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A barrier evaluation framework for forest carbon sink project implementation in China using an integrated BWM-IT2F-PROMETHEE II method

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ABSTRACT

Forest carbon sink project (FCSP) has received growing attention for its outstanding advantages in carbon emission reduction, environment protection, and achieving the carbon neutrality objective. Using a government-social capital cooperation model, FCSP helps to revitalize the ecological and economic benefits of the forest with standard and efficient management. However, the management and operation barriers of FCSP implementation are complex, multiple and indefinite in the long run, which requires a comprehensive barrier evaluation framework. Hence, this paper is devoted to constructing a barrier evaluation framework for FCSP implementation in China with an integrated multi-criteria decision-making (MCDM) method. To this end, critical barriers are identified and the criteria system is constructed with a two-stage systematic literature review and interaction with the experts. Later, an applicable and comprehensive barrier evaluation framework is built, wherein the interval type-2 fuzzy set (IT2FS) is used to process fuzziness and uncertain information, the best-worst method (BWM) is adopted to determine the criteria weight, and the Preference Ranking Organization Method for Enrichment Evaluations II (PROMETHEE II) is introduced for comprehensive barrier evaluation. The criteria weighting results indicate that FCSP implementation encounters challenges taking into account institutional and governance barriers (criteria weight: 0.3592), management barriers (0.2384), economic and market barriers (0.1637), knowledge barriers (0.0747), technical and infrastructure barriers (0.1639), C1 "Lack of clear leadership and policies" and C5 "Forest management performance" were determined the most significant criteria, A5 and A4 respectively performed the lowest and the highest barrier level. In sensitivity analysis, the ranking results were stable when the criteria changed, and Spearman's rank correlations of B2, B4, and B5 are significant. The results were validated by a comparative analysis with other methods with the help of Spearman's rank correlation coefficient, which reflects accepted high correlations (Spearman's pro values of BWM-IT2F-PROMETHEE II (Gaussian rule), BWM-IT2F-TOPSIS, and BWM-TFN-VIKOR are 1.00, 1.00, 1.00). The findings of the paper help the decision makers to develop more rational strategies and successfully implement the FCSP.

1. Introduction

Efforts have been made from many sectors to make positive response to mitigating climate change and reducing carbon emissions, such as renewable energy sectors (Saidi & Omri, 2020), transportation sectors (Jaspers, Kuo, Amladi, van Neerbos, & Aravind, 2021), fishery sectors (Zheng & Yu, 2022), and so on. Among various sectors, forest carbon sink (FCS) has an effective impact on CO2 sequestration (Gogoi, Ahirwal, & Sahoo, 2022) via forest management and other techniques (Favero, Daigneault, & Sohngen, 2020). Globally, forest accounts for 70% of the soil's organic carbon, and even a small change in forest management practice will influence the carbon cycle on earth (Gong,

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Tan, Liu, & Xu, 2021). Meanwhile, the forest is proved to be more effective in CO2 emission reduction compared with renewable energy and agriculture (Waheed, Chang, Sarwar, & Chen, 2018), which is consistent with the "nature-based solution" (NBS) put forward by China and New Zealand (Xu, Wang, & Chen, 2022). Therefore, it's of great importance to promote FCS to better respond to carbon neutrality.

In recent years, China is developing measurements and policies to promote FCS development. On one hand, Chinese Certified Emission Reduction (CCER) credits and Clean Development Mechanism (CDM) credits are applied to construct an emission trading system (Yan, Zhang, Zhang, & Li, 2020; Ye, Xiong, Li, & Li, 2021). On the other hand, a three-pronged approach is suggested to reasonably enhance carbon sink capacity and increase carbon storage, wherein forest area expansion, carbon function and storage enhancement, and existing forest protection are considered (National Forestry and Grassland Administration, 2022). In this context, forest carbon sink project (FCSP), which encourages a government-enterprise-farmer cooperation and an effect-oriented management mode, is attracting more and more attention. In the FCSP, afforestation and reforestation are recognized as the key strategies and political frameworks to increase carbon absorption and sequestration (Bastin et al., 2019; Cao, Li, & Breeze, 2020).

Different from traditional forestry projects, the FCSP involves multiple layers, bodies and elements in the developing and maturing carbon market, as Fig. 1 shows. In this context, a large number of provincial and municipal government departments and enterprises start their attempts at FCSP, which emerges not only economic and ecological benefits but also complicated technical and management barriers. In this regard, it triggers a practical and pressing need to better understand these barriers and their relations to FCSP implementation.

Under the internal and external environment full of dynamics and uncertainties, there exists a series of barriers during the construction and operation of FCSP along with unpredictable bottlenecks. For example, an FCSP is facing challenges from strict project development methodologies and dynamic trading rules of different carbon markets. In practice, development failure cases happen due to the underestimation of project evaluation requirements and risk assessments associated with the FCSP. Particularly, these political, economic, social, and technical barriers penetrate the entire ecological & forestry systems due to the myriad of challenges and complexities of the carbon trading environment in China, making the barrier analysis of FCSP more complicated and difficult. Thus, it's of significance to identify the critical barriers an FCSP might face during the construction and maintenance stages and to develop an evaluation framework for FCSP implementation in China. Therefore, the underlying research questions of the paper are three-fold:

(1) What are the critical barriers to FCSP implementation from the perspectives of government departments, enterprises and other participants?
(2) What are the significance and ranking orders of various barriers in implementing an FCSP?
(3) How to evaluate the comprehensive barriers faced by an FCSP and how to select the optimal alternative FCSP for further implementation?

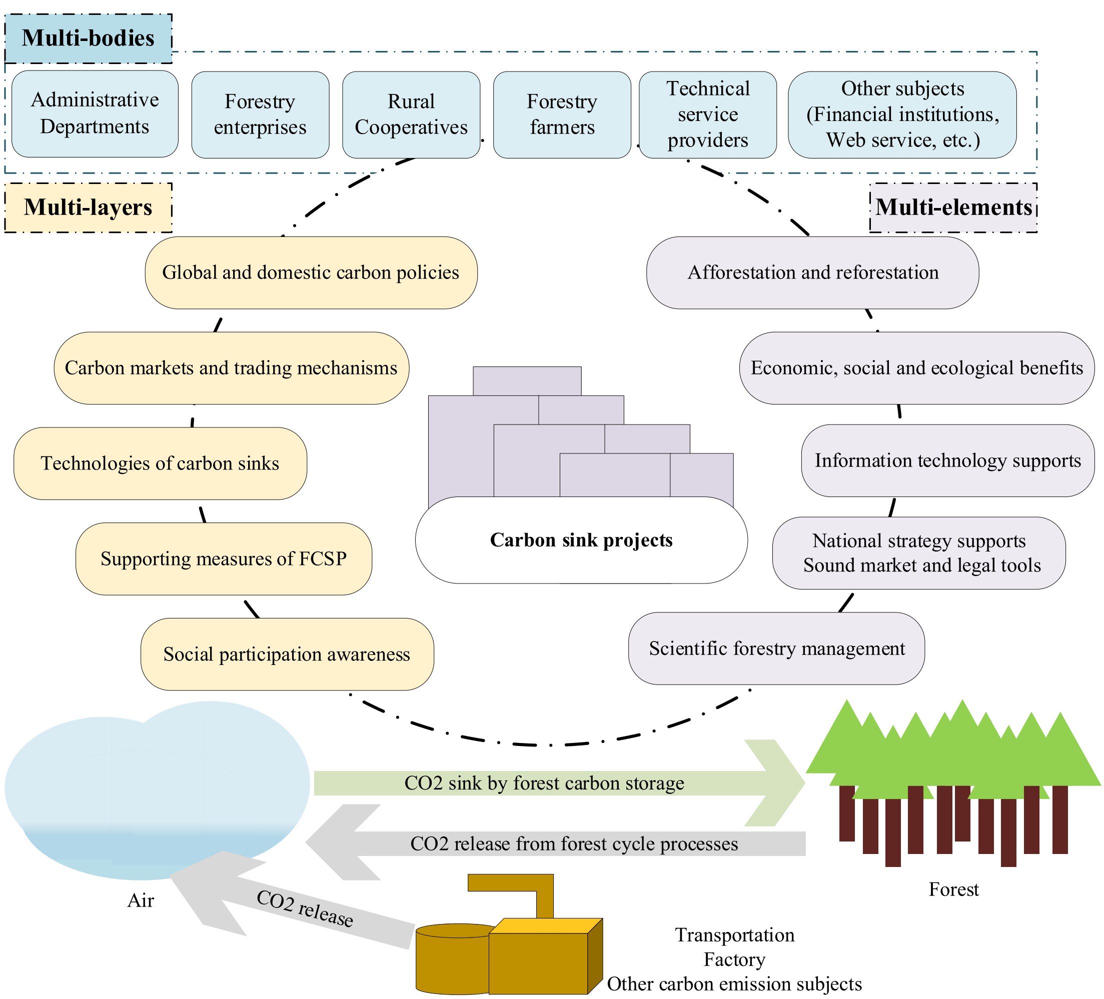

Fig. 1. Cooperation mode of FCSP.

To address the questions, a barrier evaluation framework is proposed to discuss whether and how different dimensions of barriers influence the implementation outcomes of the FCSP and how to evaluate the comprehensive barrier level of implementing an FCSP in China. A large number of papers have developed investigations for facilitating the successful implementation of related projects or industries. Batista and Caiado (2021) discussed the barriers and critical factors of municipal solid waste management to guide project implementation. Deely et al. (2020) developed a literature review to identify the barriers during the implementation procedures of blue and green infrastructures. Buga and Yousif (2021) evaluated both the drivers and barriers of adopting local sustainable energy policy to meet climate targets. Kaviani et al. (2020) integrated the Delphi method and the Best-worst method (BWM) to assess the barriers to reverse logistics implementation.

Concerning the complexity of the questions, the multi-criteria decision-making (MCDM) methodology is applied in constructing the barrier evaluation framework, which is believed to be an appropriate and effective technique in modeling complex and conflicting relationships between different factors (Gireesha, Kamalesh, Krithivasan, & Shankar Sriram, 2022; Kadziński, Wójcik, & Ciomek, 2022), aggregating alternatives' performance concerning both qualitative and quantitative criteria, and providing a compromise solution (Filatovas, Marcozzi, Mostarda, & Paulavičius, 2022). Using an MCDM-based framework helps to reveal how the FCSP implementation are impacted by the existing barriers and how to reasonably evaluate those barriers encountered during the construction and maintenance processes. As a result, we use the MCDM technique to investigate the critical barriers and their significance relations in FCSPs and to evaluate and rank the overall barrier levels of the alternative FCSPs.

Barrier evaluation of FCSP implementation contains various conflicting factors that may not be apparent clearly, certainly, and precisely under a complicated and dynamic environment, thus criteria weighting and barrier evaluation should be conducted with the help of experienced and professional experts that prefer to make linguistic judgments, which yield more reliable and accurate data and keep more in line with the practical situation (Pamucar & Faruk Görçün, 2022). Depending on the natural characteristics of the problems, the BWM and the Preference Ranking Organization Method for Enrichment Evaluations II (PROMETHEE II), which have been frequently adopted for solving ranking problems (Dwivedi et al., 2021; Ecer & Pamucar, 2020; Kheybari, Javdanmehr, Rezaie, & Rezaei, 2021; Wu et al., 2020a), are employed in the paper.

In this context, the proposed BWM-IT2F-PROMETHEE II method shows advantages considering the following aspects: (1) The BWM allows decision makers (DMs) to do more precise and efficient comparisons among various items in a systematic way, namely offering a grasp of the evaluation information that is done before the comparison process (Hosseini Dehshiri, Emamat, & Amiri, 2022; Rezaei, 2020); (2) The data collecting and processing procedures of the BWM is simple and the results are consistent and reliable (Lahri, Shaw, & Ishizaka, 2021; Shang, Yang, Barnes, & Wu, 2022); (3) Among various ranking MCDM techniques, PROMETHEE II has outstanding advantages in self-optimization (Yi, Li, & Zhang, 2021), easy application with stable outcomes (Burak, Samanlioglu, & Ülker, 2022), providing complete ranking orders in complex and difficult situations (Wu, Zhang, & Yi, 2020c), and these characteristics comply with the barrier evaluation features of FCSP implementation; (4) Interval type-2 fuzzy sets (IT2FSs), which can be malleable and easy-to-use and has been applied in a widespread application for handling fuzziness and ambiguity (İlker Gölcük, 2020; Tavana, Shaabani, Di Caprio, & Bonyani, 2022; Wei, 2021), are introduced in this paper to extend PROMETHEE II to improve the accuracy and strengthen the application of the evaluation and ranking results. (5) The proposed method shows expected performance in ranking the alternatives with stable and consistent results (see Section 4.2.1 comparative analysis), thus the proposed barrier evaluation framework using a BWM-IT2F-PROMETHEE II approach can be accepted as a reliable solution.

