A multicriteria classification approach for assessing energy security in Europe

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Abstract

In recent years, Europe has encountered an exponential growth in challenges associated with energy security. This may be attributed to rising geopolitical tensions and concerns regarding climate change. Multi Criteria Decision Analysis (MCDA) methods have been deployed extensively to evaluate the energy security performance of nations in different temporal frames. The annexation of Crimea intensified geopolitical tensions, highlighting the need for robust energy supply security measures. This study focuses on assessing the energy security of 27 European nations for years 2013 and 2018 using the ELECTRE TRI-nC method in MCDA U-Laval software. Each nations' level of energy security will be categorised, with the aim of highlighting areas of disparity and to aid the prioritisation of areas of concern, to assist further research. The analysis examines the influence of the Crimea annexation and rising climatic tensions. Eight indicators, comprehensively representing all energy security dimensions of a reputable source, were chosen. The Shannon index quantifies oil and gas supply security, revealing diversification efforts amid political conflicts. The existing literature often lacks sensitivity and robustness analysis, hindering valid results. This study validates previous findings while uncovering disparities. The United Kingdom and France consistently outperform, while Czechia, Estonia, Hungary, Poland, and Slovenia rank lowest. Norway's results remain ambiguous due to incomplete datasets and faults in the Shannon index formulation for exporting nations. All other nations exhibited moderate to good energy security performance for both years studied. The findings of this work provide valuable insights into the complex landscape of European energy security, validated by existing literature. These results illuminate both areas of agreement and disparities with previous research, underscoring the challenge of fully capturing the multifaceted concept of energy security using only eight indicators.

Introduction

Energy security is paramount in modern society, as it underpins economic stability and overall well-being. This study delves into the complex concept of energy security, which encompasses diverse dimensions, including availability, affordability, sustainability, technological advancement, and regulatory frameworks. Energy security definitions have evolved over time, but most fundamentally, it entails reliable supplies at reasonable prices.

The geopolitical landscape significantly influences energy security, as evidenced by the annexation of Crimea by Russia in 2014. This event disrupted the flow of natural gas and raised concerns regarding Europe's dependence on Russian fossil fuels. Europe's energy imports from Russia, while reduced, remain substantial. The EU is taking steps to reduce this dependency through initiatives such as REPowerEU, aimed at achieving energy independence by 2030.Climate change is another critical factor reshaping energy security priorities. The Crimea conflict accelerated efforts to decarbonize Europe's energy mix, promoting renewable energy and low-carbon technologies.

Multi Criteria Decision Aiding (MCDA) offers a robust approach to assess energy security. It integrates qualitative and quantitative information, accommodating stakeholder preferences. This study employs MCDA to comprehensively evaluate energy security in European nations from 2013 to 2018, whilst considering climate and geopolitical issues. The ELECTRE TRI-nC method, known for its analytic capabilities, is suitable for this assessment. It constructs a preference model and adheres to fundamental properties, ensuring reliability and facilitating sensitivity analysis.

This study aims to contribute to existing literature by exploring the impact of climate change and geopolitical issues on energy security. It addresses key research questions, assessing result robustness, identifying crucial energy security indicators, and pinpointing best and worst-performing nations.

This thesis is structured into eight sections. The first section establishes the context and framework for energy security. The second section reviews relevant literature, primarily focusing on MCDA in energy security studies. The third section explains the ELECTRE TRI-nC methodology's theoretical foundations. The fourth section outlines the practical methodology for data processing. The fifth section presents results and associated analyses. In section six, the results are discussed and compared with other studies. Section seven offers conclusions, highlighting key findings, and section eight provides recommendations for future research in energy security assessment.
Overall, this assessment aims at addressing the following research questions:
Are the results obtained robust?
What are the key indicators that contribute to energy security in Europe?
Which nations had the best and worst energy security assignments?
How has the Crimea conflict and the global focus on climate change impacted the energy security strategies of European countries?

