposition are the three main producers of CH_4. CH_4 is a potent greenhouse gas that is the second leading cause of global warming after CO_2. A molecule of CH_4 retains more heat than a molecule of CO_2, but CH_4 has a far shorter lifespan in the atmosphere (7 to 12 years), whereas CO_2 can last hundreds of years or more[29]. Figure 6 depicts a graph of CH_4 gas change throughout the years. With this data and information, climate change is a global issue.

Multi-criteria decision-making (MCDM) and multi-criteria group decision-making (MCGDM) are the processes of ranking alternatives according to more than one conflicting criteria and determining the best alternative based on

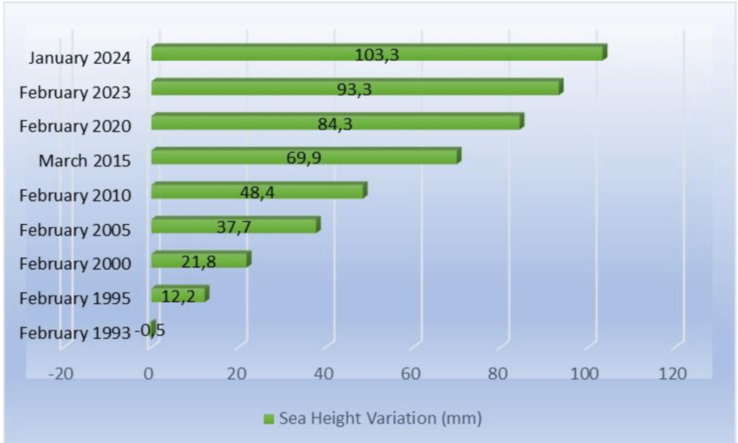

FIGURE 4. The Sea Level Increase.

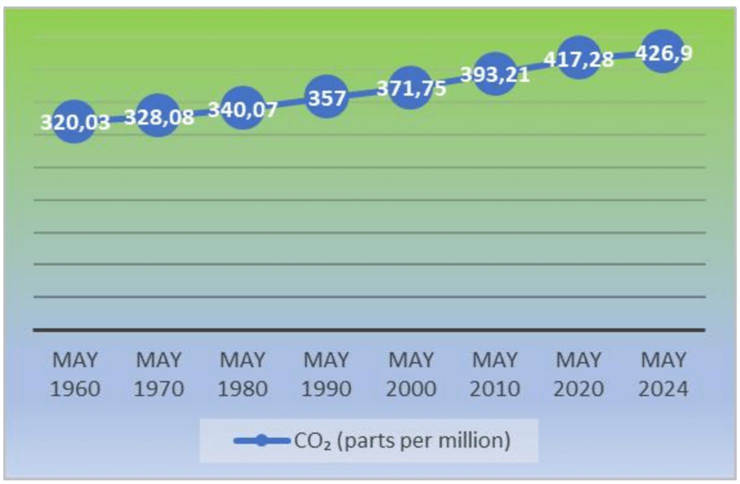

FIGURE 5. CO_2 Change Since 1960.

the criteria. In these processes, it is important to define the problem correctly, to ensure the continuity of the data received, to make appropriate definitions of the data together with expert opinions in order to obtain a consistent result. Once the problem is correctly identified under the right conditions, the solution can be approached through MCDM or MCGDM, both of which provide a comprehensive framework for problem-solving. In today's world there are too many confusing problems and it takes time to reach a conclusion. When evaluating multiple alternatives for each criterion becomes too much for the human brain, using decision-making methods creates a solution to problems in terms of both time and making the right decision. Decision-making methods offer us more than one solution to each problem. It is possible to reach more than one decision method depending on the type of decision. Several MCDM methods include ELECTRE (Elimination and Choice Expressing Reality), PROMETHEE (The Preference Ranking Organization Method for Enrichment Evaluation), AHP (Analytic Hierarchy Process), ANP (Analytic Network Process), VIKOR (VlseKriterijumska Optimizacija Kompromisno Resenje), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), EDAS (Evaluation Based on Distance from Average Solution), MAUT (Multi Attribute Utility Theory), MAVT (Multi Atribute Value Theory), SAW (Simple Additive Weighting), COPRAS (Complex Proportional Assesment), BWM (Best-Worst Method) and more. Decision-making methods are grouped under four main headings in Figure 7. The weighting of criteria is another important issue in the decision-making process. Weighting criteria makes it easier to find the right strategy or alternative. In other words, the fact that one criterion value is more dominant than the

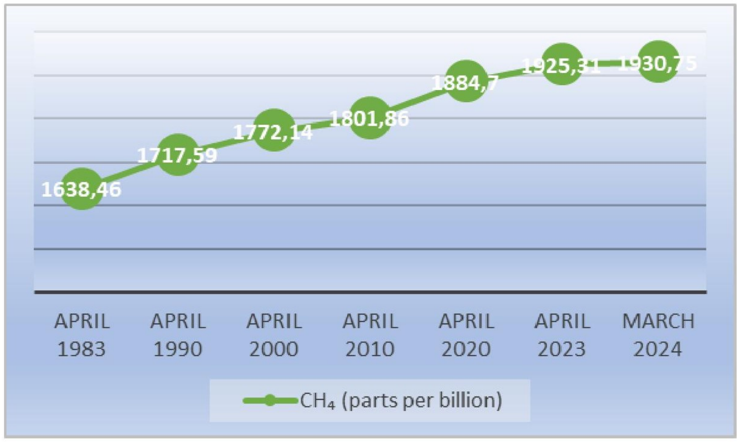

Figure 6. Atmospheric CH_4 Concentrations Since 1983.

others indicates that this criterion has a say in the decision. These MCDM methods are often used to assign these weights effectively, improving the decision process. Figure 8 shows some different ways of weighting criteria [65].

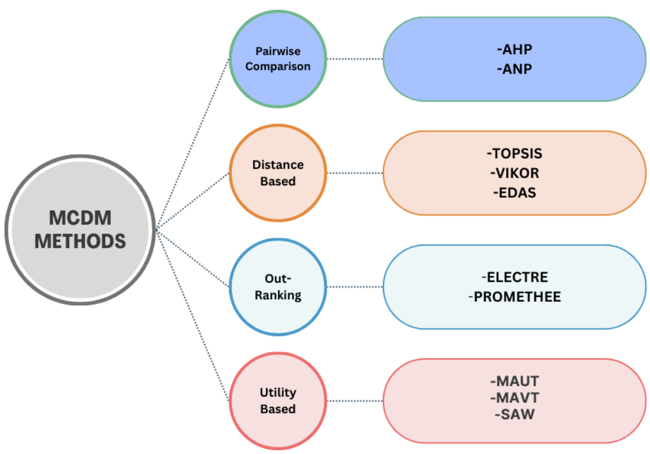

Figure 7. Classification of MC(G)DM Methods.

Fuzzy set (FS) theory, developed by Zadeh in 1965 [108], was designed to expand beyond the limitations of traditional binary logic, which strictly categorizes objects as either belonging to a set or not. A FS is an extension of the characteristic function in classical sets and is characterised by a membership function. In a fuzzy set, the membership function assumes values between 0 and 1 . That is, any function defined on the interval $[0, 1]$ from the universal set is called a fuzzy set. In 1986, Atanassov [7] defined intuitionistic fuzzy sets (IFSs) as a generalisation of FSs. An IFS is defined together with a membership function and a of non-membership function, and their sum must lie between 0 and 1. Pythagorean fuzzy sets (PFSs) [102] are a generalisation of IFSs. Whereas in an IFS the sum of the degrees of membership lies between 0 and 1, in a PFS the sum of the squares of the degrees of membership lies between 0 and 1. This shows that the family of PFSs includes the family of IFSs and that the Pythagorean degrees of belonging correspond to a point on the centripetal unit circle in the

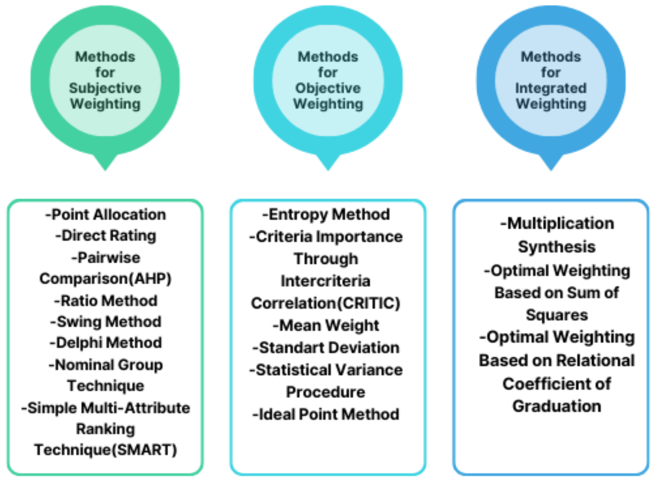

FIGURE 8. Detailed Criteria Weighting Methodology.

first region of the analytic plane. In q-rung orthopair fuzzy sets (q-ROFSs) [101], the sum of the qth powers of the degrees of belonging falls between 0 and 1 for a fixed real number $q \geq 1$.

Continuous functions are essential in mathematical analysis due to their ability to provide seamless transitions between values within a defined interval. This smoothness is crucial for modeling real-world phenomena where sudden jumps or breaks in data can lead to inaccuracies and misrepresentations. By using continuous functions, mathematical models gain the flexibility to accurately represent complex dynamics, ensuring a closer approximation to natural processes. In this context, the innovative contribution of Ünver and Olgun [92] to fuzzy set theory is particularly significant. They introduced the continuous function-valued q-rung orthopair fuzzy sets (CFV-q-ROFSs), which use continuous functions spanning a closed interval. This advancement offers a more sophisticated tool for decision-making theory. In this innovative fuzzy set framework, the degrees of membership and non-membership for an element within a fuzzy set are expressed not as discrete values, but as continuous functions. In a CFV-q-ROFS, the analysis is not limited to individual data points; rather, it encompasses sufficiently large and continuous neighborhoods around these points. The application of this methodology results in the generation of models that are more sensitive and realistic, thereby eliminating the necessity for precise fuzzy data or linguistic arguments. The historical progression of fuzzy sets up to CFV-q-ROFSs is illustrated in Figure 9.

In the FS theory, a similarity measure serves as an effective tool for gauging the extent of similarity between two fuzzy sets. In recent times, researchers have directed their attention towards various types of similarity measures within diverse fuzzy environments. Trigonometric similarity measures stand as examples. A trigonometric similarity measure utilizes the weighted arithmetic mean to aggregate the trigonometric values of the angles among the conjugate components of the vector representation of two FSs and there exist various applications of these measures in the literature. For instance, Rajarajeswari and Uma [74] proposed an intuitionistic fuzzy multi-similarity measure grounded in the cotangent function opening avenues for nuanced similarity assessments. Tian [89] introduced a distinctive fuzzy similarity measure relying on the cotangent function, demonstrating its relevance in medical diagnosis and emphasizing its potential in various applications. Ye [107] proposed cosine similarity measures for IFSs, with applications. Ye [106] extended this concept to mechanical design schemes, demonstrating the applicability of cosine similarity measures in diverse decision-making contexts. In a recent contribution, Ünver and Aydogan [93] introduced a similarity measure for CFV-q-ROFSs, expanding the TOPSIS. The exploration of distance measures for FSs constitutes a significant direction in the field of decision-making. One notable approach involves deriving a distance measure from a complementary perspective of a similarity measure. By using the fuzzy complement of a similarity measure, one can effectively capture the dissimilarity or separation between FSs. This perspective allows for a nuanced understanding of the relationships between elements within fuzzy sets, considering both their similarities and differences.

