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Evaluating barriers and strategies to green energy innovations for sustainable development: developing resilient energy systems

Donglin Wang[1], Jie Li[2]* and Yuhang Liu[3]

[1]College of Engineering, China Agricultural University, Beijing, China, [2]School of Energy and Construction Engineering, Harbin University of Commerce, Harbin, Heilongjiang, China, [3]Management School, Harbin University of Commerce, Harbin, Heilongjiang, China

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EDITED BY
Yasir Ahmed Solangi,
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Ghulam Muhammad,
Bahria University, Karachi, Pakistan
Kishwar Ali,
Jiangsu University, China

*CORRESPONDENCE
Jie Li,
101014@hrbcu.edu.cn

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Achieving sustainable development and reducing climate change require a shift to green energy sources. Yet, switching to green energy sources necessitates substantial research and development, as well as regulatory and policy adjustments. Additionally, a number of obstacles are impeding the development of green energy innovation. This study identified several key barriers and sub-barriers that obstruct the development of green energy innovation. Thus, this study identified multiple strategies to overcome those barriers. Therefore, this study uses the fuzzy Analytical Hierarchy Process (AHP) and fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods to assess and rank the barriers and strategies to building resilient energy systems in China. First, the fuzzy AHP method identifies the four barriers and sixteen sub-barriers, while the fuzzy TOPSIS method classifies six strategies for the green energy innovation system in China. According to AHP results, funding and policy constraints are the most crucial barriers to green energy innovation. The fuzzy TOPSIS findings show that providing incentives for green energy investment and strengthening policy implementation and enforcement are the most significant strategies for overcoming the barriers to green energy projects.

KEYWORDS

green energy, innovation, energy system, sustainable development, fuzzy AHP, fuzzy TOPSIS

1 Introduction

The detrimental effects of human activity on the environment have made the need for sustainable development more important (Kutlu, 2020). Climate change is one of the most urgent environmental issues that the world is currently experiencing. It results from human activities like burning of fossil fuels, which releases glasshouse gases, most notably carbon dioxide (Sen and Ganguly, 2017; Ali et al., 2021). Climate change poses a grave threat to both the ecology and human well-being. It can have a harmful effect on food security, water resources, and biodiversity while increasing the frequency and severity of natural disasters like hurricanes, floods, and droughts (IRENA, 2017). It is crucial to make the switch to clean and renewable energy (RE) sources in order to reduce the effects of climate change and promote sustainable development (Ali et al., 2022). Wind, solar, hydropower, and geothermal energy are examples of green energy sources that have the potential to meet a sizeable portion of the world's energy needs while causing the least amount of environmental harm (Vidadili et al., 2017). Innovations in green energy can also boost economic expansion and open up new work opportunities. Furthermore, the idea of sustainable development is predicated on the understanding that social advancement, environmental preservation, and economic expansion are linked and mutually supportive. Consequently, achieving a balance between social, environmental, and economic goals is necessary for sustainable development (Chel and Kaushik, 2018).

China is the largest carbon emitter in the world, contributing over 30% of all carbon emissions (Guo et al., 2018). The main cause of the country's excessive carbon emissions is its reliance on coal as its main energy source. The Chinese government has established challenging goals for cutting carbon emissions and raising the proportion of RE in the energy mix in recognition of the significance of green energy (Li et al., 2021). Notwithstanding these initiatives, China's transition to RE confronts a number of barriers. The limitations to technology are one of the key issues. In order to increase efficiency and lower prices, green energy technologies like solar and wind power still need to be researched and developed. Additionally, the intermittent nature of some RE sources, including wind and solar, necessitates the creation of energy storage devices to guarantee a steady energy supply. The absence of finance is another obstacle to green energy innovation in China. It can be difficult to get the substantial investment needed to develop and implement green energy solutions, especially for small and medium-sized businesses (Liu et al., 2019). The speed of invention can also be slowed down, and the adoption of new technology might be hampered by a lack of financing for research and development in green energy technologies. Another barrier to green energy innovation in China is policy restrictions. Although the Chinese government has set high goals for cutting carbon emissions and raising the proportion of RE in the energy mix, putting these plans into practice can be difficult (Dong et al., 2018). For instance, overcapacity and decreased profitability for RE companies have resulted from government subsidies for RE. Furthermore, the necessity for environmental conservation may occasionally be overshadowed by the government's emphasis on economic expansion.

Therefore, the goal of this study is to evaluate the major barriers and sub-barriers to green energy for sustainable growth as well as to suggest solution strategies for China's energy system development. The study uses the fuzzy analytical hierarchy process (AHP) and fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods, which enable modeling of complicated problems to solve the decision-making problem. The fuzzy AHP method is appropriate for this study because it can take into consideration the criteria and sub-criteria for the evaluation and development of green energy innovation in China. Therefore, making the switch to green energy innovation is crucial to reducing the consequences of climate change and ensuring the long-term viability of the Earth. Thus, China is a key player in this shift as the world's greatest carbon emitter.

The structure of the study is as follows. The literature review is presented in Section 2. The barriers and strategies are explained in Section 3. The research methodology is given in Section 4. The findings and analyses are presented in Section 5. The conclusion and policy implications are presented in Section 6.

