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Enhancing China's energy security: Determining influential factors and effective strategic measures

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ABSTRACT

This study investigates the most influential factors affecting China's energy security. It also identifies the most effective strategic measures for enhancing it. Fuzzy AHP has been used to determine weights for ranking the importance of Chinese energy security factors, and it has also been used to determine the priorities of the strategic measures with respect to enhancing those same factors. The study argues that a low proportion of renewable energy penetration is the most severe factor threatening China's energy security, and that conducting research and development on energy technologies and improving energy efficiency is the most salient, positive, and necessary strategic measure.

1. Introduction

Energy security, which means to ensure adequate and reliable energy supplies at reasonable prices to sustain economic prosperity, has recently received significant attention by commercial, industrial, and government actors [1]. China, as the world's second largest economy, has become the largest primary energy consumer and also the largest CO_2 emitter around the world [2]. Energy consumption in China is expected to increase by two- or even threefold between 2000 and 2020 in lock-step with the continuously rapid growth of its GDP [3]. The implication here is that the energy security threats posed by its consumption and its emissions will only become more severe over time. Furthermore, the environmental pollution associated with energy production such as serious air pollution [4] continues to grow. Social stability in rural China can be impinged by energy systems such as riots caused by building hydroelectric dams without adequate public participation [5]. Even the geopolitical security of China can be threatened by energy issues such as the ongoing conflict over resources in the South China Sea [6].

As such, we believe that Chinese stakeholders, policymakers, and decision makers need to become more attuned and aware of threats to Chinese energy security, and strategic measures that can best mitigate those threats. However, there are various barriers that prevent China from sustaining its energy prosperity, and there are also many different strategic measures that have been proposed to enhance China's energy security. Thus, China's stakeholders, policymakers, and decision makers usually face two puzzles. Firstly, what are the most influential factors that have significant effects on China's energy security? Secondly, what are the most effective strategic measures to enhance China's energy security? By answering these two questions, China's administrators, as well as analysts and researchers concerned with China, can better understand both the weak points of China's energy security and the effects of the strategic measures on overcoming these weak points. Once these are better comprehended, research can more effectively identify policies and implementation strategies to guarantee secure energy supply in China.

In other words, the objective of this study is to help China's stakeholders, policymakers, and decision makers identify the key factors that have significant effects on China's energy security and also find the most effective strategic measure for enhancing it by ranking the influential factors and prioritizing the strategic measures. The ranking of the influential factors is based on their importance in terms of their influences on China's energy security, and the prioritization of the strategic measures is based on their effects on enhancing China's energy security by determining the integrated effects on those influential factors.

A few words about methods are required before we proceed. As for the determination of the importance of the influential factors, there are many methods such as Delphi [7] and Analytic Hierarchy Process (AHP) [8], and AHP has been more frequently utilized since

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Nomenclature

$\widetilde{A}$	fuzzy number $\widetilde{A}$
$\tilde{a}$	fuzzy number $\tilde{a}$
a	the first element in the triplet for representing the fuzzy number $\widetilde{A}$
a^L	the first element in the triplet for representing the fuzzy number $\tilde{a}$
a^M	the second element in the triplet for representing the fuzzy number $\tilde{a}$
a^U	the third element in the triplet for representing the fuzzy number $\tilde{a}$
AHP	Analytic Hierarchy Process
b	the second element in the triplet for representing the fuzzy number $\widetilde{A}$
$\tilde{b}$	fuzzy number $\tilde{b}$
b^L	the first element in the triplet for representing the fuzzy number $\tilde{b}$
b^M	the second element in the triplet for representing the fuzzy number $\tilde{b}$
b^U	the third element in the triplet for representing the fuzzy number $\tilde{b}$
c	the third element in the triplet for representing the fuzzy number $\widetilde{A}$
d	is the ordinate of the highest intersection point between μ_{M_1} and μ_{M_2}
$d'(x_i)$	the i-th element in the weight vector W'
$d(x_i)$	the i-th element in the weight vector W
F_1	low reserves of primary energies per captia
F_2	low energy utilization efficiency
F_3	serious environmental problems caused by energy utilization
F_4	high dependence on imports
F_5	high risk of oil transportation route
F_6	low proportion of renewable energies
F_7	low market liquidity
$g_j(j = 1, 2, \ldots, m)$	the i-th goal
k	the arbitrary real value k
l_{gi}^j	the first element in the triplet for representing the fuzzy number M_{gi}^j
$M_{gi}^j(j = 1, 2, \ldots, m)$	extent analysis value for the i-th object regarding to the j-th goal
m_{gi}^j	the second element in the triplet for representing the fuzzy number M_{gi}^j
P_i	the priority of the i-th strategic measure
p_{ij}	he performance of the i-th strategic with respect to the j-th influential factor
S_i	the value of fuzzy synthetic extent with respect to the i-th object
ST_1	going out' strategy to seek energy supplies
ST_2	developing renewable and alternative options
ST_3	'cap-and-trade Policy' to control and reduce emission
ST_4	R&D on energy technologies: focusing on efficiency and conservation
ST_5	education of consumers for energy saving and low-carbon life
ST_6	improving the security of geopolitics and enhancing military power
ST_7	new cross-boarding oil pipelines
ST_8	developing small-scale and decentralized energy systems
ST_9	promoting the diversity of import sources
ST_{10}	establishing transparent market pricing mechanisms
U	goal set
u_{gi}^j	the third element in the triplet for representing the fuzzy number M_{gi}^j
$V(S_i \geqslant S_j)$	the degree of possibility of $S_i = (l_i, m_i, u_i) \geqslant S_1 = (l_j, m_j, u_j)$
W	the normalized weight vector
W'	the weight vector
x	the arbitrary real value
X	object set
$x_i(i = 1, 2, \ldots, n)$	the i-th object