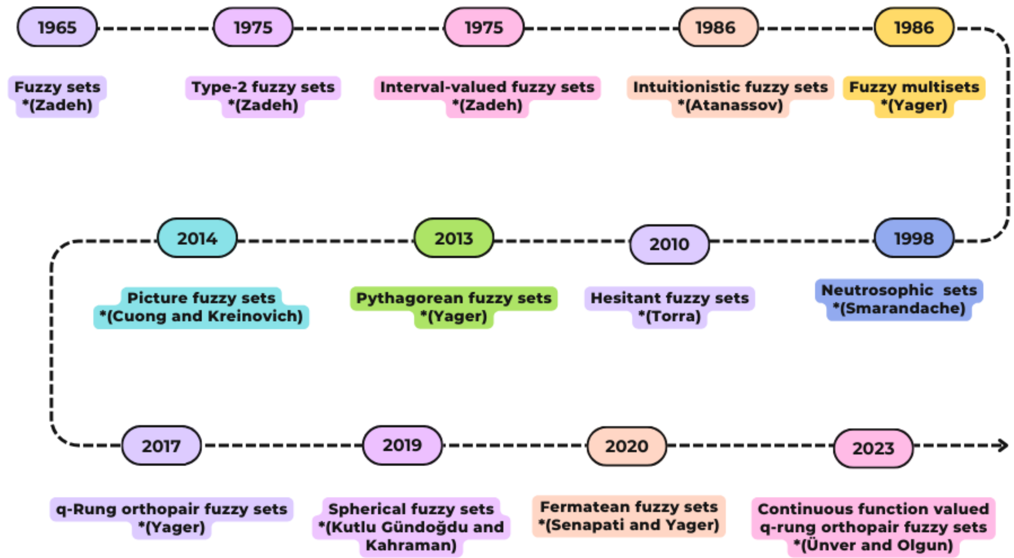

Figure 9. Historical Network of Fuzzy Sets (Zadeh[108],[109]; Atanassov[7]; Yager[103]; Smarandache[87]; Torra[90]; Yager[102]; Cuong and Kreinovich[13]; Yager[101]; Kutlu Gündoğdu and Kahraman[51]; Senapati and Yager[82]; Ünver and Olgun[92])

In response to the critical situation emerging from climate change, we formulate a MCGDM problem aimed at identifying and prioritizing effective strategies for climate change management within the CFV-q-ROFS framework. This MCGDM problem integrates various perspectives and criteria to comprehensively address the challenges posed by climate change, ensuring that the strategies adopted are both effective and sustainable. The promotion of renewable sources of energy (A_1) is a key strategy for addressing anthropogenic climate change by minimizing the impact of human activities. Fossil fuel combustion is a primary contributor to the greenhouse gas effect; thus, increasing the utilization of renewable energy sources is imperative to prevent further human-induced environmental degradation and achieve a reduction in carbon emissions. Another important strategy is the adaptation of carbon emission reduction technologies (A_2). This involves implementing innovative technologies to reduce carbon emissions from various sectors, thereby mitigating their impact on the environment. The most crucial strategy for reducing atmospheric carbon is the protection and expansion of carbon sinks (A_3). These natural reservoirs, such as seas, oceans, forests, and agricultural and grazing lands, are vital for carbon sequestration. This strategy is essential for capturing and storing CO_2, thereby reducing its concentration in the atmosphere. Environmentalization of industrial production processes (A_4) is another significant strategy. The generation of industrial waste and emissions since the Industrial Revolution has significantly contributed to the greenhouse gas effect, causing considerable harm to the natural environment. Adopting environmentally friendly industrial practices can mitigate this impact. Finally, the promotion of environmentally friendly transport systems (A_5) is necessary to reduce the emission of exhaust fumes, which significantly contribute to global warming. Adopting an environmentalist approach to transport will help minimize its adverse effects on the climate. A comprehensive account of these strategies is provided in Table 1.

Table 1. Detailed Examination of Alternatives.

Alternative	Description
A_1: The promotion of renewable sources of energy (*Lu et al.* [56], *Ragwitz et al.* [73])	This strategy promotes sustainable, renewable energy sources such as solar,wave and biomass power instead of fossil fuels, which are more polluting and depleting by the day.
A_2: Adaption of carbon emission reduction technologies (*Yang et al.* [105], *Robertson* [78])	This strategy envisages the use of environmentally friendly technologies to prevent the release of CO_2 into the environment from various sources.
A_3: The protection and expansion of carbon sinks (*Fung et al.* [20], *Hunt* [28])	This strategy aims to protect and expand the systems that store CO_2 by absorbing it from the atmosphere. Examples of carbon sinks include forests, soil and ocean water.
A_4: Environmentalisation of industrial production processes (*Pulver* [72], *Dunlap and McCright* [16])	This strategy provides for environmentally sound waste management so that the waste generated during industrial production does not harm the environment or cause air pollution.
A_5: The promotion of environmentally friendly transport systems (*Lv and Shang* [57], *Sierpiński* [84])	This strategy is environmentally friendly, such as cycling, public transport rejects transport systems that cause air pollution by supporting transport.

It is as crucial to assess the efficacy of these strategies as it is to define them. Here, we outline the evaluation criteria. Firstly, technical conformity (C_1) is essential to ensure that the strategies are feasible and can be effectively implemented using current technology. Economic sustainability and cost (C_2) are also critical, as the strategies must be financially viable and not impose undue economic burdens. Social good and justice (C_3) are important to ensure that the strategies benefit society as a whole and are equitable. The ease of management (C_4) must be considered to ensure that the strategies can be efficiently administered and overseen. Risk management and scientific reality (C_5) are necessary to address potential risks and ensure that the strategies are grounded in scientific evidence. Long-lasting impact and sustainable results (C_6) are crucial to ensure that the strategies provide enduring benefits and contribute to long-term sustainability. Finally, international cooperation and adherence to standards (C_7) are important to ensure that the strategies align with global efforts and comply with international norms. Comprehensive explanations of these criteria are provided in Table 2.

Table 2. Detailed Examination of Criteria.

Criterion	Importance
C_1: Technical conformity (*Friel et al.* [19])	The technical suitability of the strategies is assessed under this criterion.
C_2: Economic sustainability and cost (*Zhang and Wu* [114])	This criterion focuses on the economic viability and sustainability of the strategy.
C_3: Social good and justice (*Paavola* [67])	This criterion is in the interest of people and society. It also respects the same fundamental rights and social opportunities.
C_4: The ease of management (*Hsieh* [27])	This criterion requires the simplest way of applying the rules and controlling the work to achieve the objective.
C_5: Risk management and scientific reality (*Scolobig et al.* [81])	This criterion refers to the process of analysis of uncertainties and risks as well as their objective assessment.
C_6: Long-lasting impact and sustainable result (*Abbass et al.* [1])	This criterion should focus on being effective throughout the process and developing what is needed.
C_7: International cooperation and adherence to standards (*Keohane and Victor* [46])	This criterion should be taken into account as a position adopted and supported by many states. This criterion should be taken into account. It is a position adopted and supported by many states.

In this study, two MCDM methods are used by integrating them. The first method CRITIC, is preferred for weighting the criteria. This method takes into account not only the standard deviation of the criteria, but also the correlation between a criterion and another one. The TOPSIS is then used to find the farthest and closest alternative from the ideal worst solution. A distance measure is required for the distance and closeness of the alternatives. Therefore, a new definition of the distance measure is given by taking the fuzzy complement of a similarity measure. In fact, this distance measure is a cosine based distance measure, which provides a more accurate result when making a decision. In the process of applying the CRITIC-TOPSIS methodology, CFV-q-ROFS are studied. The use of CFV-q-ROFS notation provides a realistic and sensitive model for solving the problem. The theoretical part is applied to the aforementioned MCGDM problem. Thanks to the application and the theoretical part, the best strategy for climate change is determined.

This paper makes several noteworthy contributions:

- The development of diverse strategies and evaluation criteria is a primary focus, aiming to expedite solutions to the globally significant issue of climate change.
- An original perspective is introduced through the integration of two distinct methods into the decision-making process. This novel synthesis aims to develop the overall efficacy and robustness of decision-making frameworks.
- The resolution of the generated decision problem relies on CFV-q-ROFS, a departure from conventional FSs. This methodological shift introduces a more sophisticated and nuanced approach to decision analysis in the context of climate change.
- A unique distance measure is defined specifically for CFV-q-ROFS, contributing to the advancement of measurement techniques within this framework. This novel measure improves the precision and depth of the analytical processes involved in decision-making.
- The paper conducts an original study involving group decision-making with domain experts, adding a practical dimension to the research. This real-world application ensures the relevance and applicability of the proposed methodologies.

These contributions collectively aim to advance methodologies and understanding in decision-making, particularly in the critical context of climate change.

The following research questions (RQs) are addressed in the study:
RQ1 : What kind of strategies should be adopted to cope with climate change?
RQ2 : What situations and criteria should be considered to evaluate the climate change management strategies developed?
RQ3 : When choosing strategy, is it sufficient to use a single method of analysis?
RQ4 :What are the benefits of applying different methods to a problem?

The rest of the paper has the following structure. In Section 2, we conduct a review of the literature pertaining to distance-based MCDM methods relevant to our study. In Section 3, basic definitions related to CFV-q-ROFS are given. Then a new distance measure is defined. In Section 4, the continuous function-valued q-rung orthopair fuzzy CRITIC-TOPSIS method is expressed. In Section 5, the promised problem related to climate change is given and problem solving is carried out. Moreover, the results and management insights are interpreted in detail. Finally, Section 6 presents conclusions and future directions.

2|Literature review

This section methodically introduces recent distance-based MCDM approaches, then follows up climate change research within fuzzy MCDM, and ends up with a focus on the CRITIC method.

- Table 3 is introduced to provide insights into recent studies. This table offers a comprehensive overview, addressing questions such as the application environment, the nature of problems analyzed, and the specific methods employed. The listed MCDM methods in Table 3 encompass a range of techniques, including TOPSIS, AHP, SAW, EDAS, VIKOR, COPRAS, DEVADA (Dynamic Decision Analysis), CODAS, PROMETHEE, MAIRCA (The Multi-Attribute Ideal-Real Comparative Assessment), ANP, and SWARA (Step-Wise Weight Assessment Ratio Analysis).

Table 3. Distance-Based MCDM Studies.