2 Literature review

Due to the worldwide environmental catastrophe brought on by human activity, green energy innovation and sustainable development have become critical issues of discussion (Eckstein et al., 2019). The literature on green energy innovation and sustainable development is reviewed in this section, with a special emphasis on the difficulties and prospects in China.

2.1 Green energy innovation

Innovation in green energy refers to the creation and application of technologies and procedures that lessen or completely remove the damaging effects of human activity on the environment (Lai, 2020). An ample portion of the world's energy needs might be met by green energy sources, including solar, wind, hydropower, and geothermal energy, while limiting harm to the environment. As it enables the switch from fossil fuels to clean and RE sources, green energy innovation is essential for sustainable development. Innovation in green energy, however, faces a number of difficulties, including technical restrictions, financial constraints, policy constraints, and a lack of public support (Eleftheriadis and Anagnostopoulou, 2015). Notwithstanding these difficulties, green energy innovation has a great deal of promise to boost economic expansion and generate new job possibilities. Green energy use can also help reduce the consequences of climate change and guarantee the long-term viability of our planet.

2.2 Sustainable development in China

Being the largest carbon emitter in the world, China is vital to the global fight against climate change. The Chinese government has set lofty goals for cutting carbon emissions and raising the proportion of RE in the energy mix because it understands the value of sustainable development. Nevertheless, the country faces a number of barriers in its quest to achieve sustainable development. The reliance on coal as the main energy source is one of the major issues. According to the Energy Information Administration (EIA), around 55% of China's energy needs are met by coal, which also contributes significantly to the high carbon emissions (EIA, 2021), while around 19% of energy is generated from petroleum sources. Figure 1 presents the primary energy mix of China in 2021.

The lack of funding for green energy projects and the study and development of green energy technologies is another issue (Mngumi et al., 2022). Due to the high prices and lengthy commitment necessary, small and medium-sized businesses, which are essential to green energy innovation, sometimes struggle to find funding. Constraints on policy are another barrier to sustainable growth (Jiang et al., 2020). Although the government has set high goals for cutting carbon emissions and raising the proportion of RE in the country's energy mix, putting these plans into practice can be difficult. The government's emphasis on economic expansion occasionally obscures the necessity of environmental

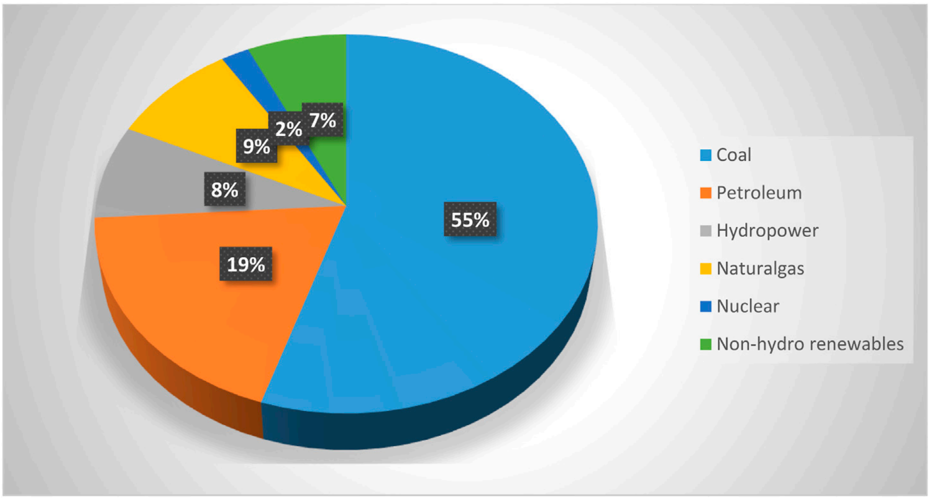

FIGURE 1
Total primary energy consumption in China.

TABLE 1 Previous studies on renewable/green energy development.

Concept	Findings	Method	Reference
Assessment of green technologies	According to the study, control technologies like variable speed drives in air handling units rank well in this situation when economic and environmental factors are taken into account	AHP	Si et al. (2016)
Renewable energy technology selection	The suggested approach can be recognized as effective in raising the value of information and regarded as a practical instrument to facilitate difficult decision-making. According to the findings, the solar–wind hybrid energy system is the greatest technology because it received the highest rating	AHP-CODAS	Ali et al. (2020)
Rank energy alternatives	The findings show that microgrids are the best option among the alternatives for producing energy in a decentralized manner and are a potential means of eradicating energy poverty	Fuzzy AHP	Kulkarni et al. (2017)
Energy planning in Turkey	The findings demonstrated that the top objective is to transform the nation into an energy hub and terminal by effectively utilizing its geostrategic location within the context of regional cooperation. Using nuclear energy technologies within energy supply systems, however, was discovered to be the least preferred priority	ANP-TOPSIS	Cayir Ervural et al. (2018)
Assessing the renewable micro-generation technologies	The study takes into account micro wind, solar thermal, and biomass boiler installations. In order to guarantee the results' robustness under the assumption that the underlying weights are disrupted, a Monte Carlo simulation is used	EDAS-WASPAS	Zhang et al. (2019a)
Implementation of EU energy policy priorities	An innovative framework for sustainable energy development indicators is presented in the article. The EU's energy policy priorities determine the choice of sustainability indicators for energy	MULTIMOORA	Siksnelyte et al. (2019)
Selection of renewable energy resources	Social, technological, environmental, economic, and political factors all have competing interests in the study. Because energy planning and energy projects are complicated, the MCDM approach was utilized to choose preferred alternative resources	TOPSIS	Rathore et al. (2021)
Innovation potential of RE technologies	The study's findings indicate that while hydroelectric power plants continue to be a significant source of energy for Latvia, the most promising RET developments are based on wind and bioenergy	TOPSIS	Suharevska and Blumberga (2019)
Innovation in the energy sector	The sensible management of a project portfolio would enable the funding of the most promising initiatives under consideration. So, the inherent risk associated with R&D initiatives would be reduced	AHP	Storch de Gracia et al. (2019)
Selection of renewable energy source	The findings show that hydropower generation is the best option for supplying energy needs, followed by wind, biomass, and solar power facilities	AHP–TOPSIS–VIKOR	Ishfaq et al. (2018)

