

IMPACT OF CLIMATE CHANGE ON AN ORGANIZATION'S OPERATIONS STRATEGY TOWARDS SUSTAINABILITY VIA HFWFSA AND THE FUZZY DEMATEL APPROACH

Chengjie DONG¹, Kuang-Hua HU^{1✉}, Gwo-Hshiung TZENG²

¹Accounting School, Nanfang College, Guangzhou, China

²Graduate Institute of Urban Planning, College of Public Affairs, National Taipei University, Taipei, Taiwan

Article History:

- received 22 July 2024
- accepted 20 August 2026
- first published online 24 September 2026

Abstract. Climate change has profoundly impacted diverse ecosystems and affected nearly all economic sectors and industries. Consequently, enterprises find themselves confronted with unavoidable climate-related challenges and are increasingly driven to embrace social responsibility, thereby accelerating the transition toward a sustainable economy. It is imperative to help achieve this objective by establishing a comprehensive practical framework. To address this challenge, this research introduces an integrated approach combining HFWFSA (hybrid filter-wrapper feature selection algorithm) and the fuzzy DEMATEL (Decision Making Trial and Evaluation Laboratory) model, leveraging insights from domain experts through a questionnaire and enabling users to identify crucial information and visualize the intricate relationships among different criteria. Our practical and valuable framework can help guide senior management in implementing robust measures for corporate sustainability in the context of climate change. Research findings indicate that, in terms of dimensions, the factors influencing sustainability are ranked in the following order: corporate governance, corporate risk management, metrics and goals, and corporate strategy. Moreover, within separate dimension, the key influencing factors are board oversight, risk response strategies, overall risk management, and low carbon policy. Therefore, to establish a sustainable development framework, businesses should prioritize these findings as key considerations to reduce environmental pressure.

Keywords: climate change, sustainability, fuzzy rough set theory (FRST), decision making trial and evaluation laboratory (DEMATEL), hybrid filter-wrapper feature selection algorithm (HFWFSA), multiple criteria decision-making (MCDM).

JEL Classification: C43, C61, D81.

✉Corresponding author. E-mail: khh0622@gmail.com

1. Introduction

There is greater increased concern in recent years about the real effects of climate change and other environmental damages on global financial system stability (Chua et al., 2022). Environmental disruption poses a significant threat to sustainable development and demands a long-term and optimal operational solution response. Many studies (Nagelkerken & Connell, 2015; Koo et al., 2018; Lachaud et al., 2022; D'Orazio & Dirks, 2022) have investigated the effects of climate change on humanity and the global economic structure. However, investors' demands for sufficient information about climate change scenarios and its potential risks on corporate financial performance have surged (Griffin & Jaffe, 2022).

It is widely accepted that climate change could lead to economic damages and social negative consequences within this century, and the severity of physical impacts is difficult to measure and predict. To avoid disastrous consequences from climate change, greenhouse gas (GHG) emission reduction and moving to a lower-carbon economy have become an international consensus. The goal globally is to see GHG emissions reach net-zero in 2050 (Intergovernmental Panel on Climate Change [IPCC], 2018; Bebbington et al., 2020; D'Orazio & Dirks, 2022), which has been supported by 22 member governments of the International Energy Agency. Thus, all governments are stepping up efforts to implement their energy and climate policies to achieve international goals (Bouckaert et al., 2021). Although organizations are confronting considerable risk under such a transition, it also creates forward momentum for those on the road towards sustainable development.

The international treaty on climate change released at the Paris Agreement in 2015 has been recognized by 196 parties and hopes to control global temperatures from increasing no more than 1.5 Celsius by the end of this century in response to threats posed by climate change (O'Dwyer & Unerman, 2020). The Intergovernmental Panel on Climate Change (IPCC) of the United Nations provided an assessment report related to climate change in 2018 and noted that global warming of 2 Celsius is expected to exude higher risk than global warming of 1.5 Celsius (IPCC, 2018; Task Force on Climate-related Financial Disclosures [TCFD], 2017a, 2017b). According to Le Quére et al. (2019), GHG emissions must be reduced by 1 to 2 billion tons per year for global warming to be controlled below 2 Celsius by 2100. Any failure to sufficiently implement energy conservation and carbon mitigation will expose entities to physical risks triggered by climate change, resulting in original business models cannot achieve the expected results (TCFD, 2017a).

Climate change poses a double jeopardy to companies' tangible assets and supply chains. It may also decrease the value of these assets, potentially threatening the stability of financial markets if these assets are used as loan collateral. Ben-Amar et al. (2023) found that climate change creates an irreversible outcome and transitional and physical risks to entities and also to the global economy. To face the substantial challenges of climate change and to accomplish the global warming limit of 1.5 Celsius according to Paris COP21, G20 countries have recognized its irreversible impacts and realize they should scale up climate-related activities (D'Orazio, 2022).

The Task Force on Climate-related Financial Disclosures (TCFD) was established by the Financial Stability Board (FSB) in 2015 (Financial Stability Board [FSB], 2015a, 2015b). The TCFD framework for climate-related financial disclosures released in 2017 has recently received great attention due to its distinctive practical applications. The 2019 status report of TCFD suggested that corporate information disclosures on climate change fall far short of market demand and fail to provide resilient solutions, thus calling for a redoubling of efforts (TCFD, 2019). Following the description in the 2020 TCFD report (TCFD, 2020), a conceptual view of TCFD was supported and adopted by 89 countries and jurisdictions. A consistent set of voluntary climate-related financial disclosures was released by TCFD to help investors and decision-makers identify the major risk factors and to more accurately assess climate-related risks and opportunities.

According to Amar et al. (2023), improving the transparency and sharing of information related to the impact of climate change on enterprises is the core value of TCFD reporting,

in order to assume the responsibility of the international community for the environmental protection. More importantly, management of climate-related risks and understanding climate change have further facilitated entities with more positive attitudes toward environment sustainability (O'Dwyer & Unerman, 2020). Despite the complexities of climate change, TCFD reporting implies sufficiently informing markets through the disclosures of longer-term climate-related financial risk so as to help executives effectively identify and manage related risks and opportunities (TCFD, 2016).

Within the context of climate change due to uncertainty and destruction, corporate operational strategy for sustainable development stands out as a difficult and urgent issue. Despite numerous studies on the influence factors of climate change, few have empirically examined corporate response measures in a comprehensive evaluation framework. The proposed framework is based on TCFD's recommendation that encompasses four thematic areas and their corresponding elements (TCFD, 2017a). One fundamental issue for entities is how to determine the key determinants across the four thematic areas and sub-criteria within a separate dimension. We realize that how to develop an adaptive response to climate change for meeting the transforming sustainability requirements for such applications is a new challenge and is tied to the creation of firm value and sustainable development.

To the authors' knowledge, there has not been a systematic and comprehensive review of literature on the integration of artificial intelligence algorithms and fuzzy multiple criteria decision-making (MCDM) for identifying multi-operational decisions of climate change in China. This paper contributes to the field of climate change by filling this gap through a rigorous and critical investigation of such studies. The study aims to address three primary questions.

Q1: *What are the key factors influencing organizational responses to climate change in China?*

Q2: *How are these factors prioritized in China's large enterprises?*

Q3: *How do crucial factors assist in validating the set-up of organizational operations strategy in China?*

According to the findings, this study contributes to the literature in three important ways. First, it extends the strand on climate-related management in China and enriches the research on the TCFD structure by focusing on the construction of corporate operations strategy of climate change. More specifically, we develop a comprehensive and useful corporate strategic framework in response to climate change to mitigate its long-term negative impacts. Second, it gives supporting evidence for the usefulness of the fuzzy MCDM model for assessing the improvement of an organization's operational and strategic activities under climate change. Stated differently, to overcome this climate change issue, a fusion evaluation model is initiated to supply practical insights for managers and to create robust operations planning. Third, the identification of key factors from climate change is a MCDM (multi-criteria decision making) problem. It combines the hybrid filter-wrapper feature selection algorithm (HFWFSA) and fuzzy DEMATEL (decision making trial and evaluation laboratory) approach and to perform this task. The former is a suitable features selection algorithm for screening key factors (Hu et al., 2021; Chen et al., 2022). The latter is an excellent prioritization technique for overcoming the complex relationships among criteria (Chang et al., 2011; Feng & Ma, 2020;

Priyanka et al., 2023). By implementing a theoretically grounded and systematic decision-making framework, we can achieve optimal outcomes in addressing climate change, rather than addressing issues on an ad hoc basis.

However, China is still in the early stages of formulating climate change response policies, and relevant regulations and standardized frameworks have not yet been fully established or implemented. Although the Chinese government has proposed the “carbon peak and carbon neutrality” targets, there is still significant room for improvement in specific policy details, industry guidance, and data disclosure standards. For instance, the methods used to quantify and assess climate-related risks vary across different enterprises and industries, and there is a lack of unified disclosure standards and regulatory requirements. Furthermore, many companies are insufficiently aware of the financial risks posed by climate change, leading to fragmented disclosures that often fail to meet the transparency and accuracy demands of investors and regulators. Therefore, in the context of climate change becoming a global issue of significant importance, this study, based on the TCFD framework and tailored to China’s national conditions, not only aligns with international standards but also contributes to advancing the improvement of China’s climate change-related policies and information disclosure framework.

The primary objective of this study is to reduce the cognitive load faced by decision-makers and to delineate the causal relationships among evaluation criteria, thereby enhancing the efficiency of resource allocation. To achieve this, the proposed architecture incorporates a feature selection mechanism: HFWFSA and a causal relationship identifier: DEMATEL. Unlike other MCDM methods such as the AHP or ANP, which are predominantly used to rank the relative importance of criteria, DEMATEL not only prioritizes the essential criteria but also elucidates the cause-effect relationships among them. This ability to reveal the directionality of influence is particularly critical for strategic decision-making, as it allows for more precise and effective resource allocation. Previous research (e.g., Tzeng et al., 2007; Lu et al., 2013; Ou Yang et al., 2013; Chen et al., 2022) has demonstrated that the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method is an effective and mature tool for analyzing these relationships. DEMATEL not only reveals both direct and indirect influences among variables but also aids decision-makers in understanding the dynamic interactions of elements within the system by constructing influence relation maps. DEMATEL clearly illustrates causal relationships through a simple matrix, and unlike ANP, it does not require a large number of pairwise comparisons. Therefore, it is more suitable in situations with limited resources or time constraints. Furthermore, the integration of traditional MCDM techniques with machine learning algorithms aims to capture the dynamic nature of complex decision environments. To address the limitation of static causal modeling in conventional DEMATEL, this study extends the method to a dynamic DEMATEL framework. This extension enables the model to reflect temporal changes in causal structures and provides deeper, data-driven insights into the evolving interrelationships among criteria.

The rest of the paper runs as follows. Section 2 reviews the related literature on dimensions and selected criteria of climate change. Section 3 explores methodologies. Section 4 demonstrates the questionnaire development and the creation of INRM based on fuzzy DEMATEL. Section 5 presents a discussion. Section 6 illustrates the theoretical contributions. Section 7 introduces practical implications. Section 8 concludes.

2. Operation strategy matrix of climate change

To implement a comprehensive operational strategy and to decrease any potential catastrophe, this study covers the full spectrum of climate change-related disclosures in an assessment matrix. The assessment matrix based on the TCFD framework includes four dimensions: governance, strategy, risk management, and metrics and targets (TCFD, 2017a). This structure provides a sturdy basis for taking into account climate change, with increased relevance for corporate information disclosures, so as to improve adaptation and resistance to environmental impacts (David & Giordano-Spring, 2022). The TCFD recommendations apply to organizations across multiple jurisdictions and sectors in response to climate change (TCFD, 2017a). The four dimensions give a fuller picture of climate change impacts for corporates to highlight important considerations for building out a reliable and valid practical framework. Against this backdrop of climate change, this study adopts the TCFD reporting as an evaluation framework. A detailed analysis of each dimension and related criteria is illustrated as follows.

