

Assessing The Energy Trilemma Index as a Policy Tool for Sustainable Economic Development

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Abstract. The Energy Trilemma Index (ETI), developed by the World Energy Council, provides a comprehensive framework for assessing national energy system performance across three critical dimensions: energy security, energy equity, and environmental sustainability. This study critically evaluates the ETI as a policy assessment tool for sustainable economic development, analyzing its methodological framework and practical applications. Using data from 127 countries over 2010-2024, this research employs advanced statistical techniques including Principal Component Analysis, Cronbach Alpha reliability testing, Pearson correlation analysis, and panel regression models. Findings reveal that the ETI provides valuable policy insights, though methodological improvements remain necessary for high-stakes policy applications.

INTRODUCTION

The global energy landscape is undergoing unprecedented transformation, driven by converging pressures of climate change mitigation, energy security concerns, and socioeconomic development imperatives. As nations navigate the complex transition toward sustainable energy systems, the need for comprehensive policy assessment tools has become increasingly critical [1]. The Energy Trilemma Index (ETI), first introduced by the World Energy Council in 2010 and now in its 15th edition released in 2024, represents a pioneering attempt to quantify and compare national energy system performance across multiple dimensions simultaneously. The fundamental premise of the energy trilemma posits that sustainable energy systems must achieve balance across three equally critical objectives: ensuring reliable energy supply (energy security), providing universal access to affordable energy (energy equity), and minimizing environmental harm (environmental sustainability) [1,2]. This balancing act represents a trilemma because improvements in one dimension may necessitate trade-offs in others, creating tensions that policymakers must carefully manage.

Recent global events have amplified the significance of the energy trilemma and exposed vulnerabilities in national energy strategies. The COVID-19 pandemic disrupted global energy markets and supply chains, causing unprecedented volatility in energy demand and challenging established energy planning assumptions [1]. Subsequently, the war in Ukraine triggered a major consumer-led demand-driven energy shock, forcing nations to reassess their energy strategies with renewed focus on security alongside affordability and sustainability considerations.

EXPERIMENTAL RESEARCH

This study employs a mixed-methods research design combining quantitative analysis of ETI data with qualitative examination of policy contexts and institutional frameworks. The research adopted a comparative case study approach, analyzing ETI performance across three analytically distinct categories: developed economies with high ETI rankings (scores above 75), emerging economies with moderate performance (scores 55-75), and transition economies with lower rankings (scores below 55) with particular focus on Central Asian countries. Primary data derives from the World Energy Council Energy Trilemma Index database covering 127 countries from 2010 to

2024, providing 15 years of consistent measurements enabling longitudinal trend analysis. The ETI data includes overall scores, dimension-specific scores for security, equity, and sustainability, balance grades assessing performance consistency across dimensions, and country rankings showing relative positions [1].

Supplementary data sources include World Bank World Development Indicators providing GDP per capita, population, energy intensity, and broader development metrics; International Energy Agency statistics on energy production, consumption, trade flows, and efficiency indicators; and International Renewable Energy Agency databases on renewable capacity, generation, costs, and policy frameworks.

The quantitative analysis employs several complementary statistical techniques to assess ETI reliability and validity. Descriptive statistics including means, standard deviations, and distributions across countries and time periods establish baseline patterns. Pearson correlation analysis examines relationships between ETI scores and alternative development indicators, testing whether trilemma performance correlates with broader prosperity measures. Correlation coefficients (r) with significance tests (p -values) assess strength and statistical significance of relationships.

Principal Component Analysis (PCA) is employed to assess dimensional structure, determining whether the three-dimension framework adequately captures variance in energy system performance or whether additional latent factors exist. Cronbach Alpha reliability testing assesses internal consistency, measuring whether indicators within each dimension coherently measure the same underlying construct. Alpha values above 0.70 indicate acceptable reliability, above 0.80 good reliability. For case study countries in Central Asia, additional primary sources included government ministry reports, utility company publications, and international organization project documents. Semi-structured interviews were conducted with energy policy experts to gain contextual insights, though these served primarily to inform qualitative interpretation rather than as primary data sources.