TABLE 2 Proposed barriers and sub-barriers for green energy innovation.

Barrier	Sub-barrier	Brief description	Reference
Technological limitations	Low efficiency of some green energy technologies	Due to the lesser efficiency of green energy as compared to conventional energy sources, some green energy technologies, like solar and wind power, may be more expensive to use and have a smaller market potential	Xuan et al. (2023)
	High costs of some green energy technologies	Particularly in developing countries like China, the high cost of some green energy sources, like solar and wind power, can be a major obstacle to their widespread adoption	Dolter and Rivers (2018)
	Intermittency of some RE sources	It can be difficult to maintain a constant and reliable energy supply, which is necessary to meet the demand for power due to the intermittent nature of various RE sources	Fthenakis et al. (2009)
	Lack of energy storage technologies	The potential for RE to displace conventional energy sources may be constrained by the lack of energy storage technology that can store energy produced from the RE sources for later consumption	Jiang et al. (2020)
Funding constraints	Difficulty in securing financing for green energy projects	It can be difficult to get the initial capital that green energy projects frequently demand, especially for small and medium-sized businesses	Zhang et al. (2016)
	Lack of funding for research and development in green energy technologies	Innovation and the uptake of new technology might be slowed down by a lack of financing for research and development in green energy technologies	Mngumi et al. (2022)
	Limited access to financing for small and medium-sized enterprises	Due to the high prices and extensive upfront investment necessary for green energy projects, small and medium-sized businesses, which are essential to green energy innovation, sometimes struggle to obtain funding	Zhang et al. (2016)
	Limited availability of international financing	China's limited access to international financing for such initiatives may limit the overall amount of financing available for green energy projects. This sub-barrier is especially important for the considerable funding required for large-scale green energy initiatives	Versal and Sholoiko (2022)
Policy constraints	Inconsistent policies and regulations	Uncertainty for investors and a challenge in obtaining funding for green energy projects might result from inconsistent rules and regulations	Zhang et al. (2016)
	Lack of policy implementation and enforcement	The implementation and enforcement of rules and regulations supporting green energy innovation can be difficult, particularly in a rapidly rising country like China	Vidadili et al. (2017)
	Subsidies that lead to overcapacity and reduced profitability for RE companies	The potential for green energy innovation may be constrained by government subsidies for RE which may result in overcapacity and decreased profitability for RE enterprises	Zameer and Wang (2018)
	Lack of clarity and transparency in policy implementation	Confusion among investors and a lack of clarity and transparency in policy execution may hinder the development of China's green energy industry. This sub-barrier has a specific bearing on grid connections and energy pricing regulations	IRENA (2017)
Public support	Lack of public awareness and understanding of green energy technologies	A lack of public understanding and awareness may hinder the adoption of green energy technologies in China	Terrados et al. (2007)
	Perception that green energy is more expensive than traditional energy sources	The idea that green energy is more expensive than conventional energy sources might prevent it from gaining widespread acceptance	Wu et al. (2018)
	Concerns about the reliability of green energy sources	Concerns about the sustainability of these sources, particularly in the face of extreme weather, may restrict green energy innovation	Egli (2020)
	Perceived high costs	Perceptions that green energy technologies are more expensive than conventional fossil fuel-based energy sources may hinder the adoption of RE by households and industries	Walmsley et al. (2018)

conservation. Despite these barriers, the country has made great strides toward sustainable development. The country has made significant investments in RE, and its percentage in the energy mix has been continuously rising (Duan et al., 2018). The literature underlines China's possibilities and difficulties, as well as the significance of green energy innovation for sustainable development. Although the country has made tremendous strides toward sustainability in recent years, there is still more work to be performed in order to meet its sustainability objectives.

In the previous studies, it was identified that the development of green energy is crucial since multiple authors discussed this issue using multi-criteria decision-making (MCDM) methods to analyze the particular decision-making problem (Pohekar and Ramachandran, 2004). Some of the relative studies on the development of green energy sources are compiled in the study, which identified the research gap to conduct this research. Table 1 shows the previous studies related to green energy sources for sustainable development.