Case Study	Year	Method(s)	Environment	Authors
Preference of the advertising company	2023	Entropy TOPSIS	Pythagorean fuzzy sets	Kumar et al[49]
The medical waste treatment	2023	Entropy SWARA-TOPSIS	Intuitionistic fuzzy sets	Patel et al [70]
Cloud service providers selection	2023	AHP TOPSIS	Pentagonal fuzzy number	Ghorui et al [21]
Shortest path problem	2022	TOPSIS SAW EDAS	Fuzzy sets	Özçelik [66]
Wheat supply chain	2023	VIKOR	Fuzzy sets	Magableh [59]
Food waste treatment	2023	SWARA COPRAS	Intuitionistic fuzzy sets	Tripathi et al [91]
Waste disposal location selection	2022	DEVADA	Intuitionistic fuzzy sets	Alkan and Kahraman [5]
The enterprise credit risk assessment	2022	Entropy CODAS	Probabilistic dual hesitant fuzzy sets	Ning et al [64]
Ensemble feature selection	2023	PROMETHEE	Fuzzy sets	Janani et al. [42]
Local investment	2023	MAIRCA	q-Rung orthopair fuzzy numbers	Wang et al.[96]
Medical diagnosis problems	2022	TOPSIS	Complex hesitant fuzzy sets	Khan et al [47]
Artificial intelligence technologies	2023	Delphi ANP TOPSIS	Fuzzy sets	Wang et al [98]

- The issue of climate change has been evaluated by experts in different contexts, both theoretically and practically, and various studies have been carried out. Some of these studies are listed in Table 4. The literature review in Table 4 examined what has been done in different contexts of climate change. These analyses also took into account the decision-making processes used and the contexts in which they were examined.

- Widely utilized as a criterion weighting technique, the CRITIC method has been a common subject of study. Below, we summarize some key studies based on the decision-making environments. Peng et al. [71] introduced the Combined Compromise Solution-CRITIC (CoCoSo-CRITIC) method and applied it to studies on PFSs related to 5G industry evaluations. Madic et al. [58] applied the CRITIC method using the ROV (Range of Value) method to study non-traditional machining processes. Kumari et al. [50] presented a combined CRITIC-CODAS method for the analysis of non-conventional machining process selection. Yalçın and Ünlü [104] evaluated a company's financial strategy using the CRITIC and VIKOR methods. Sleem et al. [86] conducted a study on the ranking factors and customer needs within the target demographic for products in the virtual reality metaverse, applying the Neutrosophic CRITIC-MCDM methodology. Akram et al. [3] introduced an integrated CRITIC method within the Pythagorean fuzzy rough environment. Ali et al. [4] employed the CRITIC method in benchmarking the financial sustainability of banks. Mishra et al. [60] integrated the GLDS (Gained and Lost Dominance Score) and CRITIC methods in a fuzzy environment. Silva et al. [85] merged the CRITIC and GRA (Grey Relational Analysis) methods for selecting investment portfolios. Zhong et al. [113] evaluated thermal coal suppliers using the CRITIC method. Bilişik et al. [9] studied the interval-valued intuitionistic fuzzy CRITIC-TOPSIS methodology. Chen et al. [11] investigated the CRITIC method with linguistic Z-numbers, applying it to green supplier selection. Zhang and Wei [112] evaluated the siting of electric vehicle charging stations using a fuzzy CRITIC method with various MCDM methods. Wang et al. [97] presented a combined DEMATEL-CRITIC method to evaluate rock slope failures using

Table 4. Literature Review on Climate Change Studies in Fuzzy MCDM.

Case Study	Environment	Method(s)	Author(s)
Analysing how nuclear energy helps mitigate climate change	Nonlinear fuzzy sets	SDM	Woo et al [100]
Renewable energy systems	Fuzzy logic	Neuro-fuzzy, ANFIS, AHP	Suganthi et al [88]
Climate change-based devices for food supply chain systems	Circular intuitionistic fuzzy set	ARAS	Alsattar et al [6]
Bridge maintenance project priority based on CO_2 emissions	Neutrosophic fuzzy sets	WASPAS, TOPSIS	Gokasar et al [22]
Sustainable enterprise risk management assessment	q-Rung orthopair fuzzy sets	VIKOR	Cheng et al [12]
Food, energy and water systems	Type-2 fuzzy sets	PSR, AHP, TOPSIS, CODAS	Gu et al [24]
Evaluating how susceptible the water supply is to climate change	Triangular fuzzy numbers	VIKOR	Kim and Chung [48]
Analysing the climate resilience of the Nile Delta	Fuzzy logic	FDMT	Batisha [8]
The solar-wind hybrid renewable energy systems	Fuzzy and Boolean logic	BWM	Aghaloo et al. [2]
Urban mobility planning's ideas for mitigating climate change in light of economic and social aspects	Fuzzy Einstein T-norms and T-conorms	WASPAS	Deveci et al.[14]
Flood risk	Triangular fuzzy numbers	The Delphi technique, TOPSIS	Jun et al. [44]
Using green mobility planning techniques to prepare for climate change	Fuzzy D numbers	PIPRECIA, DOMBI	Pamucar et al. [69]
Marine species' susceptibility to climate change	Fuzzy logic	Sensitive analysis	Jones and Cheung [43]
Imprecise probabilities of climate change	Linguistic fuzzy sets	Aggregation operators	Hall et al. [26]
Agricultural water allocation	Triangular fuzzy numbers	AHP, TOPSIS, PROMETHEE	Zamani et al. [111]
Renewable energy projects	Fuzzy environment	MOORA, VIKOR, EDAS, ARAS	Ramezanzade et al. [75]
Prioritization of water allocation for adaptation	Crisp sets	TOPSIS	Golfam et al. [23]
Assessment of the business's decarbonization plan	Grey numbers	G-MEREC, G-MAIRCA, G-TOPSIS	Esangbedo [18]
Climate change management strategies	**Continuous function valued Pythagorean fuzzy sets**	**CRITIC, TOPSIS**	**Present Study**
AHP: Analytic Hierarchy Process *ARAS: Additive Ratio Assessment* *BWM: Best Worst Method* *CODAS: Combinative Distance-Based Assessment Method* *G-MAIRCA: Grey Multi-Atributive Ideal Real Comparative Analysis* *ANFIS: Adaptive Neuro-Fuzzy Inference System*	*G-MEREC: Grey -Method Removal Effects of Criteria* *CRITIC: Criteria Importance Through Intercriteria Correlation* *WASPAS: Weighted Aggregated Sum Product Assessment* *PSR: Polymerase Spiral Reaction* *WASPAS: Weighted Aggregated Sum Product Assessment*	*FDMT: Fuzzy decision-making Technique* *SDM: System Dynamic Modelling* *PIPRECIA: Pivot Pairwise Relative Criteria Importance Assessment* *PROMETHEE: Preference Ranking Organization Method for Enrichment Evaluations* *EDAS: Evaluation Based on Distance from Average Solution*	*MOORA: Multi-Objective Optimization on The Basis of Ratio Analysis* *TOPSIS: Technique for Order of Preference by Similarity to Ideal Solution* *VIKOR: Vise Kriterijumska Optimizacija I Kompromisno Resenje*

a composite cloud model. Mohata et al. [61] evaluated the selection of commercially viable alternative fuel passenger vehicles using CRITIC-COPRAS. Zafar et al. [110] introduced an entropy-based CRITIC weighting method for an effective blockchain evaluation system. Rani et al. [76] studied the single-valued neutrosophic CRITIC method with another MCDM method. Kahraman et al. [45] studied a spherical fuzzy CRITIC method and applied it to the prioritization of supplier selection criteria. Risk management of sub-sea pipelines using the CRITIC-VIKOR method was evaluated by Li et al. [54]. Bošković et al. [10] studied the selection of mobile network operators using the combined CRITIC-ARAS method. Sharkasi and Rezakhah [83] introduced a modified CRITIC method using fuzzy logic and Hamming distance. Wang et al. [99] evaluated site selection for hospital construction using the Grey Relational Projection (GRP) and the CRITIC methods. Lai and Liao [52] presented a combined CRITIC method, evaluating blockchain platform assessments with linguistic D-numbers. Rostamzadeh et al. [80] introduced an integrated fuzzy TOPSIS-CRITIC approach to evaluate sustainable risk management in the supply chain. Lu et al. [55] studied the selection of agricultural machinery using CRITIC-entropy and GRA-TOPSIS. Haktanır and Kahraman [25] evaluated wearable health technology applications using an integrated picture fuzzy CRITIC methodology.

3|Preliminary Concepts

In this section, we introduce fundamental concepts relevant to our study and proceed to propose a novel distance measure. We begin by revisiting the concept of CFV-q-ROFS. We assume that $\Omega = \{\chi_1, ..., \chi_n\}$ is a finite set throughout this study.

[92] Let $q \geq 1$ be a real number. A CFV-q-ROFS A on Ω is defined by a non-negative membership function, denoted by $\zeta_A : \Omega \to C\,[a, b]$, and a non-negative non-membership function, denoted by $\eta_A : \Omega \to C\,[a, b]$. The functions satisfy the specified condition

$$0 \leq \|\zeta_A(\chi_i)\|^q + \|\eta_A(\chi_i)\|^q \leq 1$$

for any $i = 1, ..., n$, where $C[a, b]$ is the Banach space of all continuous real valued functions defined in the interval $[a, b]$ with $\|f\| = \sup_{a \leq t \leq b} |f\,(t)|$. The CFV-$q$-ROFS A is is represented by

$$\{\langle \chi_i, \zeta_A(\chi_i), \eta_A(\chi_i)\rangle : i = 1, ..., n\}\,.$$

A pair of non-negative functions $\rho = \langle \zeta_\rho, \eta_\rho\rangle$ is termed as a continuous function-valued q-rung orthopair fuzzy value (CFV-q-$ROFV$) when both ζ_ρ and η_ρ are mappings from Ω to $C\,[a, b]$, satisfying the condition

$$0 \leq \|\zeta_\rho\|^q + \|\eta_\rho\|^q \leq 1.$$

In Definition , when $q = 2$, these concepts are referred as continuous function-valued Pythagorean fuzzy set and continuous function-valued Pythagorean fuzzy value (CFVPFV), respectively. When provided with Pythagorean fuzzy values (PFVs), it is possible to convert them into CFVPFVs using Theorem 1 in [92]. The essence of this theorem lies in multiplying the given value by a suitable continuous function. A pair $\gamma = \langle \tau_\gamma, \eta_\gamma\rangle$ of numbers ranging from zero to one is termed a PFV if $0 \leq \tau^2 + \eta^2 \leq 1$ [102].

The following information can be found in [92]. [92] Let ρ and γ be two CFV-q-$ROFV$s and $\lambda \geq 0$. Some of the basic operations are given by

$$\rho \oplus \gamma = \left\langle \left(\zeta_\rho^q + \zeta_\gamma^q - \zeta_\rho^q \zeta_\gamma^q\right)^{1/q}, \eta_\rho \eta_\gamma \right\rangle,$$

$$\rho \otimes \gamma = \left\langle \zeta_\rho \zeta_\gamma, \left(\eta_\rho^q + \eta_\gamma^q - \eta_\rho^q \eta_\gamma^q\right)^{1/q} \right\rangle,$$

$$\lambda\rho = \left\langle \left(1 - \left(1 - \zeta_\rho^q\right)^\lambda\right)^{1/q}, \eta_\rho^\lambda \right\rangle,$$

$$\rho^\lambda = \left\langle \zeta_\rho^\lambda, \left(1 - \left(1 - \eta_\rho^q\right)^\lambda\right)^{1/q} \right\rangle.$$

The decision process utilizes the following two mathematical tools.

