ENERGY SECURITY TRANSFORMATION IN SLOVAKIA (2005–2023)

Ing. Martina Repíková

Abstract

The paper examines the evolution of Slovakia's energy security between 2005 and 2023. In parallel, it applies the same composite index to four neighbouring EU countries (Czechia, Austria, Hungary and Poland) in order to situate Slovakia's trajectory within broader Central European context. The main objective of the article is to establish a consistent national baseline of Slovakia's energy security and to assess how far a fossil fuel-based composite index remains suitable as a starting point for analysing energy security in a decarbonising energy system and for its use as a baseline in subsequent forward-looking scenario analysis. The composite energy security index uses Eurostat indicators, Z-score normalisation and equal weighting across four energy security dimensions: availability, affordability, economic and energy efficiency and environmental stewardship. The results show a common regional trajectory: gradual improvement from the mid-2000s to the mid-2010s, a temporary weakening in 2017–2019, a shared peak in 2020 and a marked deterioration during 2020–2022 with partial recovery in 2023. Slovakia broadly followed this pattern, driven by strong gains in efficiency and environmental performance. In the post-2020 period, all countries experienced a sharp decline in affordability in the context of energy crisis and Russian war in Ukraine. Availability dimension weakened, while environmental stewardship and economic and energy efficiency improved on pandemic-related reductions in economic activity and travel. These findings are consistent at the level of overall trajectories but should be interpreted with caution in light of documented methodological breaks in car emission data, gas price statistics and renewables in transport, and the simplifying assumptions of Z-score standardisation, equal weighting and additive aggregation. The study assesses the adequacy of current measurement in capturing complex character of energy security. However, energy security indicators building on traditional four-dimensional energy security frameworks capture only part of the current energy security picture. Dimensions such as governance, cyber resilience, dependence on critical materials and social justice are underrepresented in metrics measuring energy security. Addressing these limitations may require expanding operationalisation of energy security towards more complex multidimensional indices that can be linked to long-term decarbonisation scenarios.

Keywords

Energy Security, Energy Security Index, Economic and Energy Efficiency, Affordability, Availability, Environmental Stewardship, Decarbonisation, Energy Security Dimensions.

I. Introduction

Energy security concept has evolved significantly since the 1970s. Initially defined in narrow terms, it was primarily understood as the ability to ensure uninterrupted fuel supply. The oil shocks of that decade exposed the vulnerability of national economies to supply disruptions and price increases (Yergin, 1991). At that time, the main goal was to keep energy supply steady and prices affordable (Cherp & Jewell, 2011). Early policy responses focused on emergency measures such as stockpiling, diversification of sources and system redundancy. These strategies remain core components of national energy security policies for decades (IEA, 2007; EC, 2006; EC, 2015).

Today, energy security is widely understood as a complex and multidimensional concept. Traditionally, it has been framed around four core dimensions: availability, affordability, accessibility and acceptability (APERC, 2007; Kruyt, et al., 2009; Ang et al., 2015; Dodds, 2017).

- Availability ensures uninterrupted and sufficient supply of energy resources, supported by robust infrastructure and diversified mix of sources.
- Affordability requires that energy is obtainable at reasonable and stable low prices, ensuring economic accessibility without imposing undue financial burden on consumers.
- Accessibility refers to non-financial barriers, focusing on the physical capacity of consumers to reach and connect to the energy infrastructure and services.
- Acceptability aims to minimize negative environmental and social impacts of energy production and use, particularly greenhouse gas (GHG) emissions and broader ecological harm.

However, the “4A” framework has increasingly been viewed as insufficient for capturing the full complexity of energy security. Several key critiques have emerged:

- The definition of energy security was often criticized for being conceptually ambiguous (Chester, 2010).
- Its limited scope makes it inadequate for addressing broader social impacts or supporting complex and integrated policymaking processes (Siksnelyte-Butkiene et al., 2024).
- The framework lacks conceptual precision and offers limited utility for quantitative analysis and empirical measurement (Sovacool & Mukherjee, 2011).