TABLE 3 Proposed policy strategies.

Policy strategy	Description	Reference
Develop and implement new and more efficient green energy technologies	To increase the effectiveness and dependability of RE sources, China should invest in the development and application of new and more efficient green energy technologies, such as advanced solar and wind power technologies and energy storage technologies	Sorrell (2015)
Provide incentives for green energy investment	To stimulate more private investment in green energy projects and the research and development of green energy technology, China should offer incentives for green energy investment, such as tax credits, subsidies, and other financial incentives	Zhang et al. (2019b)
Strengthen policy implementation and enforcement	To ensure that laws and regulations are properly applied and enforced, the country should improve policy implementation and enforcement	Zhang et al. (2019b)
Establish a national research and development program	To assist in the development of new and more effective green energy technology, the government should set up a national research and development program	Harjanne and Korhonen (2019)
Increase public awareness and education	To improve public opinion and support for RE sources, the country should increase public awareness and promote education about green energy technologies	Qiu et al. (2018)
Ensure the reliability of green energy sources	In order to guarantee the dependability of RE sources, particularly during harsh weather conditions, China should invest in energy storage technology and other options	Zafar et al. (2018)

A comprehensive assessment of green energy innovation for sustainable development using decision-making techniques like fuzzy AHP and fuzzy TOPSIS still needs to be performed, despite there being sufficient literature on the subject. Although various studies have identified these impediments, most of them have concentrated on a specific issue, such as technological constraints or governmental restrictions (Mateo, 2012). The interplay of the numerous elements that contribute to green energy innovation has rarely been thoroughly analyzed. A small number of studies have also suggested strategies for creating resilient energy systems that take into consideration the interconnection of the many deciding factors (Zhang and Gallagher, 2016).

Some research has evaluated sustainability challenges in other sectors, including energy planning and environmental management, using decision-making techniques like the fuzzy AHP and fuzzy TOPSIS methods. By employing these techniques to undertake a thorough assessment of the barriers and strategies to green energy innovation for sustainable development in China, our research attempts to close this research gap. In order to construct resilient energy systems that take into consideration the interdependence among the various decision criteria, the study will identify the main barriers to green energy innovation and suggest policy strategies to address these barriers. The analysis will add to the body of knowledge on sustainable development and offer insightful information about the potential and the problems associated with China's transition to green energy sources.

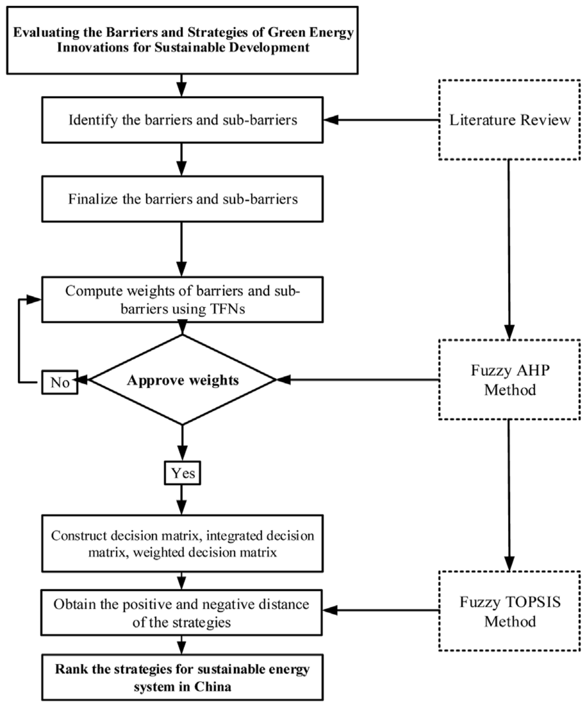

FIGURE 2
Research methodology.

3 Proposed barriers and policy strategies to green energy innovation

3.1 Barriers and sub-barriers

The study highlighted the barriers and sub-barriers to green energy innovation for sustainable development based on the existing literature. These barriers are linked and have an impact on each other. Table 2 shows the proposed barriers and sub-barriers of the study.

3.2 Policy strategies to overcome the barriers

To overcome the barriers to green energy innovation for sustainable development in China, the study proposed various policy strategies. These strategies have been identified from previous studies and are considered to be very significant to overcome the barriers and develop green innovation for sustainable development in China. Table 3 shows the policy strategies of this study.

TABLE 4 Triangular fuzzy numbers scale.

Code	Linguistic variable	TFNs
1	Equal	(1, 1, 1)
2	Equal to average	(1, 2, 3)
3	Averagely leading	(2, 3, 4)
4	Averagely to strongly leading	(3, 4, 5)
5	Strongly leading	(4, 5, 6)
6	Strongly to very strongly leading	(5, 6, 7)
7	Very strongly leading	(6, 7, 8)
8	Very strongly to extremely leading	(7, 8, 9)
9	Extremely leading	(9, 9, 9)

These policy strategies can aid in eliminating barriers to the development of green energy innovations in China. The fuzzy AHP and fuzzy TOPSIS techniques can be used to evaluate these policy options and pinpoint the best possibilities for achieving our intended goals.

