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Research article

Assessing and prioritizing drivers and strategies for transition to a green energy for sustainable development in China

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ABSTRACT

This study addresses the critical global challenge of climate change, primarily caused by the overconsumption of fossil fuels. Recognizing the urgent need for a transition to green energy (GE) sources such as wind, solar, hydro, and biomass, this research focuses on identifying effective strategies for fostering a sustainable and low-carbon energy future in China. The study employs a combination of the Analytical Hierarchy Process (AHP) and fuzzy Decision-making Trial and Evaluation Laboratory (DEMATEL), both well-established multi-criteria decision-making (MCDM) methods, to analyze various drivers, sub-drivers, and strategies crucial for this transition. Through an extensive literature review, we identified several key drivers and strategies aiding the shift towards GE for sustainable development. The AHP method was applied to evaluate and rank the major drivers and sub-drivers, such as policy, financing, and infrastructure and innovation, that are crucial for China's successful transition to GE. Simultaneously, fuzzy DEMATEL was utilized to prioritize vital strategies, including public awareness and education, financial incentives and support mechanisms, and policy and regulatory frameworks. The findings reveal that, in addition to strong policy and financial support, public awareness and education are critical for advancing GE development in China. This study underscores the importance of integrating various drivers and strategies for effective green energy development, aiming to mitigate the environmental impacts of fossil fuel use.

1. Introduction

An economic framework that relies on sustainable practices and commitment to the environment and is supported by renewable energy (RE) sources, including solar, wind, hydro, and geothermal power is referred to as green energy (GE) [1]. For organizations, governments, and society as a whole, this transformation requires a fundamental shift away from fossil fuels and toward clean energy, which brings both huge potential and problems. China, which understands the need to tackle environmental issues and pursue sustainable growth, has made great progress in making the transition to a GE [2]. The country has developed a number of regulations and incentives to stimulate the adoption of clean energy technology, and it has set ambitious objectives for the deployment of RE sources. China can continue to advance in its shift to a GE by concentrating its efforts on these important drivers and sub-drivers, supporting international efforts to combat climate change and achieve sustainable development [3]. Transitioning to GE is a complex challenge

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that extends beyond technological advancements to encompass economic, social, and political dimensions. This shift demands an integrated approach that fosters collaboration and coordination across various sectors and international boundaries. These collaborative efforts are essential to successfully navigate the complex landscape of green energy transition, ensuring that it is economically viable, socially responsible, and politically feasible [4].

The urgent need to lessen the effects of climate change is one of the primary motivating factors behind the shift to a GE. The world is on course to incur catastrophic environmental consequences unless immediate action is taken to cut greenhouse gas emissions, according to the Intergovernmental Panel on Climate Change (IPCC) [5]. The Paris Agreement, which seeks to keep global warming below 2 °C above pre-industrial levels, is only one example of the ambitious goals that numerous countries have made for reducing their carbon emissions [6]. Transitioning to a GE not only minimizes the effects of climate change but also offers enormous economic prospects. The RE sector has the potential to boost economic growth and add millions of new jobs [7]. By lowering reliance on imported fossil fuels, which may be exposed to price volatility and geopolitical hazards, it also increases energy security. But making the switch to a green economy is not without its difficulties. The field of RE is still in its infancy and faces tremendous financial and scientific obstacles. Government incentives and policies have a crucial role in the adoption of RE technologies, which also necessitate large infrastructure and research and development expenditures [8]. Additionally, resistance to change is common since it may have a detrimental impact on communities and sectors that depend on fossil fuels.

Given its status as the top emitter of greenhouse gases and its enormous economic growth, China's transition to a GE is crucial in the global context. The Chinese government has made impressive strides in embracing RE sources and putting policies and incentives in place to promote clean energy technologies. By recognizing the urgent need to solve environmental challenges while pursuing sustainable growth. As a result, China has established itself as a global leader in the use of RE and has set high goals for its growth. China may focus its efforts on major drivers while actively supporting global measures focused on tackling climate change and achieving sustainable development to further promote its transition to a GE. However, this change necessitates a comprehensive plan that integrates economic, social, political, and technological aspects, requiring cooperation and coordination amongst several stakeholders, including governments, lawmakers, investors, businesses, and consumers. China can play a significant role in reducing the consequences of climate change, fostering economic growth, and improving energy security while constructing a sustainable future by tackling these issues and utilizing its potential.

The global shift towards GE is not just an environmental imperative but also a complex socio-technical challenge [9]. This transition requires fundamental changes in energy production, distribution, and consumption practices [10]. Moving from viewing energy as a commodity to a sustainably and efficiently delivered service necessitates comprehensive infrastructure development, new regulatory frameworks, and technological innovations, alongside shifts in societal and consumer norms. The primary objective of this study is to systematically identify and evaluate the key factors - drivers, sub-drivers, and strategies - that are pivotal for a successful transition to GE, specifically in the context of China. This is achieved through the application of two robust multi-criteria decision-making methods (MCDM), i.e., the Analytical Hierarchy Process (AHP) and the fuzzy Decision-making Trial and Evaluation Laboratory (DEMATEL). The AHP method is employed to assess the various drivers and sub-drivers, integral to China's GE transition, while the fuzzy DEMATEL approach prioritizes the most impactful strategies for sustainable energy development in the country. The rationale behind this study lies in the recognition that transitioning to GE is a multifaceted process that requires coordinated efforts across different sectors. Understanding the key elements that drive this transition is critical for policymakers, investors, and stakeholders to focus their efforts and allocate resources effectively. The findings of this study aim to contribute valuable insights into the strategic planning and policy formulation necessary for fostering a sustainable and low-carbon energy future, thereby aiding not only China but potentially informing global practices in GE adoption.

The rest of the paper structure is as follows: Theoretical background is provided in Section 2. The identified drivers and sub-drivers of the study is presented in Section 3. The methodology framework is shown in Section 4. The results and discussion is given in Section 5. Finally, the conclusion and policy recommendations is presented in Section 6.