As a result, scholars have expanded the scope of the energy security concept beyond the traditional four pillars. Sovacool and Mukherjee (2011) proposed a five-dimensional framework encompassing availability, affordability, technology development and efficiency, environmental and social sustainability, and regulation and governance. Azzuni & Breyer (2017) identified fifteen dimensions, incorporating factors such as cybersecurity, resilience, health, culture, literacy and employment, to reflect the growing complexity and interconnectedness of energy systems.

Measuring energy security remains a significant challenge due to its inherently multidimensional, complex and highly context-dependent nature (Gasser, 2020). In recent decades, composite indicators have become a widely used tool for assessing and comparing energy security across countries and over time. Their popularity stems from the fact that indicator-based approaches are suitable for modelling multiple dimensions within a single analytical framework (Gasser, 2020; Ang et al., 2015). These composite indicators aggregate a range of quantitative metrics, which reflect various dimensions of energy security, into a single synthetic value or score. This aggregation process facilitates both cross-country comparisons and the monitoring of changes over time (Ang et al., 2015; Gasser, 2020; Siksnelyte-Butkiene et al., 2024).

Commonly used composite indicators cover a wide range of factors, including metrics such as resource diversity (often measured by the Herfindahl–Hirschman index or Shannon–Wiener index), import dependency, supply concentration, price volatility, energy intensity and environmental impacts like carbon emissions and air pollution (Ang et al., 2015; Azzuni & Breyer, 2017; Chalvatzis & Ioannidis, 2017; Radovanović et al., 2017; Brodny & Tutak, 2023).

Assigning weights to indicators is widely recognised as one of the most contested aspects of composite energy security index construction. Literature distinguishes between subjective approaches, such as equal weighting, expert judgement or delphi methods, and objective methods based on statistical properties of the data (Gasser, 2020). While equal weighting is commonly used for its simplicity and transparency (Brown et al., 2014; Obadi & Korček, 2017), it assumes all indicators are equally important. Subjective schemes, including policy-based or threshold-based weighting, introduce flexibility but are often criticised for their inherent subjectivity, potential bias and lack of transparency (Gasser, 2020). In contrast, objective techniques, such as the principal component analysis, factor analysis or methods used in multi-criteria decision making aim to reduce subjective bias by deriving weights from indicator variance, correlation or information value (Narula & Reddy, 2016; Gasser, 2020; Wu et al., 2021). However, these methods can be limited by data availability, complexity, and the choice of weighting method continues to significantly influence index outcomes (Muñoz et al., 2015; Kisel et al., 2016, Gasser, 2020).

In addition to conventional economic and technical dimensions, recent research highlights the need to integrate governance quality, regulatory effectiveness, institutional stability and social equity dimensions into energy security assessment frameworks (Brodny & Tutak, 2023). Meanwhile, resilience metrics have gained attention for their focus on a system's capacity not only to prevent disruptions but also to absorb, recover from, and adapt to shocks (Månsson et al., 2014; Erker et al., 2017; Martišauskas et al., 2018). This includes both geopolitical shocks and climate-related disruptions, which increasingly shape the conditions under which energy systems operate (Martišauskas et al., 2018; Zhao et al., 2025).

Although most composite indexes generally focus on retrospective evaluation based on historical data, there is increasing demand for forward-looking metrics (Augutis et al., 2017; Martišauskas et al., 2018). This is particularly relevant in light of upcoming trends, such as decarbonisation, digitalisation and decentralisation, which are rapidly transforming energy systems (Carmon et al., 2025). Emerging approaches increasingly apply advanced analytical techniques such as scenario modelling, probabilistic forecasting and system dynamics to anticipate future vulnerabilities and opportunities. However, integrating these predictive tools into standardised and robust composite metrics remains a methodological challenge. Further innovation and empirical testing are needed to overcome limitations such as the high degree of uncertainty inherent in long-term forecasts and the lack of validation for predictive metrics (Augutis et al., 2017; Martišauskas et al., 2018).