Related Work

Extensive literature on energy security has aimed to identify risk factors and strategies, often employing MCDA, in nations' level of energy security. Sovacool and Mukherjee's (2011) work stands out, with 320 simple and 52 complex indicators, emphasizing the need for integrating quantitative and qualitative metrics in energy security assessments. Key questions include which dimensions matter most and how to create a common index for measuring national performance. Azzuni and Breyer (2017, 2020) advocate for a comprehensive energy security definition that considers 15 dimensions, enabling precise evaluations. Gasser's (2020) analysis of 63 quantitative indicators reveals transparency issues in previous assessments, emphasizing the importance of robust data processing and multivariate analysis. The Global Energy Institute (GEI) provides quadrennial energy security analysis and the International Energy Security Risk Index (IESRI)[1]. Data reliability is essential for the index, but objective criteria weighting remains challenging.

This study has examined the impact of the diverse nature of energy supply. Gupta (2008) assesses oil supplier diversity, while Geng and Ji (2014) introduce an Energy Market Concentration index. Park and Bae (2021) explore energy import dependence, although there are notable data limitations. Chuang and Ma (2013) evaluate Taiwan's energy supply diversity, while Flouri et al. (2015) uses a Monte Carlo simulation to assess European natural gas supply security. Biresselioglu et al. (2015) investigated global natural gas supply. Some studies consider uncertainty drivers in a low-carbon world. Guivarch and Monjon (2015, 2017) explored climate policy impacts on energy security indicators, highlighting complex trade-offs. Huang et al. (2021) highlighted that satisfying the 3E (economic growth, energy consumption and environmental protection) trilemma poses as a major challenge when trying to achieve high levels of energy security. Augutis et al. (2017) noted in their literature review that there exists a challenge associated with objectively determining the weight of each criteria, since priorities have a political and subjective nature.

Figueira and Roy (2009) and Figueira et al. (2012) evaluated ELECTRE methods, highlighting strengths like the ability to use qualitative indicators and integrate criteria with different measurement units. Weaknesses include the absence of scores for individual actions and potential intransitive behaviour. Transparently understanding these characteristics enhances analysis insights.

Overall, the literature review reveals gaps and limitations in current research, including the lack of multi-year analyses, the absence of the Shannon index for assessing oil and gas supplier diversity in Europe, and the need for sensitivity and robustness analyses. The study aims to address these issues and consider international efforts to reduce emissions and improve energy security. It also incorporates statistical tests to identify regional trends in European energy security.

Methodology

This study analyses the evolution of energy security in 27 European nations, including EU members and the UK, during 2013 and 2018. These

[1] https://www.globalenergyinstitute.org

years saw shifts in energy strategies, due to geopolitical events and climate change concerns. The framework, based on Sovacool and Mukherjee (2011), comprises of five dimensions: availability (d1), affordability (d2), technological development (d3), environmental and social sustainability (d4), and regulation and governance (d5). Eight indicators covering these dimensions were selected for a comprehensive assessment, as detailed in Tables 1 and 2. The data sources for the input data were Eurostat[2], Our World in Data[3] and World Bank[4].
Sensitivity, robustness analysis, and a Kruksal-Wallis test complement the assessment to affirm result validity and uncover localized energy security trends in Europe.

g1	Energy intensity
g2	Nuclear electricity generation
g3	GHG emissions per capita
g4	Renewable energy generation
g5	GDP per capita (PPP)
g6	Shannon index for oil
g7	Shannon index for natural gas
g8	Energy consumption per capita

Table 1 - Indicators used in this study

	g1	*g2*	*g3*	*g4*	*g5*	*g6*	*g7*	*g8*
d1	x				x	x	x	
d2				x				
d3								x
d4	x	x	x				x	
d5					x	x		

Table 2 - Indicators and corresponding dimensions

A. Indicator descriptions

In the study, various indicators were developed to assess energy security in the context of MCDA U-Laval. Initially, 10 indicators were considered for analysis, however two were excluded. Energy efficiency and oil stock compliance were excluded as they had limitations in assessing energy security, particularly regarding oil reserves' international nature.