Compared with previous literature, the novelty of this paper are as follows: (1) The presented research is a novel direction and fills the current research gap by systematically identifying the barrier factors and offering a barrier evaluation frame in such a scope, which remains ambiguous before but is in line with FCSP implementation needs. (2) In terms of the methodology, no methodological framework in the literature has been found and proven ideal solution dedicated to this kind of research, the proposed methodology makes it possible for multiple participants (such as government officers, project managers, etc.) to objectively and easily be aware of the barrier level of an FCSP, considering 5 main criteria and 16 sub-criteria that cover the majority aspects of FCSP implementation, which provides a new supportive technique for DMs. (3) Another new research angle is the correlation discussion between different criteria dimensions and the overall ranking, which is performed and discussed by Spearman's rank correlation coefficient. From the perspective of MCDM-based barrier evaluation methodology, the research guarantees brand-new knowledge regarding the complex challenges and characteristics of FCSP implementation in China.

The main contribution of the paper lies in providing a barrier analysis and evaluation framework for decision-making of FCSP implementation with a BWM-IT2F-PROMETHEE II approach. More precisely, the contribution of the work includes the following aspects:

(1) We focus on a micro-level analysis of the FCSP, identify and discuss the barriers faced by the FCSP implementation in China, thus contributing to enriching the decision-making and developing strategies knowledge based on the FCSP and helping to construct the criteria system of barrier evaluation.
(2) We put forward a new barrier evaluation framework for barrier analysis concerning the FCSP development, i.e. the BWM-IT2F-PROMETHEE II approach, wherein the BWM helps to weigh the criteria and the IT2FSs and the PROMETHEE II help to rank alternative FCSPs effectively and reasonably. The results obtained by the proposed methodology are validated and discussed with Spearman's rank correlation coefficient and other MCDM techniques, including Gaussian rule-based PROMETHEE II, BWM-IT2F-TOPSIS, and BWM-TFN-VIKOR. In this regard, this paper contributes to verifying the robustness, feasibility, and operability of MCDM methods in the context of the dedicated research scope.
(3) The paper addresses the gap in the literature as it focuses more on decision-making supports of the FCSP with experts' opinions and qualitative terms that keep in line with practical situations and needs, rather than assessing an FCSP from a quantitative perspective, such as potential assessments, cost-benefit assessments, etc. In this regard, the methodology contributes to using interpretability and descriptive information to offer implementable, available, and targeted suggestions for government officers, project managers, forestry enterprises, and other participants involved.

The organization of the paper is outlined as follows. In Section 2, it conducts a comprehensive literature review to identify the barriers of the FCSP implementation in China. Section 3 presents the basic concepts and application steps of the methodologies and shows the implementation procedure of the proposed framework. Section 4 presents the application results and the discussions. In Section 5, the conclusions are provided. Further directions and limitations are presented in Section 6.

2. Literature review

2.1. Barrier analysis of FCSP implementation

The global awareness to limit carbon emissions has deepened the understanding of the potential role of the FSC considering both managed and unmanaged forests (Pan et al., 2011). Unlike transportation, manufacturing, building and other sectors, forests have simultaneous effects as both carbon sinks and carbon emitters (Xu et al., 2022), the carbon sink ability of poor-managed forests and old-growth forests are overestimated in some cases (Gundersen, Thybring, Nord-Larsen, Vesterdal, Nadelhoffer, & Johannsen, 2021). Therefore, a reasonable management mechanism is the prerequisite for sustainable FCSP (Yu, You, Agathokleous, Zhou, & Liu, 2021). As one major representational mechanism, the clean development mechanism (CDM) provides opportunities for forestry-related organizations to invest and operate FCSPs to produce and trade certified emission reductions (Ba, Liu, Zhu, Liu, & Zhao, 2020). To construct a trading and offset mechanism meeting China's carbon emission reduction management demands, Chinese Certified Emission Reduction (CCER), an extension of the CDM, is used as an important complement to support FCSP development (Ye et al., 2021). As a result, more and more local governments, forestry enterprises, technical service organizations and other subjects have shown their willingness in participating an FCSP. Therefore, comprehensively identifying the critical barriers faced by the FCSP is crucial to ensure the successful implementation of the projects.

Over time, researchers at home and abroad have a consensus on the significance and effectiveness of the FCS (Magerl et al., 2022; Zhang et al., 2020), a series of studies have developed simulation models to describe or predict the carbon stock capacity of the FCS (Gogoi et al., 2022; Piao, He, Wang, & Chen, 2022), and numerous FCS research have investigated the service values (Lin & Ge, 2019; Shi et al., 2022) and cost analysis of FCS (Cao et al., 2020). However, some controversies and barriers regarding the FCSP still exist. Shu et al. (2019) pointed out that environmental factors influenced the capacity of the FSC and the specific characteristics of different individuals of an FCSP were difficult to measure. Zhang et al. (2020) noted that identifying important environmental, climatic, and anthropogenic factors was essential for the sustainable outcomes of an FCSP. Magerl et al. (2022) investigated the drivers of the forest transition and believed that dynamics and uncertainties kept working from a long-term perspective. They also listed some underlying factors enabling the carbon sink effectiveness of the forest, such as forest area, timber industry and energy consumers, which should not be neglected in consideration of an FCSP since its operation period lasts for years.

Although FCS in China has been given important responsibilities at the national level, China's FCSP, the most representative and promising development mode of FCS, is still premature and lacks practical implementation and management experience, so timely investigating the environmental, social, technical, and political barriers of the FCSP is an urgent and critical issue for FCSP implementation in China. However, it's noteworthy that the current and potential barriers of the FCSP remained poorly studied, which limits both the understanding of why these barriers occur and how to evaluate their influences on the projects' future existence. On this basis, we aim to offer a brand-new research perspective for FCSP implementation and FCS development in China by identifying the underlying barriers and evaluating the comprehensive barrier levels faced by alternative FCSPs.

2.2. Barrier evaluation with MCDM

Barrier analysis has been widely investigated in different fields to clearly state the obstacles and challenges for facilitating the implementation of certain systems regarding their characteristics and prioritizations. Deely et al. (2020) identified the main barriers of blue and green infrastructures regarding institutional and governance, socio-cultural, knowledge, technical and biophysical, funding & market aspects of factors. Alattas and Wu (2022) proposed a barrier evaluation framework for applying the e-health Internet of Medical Things and identified the cost, technology infrastructure, regulations and policies, security and privacy, and data management barriers using a literature review. Buga and Yousif (2021) assessed the barriers to adopting Malta's local energy policy for reducing CO2 emission and energy consumption, wherein economic barriers, institutional barriers, informational barriers, and political/cultural barriers were considered. Barragán-Escandón, Jara-Nieves, Romero-Fajardo, Zalamea-Leon, and Serrano-Guerrero (2022) took Ecuador as the case to analyze the main barriers to renewable energy expansion. Galik, Benedum, Kauffman, and Becker (2021) investigated stakeholders' experience of forest bioenergy systems in the U.S. and analyze the present-day barriers to sustainable development. A detailed study of an FCSP practice and perceived barriers investigation is required to better understand these barrier factors (Trianni, Cagno, Worrell, & Pugliese, 2013), and it is observed in the literature that literature reviews and surveying/interviewing with related experts are widely used to determine the critical barriers in the majority of barrier analysis-related studies.

In the literature, some state-of-the-art intelligent algorithms have the potential to deal with ranking problems, such as neural matrix factorization (Zheng & Wang, 2022), which is one of deep learning-based models, data-driven support vector regression (Cheng et al., 2020), great deluge algorithm (Hong et al., 2019), and particle swarm optimization (Javanbarg, Scawthorn, Kiyono, & Shahbodaghkhan, 2012). These kinds of mathematical models exhibit certain clarity with ability to self-organize, self-learn, and respond quickly, but there exist difficulties for multiple participants of the FCSP in reading and translating such models, let alone conducting meaningful and instructive analysis or evaluation. The barrier evaluation of FCSP involves factors characterized by multiple attributes, such as forest management technologies of the forestry enterprises, encouraging policies of local government, regulations and mechanisms of the carbon market, etc., thus it's a typical MCDM problem. For such a governmental and societal decision-making problem with uncertainty and complexity, the selected methodologies should be understood and operated easily and acceptable by decision makers (various antagonistic and independent stakeholders), who concerns more about the interpretability and the descriptive information delivered instead of advanced mathematical models. Recognizing the extensive and diverse decision-making processes and application scenarios, some simplistic MCDM methods should be primary tools for providing common understandings and findings (French, 2023).

There are a series of MCDM approaches in the literature that can be applied to solve MCDM problems, including TOPSIS, VIKOR, ELECTRE, AHP, DEMATEL, etc. Since various MCDM methods have their advantages and drawbacks, it's probably a good choice to combine one MCDM method with other techniques, such as fuzzy set theory, to fulfill the requirements of barrier evaluation in practice. Tu, Wang, Zhou, Shen, and Lev (2021) integrated the DEMATEL and the VIKOR methods considering fuzzy linguistic terms for water resource coordination. Zhao, Li, Wang, and Yuan (2020) put forward a comprehensive evaluation model with the use of the cloud model, entropy method, and TOPSIS to assess the electric power development in 11 countries. Kheybari et al. (2021) tried to select the optimal site for corn cultivation using BWM and an extended PROMETHEE II.

In regard to MCDM in barrier evaluation, researchers have made contributions in different fields. Alattas and Wu (2022) proposed a barrier evaluation framework wherein an extended generalized TODIM method was used to assess the most important barriers in the context of the hesitant fuzzy environment. Chen, Faibil, and Agyemang (2020) combined a BWM approach with a fuzzy TOPSIS method for ranking critical barriers and selecting the optimal solution for an e-waste formalization management system. Kumar and Dixit (2018) adopted a DEMATEL-based framework to evaluate the barriers to waste of electrical and electronic equipment management implementation. Amiri et al. (2022) contributed to evaluating circle supply chains' barriers by proposing an MCDM approach using BWM and rough set theory. Nevertheless, there is no existing literature that considers the application of the MCDM technique in evaluating the barriers of FCSPs and ranking the alternative FCSPs, to the best of our knowledge.

As one of the most popular MCDM approaches, PROMETHEE has found its applications in site selection (Kheybari et al., 2021; Sang, Yu, Chang, & Liu, 2022; Wu, Zhang, Wu, Zhang, & Liu, 2019), sustainability evaluation (Sotiropoulou & Vavatsikos, 2021) and other fields. Compared with other MCDM techniques, PROMETHEE shows advantages in reflecting the properties of different dimensions of attributes and doesn't ask for processing raw information loss (Wu et al., 2020b). In fields related to evaluation/assessment problems considering multiple criteria, PROMETHEE has been proven to be simple, clear, and stable (Makan & Fadili, 2020). Different from classic PROMETHEE I which offers partial ranking order of alternative solutions, PROMETHEE II provides a complete ranking order for better analyzing the evaluation results (Yatsalo, Korobov, Öztayşi, Kahraman, & Martínez, 2021). Yusuf et al. (2022) used a PROMETHEE II-based method to evaluate the environmental and health effects of plastic waste. Tong, Wang, and Pu (2022) constructed a sustainable supplier selection model for SMEs with the help of PROMETHEE II. When faced with alternatives with various factors, PROMETHEE II is believed to be a superior approach for achieving the optimal solution from limited alternatives (Abedi, Ali Torabi, Norouzi, Hamzeh, & Elyasi, 2012).

Integrating a PROMETHEE II with the fuzzy set theory helps to reflect the ambiguity and uncertainty that occurred in decision-making procedures and enhance the reliability of the evaluation results. Tong, Pu, Chen, and Yi (2020) proposed an extended fuzzy PROMETHEE II approach for supplier performance evaluation, wherein fuzzy information is converted into crisp numbers. Narayanamoorthy et al. (2022) adopted a combination of fuzzy set theory and PROMETHEE II to consider the preferences of DMs and solve the MCDM issue concerning plastic waste management. Among different specific fuzzy-related methods, IT2FSs allow to formulate more accurate evaluation results as a common alternative to process linguistic variables and terms. Meanwhile, IT2FSs are easy-to-implement and make decision maker's judgments flexible and manageable without weakening the accuracy and the objectivity of their opinions (Tavana et al., 2022). Thus, we introduce IT2FSs for dealing with DM's opinions and judgments.

Criteria weighting is one important procedure in a typical MCDM problem. Since decision-making problems in the real world are always inconsistent, an appropriate method is required to handle this kind of inconsistency efficiently with few evaluations (Lahri et al., 2021). As a result, the application of BWM in criteria calculation has been investigated in solving various MCDM problems, including supplier selection (Celik, Yucesan, & Gul, 2021; Gupta & Barua, 2017; Oroojeni Mohammad Javad, 2020), performance evaluation (Dwivedi et al., 2021), barriers evaluation (Chen et al., 2020), etc. The paper uses the BWM method for weight calculation because the introduction of BWM can simplify the data collection and processing and obtain reliable weight determination results with high consistency performance (Tong et al., 2020). Therefore, an integrated BWM-IT2F-PROMETHEE II method is proposed for constructing the barrier evaluation framework for FCSP implementation.