[92] Let $\{\rho_1, ..., \rho_n\}$ be a collection of CFV-q-$ROFV$s. A weighted arithmetic aggregation operator, WAq, is defined by

$$WAq(\rho_1, ..., \rho_n) = \left\langle \left(1 - \prod_{i=1}^{n} \left(1 - \zeta_{\rho_i}^q\right)^{\omega_i}\right)^{1/q}, \prod_{i=1}^{n} \eta_{\rho_i}^{\omega_i} \right\rangle,$$

where $\omega = (\omega_1, ..., \omega_n)$ is a weight vector with $\omega_i \in [0, 1]$ such that $\sum_{i=1}^{n} \omega_i = 1$.

Theorem 5 in [92] confirms that $WAq(\rho_1, ..., \rho_n)$ also qualifies as a CFV-q-ROFV.

[92] A score function σ has a definition of

$$\sigma(\rho) = \frac{1}{2}\left(1 + \frac{1}{b-a}\int_a^b (\zeta_\rho - \eta_\rho)\, dt\right)$$

for an arbitrary CFV-q-$ROFV$ ρ. Notice here that $0 \leq \sigma(\rho) \leq 1$.

We proceed by presenting a new distance measure developed for CFV-q-ROFSs.

The weighted distance measure $\mathbb{D}$ between arbitrary CFV-q-ROFSs A and B is given by

$$\mathbb{D}(A,B) = 1 - \sum_{i=1}^{n}\left(\omega_i \int_a^b \frac{\zeta_A^q(\chi_i)\zeta_B^q(\chi_i) + \eta_A^q(\chi_i)\eta_B^q(\chi_i)}{\sqrt{\zeta_A^{2q}(\chi_i) + \eta_A^{2q}(\chi_i)}\sqrt{\zeta_B^{2q}(\chi_i) + \eta_B^{2q}(\chi_i)}} dt\right), \tag{1}$$

where $\omega = (\omega_1, ..., \omega_n)$ is a weight vector with $\omega_i \in [0,1]$ such that $\sum_{i=1}^{n}\omega_i = 1$.

This measure, $\mathbb{D}$, functions as the fuzzy complement of the similarity measure, effectively representing the negative part of the right-hand side of (1).

Next, we demonstrate certain properties of the distance measure $\mathbb{D}$. The distance measure $\mathbb{D}$ satisfies the following properties.
DM1) $0 \leq \mathbb{D}(A,B) \leq 1$ for any CFV-q-ROFSs A and B,
DM2) $\mathbb{D}(A,B) = \mathbb{D}(B,A)$ for any CFV-q-ROFSs A and B,
DM3) $\mathbb{D}(A,B) = 0$ if $A = B$.

Proof: The proof is trivial. □

4|Continuous function-valued q-rung orthopair fuzzy CRITIC-TOPSIS methodology

This section outlines a CRITIC-TOPSIS approach, specifically designed for CFVqROFS methodology.

- **Step 1:** Formulate a MCGDM problem comprising m alternatives, represented by $\{A_1, ..., A_m\}$, n criteria, represented by $\{C_1, ..., C_n\}$, and k decision makers.
- **Step 2:** Construct a decision matrix for every decision maker. Decision matrix of rth decision maker is in the form of

$$D^r = \begin{bmatrix} \rho_{11}^r & \cdots & \rho_{1n}^r \\ \vdots & \ddots & \vdots \\ \rho_{m1}^r & \cdots & \rho_{mn}^r \end{bmatrix}$$

  for $r = 1, ..., k$ where ρ_{ij}^r is a CFV-q-$ROFV$ for each $i = 1, ..., m$, $j = 1, ..., n$.
- **Step 3:** Aggregate k decision matrices into a single matrix

$$DM = \begin{bmatrix} \rho_{11} & \cdots & \rho_{1n} \\ \vdots & \ddots & \vdots \\ \rho_{m1} & \cdots & \rho_{mn} \end{bmatrix}$$

  using the weighted arithmetic aggregation operator recalled in Definition , where $\rho_{ij} = WA_q(\rho_{ij}^1, ..., \rho_{ij}^k)$.

– **Step 4:** Defuzzify DM to

$$DDM = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix}$$

utilizing the score function σ outlined in Definition .

Step 5: The next step is to evaluate the criteria weights. The CRITIC method is employed for the determination of these weights. The CRITIC method incorporates the steps outlined in [15]. For the sake of completeness, we revisit these steps as follows:

* **Step 5.1:** Normalize the defuzzified decision matrix. Specifically, for a benefit criterion, we apply

$$\chi_{ij} = \frac{r_{ij} - r_i^-}{r_i^+ + r_i^-}$$

and for a cost criterion, we use

$$\chi_{ij} = \frac{r_{ij} - r_i^+}{r_i^- + r_i^+}.$$

In this case, the decision matrix's normalized values are represented by χ_{ij}, where $r_i^+ = \max(r_{1i}, ..., r_{mi})$ and $r_i^- = \min(r_{1i}, ..., r_{mi})$. It is assumed that all values within the defuzzified decision matrix are non-zero.

* **Step 5.2:** Calculate the correlation coefficients using the formula:

$$\nabla_{jk} = \frac{\sum_{i=1}^{m}(\chi_{ij} - \chi_j^{\perp})(\chi_{ik} - \chi_k^{\perp})}{\sqrt{\sum_{i=1}^{m}(\chi_{ij} - \chi_j^{\perp})^2 \sum_{i=1}^{m}(\chi_{ik} - \chi_k^{\perp})^2}}$$

where $\chi_l^{\perp}$ represents the column-wise mean of the lth criterion, i.e.,

$$\chi_l^{\perp} = \frac{1}{m}\sum_{i=1}^{m}\chi_{il}.$$

* **Step 5.3:** Calculate the sample standard deviations using the formula:

$$\tau_j = \sqrt{\frac{1}{m-1}\sum_{i=1}^{m}(\chi_{ij} - \chi_j^{\perp})^2}.$$

* **Step 5.4:** Calculate the information quantity for each criterion using the formula:

$$\psi_j = \tau_j \sum_{k=1}^{n}(1 - \nabla_{jk}).$$

The greater the value of the ψ_j, the more information is contained in a certain criterion, so that the weight of this evaluation criterion is higher than that of the other criteria.

* **Step 5.5:** Calculate the weights of the criteria using the formula:

$$w_j = \frac{\psi_j}{\sum_{j=1}^{n}\psi_j}.$$

– **Step 6:** Calculate the positive ideal solution and the negative ideal solution as CFV-q-ROFSs. The positive ideal solution is represented by

$$I^+ = \left\{\left\langle C_j, \rho_j^+ \right\rangle : j = 1, ..., n\right\}$$

and the negative ideal solution is given by

$$I^- = \left\{\left\langle C_j, \rho_j^- \right\rangle : j = 1, ..., n\right\}$$

where

$$\rho_j^+ = \text{argmax}_{1 \leq i \leq m}\, \sigma\left(\rho_{ij}\right)$$

and

$$\rho_j^- = \text{argmin}_{1 \leq i \leq m}\, \sigma\left(\rho_{ij}\right).$$

These definitions apply if C_j is a benefit criterion and, vice versa if C_j is a cost criterion. It is important to note that ρ_j^+ and ρ_j^- are CFV-q-$ROFV$s.

– **Step 7:** Compute the distance between A_i and the positive ideal solution for each $i = 1, ..., m$ using the expression:

$$b_i^+ = \mathbb{D}(A_i, I^+).$$

Additionally, determine the distance between A_i and the negative ideal solution for each $i = 1, ..., m$:

$$b_i^- = \mathbb{D}(A_i, I^-).$$

In these equations, $\mathbb{D}$ refers to the distance measure defined in Equation 1.

– **Step 8:** Calculate the proximity coefficients for each alternative using the formula:

$$\phi_i = \frac{b_i^-}{b_i^- + b_i^+}.$$

The larger the alternative, the better the alternative. These coefficients are used to rank the alternatives. A higher value of ϕ_i indicates a better alternative.

A simplified explanation of the steps in this methodology is illustrated in Figure 10.

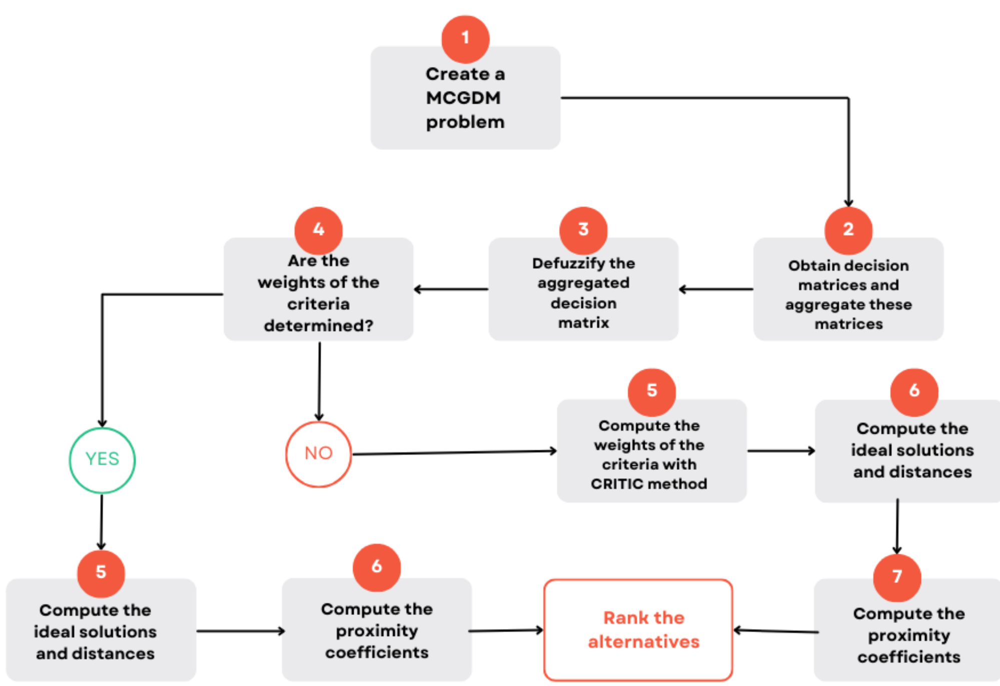

FIGURE 10. Flowchart of The Proposed Methodology.

5|Application

In this section, we solve a real life MCDGM problem using the proposed CRITIC-TOPSIS method. We first describe the problem. Then a solution to the problem is generated using the proposed CRITIC-TOPSIS method. Finally, a comparative analysis is performed.