Energy intensity (Dimension 3) measures the energy required to produce economic output. Lower scores signify energy-efficient and developed technologies. Nuclear Electricity Generation (Dimensions d1 and d4) refers to domestic nuclear power, which enhances energy security through the diversification of energy resources, reducing the risks associated with supply disruptions. Although there are some safety concerns associated with the use of nuclear energy, numerous safety measures have been instated to minimise any potential risks and hazards. This includes: the use of high quality materials, the reduction of human error, emphasis on worker safety and standardised regulations across European nations. Despite safety concerns, the reliability of nuclear power and its low carbon footprint, both contribute to its stability as an energy source. Greenhouse Gas (GHG) per Capita (Dimension 4) reflects a nation's commitment to combat climate change and prioritize emission-reducing energy sources. Lower emission per capita indicate strong compliance with global regulations, as highlighted in data sources from Our World in Data. Renewable Energy Generation (Dimension 4) promotes energy independence and climate change mitigation. This indicator reflects a nations progress towards cleaner energy sources, and will be utilised in this study using data from Eurostat that measures the share of renewable energy sources across sectors. Gross Domestic Product (GDP) per Capita corrected by Purchasing Power Parity (PPP) (Dimension 2) indicates citizens' purchasing power and economic freedom. Higher values of GDP per Capita suggest resilience to energy price shock and capacity for infrastructure investments. Shannon Index for Diversity of Oil Suppliers (Dimensions 1 and 5) measures diversity in oil import sources, considering political stability. Higher diversity scores indicate resilience to oil supply disruptions. Shannon Index for Diversity of Natural Gas Suppliers (Dimensions 1 and 5) utilises a similar methodology to the oil supplier diversity index, but focuses on natural gas instead. This indicator helps to assess resilience to natural gas supply disruptions, with penalties for nations relying on a single stable importer. Energy Consumption per Capita (Dimensions 1 and 4) refer to resource efficiency and energy demand relative to

[2] https://ec.europa.eu/eurostat
[3] https://ourworldindata.org
[4] https://www.worldbank.org

population size. Thus, lower values indicate better resource efficiency and reduced energy demands. Reduced energy demand contributes to long-term energy security and mitigates climate change risks.

These indicators collectively provide a comprehensive framework for assessing energy security, considering various dimensions and aspects of energy production, consumption, and sustainability. The careful selection and application of these indicators is essential for meaningful energy security analysis.

B. Criteria weighting

Criteria weighting is crucial in the ELECTRE TRI-nC method to determine the importance of each criterion. The chosen approach, the Deck of Cards Method, involves using physical cards representing criteria. Blank cards signify the difference in importance between criteria. The weight ratio (parameter Z) between the most and least important criteria is defined. Steps include ranking criteria, considering the relevance gap, and estimating Z. This information normalizes the criteria weights for use in the ELECTRE TRI-nC method.

The DM, a Green Hydrogen Engineer at Shell in the Netherlands, prioritized criteria using a 1-5 scale questionnaire. The scores were input into DecSpace[5] software, which determined the relative importance of criteria and the spacing between them. Parameter Z was defined as the ratio between the most and least important criteria. The DM assigned high importance to energy intensity and nuclear power, emphasizing zero-carbon solutions, GHG emissions, and renewable energy. GDP per Capita (PPP) received reasonable importance. Stable and diverse energy suppliers were highly valued through Shannon Indices. Low energy consumption per capita indicated a focus on energy production and supply for energy security.

C. Performance table descriptions

In 2013, Ireland excelled in energy intensity, while Estonia ranked the lowest. France led in nuclear electricity output, with 15 nations having no nuclear deployment. Latvia had the lowest GHG emissions per capita, while Luxembourg had the highest. Luxembourg had the least renewable energy output, and Norway had the most. Luxembourg and Bulgaria had varying levels wealth, with Luxembourg being the wealthiest. Luxembourg and Finland performed poorly in the Shannon index for oil supplier diversity, while the UK excelled. Finland, Ireland, and Sweden had low scores in the Shannon index for natural gas diversity. Romania had the lowest energy consumption per capita, while Norway had the highest.

In 2018, Ireland maintained its top position in energy intensity, while Finland and Estonia ranked lowest. France retained the highest nuclear electricity share. Luxembourg had the highest GHG emissions per capita, while Latvia and Romania had the lowest. The Netherlands had the smallest renewable energy share, while Norway led in decarbonisation. Luxembourg and Bulgaria maintained their wealth positions. Luxembourg and Czechia had limited oil suppliers, while Portugal excelled in oil diversity. Sweden diversified natural gas suppliers, while Finland and Ireland fell behind. Germany had the best natural gas supplier diversity. The most and least energy-demanding nations per capita remained consistent.