4 Research methodology

This research methodology uses the fuzzy AHP and fuzzy TOPSIS methods to evaluate the barriers to green energy innovation for sustainable development and to suggest policy strategies for building resilient energy systems in China. The fuzzy AHP technique is a useful tool for determining barriers and sub-barriers, while the fuzzy TOPSIS method is significant in ranking the best policy strategy to overcome green energy innovation barriers. Figure 2 displays the research methodology of the current study.

4.1 Fuzzy AHP

One of the main techniques used in MCDM, which consists of a goal, a set of criteria, a set of sub-criteria, and alternatives, is the AHP method (Saaty, 1995). In this study, we used a fuzzy-based AHP technique to get more trustworthy and consistent outcomes. Fuzzy set theory reduces uncertainty in a fuzzy environment (Zadeh, 1978). Both quantitative and qualitative data can be utilized using the AHP technique. The complex choice problem can be broken down into smaller ones using the fuzzy AHP method. The pairwise comparison matrix was used in this study as triangular fuzzy numbers (TNFs) to evaluate barriers and sub-barriers to green energy innovations. The TFNs scale utilized in this study is displayed in Table 4.

In this study, we employed the following procedures to determine the fuzzy pairwise comparison matrix's inconsistency ratio, as suggested by Gogus and Boucher (Gogus and Boucher, 1998):

Step 1. Transform a triangular fuzzy matrix into two independent matrices, which is presented as follows:

$$X_i = (l_i, m_i, u_i). \tag{1}$$

Then, the middle fuzzy triangular matrix can be used to generate the first triangular fuzzy matrix; this equation is written as:

$$X_m = \left[x_{ijm}\right]. \tag{2}$$

Here, a geometric mean approach can be used to generate the second triangular fuzzy matrix for the upper and lower limits of the TFNs. As a result of this equation, we get:

$$X_g = \left[\sqrt{x_{iju} x_{ijl}}\right]. \tag{3}$$

Step 2. Create the weight vector based on the Saaty technique and lambda max computation.

step 3. Create the consistency index (CI) for each matrix:

$$CI_m = \frac{\lambda^m_{max} - n}{n-1}, \tag{4}$$

$$CI_g = \frac{\lambda^g_{max} - n}{n-1}. \tag{5}$$

Step 4. Create each matrix's consistency ratio (CR). Each matrix's consistency index (CI) is divided by its random index for (RI).

$$CR_m = \frac{CI_m}{RI_m}, \tag{6}$$

$$CR_g = \frac{CI_g}{RI_g}. \tag{7}$$

When both CR_m and CR_g are less than 0.10, the fuzzy matrices are deemed to be legitimate and symmetric. However, if the range is greater than 0.10, it will not produce findings that are meaningful and will be regarded as invalid or inconsistent.

4.2 Fuzzy TOPSIS

One of the fundamental MCDM methodologies is TOPSIS (Behzadian et al., 2012). For selecting the alternatives, this method provides the distance between the positive ideal and the negative ideal solution. However, this TOPSIS method is also combined with fuzzy set theory to create fuzzy TOPSIS, just like fuzzy AHP. As a result, linguistic variables and TFNs are used in this study to evaluate the weights of the alternatives (policy strategies). The alternatives are analyzed using TFNs in relation to the study's sub-criterion (sub-barriers).

The basic steps of the fuzzy TOPSIS technique are given as follows (Cayir Ervural et al., 2018):

Step 1. Let $\tilde{K}_i = (k_{i1}, k_{i2}, k_{i3})$ are the TFNs for $i \in I$. Then, the normalized fuzzy number of each $\tilde{K}_i$ is signified as

$$\tilde{D} = \left[d_{ij}\right]_{m \times n}, \tag{8}$$

where $i = 1, 2, 3, \ldots, m$ and $j = 1, 2, 3, \ldots, n$.

For a positive ideal solution:

$$d_{ij} = \left(\frac{k_{1ij}}{k_{3j}^{+}}, \frac{k_{2ij}}{k_{3j}^{+}}, \frac{k_{3ij}}{k_{3j}^{+}}\right), \quad (9)$$

where $k_{3j}^{+} = \max k_{3ij}$.

For a negative ideal solution:

$$d_{ij} = \left(\frac{l_{1j}^{-}}{l_{3ij}}, \frac{l_{1j}^{-}}{l_{2ij}}, \frac{l_{1j}^{-}}{l_{1ij}}\right), \quad (10)$$

where $l_{1j}^{-} = min\, l_{1ij}$.

Step 3. Construct the weighted normalized fuzzy decision matrix:

$$\tilde{V} = [v_{ij}]_{m\times n}. \quad (11)$$

$i = 1, 2, 3, \ldots, m$ and $j = 1, 2, 3, \ldots, n$,where $v_{ij} = d_{ij} \times w_j$.

Step 4. Recognize the distance between positive and negative ideal solution:

$$d_i^{+} = \left(v_1^{+}, v_2^{+}, v_3^{+}, \ldots, v_n^{*}\right), \quad (12)$$

where $V_j^{+} = (1, 1, 1)$ and $j = 1, 2, 3, \ldots, n$.

$$d_i^{-} = \left(v_1^{-}, v_2^{-}, v_3^{-}, \ldots, v_n^{-}\right), \quad (13)$$

where $V_j^{-} = (0, 0, 0)$ and $j = 1, 2, 3, \ldots, n$.