2. Theoretical background

GE research and interest have grown worldwide. This section will analyze technology, politics, financing, and public awareness as key elements of a successful GE economic transition. Technology drives the GE [11]. Solar and wind energy are becoming cost-competitive with fossil fuels. RE must be widely employed to reduce greenhouse gas emissions and climate change [12]. The paper states that solar and wind energy can meet the world's energy demands while lowering greenhouse gas emissions [13]. Policy impacts the GE transition. Feed-in tariffs, renewable portfolio requirements, and carbon pricing are examples of government policies and incentives that can support the adoption of RE technology and encourage the move away from fossil fuels [14]. Furthermore, laws that support energy efficiency, such as building codes and energy efficiency standards, can aid in lowering energy demand and enhancing energy usage efficiency. The effectiveness of various policy tools in supporting the deployment of RE technology was assessed in a study [15]. According to the study, carbon pricing was found to be less successful than feed-in tariffs and renewable portfolio standards in encouraging the development of RE technology. The study also emphasized the significance of policy predictability and stability in encouraging the use of RE sources [16]. Moreover, an earlier study focused on the quantitative assessment of renewable energy sustainability in 18 European countries from 2007 to 2016, using a comprehensive model combining the projection pursuit algorithm and the real-coded accelerating genetic algorithm [17]. It finds that Germany, the UK, France, and Italy lead in sustainability, influenced significantly by factors like total energy demand and emissions, and observes an overall wave-like growth in sustainable levels across the years. Another study employed the Pressure-State-Response (PSR) model along with 24 indicators to assess water resource sustainability in Beijing, China, for the years 2012 and 2016 [18]. Using the coefficient of variation method to calculate the weights of the indicators and a matter-element extension model to evaluate, it shows that Beijing's water resource sustainability stayed at a low level of efficiency for both years. This means that basic needs are met, but long-term sustainable use is not achieved.

The shift to GE is also significantly influenced by finance [19]. The transformation depends on investing in RE technology and infrastructure, which requires significant investment. Governments, multilateral organizations, and private investors are all significant financiers of the transition, and novel financing techniques like green bonds and climate funds are gaining popularity [20]. In one of the previous studies, the authors analyzed the function of finance in the shift to a green economy. The study concluded that government regulations and incentives are required to draw private investment and that access to finance is a crucial component of the implementation of RE technology [21]. So, the value of risk mitigation strategies, such as insurance and guarantees, is in lowering the perceived risks associated with making investments in RE. Public opinion and social acceptance are additional factors that affect the shift to a GE [22]. Demand for clean energy can be fueled by public awareness of and acceptance of RE technologies, as well as the need for a future that is sustainable and low in carbon emissions. Community participation in the transition can help overcome opposition to change and uncertainty [23]. The study found that public consultation, deliberative procedures, and citizen juries are necessary for the transition's success to ensure that the public's opinions and concerns are heard and considered [24]. The study also stressed openness and trust in decision-making.

Numerous studies have been conducted on economic factors, including the affordability of RE technology and the possibility for job growth [25]. For instance, a study [26] discovered that investment in renewable energy technology can have a significant positive impact on the economy, including the creation of new jobs and a rise in GDP. In the literature, the authors developed an innovative

Table 1
The identified drivers and sub-drivers for transitions to a GE.

Driver	Sub-driver	Description	Ref.
Technology	Renewable energy technologies	RE technologies are the foundation of GE. These technologies harness natural resources such as solar, wind, hydro, and geothermal power to generate electricity without emitting greenhouse gases. The development and deployment of RE technologies are critical for reducing greenhouse gas emissions and mitigating the impacts of climate change.	[37, 38]
	Energy storage technologies	Energy storage technologies are essential for integrating intermittent RE sources into the grid. These technologies, such as batteries and pumped hydroelectric storage, can store excess energy when it is generated and release it when demand is high, providing a more stable and reliable energy supply.	[39]
	Energy efficiency technologies	Energy efficiency technology minimizes energy use and boosts output in smart networks and energy-efficient buildings.	[40]
Policy	Feed-in tariffs	Feed-in tariffs assist sustainable development by subsidizing RE.	[41]
	Renewable portfolio standards	Renewable portfolio rules require utilities to generate a certain amount of electricity from renewable sources. This law may boost RE consumption and consumer demand.	[42]
	Carbon pricing	A carbon tax or a cap-and-trade system are two examples of a policy known as carbon pricing that places a cost on greenhouse gas emissions. This policy has the potential to encourage the transition away from fossil fuels and toward clean energy.	[43]
	Energy efficiency standards and building codes	Building codes and energy efficiency standards provide the minimal standards for the energy efficiency of buildings, vehicles, and appliances. This strategy can lower energy consumption and boost energy usage effectiveness.	[44]
Finance	Government funding and subsidies	The development and use of green energy technology can greatly benefit from government funding and subsidies. These monies can be used to promote infrastructure development for clean energy, financial incentives for clean energy companies, and research and development.	[45]
	Private investment	The research and application of RE technology can benefit from private investment, including venture capital and impact investing. Private investors may also provide knowledge and capital to help the RE industry expand.	[46]
	Innovative financing mechanisms	Innovative finance methods like green bonds and climate funds are becoming more and more popular for funding RE projects. With the help of these financing solutions, RE projects may be able to access new funding sources.	[47]
Public awareness and social acceptance	Education and awareness campaigns	This sub-driver helps explain green energy technology and the need for a low-carbon future. These efforts can dispel RE myths.	[48]
	Community engagement and participation	Concerns can be addressed and resistance to change can be overcome with the help of this sub-driver, which in turn helps encourage the transition to a GE.	[49]
	Trust and transparency in decision-making	Open, transparent, and inclusive decision-making processes build trust and address public concerns about green energy.	[50]
Infrastructure and innovation	Clean energy infrastructure	A GE requires transmission lines, energy storage systems and electric car charging stations. Clean energy infrastructure can accelerate RE technologies and sector growth.	[51]
	Digital infrastructure	Smart grids and energy management systems, for example, can aid in the implementation of RE sources and increase energy consumption efficiency.	[52]
	Research and development	Research and development of new technologies and processes can drive innovation and growth in the clean energy sector. This innovation can lead to breakthroughs in RE generation, energy storage, and energy efficiency.	[53]
	Entrepreneurship	Entrepreneurship and innovation in the clean energy sector can drive the growth of the sector and enable the development and deployment of new technologies.	[54]

Each of these drivers was broken down into sub-drivers, which are specific actions or policies that support the driver.