D. Descriptive statistics

From 2013 to 2018, European energy intensity increased by 10%, suggesting decreased efficiency in converting GDP to energy. The standard deviation remained stable, indicating consistent data variability. Nuclear electricity generation saw constant average scores, with a slight increase in maximum scores. Greenhouse gas emissions per capita decreased by 6%, suggesting a convergence in environmental compliance. Average renewable energy generation increased slightly, although with increased variability among nations. GDP per capita (PPP) slightly increased, reflecting economic resilience. Shannon indices for oil and natural gas supplier diversity improved, with reduced standard deviations. Energy consumption per capita slightly decreased due to improved energy efficiency offsetting rising energy-intensive lifestyles.

E. Data remarks

[5] http://app.decspacedev.sysresearch.org

The MCDA U-Laval software requires complete datasets; some gaps were present during data collection. To address this, when using the Shannon-Wiener diversity index for oil, groups of nations without explicit political stabilities (e.g., "Other European Countries") were averaged, and this value was applied to the index. Notable gaps remained in renewable energy generation for the United Kingdom and Shannon-Wiener Diversity Index values for oil and natural gas in specific nations. These gaps were filled by deducing the average scores from other nations for each respective indicator, assuming it provides a reasonable approximation for the missing values, such as the United Kingdom's renewable energy generation.

Results

The MCDA U-LAVAL software applied the ELECTRE TRI-nC algorithm with weights generated through DM prioritization using DecSpace. Categories 1 to 5 represented energy security levels from "bad" to "excellent." A sensitivity analysis determined the discrimination threshold, set at 0.55. Table 3 displays the results obtained from the analysis in MCDA U-Laval.

Out of 27 nations, 12 maintained the same energy security categories for 2013 and 2018, indicating high levels of stability. Austria dropped from category 4 to 3, Belgium and Bulgaria remained in categories 4 and 3, Croatia improved from 3 to 4, and Czechia shifted from category 3 to 2. Denmark and Estonia stayed in categories 4 and 2, while Finland improved from category 2 to 3. France consistently ranked in category 5, and Germany in category 4. Greece stayed in category 3, Hungary moved slightly between categories 2 and 3, and Ireland improved from categories 2-3 to 3-4. Italy remained in category 4, Latvia improved from category 3 to 4, and Lithuania moved from category 3 to 3-4. Luxembourg had an ambiguous placement between categories 2 and 4, while the Netherlands improved from categories 2-3 to 2-4, and Norway ranged from category 1 to 5. Poland shifted partially from category 2 to 2-4, while Portugal remained in category 4, Romania slipped from category 4 to 3-4, Slovakia moved slightly from categories 2-3 to 3, and Slovenia stayed in the 2-3 category range. Spain saw impressive placements, with an upper bound shift from category 5 to 4, while Sweden improved from category 4 to 4-5. The United Kingdom, like France, held the highest category placement.

	2013		2018	
Alternatives	-	+	-	+
Austria	4	4	3	3
Belgium	4	4	4	4
Bulgaria	3	3	3	3
Croatia	3	4	4	4
Czechia	3	3	2	2
Denmark	4	4	4	4
Estonia	2	2	2	2
Finland	2	2	3	3
France	5	5	5	5
Germany	4	4	4	4
Greece	3	3	3	3
Hungary	2	3	2	2
Ireland	2	3	3	4
Italy	4	4	4	4
Latvia	3	3	4	4
Lithuania	3	3	3	4
Luxembourg	2	4	2	4
Netherlands	2	3	2	4
Norway	1	5	1	5
Poland	2	2	2	4
Portugal	4	4	4	4
Romania	4	4	3	4
Slovakia	2	3	3	3
Slovenia	2	3	2	3
Spain	4	5	4	4
Sweden	4	4	4	5
United Kingdom	5	5	5	5

