Adjusting energy polices based on the Energy Trilemma Index

Shuai Wu*

Tsinghua-Berkeley Shenzhen Institute, Tsinghua University, Shenzhen, 518071, China

Abstract. In response to the imperative of climate change, global governments are steering energy systems towards sustainability. However, this transition encounters challenges from climate, geopolitical, and economic factors. Decision-makers must craft adaptive policies to address these complexities. This study proposes a method, utilizing the Energy Trilemma Index, to adjust energy goals and policies. Drawing on World Energy Council data spanning 2000 to 2022 for 124 countries, the Analytic Hierarchy Process refines policies at strategic, indicator, and operational levels. Using China as a case study, the study recommends that decision-makers prioritize environmental investment, equitable resource distribution, and strengthened energy security.

1 Introduction

To address the challenges posed by climate change, governments worldwide are progressively steering their energy systems towards a green, clean, and sustainable transformation. However, this energy transition process confronts multifaceted challenges, not only from the direct impact of extreme weather conditions but also from geopolitical and economic complexities. Consequently, decision-makers must formulate rational and flexible energy policies to address these intricate energy issues. To assist decision-makers in formulating and adjusting energy policies to address the complex and dynamic challenges in the energy sector, prior research has frequently employed comprehensive assessment methods to evaluate the status of energy systems as feedback for energy policies. In these researches, the Energy Trilemma Theory proposed by the World Energy Council (WEC) has garnered widespread attention [1]. This theory emphasizes that energy policies should not only consider energy security but also simultaneously address energy equity and environmental sustainability. Energy security involves evaluating a nation's capacity to ensure a secure and stable energy supply and establish a resilient energy system. Energy equity assesses whether an energy system can cover a sufficient number of citizens and provide services to them at an affordable price. Environmental sustainability signifies the capability to establish an energy system that is energy-efficient, green, and low-carbon. The Energy Trilemma Theory posits a complex triangular relationship among these three goals, presenting a challenge for energy policies to balance and trade-off these objectives during their pursuit, which has become a focal point of researchers' attention.

In related studies based on the Energy Trilemma Theory, several scholars have conducted applied research [2-4]. For instance, Heffron applied the Energy Trilemma Theory to study energy prices in Indonesia. By proposing node-based, regional, and national electricity pricing models, he provided policy recommendations for the government. This theoretical-based applied research contributes to a deeper understanding of how the Energy Trilemma manifests in specific countries or regions. Additionally, some scholars focus on the interaction between other factors and the Energy Trilemma [5-6]. Marti, for example, used cluster analysis to study the impact of a country's economic development on the ranking of the Energy Trilemma Index. The study found that high-income countries with low GDP growth rates tend to have higher rankings, although there is no such correlation for sub-indices. The author speculated that these countries ranked higher due to stable political and economic environments, enabling them to flexibly implement economic measures. Furthermore, some scholars concentrate on exploring how to address the Energy Trilemma [7]. Poudineh analyzed the role of smart grids in transitioning to a new energy paradigm, suggesting that, despite the challenges for the existing power sector in avoiding the Energy Trilemma, the development of smart grid technology offers prospects for resolving this issue. Weiss simulated the energy transition process in Switzerland using models, studying the impact of international and domestic policies on short-term and long-term energy policies. The study emphasized that a profound understanding of the interrelationships between policies is essential for efficiently achieving low-carbon development goals. These studies provide valuable insights and methods for addressing the challenges posed by the Energy Trilemma.

However, there is a significant gap between existing approaches and the goals of energy research. Faced with complex and dynamic energy issues, current research lacks a systematic method to adjust energy strategic goals and policies based on the evaluation results of the Energy Trilemma Index. In order to address these issues, this study proposes a method based on the Energy Trilemma...
Index to adjust energy strategic goals and policies. Additionally, this adjustment method takes into account the new expectations of decision-makers regarding energy strategic goals, aligning them more closely with real-world needs. To achieve this research goal, the study utilizes data from the Energy Trilemma Index published by the World Energy Council, which evaluates the energy system conditions of 124 countries globally from 2000 to 2022 across the dimensions of energy security, energy accessibility, and environmental sustainability. Based on this data, the study employs the Analytic Hierarchy Process (AHP) to systematically adjust energy policies at three levels: modifying energy strategic goals, adjusting energy indicators, and refining specific energy policies. Finally, using China's Energy Trilemma Index data as an example and integrating it with China's energy strategic goals, the study provides recommendations for adjusting China's energy policies using the Analytic Hierarchy Process. The results of this study demonstrate that, in the face of various challenges such as international geopolitics, economics, and extreme climate conditions, China should comprehensively and equitably enhance its energy system performance. Firstly, China should increase investments in the environmental sector to effectively reduce the adverse environmental impacts of the energy system. Secondly, there is a need to progressively enhance energy equity, ensuring a more balanced distribution of resources. Finally, efforts should be directed towards consolidating and strengthening energy security to ensure China's resilience and sustainability in energy supply.