2.1. Corporate governance

Stakeholders are interested in understanding board roles and management attitude when facing climate-related issues (TCFD, 2017a). It is important that such information receives much attention from the board of directors and management and is effectively utilized to support evaluations of climate change. Luo and Tang (2021) indicated that corporate board sustainability committees play an essential role in achieving processes and objectives related to environmental issues such as climate change (Orazalin et al., 2023). According to García-Sánchez et al. (2023), corporate boards have a significant effect on sustainability achievement, particularly in monitoring and overseeing climate change exposures. The board of directors can help develop goals and targets relevant for improving the quality of climate change-related disclosure, as well as guarantee an effective supervision of implementation for any post-integration framework of related issues in corporate operations and business strategy (Cosma et al., 2022). Senior management make efforts to improve and implement business strategies in considering climate change and take responsibilities for corporate sustainability (Birchall & Bonnett, 2021). Top management exhibits key intrinsic motivation for promoting climate change-related disclosure for the need of global environmental sustainability (Velte, 2023). Furthermore, how accountability issues are addressed and give a pragmatic accountability initiative to promote and support global environmental governance is an important task for enterprises (Rana et al., 2023).

2.2. Corporate strategy

An improved operation strategy is established by taking into consideration climate change impacts for achieving the goals of corporate sustainability (Zhang et al., 2022). Teale and Quiring (2022) pointed out that an entity should put in place actions based on climate change response to present a comprehensive and systematic operation strategy. As a result of climate change becoming defining challenges for companies, it is necessary to overcome

such potential issues so as to providing a reliable risk response strategy (Xue et al., 2021). To avoid the risks posed by climate change, a risk information processing mechanism and appropriate risk response strategies are assimilated into corporate overall operation strategy (Cao et al., 2023). Given the recent focus on environmental change problems, corporate financial decisions affected by climate change should be appropriately tailored that will allow for better long-term stable development (Calvet et al., 2022). Scaled-up financial support in response to the risks posed by climate change should also be considered for maintaining the normal operations of a company (Savvidou et al., 2021). Due to emergency situations arising from climate change and resulting in potential economic losses, the actual financial planning preparation for related expenses becomes important (Badina, 2020). According to Solana (2020), the disclosure of the actual and potential effects of climate change on an entity's strategy and financial planning is urgent and can materially influence the financial landscape (Rijal et al., 2022).

2.3. Corporate risk management

An effective risk management strategy can protect a business from harm and create opportunities to improve its performance (Thekdi & Aven, 2016). However, the emerging risks from climate change should be integrated into corporate risk management policies and practices to cope with severe and multiple risks and crises (Mbanyele & Muchenje, 2022). Moreover, entities are motivated to invest more in the improvement of risk management standards to immunize themselves from climate-change hazards. Fostering the rationalities and responses of corporate risk management can mitigate the adverse effects of climate change, as stated by Rana et al. (2023). One corporate has recognized the need to include climate change factors in developing risk management practices to address public concerns and its effectiveness (Kunreuther, 2020). The results of Kiesel and Stahl (2023) showed that an assessment framework based on precautionary and resilient principles adopted risk management processes to climate change-related risk. To provide a robust risk management framework under climate change, the identification and assessment of climate-related potential risk factors should be first achieved (Braunschweiger & Ingold, 2023). Governments are attempting to manage the risk of climate change so that adverse outcomes in terms of corporate operations can be avoided (Shear et al., 2023).

2.4. Metrics and targets

Organizations establish metrics and targets related to climate-related risks and opportunities, disclosing them to investors and other stakeholders. This disclosure aims to enhance understanding of how an organization adjusts potential risks, improves economic performance, and manages or adapts to these challenges through actions and strategies (Maji & Kalita, 2022; TCFD, 2017b). As stressed by Amar et al. (2022), voluntary climate-related information disclosure by entities is considered one of the main pathways to achieve sustainability that improves investors' understanding of financial performance under climate change. According to John et al. (2020) and Vangala et al. (2022), specific climate-related metrics and corresponding information disclosures enable direct alignment of responses with the anticipated

impacts of climate change. Companies should present optimal adaptation strategies that adhere to greenhouse gas (GHG) emission standards, address associated risks, aim to prevent severe impacts of climate change, and contribute to the mitigation of global warming (Llopis-Albert et al., 2021). Comprehending and tracking greenhouse gas (GHG) emissions on a global scale are vital for informing climate change policymaking and gaining insights into the challenges and successes countries experience during the transition to green energy (Franco et al., 2023). Additionally, a low-carbon development strategy has emerged as a crucial guideline for countries' sustainable objectives. Substantial resources are being allocated to low-carbon technology, and companies are making key strides in aligning themselves with national policies (Adenle et al., 2017; Xian et al., 2023).

3. A hybrid methodology

This study introduces a two-stage hybrid assessment model. In the initial stage, HFWFSA screens core factors from a multitude of influencing factors for the completion of a pre-test questionnaire. In the context of climate change and sustainability, organizations typically operate with large and complex datasets involving numerous variables related to environmental, economic, and operational factors. The HFWFSA helps reduce the dimensionality of the problem by identifying the most significant features, improving the computational efficiency and focus of the analysis. This approach enhances prediction accuracy and ensures that only the most relevant variables are considered in developing effective responses to climate change. Following this and by leveraging the results of the pre-test questionnaire, an official questionnaire is formulated and subjected to analysis using fuzzy DEMATEL methods. The objective is to discern the interdependent relationships among selected criteria while concurrently establishing the priority of influencing factors. One of the key challenges in analyzing the effects of climate change on an organization's strategy is the uncertainty and vagueness of the data involved. The fuzzy logic embedded in the DEMATEL model allows decision-makers to handle these uncertainties effectively. By using fuzzy sets, the model can accommodate imprecise and subjective judgments from experts, ensuring that the analysis is robust even when precise data is unavailable or too ambiguous to interpret with certainty. Figure 1 illustrates an integrated framework incorporating HFWFSA and the Fuzzy DEMATEL method.

3.1. Hybrid filter-wrapper feature selection algorithm (HFWFSA)

In this section we employ feature selection techniques, specifically utilizing both filter and wrapper methods, as a preprocessing step to identify the optimal subset of relevant features related to climate change, including the following two steps. Filter methods for feature selection are prized for their speed, as they operate independently of any learning algorithm and facilitate swift evaluation and extraction of valuable attributes (Ansari et al., 2019). Wrapper methods are proficient in mitigating correlations between features and implementing effective optimization algorithms to capture the best feature subset (Apolloni et al., 2016). Hybrid techniques such as a filter-wrapper combination enhance model performance and offer efficient results to the feature selection problems – that is, the core concept of the hybrid model

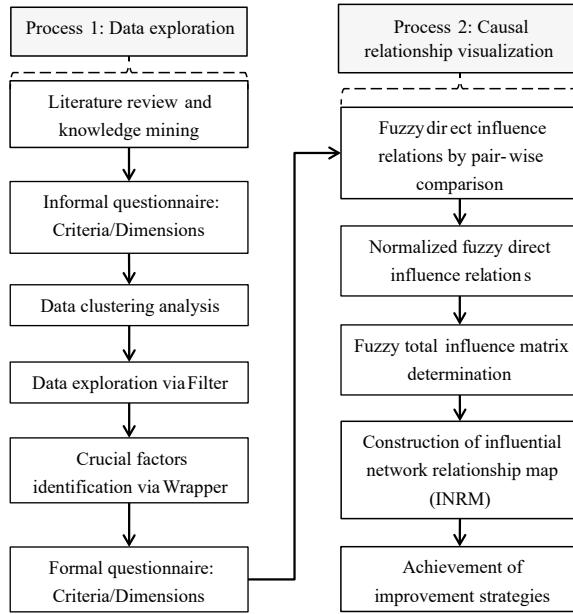


Figure 1. An integrative research framework for climate change

is to utilize the output of the filter method to guide the wrapper method. This study utilizes information gain as the filter method and adopts sequential floating forward selection (SFFS) as the wrapper method (Bermejo et al., 2012). Each step is presented as follows.

In the initial step of the filter process, the information gain method assesses the significance of a feature by computing its information gain (*IFG*) relative to the target class label. Essentially, it measures the amount of information gained to predict the target class label based on the presence or absence of a feature. Equation (1) illustrates the information gain (*IFG*) between a feature u and the target class label. In this equation, $W(Class_label)$ signifies the marginal entropy, while $W(Class_label|u)$ computes the conditional entropy of u given the target class label.

$$IFG(u, class_label) = W(class_label) - W(class_label|u). \quad (1)$$

The determined features are ranked in descending order of their scores.

Sequential forward selection (SFS) involves iteratively selecting features to build a model based on their impact on forecasting performance until a stopping criterion is reached (Fallahpour et al., 2017). Once a feature is selected by SFS, it cannot be discarded, potentially leading to a nesting problem where the optimal three-feature subsets are not fully contained within the optimal four-feature subset (Tan et al., 2014). To mitigate this, the floating mechanism is integrated into SFS. In sequential floating forward selection (SFFS), features are assessed and potentially removed at each stage of the process (Chang & Lin, 2008). Following the selection of a feature at any given stage, each previously chosen feature undergoes individual evaluation for potential elimination, while their subsets are analyzed to ensure the continued optimality of the selected features (Fallahpour et al., 2017). This method allows for

identification and removal of non-ideal features from previously selected subsets. It achieves this by iteratively adding to or eliminating features from the subset to develop an optimal configuration. Initially, the value of m representing the number of added or deleted features is set to zero. The selected feature subset, denoted by r_m , is an empty set, with the corresponding maximum prediction accuracy (MPA) given by $A(m)$ initially set to zero.

Adding a feature: The objective is to identify a feature containing $w^+ = w - r_m$ for inclusion in the set r_m .

$$w^+ = \arg_matrix MPA_B \left(U_j^{r_m} \cup \{W\} \right), W = w - r_m, \quad (2)$$

where B represents the replication number of cross-validation (CV) chosen by the technique implementer. Once w^+ is determined, the key feature is appended to the selected feature subset $\{W_m^+\} \cup r_m = r_{m+1}$ and subsequently followed by the renewal of the maximum prediction accuracy (MPA).

$$J(m+1) = MPA_B \left(U_j^{r_m} \cup \{W\} \right) \text{ and } m = m+1. \quad (3)$$

To prevent being ensnared in a local optimum, a vital provisional process is conducted, involving an elimination procedure aimed at identifying a feature meeting specific conditions.

$$\begin{aligned} w^- &\in r_m, \\ MPA_B \left(U_j^{X_m - \{w^-\}} \right) &> r_m, \\ X_m &\in W, \\ w^- &= \arg_max MPA_B \left(U_j^{X_m - \{w\}} \right). \end{aligned} \quad (4)$$

In the wrapper step, we refine the selected features using sequential forward selection (SFS) to effectively handle the challenge posed by big data. SFS starts by assessing each feature individually, selecting the one with the highest classification accuracy. It then progressively adds unused features to the selected subset, recalculating the computation procedure for each newly included attribute. SFS only keeps features that enhance its forecasting performance. If no additional attribute contributes to improved forecasting, then the feature selection process terminates.

3.2. Fuzzy decision making trial and evaluation laboratory (fuzzy DEMATEL)

The decision-making approach known as DEMATEL (Gabus & Fontela, 1972, 1973) holds a prominent position as it is widely utilized for creating a structured model for visualization and offering practical solutions. This method relies on an influential network relationship map (INRM) that incorporates expert opinions to discern the prioritization of criteria within a system (Orazalin et al., 2023; Rostamzadeh et al., 2023). Utilizing a graphical representation, this approach enables the analysis of cause-effect relationships among intricate factors, providing decision-makers with insights to implement a more effective solution.

Despite its superiority in addressing MCDM problems, DEMATEL encounters challenges as human assessments are influenced by preferences, often resulting in unclear evaluations and

rendering numerical computations inadequate (Kabak & Dağdeviren, 2014; Patil & Kant, 2014; Hu et al., 2018). The integration of fuzzy set theory into the DEMATEL approach serves to address complex issues (Lu et al., 2022). Successfully employed across diverse fields (Vinodh and Wankhede, 2021; Feldmann et al., 2022; Saroha et al., 2022; Dogra & Adil, 2023), the fuzzy DEMATEL method is a valuable tool for addressing the vagueness and uncertainty of information in real-life environments. The procedures of this approach are seen as follows.

