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A framework for evaluating global national energy security

Qiang Wang [a,b], Kan Zhou [c,d,*]

[a] College of Geographical Sciences, Fujian Normal University, Fuzhou 350007, China
[b] State Key Laboratory of Subtropical Mountain Ecology, Fujian Normal University, Fuzhou 350007, China
[c] Key Laboratory of Regional Sustainable Development Modelling, Chinese Academy of Sciences, Beijing 100101, China
[d] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

HIGHLIGHTS

- We construct an evaluation framework to identify global spatial disparities in national energy security.
- The framework considers three dimensions: energy supply chain, energy consumption, and political-economic environment.
- The study identifies key deficiencies affecting the energy security performance of several country types.
- We recommend policy prescriptions based on the evaluation results.

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ABSTRACT

Unlike most ES evaluation frameworks in the literature, this study provides a new evaluation technique based on the integrated application of subjective and objective weight allocation methods—SOWA (Subjective & Objective Weight Allocation), and introduces a balance score matrix (BSM) highlighting how well a country manages the trade-offs between the three competing dimensions for evaluating global national energy security. The results show that countries are struggling to develop a comprehensively secure energy system, with only one country out of 162 achieving an 'Excellent' score and 37 countries achieving a 'Good' score, together accounting for approximately one-fourth of the sampled countries. Meanwhile, the spatial disparity in the global performance of national ES is very significant: 'Excellent' and 'Good' groups are concentrated in Western Europe and North America, while the 'Limited' are concentrated in Europe, Middle East and Asia; the 'Weak' and 'Poor' groups are concentrated in Africa and Asia. Overall, this proposed framework allows for the quick identification of deficiencies within three dimensions in the ES context by pinpointing the main weaknesses. The study also offers suggestions for improving the performance of countries in different categories.

1. Introduction

Since the 2000s, the importance of energy security (ES) has been increasing as a public issue amidst concerns among scholars and policymakers driven by rising volatility in energy prices, scarce fossil fuels, pressure to de-carbonize energy systems, and geopolitical supply tensions [1–4]. However, contemporary ES studies differ from historical ones in important ways. During the 1970s and 1980s, ES concerns focused on a stable supply of cheap oil due to the threat of embargoes and price manipulation by exporters [5,6]. Today, ES has returned to the public eye not only because of energy supply issues but also because of its close linkage with other energy policy problems, such as equitable access to modern energy and the mitigation of climate change [7]. Moreover, the centres of energy disturbance extend from America and Europe to Asia, and oil and gas reserves remain concentrated in a few politically unstable countries, such as those in the Middle East [8–10]. ES is undeniably one of the key parameters required for determining the current position and future orientation of development in all countries [11].

Defining ES precisely is difficult, and numerous definitions have been offered by researchers and policymakers. Given the growing dominance of fossil fuels, the liberalization of energy markets, escalating energy demand in developing nations, and continuous instability due to political unrest and large-scale natural disasters, the prior usage of the term 'ES' had been enhanced by a focus on securing the supply of two primary energy sources: oil and gas.

* Corresponding author at: Key Laboratory of Regional Sustainable Development Modelling, Chinese Academy of Sciences, No. 11 Datun Road, Chaoyang District, Beijing 100101, China.
E-mail address: zhoukan2008@126.com (K. Zhou).

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Therefore, ES is commonly defined as the reliable and adequate supply of the primary energy at reasonable prices. The use of this definition can be found in the publications of the UNDP [12], Bielecki [1], IEA [13], Müller-Kraenner [14], Chester [15], and Cabalu [16]. Usage of the term has also been deeply influenced by geopolitics [17–22]. Diversification is another key issue that determines energy availability and security in ES studies such as those of Jansen et al. [23] and Thangavelu et al. [24]. Energy conversion and delivery infrastructure in the energy supply chain have also been discussed; a good infrastructure is a commonly suggested prerequisite for stable energy supplies and an important component of economic security [22,25]. As global warming and air pollution have received increasing attention, the recent literature has recognised the importance of the close relationship between environmental sustainability and energy consumption [26–30]. Nevertheless, ES also consists of political and governmental dimensions, such as the social stability of the energy supply, as suggested by Chevalier [31], Jansen et al.[23], and Brown et al. [32], and effective energy planning for national ES, as proposed by Goldthau and Sovacool [33] and Yao and Chang [34]. Some studies extend ES concepts to include the efficient use of energy and the improvement of communities' living environment. For instance, Kemmler and Spreng [35] included 'promoting energy efficiency and reducing energy intensity' as a main policy for tackling ES problems, and Hughes argued similarly [36]. Lesbirel posited that ES should ensure that a population has adequate access to energy sources to sustain acceptable levels of social and economic welfare [37]. Vivoda held that a new ES conceptualization must consider providing basic energy services such as access to electricity, which has been ignored by the traditional conceptualization of ES [38]. These definitions in the literature reflect seven major ES themes or dimensions: energy availability, infrastructure, energy prices, societal effects, environment, governance, and energy efficiency. Following recent developments in the literature, ES can be defined as 'equitably providing available, affordable, reliable, efficient, environmentally benign, proactively governed and socially acceptable energy services to end-users' for the purpose of this study, as stated in Sovacool and Brown's review of the ES literature [39].