DPSIRM-RAGA-PP model to evaluate the sustainability of the shale gas industry, focusing on Chongqing and Sichuan in China, which account for over 90% of the country's shale gas production [27]. The model identifies water shortage, pollution, and pipe network density as key sustainability factors, while geological conditions, market risks, and core technology have lesser impacts. Besides, another study assessed the sustainability of renewable energy in 27 EU countries, using a comprehensive model to analyze energy, economy, society, and environment factors [28]. Key findings include Denmark and Sweden having the strongest sustainability, a general wave-like growth in sustainability over time, and a central European belt of countries with higher sustainable development. In the previous study, it was found that regional carbon emission efficiency in China was getting worse. To solve this problem, the researchers came up with a new method that combines a logarithmic mean divisia index with production theoretical decomposition analysis [29]. It reveals that most provinces, except Ningxia and Xinjiang, have improved energy utilization efficiency and are transitioning towards less carbon-intensive fossil energy. In 2019, Eurobarometer research found that the majority of Europeans support the development of RE sources and see it as crucial to combating climate change [30]. Aside from that, study by Ref. [31] highlighted the significance of good communication and public engagement tactics in encouraging public acceptance and participation in the transition.

The International Renewable Energy Agency (IRENA) has been at the forefront of research on the dynamics of changes in the green energy sector in both global and European studies [32]. Their studies, which include "Renewable Power Generation Costs in 2020″ and "Global Energy Transformation: A Roadmap to 2050," offer thorough analyses of the deployment of renewable energy, its costs, and various routes to a sustainable energy future [33]. Furthermore, studies by the European Commission, such as the "Renewable Energy Progress Report" and the "European Green Deal," shed light on the efforts made by the European Union to transition to a green economy and the corresponding policy developments [34].

The components that will aid in a seamless shift to a GE are interconnected and their relationships can be complex. For instance, incentives and legislation can encourage the use of RE technology, which can lower the cost of producing RE and boost customer demand. Similar to how political choices and the adoption of RE technologies can be influenced by public perception and social acceptance. In a study [35], evaluated the interdependences between the forces accelerating the shift to a GE. The study employed a systems thinking methodology to assess the efficacy of various policy interventions and uncover feedback loops and causal linkages among the drivers. The study discovered that cooperation and collaboration across sectors and countries are essential for the success of the transition and that policy, finance, and technology are interconnected drivers of the change. In another piece of work [36], evaluated the factors influencing China's transition to a GE using the AHP method. The most significant factors, according to the study, were policy, finance, and technology, with policy having the most impact on the other variables.

This study solved this challenging decision-making dilemma using the AHP and fuzzy DEMATEL methods. Moreover, there still room for more locally focused studies that can capture the distinctive challenges and opportunities of various regions and communities, even though many studies have evaluated the drivers in a global or national context. There is no one-size-fits-all method for switching to a GE; rather, regional factors like resource availability, political and social structures, and cultural norms can have a significant impact on the viability and efficiency of the transition.

3. The drivers and strategies for transition to a green energy in China

3.1. Identified drivers and sub-drivers

In the study, multiple key drivers and sub-drivers have been identified after a comprehensive set of literature reviews. These drivers are crucial for a successful transition to a GE in China. These drivers can be further broken down into sub-drivers, which are provided in Table 1.

3.2. Identified strategies for the development of green energy

In this study, several important strategies have been identified from the literature that are most feasible for the transition and development of green energy. These strategies would help through the identified drivers for successful energy development in China.

3.2.1. Energy efficiency measures

Implement energy-saving strategies in all industries to cut energy use and boost overall efficiency. Promoting energy-efficient industrial practices, appliances, and architectural designs are a few examples. To find potential for energy savings, promote the use of energy management systems and assist in energy audits [55].

3.2.2. Renewable energy infrastructure development

Ensure that the infrastructure for RE is improved and expanded. For a larger proportion of RE sources, this includes modernizing and expanding the grid systems [56]. To combat the erratic nature of RE, build electric vehicle charging infrastructure and invest in energy storage facilities.

3.2.3. Technology Innovation and research

Invest in R&D projects to encourage the development of new RE technology. This covers energy sources like the sun, wind, hydro, and bioenergy as well as methods for storing energy [57]. To hasten the development and commercialization of green energy technology, promote collaboration between business, academia, and government.

3.2.4. Financial incentives and support mechanisms

Create financial rewards and assistance programs to promote investment in green energy initiatives. This can involve providing customers and producers of RE with low-interest loans, subsidies, and tax breaks [58]. Establish green financing platforms to facilitate the financing of renewable energy projects for investors.

3.2.5. Public awareness and education

Encourage public education and awareness efforts to inform and involve the public about the advantages of switching to a GE. Moreover, increase public understanding of the negative effects that fossil fuels have on the environment and the benefits of RE sources [59]. Also, encourage a culture of sustainable energy use through educational campaigns and neighborhood projects.

3.2.6. Policy and regulatory framework

Create thorough policies and rules that create a welcoming environment for the switch to a GE. This entails establishing precise goals for RE, passing supportive legislation, and expediting the regulatory and approval procedures for projects involving RE [60]. Finally, to guarantee that green energy regulations are implemented effectively, strengthen the enforcement and compliance measures.

These strategies, when implemented holistically, can drive the transition to a GE in China, contributing to sustainable and low-carbon development.