Table 3 - Results of MCDA U-Laval Analysis

Sensitivity and robustness analysis

The discrimination threshold, denoted as λ, plays a vital role in decision-making. Adjusting λ influences the categorization of alternatives. A sensitivity analysis evaluated thresholds of 0.55, 0.6, 0.65, and 0.7, with 0.55 offering the most consistent results. Overall, λ minimally affected category distribution, enhancing result reliability. Criteria weight sensitivity assessed how altering weights affected categorical assignments. Minor changes in weights induced at most 2 category shifts, with nuclear electricity generation and Shannon indices being most influential, aligning with their high weights. Sensitivity analyses of q,β , p,β and v,β assessed result robustness. Changes within 5%-15% minimally impacted categories, except for renewable energy generation. The veto threshold showed slight influence and yearly variation in sensitivity implied robust data inputs. The Kruskal-Wallis Test assessed regional energy security differences. Data was grouped by UN Geoscheme[6] regions, and nonparametric analysis in SPSS was performed.

Results in both 2013 and 2018 failed to reject the null hypothesis, suggesting no significant regional energy security differences. Limitations include using only 8 indicators, a 1-5 category scale, and capturing static temporal snapshots rather than trends across time.

Discussion

A. Discussion of results

To analyse the changes in energy security performance scores in 2013 and 2018, percentile rankings for each indicator and country were calculated. This approach allowed for a deeper understanding of the factors contributing to performance changes. Percentile scores for 2013 and 2018 were deduced, with values ranging from 0 to 1. Inverted values were used for minimised indicators to maintain consistency.

Austria's energy security indicators remained stable, except for the Shannon index for oil, which dropped significantly from the 65th percentile to the 19th. This decrease pointed to reduced supplier diversity and political stability among oil suppliers. Belgium maintained consistent percentile scores for most indicators across both years, with high scores in the three most heavily weighted criteria: nuclear electricity capacity and the Shannon indices for oil and natural gas. However, lower scores in renewable energy generation, energy consumption per capita, and energy intensity indicated areas for improvement in Belgium. Bulgaria's energy security remained at a moderate level for both years, with minimal changes in percentile scores. However, Bulgaria had the lowest GDP per capita among the studied nations highlighted an economic aspect that could impact other indicators. Croatia's analysis demonstrated that percentile comparisons could be misleading, as the overall categorical placement improved slightly, despite the majority of indicators showing a decrease. However, Croatia maintained relatively strong performances in GHG emissions per capita, renewable energy generation, and energy consumption per capita, though saw a significant decrease in the Shannon index for natural gas, revealing a lack of effort in diversifying natural gas suppliers. Czechia experienced performance regression from 2013 to 2018, driven by substantial drops in the Shannon indices for oil and natural gas. High dependence on Russian oil was a significant factor contributing to this decline in Czechia's scores. Denmark maintained good energy security categorical placements, with marginal improvements in several indicators. However, a decrease in the Shannon index for natural gas highlighted the need for supplier diversification in this Denmark.

Estonia remained in the weak energy security category, with no significant improvement from 2013 to 2018. Estonia's GHG emissions per capita score stood out as an area that needed attention. Finland's performance improved slightly, although only reaching the moderate category in 2018. While excelling in nuclear electricity capacity and renewable energy generation, Finland lagged behind in other indicators such as the Shannon indices for oil and natural gas and energy consumption per capita. France consistently held the highest energy security category for both years, due to strong performances in nuclear electricity generation, GHG emissions per capita, and the Shannon indices for oil and natural gas. However, there was room for improvement in renewable energy generation, energy consumption per capita, and energy intensity. Germany maintained a good energy security category with no significant changes in indicator percentiles. Renewable energy generation was an area where improvement is needed. Greece sustained a moderate category