Problem Solution

– **Step 1:** The climate system is a complex and interacting system that includes the atmosphere, land surfaces, snow and ice, oceans, other bodies of water, and living beings [17]. The system undergoes gradual changes over time, either as a result of its inherent dynamics or external factors, known as forcings. Forcings can be classed as natural processes (e.g., volcanic eruptions and solar fluctuation) or manmade changes in atmospheric composition [77]. Climate change is described as a rise in Earth's average surface temperatures and climate changes caused by the fast buildup of greenhouse gases [63]. Given these problems, we determine a new strategy designed to combat climate change. This strategy aims to reduce carbon emissions, promote renewable energy sources, enhance societal benefits, and ensure economic sustainability. However, the urgency, cost, and impact on society of this decision should be taken into consideration. Therefore, it is necessary to determine the most appropriate strategy by taking into account the views of different stakeholders. This scenario forms the basis of a realistic problem that requires a complex balancing act in the decision-making process. This balance must be struck between environmental benefits, economic costs, and societal impacts. Using this information, an auxiliary problem is created for this complex problem structure. The following strategies (alternatives) are identified in the design of the problem and visualisation in Figure 11: (A_1) the promotion of renewable sources of energy, (A_2) adaption of carbon emission reduction technologies, (A_3) the protection and expansion of carbon sinks, (A_4) environmentalisation of industrial production processes, and (A_5) the promotion of environmentally friendly transport systems.

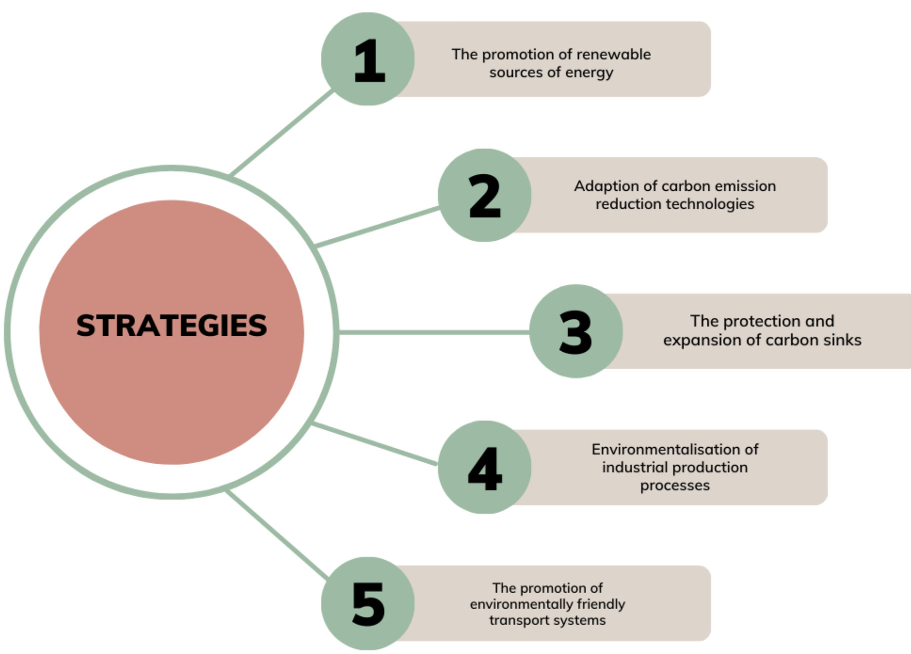

Figure 11. Defining Strategies.

Evaluating policies are as important as formulating them. All aspects of the problem should be considered and appropriate criteria should be established. In accordance with the aforementioned criteria, the evaluation is to be conducted as illustrated in Figure 12: (C_1) technical conformity, (C_2) economic sustainability and cost, (C_3) social good and justice, (C_4) the ease of management, (C_5) risk management and scientific reality, (C_6) long-lasting impact and sustainable result, (C_7) international cooperation and adherence to standards.

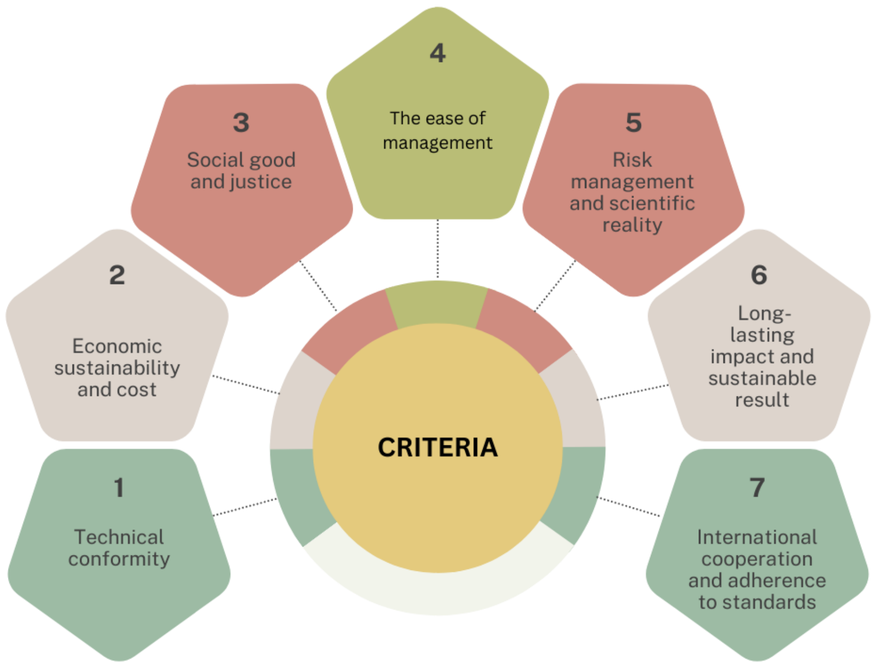

FIGURE 12. Defining Criteria.

Six decision makers from the Department of Biology, Faculty of Science at Ankara University served as experts in this study.

– **Steps 2-4:** Decision makers assess the alternatives based on the provided criteria, utilizing the linguistic terms outlined in the left column of Table 5 to construct the decision matrices.

TABLE 5. Linguistic Scale.

Linguistic terms	PFV
Incredibly High(IH)	$(0.95, 0.15)$
Very High(VH)	$(0.80, 0.25)$
High(H)	$(0.70, 0.40)$
Medium(M)	$(0.55, 0.55)$
Low(L)	$(0.45, 0.70)$
Very Low(VL)	$(0.30, 0.80)$
Incredibly Low(IL)	$(0.20, 0.95)$

We convert these decision matrices into a Pythagorean fuzzy decision matrix using the scale provided in the right column Table 5. Subsequently, we translate this information into CFVPFVs utilizing Remark . To achieve this, we employ a family of continuous functions denoted as $F = \{f_{\beta_k} : k = 1, ..., 6\}$, where each function is defined as $f_{\beta_k}(t) = \beta_k \ln(1 + t)$. Each value is

Table 6. Coefficients for Expert Opinion.

β_1	β_2	β_3	β_4	β_5	β_6
0.2	0.3	0.2	0.4	0.3	0.4

now associated with a continuous function. The coefficients β_k are assigned to decision makers to delineate the fuzzy sets and are presented in Table 6. Decision makers receive coefficients based on their level of experience and importance in the decision-making process. This approach aims to ensure that decision makers with more expertise carry more weight. Finally, the decision matrices are aggregated and defuzzified to DDM:

$$DDM = \begin{bmatrix} 0.7910 & 0.7454 & 0.7888 & 0.7493 & 0.7412 & 0.7886 & 0.7957 \\ 0.7460 & 0.7176 & 0.7916 & 0.7150 & 0.7120 & 0.7418 & 0.7419 \\ 0.7930 & 0.7919 & 0.7876 & 0.7984 & 0.7923 & 0.7886 & 0.7922 \\ 0.7165 & 0.7178 & 0.7908 & 0.7189 & 0.6626 & 0.7427 & 0.7466 \\ 0.7115 & 0.7446 & 0.7886 & 0.7155 & 0.7428 & 0.7918 & 0.7950 \end{bmatrix}.$$

– **Step 5:** When the CRITIC steps are applied as specified, the criteria weights are obtained as shown in Table 7 .

Table 7. Criteria Weights.

w_1	w_2	w_3	w_4	w_5	w_6	w_7
0.124885	0.089619	0.336849	0.102268	0.08074	0.133461	0.132213

– **Steps 6, 7:** Positive and negative ideal solutions are determined. The distances are calculated and expressed as follows:

$$b_1^+ = 0.0438,\ b_2^+ = 0.4104,\ b_3^+ = 0.0043,\ b_4^+ = 1,\ b_5^+ = 0.1928$$
$$b_1^- = 0.6317,\ b_2^- = 0.1199,\ b_3^- = 1,\ b_4^- = 0.6317,\ b_5^- = 0.5518.$$

– **Step 8:** The proximity coefficients are determined as follows:

$$\phi_1 = 0.9957, \quad \phi_2 = 0.226, \quad \phi_3 = 0.9957, \quad \phi_4 = 0.3871, \quad \phi_5 = 0.7411.$$

Based on this information, the alternatives are ranked as follows:

$$A_3 \succ A_1 \succ A_5 \succ A_4 \succ A_2.$$

This ranking indicates that alternative A_3 is the most important strategy to prioritize, followed by A_1, A_5, A_4, and A_2. It provides a hierarchy of importance for each alternative in addressing the problem. Notably, A_2 is identified as the least important strategy among the alternatives.

The choice of the functions $f_{\beta_k}(t) = \beta_k \ln(1+t)$ for the transformation to CFVPFVs is grounded in their mathematical properties and characteristics. The natural logarithm function $g(t) = \ln(1+t)$ is commonly used to introduce a smooth and gradual variation, suitable for capturing the nuanced nature of fuzzy values. The parameter β_k allows for adjusting the degree of influence of each decision maker, providing a flexible framework for incorporating individual preferences.

Here are some reasons justifying the choice:

– The logarithmic function ensures a smooth transformation, accommodating gradual changes in the input values. This is valuable in representing fuzzy memberships with a continuous and evolving nature.

– The parameter β_k offers flexibility, allowing customization for each decision maker. Different β_k values enable the tailoring of the transformation based on the decision makers' preferences and attitudes.

– The logarithmic function is monotonically increasing, ensuring that as the input values increase, the transformed values also increase. This aligns with the intuitive notion that higher input values should lead to higher fuzzy memberships.

– The logarithmic function provides mathematical consistency and is commonly used in various mathematical models, making it a suitable choice for creating a consistent and well-behaved transformation.

The functions are represented in Figure 13.

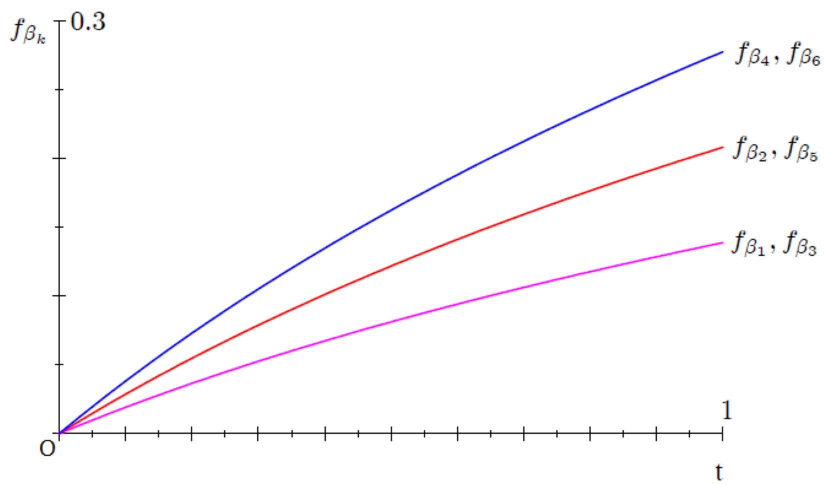

FIGURE 13. Decision Functions.