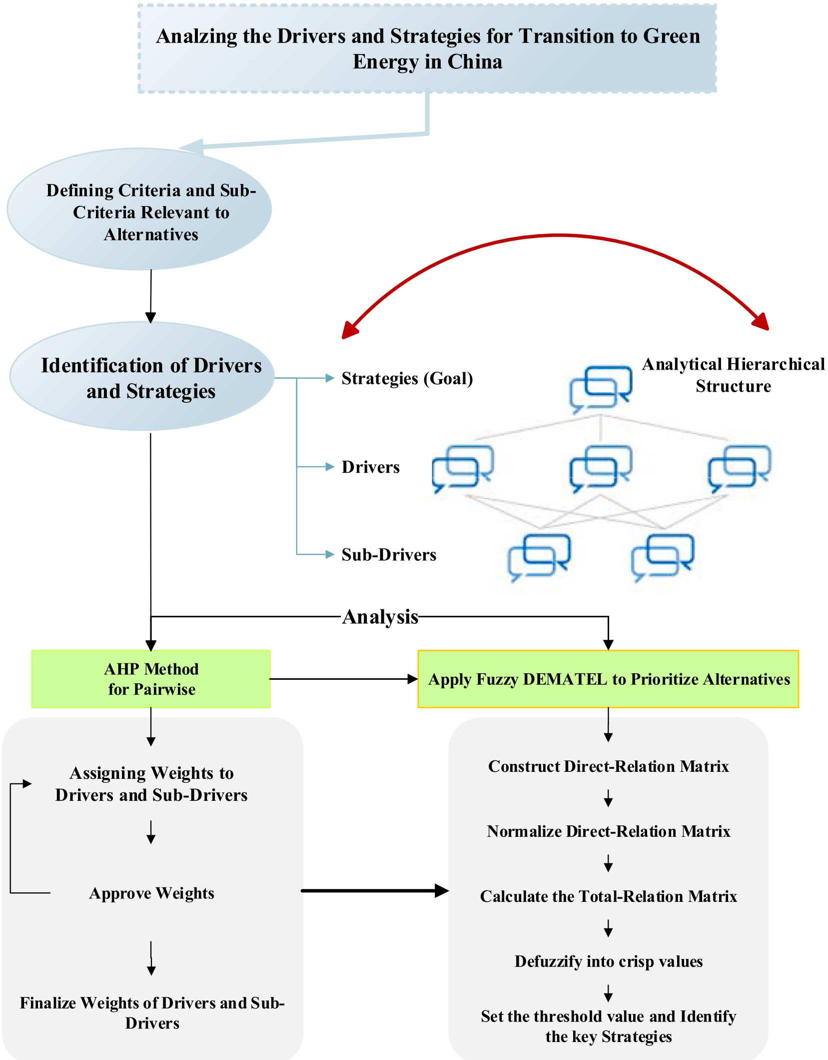

Fig. 1. Study framework.

4. Methodology

In this study, we adopted the AHP and fuzzy DEMATEL methods as an analysis. The AHP method is used to assess the drivers and sub-drivers, while fuzzy DEMATEL method is used to prioritize the key strategies for shifting to sustainable and low-carbon future in China. The AHP method has been widely recognized for its ability to simplify and quantify complex decision-making scenarios, as evidenced in numerous studies across different fields [61–63]. Similarly, the fuzzy DEMATEL method has been undertaken for its ability to handle ambiguity and complexity in data, making it a popular choice in multidimensional analyses [64,65]. Fig. 1 presents the methodology of this study.

4.1. AHP method

AHP is the most widely used MCDM technique for handling complex decision-making problems [58]. This method offers a way of breaking down the difficult problem into a hierarchy of sub-problems that are then further appraised subjectively. Later, the subjective evaluations are reduced to numbers and grouped to rate each choice on a scale. In the 1970s, Thomas L. Saaty created the AHP methodology, which is carried out utilizing the stages below [66].

Step 1. The decision problem is divided into several levels using an aim, a set of criteria, and a set of sub-criteria.

Step 2. Data were gathered from the decision-makers in accordance with the hierarchy structure using pairwise comparison of the criteria on a numerical scale, as shown in Fig. 2 [67].

Step 3. Comparing the comparison matrix's principal eigenvalue and normalized eigenvector assigns relative importance to the criterion.

Step 4. Compute the Consistency index (CI):

$$CI = \frac{(\lambda \max - n)}{(n-1)} \tag{1}$$

Where n is the number of judgmental elements and λ max is the judgment matrix's maximum eigenvalue. The consistency ratio (CR) is determined as follows:

$$CR = \frac{CI}{RI} \tag{2}$$

where the RI is called Random Consistency Index. Table 2 shows the RI values of a randomly created pairwise comparison matrix. According to Saaty, the consistency ratio (CR) value should be less than 0.1; for values higher than 0.1, meaningless results may be obtained [68].

4.2. Fuzzy DEMATEL method

The fuzzy DEMATEL technique provides an accurate representation of the relationships between the detected items by allowing for uncertainty and imprecision in the decision-making process [69]. This method is used to understand and analyze the cause-and-effect relationships within a group of factors or criteria in various fields. It is particularly useful in situations where the interactions between factors are complex and not easily quantifiable. By incorporating fuzzy logic into DEMATEL, the method becomes capable of handling the uncertainty and vagueness that is often inherent in human judgments and perceptions. The fuzzy scale employed in the model is displayed in Table 3. The following steps are involved in the fuzzy DEMATEL technique [64,70].

Step 1a. Create the fuzzy direct-relation matrix:

$$z = \begin{bmatrix} 0 & \cdots & \tilde{z}_{n1} \\ \vdots & \ddots & \vdots \\ \tilde{z}_{1n} & \cdots & 0 \end{bmatrix} \tag{3}$$

Step 2. Normalize the fuzzy direct-relation matrix:

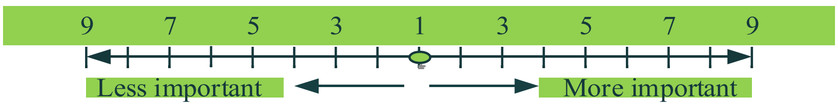

Fig. 2. Pair-wise comparison matrix scale.

Table 2
Random consistency index scale.

n	1	2	3	4	5	6	7	8	9	10
Random Index	0.00	0.00	0.058	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The AHP steps applied to prioritize the key drivers and sub-drivers for a successful transition to a GE.

Table 3
Fuzzy scale.