[6] https://unstats.un.org/unsd/methodology/m49

throughout the analysis, with relatively mediocre scores across most indicators. Notable strengths in Greece's level energy security included energy consumption per capita, while the Shannon index for oil showed room for improvement. Hungary's energy security remained weak, with minor category regression from 2013 to 2018. Factors contributing to this included a decrease in renewable energy generation and limited diversity of oil suppliers. Ireland experienced improvements, moving into the moderate category from 2013 to 2018. Ireland excelled in GDP per capita ratings and energy intensity but lacked nuclear electricity generation and had low scores in renewable energy generation. Italy demonstrated good energy security performance, with strengths in several indicators. However, the absence of nuclear electricity generation stood out as an area for potential improvement. Latvia saw progress in energy security, with excellent percentile scores for several low-carbon indicators. Diversification of natural gas suppliers also contributed to its improvement. Lithuania improved marginally in categorical placement, with strong performances in GHG emissions per capita and energy consumption per capita. Efforts to diversify natural gas supplies were evident in this nation. Luxembourg had a mediocre energy security performance, with a wide category range due to polarized indicator scores. The country's economic superiority and energy intensity were strengths, but environmental indicators were weak. The Netherlands had an ambiguous categorical placement in both years due to polarized performance scores. Although, efforts to improve renewable energy generation were noted from 2013 to 2018. Norway had a broad categorical placement, indicating significant variability in its energy security. Strong performances in renewable energy capacity and GDP per capita contrasted with the absence of data in Norway's oil and natural gas imports. Poland exhibited generally poor energy security performance, with weaknesses in GHG emissions per capita, renewable energy capacity, GDP per capita, and energy intensity. However, progress was evident in natural gas security. Portugal maintained good energy security levels, with strengths in GHG emissions per capita, renewable energy capacity, and energy consumption per capita. The absence of nuclear electricity generation would be an area for consideration in this nation. Romania performed well in most indicators, with good energy security levels. However, diversity in oil and gas suppliers may need improvement. Slovakia showed marginal improvements in energy security, though it remained moderately secure overall. Weaknesses were seen in renewable energy generation, energy intensity, and natural gas security. Slovenia demonstrated weak to moderate energy security, with renewable energy capacity as a notable strength. Heavy reliance on Austria for natural gas raised security concerns. Spain maintained strong energy security performance, with strengths in nuclear electricity generation, GHG emissions per capita, and both Shannon indices. Renewable energy generation in Spain may require attention. Sweden maintained strong energy security, with marginal improvements in categorical placement. Most indicators performed well, except for the Shannon index for natural gas, energy consumption per capita, and energy intensity. The United Kingdom, similarly to France, consistently performed well and had no indicators performing poorly. Notable improvements were seen in GHG emissions per capita, indicating progress in environmental sustainability. The use of an average score for renewable energy generation in the United Kingdom had minimal impact on the overall results.

This comprehensive analysis highlights the strengths and weaknesses of each country's energy security and provides insights into the factors driving performance changes over the five-year period.

B. Comparison with the IESRI index

This study introduced a novel categorization of nations' energy security levels and compared them to the IESRI risk index. It is worth noting that the IESRI index only covered the top 75 energy-consuming countries, excluding Estonia, Latvia, Lithuania, Luxembourg, and Slovenia from this study's comparisons. The data for the remaining countries were processed to determine relative percentile performances, facilitating comparisons between the two models.

Among the 29 indicators used, nine remained constant across all countries. There was considerable overlap between the indicators used in this study and the IESRI index, suggesting some convergence in measuring energy security. To facilitate comparison, IESRI risk index scores were converted into approximate categorical placements based on percentiles relative to other scores. The results showed strong alignment for Austria, Bulgaria, Denmark, Finland, Germany, Greece, Hungary, Ireland, Slovakia, Sweden, and Spain. Moderate differences were observed for Czechia, France, the Netherlands, and Romania. Although notable discrepancies were found for Belgium, Croatia, Italy, Norway, Poland, Portugal, and Spain.