2.3. Critical barriers of FCSP

Barriers will get in the way of green practices and its development, including barriers from economic, motivational, and many other aspects (Gomes da Silva & Gouveia, 2020). Although FCSP shows outstanding potential in carbon reduction and forestry development, it's still at an immature stage of practical and theoretical exploration in China, it's of great significance to identify the critical barriers and fully describe the characteristics of the FCSP. The implementation of FCSP involves a variety of political, economic, social, and technical factors and several cooperation subjects, difficulties and uncertainties such as lack of clear leadership and policies, poor project operation capacity, absence of cooperation mechanism among participants, and other barriers might occur occasionally. By presenting the barriers an FCSP might encounter, it allows the DMs to foresee various obstacles and challenges the project may face during its implementation life cycle.

Motivated by the research question "What barriers can impact the implementation of FCSP", a systematic literature review is conducted to identify these barriers, and some studies were deemed appropriate for the present paper to investigate the barriers from different dimensions. In this part, 16 critical barriers are identified and categorized into 5 barrier dimensions as follows: i) Institutional and governance barriers; ii) Management barriers; iii) Economic and market barriers; iv) Knowledge barriers, and v) Technical and infrastructure barriers. The critical barriers are divided into several dimensions according to the differences among them. Institutional and governance barriers occur due to poor governance subjects and the absence of FCSP development-related policies, including top-level system design and supporting legislation or regulation. Management barriers originate from inadequate forest management and project operation experiences on FCSP and the interagency cooperation problems of multiple participants. FCSP implementation may also be hindered by economic and market barriers that affect the product and service supply and trading, such as the market construction of CCER. Meanwhile, the absence of knowledge on FCSP and FCS like inadequacy of relative project development experience can also make DMs find inhibited. Last but not the least, technical and infrastructure barriers like project design challenges, a lack of skills in high-quality forest cultivation, afforestation and reforestation, and a lack of related infrastructure construct. Here, both the FCSP-related papers and the barrier analysis-related papers are reviewed to comprehensively identify barrier items. Table 1 presents the most critical barriers to FCSP implementation from the literature.

3. Methodology

Barrier evaluation of the alternative FCSPs is essential to make better decisions. However, it's also a challenging step since DMs need to select the optimal alternative when facing conflicting and complicated requirements. We propose a barrier evaluation framework to address the underlying research questions of FCSP implementation with an integrated BWM-IT2F-PROMETHEE II method (see Fig. 2). The barrier evaluation framework is described as follows:

Phrase 1: problem formulation. A research problem formulation is necessary before applying the barrier evaluation framework, including defining the alternative FCSPs set of i alternatives $A = \{A_1, A_2, \cdots, A_m\}$, determining the barrier criteria set of j sub-criteria $C_j = \{C_1, C_2, \cdots, C_n\}$ and the criteria weight set $W_j = \{w_1, w_2, \cdots, w_j\}$. Assume that p experts are invited to evaluate the barrier levels and set the expert set as $E = [E_1, E_2, \cdots, E_p]$. Further define the decide matrix of *k-th* expert as $X_k = [x_{ij}^k]_{m \times n}$, wherein x_{ij}^k is the barrier level of alternative A_i regarding criterion C_j from the perspective of the *k-th* expert. The experts are required to provide judgments and opinions to evaluate the barrier level of alternative FCSPs and determine the criteria significance with linguistic terms based on their knowledge and experience.

Phrase 2: criteria weighting with the BWM. In the literature review section, 5 dimensions of criteria and 16 sub-criteria are determined, and they are used to construct the barrier evaluation criteria system. After that, the BWM technique is adopted to determine the significance weights of various barriers combined with field experts' opinions.

Phrase 3: data processing with IT2FSs. Since fuzziness and ambiguity are inevitable in the barrier evaluation of FCSP, IT2FSs are used to deal with linguistic variables provided by field experts in describing the barriers and sub-barriers encountered by different alternative FCSPs.

Phrase 4: ranking alternative FCSPs with PROMETHEE II. Based on step 3, the integrated IT2F-PROMETHEE II method is constructed and applied to comprehensively assess the overall barrier levels of alternative FCSPs.

Phrase 5: conducting comparative and sensitivity analysis. To further discuss the proposed framework and the barriers encountered by FCSPs, a comparative analysis and a sensitivity analysis are launched to prove the robustness and feasibility of the proposed barrier evaluation

Table 1
Critical barriers of FCSP implement.

Barriers	Sub-barriers	References									
		Peterson St-Laurent, Hagerman, and Hoberg (2017)	Deely et al. (2020)	Kaviani et al. (2020)	Diao, Liu, Zhu, Wei, and Li (2022)	Lin and Ge (2020)	Aggarwal (2020)	Smith, Wilson, and Hassall (2022)	Barragán-Escandón et al. (2022)	Chen et al. (2020)	Kumar and Dixit (2018)
Institutional and governance barriers (B1)	Lack of clear leadership and policies (C1)	√	√	√	√				√	√	√
	Legislation & regulation (C2)		√	√			√	√	√	√	√
	Insufficient public and stakeholder engagement (C3)	√					√		√		√
	Competing priorities (C4)		√				√		√		
Management barriers (B2)	Forest management performance (C5)	√			√	√					
	Interagency & interinstitutional cooperation (C6)		√	√		√	√		√		√
	Low emphasis comparing to other barriers (C7)			√		√			√		
Economic and market barriers (B3)	Limited economic benefits (C8)	√				√		√	√	√	
	Insufficient funding (C9)		√	√						√	√
	Difficulties with undeveloped market (C10)			√				√			
Knowledge barriers (B4)	Lack of general knowledge (C11)		√	√				√	√	√	√
	Absence of past experiences (C12)		√	√				√			√
	Obstacles with immature industry (C13)			√							
Technical and infrastructure barriers (B5)	Design, construction and maintenance challenges (C14)		√		√			√	√		
	Lack of newest technologies, protocols and standards (C15)		√	√	√			√	√		√
	Lack of related infrastructure (C16)			√					√	√	√

framework of FCSP.

In this section, the integrated BWM-IT2F-PROMETHEE II method is briefly described, including the BWM, the IT2FSs, and the PROMETHEE II method, which are illustrated in the following sub-sections.

3.1. Criteria weighting with the BWM

The BWM was put forward by Rezaei (2015) as an efficient MCDM technique for criteria weight determination, and it has proven to be applicable and feasible in scenarios where the aim is to make decisions among multiple alternatives, taking into account experts' preferences (Dwivedi et al., 2021). Compared with traditional pairwise comparison-based methods, such as AHP, BWM addresses the inconsistency issue and demonstrates exceptional performance in arriving at more reliable, stable, and consistent solutions, requiring fewer and simpler pairwise comparisons and computations (Kaviani et al., 2020; Paul, Chakraborty, & Chakraborty, 2022). Considering the advantages of BWM, it has been adaptively integrated with other MCDM approaches to derive criteria weights, thus a wide range of BWM-based applications have been found, such as barrier evaluation (Chen et al., 2020), supplier selection (Wei & Zhou, 2022), and technology selection (Torkayesh, Malmir, & Rajabi Asadabadi, 2021).

On the basis of the criteria system, BWM measures the criteria weights by conducting systematic pairwise comparisons among the identified criteria. Firstly, the ideal (best) and the anti-ideal (worst) criteria are selected as the benchmarks by the experts or DMs, wherein the ideal (best) criterion is considered the most influential factor in making decisions, while the anti-ideal (worst) criterion is deemed the least important. Secondly, a pre-determined scale of 1 to 9 is applied and the significance of all the other criteria is compared against the benchmarks with pairwise comparisons, which encompass experts' or DMs' preferences of the ideal (best) criterion over the remaining criteria and preferences of all other criteria over the anti-ideal (worst) criterion (Ishizaka & Resce, 2021). This process results in the best-to-others

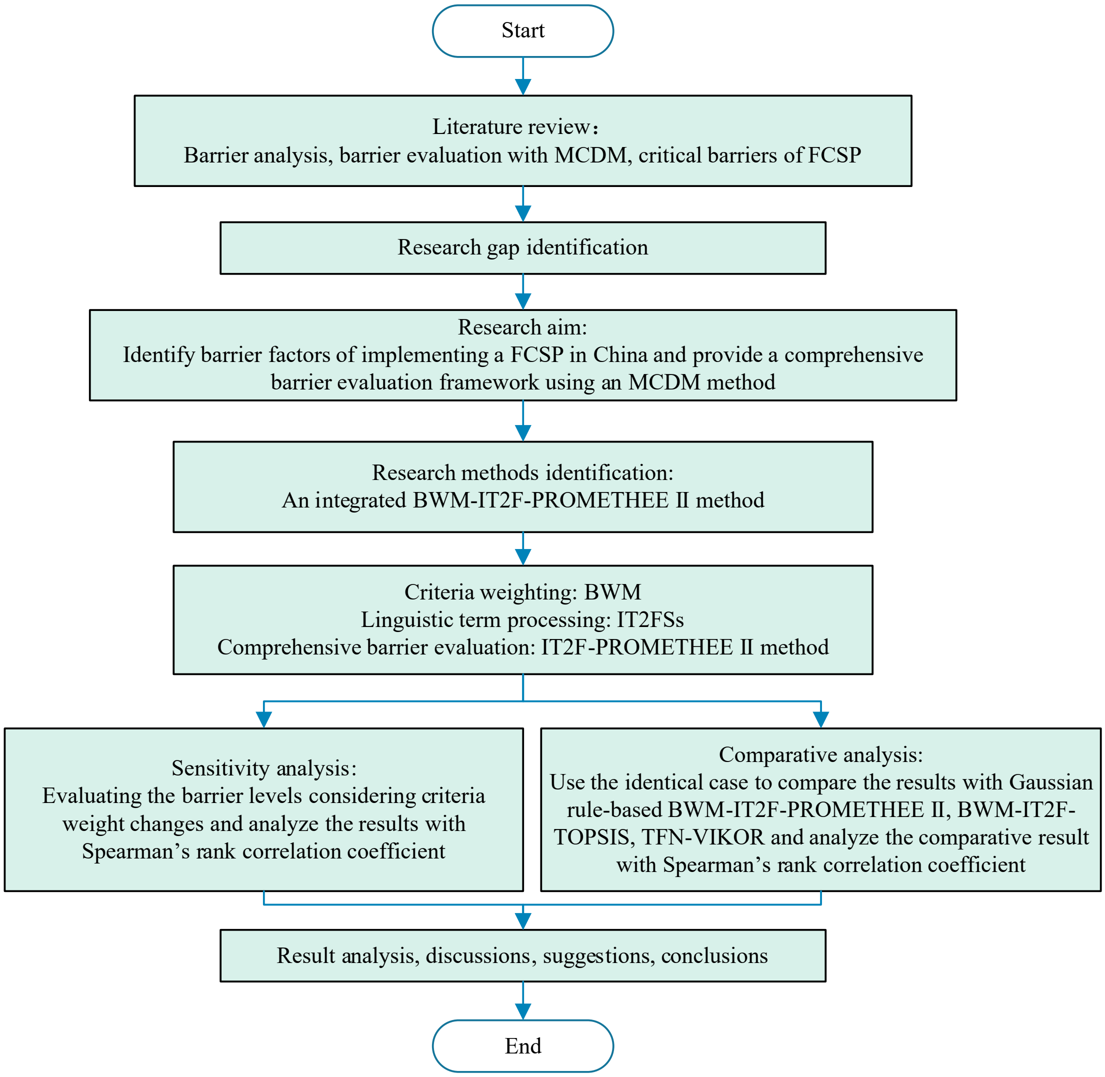

Fig. 2. Flowchart of the methodology.

judgment matrix (V_B) and others-to-worst judgment matrix (V_W). In the third step, take the judgment matrices V_B and V_W as the inputs of a linear programming function, which is an optimization problem, and then the criteria weighting results are obtained once the problem is solved. The computation of determining criteria weights with the BWM consists of the following steps.

Step 1: Construct judgment matrix on criteria significance. A criteria set $C_j = \{C_1, C_2, \cdots, C_n\}$ is identified for making decisions. After extensive analysis and discussion, the experts reached a consensus on the ideal (best) and the anti-ideal (worst) criteria among main criteria and sub-criteria, thus the ideal (best) and the anti-ideal (worst) criteria *VB* and *VW* are determined.