Code	Linguistic terms	L	M	U
1	No influence	1	1	1
2	Very low influence	2	3	4
3	Low influence	4	5	6
4	High influence	6	7	8
5	Very high influence	8	9	9

$$\widetilde{x}_{ij} = \frac{\widetilde{z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right) \tag{4}$$

where

$$r = \max_{i,j}\left\{\max_i \sum_{j=1}^{n} u_{ij}, \max_j \sum_{i=1}^{n} u_{ij}\right\} \tag{5}$$

$$i,j \in \{1,2,3,\ldots,n\}$$

Step 3. Calculate the fuzzy total-relation matrix:

$$\widetilde{T} = \lim_{k\to+\infty}\left(\widetilde{x}^1 \oplus \widetilde{x}^2 \oplus \ldots \oplus \widetilde{x}^k\right) \tag{6}$$

If each element of the fuzzy total-relation matrix is expressed as $\widetilde{t}_{ij} = (l''_{ij}, m''_{ij}, u''_{ij})$, it can be calculated as follows:

$$\left[l''_{ij}\right] = x_l \times (I - x_l)^{-1} \tag{7}$$

$$\left[m''_{ij}\right] = x_m \times (I - x_m)^{-1} \tag{8}$$

$$\left[u''_{ij}\right] = x_u \times (I - x_u)^{-1} \tag{9}$$

After computing the inverse of the normalized matrix and deducting it from the initial matrix I, the normalized matrix is multiplied by the resulting matrix.

Step 4. Defuzzify into crisp values:

A crisp value of the total-relation matrix was obtained using the Defuzzification within a multicriteria decision model (CFCS) method suggested by Opricovic and Tzeng [71]. The following are the steps of the CFCS method:

$$l^n_{ij} = \frac{\left(l^t_{ij} - \min l^t_{ij}\right)}{\Delta^{max}_{min}} \tag{10}$$

$$m^n_{ij} = \frac{\left(m^t_{ij} - min\ l^t_{ij}\right)}{\Delta^{max}_{min}} \tag{11}$$

$$u^n_{ij} = \frac{\left(u^t_{ij} - min\ l^t_{ij}\right)}{\Delta^{max}_{min}} \tag{12}$$

So that, $\Delta^{max}_{min} = \max u^t_{ij} - \min l^t_{ij}$.

Determining the normalized values' upper and lower bounds:

$$l_{ij}^{s} = m_{ij}^{n} \Big/ \left(1 + m_{ij}^{n} - l_{ij}^{n}\right) \tag{13}$$

$$u_{ij}^{s} = u_{ij}^{n} \Big/ \left(1 + u_{ij}^{n} - l_{ij}^{n}\right) \tag{14}$$

The output of the CFCS algorithm is crisp values.
Calculating total normalized crisp values:

$$x_{ij} = \frac{\left[l_{ij}^{s}\left(1 - l_{ij}^{s}\right) + u_{ij}^{s} \times u_{ij}^{s}\right]}{\left[1 - l_{ij}^{s} + u_{ij}^{s}\right]} \tag{15}$$

Step 5. Set the threshold value:

The internal relations matrix requires the threshold value. The network relationship map (NRM) ignores partial relations. The NRM only shows relations with matrix T values bigger than the threshold. Calculating the matrix T's average values yields the related threshold value. After determining the threshold intensity, any matrix T values below the threshold value are set to zero, ignoring the causal relation described before. This study's threshold is 0.3650. Matrix T values below 0.3650 are set to zero, ignoring the causal linkage.

Step 6. Final output and create a causal relation diagram:

The next step is to find out the sum of each row and each column of T. The sum of rows (D) and columns (R) can be calculated as follows:

$$D = \sum_{j=1}^{n} T_{ij} \tag{16}$$

$$R = \sum_{i=1}^{n} T_{ij} \tag{17}$$

Then, the values of D + R and D-R can be calculated by D and R, where D + R represent the degree of importance of factor *i* in the entire system and D-R represent net effects that factor *i* contributes to the system.

Step 7. Interpret the findings

By recognizing the strategies, policymakers and corporate executives may allocate resources and prioritize efforts to ensure sustainable development based on the transitions to a GE in China.

4.3. Data analysis

In this study, to ensure a thorough understanding of the key factors influencing the transition to GE in China, we conducted a detailed data collection process by engaging with a group of five experts through a webmail service. This group included policymaker, who provided insights on regulatory and legislative frameworks; industry expert, offering perspectives on market dynamics and technological advancements in the GE sector; investor, sharing their views on financial aspects and investment trends; academic researchers, contributing their knowledge on the latest scientific developments and sustainability considerations. This multifaceted approach allowed for a comprehensive analysis of the decision-making problem in transitioning to GE. To systematically evaluate the complex factors involved in this transition, we employed the AHP and the fuzzy DEMATEL. The AHP method was specifically utilized to identify and prioritize the drivers and sub-drivers of the transition, breaking down the problem into manageable components and evaluating them in a structured hierarchy. Conversely, the fuzzy DEMATEL method was applied to determine and rank the key strategies required for the shift towards a sustainable and low-carbon energy future in China. This combination of methodologies ensured a robust and comprehensive analysis of the drivers, sub-drivers, and strategies essential for the effective implementation of GE initiatives.

4.4. Case analysis

China has demonstrated considerable progress in its transition to GE, especially in solar, wind, and hydropower. This is supported by a range of policies and incentives, establishing the country as a global leader in energy manufacturing. Notable policy measures include feed-in tariffs and tax incentives, which have been instrumental in promoting the adoption of clean energy technologies [72,73]. The AHP in this context has identified several key drivers and sub-drivers in the transition to GE. Furthermore, the fuzzy DEMATEL method has been employed to prioritize strategies for this transition. The findings suggest that efforts should be focused on enhancing financial support and incentives for RE technologies, strengthening regulatory and policy frameworks, fostering public awareness and acceptance, encouraging energy-efficient practices, and promoting international collaboration. These strategies are vital for reinforcing China's commitment to sustainable energy and its role in the global transition to cleaner energy solutions.

5. Results and discussion

The drivers, sub-drivers, and key strategies for a successful transition to a GE in China have been analyzed and ranked using the AHP and fuzzy DEMATEL techniques. In the sub-sections, we determined the findings with special focus on a GE in China. The detailed analysis is given in the supplementary section of this paper.