In addressing the ambiguity and uncertainty inherent in human judgments, it is essential to engage in group decision-making using five linguistic terms (no influence, low influence, medium influence, high influence, very high influence) by employing fuzzy scales with five values (Mavi & Standing, 2018). A defuzzification process transforms fuzzy data into crisp scores (CFCS) by converting fuzzy values, as introduced by Opricovic and Tzeng (2003). Keskin (2015) showed that the CFCS defuzzification method exhibits better outcomes in calculating criteria weights compared to other tools in the same domain. The linguistic variables associated with the linguistic values (l_{ij}, m_{ij}, r_{ij}) , left (l), medium (m), and right (r) scores, are presented in Table 1, and a weighted average is calculated. By considering domain/expert knowledge and utilizing linguistic term estimates, Equation (4) is employed for the calculation of the fuzzy relation matrix $\tilde{\mathbf{B}}$.

Table 1. Fuzzy linguistic evaluation scale and the corresponding values

Fuzzy linguistic item	Fuzzy linguistic scales (l_{ij}, m_{ij}, r_{ij})
No influence	(0.0, 0.1, 0.3)
Low influence	(0.1, 0.3, 0.5)
Medium influence	(0.3, 0.5, 0.7)
High influence	(0.5, 0.7, 0.9)
Very high influence	(0.7, 0.9, 1.0)

$$\tilde{\mathbf{B}} = [\tilde{b}_{ij}], \text{ where } \tilde{b}_{ij} = (b_{ij}^l, b_{ij}^m, b_{ij}^r). \quad (5)$$

The normalized fuzzy directed-relation matrix $\tilde{\mathbf{Y}}$ is obtained by applying Eqs. (6)–(7).

$$\tilde{\mathbf{Y}} = \kappa \tilde{\mathbf{B}}; \quad (6)$$

$$\kappa = \frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^n b_{ij}}, \quad i, j = 1, 2, \dots, n. \quad (7)$$

where $\tilde{\mathbf{Y}} = (Y^l, Y^m, Y^r)$, $Y^l = [y_{ij}^l]_{n \times n}$, $Y^m = [y_{ij}^m]_{n \times n}$, and $Y^r = [y_{ij}^r]_{n \times n}$. Equation (8) helps find the total fuzzy relation matrix $(\tilde{\mathbf{T}})$.

$$\tilde{\mathbf{T}} = [\tilde{t}_{ij}]_{n \times n}, \text{ where } \tilde{t}_{ij} = (t_{ij}^l, t_{ij}^m, t_{ij}^r), \quad (8)$$

where:

$$\tilde{\mathbf{T}}^l = [t_{ij}^l]_{n \times n} = \mathbf{Y}^l (\mathbf{I} - \mathbf{Y}^l)^{-1}, \tilde{\mathbf{T}}^m = [t_{ij}^m]_{n \times n} = \mathbf{Y}^m (\mathbf{I} - \mathbf{Y}^m)^{-1}, \text{ and } \tilde{\mathbf{T}}^r = [t_{ij}^r]_{n \times n} = \mathbf{Y}^r (\mathbf{I} - \mathbf{Y}^r)^{-1}.$$

The CFCS defuzzification technique is applied to transform the total fuzzy relation matrix $\tilde{\mathbf{T}} = (\tilde{\mathbf{T}}^l, \tilde{\mathbf{T}}^m, \tilde{\mathbf{T}}^r)$ into a crisp value relation matrix. Following that, INRM is illustrated, mirroring the approach of the traditional DEMATEL method, through the mapping of the

$(\tilde{D}_i + \tilde{R}_i, \tilde{D}_i - \tilde{R}_i)$ set for the analysis of the causal model. The $(\tilde{D}_i + \tilde{R}_i)$ value reflects the degree of importance associated with each criterion in the overall system, whereas $(\tilde{D}_i - \tilde{R}_i)$ represents the cause-and-effect set, which is of greater concern to us.

4. Analysis of results

This illustration of results' analysis is segmented into two sections: (1) questionnaire design process, and (2) formulation of INRM using the fuzzy DEMATEL technique. We draw on the outcomes derived from expert knowledge and experience.

4.1. Questionnaire design and development

The questionnaire design process in this study consists of the following three stages, as depicted in Figure 2. First, the related literature (TCFD, 2017a, 2017b, 2019, 2020; Mbanyele & Muchenje, 2022; Cao et al., 2023; Orazalin et al., 2023; García-Sánchez et al., 2023) on corporate climate change strategy was reviewed, followed by expert brainstorming to identify potential influencing factors. Following this, the authors categorized these factors into a hierarchical framework comprising four dimensions and 28 criteria for a preliminary questionnaire, as presented in Table 2.

Second, the authors submitted questionnaires to all 50 selected domain experts, of whom 18, working for 12 companies in Guangzhou and Shenzhen, agreed to participate either verbally or in writing, reaching a return rate of 36%. Among the 18 domain experts were 10

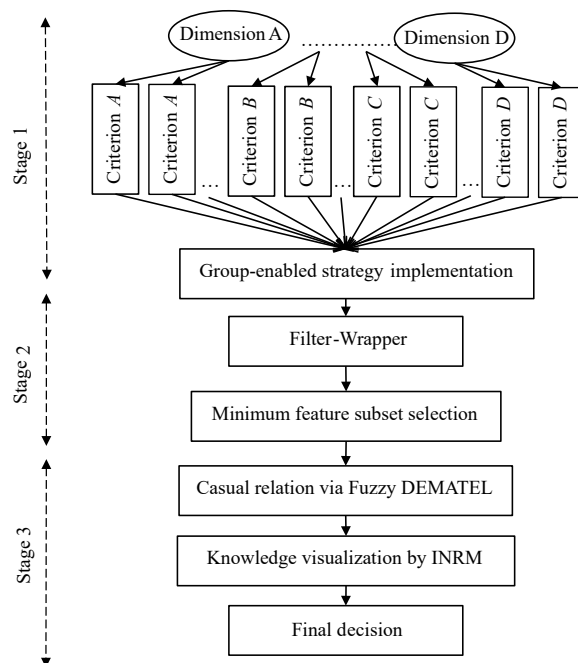


Figure 2. A three-stage questionnaire design and development

senior managers from investment institutions and 8 managers from the sustainability departments of listed companies. They were tasked with rating the preliminary questionnaire on a scale from 0 (low) to 10 (high) to assess the importance of all criteria. The interviews, which occurred between September 2023 and November 2023, had varying durations, ranging from 25 to 65 minutes, with an average duration of 45 minutes.

We must assign a class label and then proceed to implement HFWFSA for filtering the pivotal determinants of climate change and policy response. The K-means algorithm is a promising tool in non-hierarchical cluster algorithms and effectively identifies the class label (Erisoglu et al., 2011; Fahim, 2021). The assessment benchmark, known as the overall score of forecasting precision and rule coverage (OSFPRC), is utilized. Out of the 24 criteria initially considered, the processes resulted in the retention of 14 key criteria, as indicated in Tables 3–4. In this context, the parameter k ranges from 2 to 5, with the observation that setting k to 2 yields the optimal performance, as illustrated in Table 3. In order to demonstrate the superiority of HFWFSA proposed in this paper over other methods, the Friedman test is employed for this purpose, with the corresponding outcomes presented in Table 5. Table 6 provides a comprehensive breakdown of each criterion, elucidating the corresponding details.

Table 2. Criteria of climate change for the preliminary questionnaire

Dimension	criteria
(A)Corporate governance	A1: Board sustainability committees
	A2: Chief sustainability officer expertise
	A3: Board oversight (Monitor and supervise)
	A4: Management Accountability.
	A5: Understanding of climate-related issues for senior management
	A6: Supervision of the company's senior management
(B)Corporate strategy	B1: Risk response strategies
	B2: Financial decisions
	B3: Financial planning process
	B4: Risk prioritization
	B5: Resilience of corporate strategies
	B6: Value creation
	B7: Short, medium and long-term climate-related risks
(C)Corporate Risk management	C1: Identification and assessment of climate-related risks
	C2: The processes for managing climate-related risks
	C3: Low-carbon transition risk
	C4: Risks related to physical impacts
	C5: Overall risk management
(D)Metrics and targets	D1: Key performance indicators
	D2: Remuneration policy
	D3: Lower-carbon economy
	D4: GHG emissions
	D5: Key climate-related targets
	D6: GHG emissions for historical periods

Table 3. The selected features by HFWFSA techniques

Criteria Subset	Testing accuracy	Rule coverage	OSFPRC*
Cluster numbers: K = 2			
Subset 1: A1, A2, A3, A5, B1, B3, B4, C2, C4, C5, D2, D3	0.85	0.83	1.68
Subset 2: A1, A3, A4, A5, B1, B2, B3, B5, C1, C2, C5, D1, D3, D4	0.93	0.96	1.89
Subset 3: A2, A3, B1, B2, B4, C1, C3, D1, D2, D3	0.85	0.82	1.67
Subset 4: A1, A2, A5, B1, B4, C1, C3, D1, D4, D5	0.89	0.84	1.73
Cluster numbers: K = 3			
Subset 1: A1, A3, A4, B2, B3, C5, D1	0.72	0.74	1.46
Subset 2: A4, A5, B3, C2, C3, D1, D2	0.79	0.78	1.57
Subset 3: A1, A3, B2, C1, C3, D5	0.81	0.79	1.60
Subset 4: A2, A5, B1, B2, C1, C3, D1, D3	0.82	0.84	1.66
Cluster numbers: K = 4			
Subset 1: A1, B2, C2, C4, D5	0.67	0.72	1.39
Subset 2: A5, A6, B3, D1, D2	0.70	0.73	1.43
Subset 3: A2, A3, B2, C1, D2	0.68	0.70	1.38
Cluster numbers: K = 5			
Subset 1: A2, B2, C1, D3	0.65	0.66	1.31
Subset 2: A3, B1, C2, C3	0.66	0.69	1.35

Note: *OSFPRC: The overall score of forecasting precision and rule coverage.

Table 4. The criteria used in the official questionnaire

Dimensions	Criteria (Preliminary questionnaire)	(▲: selection; △: no selection)	
		Official questionnaire received from HFWFSA	
		New code	Result
A	A1: Board sustainability committees	a_1	▲
	A2: Chief sustainability officer expertise	–	△
	A3: Board oversight	a_2	▲
	A4: Management accountability	a_3	▲
	A5: Understanding of climate-related issues for senior management	a_4	▲
	A6: Supervision of the company's senior management	–	△
B	B1: Risk response strategies	b_1	▲
	B2: Financial decisions	b_2	▲
	B3: Financial planning process	b_3	▲
	B4: Risk prioritization	–	△
	B5: Resilience of corporate strategies	b_4	▲
	B6: Value creation	–	△
	B7: Short, medium and long-term climate-related risks	–	△

End of Table 4

Dimensions	Criteria (Preliminary questionnaire)	(▲: selection; △: no selection)	
		Official questionnaire received from HFWFSA	
		New code	Result
C	C1: Identification and assessment of climate-related risks	c_1	▲
	C2: The processes for managing climate-related risks	c_2	▲
	C3: Low-carbon transition risk	–	△
	C4: Risks related to physical impacts	–	△
	C5: Overall risk management	c_3	▲
D	D1: Key performance indicators	d_1	▲
	D2: Remuneration policy	–	△
	D3: GHG emissions	d_2	▲
	D4: Low carbon policy	d_3	▲
	D5: Key climate-related targets	–	△
	D6: GHG emissions for historical periods	–	△

Table 5. The comparison results of different techniques (K = 2,3,4,5)

Techniques	The number of clusters were determined by K-means			
	K = 2	K = 3	K = 4	K = 5
TSFWFSM (Benchmark)	91.0 (1)	87.0 (1)	83.0 (1)	76.3 (1)
RST-HC	83.3 (4)	80.2 (5)	77.8 (3)	70.6 (4)
IFWA	82.6 (5)	82.0 (3)	78.0 (2)	73.3 (2)
DRSA	83.4 (3)	81.1 (4)	74.3 (4)	69.2 (5)
FRST-C	86.5 (2)	82.3 (2)	72.1 (5)	72.6 (3)
Statistical test (p-value)	0.012**	0.017**	0.031**	0.009***

Notes: Assessment criterion: accuracy = (true negative + true positive) / (true positive + false positive + false negative + true negative); *, **, *** denotes significance at 10, 5, 1 percent level of significance.