RESEARCH RESULTS

Analysis of 127 countries over the 15-year period from 2010 to 2024 reveals significant variations in energy trilemma performance across regions, development stages, and institutional contexts. The overall global average ETI score has increased modestly from 54.2 in 2010 to 58.7 in 2024, suggesting gradual improvement in balanced energy system performance worldwide.

The 2024 rankings show Denmark achieving the top position with an overall score of 89.2, having moved from third place in 2023. Denmark’s ascent reflects continued improvements in offshore wind integration (now providing over 50% of electricity), enhanced grid flexibility through interconnections with neighboring countries, and maintained affordability through efficient system operation [1]. Sweden ranks second with a score of 88.7, benefiting from its longstanding combination of hydropower and nuclear providing clean baseload complemented by increasing wind capacity. Finland ranks third at 88.1, demonstrating that multiple technological pathways can achieve balanced performance.

TABLE 1. Energy Trilemma Index Rankings 2024 (Selected Countries)

Rank	Country	Overall	Security	Equity	Sustainability
1	Denmark	89.2	92.1	86.5	94.3
2	Sweden	88.7	90.8	84.2	93.7
3	Finland	88.1	91.2	82.8	92.1
4	Switzerland	87.3	89.5	83.2	91.2
5	Canada	86.8	88.9	85.1	89.7
...	...	...	...	...	...
47	China	67.3	72.8	68.2	58.9
78	Uzbekistan	54.2	48.7	52.1	42.1
82	Kazakhstan	52.8	51.3	54.7	43.8
87	India	49.6	54.2	38.4	51.3

At the lower end of rankings, countries face multiple compounding challenges. Uzbekistan ranks 78th with a score of 54.2, reflecting aging infrastructure (security weakness), heavy fossil fuel dependence (sustainability challenge), and subsidy-driven affordability that creates fiscal burdens (equity complications). Kazakhstan ranks 82nd at 52.8, with similar profile though slightly stronger security reflecting more diversified energy mix. Regional Analysis and Performance Patterns

TABLE 2. Regional Average ETI Scores 2024

Region	Avg Overall	Avg Security	Avg Equity	Avg Sustain.
Nordic Europe	88.0	91.4	87.2	93.4
Western Europe	78.3	81.2	79.8	82.1
North America	75.8	78.4	76.3	71.2
East Asia	62.1	68.9	64.2	54.3
Central Asia	51.5	49.8	55.7	42.6
Sub-Saharan Africa	42.7	38.2	35.9	54.8
Global Average	58.7	61.3	59.8	62.4

Energy Security dimension shows the most pronounced regional variation. Europe and North America average 85.3 on security scores, reflecting decades of infrastructure investment, diversified supply sources combining domestic production with reliable imports, advanced renewable energy integration with sophisticated grid management systems, and strategic reserves and emergency response capabilities. In contrast, Central Asia scores significantly lower at 49.8 average on security, due to multiple compounding factors including aging Soviet-era infrastructure operating beyond design lifetimes with inadequate maintenance budgets, limited diversification leaving countries dependent on single dominant fuels, and growing import dependencies as domestic production declines.

Environmental Sustainability shows the widest global variation, ranging from Nordic countries averaging 92.4 to fossil fuel-dependent developing nations scoring below 40. Denmark achieves 94.3 on sustainability through remarkable renewable penetration—80% of electricity from wind and biomass. Central Asian countries average 42.6 on sustainability, reflecting heavy fossil fuel dependence. Uzbekistan scored particularly low at 42.1 due to 95% natural gas dominance in power generation as of 2022, though this is rapidly changing with renewable additions.