In comparison to previous studies, our research contributes in several key aspects:

- We propose a method to adjust energy strategic goals and policies based on the evaluation results of the Energy Trilemma Index. Compared to other energy policy management tools, this method can assist policymakers in dynamically adjusting energy policies to address complex and evolving energy issues.
- We have provided recommendations for the adjustment of China's energy policies using the Analytic Hierarchy Process (AHP). The AHP, as a qualitative and quantitative integrated, systematic, and hierarchical analysis method, offers policymakers effective references and suggestions tailored to the national context for the formulation of energy policies.
- We have incorporated subjective judgments from decision-makers and expert teams, emphasizing their viewpoints on energy strategic goals and policy expectations. Through this supplementary perspective, we ensure that our adjustment proposals align closely with decision-makers' expectations and practical requirements.

2 Conclusion

2.1 Data Source

The secondary data utilized in this study is derived from the World Energy Council's Energy Trilemma Index, which assesses the energy system conditions of 124 countries globally from 2000 to 2022. The fundamental raw data for the Energy Trilemma Index originate from approximately 60 well-known publicly available datasets, including IEA World Energy Balances, World Energy Prices, and Emissions, as well as the World Bank Getting Electricity report. Subsequently, these raw data are consolidated into 20 sub-indicators, each assigned weights by experts based on their respective significance. Ultimately, all sub-indicators are aggregated into three dimensions: energy security, energy equity, and environmental sustainability.

2.2 China's Energy System Status

Figure 1 introduces the Energy Trilemma Index data of China. Based on the evaluation data, China's Energy Balance Index has shown a significant improvement from 56.8 to 65.3 during the period from 2000 to 2022. The global ranking has advanced from 90th to 40th, marking a progress of 50 positions and making China the second-highest improver in Energy Trilemma Index ranking. In terms of energy security, China's overall energy security score has exhibited an upward trend, increasing from 63 to 66.28, maintaining an A-grade rating. The global ranking among 124 countries has progressed from 31st to 27th, achieving a gain of 4 positions, emphasizing China's achievements in ensuring energy supply and enhancing energy security. Regarding energy equity, China's score has consistently risen from 47.26 to 71.8 between 2000 and 2022, resulting in an upgrade from C to B rating. The global ranking among 124 countries has improved from 75th to 66th, indicating a significant advancement and reflecting China's substantial efforts in fair energy network development and resource allocation. Additionally, while the Environmental Sustainability score has experienced some fluctuations, the overall trend has been positive, increasing from 44.29 to 59.38, leading to an upgrade from D to C rating. The global ranking among 124 countries has progressed from 119th to 93rd, showing a 26-position improvement, reflecting China's efforts in prioritizing environmental protection and sustainable development. In summary, China has made remarkable progress in energy balance over the past two decades, particularly in energy equity and environmental sustainability. In terms of energy security, China has maintained a high level and achieved certain accomplishments.

![Energy Trilemma Index data of China (2000-2022).](image)
2.3 China's Energy Strategic Direction

The Chinese government has committed to achieving carbon peaking by 2030 and carbon neutrality by 2060, forming the central focus of China's energy policy. Therefore, ensuring energy security and equity while promoting the green and low-carbon transformation of the energy system, gradually achieving carbon peaking and neutrality over the coming decades, is a core consideration in China's energy policy formulation [8]. In the fourteenth Five-Year Plan for Economic and Social Development, the Chinese government further clarified the strategic overall goal. By the end of 2025, it aims to achieve a green transformation in production and lifestyle, rationalize energy resource allocation, significantly improve utilization efficiency, and reduce energy consumption and carbon dioxide emissions per unit of GDP by 13.5% and 18%, respectively. These binding requirements provide a clear direction for the comprehensive optimization and green upgrading of China's energy system.

2.4 Recommendations for Adjusting China's Energy Strategic Goals

<table>
<thead>
<tr>
<th>Scale</th>
<th>Rating</th>
<th>Scale</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely preferred</td>
<td>9</td>
<td>Moderately to strongly</td>
<td>4</td>
</tr>
<tr>
<td>Very strongly to extremely</td>
<td>8</td>
<td>Moderately preferred</td>
<td>3</td>
</tr>
<tr>
<td>Very strongly preferred</td>
<td>7</td>
<td>Equally to moderately</td>
<td>2</td>
</tr>
<tr>
<td>Strongly to very strongly</td>
<td>6</td>
<td>Equally preferred</td>
<td>1</td>
</tr>
<tr>
<td>Strongly preferred</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Based on the 1-9 scale proposed by Saaty in table 1, a judgment matrix J in table 2 representing energy policy was obtained after pairwise comparisons for three dimensions.