Step 2: Determine the preference of the ideal (best) criterion over other criteria to obtain the best-to-others judgment matrix V_B with a predetermined scale from 1 to 9, where a score of 1 represents an equal significance between the criterion and the another while a score of 9 means an extreme preference (Dwivedi et al., 2021). Similarly, determine the others-to-worst judgment matrix V_W by determining the preference of other criteria against the anti-ideal (worst) criterion. Thus, the best-to-others judgment matrix V_B and the others-to-worst judgment matrix V_W are created (Kaviani et al., 2020):

$$V_B = (v_{B1}, v_{B2}, \cdots, v_{Bn}) \tag{1}$$

$$V_W = (v_{1W}, v_{2W}, \cdots, v_{nW})^T \tag{2}$$

Where, v_{Bj} and v_{jW} are respectively the preference of the ideal (best) criterion *VB* over criterion *j* and the preference of the criterion over the anti-ideal (worst) criterion *VW*. v_{Bj} is an integer variable and $v_{Bj} \in (1, 2, \cdots, 9)$, v_{jW} is an integer variable and $v_{jW} \in (1, 2, \cdots, 9)$. Additionally, $v_{BB} = 1$ and $v_{WW} = 1$.

Step 3: Find the optimal weights. The optimal criteria weights $W = (w_1^*, w_2^*, \cdots, w_n^*)$ should meet the following requirements, namely $w_B/w_j = v_{Bj}$ and $w_j/w_W = v_{jW}$ for each pair of w_B/w_j and w_j/w_W (Rezaei, 2015). Find the solution μ^* that satisfies Eqs. (3) to (5):

$$\min \mu^* \tag{3}$$

$$\mu^* = \max_j \left\{ \left| \frac{w_B}{w_j} - v_{Bj} \right|, \left| \frac{w_j}{w_W} - v_{jW} \right| \right\} \tag{4}$$

$$s.t. \sum_{j=1}^{n} w_j = 1, \quad w_j \geqslant 0 \ for\ all\ j \tag{5}$$

Convert Eqs. (3) and (4) into linear programming functions to drive the criteria weights *W* and obtain the solution μ^*. Subsequently, obtain the consistency ratio *CR* with Equation (6):

$$CR = \mu^*/CI \tag{6}$$

Where *CI* is the consistency index (see details in reference (Rezaei, 2015)).

Step 4: Discuss the consistency of BWM-based weight coefficients. Usually, the magnitude of *CR* illustrates the consistency level, and the closer *CR* value to zero represents higher consistency of the weight coefficients (Hafezalkotob & Hafezalkotob, 2017; Kaviani et al., 2020; Rezaei, 2015).

3.2. Data processing with IT2FSs

When giving judgments or preference on barriers encountered by FCSPs, experts and DMs often use linguistic terms to express their opinions, thus uncertainty and ambiguity occur and proper data processing is crucial for further evaluation. Among methods for dealing with this kind of situation, IT2FSs-based theory has wide applications and its advantages have been proved, such as modeling convenience and outstanding capability in quantifying ambiguity. Basic definitions and operation theories of IT2FSs are briefly described in this section (Hong, Pasman, Quddus, & Mannan, 2020; Liu, Wang, Yin, Li, & Lu, 2020; Tavana et al., 2022; Yi et al., 2021).

Definition 1. *Set $\widetilde{\widetilde{A}}$ as an IT2FS in universe X and let $\widetilde{\widetilde{A}}_i = [\widetilde{A}_i^U, \widetilde{A}_i^L]$, $\widetilde{A}$ is characterized with Equation (7)*:

$$\widetilde{A}_i = [\widetilde{A}_i^U, \widetilde{A}_i^L] = \begin{bmatrix} \left(a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U; H_1(\widetilde{A}_i^U), H_2(\widetilde{A}_i^U)\right), \\ \left(a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L; H_1(\widetilde{A}_i^L), H_2(\widetilde{A}_i^L)\right) \end{bmatrix} \tag{7}$$

Where $\widetilde{A}_i^U$ and $\widetilde{A}_i^L$ are respectively the upper and lower bound membership functions of $\widetilde{A}$ and they are interval type-1 membership functions; the constraints in criteria values are: $\widetilde{A}_i^L \subset \widetilde{A}_i^U$, $a_{i1}^L < a_{i2}^L < a_{i3}^L < a_{i4}^L$, $a_{i1}^U < a_{i2}^U < a_{i3}^U < a_{i4}^U$, $a_{i1}^U < a_{i1}^L$ and $a_{i4}^L < a_{i4}^U$. In the present paper, we use IT2FSs in Table 2 to deal with linguistic variables. According to the research of Klir (1997) and Ngan (2021), the standard fuzzy arithmetic requires no known constraints when dealing with linguistic variables, and the introduction of requisite constraints might lead to incorrect outcomes. Therefore, the expert opinions are asked to provide using the linguistic terms in Table 2, and then standard fuzzy arithmetic is applied.Tables 3a and 3b.

Definition 2. *The arithmetic operations among the IT2FS $\widetilde{\widetilde{A}}_1$, the IT2FS $\widetilde{\widetilde{A}}_2$, and a constant k can be illustrated with Equation (8)*:

$$\begin{aligned}
\widetilde{\widetilde{A}}_1 \oplus \widetilde{\widetilde{A}}_2 &= \begin{pmatrix} (a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U; \min(H_1(\widetilde{A}_1^U), H_1(\widetilde{A}_2^U)), \min(H_2(\widetilde{A}_1^U), H_2(\widetilde{A}_2^U))), \\ (a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L; \min(H_1(\widetilde{A}_1^L), H_1(\widetilde{A}_2^L)), \min(H_2(\widetilde{A}_1^L), H_2(\widetilde{A}_2^L))) \end{pmatrix}; \\
\widetilde{\widetilde{A}}_1 \otimes \widetilde{\widetilde{A}}_2 &= \begin{pmatrix} (a_{11}^U * a_{21}^U, a_{12}^U * a_{22}^U, a_{13}^U * a_{23}^U, a_{14}^U * a_{24}^U; \min(H_1(\widetilde{A}_1^U), H_1(\widetilde{A}_2^U)), \min(H_2(\widetilde{A}_1^U), H_2(\widetilde{A}_2^U))), \\ (a_{11}^L * a_{21}^L, a_{12}^L * a_{22}^L, a_{13}^L * a_{23}^L, a_{14}^L * a_{24}^L; \min(H_1(\widetilde{A}_1^L), H_1(\widetilde{A}_2^L)), \min(H_2(\widetilde{A}_1^L), H_2(\widetilde{A}_2^L))) \end{pmatrix}; \\
k\widetilde{\widetilde{A}}_1 &= \left((ka_{11}^U, ka_{12}^U, ka_{13}^U, ka_{14}^U; H_1(\widetilde{A}_1^U), H_2(\widetilde{A}_1^U)), (ka_{11}^L, ka_{12}^L, ka_{13}^L, ka_{14}^L; H_1(\widetilde{A}_1^L), H_2(\widetilde{A}_1^L))\right); \\
\sqrt[1/k]{\widetilde{\widetilde{A}}_1} &= \left(\left(\sqrt[1/k]{a_{11}^U}, \sqrt[1/k]{a_{12}^U}, \sqrt[1/k]{a_{13}^U}, \sqrt[1/k]{a_{14}^U}; H_1(\widetilde{A}_1^U), H_2(\widetilde{A}_1^U)\right), \sqrt[1/k]{a_{11}^L}, \sqrt[1/k]{a_{12}^L}, \sqrt[1/k]{a_{13}^L}, \sqrt[1/k]{a_{14}^L}; H_1(\widetilde{A}_1^L), H_2(\widetilde{A}_1^L)\right)
\end{aligned} \tag{8}$$

Definition 3. *Set the ranking value of IT2FS $\widetilde{\widetilde{A}}_i$ with $RV(\widetilde{\widetilde{A}}_i)$, and its calculation is as illustrated in Equation (9)* (Cengiz Toklu, 2018).

Table 2
Linguistic terms for evaluation and corresponding IT2FSs (Liu et al., 2020).

Linguistic terms	IT2FSs
Extremely low (EL)	((0,0,0,0.1;1,1), (0,0,0,0.05;0.9,0.9))
Relatively low (RL)	((0,0.1,0.1,0.3;1,1), (0.05,0.1,0.1,0.2;0.9,0.9))
Low (L)	((0.1,0.3,0.3,0.5;1,1), (0.2,0.3,0.3,0.4;0.9,0.9))
Medium (M)	((0.3,0.5,0.5,0.7;1,1), (0.4,0.5,0.5,0.6;0.9,0.9))
High (H)	((0.5,0.7,0.7,0.9;1,1), (0.6,0.7,0.7,0.8;0.9,0.9))
Relatively high (RH)	((0.7,0.9,0.9,1;1,1), (0.8,0.9,0.9,0.95;0.9,0.9))
Extremely high (EH)	((0.9,1,1,1;1,1), (0.95,1,1,1;0.9,0.9))

$$RV(\widetilde{\widetilde{A}}_i) = E_r(\widetilde{A}_i^U) + E_r(\widetilde{A}_i^L) - \frac{1}{4}(SDV) + H_1(\widetilde{A}_i^U) + H_1(\widetilde{A}_i^L) + H_2(\widetilde{A}_i^U) + H_2(\widetilde{A}_i^L) \tag{9}$$

Where $E_r(\widetilde{A}_i^U)$ and $E_r(\widetilde{A}_i^L)$ are the even, *SDV* is the sum of the standard deviation of $SD_r(\widetilde{A}_i^L)$ and $SD_r(\widetilde{A}_i^U)$, $1 \leqslant r \leqslant 3$, and calculate the values with the following equations:

$$E_r(\widetilde{A}_i^t) = \frac{1}{2}\left(a_{is}^t + a_{i(s+1)}^t\right), t \in \{U, L\}, 1 \leqslant s \leqslant 3 \tag{10}$$

$$\begin{aligned}
SDV &= SD_r(\widetilde{A}_i^U) + SD_r(\widetilde{A}_i^L) \\
SD_r(\widetilde{A}_i^t) &= \sqrt{\frac{1}{2}\sum_{k=r}^{r+1}\left(a_{ir}^j - \frac{1}{2}\sum_{k=r}^{r+1} a_{ir}^t\right)^2} \\
SD_4(\widetilde{A}_i^j) &= \sqrt{\frac{1}{4}\sum_{k=1}^{4}\left(a_{ik}^j - \frac{1}{4}\sum_{k=1}^{4} a_{ik}^j\right)^2}
\end{aligned} \tag{11}$$

After an introduction of the alternative FCSPs, we conduct an expert committee evaluation of the alternatives' overall barrier levels on the basis of the criteria system. For better processing the data represented by linguistic terms, the decide matrix can be constructed using the IT2FSs as shown in Table 2 to transform the subjunctive and uncertain descriptive information into acceptable numbers for further evaluation.

3.3. Ranking alternative FCSPs with IT2F-PROMETHEE II

Barrier evaluation of FCSP uses experts' opinions/judgments/preferences to derive the optimal solution, thus a proper knowledge-based method is needed. As one of the most popular knowledge-based MCDM methods, PROMETHEE II uses pair-by-pair comparison analysis regarding a set of criteria to make decisions by offering the full ranking of alternatives. It has been successfully used in different fields for ranking and selecting alternatives regarding a set of conflicting criteria (Abedi et al., 2012).

In our work, experts' evaluation data about alternative FCSPs

Table 3a
Information of the alternative FCSPs.

FCSP	Description	Implement-ation mode	Period	Location
A1	Species: Pinus, Liquidamber, Cunninghamia lanceolata, Formosana, and Eucalyptus; Expected carbon emission reduction magnitude: 25,795 ton/year; Scale: 4,000 hm^2.	CMD	30 years	Guangxi
A2	Specie: Moso bamboo; Expected carbon emission reduction magnitude: a total of 249,658 tons and an average of 8,322 ton/year; Scale: 1,426.27 hm^2.	CCER	30 years	Zhejiang
A3	Species: Pinus, Cunninghamia lanceolata, Eucalyptus, Betula luminifera, Choerospondias axillaris, etc.; Expected carbon emission reduction magnitude: a total of 1,746,158 tons; Scale: 8,671.3 hm^2.	CMD	20 years	Guangxi
A4	Species: Green chloroplast hellebore, Subalpine coniferous forests, etc.; Expected carbon emission reduction magnitude: 6,093 ton/year; Scale: 4,058.4 hm^2.	–	20 years	Shaanxi
A5	Species: Lotus, Liquidambar, Sanduroy, etc.; Expected carbon emission reduction magnitude: a total of 347,000 tons and an average of 17,400 ton/year; Scale: 866.7 hm^2.	CCER	20 years	Guangdong

regarding 5 dimensions of criteria is collected with linguistic terms (as illustrated in Table 2), thus an IT2F-PROMETHEE II method is used, wherein the decision matrix is constructed and processed with IT2FSs and the barrier evaluation results are obtained with the help of PROMETHEE II. The application of IT2F-PROMETHEE II requires two additional data set, i.e., the criteria weights $W = (w_1^*, w_2^*, \cdots, w_n^*)$ and the DM's preference function $PF_j(a,b)$. The procedural steps of applying the IT2F-PROMETHEE II method in ranking the barrier levels of alternative FCSPs are outlined as follows (Athawale, Chatterjee, & Chakraborty, 2012; Ishizaka & Resce, 2021; Yusuf et al., 2022):

Step 1: Data collection and decision matrix construction. Based on the criteria system, experts are asked to evaluate the barrier levels of alternative FCSPs and provide corresponding judgments with linguistic terms in Table 2. Subsequently, process those linguistic variables and construct the decide matrix of *k-th* expert $X_k = [x_{ij}^k]_{m\times n}$, where x_{ij}^k are expressed with IT2FSs. Then, aggregate all experts' decision matrices into the average decision matrix $X = [x_{ij}]_{m\times n}$ with Eq. (12).

$$x_{ij} = \frac{x_{ij}^1 \oplus \cdots \oplus x_{ij}^k \oplus \cdots \oplus x_{ij}^p}{p} \tag{12}$$

Meanwhile, calculate the ranking values of x_{ij} in X with Equations

Table 3b
Significance pairwise comparison result of main-criteria.