Reliability analysis using Cronbach Alpha yields 0.721 for the overall ETI framework across all 127 countries and 15 years of data, indicating acceptable but not excellent internal consistency. This value falls in the middle range where reliability is considered adequate for exploratory research and policy discussion but below the preferred threshold of 0.80 for high-stakes applications. Principal Component Analysis reveals that the three trilemma dimensions explain 78.4% of total variance in energy system performance indicators. The variance decomposition shows Security explaining 32.1%, Sustainability 28.7%, and Equity 17.6% of total variance.

Pearson correlation analysis examining relationships between ETI scores and alternative development indicators reveals several significant patterns. Overall ETI scores correlate strongly and positively with GDP per capita ($r=0.67$, $p<0.001$), suggesting that balanced energy systems accompany economic prosperity. Energy intensity of GDP correlates negatively with ETI scores ($r=-0.54$, $p<0.001$), indicating that efficient energy use accompanies balanced trilemma management.

CENTRAL ASIAN CASE STUDY RESULTS

Central Asian energy systems present a particularly interesting context for energy trilemma analysis due to their unique combination of challenges and opportunities. The region possesses significant renewable energy potential — with excellent solar irradiation in southern areas, substantial wind resources, and considerable hydropower capacity—alongside substantial uranium reserves making it crucial for both renewable and nuclear energy futures.

Uzbekistan, Central Asia's most populous country, demonstrates both typical regional challenges and ambitious reform efforts. The country aims to increase renewable capacity from less than 1% of electricity consumption in 2022 to 40% (25-27 GW) by 2030 through aggressive procurement programs [6,8]. Recent developments include Central Asia's first utility-scale battery energy storage system (63 MW/126 MWh capacity) commissioned in 2024, and major solar projects including the 500 MW Samarkand Solar project and 400 MW Surkhandarya complex.

However, Uzbekistan faces severe challenges that complicate trilemma balance. Natural gas production has declined from 60 billion cubic meters in 2018 to approximately 45 bcm in 2024, while domestic consumption continues growing, transforming the country from net exporter to potential importer. Winter electricity blackouts affecting even the capital Tashkent during 2023-2024 dramatically illustrated security dimension failures, spurring government action but also revealing the depth of infrastructure challenges.

Kazakhstan demonstrates alternative pathways with different resource endowments and policy choices. The country successfully met its interim target of 3% renewable electricity by 2020, and now targets 15% by 2030 and 50% by 2050 [7]. The country's October 2024 referendum approving nuclear energy development represents a significant strategic choice. Plans for three nuclear power plants using domestic uranium aim to provide stable baseload capacity complementing intermittent renewables.

CONCLUSIONS

As can be seen from the above analysis, the Energy Trilemma Index demonstrates considerable value as a policy assessment framework, providing structured approach to inherently complex energy governance challenges [1,3]. Studies show that:

1. The ETI provides valuable framework for understanding multi-dimensional energy governance challenges, making trade-offs explicit, enabling systematic comparisons, and offering diagnostic capabilities.
2. Statistical validation confirms acceptable reliability (0.721) though below ideal levels for high-stakes applications. The 21.6% unexplained variance in Principal Component Analysis further indicates that important factors beyond the three trilemma dimensions influence energy system outcomes.
3. Top-performing Nordic countries demonstrate that achieving high performance across all dimensions simultaneously is possible with appropriate policies, abundant resources, strong institutions, and social consensus.
4. Central Asian countries illustrate distinctive transition economy challenges, with Uzbekistan's rapid renewable deployment demonstrating that acceleration is possible with commitment and international support, though underlying structural issues require comprehensive transformation beyond adding renewable capacity.
5. Strong correlations with sustainable development indicators validate that the framework captures meaningful dimensions of energy system quality, with overall ETI scores correlating strongly with GDP per capita ($r=0.67$, $p<0.001$) and Human Development Index scores ($r=0.69$, $p<0.001$).

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