Belgium performed poorly in the IESRI results, primarily due to import exposure indicators. In contrast, it performed well in this study's Shannon Indices for import exposure risks, which consider political stability and supplier importance. Differences in indicator formulation may explain the variance in Belgium's scores. Croatia's strong performance in this study contrasted with its poor IESRI results, mainly due to high coal import exposure, an indicator not considered in this study. Common indicators like energy intensity, consumption per capita, non-carbon energy sources, and emissions per capita supported Croatia's performance in this study. Italy achieved a positive result in this study but scored poorly in the IESRI report, primarily due to coal-related indicators. The IESRI report also considered retail electricity prices and non-carbon generation, which impacted Italy's energy security risk index score. Norway displayed polarized results, categorised between bad and excellent in this study, while the IESRI report rated it as having an excellent energy security score. Discrepancies were mainly observed in energy consumption per capita, where the units used for measurement differed between the two assessments. Poland had a low energy security risk score in the IESRI report but performed lower in this study, primarily because of differences in energy consumption per capita units. Other indicators showed similar mediocre performance scores for both indices. Portugal's performance scores varied between the two indices, with this paper indicating good results and the IESRI report suggesting high energy security risk. Import exposure risk scores in the IESRI report were poor, whereas the Shannon Index score for oil and natural gas in this study showed better results. CO_2 emissions trends, a metric not considered in this paper, impacted the IESRI report's score. Spain also experienced significant score differences, falling in category 4 in this paper and category 1 in the IESRI report. Import exposure scores, particularly for gas and coal, contributed to Spain's poor IESRI index performance. However, the Shannon Indices for supplier diversity in this study showed above-average results. Differences in metric formulation explained these disparities. In most other metrics, except CO_2 emissions trends, Spain performed around or better than average in the IESRI report.

Overall, this study's novel categorisation approach yielded varying results when compared to the IESRI index, with differences often attributed to disparities in indicator formulation and the inclusion of certain metrics.

Conclusions

Various analysis techniques were employed to validate the results. A sensitivity analysis on the MCDA U-Laval threshold values and criteria weights confirmed the robustness of the findings. Minor changes observed in the discrimination threshold sensitivity analysis highlighted the overall robustness of the dataset, ensuring consistent results for future energy security assessments in Europe.

In investigating the influence of criteria weight, the study identified the most and least influential metrics for assessing energy security. It became clear that nuclear electricity generation and Shannon indices for oil and natural gas had the most significant impact in both 2013 and 2018, aligning with the decision maker's priorities. Conversely, energy consumption per capita had the smallest influence on the results.

An energy security performance hierarchy among European nations was established. France and the United Kingdom consistently ranked the highest in both 2013 and 2018. Other strong performers included Belgium, Denmark, Germany, Italy, Portugal, Sweden, and Spain. Nations like Estonia and Slovenia raised concerns with their performance, while Czechia and Hungary experienced declines. On the positive side, Finland, Ireland, and Poland demonstrated improvements. The ambiguous placement of Norway was due to data limitations and limitations of the Shannon index.

Active efforts to mitigate energy security risks in response to geopolitical and climatic concerns were observed. The improvements in the Shannon index scores for oil and natural gas indicated increased energy supply security, particularly in response to the Crimea conflict. European nations were proactive in deploying renewable energy sources to enhance domestic energy independence and meet energy security directives. Furthermore, the reduction in GHG emissions per capita demonstrated compliance with climate policies like the Paris Agreement, promoting a sustainable, secure European energy landscape.

Overall, this study aimed to assess energy security in 27 European nations using the ELECTRE TRI-nC method in MCDA U-Laval. Initially, the energy security performance for years 2013 and 2018 was assessed using 10 indicators, with generally marginal year-to-year changes. Two indicators, energy efficiency and oil stock compliance, were removed for clearer results. The study focused on the remaining 8 indicators, aiming to capture all dimensions of energy security. It validated results through a comparison to the IESRI report, offering insights into nations' energy security and recommending areas for further research in Europe's transition to a sustainable and secure energy landscape.

References

Augutis, J., Krikštolaitis, R., Martišauskas, L., Pečiulytė, S., & Žutautaitė, I. (2017a). Integrated Energy Security Assessment. *Energy*, *138*, 890–901. https://doi.org/10.1016/j.energy.2017.07.113

Augutis, J., Krikštolaitis, R., Martišauskas, L., Pečiulytė, S., & Žutautaitė, I. (2017b). Integrated Energy Security Assessment. *Energy*, *138*, 890–901. https://doi.org/10.1016/j.energy.2017.07.113

Azzuni, A., & Breyer, C. (2017). Definitions and dimensions of energy security: A literature review. *Wiley Interdisciplinary Reviews: Energy and Environment*, *7*(1). https://doi.org/10.1002/wene.268

Azzuni, A., & Breyer, C. (2020). Global Energy Security index and its application on national level. *Energies*, *13*(10), 2502. https://doi.org/10.3390/en13102502