Comparative Analysis

In this section, a comparative analysis of the proposed approach with six commonly used MCDM methods is presented and the CRITIC-TOPSIS method is compared with the classical TOPSIS, COPRAS, ARAS, VIKOR, MOORA, EDAS approaches. Based on these comparisons, the defuzzified DDM matrix is used and the necessary operations are performed on this matrix. The comparison results are given in Table 8. Moreover, the results are illustrated in a graph presented in Figure 14.

	Ranking
COPRAS	$A_3 \succ A_4 \succ A_1 \succ A_5 \succ A_2$
ARAS	$A_3 \succ A_1 \succ A_5 \succ A_2 \succ A_4$
VIKOR	$A_5 \succ A_3 = A_4 \succ A_2 \succ A_1$
MOORA	$A_3 \succ A_4 \succ A_5 \succ A_2 \succ A_1$
TOPSIS	$A_3 \succ A_1 \succ A_5 \succ A_2 \succ A_4$
EDAS	$A_3 \succ A_4 \succ A_2 \succ A_5 \succ A_1$
CRITIC-TOPSIS	$\boldsymbol{A_3 \succ A_1 \succ A_5 \succ A_4 \succ A_2}$

TABLE 8. Comparative Analysis Results.

A detailed analysis shows that the best strategy is A_3. Although other strategies vary, the importance of strategy A_3 is clear. Since the problem of climate change is one that needs to be addressed as soon as possible, it is very important to take the first step with a clear result in terms of solving the problem. Thanks to the comparative study, both the reliability of the applied CRITIC-TOPSIS method and the first strategy to be applied as a result of the comparisons have been clarified.

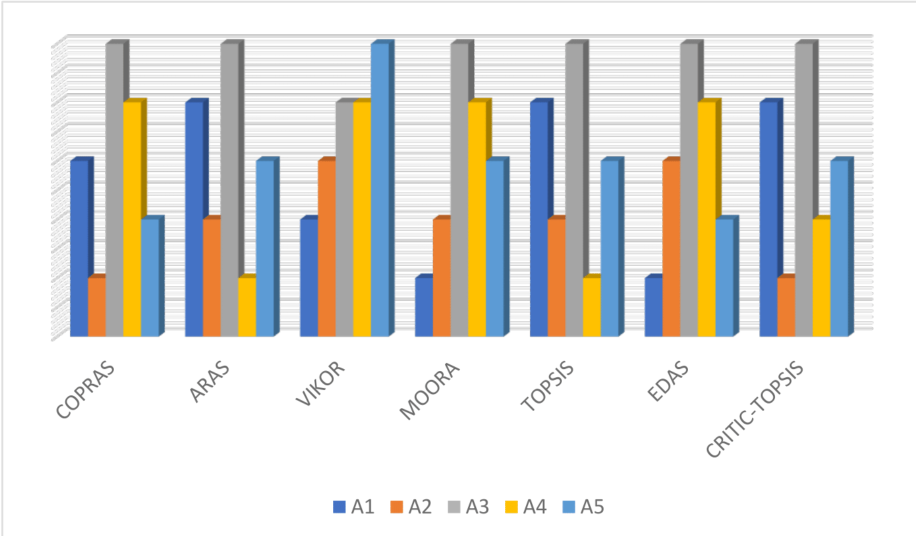

FIGURE 14. Comparative Analysis.

6|Findings and Discussion

This section presents the management insights learned from the case study conducted and the extensive comparative analysis.

- The paper answers **RQ1** by proposing and discussing various climate change management strategies. The identified strategies include:

    * A_1: This involves encouraging and supporting the use of renewable energy sources to mitigate the impact of climate change.
    * A_2: This strategy focuses on adopting technologies that reduce carbon emissions, contributing to efforts to combat climate change.
    * A_3: This strategy involves safeguarding existing carbon sinks (such as forests) and expanding their coverage to absorb more carbon from the atmosphere.
    * A_4: This strategy aims to make industrial production processes more environmentally friendly, reducing their negative impact on the climate.
    * A_5: This strategy involves encouraging and prioritizing transportation systems that are environmentally friendly and have a lower carbon footprint.

  The paper provides a detailed examination of each strategy, considering its potential impact on climate change, feasibility, and alignment with specific criteria such as technical conformity, economic sustainability, social good, and more. By presenting these strategies, the paper contributes valuable insights to the discourse on effective approaches to cope with climate change.

- The paper addresses **RQ2** by proposing and employing a comprehensive set of criteria and situations for evaluating climate change management strategies. The identified situations include considerations related to technical conformity, economic sustainability and cost, social good and justice, ease of management, risk management and scientific reality, long-lasting impact, sustainable results, and international cooperation and adherence to standards. These situations cover a wide spectrum of factors that should be taken into account when evaluating climate change management strategies. Additionally, the paper introduces a set of criteria, each associated with specific aspects of the evaluation process. The criteria encompass technical conformity, economic sustainability and cost, social good and justice, ease of management, risk management and scientific reality, long-lasting impact, sustainable results, and international cooperation and adherence to standards. By incorporating these criteria, the paper provides a structured approach for assessing the effectiveness and suitability of climate change management strategies.

– The paper addresses **RQ3** by emphasizing the complexity of climate change management and the need for a comprehensive approach in the decision-making process. It argues that relying on a single method of analysis may not be sufficient due to the multifaceted nature of the problem. Instead, the paper advocates for a more robust methodology that integrates multiple decision-making methods to evaluate and prioritize climate change management strategies. To support this perspective, the paper introduces and utilizes a combination of methodologies, including a fuzzy CRITIC-TOPSIS approach. By employing a hybrid approach, the paper demonstrates a more nuanced and comprehensive analysis that considers various dimensions of the problem. This not only enhances the reliability of the decision-making process but also allows for a more balanced consideration of factors such as technical feasibility, economic sustainability, social impact, and long-term effectiveness. Moreover, the paper addresses **RQ3** by recognizing the importance of comparative analysis in the evaluation of climate change management strategies. It contends that a thorough understanding of the strengths and weaknesses of different strategies requires a comparative assessment using multiple analysis methods. The paper advocates against the reliance on a singular method and emphasizes the need for a comparative framework to discern the most effective strategies.

– Applying different methods to a problem is important in terms of whether the results are consistent. Doing an analysis and comparing the results with the results from different methods tells us how accurate the result is. It is also important to ask how much the results differ. The answer to this question is important for us to understand whether the results of the problem are consistent. From another point of view, it adds a sensitive evaluation to the problem. For example, if we examine the solved problem, the result obtained is compared with six different methods. The result shows that A_3 is the best strategy. In fact, if we examine the other strategy rankings, we see that there are not very significant differences. There is a change in the result for only one method. This is due to the fact that a sensitive analysis is performed and this does not affect the generality. Thus, when the result obtained with CRTIC-TOPSIS is compared with the results of the other six methods, it can be seen that our problem and the result are consistent. All these aspects collectively contribute to addressing **RQ4**

7|Conclusion

Climate change has become a complex problem that affects the whole world. Management strategies should be developed to solve this problem. The strategies should achieve the fastest solution in the shortest time. Every strategy that is not created and implemented is a harbinger of dark days to come for the world. Our contribution is to plan appropriate climate change management strategies, evaluate these strategies and identify the fastest strategy to implement. This will save time and allow implementation to start immediately. In order to develop and evaluate management strategies, the first step was to use expert judgement to define and assess the problem. For the theoretical needs that arose during this evaluation, CFV-q-ROFS were used to generate more precise decisions. The criteria were weighted using the CRITIC method, which incorporates correlation and standard deviation into a common denominator. With the TOPSIS, the distance between alternatives was calculated using the new distance measure and the most appropriate strategy was determined. In addition, a new perspective was created by integrating two different methods during the application. A comparative analysis was then carried out to check the consistency of the results. This analysis involved the reassessment of the problem using six distinct methodologies, thereby initiating an original study dedicated to climate change.

In the future, new problems facing the world and its people, such as electronic waste, investment strategy and melting glaciers, will be analysed and solutions sought. These new problems will be solved by integrating different methods. Different fuzzy environments will be used in the studies and the necessary theoretical dimensions will be gained from the literature.

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Author Contributions

The authors equally contributed to the study.

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Conflicts of Interest

The authors have no relevant financial or non-financial interests to disclose.

Data Availability

No datasets were used in the preparation of this paper.

References

[1] Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., & Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environmental Science and Pollution Research*, 29(28), 42539–42559.

[2] Aghaloo, K., Ali, T., Chiu, Y. R., & Sharifi, A. (2023). Optimal site selection for the solar-wind hybrid renewable energy systems in Bangladesh using an integrated GIS-based BWM-fuzzy logic method. *Energy Conversion and Management*, 283, 116899.

[3] Akram, M., Zahid, S., & Deveci, M. (2024). Enhanced CRITIC-REGIME method for decision making based on Pythagorean fuzzy rough number. *Expert Systems with Applications*, 238, 122014.

[4] Ali, J., Hussain, K. N., Alnoor, A., Muhsen, Y. R.,& Atiyah, A. G. (2024). Benchmarking Methodology of Banks Based on Financial Sustainability Using CRITIC and RAFSI Techniques. *Decision Making: Applications in Management and Engineering*, 7(1), 315–341.

[5] Alkan, N., & Kahraman, C. (2022). An intuitionistic fuzzy multi-distance based evaluation for aggregated dynamic decision analysis (IF-DEVADA): Its application to waste disposal location selection.*Engineering Applications of Artificial Intelligence*, 111, 104809.

[6] Alsattar, H. A., Mourad, N., Zaidan, A. A., Deveci, M., Qahtan, S., Jayaraman, V., & Khalid, Z. (2023). Developing IoT sustainable real-time monitoring devices for food supply chain systems based on climate change using circular intuitionistic fuzzy set. *IEEE Internet of Things Journal*.

[7] Atanassov, K.T. (1986). Intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, 20, 87–96.

[8] Batisha, A. F. (2015).Implementing fuzzy decision making technique in analyzing the Nile Delta resilience to climate change. *Alexandria Engineering Journal*, 54(4), 1043–1056.

[9] Bilişik, Ö. N., Duman, N. H., & Taş, E. (2024).A novel interval-valued intuitionistic fuzzy CRITIC-TOPSIS methodology: An application for transportation mode selection problem for a glass production company.*Expert Systems with Applications*, 235, 121134.

[10] Bošković, S., Radonjić-Djogatović, V., Ralević, P., Dobrodolac, M., & Jovčić, S. (2021). Selection of mobile network operator using the CRITIC-ARAS method. *International Journal for Traffic Transport Engineering*, 11(1).

[11] Chen, B., Cai, Q., Wei, G., & Mo, Z. (2023).A flexible group decision-making method for green supplier selection integrating MABAC and CRITIC method under the linguistic Z-numbers environment.*Journal of Intelligent and Fuzzy Systems*, (Preprint), 1–16.