Third, the official questionnaire, derived from the results of HFWFSA, was distributed to a targeted group comprising 20 sustainability leaders from listed companies, 10 CPAs with professional certification of sustainability reporting, and 12 professionals specializing in evaluating sustainability performance for investment institutions. These individuals are based in 4 first-tier cities (Beijing, Shanghai, Guangzhou, and Shenzhen) in China and possess a strong grasp of climate change dynamics. Each survey questionnaire conducted between December 2023 and February 2024 typically lasted around 1.5 hours and was administered through face-to-face or web-based interviews. Experts examined the impact of each criterion on another by assigning a ranking on a scale from 0 to 4, where 0 indicates no influence, and 4 signifies extreme influence. To assess the reliability of the sample collection, a random selection of 31 questionnaires was analyzed to determine the level of consensus. The average gap ratio was found to be 1.32%, which is well below the 5% threshold, indicating a high level of consensus with more than 95% confidence (see the note in Table 8). Finally, all filled-out questionnaires were entered into the fuzzy DEMATEL approach for additional analysis.

Table 6. Adoption of climate change evaluation framework

Dimensions/Criteria	Descriptions	Sources
Corporate governance (A)		
Board sustainability committees (a_1)	Whether the company has established board sustainability committees	Luo and Tang (2021), Orazalin et al. (2023)
Board oversight (a_2)	Supervisory responsibilities of the board regarding climate-related issues	Cosma et al. (2022), García-Sánchez et al. (2023)
Management Accountability (a_3)	The execution of duties and obligations by senior executives concerning climate-related matters	Birchall and Bonnett (2021), Rana et al. (2023)
Senior executives' perceptions (a_4)	The level of awareness among senior executives regarding issues related to climate change	Velte (2023)
Corporate strategy (B)		
Risk response strategies (b_1)	Enterprises can formulate effective response strategies to address potential risks arising from climate change	Xue et al. (2021), Cao et al. (2023)
Financial decisions (b_2)	Sufficient financial support dedicated to addressing climate change	Savvidou et al. (2021)
Financial planning process (b_3)	Climate change-related potential expenses are factored into the comprehensive financial planning of corporations	Badina (2020), Solana (2020), Cao et al. (2023), Rijal et al. (2022)
Resilience of corporate strategies (b_4)	In the context of climate change, companies maintain optimal operational flexibility	Calvet et al. (2022)
Corporate risk management (C)		
Identification and assessment of climate-related risks (c_1)	A proficient method to confirming and evaluating climate-related risks	Braunschweiger and Ingold (2023), Kiesel and Stahl (2023)
The processes for managing climate-related risks (c_2)	Businesses fortify their processes to manage climate risks	Shear et al. (2023)
Overall risk management (c_3)	Enterprise risk management practices integrate considerations for climate change	Mbanyele and Muchenje (2022)
Metrics and targets (D)		
Key performance indicators (d_1)	How businesses can improve performance across climate-related risks and opportunities	TCFD (2017a, 2017b), John et al. (2020), Amar et al. (2022), Maji and Kalita (2022), Vangala et al. (2022)
GHG emissions (d_2)	Organizations disclose sector-specific greenhouse gas (GHG) emissions in accordance with the GHG Protocol	Llopis-Albert et al. (2021)
Low carbon policy (d_3)	Organizations define carbon targets for their products and services as a step towards advancing in a low-carbon economy	Adenle et al. (2017), Xian et al. (2023)

4.2. Creation of INRM using fuzzy DEMATEL

Using the fuzzy DEMATEL approach, we can derive fuzzy relation matrices (called defuzzified relation matrices) denoted as $\tilde{T}^l$, $\tilde{T}^m$, and $\tilde{T}^r$ representing lower, medium, and upper matrices, respectively. The average fuzzy relation matrix can then be measured, as shown in Table 7. Table 8 illustrates the cause-and-effect correlation among determinants, while Figure 3 visually represents the influential network relationship map (INRM). Accordingly, corporate governance (A) emerges as the paramount factor, boasting the highest value (0.03) of $\tilde{D}_i - \tilde{R}_i$ among dimensions. This underscores its pivotal role in influencing other dimensions. Conversely, corporate risk management ($\tilde{D}_i - \tilde{R}_i = -0.004$), metrics and targets ($\tilde{D}_i - \tilde{R}_i = -0.008$), and corporate strategy ($\tilde{D}_i - \tilde{R}_i = -0.016$) exhibit negative values, implying their status as influenced dimensions. Risk response strategies (b_1), commanding the highest value (0.19) of $\tilde{D}_i - \tilde{R}_i$ among factors, signify their primary role as the leading influencing factor. Following closely are board oversight (a_2) and overall risk management (c_3), ranking second and third in terms of $\tilde{D}_i - \tilde{R}_i$ values, respectively. Likewise, in a distinct dimension, board oversight (a_2), risk response strategies (b_1), overall risk management (c_3), and low carbon policy (d_3) exhibit the highest values of $\tilde{D}_i - \tilde{R}_i$ in respective order.

Table 7. Fuzzy total average relation matrix for the criteria.

Criterion	a_1	a_2	a_3	a_4	b_1	b_2	b_3	b_4	c_1	c_2	c_3	d_1	d_2	d_3
a_1	0.135	0.158	0.167	0.167	0.160	0.177	0.168	0.170	0.171	0.170	0.157	0.174	0.173	0.151
a_2	0.212	0.160	0.212	0.209	0.207	0.222	0.214	0.221	0.228	0.219	0.201	0.216	0.223	0.195
a_3	0.171	0.160	0.137	0.169	0.170	0.177	0.174	0.169	0.174	0.173	0.158	0.170	0.172	0.152
a_4	0.163	0.156	0.164	0.133	0.158	0.167	0.169	0.169	0.172	0.167	0.156	0.172	0.171	0.154
b_1	0.211	0.203	0.211	0.209	0.161	0.218	0.215	0.218	0.218	0.214	0.197	0.213	0.217	0.192
b_2	0.169	0.161	0.170	0.165	0.162	0.139	0.171	0.167	0.177	0.173	0.159	0.166	0.172	0.152
b_3	0.149	0.148	0.149	0.149	0.147	0.160	0.127	0.156	0.158	0.155	0.147	0.152	0.160	0.137
b_4	0.153	0.150	0.160	0.156	0.152	0.162	0.160	0.130	0.163	0.156	0.144	0.154	0.160	0.144
c_1	0.157	0.152	0.161	0.157	0.156	0.161	0.154	0.160	0.134	0.161	0.150	0.161	0.167	0.147
c_2	0.151	0.140	0.146	0.145	0.148	0.155	0.153	0.156	0.159	0.127	0.146	0.156	0.156	0.143
c_3	0.210	0.200	0.213	0.208	0.202	0.215	0.215	0.214	0.216	0.213	0.156	0.211	0.216	0.191
d_1	0.161	0.152	0.160	0.159	0.152	0.162	0.160	0.160	0.162	0.163	0.147	0.131	0.163	0.143
d_2	0.152	0.149	0.155	0.148	0.151	0.156	0.155	0.159	0.159	0.154	0.146	0.154	0.130	0.142
d_3	0.195	0.186	0.195	0.199	0.193	0.204	0.198	0.202	0.206	0.202	0.190	0.198	0.201	0.145

Table 8. Evaluation of cause $\tilde{D}_i$ and effect $\tilde{R}_i$ among dimensions and criteria

Dimensions/Criteria	Row sum ($\tilde{D}_i$)	Column sum ($\tilde{R}_i$)	$\tilde{D}_i + \tilde{R}_i$	$\tilde{D}_i - \tilde{R}_i$
Corporate governance (A)	0.704	0.674	1.378	0.030
Board sustainability committees (a_1)	0.627	0.681	1.308	-0.055
Board oversight (a_2)	0.794	0.634	1.428	0.161
Management Accountability (a_3)	0.636	0.680	1.316	-0.044
Senior executives' perceptions (a_4)	0.616	0.681	1.297	-0.065
Corporate strategy (B)	0.675	0.691	1.366	-0.016
Risk response strategies (b_1)	0.812	0.622	1.434	0.190
Financial decisions (b_2)	0.639	0.679	1.318	-0.040
Financial planning process (b_3)	0.589	0.672	1.261	-0.083
Resilience of corporate strategies (b_4)	0.604	0.672	1.276	-0.068
Corporate risk management (C)	0.679	0.683	1.361	-0.004
Identification and assessment of climate-related risks (c_1)	0.445	0.509	0.954	-0.064
The processes for managing climate-related risks (c_2)	0.431	0.500	0.931	-0.069
Overall risk management (c_3)	0.585	0.452	1.037	0.133
Metrics and targets (D)	0.665	0.673	1.338	-0.008
Key performance indicators (d_1)	0.436	0.483	0.919	-0.047
GHG emissions (d_2)	0.426	0.494	0.920	-0.068
Low carbon policy (d_3)	0.544	0.430	0.974	0.114

Note: Average gap ratio = $\frac{1}{n \times (n-1)} \sum_{i=1}^n \sum_{j=1}^n \left(\left| \bar{z}_{ij}^{42} - \bar{z}_{ij}^{41} \right| / \bar{z}_{ij}^{42} \right) \times 100\% = 1.32\% < 5\%$, $n = 14$ is number of selected criteria. This result shows that significant confidence of consensus is 98.68%, where $\bar{z}_{ij}^{41}$ and $\bar{z}_{ij}^{42}$ are the average scores of the domain experts for 41 and 42, respectively.

5. Discussion

This research investigates the key influence factors of climate change in an organization's operational strategy based on the expertise of domain specialists. It employs fuzzy DEMATEL technology to build INRM (Figure 3) and analyzes the causal relations among the systems and sub-systems. As per the assessment of the impact relationships concerning the critical factors of a sustainability strategy for addressing climate change, the priority for enhancing dimensions is as follows: corporate governance (A), corporate risk management (C), metrics and targets (D), and corporate strategy (B). The significantly direct impact of influential relationships on other dimensions is clearly evident in corporate governance. Corporate governance, by its nature, sets the tone for decision-making processes within an organization. This is because governance frameworks guide the allocation of resources, set strategic priorities, and ensure that the organization is accountable to both internal and external stakeholders (Annesi et al., 2025). Hence, by strengthening governance mechanisms, organizations are more likely to integrate sustainability and climate resilience into their operations (Suprayitno et al., 2024).