5.1. Results of drivers using AHP

In this section, we determine the findings of main drivers. Table 4 presents the ranking of drivers with respect to the goal of the study. The results indicate that policy is the most critical driver in the transition to a GE in the context of China. This reflects the importance of policy frameworks that incentivize the deployment of green energy technologies, promote energy efficiency, and reduce greenhouse gas emissions [74]. Finance is considered a second vital driver, which reflects the importance of mobilizing capital and investment to support the deployment of green energy technologies and infrastructure. Moreover, infrastructure and innovation is observed as the next crucial driver; this shows the importance of investing in clean energy infrastructure and supporting innovation to enable the deployment and integration of RE sources. Technology is recognized as the fourth most important driver. Finally, public awareness and social acceptance are revealed to be the least crucial drivers in the transition to a GE in China.

5.2. Results of sub-drivers using AHP

The AHP method also identified and determined the weight and ranking of sub-drivers for each key driver. Fig. 3 displays the ranking of sub-drivers related to technology. From a technology driver perspective, the results indicate that RE technologies are the most important sub-driver. While this sub-driver is critical for achieving a sustainable and low-carbon energy system, they are dependent on the support of energy storage and energy efficiency technologies to maximize their effectiveness. Energy efficiency technologies and energy storage technologies are considered second and third most important sub-drivers, respectively. Since energy efficiency technologies are important for reducing energy demand and mitigating the need for new energy generation capacity, as well as reducing energy costs for consumers and businesses.

From a policy driver perspective, the findings show that carbon pricing is the most crucial sub-driver in the transition to a GE, followed by renewable portfolio standards, feed-in tariffs, and energy efficiency standards and building codes. Fig. 4 shows the ranking of sub-drivers related to the policy driver. Carbon pricing mechanisms such as carbon taxes and cap-and-trade systems are essential for incentivizing the adoption of clean energy technologies and reducing greenhouse gas emissions [14]. Renewable portfolio standards require a certain percentage of electricity to be generated from RE sources, providing a clear and long-term signal for the deployment of RE technologies. Feed-in tariffs additionally offer a financial incentive for the adoption of RE technologies, especially for small-scale producers.

According to the findings, the most important sub-driver in the shift to a GE is creative financing structures, which are followed by private investment, government funding and subsidies. The ranking of sub-drivers associated with finance is shown in Fig. 5. While private investment in RE projects can provide significant capital and expertise to support the transition to a GE, innovative financing mechanisms such as green bonds, crowdfunding, and public-private partnerships can also provide new sources of capital for RE projects and accelerate the transition to a GE [75].

From a public awareness and social acceptance driver perspective, the analysis specifies that trust and transparency in decision-making is the most dynamic sub-driver in the transition to a GE, followed by education and awareness campaigns and community engagement and participation. Fig. 6 shows the ranking of sub-drivers related to public awareness and social acceptance. Building trust and transparency in decision-making can help to improve public support and engagement in the transition to a GE, as well as increase accountability and reduce the risk of opposition from stakeholders. Education and awareness campaigns can help to increase public awareness and understanding of the benefits and importance of a GE, as well as reduce misinformation and disagreement [76]. Whereas community engagement and participation are essential for building support and promoting inclusivity in the transition to a GE, they are perceived as less critical than trust and transparency in decision-making and education and awareness campaigns.

From an Infrastructure and innovation driver viewpoint, the outcomes reveal that research and development is the most critical sub-driver in the transition to a GE, followed by entrepreneurship, clean energy infrastructure, and digital infrastructure. Fig. 7 shows the ranking of sub-drivers associated with infrastructure and innovation. Research and development can drive innovation and technological advancements in RE and energy efficiency, as well as reduce costs and improve performance. Entrepreneurship can support the development and deployment of new and innovative solutions for the transition to a GE, as well as promote private sector

Table 4
Ranking of drivers based on the goal of the study.

Driver	Weight	Rank
Technology	0.164	4
Policy	0.264	1
Finance	0.231	2
Public awareness and social acceptance	0.135	5
Infrastructure and innovation	0.205	3

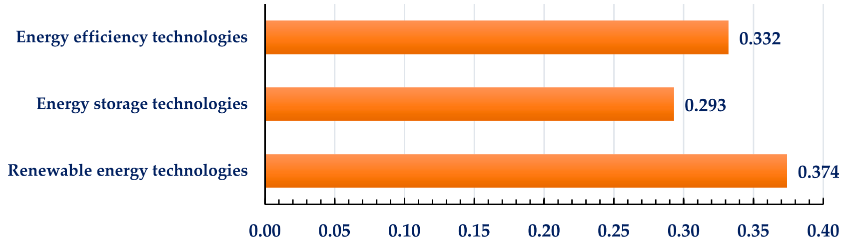

Fig. 3. Ranking of sub-drivers from a technology perspective.

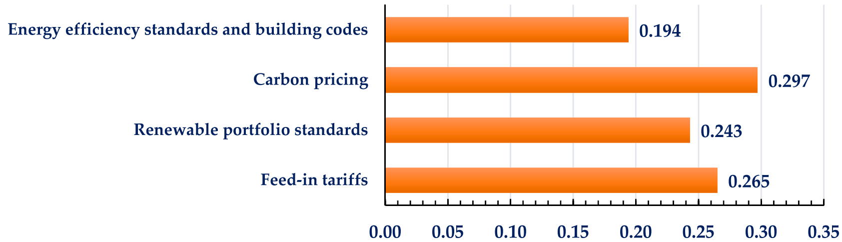

Fig. 4. Ranking of sub-drivers from a policy perspective.

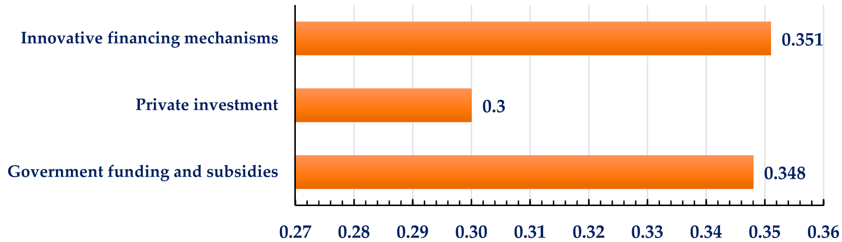

Fig. 5. Ranking of sub-drivers from a finance perspective.