[12] Cheng, S., Jianfu, S., Alrasheedi, M., Saeidi, P., Mishra, A. R., & Rani, P. (2021).A new extended VIKOR approach using q-rung orthopair fuzzy sets for sustainable enterprise risk management assessment in manufacturing small and medium-sized enterprises. *International Journal of Fuzzy Systems*, 23, 1347–1369.

[13] Cuong, B. C., & Kreinovich, V. (2014). Picture fuzzy sets. *Journal of computer science and cybernetics*, 30(4), 409–420.

[14] Deveci, M., Pamucar, D., Gokasar, I., Isik, M., & Coffman, D. M. (2022).Fuzzy Einstein WASPAS approach for the economic and societal dynamics of the climate change mitigation strategies in urban mobility planning. *Structural Change and Economic Dynamics*, 61, 1–17.

[15] Diakoulaki, D., Mavrotas, G., & Papayannakis, L. (1995). Determining objective weights in multiple criteria problems: The critic method.*Computers Operations Research*, 22(7), 763–770.

[16] Dunlap, R. E., & McCright, A. M. (2010). Climate change denial: sources, actors and strategies. *Routledge handbook of climate change and society*, 240.

[17] Eroğlu, H. E. (2022). The polyploıdy mechanısm as response to global climate change. *Global Climate Change: Agriculture and Food Science Perspective*, 135–147, İksad Publishing.

[18] Esangbedo, M. O., & Tang, M. (2023). Evaluation of enterprise decarbonization scheme based on grey-MEREC-MAIRCA hybrid MCDM method. *Systems*, 11(8), 397.

[19] Friel, S., Schram, A., & Townsend, B. (2020). The nexus between international trade, food systems, malnutrition and climate change. *Nature Food*, 1(1), 51–58.

[20] Fung, I. Y., Doney, S. C., Lindsay, K., & John, J. (2005).Evolution of carbon sinks in a changing climate. *Proceedings of the National Academy of Sciences*, 102(32), 11201–11206.

[21] Ghorui, N., Mondal, S. P., Chatterjee, B., Ghosh, A., Pal, A., De, D., & Giri, B. C. (2023).Selection of cloud service providers using MCDM methodology under intuitionistic fuzzy uncertainty. *Soft Computing*, 27(5), 2403–2423.

[22] Gokasar, I., Deveci, M., & Kalan, O. (2022). CO_2 Emission based prioritization of bridge maintenance projects using neutrosophic fuzzy sets based decision making approach. *Research in Transportation Economics*, 91, 101029.

[23] Golfam, P., Ashofteh, P. S., Rajaee, T., & Chu, X. (2019). Prioritization of water allocation for adaptation to climate change using multi-criteria decision making (MCDM).*Water Resources Management*, 33, 3401–3416.

[24] Gu, D., Guo, J., Fan, Y., Zuo, Q., & Yu, L. (2022). Evaluating water-energy-food system of Yellow River basin based on type-2 fuzzy sets and Pressure-State-Response model. *Agricultural Water Management*, 267, 107607.

[25] Haktanır, E., & Kahraman, C. (2022). A novel picture fuzzy CRITIC - REGIME methodology: Wearable health technology application. *Engineering Applications of Artificial Intelligence*, 113, 104942.

[26] Hall, J., Fu, G., & Lawry, J. (2007). Imprecise probabilities of climate change: aggregation of fuzzy scenarios and model uncertainties. *Climatic Change*, 81(3-4), 265–281.

[27] Hsieh, Y. P., Lin, C. C., & Huang, Y. C. (2012). Exploration of long-term care institution managers' perceptions of institutional indoor environment quality and ease of administration. *Care Management Journals*, 13(3), 121–133.

[28] Hunt, C. A. (2009). Carbon sinks and climate change: forests in the fight against global warming.*Edward Elgar Publishing*.

[29] https://science.nasa.gov/climate-change/

[30] https://www.ncei.noaa.gov/monitoring

[31] https://crudata.uea.ac.uk/cru/data/temperature/

[32] http://data.giss.nasa.gov/gistemp

[33] https://www.giss.nasa.gov/research/news/20170118/

[34] https://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/index3.html

[35] https://nsidc.org/sotc/glacier_balance.html

[36] https://nsidc.org/learn

[37] http://nsidc.org/cryosphere/sotc/snow_extent.html

[38] http://climate.rutgers.edu/snowcover/docs.php?target=vis

[39] https://nsidc.org/cryosphere/sotc/sea_ice.html

[40] http://psc.apl.washington.edu/research/projects/arctic-sea-ice-volume-anomaly/

[41] http://psc.apl.uw.edu/research/projects/projections-of-an-ice-diminished-arctic-ocean/

[42] Janani, K., Mohanrasu, S. S., Kashkynbayev, A., & Rakkiyappan, R. (2023).Minkowski distance measure in fuzzy PROMETHEE for ensemble feature selection.*Mathematics and Computers in Simulation*.

[43] Jones, M. C., & Cheung, W. W. (2018). Using fuzzy logic to determine the vulnerability of marine species to climate change. *Global change biology*, 24(2), e719–e731.

[44] Jun, K. S., Chung, E. S., Kim, Y. G., & Kim, Y. (2013). A fuzzy multi-criteria approach to flood risk vulnerability in South Korea by considering climate change impacts. *Expert Systems with Applications*, 40(4), 1003–1013.

[45] Kahraman, C., Onar, S. C., & Öztayşi, B. (2022). A Novel spherical fuzzy CRITIC method and its application to prioritization of supplier selection criteria.*Journal of Intelligent and Fuzzy Systems*, 42(1), 29–36.

[46] Keohane, R. O., & Victor, D. G. (2011). The regime complex for climate change.*Perspectives on politics*, 9(1), 7-23.

[47] Khan, M. S. A., Anjum, F., Ullah, I., Senapati, T., & Moslem, S. (2022). Priority Degrees and Distance Measures of Complex Hesitant Fuzzy Sets With Application to Multi-Criteria Decision Making. *Ieee Access*, 11, 13647–13666.

[48] Kim, Y., & Chung, E. S. (2013).Fuzzy VIKOR approach for assessing the vulnerability of the water supply to climate change and variability in South Korea.*Applied Mathematical Modelling*, 37(22), 9419–9430.

[49] Kumar, R., & Gandotra, N. (2023).A novel pythagorean fuzzy entropy measure using MCDM application in preference of the advertising company with TOPSIS approach.*Materials Today: Proceedings*, 80, 1742–1746.

[50] Kumari, A., Acherjee, B. (2022).Selection of non-conventional machining process using CRITIC-CODAS method.*Materials Today: Proceedings*, 56, 66–71.

[51] Kutlu Gündoğdu, F., & Kahraman, C. (2019). Spherical fuzzy sets and spherical fuzzy TOPSIS method.*Journal of intelligent fuzzy systems*, 36(1), 337–352.

[52] Lai, H., Liao, H. (2021). A multi-criteria decision making method based on DNMA and CRITIC with linguistic D numbers for blockchain platform evaluation. *Engineering Applications of Artificial Intelligence*, 101, 104200.

[53] Levitus, S., Antonov, J., Boyer, T., O Baranova, Garcia, H., Locarnini, R., Mishonov, A., Reagan, J., Seidov, D., Yarosh, E., & Zweng, M. (2017)."NCEI ocean heat content, temperature anomalies, salinity anomalies, thermosteric sea level anomalies, halosteric sea level anomalies, and total steric sea level anomalies from 1955 to present calculated from in situ oceanographic subsurface profile data (NCEI Accession 0164586), Version 4.4. ,*NOAA National Centers for Environmental Information*.

[54] Li, X., Han, Z., Yazdi, M., & Chen, G. (2022).A CRITIC-VIKOR based robust approach to support risk management of subsea pipelines.*Applied Ocean Research*, 124, 103187.

[55] Lu, H., Zhao, Y., Zhou, X., & Wei, Z. (2022). Selection of agricultural machinery based on improved CRITIC-entropy weight and GRA-TOPSIS method. *Processes*, 10(2), 266.

[56] Lu, Y., Khan, Z. A., Alvarez Alvarado, M. S., Zhang, Y., Huang, Z., & Imran, M. (2020).A critical review of sustainable energy policies for the promotion of renewable energy sources.*Sustainability*, 12(12), 5078.

[57] Lv, Z., & Shang, W. (2023).Impacts of intelligent transportation systems on energy conservation and emission reduction of transport systems: A comprehensive review. *Green Technologies and Sustainability*, 1(1), 100002.

[58] Madic, M., & Radovanovic, M. (2015). Ranking of some most commonly used nontraditional machining processes using ROV and CRITIC methods.*UPB Sci. Bull., Series D*, 77(2), 193–204.

[59] Magableh, G. M. (2023).Evaluating Wheat Suppliers Using Fuzzy MCDM Technique.*Sustainability*, 15(13), 10519.

[60] Mishra, A. R., Chen, S. M., & Rani, P. (2023). Multicriteria decision making based on novel score function of Fermatean fuzzy numbers, the CRITIC method, and the GLDS method. *Information Sciences*, 623, 915–931.

[61] Mohata, A., Mukhopadhyay, N., & Kumar, V. (2023).CRITIC-COPRAS-Based Selection of Commercially Viable Alternative Fuel Passenger Vehicle. In Advances in Modelling and Optimization of Manufacturing and Industrial Systems: Select Proceedings of CIMS 2021 (pp. 51–69).*Singapore: Springer Nature Singapore*.

[62] Nerem, R.S., Beckley, B.D., Fasullo J. T.,Hamlington, B.D. , Masters, D., & Mitchum, G.T.(2018).Climate-change–driven accelerated sea-level rise detected in the altimeter era. *PNAS 15, no. 9 : 2022-2025*. https://doi.org/10.1073/pnas.1717312115.

[63] Nesbitt, L. (2024).Uncovering millennia of wildfire occurrence during the Holocene at local and regional scales in the Northwest Territories, Canada.

[64] Ning, B., Lei, F., & Wei, G. (2022).CODAS Method for Multi-Attribute Decision-Making Based on Some Novel Distance and Entropy Measures Under Probabilistic Dual Hesitant Fuzzy Sets. *International Journal of Fuzzy Systems*, 24(8), 3626–3649.

[65] Odu, G. O. (2019).Weighting methods for multi-criteria decision making technique. *Journal of Applied Sciences and Environmental Management*, 23(8), 1449–1457.

[66] Özçelik, G. (2022). The attitude of MCDM approaches versus the optimization model in finding the safest shortest path on a fuzzy network. *Expert Systems with Applications*, 203, 117472.

[67] Paavola, J. (2008).Science and social justice in the governance of adaptation to climate change.*Environmental Politics*, 17(4), 644–659.

[68] Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS, Zhang and Rothrock, 2003)

[69] Pamucar, D., Deveci, M., Stević, Ž., Gokasar, I., Isik, M., & Coffman, D. M. (2022).Green strategies in mobility planning towards climate change adaption of urban areas using fuzzy 2D algorithm.*Sustainable Cities and Society*, 87, 104159.