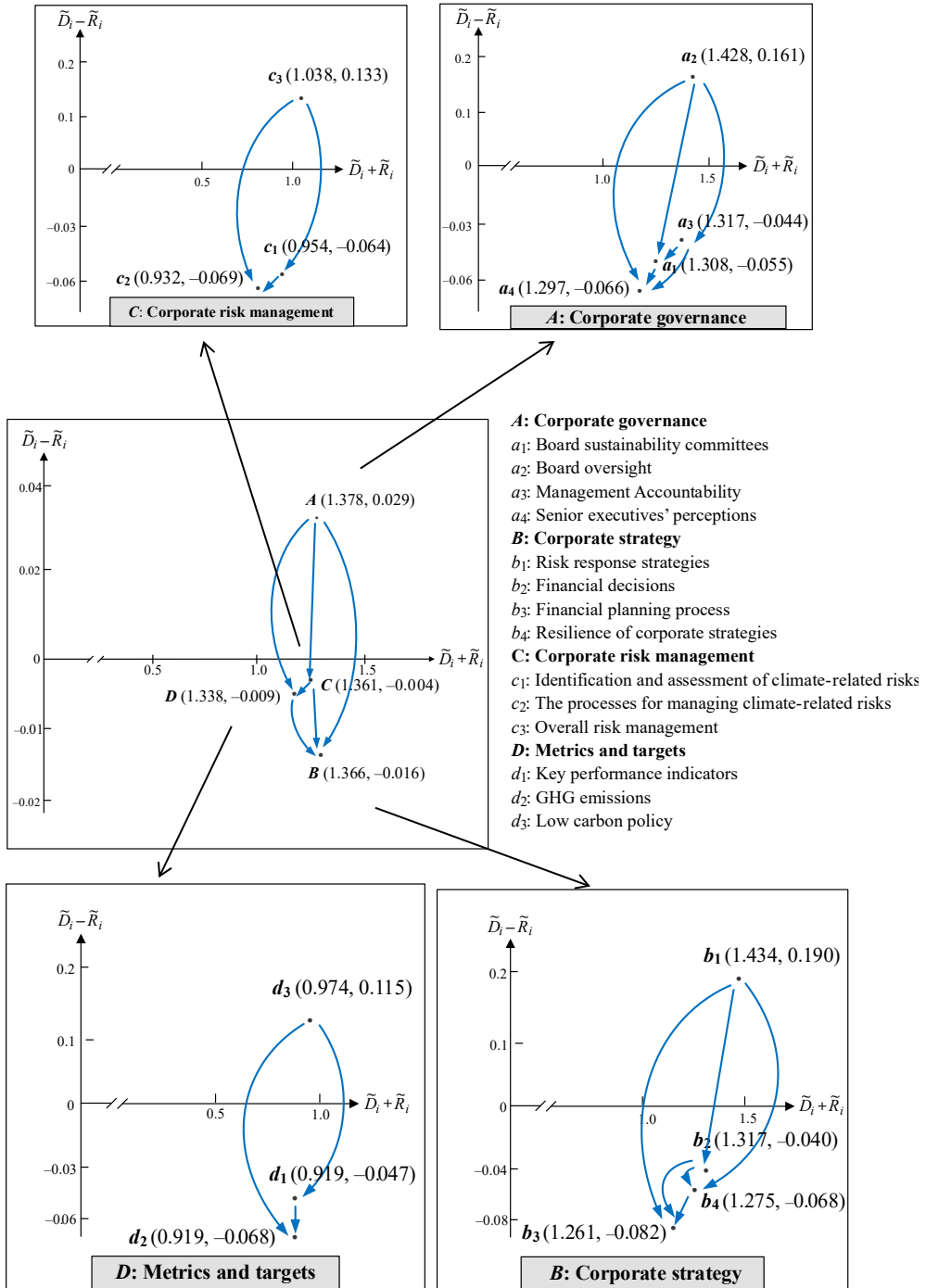


Figure 3. The INRM of influential relationships based on fuzzy DEMATEL

Put differently, prioritizing corporate governance can help firms incorporate sustainability into their strategies more effectively, creating a multiplier effect in terms of long-term operational success and climate change adaptation (Alhadi & Alrubaiee, 2018; González & Miller, 2020). Consistent with Sarkodie et al. (2020), this study argues that corporate governance quality matters in supporting sustainability practices and consequently climate change. Cosma et al. (2022) also examined the relationship between corporate governance and climate change, highlighting the pivotal role of corporate governance in assessing an entity's strategies to climate change. Cosma et al. (2022) examined the relationship between corporate governance and climate change, highlighting the pivotal role of corporate governance in assessing an entity's strategies to climate change.

There are those who argue that the negative effect caused by climate change may harm legacy corporate governance activities (Bulder et al., 2023). According to Albitar et al. (2023), there exists an urgent necessity to pivot corporate governance towards a specialized emphasis on climate change governance in this era of a changing environment. This involves surpassing traditional corporate governance mechanisms to ensure they adequately reflect a company's dedication to addressing climate change issues. A key insight from this research is the argument that corporate governance must evolve to become more flexible in the face of climate change. The dynamic nature of climate change requires governance structures to be agile and responsive to new risks, regulations, and stakeholder expectations (Mbanyele & Muchenje, 2022). Clearly, flexible corporate governance is crucial in addressing climate change, as it bolsters organizational resilience and enables prudent responses to change to be achieved. Resilient governance frameworks enable organizations to bounce back from climate-induced disruptions and adjust strategies in real time (Quay, 2010). This adaptability is key to ensuring that businesses not only survive but thrive in the face of climate change. Considering the inherent adjustability and adaptability of corporate governance in the realm of environmental sustainability, coupled with the already significant impacts of climate change, it is reasonable to anticipate that embracing innovative changes will prove to be a valuable approach for evolving governance efforts (Gonzales-Iwanciw et al., 2020). Moreover, a resilient governance framework serves as a pivotal mechanism for confronting these challenges, expediting adaptation, and bridging the gap in adaptation efforts (Lawrence et al., 2022). The contours of the potential negative effects of climate change are investigated, which cannot be effectively prevented without new governing methods to organizations. Therefore, it is imperative for organizations to invest in transforming their governance structures to embrace sustainability practices and climate risk assessments fully.

6. Robustness test

This study proposes an integrated approach that combines the HFWFSA with Fuzzy DEMATEL to prioritize the critical factors influencing a corporation's ability to achieve sustainable development under climate change risk exposure. The proposed methodology addresses the issue of information overload and uncovers the interrelationships among evaluation criteria, thereby assisting decision-makers in analyzing the current environmental context and making well-informed judgments (Wang et al., 2022; Xue et al., 2024). Although the effectiveness and

robustness of this approach have been demonstrated, it operates within a static framework that does not account for the evolving nature of climate change-related challenges. To address this limitation, the study incorporates dynamic elements into the analysis by collecting questionnaire data at two distinct time intervals. The first dataset, comprising 42 valid responses, was collected between December 2023 and February 2024 (i.e., time period 1). The second dataset, consisting of 32 valid responses, was gathered between February 2025 and April 2025 (i.e., time period 2). To maintain consistency and minimize potential judgment bias, the same group of respondents was surveyed during both intervals. This group included 20 sustainability executives from publicly listed companies, 10 certified public accountants (CPAs) with professional credentials in sustainability reporting, and 12 investment professionals specializing in sustainability performance evaluation. The results are illustrated in Table 9. Corporate governance consistently emerges as the most influential factor across both time intervals, underscoring its role as a foundational structure that ensures accountability, strategic direction, and alignment with sustainability goals in the face of climate-related risks. A plausible explanation for this finding is that robust corporate governance mechanisms enhance the effective implementation of strategic initiatives. Furthermore, a shift in factor prioritization is observed between the two time periods. In the initial dataset, corporate risk management was perceived as marginally more critical than metrics and targets, reflecting firms' early-stage focus on identifying and understanding climate-related risks at a conceptual level. However, in the second dataset, the priority order reversed, with metrics and targets overtaking corporate risk management. This shift suggests that, over time, organizations tend to move beyond qualitative risk identification toward more systematic, data-driven approaches that emphasize the measurement, monitoring, and tracking of sustainability performance. As the survey spans two distinct time periods, this evolution is both reasonable and theoretically aligned with the developmental nature of sustainability practices: in the earlier stage, risk management often relies on qualitative assessments and narrative-based disclosures, whereas in the later stage, firms increasingly adopt quantifiable indicators that can be evaluated consistently and objectively. The observed increase in the prominence of metrics

Table 9. The outcomes across two time periods.

Dimensions/Criteria	Time period 1		Time period 2	
	$\tilde{D}_i + \tilde{R}_i$	$\tilde{D}_i - \tilde{R}_i$	$\tilde{D}_i + \tilde{R}_i$	$\tilde{D}_i - \tilde{R}_i$
Corporate governance (A)	1.378	0.030	1.369	0.021
Corporate strategy (B)	1.366	-0.016	1.358	-0.02
Corporate risk management (C)	1.361	-0.004	1.349	-0.015
Metrics and targets (D)	1.338	-0.008	1.353	-0.005
Dynamism	$\tilde{D}_i + \tilde{R}_i$		$\tilde{D}_i - \tilde{R}_i$	
Δ in Corporate governance	-0.009		-0.009	
Δ in Corporate strategy	-0.008		-0.004	
Δ in Corporate risk management	-0.012		-0.011	
Δ in Metrics and targets	0.015		0.003	

Note: Δ denotes the difference between two time periods.

and targets may therefore reflect a growing corporate recognition that measurable indicators provide stronger managerial guidance and enhance accountability. Practical, data-supported metrics are also more acceptable to decision makers because they reduce ambiguity and provide concrete evidence for evaluating progress, allocating resources, and demonstrating compliance with stakeholder expectations. In contrast, qualitative assessments—although valuable—may be perceived as less reliable or more subjective. Consequently, the outcome suggests that as sustainability frameworks mature, organizations naturally gravitate toward indicators that offer clearer evaluative power and operational clarity. This reinforces the view that the transition from qualitative conceptualization to quantitative measurement represents a meaningful and expected progression in corporate sustainability management.

Moreover, to further validate the robustness and reliability of the results, a statistical verification procedure was implemented. A paired-sample t-test was conducted under two conditions: (1) using the complete dataset to examine differences between the two time periods, and (2) randomly removing approximately 5% of the survey responses and re-estimating the differences across the two periods. The results, summarized in Table 10, indicate that the priority rankings of the indicators remain unchanged in both scenarios. This consistency demonstrates that the findings are stable and not sensitive to minor variations in the data. Accordingly, managers can rely on these results to allocate resources toward sustainability initiatives with confidence, ensuring that their decisions align with long-term corporate sustainability objectives and contribute to a mutually beneficial outcome for both the organization and its stakeholders.

Table 10. The comparison outcomes under two dissimilar scenarios.

Scenario	Full survey data	
	Time period 1 ($\tilde{D}_i + \tilde{R}_i$)	Time period 2 ($\tilde{D}_i + \tilde{R}_i$)
Corporate governance (A)	1.378	1.369
Corporate strategy (B)	1.366	1.358
Corporate risk management (C)	1.361	1.349
Metrics and targets (D)	1.338	1.353
Statistical test	P-value = 0.613 > 0.05 (The priority ranking of the criteria remains unchanged across the two time periods)	
Priority ranking ($\tilde{D}_i + \tilde{R}_i$)	A > B > C > D	
Scenario	Randomly Deleting 5% of Survey Data	
Corporate governance (A)	1.357	1.359
Corporate strategy (B)	1.341	1.343
Corporate risk management (C)	1.336	1.334
Metrics and targets (D)	1.313	1.336
Priority ranking ($\tilde{D}_i + \tilde{R}_i$)	A > B > C > D	
Statistical test	P-value = 0.6350 > 0.05 (The priority ranking of the criteria remains unchanged across the two time periods)	

7. Sensitivity analysis

To ensure the reliability of the results, a sensitivity analysis was conducted by adjusting the weights assigned to different experts. The first expert was given the biggest weight, with the remaining weights distributed equally among the other experts. This approach allowed for testing the robustness of the model. Table 11 shows the rankings of the key factors before and after the sensitivity analysis. The differences in rankings are visualized in the spider web diagram in Figure 4. It is evident that the top three criteria retain the same ranking both before and after the sensitivity analysis. This indicates that the selected factors, such as "Risk response strategies," "Board oversight," and "Overall risk management," are the most important among all the identified criteria.