Here, the distance between $\tilde{K} = (k_1, k_2, k_3)$, $\tilde{N} = (n_1, n_2, n_3)$ is shown as

$$d\left(\tilde{K}, \tilde{L}\right) = \sqrt{\frac{1}{3}\left[(k_1 - l_1)^2 + (k_2 - l_2)^2 + (k_3 - l_3)^2\right]}. \quad (14)$$

Step 5. Construct the closeness coefficient (CC_i) using Eq. 15:

$$CC_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}}, \quad (15)$$

where $i = 1, 2, 3, \ldots, m$, d_i^{+} is the distance from positive ideal solution, and d_i^{-} is the distance from a negative ideal solution.

Step 6. Identify the suitable green supplier based on descending order of CC_i value.

For this study, five specialists in green energy innovation and sustainable development in China were consulted. The professionals we contacted were knowledgeable about numerous green energy technologies, their efficacy, and their potential for advancement and application in China. To ensure a thorough study of the barriers to green energy innovation for sustainable development in China, all of the chosen experts come from a variety of backgrounds, including academics, researchers, industry professionals, and policymakers. As a result, the study methodology entails evaluating the barriers and strategies to green energy innovation using the fuzzy AHP and fuzzy TOPSIS methods to create resilient energy systems.

5 Results and discussion

The current case study offers a thorough analysis of the potential and the problems associated with the switch to green energy sources, as well as the success of the suggested solutions in removing the barriers to green energy innovation. The study evaluated and ranked the barriers, sub-barriers, and policy strategies for the development of green energy using the fuzzy AHP and fuzzy TOPSIS techniques. This case study will have a great impact on sustainable development and green energy innovation in China and other countries.

5.1 Results of barriers

The study identified barriers using the fuzzy AHP method. As is seen, the funding and policy constraints have the highest weights, indicating their importance in the evaluation of green energy innovation development. The technological limitations and public support are the next important barriers in the evaluation process. The ranking of barriers is useful in identifying the most critical dimensions of the sustainable energy system and can be used to guide policy development and decision-making. Figure 3 shows the results of barriers to green energy innovation.

5.2 Results of sub-barriers

The study also presents the outcomes of sub-barriers related to each primary barrier. Within the category of technological limitations, it is found that the lack of energy storage technologies holds the top position as a significant sub-barrier in the transition towards a green energy innovation. High costs of some green energy technologies emerge as the second most crucial sub-barrier. Meanwhile, the intermittency of some RE sources and the low efficiency of some green energy technologies are deemed less critical sub-barriers that impede the development of green energy innovations. Table 5 illustrates the weights and rankings of these technological limitations sub-barriers.

Within the funding constraints category, the findings reveal that the sub-barrier of difficulty in securing financing for green energy projects has attained the utmost significance in green energy innovation development. Lack of funding for research and development in green energy technologies is ranked as the second most essential sub-barrier, followed by limited access to financing for small and medium-sized enterprises and limited availability of international financing for sustainable resilient energy systems in China. Table 6 showcases the weights and rankings of the funding constraints sub-barriers.

Within the policy constraints category, the results indicate that inconsistent policies and regulations are the most critical sub-barrier that obstructs the development of green energy innovation. The subsidies that lead to overcapacity and reduced profitability for RE companies are ranked as the second most important sub-barrier, followed by a lack of policy implementation and enforcement and a lack of clarity and transparency in policy implementation. Consequently, these sub-barriers are deemed highly significant for green energy innovation and addressing climate change. Table 7 depicts the weights and rankings of the policy constraints sub-barriers.

In the public support category, the results reveal that a lack of public awareness and understanding of green energy technologies is the most crucial sub-barrier. Perceived high costs are regarded as the second most important sub-barrier, while perceptions that green

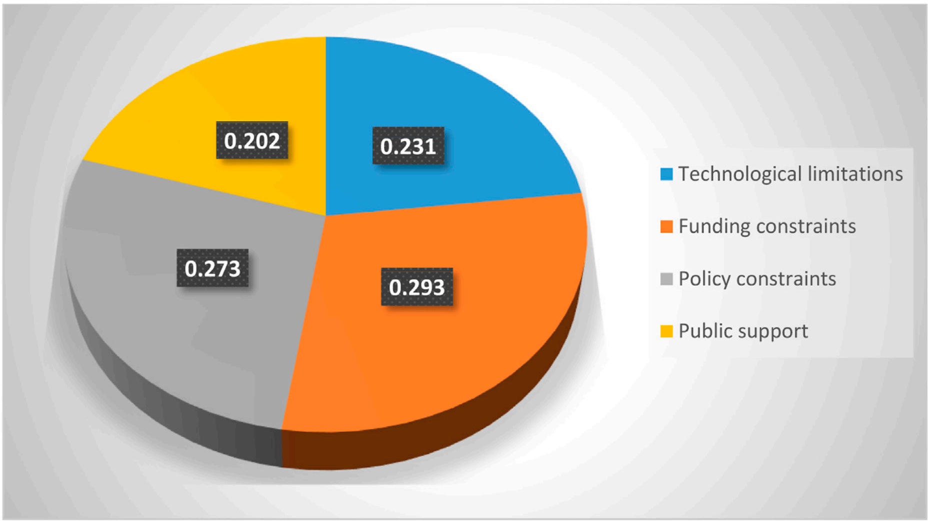

FIGURE 3
Final ranking of barriers for green energy innovation.