[70] Patel, A., Jana, S., & Mahanta, J. (2023). Intuitionistic fuzzy EM-SWARA-TOPSIS approach based on new distance measure to assess the medical waste treatment techniques. *Applied Soft Computing*, 110521.

[71] Peng, X., Zhang, X., & Luo, Z. (2020).Pythagorean fuzzy MCDM method based on CoCoSo and CRITIC with score function for 5G industry evaluation.*Artificial Intelligence Review*, 53(5), 3813–3847.

[72] Pulver, S. (2007).Making sense of corporate environmentalism: An environmental contestation approach to analyzing the causes and consequences of the climate change policy split in the oil industry.*Organization environment*, 20(1), 44–83.

[73] Ragwitz, M., Huber, C., & Resch, G. (2007). Promotion of renewable energy sources: effects on innovation. *International Journal of Public Policy*, 2(1-2), 32–56.

[74] Rajarajeswari, P.,& Uma, N., (2013). Intuitionistic fuzzy multi similarity measure based on cotangent function. *Int J Eng Res Technol.*, 2(1), 1323–1329.

[75] Ramezanzade, M., Karimi, H., Almutairi, K., Xuan, H. A., Saebi, J., Mostafaeipour, A., & Techato, K. (2021). Implementing MCDM techniques for ranking renewable energy projects under fuzzy environment: A case study.*Sustainability*, 13(22), 12858.

[76] Rani, P., Mishra, A. R., Krishankumar, R., Ravichandran, K. S., & Kar, S. (2021).Multi-criteria food waste treatment method selection using single-valued neutrosophic-CRITIC-MULTIMOORA framework. *Applied Soft Computing*, 111, 107657.

[77] Akçakaya, A., Sümer, U. M., Demircan, M., Demir, Ö., Atay, H., Eskioğlu, O., Gürkan, H., Yazıcı, B., Kocatürk, A., Şensoy, S., Bölük, E., Arabacı, H., Açar, Y., Ekici, M., Yağan,S., & Çukurçayır, F. (2015).Yeni Senaryolar İle Türkiye İklim Projeksiyonları Ve İklim Değişikliği, *Turkish State Meteorological Service*.

[78] Robertson, S. (2018).A carbon footprint analysis of renewable energy technology adoption in the modal substitution of high-speed rail for short-haul air travel in Australia. *International Journal of Sustainable Transportation*, 12(4), 299–312.

[79] Robinson, D.A., Hall, D. K. & Mote, T. L. (2017).Measures Northern Hemisphere Terrestrial Snow Cover Extent Daily 25km EASE-Grid 2.0, Version 1. Boulder, Colorado USA. *NASA National Snow and Ice Data Center Distributed Active Archive Center*. doi: https://doi.org/10.5067/MEASURES/CRYOSPHERE/nsidc-0530.001

[80] Rostamzadeh, R., Ghorabaee, M. K., Govindan, K., Esmaeili, A., & Nobar, H. B. K. (2018). Evaluation of sustainable supply chain risk management using an integrated fuzzy TOPSIS-CRITIC approach. *Journal of Cleaner Production*, 175, 651–669.

[81] Scolobig, A., Prior, T., Schröter, D., Jörin, J., & Patt, A. (2015). Towards people-centred approaches for effective disaster risk management: Balancing rhetoric with reality. *International journal of disaster risk reduction*, 12, 202–212.

[82] Senapati, T., & Yager, R. R. (2020). Fermatean fuzzy sets. *Journal of Ambient Intelligence and Humanized Computing*, 11, 663–674.

[83] Sharkasi, N., & Rezakhah, S. (2022). A modified CRITIC with a reference point based on fuzzy logic and hamming distance. *Knowledge-Based Systems*, 255, 109768.

[84] Sierpiński, G. (2017). Promotion of environmentally friendly transport behaviour using a multicriterial multimodal trip planner as a means to support reduction of external costs. *In Sustainable Transport Development, Innovation and Technology: Proceedings of the 2016 TranSopot Conference* (pp. 271–282). Springer International Publishing.

[85] Silva, N. F., dos Santos, M., Gomes, C. F. S., & de Andrade, L. P. (2023).An integrated CRITIC and Grey Relational Analysis approach for investment portfolio selection. *Decision Analytics Journal*, 100285.

[86] Sleem, A., Mostafa, N., & Elhenawy, I. (2023). Neutrosophic CRITIC MCDM methodology for ranking factors and needs of customers in product's target demographic in virtual reality metaverse. *Neutrosophic Systems with Applications*, 2, 55–65.

[87] Smarandache, F. (1998). Neutrosophy: neutrosophic probability, set, and logic: analytic synthesis synthetic analysis.

[88] Suganthi, L., Iniyan, S.,& Samuel, A. A. (2015).Applications of fuzzy logic in renewable energy systems–a review.*Renewable and sustainable energy reviews*, 48, 585–607.

[89] Tian, M. Y., (2013). A new fuzzy similarity based on cotangent function for medical diagnosis. *Adv Model Optim.*, 15(2), 151–156.

[90] Torra, V. (2010).Hesitant fuzzy sets. *International journal of intelligent systems*, 25(6), 529–539.

[91] Tripathi, D., Nigam, S. K., Mishra, A. R., & Shah, A. R. (2023).A novel intuitionistic fuzzy distance measure-SWARA-COPRAS method for multi-criteria food waste treatment technology selection.*Operational Research in Engineering Sciences: Theory and Applications*, 6(1).

[92] Ünver, M., & Olgun, M. (2023). Continuous Function Valued q-Rung Orthopair Fuzzy Sets and an Extended TOPSIS. *International Journal of Fuzzy Systems*, 1–15.

[93] Unver, M., & Aydogan, B. (2023). Information measures for continuous function-valued q-rung orthopair fuzzy sets and an extended TOPSIS. *Journal of Uncertain Systems*, doi.org/10.1142/S1752890923500125

[94] Velicogna, I., Mohajerani Yara, Geruo, A., Landerer, F. , Mouginot, J., Noel, B., Rignot, E., Sutterly, T., van den Broeke, M., Wessem, M., & Wiese, D. (2020). Continuity of Ice Sheet Mass Loss in Greenland and Antarctica From the GRACE and GRACE Follow-On Missions.*Geophysical Research Letters* 47, Issue 8 , e2020GL087291. https://doi.org/10.1029/2020GL087291

[95] von Schuckmann,K., Cheng, L., Palmer, L,. D., Hansen, J., Tassone, C., Aich, V., Adusumilli, S., Beltrami, H., Boyer, H., T., Cuesta-Valero, F., Desbruyeres, D., Domingues, C., Garcia-Garcia, A., Gentine, P., Gilson, J., Gorfer, M., Haimberger, L., Ishii, M., G. Johnson, M., Killick, R., King, B., Kirchengast, G., Kolodziejczyk, N., Lyman, J.,Marzeion, B., Mayer, M., Monier, M.,Monselesan, D., Purkey, S., Roemmich, D., Schweiger, A., Seneviratne, S., Shepherd, A., Slater, D., Steiner, A., Straneo, F., Timmermans, M.L., & Wijffels, S. (2020). "Heat stored in the Earth system: where does the energy go?" *Earth System Science Data 12*, Issue 3 : 2013-2041. https://doi.org/10.5194/essd-12-2013-2020.

[96] Wang, H., Xu, T., Pamucar, D., Li, X., & Feng, L. (2023). A Lance Distance-Based MAIRCA Method for q-Rung Orthopair Fuzzy MCDM with Completely Unknown Weight Information. *Informatica*, 1–24.

[97] Wang, H. L., Zhao, X. F., Chen, H. J., Yi, K., Xie, W. C., & Xu, W. Y. (2023).Evaluation of toppling rock slopes using a composite cloud model with DEMATEL–CRITIC method.*Water Science and Engineering.*

[98] Wang, K., Ying, Z., Goswami, S. S., Yin, Y., & Zhao, Y. (2023). Investigating the role of artificial intelligence technologies in the construction industry using a Delphi-ANP-TOPSIS Hybrid MCDM concept under a fuzzy environment.*Sustainability*, 15(15), 11848.

[99] Wang, S., Wei, G., Lu, J., Wu, J., Wei, C., & Chen, X. (2022). GRP and CRITIC method for probabilistic uncertain linguistic MAGDM and its application to site selection of hospital constructions. *Soft Computing*, 26, 237–251.

[100] Woo, T. H., Jang, K. B., Baek, C. H., & Du Choi, J. (2022).Analysis of climate change mitigations by nuclear energy using nonlinear fuzzy set theory.*Nuclear Engineering and Technology*, 54(11), 4095–4101.

[101] Yager, R.R. (2016). Generalized orthopair fuzzy sets. *IEEE Transactions on Fuzzy Systems*, 25(5), 1222–1230.

[102] Yager, R.R. (2013). Pythagorean fuzzy subsets. *2013 Joint IFSA World Congress and NAFIPS Annual Meeting (IFSA/NAFIPS)*, 57–61.

[103] Yager, R. R. (1986).On the theory of bags.*International Journal of General System*, 13(1), 23–37.

[104] Yalcin, N., & Ünlü, U. (2018).A multi-criteria performance analysis of Initial Public Offering (IPO) firms using CRITIC and VIKOR methods. *Technological and Economic development of Economy*, 24(2), 534–560.

[105] Yang, F., Chou, J., Dong, W., Sun, M.,& Zhao, W. (2020). Adaption to climate change risk in eastern China: Carbon emission characteristics and analysis of reduction path. *Physics and Chemistry of the Earth*, Parts A/B/C, 115, 102829.

[106] Ye, J., (2016). Similarity measures of intuitionistic fuzzy sets based on cosine function for the decision making of mechanical design schemes.*J Intell Fuzzy Syst.*, 30(1), 151–158.

[107] Ye, J., (2011).Cosine similarity measures for intuitionistic fuzzy sets and their applications. *Mathematical and computer modelling.* 53(1–2), 91–97.

[108] Zadeh, L.A. (1965). Fuzzy sets. *Information and Control*, 8(3) 338–353.

[109] Zadeh, L. A. (1975). The concept of a linguistic variable and its application to approximate reasoning—I. *Information sciences*, 8(3), 199–249.

[110] Zafar, S., Alamgir, Z., & Rehman, M. H. (2021).An effective blockchain evaluation system based on entropy-CRITIC weight method and MCDM techniques. *Peer-to-Peer Networking and Applications*, 14(5), 3110–3123.

[111] Zamani, R., Ali, A. M. A., & Roozbahani, A. (2020). Evaluation of adaptation scenarios for climate change impacts on agricultural water allocation using fuzzy MCDM methods.*Water Resources Management*, 34, 1093–1110.

[112] Zhang, H., & Wei, G. (2023). Location selection of electric vehicles charging stations by using the spherical fuzzy CPT–CoCoSo and D-CRITIC method.*Computational and Applied Mathematics*, 42(1), 60.

[113] Zhong, S., Chen, Y., & Miao, Y. (2023).Using improved CRITIC method to evaluate thermal coal suppliers.*Scientific Reports*, 13(1), 195.

[114] Zhong, Y., & Wu, P. (2015).Economic sustainability, environmental sustainability and constructability indicators related to concrete-and steel-projects.*Journal of Cleaner Production*, 108, 748–756.