Table 11. Comparison of ranks and after sensitivity

Code	Criteria	Rank before sensitivity analysis	Rank after sensitivity analysis
a_1	Board sustainability committees	8	7
a_2	Board oversight	2	2
a_3	Management Accountability	6	4
a_4	Senior executives' perceptions	10	11
b_1	Risk response strategies	1	1
b_2	Financial decisions	5	6
b_3	Financial planning process	14	14
b_4	Resilience of corporate strategies	13	12
c_1	Identification and assessment of climate-related risks	9	9
c_2	The processes for managing climate-related risks	12	13
c_3	Overall risk management	3	3
d_1	Key performance indicators	7	8
d_2	GHG emissions	11	10
d_3	Low carbon policy	4	5

8. Theoretical contributions

This paper provides numerous theoretical contributions to the existing body of literature. First, it is a pioneer in gathering diverse climate change challenges for an organizational operations strategy in China, accompanied by a comprehensive review of relevant literature. Second, no existing paper in the field of climate change has introduced a fusion model that integrates Multiple Criteria Decision Making (MCDM) and soft computing technologies. Such a model aims to aid decision-makers in crafting a suitable operational strategy, thereby mitigating challenges encountered in practical applications. This study represents a significant advancement as it harnesses crucial insights from vast datasets using AI algorithms, including HFWFSA. It not only eliminates the need for extensive storage, but also enables users to focus more on specific essential criteria. Additionally, the study delves into revealing causal relationships among factors and elucidates the essence of each factor through the implementation of

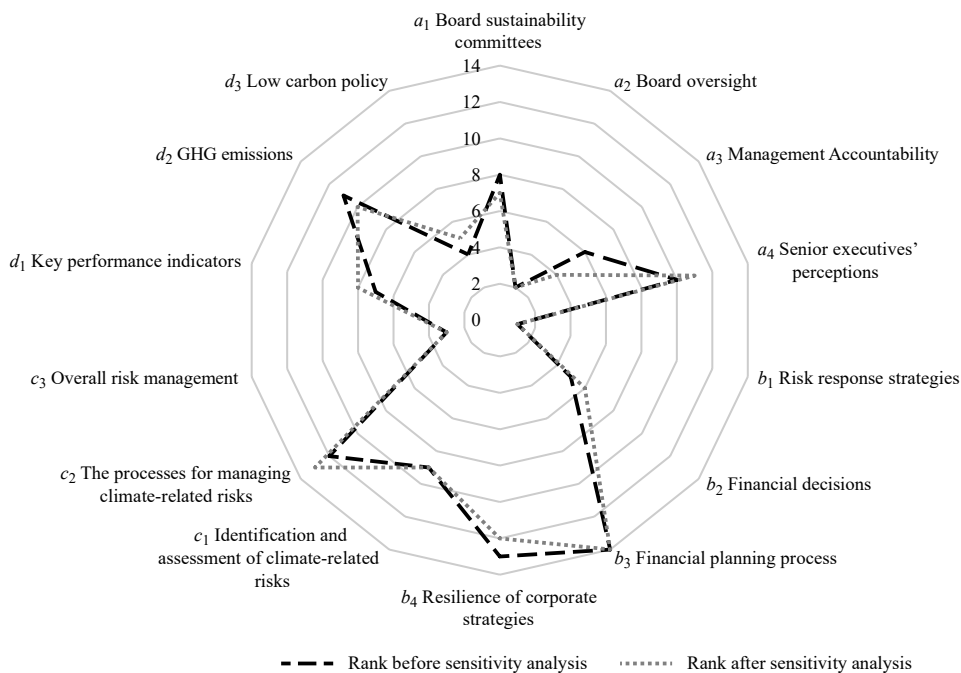


Figure 4. Sensitivity analysis result

the MCDM methods. Third, extending DEMATEL to incorporate other approximate reasoning theories, such as FRST, can enhance its flexibility, enabling the extraction of deeper insights. Consequently, this study integrates the distinctive features of FRST and DEMATEL, specifically fuzzy DEMATEL, to identify key determinants for developing new operational plans in the context of climate change. This integration not only facilitates the extraction of more profound messages, but also contributes to sustaining and improving firms' competitiveness and sustainability. Moreover, the utilization of meta-heuristic optimization algorithms, such as the white shark equilibrium optimizer proposed by Çetinbaş et al. (2023), could strengthen the validity and effectiveness of the analysis. Applying multi-criteria group decision-making techniques like the fuzzy ELECTRE-based method can mitigate conflicts and discrepancies among experts, fostering a more reliable consensus (Akram et al., 2023).

9. Practical implication

The integrated framework introduced here presents several practical implications for an organization's operations strategy in China to effectively respond to climate change. As per the criteria, experts consistently concur that risk response strategies stand out as the most pivotal element in addressing climate change within the revision of a corporation's operations. This finding supports the conclusions of Hewa et al. (2023), who demonstrated a significantly positive association between climate change and companies' risk responses. In adjusting operations to address vulnerabilities related to climate change, research on risk emphasizes that implementing a timely and effective risk-response strategy is imperative for sustainability

(Rana et al., 2023). Loehr and Becken (2023) argued that transformative governance changes are necessary to address the current climate emergency, and a risk response plan provides support for advancing such changes. Steiger et al. (2019) suggested that companies have an obligation to fulfill the information requirements of stakeholders regarding climate change. They should also develop risk response strategies that effectively address the potential negative impacts arising from climate change. By adopting such measures, companies can strive towards a win-win outcome. Hence, in the realm of climate change, incorporating risk response strategies becomes an immediate and imperative action for promoting corporate sustainability (Liao et al., 2023).

The empirical findings further indicate that, within the corporate landscape, both board oversight and overall risk management play significant roles as the second and third critical factors in effectively addressing climate change concerns. Ben-Amar and McIlkenny (2015) argued that the board of directors wields considerable influence in the disclosure of climate change-related information. Their study established a positive link between board effectiveness and the voluntary disclosure of information pertaining to climate change. Kouloukoui et al. (2020) conducted research that reaffirms the crucial role of the board of directors in a company's involvement in climate-related matters, as well as its influence on climate change performance. This highlights the boardroom's significance in effectively addressing and managing climate concerns within the organization. In order to uphold the effectiveness and sustainability of corporate governance, companies must recognize the invaluable role of the board in monitoring and disclosing information about climate change, thereby enabling them to make necessary improvements and maintain their commitment to sustainable practices (Nathalia & Setiawan, 2022). Furthermore, as highlighted by Nasr et al. (2020), climate change is expected to have diverse and far-reaching consequences on the safety and functionality of infrastructure. Consequently, it becomes crucial to establish practical and comprehensive risk management systems to effectively address and mitigate these impacts. However, in light of the evolving risk landscape posed by climate change, it is essential for enterprises to recalibrate their overarching risk management framework (Huggel et al., 2022). This entails revisiting and refining risk assessment methodologies and identifying risks that should be mitigated or adapted to effectively reduce the consequences of climate change. By proactively adjusting their risk management strategies, enterprises can better prepare for and mitigate the impacts of climate change on their operations and overall resilience.

10. Conclusions

This study employs a fuzzy integrated methodology, including HFWFSA and the fuzzy DEMATEL approach, to listed firms in China and employs expert knowledge and expert experience to analyze how companies adjust their operations strategy to achieve sustainable development goals in the face of climate change. HFWFSA is utilized to preliminarily screen the essential factors and to capture the curse of dimensionality, while the fuzzy DEMATEL technique identifies causal relationships within the system and subsystems, enabling the achievement of INRM. INRM elucidates how factors interact, providing decision-makers with insights into the underlying issues of climate change disclosure and facilitating the

effectiveness and feasibility of corporate sustainability. For dimensions, improvement priorities center around corporate governance, corporate risk management, metrics and targets, and corporate strategy. Among 14 criteria, risk response strategies hold utmost importance in improving operational strategies within climate change scenarios for listed companies, simultaneously serving as crucial content for advancing sustainable development and environmental responsibility. Additionally, by pinpointing the key factors that yield the highest impact on each subsystem, we can optimize the effectiveness of both the individual subsystems and the overarching framework, resulting in overall enhancement.

While this study gives valuable insights into the development of an effective operational strategy for achieving sustainability in the context of global climate change, several limitations must be acknowledged. Firstly, the relatively narrow pool of domain experts may introduce gaps in comprehensiveness, which could impact the generalizability of the findings. Additionally, the risk of biased judgments among experts could potentially skew the results. Another limitation is the small sample size, which may undermine the robustness of the empirical analysis. To enhance the validity and breadth of future research, expanding the sample to include experts from a broader range of cities—particularly those beyond the first-tier cities—would be beneficial. Furthermore, a comparative study between first-tier and other-tier cities could offer a more nuanced understanding of the issue. The evaluation criteria outlined in this study adhere to TCFD recommendations. Future research endeavors may consider integrating the influence of additional standards within this framework.

Funding

This research is in part supported by research grants provided by the Department of education of Guangdong Province, China for financially support this project under contract No. 2025WTSCX147 and No. 2025XSJ001.

Acknowledgements

The authors would like to thank the Department of education of Guangdong Province, China, No. 2025WTSCX147 and No. 2025XSJ001.

Author contributions

CD conceived the study and was responsible for the design and development of the questionnaire. CD was responsible for software and validation. KHH was responsible for data collection and analysis. KHH was responsible for data interpretation. KHH wrote the original draft of the article. GHT conducts the final supervision. All authors read and approved the final manuscript.

Disclosure statement

The authors declare that they have no competing interests in this manuscript.

References

- Adenle, A. A., Manning, D. T., & Arbiol, J. (2017). Mitigating climate change in Africa: Barriers to financing low-carbon development. *World Development*, 100, 123–132. <https://doi.org/10.1016/j.worlddev.2017.07.033>
- Akram, M., Zahid, K., & Deveci, M. (2023). Multi-criteria group decision-making for optimal management of water supply with fuzzy ELECTRE-based outranking method. *Applied Soft Computing*, 143, Article 110403. <https://doi.org/10.1016/j.asoc.2023.110403>
- Albitar, K., Al-Shaer, H., & Liu, Y. S. (2023). Corporate commitment to climate change: The effect of eco-innovation and climate governance. *Research Policy*, 52(2), Article 104697. <https://doi.org/10.1016/j.respol.2022.104697>
- Alhadi, A. M., & Alrubaiee, L. M. (2018). The impact of corporate governance on firm performance and sustainability. *Corporate Governance and Sustainability Review*, 9(2), 25–45. <https://doi.org/10.22495/cgsrv9i2p2>
- Amar, J., Demaria, S., & Rigot, S. (2022). Enhancing financial transparency to mitigate climate change: Toward a climate risks and opportunities reporting index. *Environmental Modeling & Assessment*, 27, 425–439. <https://doi.org/10.1007/s10666-021-09800-7>
- Amar, J., Demaria, S., & Rigot, S. (2023). What are the drivers of corporates' climate transparency? Evidence from the S&P 1200 index. *Ecological Economics*, 213, Article 107945. <https://doi.org/10.1016/j.ecolecon.2023.107945>
- Annesi, N., Battaglia, M., Ceglia, I., & Mercuri, F. (2025). Navigating paradoxes: Building a sustainable strategy for an integrated ESG corporate governance. *Management Decision*, 63(2), 531–559. <https://doi.org/10.1108/MD-10-2023-2006>
- Ansari, G., Ahmad, T., & Doja, M. N. (2019). Hybrid filter-wrapper feature selection method for sentiment classification. *Arabian Journal for Science and Engineering*, 44, 9191–9208. <https://doi.org/10.1007/s13369-019-04064-6>
- Apolloni, J., Leguizamón, G., & Alba, E. (2016). Two hybrid wrapper-filter feature selection algorithms applied to high-dimensional microarray experiments. *Applied Soft Computing*, 38, 922–932. <https://doi.org/10.1016/j.asoc.2015.10.037>
- Badina, S. V. (2020). Prediction of socioeconomic risks in the cryolithic zone of the Russian arctic in the context of upcoming climate changes. *Studies on Russian Economic Development*, 31(4), 396–403. <https://doi.org/10.1134/S1075700720040036>
- Bebbington, J., Schneider, T., Stevenson, L., & Fox, A. (2020). Fossil fuel reserves and resources reporting and unburnable carbon: Investigating conflicting accounts. *Critical Perspectives on Accounting*, 66, Article 102083. <https://doi.org/10.1016/j.cpa.2019.04.004>
- Ben-Amar, W., & McIlkenny, P. (2015). Board effectiveness and the voluntary disclosure of climate change information. *Business Strategy and the Environment*, 24(8), 704–719. <https://doi.org/10.1002/bse.1840>
- Ben-Amar, W., Comyns, B., & Martinez, I. (2023). The COVID-19 pandemic: Opportunity or challenge for climate change risk disclosure? *Accounting, Auditing & Accountability Journal* 36(2), 649–676. <https://doi.org/10.1108/AAAJ-08-2020-4805>
- Bermejo, P., Ossa, L., Gámez, J. A., & Puerta, J. M. (2012). Fast wrapper feature subset selection in high-dimensional datasets by means of filter re-ranking. *Knowledge-Based Systems*, 25(1), 35–44. <https://doi.org/10.1016/j.knosys.2011.01.015>
- Birchall, S. J., & Bonnett, N. (2021). Climate change adaptation policy and practice: The role of agents, institutions and systems. *Cities*, 108, Article 103001. <https://doi.org/10.1016/j.cities.2020.103001>