Biresselioglu, M. E., Yelkenci, T., & Oz, I. O. (2015). Investigating the Natural Gas Supply Security: A new perspective. *Energy*, *80*, 168–176. https://doi.org/10.1016/j.energy.2014.11.060

Chuang, M. C., & Ma, H. W. (2013). Energy security and improvements in the function of diversity indices—Taiwan Energy Supply Structure Case Study. *Renewable and Sustainable Energy Reviews*, *24*, 9–20. https://doi.org/10.1016/j.rser.2013.03.021

Figueira, J. R., Greco, S., & Roy, B. (2009). Electre methods with interaction between criteria: An extension of the concordance index. *European Journal of Operational Research*, *199*(2), 478–495. https://doi.org/10.1016/j.ejor.2008.11.025

Figueira, J. R., Greco, S., Roy, B., & Słowiński, R. (2012). An overview of Electre methods and their recent extensions. *Journal of Multi-Criteria Decision Analysis*, *20*(1–2), 61–85. https://doi.org/10.1002/mcda.1482

Flouri, M., Karakosta, C., Kladouchou, C., & Psarras, J. (2015). How does a natural gas supply interruption affect the EU gas security? A Monte Carlo Simulation. *Renewable and Sustainable Energy Reviews*, *44*, 785–796. https://doi.org/10.1016/j.rser.2014.12.029

Gasser, P. (2020). A review on energy security indices to compare country performances. *Energy Policy*, *139*, 111339. https://doi.org/10.1016/j.enpol.2020.111339

Geng, J.-B., & Ji, Q. (2014a). Multi-perspective analysis of China’s Energy Supply Security. *Energy*, *64*, 541–550.

https://doi.org/10.1016/j.energy.2013.11.036

Geng, J.-B., & Ji, Q. (2014b). Multi-perspective analysis of China's Energy Supply Security. *Energy*, *64*, 541–550. https://doi.org/10.1016/j.energy.2013.11.036

Guivarch, C., & Monjon, S. (2017). Identifying the main uncertainty drivers of energy security in a low-carbon world: The case of europe. *Energy Economics*, *64*, 530–541. https://doi.org/10.1016/j.eneco.2016.04.007

Guivarch, C., Monjon, S., Rozenberg, J., & Vogt-Schilb, A. (2015). Would climate policy improve the European Energy Security? *Climate Change Economics*, *06*(02), 1550008. https://doi.org/10.1142/s2010007815500086

Gupta, E. (2008). Oil vulnerability index of oil-importing countries. *Energy Policy*, *36*(3), 1195–1211. https://doi.org/10.1016/j.enpol.2007.11.011

Huang, B., Zhang, L., Ma, L., Bai, W., & Ren, J. (2021). Multi-criteria decision analysis of China's energy security from 2008 to 2017 based on fuzzy BWM-dea-AR model and Malmquist Productivity index. *Energy*, *228*, 120481. https://doi.org/10.1016/j.energy.2021.120481

Huang, S.-W., Chung, Y.-F., & Wu, T.-H. (2021). Analyzing the relationship between Energy Security Performance and decoupling of Economic Growth from CO2 emissions for OECD Countries. *Renewable and Sustainable Energy Reviews*, *152*, 111633. https://doi.org/10.1016/j.rser.2021.111633

Kruskal-Wallis H test using SPSS statistics. Kruskal-Wallis H Test in SPSS Statistics | Procedure, output and interpretation of the output using a relevant example. (n.d.). https://statistics.laerd.com/spss-tutorials/kruskal-wallis-h-test-using-spss-statistics

Park, H., & Bae, S. (2021). Quantitative assessment of energy supply security: Korea case study. *Sustainability*, *13*(4), 1854. https://doi.org/10.3390/su13041854

Rogers, M., & Bruen, M. (1998). Choosing realistic values of indifference, preference and veto thresholds for use with environmental criteria within Electre. *European Journal of Operational Research*, *107*(3), 542–551. https://doi.org/10.1016/s0377-2217(97)00175-6

Sovacool, B. K., & Mukherjee, I. (2011). Conceptualizing and measuring energy security: A synthesized approach. *Energy*, *36*(8), 5343–5355. https://doi.org/10.1016/j.energy.2011.06.043