The understanding of energy security in Central Europe evolved significantly from 2005 onwards, following the region's accession to the European Union in 2004. This period was characterised by the adoption of new EU regulatory frameworks and market liberalisation (Brodny & Tutak, 2021). It shifted energy security concerns from technical supply and availability issues to broader vulnerabilities related to market dynamics, regulatory complexity and institutional stability (Brodny & Tutak, 2021).

Historically, countries in this region relied heavily on energy imports, particularly oil and natural gas from Russia, making physical availability a primary concern. EU accession facilitated their gradual integration into wider energy markets and promoted increased competition (Brodny & Tutak, 2021). While this integration improved system efficiency and reduced regional political vulnerability, it simultaneously introduced new risks linked to market volatility, cross-border infrastructure and geopolitical issues (LaBelle, 2024).

Slovakia shows the regional shift in energy security priorities. Despite relying heavily on nuclear power as a low-carbon source, Slovakia remains highly dependent on external energy sources, with high oil and gas import dependency (Mišík & Oravcová, 2024). In parallel, Slovakia continues to experience socio-economic imbalances and growing concerns around energy affordability, reflecting broader trends among post-communist "new EU" member states, where energy poverty remains more prevalent than in Western Europe (Brodny & Tutak, 2023). These structural and dependency-related vulnerabilities became visible during crises, such as the gas disputes in 2006 and 2009, and again during the 2022 energy crisis, when price shocks and supply underscored the urgency of reducing reliance on a single external supplier (Osička & Černoch, 2022; Mišík & Nosko, 2023).

This period also saw a growing emphasis on environmental dimension of energy security, largely driven by broader EU climate policies aimed at achieving a low-carbon, secure, and affordable energy system. Slovakia and its Central European neighbours had to balance primary energy supply security (traditional economic concerns) with commitments to emissions reduction, decarbonisation and renewable energy deployment. This balancing act underscores the multidimensional nature of contemporary energy security and highlights the need for integrated policy approaches (Brodny & Tutak, 2023).

Many studies continue to focus on retrospective assessment based on historical data and overlook prospective forecasting (Augutis et al., 2017; Martišauskas et al., 2018; Gasser, 2020; Demir & Cergibozan, 2025). This limits their relevance in today's rapidly evolving energy landscape, shaped by decarbonisation, decentralisation and digitalisation (Carmon et al., 2025). There is, therefore, a growing need for integrated modelling incorporating scenario-based analysis and probabilistic risk assessments to inform strategic planning and evaluate energy security for future pathways (Augutis et al., 2017; Bompard et al., 2017; Martišauskas et al., 2018; Gasser, 2020). This highlights a clear need for approaches that can bridge historical assessment with forward-looking policy-relevant scenario work, an area this study aims to inform through the establishment of a composite index as a foundation for future scenario-based modelling.

Moreover, many conventional frameworks fail to adequately incorporate institutional and governance dimensions, such as corruption, intransparency, regulatory effectiveness, or for social equity concerns, such as energy poverty and affordability. Yet, these factors play a critical role in shaping real-world energy security (Sovacool & Mukherjee, 2011; Azzuni & Breyer, 2017).

Addressing these gaps requires harmonised data collection, interdisciplinary methodologies beyond narrow technical or economic perspectives and enhanced collaboration between academia, industry and policymakers (Augutis et al., 2017; Erker et al., 2017; Gasser, 2020; Siksnelyte-Butkiene et al., 2024). Advances in predictive analytics, scenario modelling and real-time monitoring offer promising tools for strategic planning , yet their integration into standardised composite metrics remains methodologically challenging (Augutis et al., 2017; Martišauskas et al., 2018; Valdés, 2018). Closing these gaps is essential to support more resilient and socially just energy policies in the context of global energy transitions.

II. Methodology

The assessment of energy security in this study is a first methodological step in an integrated framework that distinguishes between historical performance and future projections. This approach is aligned with the methodology by Augutis et al. (2017), who divided their analysis into two phases: the establishment of an empirical baseline based on historical statistical data and a subsequent prospective modelling of decarbonization scenarios.