- Bouckaert, S., Pales, A. F., McGlade, C., Remme, U., Wanner, B., Varro, L., D'Ambrosio, D., & Spencer, T. (2021). *Net Zero by 2050: A roadmap for the global energy sector*. International Energy Agency. <https://iea.blob.core.windows.net/assets/063ae08a-7114-4b58-a34e-39db2112d0a2/NetZeroBy2050-ARoadmapfortheGlobalEnergySector.pdf>
- Braunschweiler, D., & Ingold, K. (2023). What drives local climate change adaptation? A qualitative comparative analysis. *Environmental Science & Policy*, 145, 40–49. <https://doi.org/10.1016/j.envsci.2023.03.013>
- Bulder, C., Todd, I., McCauley, D., & Burns, M. K. (2023). The influence of COVID-19 on modes of governance for climate change—Expert views from the Netherlands and the UK. *Environmental Policy and Governance*, 33(4), 351–363. <https://doi.org/10.1002/eet.2042>
- Calvet, L., Gianfrate, G., & Uppal, R. (2022). The finance of climate change. *Journal of Corporate Finance*, 73, Article 102162. <https://doi.org/10.1016/j.jcorpfin.2022.102162>
- Cao, M., Zhang, F., Li, J., & Meng, G. (2023). Does climate change surprise the profitability of energy firms? Empirical evidence from China. *Business Strategy and the Environment*, 32(4), 1418–1431. <https://doi.org/10.1002/bse.3196>
- Çetinbaş, İ., Tamyurek, B., & Demirtaş, M. (2023). Parameter extraction of photovoltaic cells and modules by hybrid white shark optimizer and artificial rabbits optimization. *Energy Conversion and Management*, 296, Article 117621. <https://doi.org/10.1016/j.enconman.2023.117621>
- Chang, B., Chang, C. W., & Wu, C. H. (2011). Fuzzy DEMATEL method for developing supplier selection criteria. *Expert systems with Applications*, 38(3), 1850–1858. <https://doi.org/10.1016/j.eswa.2010.07.114>
- Chang, C. C., & Lin, T. Y. (2008). Linear feature extraction by integrating pairwise and global discriminatory information via sequential forward floating selection and kernel QR factorization with column pivoting. *Pattern Recognition*, 41(4), 1373–1383. <https://doi.org/10.1016/j.patcog.2007.09.008>
- Chen, F. S., Hsu, M. F., & Hu, K. H. (2022). Enterprise's internal control for knowledge discovery in a big data environment by an integrated hybrid model. *Information Technology and Management*, 23, 213–231. <https://doi.org/10.1007/s10799-021-00342-8>
- Chua, W. F., James, R., King, A., Lee, E., & Soderstrom, N. (2022). Task force on climate-related financial disclosures (TCFD) implementation: An overview and insights from the Australian accounting standards board dialogue series. *Australian Accounting Review*, 32(102), 396–405. <https://doi.org/10.1111/auar.12388>
- Cosma, S., Principale, S., & Venturelli, A. (2022). Sustainable governance and climate-change disclosure in European banking: The role of the corporate social responsibility committee. *Corporate Governance*, 22(6), 1345–1369. <https://doi.org/10.1108/CG-09-2021-0331>
- David, B., & Giordano-Spring, S. (2022). Climate reporting related to the TCFD framework: An exploration of the air transport sector. *Social and Environmental Accountability Journal*, 42(1–2), 18–37. <https://doi.org/10.1080/0969160X.2021.2007784>
- D'Orazio, P. (2022). Mapping the emergence and diffusion of climate-related financial policies: Evidence from a cluster analysis on G20 countries. *International Economics*, 169, 135–147. <https://doi.org/10.1016/j.inteco.2021.11.005>
- D'Orazio, P., & Dirks, M. W. (2022). Exploring the effects of climate-related financial policies on carbon emissions in G20 countries: A panel quantile regression approach. *Environmental Science and Pollution Research*, 29, 7678–7702. <https://doi.org/10.1007/s11356-021-15655-y>
- Dogra, N., & Adil, M. (2023). Factors influencing travellers' decision-making behaviour towards online travel purchases: A fuzzy-DEMATEL approach. *Current Issues in Tourism*, 27(20), 3313–3332. <https://doi.org/10.1080/13683500.2023.2262707>
- Erisoglu, M., Calis, N., & Sakalliglu, S. (2011). A new algorithm for initial cluster centers in k-means algorithm. *Pattern Recognition Letters*, 32(14), 1701–1705. <https://doi.org/10.1016/j.patrec.2011.07.011>

- Fahim, A. (2021). K and starting means for k-means algorithm. *Journal of Computational Science*, 55, Article 101445. <https://doi.org/10.1016/j.jocs.2021.101445>
- Fallahpour, S., Lakvan, E. N., & Zadeh, M. H. (2017). Using an ensemble classifier based on sequential floating forward selection for financial distress prediction problem. *Journal of Retailing and Consumer Services*, 34, 159–167. <https://doi.org/10.1016/j.jretconser.2016.10.002>
- Feldmann, F. G., Birkel, H., & Hartmann, E. (2022). Exploring barriers towards modular construction – A developer perspective using fuzzy DEMATEL. *Journal of Cleaner Production*, 367, Article 133023. <https://doi.org/10.1016/j.jclepro.2022.133023>
- Feng, C., & Ma, R. (2020). Identification of the factors that influence service innovation in manufacturing enterprises by using the fuzzy DEMATEL method. *Journal of Cleaner Production*, 253, Article 120002. <https://doi.org/10.1016/j.jclepro.2020.120002>
- Franco, C., Melica, G., Treville, A., Baldi, M. G., Ortega, A., Bertoldi, P., & Thiel, C. (2023). Key predictors of greenhouse gas emissions for cities committing to mitigate and adapt to climate change. *Cities*, 137, Article 104342. <https://doi.org/10.1016/j.cities.2023.104342>
- Financial Stability Board. (2015a, December 4). *FSB to establish task force on climate-related financial disclosures* (Press release, 4).
- Financial Stability Board. (2015b, November 9). *Proposal for a disclosure task force on climate-related risks*. <https://www.fsb.org/uploads/Disclosure-task-force-on-climate-related-risks.pdf>
- Gabus, A., & Fontela, E. (1972). *World problems, an invitation to further thought within the framework of DEMATEL*. Battelle Geneva Research Centre.
- Gabus, A., & Fontela, E. (1973). *Perceptions of the world problematique: Communication procedure, communicating with those bearing collective responsibility*. Battelle Geneva Research Centre.
- García-Sánchez, I. M., S Monteiro, S., Piñeiro-Chousa, J. R., & Beatriz Aibar-Guzmán, B. (2023). Climate change innovation: Does board gender diversity matter? *Journal of Innovation & Knowledge*, 8(3), Article 100372. <https://doi.org/10.1016/j.jik.2023.100372>
- González, L. R., & Miller, P. R. (2020). Corporate governance and climate change: A Study on the role of boards of directors in climate-related risk management. *Journal of Business Ethics*, 164(3), 1–20. <https://doi.org/10.1007/s10551-019-04177-w>
- Gonzales-Iwanciw, J., Dewulf, A., & Karlsson-Vinkhuyzen, S. (2020). Learning in multi-level governance of adaptation to climate change – a literature review. *Journal of Environmental Planning and Management*, 63(5), 779–797. <https://doi.org/10.1080/09640568.2019.1594725>
- Griffin, P., & Jaffe, A. M. (2022). Challenges for a climate risk disclosure mandate. *Nature Energy*, 7, 2–4. <https://doi.org/10.1038/s41560-021-00929-z>
- Hewa, S. I., Chen, J., & Mala, R. (2023). Corporate responses to climate change risks: Evidence from Australia. *Australasian Journal of Environmental Management*, 30(2), 188–214. <https://doi.org/10.1080/14486563.2023.2220297>
- Huggel, C., Bouwer, L. M., Juhola, S., Mechler, R., Muccione, V., Orlove, B., & Wallimann-Helmer, I. (2022). The existential risk space of climate change. *Climatic Change*, 174(1), Article 8. <https://doi.org/10.1007/s10584-022-03430-y>
- Hu, K. H., Chen, F. S., Hsu, M. F., & Tzeng, G. H. (2021). Identifying key factors for adopting artificial intelligence-enabled auditing techniques by joint utilization of fuzzy-rough set theory and MRDM technique. *Technological and Economic Development of Economy*, 27(2), 459–492. <https://doi.org/10.3846/tede.2020.13181>
- Hu, K. H., Chen, F. S., & Tzeng, G. H. (2018). CPA firm's cloud auditing provider for performance evaluation and improvement: An empirical case of China. *Technological and Economic Development of Economy*, 24(6), 2338–2373. <https://doi.org/10.3846/tede.2018.6619>
- Intergovernmental Panel on Climate Change. (2018). *Global warming of 1.5 degrees: Summary for policymakers* (Technical report).

- John, A., Nathan, R., Horne, A., Stewardson, M., & Webb, J. A. (2020). How to incorporate climate change into modelling environmental water outcomes: a review. *Journal of Water and Climate Change*, 11(2), 327–340. <https://doi.org/10.2166/wcc.2020.263>
- Kabak, M., & Dağdeviren, M. (2014). A hybrid MCDM approach to assess the sustainability of students' preferences for university selection. *Technological and Economic Development of Economy*, 20(3), 391–418. <https://doi.org/10.3846/20294913.2014.883340>
- Keskin, G. A. (2015). Using integrated fuzzy DEMATEL and fuzzy C: Means algorithm for supplier evaluation and selection. *International Journal of Production Research*, 53(12), 3586–3602. <https://doi.org/10.1080/00207543.2014.980461>
- Kiesel, R., & Stahl, G. (2023). An uncertainty-based risk management framework for climate change risk. *Annals of Actuarial Science*, 17(3), 420–437. <https://doi.org/10.1017/S1748499523000179>
- Koo, C., Hong, T., & Park, J. (2018). Development of the life-cycle economic and environmental assessment model for establishing the optimal implementation strategy of the rooftop photovoltaic system. *Technological and Economic Development of Economy*, 24(1), 27–47. <https://doi.org/10.3846/20294913.2015.1074127>
- Kouloukoui, D., Marinho, M. M. O., Gomes, S. M. S., de Jong, P., Kiperstok, A., & Torres, E. A. (2020). The impact of the board of directors on business climate change management: Case of Brazilian companies. *Mitigation and Adaptation Strategies for Global Change*, 25, 127–147. <https://doi.org/10.1007/s11027-019-09864-7>
- Kunreuther, H. (2020). Risk management solutions for climate change-induced disasters. *Risk Analysis*, 40(S1), 2263–2271. <https://doi.org/10.1111/risa.13616>
- Lachaud, M. A., Bravo-Ureta, B. E., & Ludena, C. E. (2022). Economic effects of climate change on agricultural production and productivity in Latin America and the Caribbean (LAC). *Agricultural Economics*, 53(2), 321–332. <https://doi.org/10.1111/agec.12682>
- Lawrence, J., Wreford, A., & Allan, S. (2022). Adapting to avoidable and unavoidable climate change: What must Aotearoa New Zealand do? *Policy Quarterly*, 18(2), 51–60. <https://doi.org/10.26686/pq.v18i2.7575>
- Le Quére C., Korsbakken J. I., Wilson C., Tosun J., Andrew R., An-dres R. J., Canadell, J. G., Jordan, A., Peters G. P., & van Vuuren, D. P. (2019). Drivers of declining CO₂ emissions in 18 developed economies. *Nature Climate Change*, 9(3), 213–217. <https://doi.org/10.1038/s41558-019-0419-7>
- Liao, H., Wu, Z., Liu, F., & Zhang, C. (2023). Applications of social network analysis in promoting circular economy: A literature review. *Technological and Economic Development of Economy*, 29(5), 1559–1586. <https://doi.org/10.3846/tede.2023.20104>
- Llopis-Albert, C., Palacios-Marqués, D., & Simón-Moya, V. (2021). Fuzzy set qualitative comparative analysis (fsQCA) applied to the adaptation of the automobile industry to meet the emission standards of climate change policies via the deployment of electric vehicles (EVs). *Technological Forecasting and Social Change*, 169, Article 120843. <https://doi.org/10.1016/j.techfore.2021.120843>
- Loehr, J., & Becken, S. (2023). Leverage points to address climate change risk in destinations. *Tourism Geographies*, 25(2–3), 820–842. <https://doi.org/10.1080/14616688.2021.2009017>
- Luo, L., & Tang, Q. (2021). Corporate governance and carbon performance: Role of carbon strategy and awareness of climate risk. *Accounting and Finance*, 61, 2891–2934. <https://doi.org/10.1111/acfi.12687>
- Lu, M. T., Chang, S. C., & Huang, L. H. (2022). Using the sustainability-balanced scorecard for assessing sustainability issues of the green energy companies. *Technological and Economic Development of Economy*, 28(2), 483–499. <https://doi.org/10.3846/tede.2022.16334>
- Lu, M. T., Lin, S. W., & Tzeng, G. H. (2013). Improving RFID adoption in Taiwan's healthcare industry based on a DEMATEL technique with a hybrid MCDM model. *Decision Support Systems*, 56, 259–269. <https://doi.org/10.1016/j.dss.2013.06.006>