TABLE 5 Sub-barrier ranking (technological limitations).

Sub-barrier	Weight	Rank
Low efficiency of some green energy technologies	0.234	4
High costs of some green energy technologies	0.253	2
Intermittency of some RE sources	0.241	3
Lack of energy storage technologies	0.271	1

energy is more expensive than traditional energy sources and concerns about the reliability of green energy sources hold moderate to lower significance. Table 8 illustrates the weights and rankings of the public support sub-barriers.

5.3 Results of policy strategies

The results of the analysis are typically based on a range of barriers that are considered important for achieving sustainable energy development. Thus, the results of the fuzzy TOPSIS analysis indicate that providing incentives for green energy investment was found to be the most important strategy to overcome the barriers to transitioning to a sustainable energy future and addressing climate change, followed by strengthening policy implementation and enforcement and developing and implementing new and more efficient green energy technologies. The fuzzy TOPSIS analysis is a sophisticated decision-making instrument that assists in determining and prioritizing crucial strategies for green energy innovation in China. The final ranking of different policy strategies for green energy innovation is presented in

TABLE 6 Sub-barrier ranking (funding constraints).

Sub-barrier	Weight	Rank
Difficulty in securing financing for green energy projects	0.285	1
Lack of funding for research and development in green energy technologies	0.256	2
Limited access to financing for small and medium-sized enterprises	0.236	3
Limited availability of international financing	0.222	4

TABLE 7 Sub-barrier ranking (policy constraints).

Sub-barrier	Weight	Rank
Inconsistent policies and regulations	0.275	1
Lack of policy implementation and enforcement	0.239	3
Subsidies that lead to overcapacity and reduced profitability for RE companies	0.261	2
Lack of clarity and transparency in policy implementation	0.224	4

TABLE 8 Sub-barrier ranking (public support).

Sub-barrier	Weight	Rank
Lack of public awareness and understanding of green energy technologies	0.268	1
Perception that green energy is more expensive than traditional energy sources	0.245	3
Concerns about the reliability of green energy sources	0.225	4
Perceived high costs	0.261	2

TABLE 9 Final ranking of multiple strategies.

Strategy	d^+	d^-	CC_i	Rank
Develop and implement new and more efficient green energy technologies	8.432	8.643	0.5076	3
Provide incentives for green energy investment	5.543	12.768	0.6978	1
Strengthen policy implementation and enforcement	6.654	11.234	0.6412	2
Establish a national research and development program	9.989	8.321	0.4865	4
Increase public awareness and education	10.378	7.440	0.4175	6
Ensure the reliability of green energy sources	9.543	8.121	0.4443	5

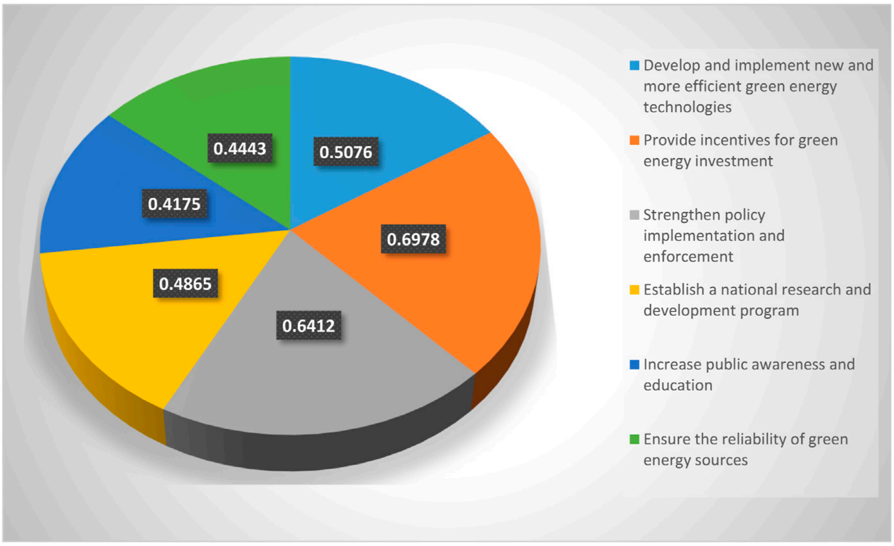

FIGURE 4
Ranking of strategies based on the highest CCi value.

Table 9. Moreover, the ranking value based on CCi is presented in Figure 4.

The analysis using the fuzzy TOPSIS method will provide valuable insights into the most effective strategy for promoting green energy innovation and achieving sustainable development in China.