Criteria	B1	B2	B3	B4	B5	
Best-to-others	1	2	3	4	3	Best criteria: B1
Others-to-worst	5	4	3	1	3	Worst criteria: B4

(9)-(11) and obtain the decision matrix $Y = [y_{ij}]_{m\times n}$, where y_{ij} is crisp values.

Step 2: Normalize the decision matrix and calculate the weighted normalized decision matrix. Since the critical barrier factors of FCSPs are non-beneficial attributes, use Eq. (13) to normalize the decide matrix Y into the normalized matrix $R_{ij} = [r_{ij}]_{m\times n}$.

$$r_{ij} = \frac{\max(y_{ij}) \text{ - } (y_{ij})}{\max(y_{ij}) \text{ - } \min(y_{ij})} (i = 1, 2, \cdots, m; j = 1, 2, \cdots, n) \tag{13}$$

Step 3: Determine the barrier level differences and the preference function. Define the barrier level difference between alternatives A_i and $\widetilde{\widetilde{A}}_i$ as $d_j(A_i, \widetilde{\widetilde{A}}_i)$ with respect to the j - th criterion, and $d_j(A_i, \widetilde{\widetilde{A}}_i) = r_{A_ij} - r_{\widetilde{\widetilde{A}}_ij}$. Define the preference function with $P_j(A_i, \widetilde{\widetilde{A}}_i), P_j(A_i, \widetilde{\widetilde{A}}_i) \in [0,1]$. Noteworthily, the value of $P_j(A_i, \widetilde{\widetilde{A}}_i)$ represents the expert's preference of the i - th alternative over the $\widetilde{i}$ - th alternative with respect to the j - th criterion. The preference function can be obtained with Eq. (14) (Yusuf et al., 2022).

$$P_j(A_i, \widetilde{\widetilde{A}}_i) = \begin{cases} 0, if \ d_j(A_i, \widetilde{\widetilde{A}}_i) \leqslant 0 \\ r_{A_ij} - r_{\widetilde{\widetilde{A}}_ij}, if \ d_j(A_i, \widetilde{\widetilde{A}}_i) > 0 \end{cases} \forall A_i, \widetilde{\widetilde{A}}_i \in A \tag{14}$$

Step 4: Calculate the aggregated preference indices $\lambda_j(A_i, \widetilde{\widetilde{A}}_i)$ of each pair of alternatives and the overall aggregated preference indices $\xi(A_i, \widetilde{\widetilde{A}}_i)$ with the following Eqs. (15) and (16).

$$\lambda_j(A_i, \widetilde{\widetilde{A}}_i) = P_j(A_i, \widetilde{\widetilde{A}}_i) w_j \tag{15}$$

$$\xi(A_i, \widetilde{\widetilde{A}}_i) = \sum_{j=1}^{n} \lambda_j(A_i, \widetilde{\widetilde{A}}_i) \tag{16}$$

Step 5: For each alternative A_i, determine the positive and negative outranking flows $\phi^+(A_i)$ and $\phi^-(A_i)$ with Eqs. (17) and (18). It's noteworthy that outranking flows represent the overall outranking degrees of corresponding alternatives, $\phi^+(A_i)$ illustrates how much the alternative A_i dominants the others while $\phi^-(A_i)$ explains how much other alternatives dominate A_i.

$$\phi^+(A_i) = \frac{\sum_{x\in A} \xi(A_i, x)}{m-1}, A_i \neq x \tag{17}$$

$$\phi^-(A_i) = \frac{\sum_{x\in A} \xi(x, A_i)}{m-1}, A_i \neq x \tag{18}$$

Step 6: Calculate the net ranking flow. For each A_i, use the following equation to obtain its net ranking flow, which is adopted to provide the final ranking orders of barrier levels of alternative FCSPs, and the larger net ranking flow value means a better solution.

$$\phi(A_i) = \phi^+(A_i) \text{ - } \phi^-(A_i) \tag{19}$$

4. Application in FCSP

China owns abundant forest resources but the geographical environment among different regions is complex and different. Under the pressure of carbon neutrality and the strong support of national and local governments, more and more enterprises, organizations, and other relative subjects have shown their attention to participate in the FCSP. In this section, a case study is used to determine the barrier levels of alternative FCSPs A1, A2, A3, A4, A5 and discuss the robustness and feasibility of the framework, and the details of the alternative FCSPs are listed in Table 3. All of the alternatives are put forward by the local governments, and their implementation and management are conducted in the cooperation mode of FCSP. To make efficient decisions, barrier evaluation of alternative FCSPs has become an urgent and practical issue. Therefore, we try to apply the proposed framework in evaluating the barrier levels of alternatives with the help of the integrated BWM-IT2F-PROMETHEE II method.

4.1. Results

We set up an expert group to identify the significance of the criteria and collect experts' evaluation judgments on the alternatives. As a result, professor E_1 who has outstanding academic achievements in the forestry field, a project manager E_2 from an investment enterprise, and an officer E_3 from the forestry department, are invited to make judgments on alternatives' barrier situations with linguistic terms in Table 2. After discussion and comprehensive analysis, the experts provide their opinions on criteria significance and barrier evaluation results. Based on the proposed barrier evaluation framework for FCSP implementation in this work, the alternative FCSP with the lowest barrier level is selected as the optimal solution. The application steps are illustrated as follows.

Step 1: Criteria weighing with the BWM.

Criteria weight determination is carried out by calculating the global weights of main criteria and the local weights of sub-criteria of all criteria dimensions, the final weights of all sub-criteria are obtained with Eq. (20) (Dwivedi et al., 2021):

$$Finalweightofsub-criterion = Globalweightofmaincriterion \times Localweightofsub-criterion \quad (20)$$

To better determine the criteria weights, several steps are necessary to fully aggregate the experts' opinions: 1) Gather experts and engage them to conduct a comprehensive discussion about main criteria and sub-criteria, as well as criteria's potential influences on FCSP implementation in China. Based on literature review about barrier analysis of FCSP, the experts reached a consensus on the ideal (best) and the anti-ideal (worst) criteria; 2) The experts conduct another discussion about the relative importance of the remaining main criteria and sub-criteria within the same criteria dimension on this basis of the ideal (best) and the anti-ideal (worst) criteria, and the experts should aim to reach a consensus on the relative significance of the criteria; 3) Based on the valued opinions from the previous discussions, select one expert to represent the group's consensus and this expert is responsible for launching the significance pairwise comparisons with a pre-determined scale from 1 to 9. 4) The best-to-others judgment matrices and the others-to-worst judgment matrices were built accordingly, and these matrices will help quantify the relative importance of each criterion. As a result, experts' opinions about the relative significance of all the criteria are aggregated, ensuring a more informed and reliable decision-making process.

(1) Global weights of main criteria.

Among all the main criteria, institutional and governance barriers (B1) is selected as the ideal (best) criterion and knowledge barriers (B4) is identified as the anti-ideal (worst) criterion. The comparison results of criteria significance comparison of main criteria are shown in Table 3.

Subsequently, the best-to-others judgment matrix V_B and the others-to-worst judgment matrix V_W are created accordingly, wherein v_{B1} and v_{W4} denote the best and the worst criteria respectively.

$$V_B = (1, 2, 3, 4, 3); \quad V_W = (5, 4, 3, 1, 3)^T$$

Following the implementation steps discussed in Section 3.1, construct the corresponding optimization problem and use MATLAB software to solve the following linear programming functions to produce the global weights of the main criteria.

$$\min \mu^*$$

$$\mu^* = \max_j \left\{ \left| \frac{w_1}{w_j} - v_{1j} \right|, \left| \frac{w_j}{w_4} - v_{j4} \right| \right\}$$

$$s.t. \sum_{j=1}^{5} w_j = 1$$

$$w_j \geqslant 0, \forall j = 1, 2, \cdots, 5$$

The derived optimal weights of main criteria are 0.3592 (B1), 0.2384 (B2), 0.1637 (B3), 0.0747 (B4), 0.1639 (B5), respectively. Institutional and governance barriers (B1) are believed the most significant factor in assessing the barrier level of an FCSP since this kind of project is developed and promoted by related institutional and governance subjects. Management barriers (B2) are considered important factor in describing the obstacles to FCSP implementation since it involves not only complicated forest and project management but also internal and external economic and market challenges. The DMs might pay attention to technical and infrastructure barriers (B5) and economic and market barriers (B3) considering that the newest technologies, protocols and standards required for successful project implementation are still immature in the domestic industry. Meanwhile, knowledge barriers (B4) cannot be ignored, a lack of general knowledge and past experience in an undeveloped market will lead to a series of unexpected problems.

(2) Local weights of sub-criteria.

Significance pairwise comparison result of institutional and governance barriers (B1) is shown in Table 4, wherein criteria C1 and C4 are respectively identified as the ideal (best) and anti-ideal (worst) criteria. Following the computations steps of the BWM, the local weights are obtained: 0.5182 (C1), 0.2715 (C2), 0.1496 (C3), 0.060 (C4). On the basis of the global weight of main criteria B1, solve Eq. (20) to obtain the final weights of sub-criteria under B1, i.e., 0.1862 (C1), 0.0975 (C2), 0.0537 (C3), 0.0218 (C4).

The significance pairwise comparisons of sub-criteria under the dimensions of management barriers (B2), economic and market barriers (B3), knowledge barriers (B4) are shown in Tables 5-7, wherein the ideal (best) and anti-ideal (worst) criteria are identified by the expert. Table 8.

According to comparison results, best-to-others judgment matrix V_B and the others-to-worst judgment matrix V_W are constructed (see Table 9). According to Table 9, the best criteria under main criteria are: v_{B1} (B1), v_{B1} (B2), v_{B1} (B3), v_{B3} (B4), v_{B2} (B5), the worst criteria under main criteria are: v_{W4} (B1), v_{W3} (B2), v_{W2} (B3), v_{W2} (B4), v_{W3} (B5).

Similarly, construct the corresponding optimization problems under different main criteria dimensions and use MATLAB to solve the following linear programming functions to produce all sub-criteria's local weight coefficients:

$$\min \mu^*$$

$$sub-criteriaunderB1: \mu^* = \max_j \left\{ \left| \frac{w_1}{w_j} - v_{1j} \right|, \left| \frac{w_j}{w_4} - v_{j4} \right| \right\}, \sum_{j=1}^{4} w_j = 1, w_j \geqslant 0, \forall j = 1, 2, 3, 4$$

$$sub-criteriaunderB2: \mu^* = \max_j \left\{ \left| \frac{w_1}{w_j} - v_{1j} \right|, \left| \frac{w_j}{w_3} - v_{j3} \right| \right\}, \sum_{j=1}^{3} w_j = 1, w_j \geqslant 0, \forall j = 1, 2, 3$$

Table 4
Significance pairwise comparison result of institutional and governance barriers (B1).

Criteria	C1	C2	C3	C4	
Best-to-others	1	2	5	7	Best criteria: C1
Others-to-worst	8	6	4	1	Worst criteria: C4

Table 5
Significance pairwise comparison result of management barriers (B2).

Criteria	C5	C6	C7	
Best-to-others	1	5	8	Best criteria: C5
Others-to-worst	7	4	1	Worst criteria: C7

Table 6
Significance pairwise comparison result of economic and market barriers (B3).

Criteria	C8	C9	C10	
Best-to-others	1	7	4	Best criteria: C8
Others-to-worst	6	1	5	Worst criteria: C9

Table 7
Significance pairwise comparison result of knowledge barriers (B4).