To establish Slovakia's energy security baseline in 2005-2023, this study adapts the multidimensional energy security index developed by Obadi & Korček (2017) for 26 EU countries (excluding Malta and Cyprus). Their framework is based on Brown et al. (2014), who applied a similar methodology to OECD countries over a 40-year period. Their energy security index comprises eleven indicators across four dimensions: energy and economic efficiency, affordability, availability and environmental stewardship. The data are normalised using cross-country Z-score standardisation and indicators are aggregated using equal weights through linear aggregation.

This methodology is adapted to establish and test the baseline. The dimensions and indicators were maintained because their framework specifically incorporated Slovakia, providing regional consistency and a starting point for an expanded timeseries analysis assuming accessible national data. However, the application of Z-score normalisation follows a precedent set by Martchamadol and Kumar (2014), who applied standardization to a longitudinal timeline (1986–2030) to track national performance over time, as this study is specifically intended to establish a dimensionless baseline that would, in later stages of research, serve as a foundation for the future integration of the index with scenario-based analysis toward carbon neutrality in 2050.

This study draws data primarily from Eurostat datasets (Eurostat, 2025) and the European commission's weekly oil bulletin (EC, 2025). The database provide consistent and robust statistics on key energy security indicators throughout the 2005-2023 period, ensuring sufficient coverage to operationalise the multidimensional framework effectively.

The energy security index was built on eleven indicators grouped into four dimensions, as shown in Table 1. All indicators originate from Eurostat, which ensures unified definitions and transparency, but not full temporal consistency. Several series contain methodological breaks that affect long-term comparability.

CO_2 emissions from new cars (sdg_13_31) were retained for continuity with the reference study, but have a clear break in 2017 due to the switch from the New European driving cycle (NEDC) to the Worldwide harmonised light vehicle test procedure (WLTP) for new cars, directly affecting the Economic and energy efficiency dimension.

For the sdg_13_31 dataset, NEDC-based data are used until 2016. The transition officially began in 2017, with all new cars having to be certified under WLTP by September 2018. CO_2 emissions data based on WLTP are higher than those based on NEDC for the same car model, as it reflects real driving conditions and accounts for optional vehicle equipment. A specific conversion factor was applied to the 2017–2019 data based on the dual reporting in 2020. From 2021 onwards, the indicator contains clean WLTP values. Hence, the annual change was calculated, and the statistical jump in the series in 2017 was smoothed by setting the value to zero. This affects the temporal comparability of the Economic and energy efficiency and is considered when interpreting long-term trends.

Natural gas price data for households and industry (nrg_pc_202, nrg_pc_203) are published as semi-annual averages. Annual averages were calculated from semi-annual data to keep the scale consistent with other indicators. This smooths volatility and reduces the visibility of short-term price spikes, especially those in 2021–2022. More importantly, the methodology changed in the second half of 2007 as a result of market liberalisation (following Commission Decision 2007/394/EC, Eurostat, 2025). Before 2007, Eurostat used standard reference consumers and tariff-based data. After 2007, the system shifted to real transaction data, new consumption bands and detailed cost components including taxes and network fees. The break makes values before and after 2007 not directly comparable, yet for the purpose of the construction of the energy security index this is acceptable. Timeseries were constructed by combining the old and new series.

The share of renewables in transport (nrg_ind_ren) reflects energy content rather than the life-cycle emissions, so it overestimates climate performance. It has a significant break in 2020–2021 following the transition from RED I to RED II. None of this is directly affecting the calculation and meaning of the energy security index.