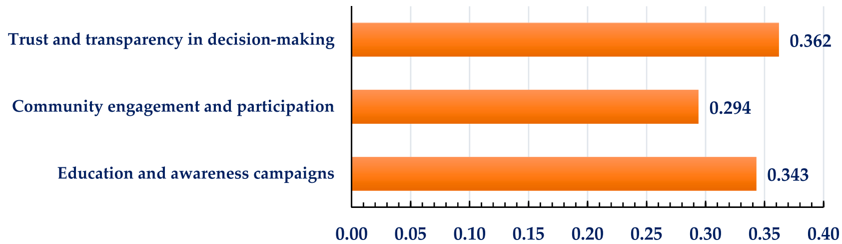

Fig. 6. Ranking of sub-drivers from public awareness and social acceptance perspective.

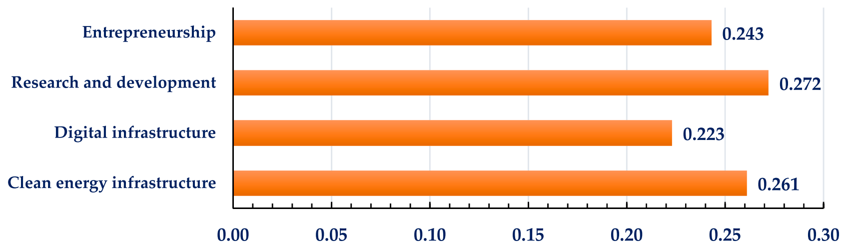

Fig. 7. Ranking of sub-drivers from infrastructure and innovation perspective.

investment and participation [54]. Furthermore, clean energy infrastructure, including transmission and distribution networks, can support the deployment and integration of RE sources into the grid. Lastly, digital infrastructure, such as smart grid technologies, can improve grid efficiency and support the integration of RE sources.

5.3. Results of overall sub-drivers using AHP

In this sub-section, the results of the overall sub-drivers have been identified using the AHP method. The overall weight has been obtained by multiplying the main drivers weight by their particular sub-driver. Table 5 presents the ranking of sub-drivers with respect to the decision-making goal of this study. The findings indicated innovative financing mechanisms.

5.4. Results of strategies using fuzzy DEMATEL

The model of relevant relations is shown in Fig. 8. The values of (D + R) can be plotted on the horizontal axis of a diagram, while the values of (D-R) can be plotted on the vertical axis. The coordinate system determines the position of each factor and how it interacts with a point in the coordinates (D + R, D-R).

Fig. 8 shows the following criteria that can be used to evaluate each factor. The horizontal vector (D + R) shows the relative weight that each factor has inside the whole system. In other words, (D + R) represents both the influence of factor on the system as a whole and the influence of other system components on the factor. In terms of degree of importance, public awareness and education is ranked in first place, followed by financial incentives and support mechanisms, and policy and regulatory framework. In addition, the vertical vector (D-R) indicates the extent to which a factor influences the system. In general, a causal variable is represented by a positive value of D-R, while an effect is represented by a negative value of D-R. in terms of degree of importance, Public Awareness and Education is priortized in top place and Financial Incentives and Support Mechanisms, Policy and Regulatory Framework, RE Infrastructure Development, Technology Innovation and Research and Energy Efficiency Measures, are ranked in the next places.In this study, RE Infrastructure Development, Technology Innovation and Research, Financial Incentives and Support Mechanisms, Policy and Regulatory Framework are considered to be as a causal variable, Energy Efficiency Measures, Public Awareness and Education are regarded as an effect.

5.5. Discussion

The AHP and fuzzy DEMATEL are dominant methods of MCDM for determining the weights among the drivers, sub-drivers, and strategies of a transition to a GE in China. The analysis can provide valuable understandings for achieving a sustainable and low-carbon future. The outcomes would show that the drivers and strategies for a successful shift to a GE are interdependent, and that of the transition depends on the effective coordination and integration of these drivers and strategies. The study also demonstrates that some drivers, sub-drivers, and strategies are more essential than others, so governments, investors, and other stakeholders must prioritize their efforts and resources.

The emphasis on technology, particularly solar and wind energy, in our study aligns with literature asserting the increasing cost-competitiveness of renewable energy sources with fossil fuels [11,12]. This underlines the continuous need for technological advancement and widespread deployment to meet energy demands sustainably. Our analysis underscored the critical role of policy in driving the GE transition, resonating with the literature that highlights the effectiveness of government initiatives like feed-in tariffs and renewable portfolio standards [14]. This concurrence suggests that policy predictability and stability are vital for encouraging renewable energy adoption, aligning with findings that view policy as a major influence on renewable energy development [15]. The

Table 5
The overall weights of sub-drivers.

Sub-driver	Weight	Final rank
Renewable energy technologies	0.061	7
Energy storage technologies	0.048	14
Energy efficiency technologies	0.054	9
Feed-in tariffs	0.070	4
Renewable portfolio standards	0.064	6
Carbon pricing	0.078	3
Energy efficiency standards and building codes	0.051	11
Government funding and subsidies	0.080	2
Private investment	0.069	5
Innovative financing mechanisms	0.081	1
Education and awareness campaigns	0.046	15
Community engagement and participation	0.039	17
Trust and transparency in decision-making	0.048	13
Clean energy infrastructure	0.053	10
Digital infrastructure	0.045	16
Research and development	0.055	8
Entrepreneurship	0.049	12