Criteria	C11	C12	C13	
Best-to-others	2	4	1	Best criteria: C13
Others-to-worst	2	1	3	Worst criteria: C12

$$sub-criteriaunderB3 : \mu^* = \max_j \left\{ \left| \frac{w_1}{w_j} - v_{1j} \right|, \left| \frac{w_j}{w_2} - v_{j2} \right| \right\}, \sum_{j=1}^{3} w_j = 1, w_j \geqslant 0 \ , \forall j = 1,2,3$$

$$sub-criteriaunderB4 : \mu^* = \max_j \left\{ \left| \frac{w_3}{w_j} - v_{3j} \right|, \left| \frac{w_j}{w_2} - v_{j2} \right| \right\}, \sum_{j=1}^{3} w_j = 1, w_j \geqslant 0 \ , \forall j = 1,2,3$$

$$sub-criteriaunderB5 : \mu^* = \max_j \left\{ \left| \frac{w_2}{w_j} - v_{2j} \right|, \left| \frac{w_j}{w_3} - v_{j3} \right| \right\}, \sum_{j=1}^{3} w_j = 1, w_j \geqslant 0 \ , \forall j = 1,2,3$$

The derived optimal local weights of sub-criteria are shown in Table 10. Meanwhile, use Eq. (20) to compute the final weights of all sub-criteria, as Table 10 illustrates.

Step 2: Evaluation information collection and decision matrix construction. According to the criteria system, experts comprehensively evaluate the overall barriers encountered by all alternative FCSPs and provide their evaluation information using linguistic scales (see Table 11). Tables 12a and 12b.

Transform all of the linguistic variables from individual expert's evaluation information into IT2FSs. For example, the evaluation information of alternative A1 concerning sub-criteria C1 received by the expert E1 is the linguistic term "RL", transform the linguistic terms into an IT2FS based on Table 2, i.e.:

$$x_{11}^1 = [x_{11}^{1L}, x_{11}^{1U}] = \left[\begin{array}{c} (0, 0.1, 0.1, 0.3; 1, 1), \\ (0.05, 0.1, 0.1, 0.2; 0.9, 0.9) \end{array} \right]$$

Step 3: Aggregation of the decision matrices and formation of the normalized matrix. Aggregate all experts' decision matrices into the average decision matrix $X = [x_{ij}]_{5\times16} (1 \leqslant i \leqslant 5, 1 \leqslant j \leqslant 16)$ with Equation (12). Such as:

$$x_{11} = \frac{x_{11}^1 \oplus x_{11}^2 \oplus x_{11}^3}{3} = \left[\begin{array}{c} (0.03, 0.13, 0.13, 0.30; 1, 1), \\ (0.08, 0.13, 0.13, 0.22; 0.9, 0.9) \end{array} \right]$$

Where,

$$x_{11}^1 = \left[\begin{array}{c} (0, 0.1, 0.1, 0.3; 1, 1), \\ (0.05, 0.1, 0.1, 0.2; 0.9, 0.9) \end{array} \right], x_{11}^2 = \left[\begin{array}{c} (0.1, 0.3, 0.3, 0.5; 1, 1), \\ (0.2, 0.3, 0.3, 0.4; 0.9, 0.9) \end{array} \right], x_{11}^3 = \left[\begin{array}{c} (0, 0, 0, 0.1; 1, 1), \\ (0, 0, 0, 0.05; 0.9, 0.9) \end{array} \right]$$

Table 8
Significance pairwise comparison result of technical and infrastructure barriers (B5).

Criteria	C14	C15	C16	
Best-to-others	6	1	9	Best criteria: C15
Others-to-worst	7	9	1	Worst criteria: C16

Table 9
Judgment matrix.

Criteria dimension	V_B	V_W
B1	(1,2,5,7)	$(8,6,4,1)^T$
B2	(1,5,8)	$(7,4,1)^T$
B3	(1,7,5)	$(6,1,5)^T$
B4	(2,4,1)	$(2,1,3)^T$
B5	(6,1,9)	$(7,9,1)^T$

Calculate the corresponding ranking values with Equations (9)-(11). For example, the ranking value of x_{11} is obtained following the computations:

Table 10
Criteria weights and significance ranking result.

Criteria	Sub-criteria	Global weight	Local weight	Final weight	Rank
Institutional and governance barriers (B1)	Lack of clear leadership and policies (C1)	0.3592	0.5182	0.1862	1
	Legislation & regulation (C2)		0.2715	0.0975	5
	Insufficient public and stakeholder engagement (C3)		0.1496	0.0537	6
	Competing priorities (C4)		0.0607	0.0218	12
Management barriers (B2)	Forest management performance (C5)	0.2384	0.7113	0.1696	2
	Interagency & interinstitutional cooperation (C6)		0.2053	0.0490	7
	Low emphasis comparing to other barriers (C7)		0.0833	0.0199	13
Economic and market barriers (B3)	Limited economic benefits (C8)	0.1637	0.6403	0.1048	4
	Insufficient funding (C9)		0.0833	0.0136	14
	Difficulties with undeveloped market (C10)		0.2764	0.0452	8
Knowledge barriers (B4)	Lack of general knowledge (C11)	0.0747	0.3414	0.0255	11
	Absence of past experiences (C12)		0.1463	0.0109	15
	Obstacles with immature industry (C13)		0.5122	0.0383	10
Technical and infrastructure barriers (B5)	Design, construction and maintenance challenges (C14)	0.1639	0.2353	0.0386	9
	Lack of newest technologies, protocols and standards (C15)		0.7059	0.1157	3
	Lack of related infrastructure (C16)		0.0588	0.0096	16

Table 11
Evaluation information of alternative FCSPs.

Criteria	A1			A2			A3			A4			A5		
	E1	E2	E3	E1	E2	E3	E1	E2	E3	E1	E2	E3	E1	E2	E3
C1	RL	L	EL	EL	M	L	M	M	M	H	M	H	L	RL	RL
C2	H	RH	H	RH	H	M	H	RH	M	RH	H	H	L	EL	L
C3	M	RH	H	RL	EL	L	M	EH	H	H	RH	EH	L	EL	RL
C4	L	EL	M	M	M	RL	M	RL	L	M	L	M	EL	L	L
C5	EL	L	RL	RL	M	M	EL	L	RL	H	M	L	EL	EL	RL
C6	H	M	RH	H	H	M	H	RL	H	H	H	H	L	RL	EL
C7	M	L	RL	M	RL	L	M	RL	M	M	M	L	EL	L	EL
C8	EL	EL	RL	RH	H	H	RL	L	L	H	H	M	EL	EL	L
C9	EL	EL	L	H	RH	H	RL	RL	EL	M	M	H	L	EL	RL
C10	RL	L	EL	H	EH	RH	M	H	H	H	EH	H	L	EL	L
C11	L	M	RL	RH	H	M	M	RL	M	H	M	H	EL	L	RL
C12	EL	L	L	M	M	H	L	M	M	H	H	H	L	RL	L
C13	L	RL	L	H	RH	M	M	L	M	M	H	M	M	EL	L
C14	H	M	RH	L	RL	M	RH	M	EH	M	M	M	L	EL	L
C15	RL	L	M	H	M	RH	L	RL	M	M	RH	EH	RL	EL	EL
C16	RL	L	L	M	L	M	RL	L	RL	M	M	H	RL	L	RL

$$RV(x_{11})=E_r(x_{11}^U)+E_r(x_{11}^L)-\frac{1}{4}(SDV)+H_1(x_{11}^U)+H_1(x_{11i}^L)+H_2(x_{11}^U)+H_2(x_{11i}^L)=4.5641$$

$$E_r(x_{11}^U)=\frac{1}{2}(0.03+0.13)+\frac{1}{2}(0.13+0.13)+\frac{1}{2}(0.13+0.30)=0.425$$

$$E_r(x_{11}^L)=\frac{1}{2}(0.08+0.13)+\frac{1}{2}(0.13+0.13)+\frac{1}{2}(0.13+0.22)=0.41$$

$$SDV=SD_1(x_{11}^U)+SD_1(x_{11}^L)+SD_2(x_{11}^U)+SD_2(x_{11}^L)+SD_3(x_{11}^U)+SD_3(x_{11}^L)+SD_4(x_{11}^U)+SD_4(x_{11}^L)$$

$$SD_1(x_{11}^U)=\sqrt{\frac{1}{2}[(0.03-\frac{0.03+0.13}{2})^2+(0.13-\frac{0.03+0.13}{2})^2]}=0.05$$

$$SD_1(x_{11}^L)=\sqrt{\frac{1}{2}[(0.08-\frac{0.08+0.13}{2})^2+(0.13-\frac{0.08+0.13}{2})^2]}=0.025$$

$$SD_2(x_{11}^U)=0,\ SD_2(x_{11}^L)=0,\ SD_3(x_{11}^U)=0.0833,\ SD_3(x_{11}^L)=0.042,\ SD_4(x_{11}^U)=0.0957,\ SD_4(x_{11}^L)=0.048,\ H_1(x_{11}^U)=1,H_1(x_{11}^L)=0.9,H_2(x_{11}^U)=1,\ H_2(x_{11}^L)=0.9$$

Based on the ranking values, use Eq. (13) to get the normalized matrix $R_{ij}=[r_{ij}]_{5\times16}$ (the details are illustrated in Table 12).

Step 4: Compute the barrier level differences and the preference function $P_j(A_i,\widetilde{\widetilde{A}}_i)$ with Eq. (14). As illustrated in Table 12, the difference $d_1(A_1,A_2)=1-0.7176=0.2824$ and the preference function $P_1(A_1,A_2)=d_1(A_1,A_2)=0.2824$.

Step 5: Use Eq. (15) and Eq. (16) to obtain the overall aggregated preference indices. In this step, the criteria weight coefficients are introduced. For example, the aggregated preference indices of alternative A1 and A2 over criteria C1 is $\lambda_1(A_1,A_2)=P_1(A_1,A_2)\times w_1=0.2824\times0.1862=0.0526$. The overall aggregated preference indice of alternative A1 and A2 over all the sub-criteria is $\xi(A_1,A_2)=\sum_{j=1}^{16}\lambda_j(A_1,A_2)=0.4414$. The overall aggregated preference indices are as shown in Table 12.

Step 6: Eqs. (17) and (18) are conducted to calculate the positive and negative outranking flows $\phi^+(A_i)$ and $\phi^-(A_i)$ of all alternatives, and subsequently obtain the net ranking flow with Eq. (19). The results are presented in Table 13.

According to Table 13, the barrier levels of three alternative FCSPs ranked through the net ranking flows are A5 > A1 > A3 > A2 > A4. Based on the barrier level evaluation result obtained by the proposed framework, alternative A5 has the lowest barrier level to successfully implement an FCSP in China.

4.2. Discussions

4.2.1. Sensitivity analysis

Since critical barriers remain the causes of uncertainties of FCSP implementation and criteria weights may significantly influence the evaluation results, a sensitivity analysis considering criteria weight changes should be performed to check changes in the alternative

Table 12a
The values of the normalized matrix.

	A1	A2	A3	A4	A5
C1	1.00	0.72	0.22	0.00	0.93
C2	0.00	0.12	0.12	0.00	1.00
C3	0.23	1.00	0.18	0.00	1.00
C4	0.70	0.27	0.57	0.00	1.00
C5	0.79	0.29	0.79	0.00	1.00
C6	0.00	0.12	0.35	0.00	1.00
C7	0.41	0.41	0.19	0.00	1.00
C8	1.00	0.00	0.74	0.19	0.91
C9	0.95	0.00	1.00	0.29	0.91
C10	1.00	0.00	0.32	0.09	0.92
C11	0.71	0.00	0.59	0.12	1.00
C12	1.00	0.27	0.54	0.00	0.94
C13	1.00	0.00	0.58	0.29	0.92
C14	0.17	0.84	0.00	0.51	1.00
C15	0.67	0.14	0.67	0.00	1.00
C16	0.84	0.34	1.00	0.00	1.00

Table 12b
The overall aggregated preference indices.

FCSP	A1	A2	A3	A4	A5
A1	0.0000	0.4414	0.2432	0.6313	0.0295
A2	0.0842	0.0000	0.1727	0.3026	0.0000
A3	0.0309	0.3176	0.0000	0.4256	0.0012
A4	0.0129	0.0414	0.0196	0.0000	0.0000
A5	0.3200	0.6477	0.5041	0.9089	0.0000

Table 13
Ranking flow and alternative ranking results.

FCSP	Positive outranking flow	Negative outranking flow	Net ranking flow	Ranking
A1	0.3364	0.1120	0.2243	2
A2	0.1399	0.3620	−0.2221	4
A3	0.1938	0.2349	−0.0411	3
A4	0.0185	0.3364	−0.3179	5
A5	0.5952	0.1120	0.4832	1

ranking results. The sensitivity analysis is launched by swapping the criteria weights of two of the five main criteria dimensions and keeping the same fluctuation among sub-criteria within this dimension, and the criteria weights of the rest dimensions remain unchanged. For example, the criteria weights of institutional and governance barriers (B1) and management barriers (B2) are swapped in Scenario 2, then the criteria weight of B1 is changed to 0.21 from 0.36 while the weight of B2 is changed from 0.21 to 0.36. The original criteria weights are used as the baseline (Scenario S1) and ten scenarios from Scenario S2 to S11 are performed, and the criteria weights in each scenario are listed in Table 14.