5.4 Discussion

To attain sustainable development and mitigate climate change, there is a need to transition toward green energy sources. However, this shift necessitates significant expenditures for research and development, as well as significant regulatory and policy adjustments. Policy restrictions are a relatively less important barrier, according to the fuzzy AHP research, with inconsistent rules and regulations being the most important sub-barrier. To get around this barrier, the study suggested that uniform policies and rules be put in place to encourage green energy innovation and offer a secure investment environment for green energy projects (Mirjat et al., 2017). Increasing public knowledge and education about green energy technology is essential for overcoming the public support barrier. We have suggested a mix of encouraging the use of green

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energy and raising public consciousness and education to get around this barrier. In order to deal with the inconsistent nature of RE sources and increase the dependability of the energy system, the research has also recommended making investments in energy storage technology (Zhang et al., 2016). It is crucial to recognize the connections and interactions between China's constraints on green energy innovation and sustainable development. For instance, a lack of financing for green energy technology research and development may restrict the creation of new technologies, which may restrict the possibility of cost savings and improved efficiency (Mngumi et al., 2022). Inconsistent laws and regulations can lead to uncertainty for investors and difficulty obtaining funding for green energy projects (Solangi et al., 2021). We have been able to simulate the intricate relationships between choice criteria and alternative options using the fuzzy AHP and fuzzy TOPSIS methods. These methods have allowed us to conduct a thorough investigation of the challenges and solutions for building resilient energy systems in China.

The findings could have a big impact on how China and other countries make uniform policies. The suggested actions can help policymakers make choices that will advance green energy innovation and help the nation reach its sustainability objectives (Kamran, 2018). More private investment in green energy projects and research and development can be attracted, in particular, by establishing a green energy fund, offering tax benefits, and funding energy storage technology. A stable investment environment for green energy projects and support for the expansion of the green energy industry can be achieved by establishing uniform laws and regulations and enhancing policy implementation and enforcement (Baležentis and Streimikiene, 2017; Ali et al., 2023). In addition, raising public knowledge and understanding of green energy technologies can encourage public acceptance of and growth in the use of RE sources. In the end, these actions can help China establish a more sustainable and resilient energy system and lessen the effects of climate change.

6 Conclusion and implications

This study used the fuzzy AHP and fuzzy TOPSIS methods to assess the barriers to green energy innovation and policy strategies for a sustainable energy system in China. Based on the findings, the most important barriers, sub-barriers, and strategies have been identified and weighted in the evaluation process of decision-making. According to the fuzzy AHP results, funding constraints are crucial barriers to green energy innovation in China. The study suggested the creation of a green energy fund and tax breaks to promote more private investment in green energy projects in order to eliminate this barrier. Policy constraints are the second most important barrier. The study also suggested that uniform policies and rules be put in place to encourage green energy innovation and offer a secure investment environment for green energy projects. To overcome the barriers of public support, we have also recommended combining the provision of incentives for the use of green energy with an increase in public awareness and education. The intermittent nature of RE sources must be addressed, and the dependability of the energy system must be increased by making investments in energy storage technology. The suggested policy actions can help policymakers make choices that will advance green energy innovation and help the country reach its sustainability objectives.

6.1 Policy implications

The findings have important policy implications for China's efforts to advance green energy innovation and sustainable development. The suggested actions can help guide policy choices that can boost public support for RE sources, encourage more private investment in green energy projects, and create a stable investment climate for green energy innovation.

- By offering tax benefits for green energy investments, tax incentives can also promote increased private investment in green energy projects.
- The government can establish and enforce policies and rules that encourage green energy innovation and provide fair playing conditions for green energy projects. Uniform laws and rules help lessen investor uncertainty and create a secure environment for green energy innovation.
- The government can offer financial incentives to individuals and companies that employ RE sources like solar and wind power. Public support for RE sources can be increased by raising awareness of green energy technology and educating the public about it.
- The suggested actions can help build a more robust and sustainable energy system and lessen the effects of climate change. The nation can minimize its carbon footprint and help the world transition to a more sustainable energy system by encouraging green energy innovation and lowering its dependency on fossil fuels.

The proposed regulatory changes will have a big impact on China's efforts to advance green energy innovation and sustainable development. The government can use these policies to increase public support for renewable energy sources, encourage private investment in green energy projects, and foster a secure investment environment for green energy innovation.

6.2 Limitations and future research

The study has various drawbacks that could be resolved in future studies. First, since the analysis was limited to China, it is possible that the conclusions cannot be applied to other regions. In order to conduct a more thorough study of the barriers to green energy innovation, future research could broaden the scope of the analysis to include particular regions or areas in that country. In addition, the proposed solutions to barriers to green energy innovation were based on the opinions of experts and might not accurately represent the desires and concerns of other stakeholders. In the future, surveys or focus groups with these stakeholders could be used to gather their perspectives and develop further strategies to remove the barriers. Finally, the proposed initiatives ignored the larger social and environmental effects of green energy development in favor of boosting green energy innovation in China. Future studies could conduct a thorough sustainability analysis of green energy development, taking into account the effects on the economy, society, and environment.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

Methodology: DW and JL. Formal analysis: YL. Investigation: DW. Data collection: YL. Writing—original draft preparation: DW, JL, and YL. Writing—review and editing: JL and YL. Funding acquisition: JL. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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