In addition, researchers have shown a growing interest in establishing a methodology for quantitatively assessing national ES. A number of scientific assessment methods of approaching ES from various angles have been proposed. A recent comprehensive literature survey by Ang et al. [40] indicates considerable diversity among studies that identify ES indicators/indices; the number of ES dimensions ranges from 1 to 20 and the number of indicators ranges from 1 to 320. Meanwhile, as surveyed by Radovanović et al. [41], 11 methodologies have been identified as the most commonly used measures of ES: the Herfindahl-Hirschmann Index, Supply/Demand Index for the long-term security of supply, the Oil Vulnerability Index, the Vulnerability Index, Risky External Energy Supply, Socioeconomic Energy Risk, the US Energy Security Risk Index, the Energy Sustainability Index developed by the World Energy Council (WEC) in association with Oliver Wyman, MOSES—The IEA Model of Short-term Energy Security, the Energy Security Index developed by the EU Joint Research Centre in Italy, and the Energy Architecture Performance Index (EAPI) proposed by the World Economic Forum (WEF). Seeking a balance between maximising comprehensiveness and being pragmatic given data scarcity, Tongsopit et al. [42] and Yao and Chang [34] used fewer dimensions but retained a meaningful and rigorous evaluation of ES. Both studies examined national ES performance through social, economic, and environmental dimensions.

Several observations can thus be made from a literature review on issues concerning the definition and assessment of ES. First, comprehensive dimensions such as economic, environmental, and social dimensions are widely used to define the concept of ES and evaluate national or regional ES performance. Second, comprehensive and comparative analyses of national ES are increasingly important for informing policymakers on energy policies [42]. Third, subjective weight allocation is the most widely used aggregation method [43] among ES assessment studies with comprehensive dimensions. The assessment can never be absolutely accurate, but it should attempt to be as realistic as possible, as Ang et al. [40] assert. In this sense, ample opportunity remains to develop the evaluation method and choices related to the scale and variables.

This paper seeks to comprehensively and systematically assess the overall performance of 162 countries' energy systems, thereby highlighting their spatial disparities, and providing a new evaluation technique based on the integrated application of subjective and objective weight allocation methods, SOWA, which are rarely used in existing studies. In addition, unlike in most ES frameworks in the literature, BSM, a balance score matrix highlighting how well a country manages the trade-offs between these three competing dimensions, is introduced. The benefits of using this scoring system include interpretability, non-linear scaling, and reduced decisive influence from a specific dimension. The framework's application leads to interesting results, and their policy implications are discussed. We expect this study to enrich our knowledge and understanding of ES issues.

The remainder of the paper is organised as follows. In Section 2, the assessment framework, the methodology for calculating the Energy Security Index (ESI), and data sources are briefly presented. Section 3 presents the spatial pattern of national ES across the globe and compares it with those obtained by other studies. Section 4 analyses the average results for each geographic region and the classification of countries in each region. Finally, conclusions and suggested policy paths are presented in Section 5.

2. Material and methodology

Though several approaches to measuring ES have been developed, policymakers constantly struggle to find the proper indicators and approaches that will help formulate stronger energy policies. We construct our ESI in three steps. First, a framework addressing the scope, objectives, and structure of the indicator selection is proposed. Second, the selected indicators are normalised to address the different measuring units used for the indicators. Finally, the normalised indicators are weighted according to their perceived importance and then aggregated to form a composite index.

2.1. Hierarchical structure for energy system assessment

Among the variety of methodologies, two basic approaches can be used to assess ES: the supply-orientated approaches and the methods that apply composite indices. The supply-oriented approaches, which mainly include the Herfindahl–Hirschmann index, supply/demand index, risky external energy supply index, and the IEA Model of Short-term Energy Security (MOSES), are extremely useful methods that emphasize the safety in procuring and transporting energy generating products. However, these models do not incorporate social and environmental concerns when measuring ES. The second set of approaches, including the oil vulnerability index, vulnerability index, socioeconomic energy risk index, US energy security risk index, energy sustainability index, energy security index, and energy architecture performance index, is regarded as acceptable for ES assessments because it allows the use of different indicators according to the researchers'