Use the updated criteria weights in all scenarios for sensitivity analysis with the proposed barrier evaluation framework to obtain the alternative ranking results (see Fig. 3 and Fig. 4).

According to Fig. 3, it's obvious that the net ranking flow results are sensitive to criteria weight changes. For example, when the criteria weights of B1 and B4 are swapped in Scenario S4, the net ranking flow values of the alternatives show the most significant fluctuation and the largest differences. Meanwhile, the net ranking flows in Scenario S3 (weight swapping between B1 and B3), S7 (weight swapping between B2 and B4), S5 (weight swapping between B1 and B5) are also sensitive while there is a slight difference in the rest scenarios. It's noteworthy that the criteria weight swapping related to B1 (institutional and governance barriers) might affect the result with a relatively larger impact.

In Fig. 4, the ranking orders in all scenarios remain A5 > A1 > A3 > A2 > A4 and it's obvious that the ranking orders among five alternatives are less sensitive to criteria weight swapping. Although the net ranking flows in several scenarios are changed to be larger or smaller, their values remain at a relatively stable level, i.e., the net ranking slows of A1 and A5 are positive and the largest values in each scenario and that of A4 are always negative and the smallest values in each scenario.

Furthermore, we calculate the net ranking flow $\phi(A_i)$ and alternatives' ranking orders based on different main criteria dimensions (see Table 15). It's noteworthy that the local weights of sub-criteria are used as the weight coefficients instead of the final weights in different dimensions. Compared with the overall ranking A5 > A1 > A3 > A2 > A4 (all sub-criteria weights are taken into account), the ranking results under different main criteria dimensions are generally consistent, namely A5 ranks first and A4 ranks last, but there are differences between A2, A3, and A4. Meanwhile, A3 and A4 respectively rank third and fifth with an 83% of percentage. Noteworthily, A1 shows a better performance than A5 in B4 dimension, and the reason could be that alternative A1 faces fewer knowledge barriers (B4) because A1 is richer in general knowledge and past experience within a relatively mature industry environment.

Based on the ranking results in Table 15, we conduct a Spearman's rank correlation analysis among the main criteria dimension based ranking results with the overall ranking order (Biswas & Joshi, 2023) (see Table 16). It can be observed that the ranking results under B2 (management barriers), B4 (knowledge barriers), and B5 (technical and infrastructure barriers) are significantly consistent with the ranking considering all of the sub-criteria (i.e., Overall_rank in Table 16). The results provide some useful observations. On one hand, the criteria system constructed is reliable and feasible to evaluate the barrier level of alternative FCSP and help to provide the ranking orders whenever this kind of decision is required. On the other hand, we note that the Spearman's rank coefficients under B1 (institutional and governance barriers) and B3 (economic and market barriers) dimensions do not show a significant correlation with the overall barrier level ranking result although the Spearman's rho values reach 0.7 and 0.8 respectively. This is because the FCSPs that have better performance from the perspective of institutional and governance barriers economic and market barriers do not show equivalent performance in all aspects.

4.2.2. *Comparative analysis*

To certify the effectiveness and feasibility of the proposed barrier evaluation framework for FCSP implementation, a comparative analysis is conducted. In general, barrier evaluation can be handled as an MCDM question since there is an independent correlation among various conflicting criteria. Some popular MCDM methods are feasible to address an MCDM problem, including PROMETHEE II (Yusuf et al., 2022), TOPSIS (Chen et al., 2020), and VIKOR (Çalı & Balaman, 2019). Since the barrier evaluation of FCSP contains imprecise and ambiguous information during the newly-developed and dynamic FCS industry, the application of some MCDM methods has practical application challenges. As a result, fuzzy-based approaches are widely used to address uncertainty and imprecise information in the barrier evaluation of FCSP. To validate the results, a Gaussian rule-based BWM-IT2F-PROMETHEE II method, a BWM-IT2F-TOPSIS method, and a triangle fuzzy numbers-based VIKOR (TFN-VIKOR) method are introduced to obtain the ranking results of the present case, and a Spearman's rank correlation coefficient is applied to discuss the obtained results.

In a Gaussian rule-based PROMETHEE II method, the difference $d_j(A_i, \widetilde{\widetilde{A}}_i)$ between alternatives A_i and $\widetilde{\widetilde{A}}_i$ with respect to the j - th criterion is calculated by a normalized Euclidean distance, and the prefer-

Table 14
Criteria weights in different scenarios.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
B1	**0.36**	**0.24**	**0.16**	**0.07**	**0.16**	**0.36**	**0.36**	**0.36**	**0.36**	**0.36**	**0.36**
C1	0.19	0.12	0.08	0.04	0.08	0.19	0.19	0.19	0.19	0.19	0.19
C2	0.10	0.06	0.04	0.02	0.04	0.10	0.10	0.10	0.10	0.10	0.10
C3	0.05	0.04	0.02	0.01	0.02	0.05	0.05	0.05	0.05	0.05	0.05
C4	0.02	0.01	0.01	0.00	0.01	0.02	0.02	0.02	0.02	0.02	0.02
B2	**0.24**	**0.36**	**0.24**	**0.24**	**0.24**	**0.16**	**0.07**	**0.16**	**0.24**	**0.24**	**0.24**
C5	0.17	0.26	0.17	0.17	0.17	0.12	0.05	0.12	0.17	0.17	0.17
C6	0.05	0.07	0.05	0.05	0.05	0.03	0.02	0.03	0.05	0.05	0.05
C7	0.02	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02
B3	**0.16**	**0.16**	**0.36**	**0.16**	**0.16**	**0.24**	**0.16**	**0.16**	**0.07**	**0.16**	**0.16**
C8	0.10	0.10	0.23	0.10	0.10	0.15	0.10	0.10	0.05	0.10	0.10
C9	0.01	0.01	0.03	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01
C10	0.05	0.05	0.10	0.05	0.05	0.07	0.05	0.05	0.02	0.05	0.05
B4	**0.07**	**0.07**	**0.07**	**0.36**	**0.07**	**0.07**	**0.24**	**0.07**	**0.16**	**0.07**	**0.16**
C11	0.03	0.03	0.03	0.12	0.03	0.03	0.08	0.03	0.06	0.03	0.06
C12	0.01	0.01	0.01	0.05	0.01	0.01	0.03	0.01	0.02	0.01	0.02
C13	0.04	0.04	0.04	0.18	0.04	0.04	0.12	0.04	0.08	0.04	0.08
B5	**0.16**	**0.16**	**0.16**	**0.16**	**0.36**	**0.16**	**0.16**	**0.24**	**0.16**	**0.16**	**0.07**
C14	0.04	0.04	0.04	0.04	0.08	0.04	0.04	0.06	0.04	0.04	0.02
C15	0.12	0.12	0.12	0.12	0.25	0.12	0.12	0.17	0.12	0.12	0.05
C16	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.004

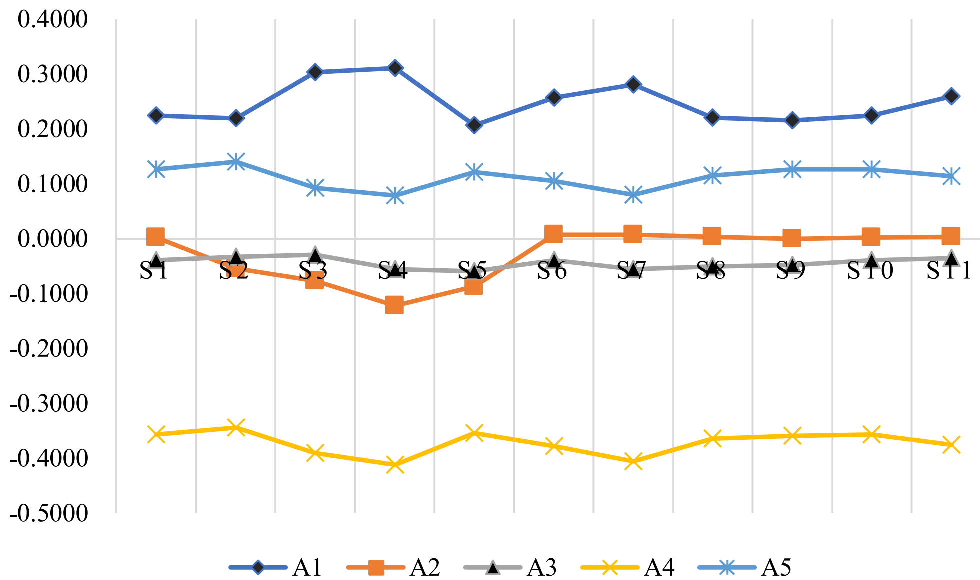

Fig. 3. Net ranking flows of alternative FCSPs in different scenarios.

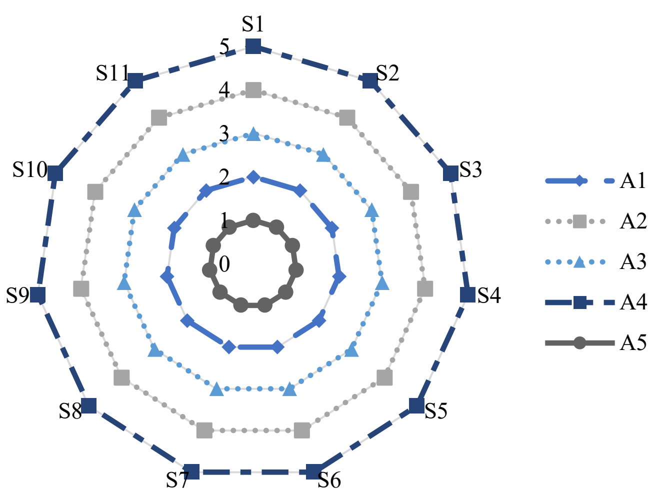

Fig. 4. Ranking result of alternative FCSPs in different scenarios.

ence function is improved by the Gaussian rule (Tong et al., 2022). Different from PROMETHEE II, a TOPSIS method uses a relative closeness to obtain the alternative ranking result instead of the net ranking flow. BWM-IT2F-TOPSIS method uses the BWM method (Oroojeni Mohammad Javad, 2020) to calculate the criteria weight and construct the decision matrix with IT2FS and compute each alternative's distances from the positive and negative ideal solutions. Meanwhile, a BWM-TFN-VIKOR method, which is a TFN-based MCDM approach in ranking problems and makes decisions with a compromise solution, is adopted to rank the alternative FCSPs (Wei & Zhou, 2022). Based on the identical explanatory case, use the obtained criteria weights and the valuation information of alternative FCSPs (Table 11), the calculation results of the listed methods considering barrier evaluation of FCSP implementation are achieved (see Table 17 and Figs. 5-7). It can be observed that the ranking orders of all alternative FCSPs are consistent with the result obtained by the proposed framework in this work, namely A5 > A1 > A3 > A2 > A4. A5 always remains an optimal choice among 5 alternatives, A1 ranks second, A3 maintains a moderate barrier level and the barriers encountered by alternatives A2 and A4 are the most challenging for DMs. Additionally, compare the ranking results with Spearman's rank correlation test for the overall ranking (see Table 18), it's evident that the results achieved by using the listed methods are consistent with the proposed barrier evaluation framework, thus the robustness and the methodology are verified.

With respect to the comparative results of BWM-IT2F-PROMETHEE II and Gaussian rule-based BWM-IT2F-PROMETHEE II, it may be worthy to mention that the descending orders of outranking and net ranking flows are the same, but the corresponding values obtained by a Gaussian rule-based PROMETHEE II method are relatively smaller, namely a Gaussian rule-based PROMETHEE II makes the gap between the best and the worst alternatives smaller, which makes the results not

Table 16
Spearman's rank correlation among main criteria dimensions.

Coefficient	B1	B2	B3	B4	B5	Aspect
Spearman's rho	0.700	0.900*	0.800	0.900*	0.900*	Overall_rank

* Correlation is significant at the 0.05 level (2 tailed).

Table 15
Ranking under different main criteria dimensions.

	Main criteria dimension										Overall rank	
	B1		B2		B3		B4		B5		Overall	
	$\phi(A_i)$	Rank	$\phi(A_i)$	Rank	$\phi(A_i)$	Rank	$\phi(A_i)$	Rank	$\phi(A_i)$	Rank	$\phi(A_i)$	Rank
A1	0.159	2	0.121	2	0.564	1	0.464	2	0.069	2	0.224	2
A2	0.128	3	−0.300	5	−0.682	5	−0.614	5	−0.238	5	−0.222	4
A3	−0.324	5	0.188	3	0.129	3	0.058	3	0.030	3	−0.041	3
A4	−0.305	4	−0.244	4	−0.523	4	−0.442	4	−0.191	4	−0.318	5
A5	0.484	1	0.497	1	0.482	2	0.512	1	0.449	1	0.483	1

Table 17
Barrier evaluation results of different MCDM approaches on explanatory case.