Greek symbols

$\mu_{\widetilde{A}}(x)$	the membership of x belongs to fuzzy number $\widetilde{A}$
$\mu_{\tilde{B}}(x)$	the membership of x belongs to fuzzy number $\tilde{B}$
$\mu_{\widetilde{A}\cap\tilde{B}}(x)$	the 'and' operation between $\mu_{\widetilde{A}}(x)$ and $\mu_{\tilde{B}}(x)$
$\mu_{\widetilde{A}\cup\tilde{B}}(x)$	the 'or' operation between $\mu_{\widetilde{A}}(x)$ and $\mu_{\tilde{B}}(x)$
ω_j	the weight of the j-th influential factor of energy security

it decompose a complex system into several subsystems [9,10]. That said, AHP relies on a scale of 1–9 to assess the intensity of preference between two elements, so it does not perform optimally for some decision making problems due to vagueness, ambiguity and subjectivity of human judgments [10]. Thus, in this study we rely on fuzzy set theory combined with AHP (i.e., fuzzy Analytic Network Process) to overcome this drawback [11,12].

As for the prioritization of the strategic measures, it is based on determining the priorities of their integrated effects on the influential factors, thus, it is a multi-criteria decision making (MCDM) problem. There are many MCDM methods such as AHP [10], grey relational analysis [13], Analytic Network Process [14], TOPSIS [15], PROMETHEE [16], extension theory [17], ELECTRE [18], and Data Envelopment Analysis (DEA) [19,20]. However, these MCDM methods are usually extended and improved when combined with fuzzy theory. It is easy for the stakeholders/decision-makers to use linguistic terms to express their opinions, and these linguistic terms can be transformed into fuzzy numbers by fuzzy theory [21]. In the prioritization of the strategic measures, it is also difficult for the stakeholders/decision-makers to use crisp numbers to express the effects of the strategic measures on the influential factors, so fuzzy theory based MCDM method is a prerequisite.

In this paper, we rely on fuzzy Analytic Hierarchy Process (AHP) to accomplish both of these tasks, firstly determining the most influential factors affecting Chinese energy security and secondly determining the priorities of the strategic measures with respect to each of the influential factors, then determining the most effective strategies for addressing these threats by aggregating the priorities into a weighted index. The remainder part of this study is organized as follows: Section 2 presents the method used in this study for prioritizing Chinese energy security concerns. Then, fuzzy theory and fuzzy AHP are introduced in Section 3. The results and discussion are presented in Section 4. Finally, Section 5 presents the study's conclusions.

2. Prioritizing Chinese energy security concerns

There are various studies which define the concept of energy security and establish criteria for evaluating it [22–28], and among these, the four 'A's method developed by the Asia Pacific Energy Research Center [28] is perhaps the most efficacious. The four A model can characterize the multi-dimensional and complex nature of energy by using 'Availability', 'Accessibility', 'Affordability' and