- Maji, S. G., & Kalita, N. (2022). Climate change financial disclosure and firm performance: Empirical evidence from Indian energy sector based on TCFD recommendations. *Society and Business Review*, 17(4), 594–612. <https://doi.org/10.1108/SBR-10-2021-0208>
- Mavi, R. K., & Standing, C. (2018). Critical success factors of sustainable project management in construction: A fuzzy DEMATEL-ANP approach. *Journal of Cleaner Production*, 194, 751–765. <https://doi.org/10.1016/j.jclepro.2018.05.120>
- Mbanyele, W., & Muchenje, L. T. (2022). Climate change exposure, risk management and corporate social responsibility: Cross-country evidence. *Journal of Multinational Financial Management*, 66, Article 100771. <https://doi.org/10.1016/j.mulfin.2022.100771>
- Nagelkerken, I., & Connell, S. D. (2015). Global alteration of ocean ecosystem functioning due to increasing human CO₂ emissions. *Proceedings of the National Academy of Sciences*, 112(43), 13272–13277. <https://doi.org/10.1073/pnas.15108561>
- Nasr, A., Kjellström, E., Björnsson, I., Honfi, D., Ivanov, O. L., & Johansson, J. (2020). Bridges in a changing climate: A study of the potential impacts of climate change on bridges and their possible adaptations. *Structure and Infrastructure Engineering*, 16(4), 738–749. <https://doi.org/10.1080/15732479.2019.1670215>
- Nathalia, C., & Setiawan, D. (2022). Does board capital improve climate change disclosures? *Cogent Business & Management*, 9(1), Article 2121242. <https://doi.org/10.1080/23311975.2022.2121242>
- O'Dwyer, B., & Unerman, J. (2020). Shifting the focus of sustainability accounting from impacts to risks and dependencies: researching the transformative potential of TCFD reporting. *Accounting, Auditing & Accountability Journal*, 33(5), 1113–1141. <https://doi.org/10.1108/AAAJ-02-2020-4445>
- Opricovic, S., & Tzeng, G. H. (2003). Defuzzification within a multicriteria decision model. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, 11(5), 635–652. <https://doi.org/10.1142/S0218488503002387>
- Orazalin, N. S., Ntim, C. G., & Malagila, J. K. (2023). Board sustainability committees, climate change initiatives, carbon performance, and market value. *British Journal of Management*, 35(1), 295–320. <https://doi.org/10.1111/1467-8551.12715>
- Ou Yang, Y. P., Shieh, H. M., & Tzeng, G. H. (2013). A VIKOR technique based on DEMATEL and ANP for information security risk control assessment. *Information Sciences*, 232, 482–500. <https://doi.org/10.1016/j.ins.2011.09.012>
- Patil, S. K., & Kant, R. (2014). A hybrid approach based on fuzzy DEMATEL and FMCDM to predict success of knowledge management adoption in supply chain. *Applied Soft Computing*, 18, 126–135. <https://doi.org/10.1016/j.asoc.2014.01.027>
- Priyanka, R., Ravindran, K., Sankaranarayanan, B., & Ali, S.M. (2023). A fuzzy DEMATEL decision modeling framework for identifying key human resources challenges in start-up companies: Implications for sustainable development. *Decision Analytics Journal*, 6, Article 100192. <https://doi.org/10.1016/j.dajour.2023.100192>
- Quay, R. (2010). Anticipatory governance: A tool for climate change adaptation. *Journal of the American Planning Association*, 76(4), 496–511. <https://doi.org/10.1080/01944363.2010.508428>
- Rana, T., Lowe, A., & Azam, M. S. (2023). Green governmentality and climate change risk management: The case of a regulatory reform in Bangladesh. *Accounting, Auditing & Accountability Journal*, 36(3), 801–829. <https://doi.org/10.1108/AAAJ-05-2021-5286>
- Rijal, S., Gentle, P., Khanal, U., Wilson, C., & Rimal, B. (2022). A systematic review of Nepalese farmers' climate change adaptation strategies. *Climate Policy*, 22(1), 132–146. <https://doi.org/10.1080/14693062.2021.1977600>
- Rostamzadeh, S., Abouhossein, A., Chalak, M. H., Vosoughi, S., & Norouzi, R. (2023). An integrated DEMATEL-ANP approach for identification and prioritization of factors affecting fall from height

- accidents in the construction industry. *International Journal of Occupational Safety and Ergonomics*, 29(2), 474–483. <https://doi.org/10.1080/10803548.2022.2052479>
- Saroha, M., Garg, D., & Luthra, S. (2022). Identification and analysis of circular supply chain management practices for sustainability: A fuzzy-DEMATEL approach. *International Journal of Productivity and Performance Management*, 71(3), 722–747. <https://doi.org/10.1108/IJPPM-11-2020-0613>
- Sarkodie, S. A., Adams, S., & Leirvik, T. (2020). Foreign direct investment and renewable energy in climate change mitigation: Does governance matter? *Journal of Cleaner Production*, 263, Article 121262. <https://doi.org/10.1016/j.jclepro.2020.121262>
- Savvidou, G., Atteridge, A., Omari-Motsumi, K., & Trisos, C. H. (2021). Quantifying international public finance for climate change adaptation in Africa. *Climate Policy*, 21(8), 1020–1036. <https://doi.org/10.1080/14693062.2021.1978053>
- Shear, F. Ashraf, B. N., & Butt, S. (2023). Sensing the heat: Climate change vulnerability and foreign direct investment inflows. *Research in International Business and Finance*, 66, Article 102005. <https://doi.org/10.1016/j.ribaf.2023.102005>
- Solana, J. (2020). Climate change litigation as financial risk. *Green Finance*, 2(4), 344–372. <https://doi.org/10.3934/GF.2020019>
- Steiger, R., Scott, D., Abegg, B., Pons, M., & Aall, C. (2019). A critical review of climate change risk for ski tourism. *Current Issues in Tourism*, 22(11), 1343–1379. <https://doi.org/10.1080/13683500.2017.1410110>
- Suprayitno, D., Iskandar, S., Dahurandi, K., Hendarto, T., & Rumambi, F. J. (2024). Public policy in the era of climate change: Adapting strategies for sustainable futures. *Migration Letters*, 21(S6), 945–958.
- Tan, M., Pu, J., & Zheng, B. (2014). Optimization of breast mass classification using sequential forward floating selection (SFFS) and a support vector machine (SVM) model. *International Journal of Computer Assisted Radiology and Surgery*, 9, 1005–1020. <https://doi.org/10.1007/s11548-014-0992-1>
- Task Force on Climate-related Financial Disclosures. (2016, March 16). *Phase I Report of the Task Force on Climate-Related Financial Disclosures*.
- Task Force on Climate-related Financial Disclosures. (2017a, June). *Recommendations of the Task Force on Climate-Related Financial Disclosures*.
- Task Force on Climate-related Financial Disclosures. (2017b, June). *Technical supplement: The use of scenario analysis in disclosure of climate related risks and opportunities*.
- Task Force on Climate-related Financial Disclosures. (2019). *Task Force on climate-related financial disclosures: status report*. Retrieved July 10, 2022, from <https://www.fsb-tcfd.org/wp-content/uploads/2019/06/2019-TCFD-Status-Report-FINAL-053119.pdf>
- Task Force on Climate-related Financial Disclosures. (2020). *Task force on climate-related financial disclosures: 2020 status report*. Retrieved March 20, 2023, from www.fsb.org/wp-content/uploads/P291020-1.pdf
- Teale, N., & Quiring, S. M. (2022). Conducting climate change risk assessments for companies. *Bulletin of the American Meteorological Society*, 103(12), E2836–E2844. <https://doi.org/10.1175/BAMS-D-21-0339.1>
- Thekdi, S., & Aven, T. (2016). An enhanced data-analytic framework for integrating risk management and performance management. *Reliability Engineering & System Safety*, 156, 277–287. <https://doi.org/10.1016/j.ress.2016.07.010>
- Tzeng, G. H., Chiang, C. H., & Li, C. W. (2007). Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL. *Expert Systems with Applications*, 32(4), 1028–1044. <https://doi.org/10.1016/j.eswa.2006.02.004>
- Vangala, S., Hung, K., & South, D. (2022). Revisiting the Biden administration's approach to climate change. *Climate and Energy*, 39(1), 1–12. <https://doi.org/10.1002/gas.22299>

- Velte, P. (2023). Automated text analyses of sustainability & integrated reporting. A literature review of empirical-quantitative research. *Journal of Global Responsibility*, 14(4), 530–566. <https://doi.org/10.1108/JGR-09-2022-0090>
- Wang, Q., Jia, G., & Song, W. (2022). Identifying critical factors in systems with interrelated components: A method considering heterogeneous influence and strength attenuation. *European Journal of Operational Research*, 303, 456–470. <https://doi.org/10.1016/j.ejor.2022.02.012>
- Xian, C., Gong, C., Lu, F., Wu, H., & Ouyang, Z. (2023). The evaluation of greenhouse gas emissions from sewage treatment with urbanization: Understanding the opportunities and challenges for climate change mitigation in China's low-carbon pilot city, Shenzhen. *Science of the Total Environment*, 855, Article 158629. <https://doi.org/10.1016/j.scitotenv.2022.158629>
- Xue, D., Zhou, J., Zhao, X., Liu, C., Wei, W., Yang, X., Li, Q., & Zhao, Y. (2021). Impacts of climate change and human activities on runoff change in a typical arid watershed, NW China. *Ecological Indicators*, 121, Article 107013. <https://doi.org/10.1016/j.ecolind.2020.107013>
- Xue, P., Huang, S., Xie, K., Sun, Y., & Fei, L. (2024). Identification of the critical factors in flood vulnerability assessment based on an improved DEMATEL method under uncertain environments. *International Journal of Disaster Risk Reduction*, 100, Article 104217. <https://doi.org/10.1016/j.ijdrr.2023.104217>
- Zhang, X., Zhang, S., & Lu, L. (2022). The banking instability and climate change: Evidence from China. *Energy Economics*, 106, Article 105787. <https://doi.org/10.1016/j.eneco.2021.105787>