<table>
<thead>
<tr>
<th>Energy Equity</th>
<th>Energy Security</th>
<th>Environmental Sustainability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>2</td>
<td>1/3</td>
</tr>
<tr>
<td>1/2</td>
<td>1</td>
<td>1/4</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

The criteria for the judgment matrix were determined based on China's energy system status and decision-makers' directional choices. In this context, environmental sustainability is moderately to significantly more important than energy security, assigned a score of 4; environmental sustainability is moderately more important than energy equity, assigned a score of 3. Between energy equity and energy security, energy equity is slightly more important than energy security, assigned a score of 2. Subsequently, a consistency check was performed on the judgment matrix, resulting in the consistency matrix S in table 3.

By calculation, \[ \lambda = 3.018337257 \], \[ Cl = 0.004584314 \], \[ RI = 0.52 \], \[ CR = 0.008815989 \], passing the consistency check.

Combining the above calculation results, the weights for each dimension can be determined: the weight for environmental sustainability is 0.62, for energy equity is 0.24, and for energy security is 0.14. This weight allocation reflects the relative importance of each dimension in adjusting China's energy policy.

<table>
<thead>
<tr>
<th>Energy Equity</th>
<th>Energy Security</th>
<th>Environmental Sustainability</th>
<th>( w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.222</td>
<td>0.286</td>
<td>0.211</td>
<td>0.24</td>
</tr>
<tr>
<td>0.111</td>
<td>0.143</td>
<td>0.158</td>
<td>0.14</td>
</tr>
<tr>
<td>0.667</td>
<td>0.571</td>
<td>0.632</td>
<td>0.62</td>
</tr>
</tbody>
</table>

2.5 Recommendations for Adjusting China's Energy Polices

After clarifying the weights of energy strategic indicators, the next step involves adjusting specific energy policies. From 2000 to 2022, China has made significant progress in its energy system concerning energy security, energy equity, and environmental sustainability, reflecting the effectiveness of China's energy policies. Therefore, the purpose of policy adjustment is to maintain the existing policies while further increasing investment in policies aimed at enhancing the environmental sustainability dimension.

In terms of environmental sustainability, firstly, China should continue to promote an energy consumption revolution by restraining irrational energy consumption, adhering to the priority of energy conservation, and improving total energy consumption management to comprehensively enhance energy efficiency. These efforts aim to foster a production and lifestyle that conserve energy and use green energy, accelerating the construction of an energy-saving society. Secondly, China should drive an energy technology revolution, considering it a key driver for industrial upgrading. To achieve this goal, China is committed to strengthening basic research, common technology, and disruptive technological innovations, emphasizing the integration innovation of digitalization, big data, artificial intelligence, and technologies for the clean and efficient development and utilization of energy.

Regarding energy equity, the Chinese government should continue to increase infrastructure investment in the energy network to expand the coverage of modern clean energy. China should persist in the decisive role of the market in resource allocation, promote market-oriented reforms in the energy sector, and establish a unified, open, and orderly competitive energy market. Additionally, China should focus on innovating the legal system for energy, improving industry regulatory systems.
to provide a more stable operating environment for the market.

Finally, the Chinese government should continue to increase investment in the dimension of energy security. Firstly, China should advance an energy revolution by accelerating the development of non-fossil energy, constructing a clean, low-carbon, safe, and efficient energy system to enhance energy supply security. Secondly, China should pay attention to the construction of the coal, electricity, oil, and gas production-supply-storage-sales system, the improvement of energy transmission networks, and storage facilities to improve the quality and security capabilities of energy supply. Lastly, China should comprehensively strengthen international cooperation and strive to achieve energy security under open conditions.

2.6 Future research directions

Given the protracted and ever-evolving nature of climate change, scholars should thoroughly investigate the enduring patterns and prospective hurdles within the energy system. This undertaking becomes paramount in furnishing indispensable assistance to decision-makers, enabling them to craft policies adept at accommodating imminent transformations. Future research initiatives can strategically capitalize on the annual unveiling of the World Energy Council’s Energy Trilemma Index, harnessing it as a valuable mechanism to appraise the efficacy of energy policies. By implementing the methodologies articulated in this study, researchers are aptly positioned to systematically fine-tune energy policies, effectively navigating the intricate and dynamic challenges inherent in the energy landscape. Such scholarly pursuits not only contribute substantively to the strategic policymaking process but also offer a nuanced foundation for the formulation of adaptive policies capable of deftly responding to the fluid nature of energy challenges.

2.7 Summary

Based on the aforementioned results and discussions, the conclusions are obtained as below:

- The findings indicate that China has made significant progress in energy system situation over the past two decades, particularly in terms of energy equity and environmental sustainability. In the realm of energy security, China has maintained a high level and achieved notable accomplishments, reflecting the effectiveness of China’s energy policies.
- Confronted with multifaceted challenges such as international geopolitics, economics, and extreme climatic conditions, China should intensify its investments in the environmental sector to effectively mitigate the adverse environmental impacts of the energy system.
- It is concluded that China’s energy policies need to gradually enhance energy equity to ensure more equitable resource allocation. Additionally, there is a need to consolidate and strengthen energy security, ensuring that China’s energy supply is more resilient and sustainable.

References