	BWM-IT2F-PROMETHEE II		BWM-IT2F-PROMETHEE II (Gaussian rule)		BWM-IT2F-TOPSIS		BWM-TFN-VIKOR	
	$\phi(A_i)$	Rank	$\phi(A_i)$	Rank	CC	Rank	Q_i	Rank
A1	0.2243	2	0.1690	2	0.6523	2	0.3936	2
A2	−0.2221	4	−0.1660	4	0.3632	4	0.5922	4
A3	−0.0411	3	−0.0334	3	0.5044	3	0.4738	3
A4	−0.3179	5	−0.2290	5	0.0989	5	1	5
A5	0.4832	1	0.3456	1	0.9510	1	0	1

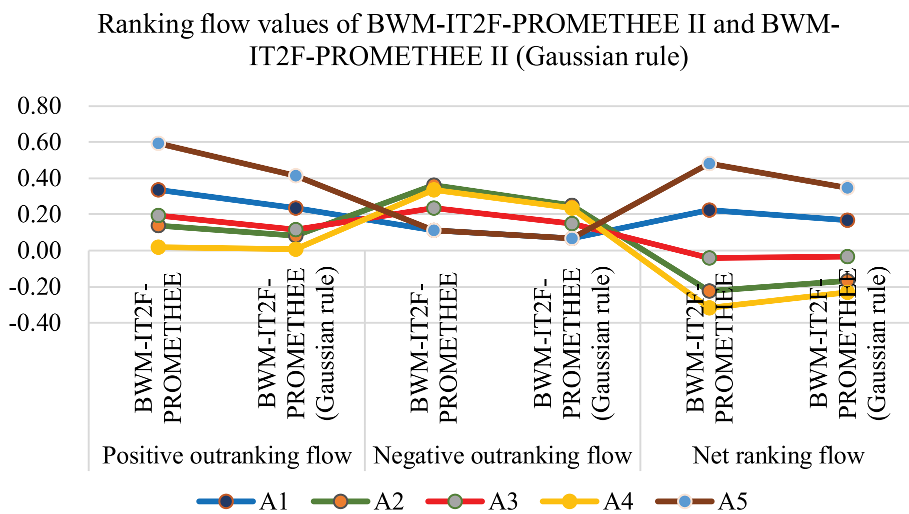

Fig. 5. Ranking flow values of PROMETHEE II-based methods.

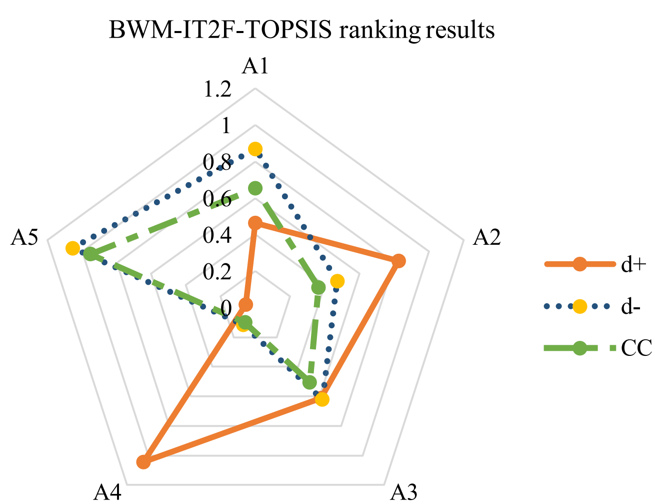

Fig. 6. Ranking flow values of BWM-IT2F-TOPSIS method.

so sensitive to experts' knowledge and experience. Nevertheless, the positive outranking flow outranking illustrates how A_i dominants the others while the negative outranking flow explains how much the others dominate A_i, a Gaussian rule-based makes this information not so obvious. Since the subject opinions during the decision-making process of barrier evaluation of FCSP implementation are influenced by experts' knowledge and relative experience, the proposed BWM-IT2F-PROMETHEE II method makes the results more in line with experts' expectations.

TOPSIS-based method determines an optimal alternative by selecting the one with the shortest distance from the ideal solution and the largest closeness coefficient, which is completely rational and unable to present different functional preference functions in making a decision (Wu et al., 2019). Nevertheless, the decision-making process of barrier evaluation of FCSP implementation depends on experts' diverse and uncertain psychological behaviors with bounded rationality. Therefore, applying a PROMETHEE II-based framework in barrier evaluation has noteworthy superiority since this method operates by taking DM's preference functions into account, it makes the DM's knowledge and bounded rationality highly valued and makes the results more convincing. Thus, the proposed BWM-IT2F-PROMETHEE II method is more suitable and reasonable for addressing the barrier evaluation problem of FCSP implementation.

As illustrated above, the alternative ranking results of the proposed framework and the TFN-VIKOR-based method are consistent, which indicates that using TFNs and IT2FSs to process uncertain and fuzzy expert opinions does not lead to significant differences in ranking alternatives and both of them are capable to verify the feasibility and rationality of the results. Dislike PROMETHEE II which ranks the alternatives in descending order, the VIKOR reflects the rankings in ascending order. Similar to TOPSIS, VIKOR focuses on the alternative's distance from the positive/negative solution, but there exists a great complementarity between criteria values when making decisions. Compensate for this, the PROMETHEE II method takes all criteria into account via the use of the preference function (Wu et al., 2020c), thus the criteria will not influence each other and the obtained results turn out more in line with the practical situation.

4.2.3. Suggestions

Implementing an FCSP in China confronts multiple barriers, including institutional and governance barriers, management barriers, economic and market barriers, knowledge barriers, and technical and infrastructure barriers. Effective barrier evaluation and analysis are essential to help governments, forestry enterprises, project managers and other participants deal with different critical barriers and make

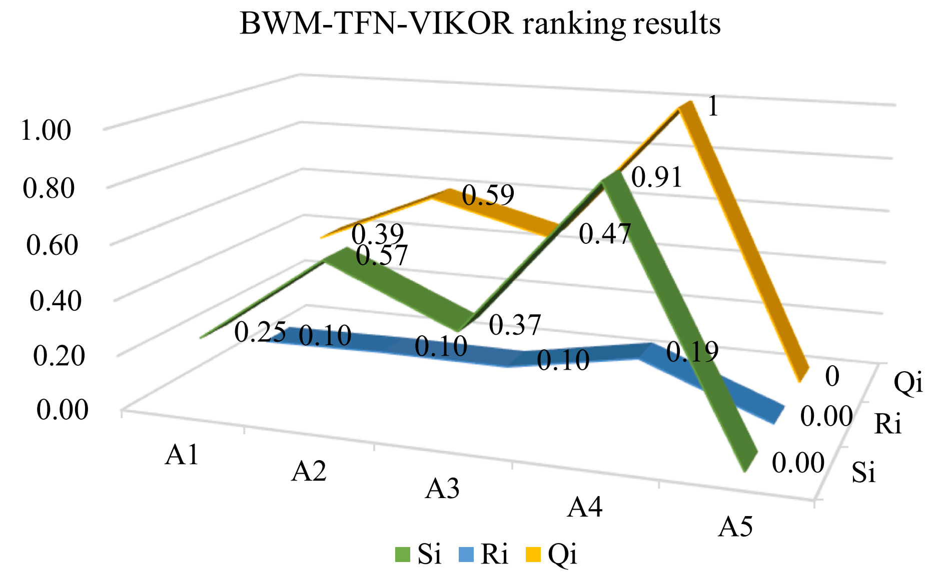

Fig. 7. Ranking flow values of BWM-TFN-VIKOR method.

Table 18
Correlation coefficient among overall rankings of different MCDM approaches.

Aspect	Method	Spearman's rho
BWM-IT2F-PROMETHEE II rank	BWM-IT2F-PROMETHEE II (Gaussian rule) rank	1.000**
	BWM-IT2F-TOPSIS rank	1.000**
	BWM-TFN-VIKOR rank	1.000**

** Correlation is significant at the 0.01 level (2 tailed).

solid decisions. According to the barrier evaluation results, we make some suggestions as follows.

(1) Institutional and governance barriers (B1) play a significant role with the highest weight of 0.3592 and the sub-criteria lack of clear leadership and policies ranks first among all critical barriers. The main participants of FCSP implementation, such as government officers, project managers, and investors, should pay attention to establishing a sound leadership and policy system concerning the overall lifecycle of FCSP. On one hand, related legislation & regulation needs to be developed and promoted to improve governance efficiency; On the other hand, increasing public and stakeholder engagement across sectors helps to establish a robust partnership of multiple participants and make use of their advantages and initiatives. In addition, decreasing competing priorities issues are also helpful.

(2) Management barriers emerge in managing and operating an FCSP. To better improve the management efficiency of the FCSP, DMs should make efforts in promoting forest management performance via appropriate planning and management practices. Interagency & interinstitutional cooperation remains a challenge for project implementation, thus it's suggested to build a flexible and sustainable project management mode that provides a smooth corporation mechanism. Meanwhile, endeavors should be made to improve participants' awareness of management barriers because the successful implementation of FCSP involves multiple management attributes.

(3) In economic barriers, forestry departments and related participants should fully assess the economic feasibility during project planning to deal with the possible impacts of economic fluctuations. Difficulties with the undeveloped market need more attention, although some FCSPs like *Facilitating Reforestation for Guangxi Watershed Management in Pearl River Basin Project* have received support at home and abroad and have generated economic benefits, forest carbon storage trading market in China is still immature. At the same time, a series of measures are needed to improve project financing, including creating diversified financing methods, promoting the participation of social capital, enriching the benefit-sharing mechanism, and so on.

(4) Obstacles with immature industry has the highest weight in knowledge barriers. The forest carbon storage industry is an emerging industry in China, obstacles and challenges of immature development, lack of general knowledge, and absence of past experiences require the integration of management, forestry, ecology, economics, and other disciplines. Therefore, it's suggested to construct an expert alliance and break the knowledge bottleneck that restricts the development of FCSP.

(5) In the technical and infrastructure barriers, the lack of newest technologies, protocols and standards is believed the most critical barrier factor. Meanwhile, design, construction and maintenance challenges and a lack of related infrastructure also need to be carefully handled. Thus, it's recommended to strengthen research on forest carbon sink functions of forestry ecosystems and technological innovation in key areas.

5. Conclusions

Forest carbon sink has received worldwide attention as an effective nature-based solution for carbon emission reduction. In this context, China has issued a series of policies and measures to support the FCSP development. A tremendous rise in FCSP implementation has posed management and economic challenges. Therefore, it's important to help DMs to better understand the critical barriers in FCSP implementation and to comprehensively evaluate the overall barrier level of the FCSP in China. However, the solution cannot be easily obtained but requires a comprehensive investigation.

To address this problem, the paper conducts a preliminary analysis of the critical barriers with a thorough literature review and proposes a barrier evaluation framework for FCSP implementation with an integrated BWM-IT2F-PROMETHEE II method. Firstly, 16 critical barriers are used to construct the criteria system and the criteria weighting is determined with the BWM method. Secondly, the barrier evaluation information is collected with linguistic terms and the decision matrix is constructed with the help of IT2FSs. Thirdly, the overall barrier levels of alternative FCSPs and the ranking results are obtained using the PROMETHEE II method. Last, a sensitivity analysis and a comparative analysis are used to certify the robustness of the proposed framework. The results indicate that: (1) The lifecycle of implementing an FCSP might encounter institutional and governance barriers, management barriers, economic and market barriers, knowledge barriers, and technical and infrastructure barriers; (2) Alternative A5 has the lowest barrier level and it deserves more attention in making decisions; (3) The proposed barrier evaluation framework is feasible and the method has the practicality to provide a reference. It also gives an indication that actions should be taken to mitigate the barriers faced by implementing the FCSP in China to reduce carbon emissions.

Future directions and limitations.

The proposed methodology and the present paper can be imitated for similar barrier evaluation research, and the research limitations provide possibilities to formulate future directions.

As a limitation of this paper, the research is specifically launched in the context of China's FCSP implementation, thus the criteria system we constructed may not be completely feasible for other countries considering different characteristics. It indicates the further direction could be conducting a barrier evaluation of FCSP implementation in other countries and target cities considering different economic, market and technology barriers, and so on. This may bring a richer and broader analysis and result in more specific and applicable FCSP implementation suggestions.

As a limitation of the proposed methodology, the constructed criteria system and barrier evaluation methodology doesn't target special situation of an individual project that needs to be dealt with specifically and separately. Meanwhile, some state-of-the-art algorithms and more MCDM approaches might have the potential to solve the research question. In this context, the future direction could be improving the criteria system by taking some specific FCSPs into account to provide targeted theoretical references, exploring some intelligent algorithms and hybrid MCDM approaches for such research, and observing the potential improvements.

CRediT authorship contribution statement

Qiushuang Wei: Writing – original draft, Writing – review & editing, Methodology, Investigation. **Chao Zhou:** Resources. **Qiong Liu:** Conceptualization, Investigation. **Weidong Zhou:** Software. **Junjie Huang:** Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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