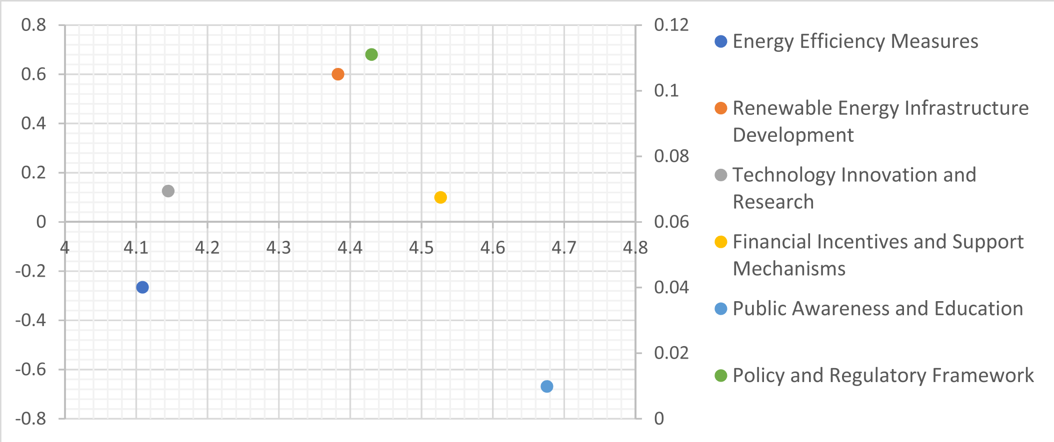

Fig. 8. The cause-effect diagram.

significance of finance in transitioning to GE identified in our study parallels previous research that emphasizes the necessity of investment in renewable energy technologies and infrastructure [19,20]. This is consistent with the notion that government regulations and incentives are pivotal in attracting private investment and that risk mitigation strategies are crucial for reducing investment uncertainties in renewable energy [21]. Moreover, the findings on the importance of public awareness and social acceptance in the GE transition are supported by literature stating that public consultation and involvement are essential for successful energy transitions [22–24]. This reinforces the idea that fostering a positive public perception and ensuring community participation are key to overcoming resistance and uncertainty in adopting new technologies.

The AHP method ranks policy as the most important aspect in a successful GE transition, followed by finance, infrastructure, and innovation. IRENA identified four primary drivers: enabling frameworks, investment, innovation, and skills and capacity building [77]. These drivers will help society adopt RE for sustainable development [78]. These components are similar to those in the AHP technique, with finance and policy playing important roles as bridging elements. The importance of innovation, skill development, and capacity building is also emphasized in the IRENA study even though these components are not explicitly listed as sub-drivers in the AHP approach. This suggests that policymakers, investors, and other stakeholders should concentrate on encouraging technological innovation and building the necessary skills and capacity to support the adoption of clean energy technologies [79]. Innovation and capacity development should be seen as crucial sub-drivers for the success of the transition. Technology, policy, and investment were identified as being crucial for a smooth transition to a future powered by sustainable energy, according to a separate study by the International Energy Agency (IEA) [80]. These factors—which are comparable to those found in the MCDM analysis—highlight the requirement for strong legislative and financial frameworks for encouraging the use of RE technology. Energy efficiency is a key sub-driver for the shift, according to the IEA analysis [81]. In order to reduce energy consumption and speed the adoption of clean energy technology, it is said that policies, investors, and other stakeholders should emphasize energy efficiency, and that actions should be done to promote and encourage energy efficiency measures [82]. The findings of this study broadly concur with findings from prior investigations into the variables influencing the growth of an economy based on RE sources.

6. Conclusion and implications

The successful transition to GE involves the coordinated integration of various drivers, sub-drivers, and strategies in China. The AHP and fuzzy DEMATEL methods have proven to be effective techniques for assessing these critical factors. These methods enable a comprehensive evaluation of the essential components required to establish a sustainable and low-carbon future in China.

The findings from the AHP highlight key drivers in the transition to GE, namely policy, financing, infrastructure, innovation, technology, and the critical roles of public awareness and societal acceptance. These insights are pivotal for facilitating the shift to GE. Based on these findings, several recommendations can be proposed to support this transition. These include implementing supportive regulatory and policy frameworks for clean energy, enhancing public awareness about clean energy benefits, promoting energy efficiency measures, and bolstering international cooperation and collaboration. The case study focusing on China demonstrates the applicability of the AHP technique to a specific national context. It explicates the primary factors influencing the move towards GE and offers targeted areas for policymakers and other stakeholders to focus on, thereby accelerating the transition process.

Furthermore, the fuzzy DEMATEL method has been employed to prioritize strategies for this transition. The results indicate that enhancing public awareness and education emerges as the top strategic priority, followed closely by the development of financial incentives and support mechanisms, as well as the establishment of a strong policy and regulatory framework. By focusing on these strategies, policymakers and stakeholders can collaboratively work towards a sustainable and low-carbon future.

6.1. Practical implications

A number of practical implications stem from China's move to GE. These are.

1 Strengthening policies with regulations and incentives to promote renewable energy technologies, crucial for guiding the transition.
2 Implementation of financial mechanisms such as feed-in tariffs, tax incentives, and subsidies to encourage investment in renewable energy.
3 Establishing efficient systems for monitoring and enforcing environmental legislation and targets to ensure compliance.
4 Opportunities for growth in renewable sectors and challenges for fossil fuel-dependent industries to adapt to a low-carbon economy.
5 Encouraging the development and marketing of sustainable products and services, leading to economic growth and job creation.
6 Fostering energy conservation and sustainable practices at the community and individual levels, enhancing local employment opportunities and energy accessibility.

6.2. Limitations and future direction

The study is limited by the subjective assessment of the experts using a pairwise comparison matrix. Future research might use a wider range of participants and data sources, including public opinion polls or an examination of energy market patterns, in order to lessen this limitation. The analysis assumption of a static link between the drivers and sub-drivers may not accurately reflect the dynamic and evolving character of the shift to a GE. A future study might use dynamic modeling methods, such as system dynamics or agent-based modeling, to replicate the behavior of the system over time and capture any feedback loops and nonlinearities that may exist in the transition. This would help to overcome the limitation. Future research should investigate the relevance of the MCDM methods to other fields, such as sustainable agriculture, water resource management, or the circular economy, and compare the analysis' efficacy to that of other methods for making decisions.

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CRediT authorship contribution statement

Juan Yang: Writing – review & editing, Supervision, Resources, Methodology, Formal analysis. **Run Li:** Writing – review & editing, Visualization, Investigation, Funding acquisition. **Yasir Ahmed Solangi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that there is no conflict of interest with anyone else.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e25685.

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