Table 1: Indicators and data sources

Dimension	Indicator name	Unit	Dataset	Method
Energy and economic efficiency	Energy intensity	kg o.e. / €1,000 GDP	nrg_ind_ei	Invert (higher = worse)
Energy and economic efficiency	CO_2 emissions from new cars	Annual change, grams CO_2 / km	sdg_13_31	Invert
Energy and economic efficiency	Electricity consumption per capita	kWh / person	nrg_cb_e a demo_gind	Invert
Affordability	Gasoline price	Eur / liter	EU_price_with _tax_euro95	Invert
Affordability	Gas price for industry	Eur / GJ	nrg_pc_203, nrg_pc_203_c	Invert
Affordability	Gas price for households	Eur / GJ	nrg_pc_202, nrg_pc_202_c	Invert
Availability	Oil import dependency	%	nrg_ind_id (Oil)	Invert
Availability	Gas import dependency	%	nrg_ind_id (Gas)	Invert
Availability	Share of RES in transport	%	nrg_ind_ren	No inversion (higher = better)
Environmental stewardship	GHG emissions per capita	tonnes CO_2-eq / person	sdg_13_10	Invert

Environmental stewardship	GHG of energy consumption	thousand tonnes CO_2-eq	env_air_gge	Invert

Source: Author, based on study by Obadi and Korček, 2017, EC, 2025 and Eurostat, 2025

From other indicators, the energy intensity (nrg_ind_ei) depends on GDP in chain-linked volumes. Structural changes in the economy affect the denominator. The indicator is sensitive to GDP base-year revisions and changes in energy balances. Electricity consumption per capita (nrg_cb_e, demo_gind) was calculated by combining data from two Eurostat tables: electricity available for final consumption and average population total.

Gasoline prices (EU_price_with_tax_euro95) originate from the European Commissions's Weekly Oil Bulletin (EC, 2025), published through Eurostat. The series represents the average retail price at the petrol stations, including all taxes and levies. The reporting methodology has been stable and no major breaks are documented. Oil and gas import dependency (nrg_ind_id) is methodologically coherent across the period, with only minor recalculations. GHG indicators (sdg_13_10, env_air_gge) use different system boundaries: one is per-capita total, the other energy-related only. These Eurostat indicators are periodically recalculated to reflect updates in inventories and emission factors. The dataset is not fully reliable for historical timeseries comparison. Methodological breaks in 2007, 2017, and 2020–2021 in data for gas prices, car emissions and share of renewables in transport introduce uncertainty and limit indicators suitability for uninterrupted long-term trend analysis.

While the indicators include three emission-related metrics, they serve distinct analytical functions. CO_2 emissions from new cars (Economic and Energy Efficiency dimension) act as a proxy for technological progress and fleet efficiency in transport. In contrast, GHG emissions per capita and from energy consumption (Environmental Stewardship dimension) reflect broad systemic developments shaped by macroeconomic cycles and energy demand. The sensitivity of these indicators to specific policy interventions is demonstrated by the coal phase-out in Nováky, which is directly reflected in the improved environmental scores of the composite index.

In addition, the price indicators incorporate domestic taxes and subsidies and thus reflect also regulatory choices rather than purely market-driven aspects of energy security, they were retained to capture the actual financial burden on consumers and the effects of government mitigation measures.

A later methodological iteration (Obadi & Korček, 2020) introduced several refinements to their framework. This revised version reduced the number dimensions from four to three and the number of indicators from eleven to ten, and was applied to a limited country sample of seven EU member states. The earlier dimension of availability was simplified into security of supply. This dimension replaced import dependence with the calculated Herfindahl–Hirschman index (HHI) for natural gas imports, a metric used to better reflect supplier concentration (Sovacool & Mukherjee, 2011, Chalvatzis & Ioannidis, 2017). Additionally, the dimensions of energy and economic efficiency and affordability used in the 2017 study were consolidated into a single category of economic availability, with indicators such as energy productivity and electricity prices. The analytical approach employs statistical techniques to construct a composite energy security index. Each data indicator is standardised using the Z-score method, which subtracts the mean and is divided by the standard deviation of the sample set. The Z-score standardization method is a linear transformation of the data and is applied in roughly 11% of energy security indices (Gasser, 2020). This standardisation procedure converts the data measured in different units into "dimensionless" values, enabling the meaningful comparison across indicators and dimensions (Brown et al., 2014; Gasser, 2020).

$$Z_{it} = \frac{X_{it} - \mu_i}{\sigma_i}$$

where X_{it} is indicator value *i* in year *t*, μ_i is the mean of the indicator timeseries and σ_i is the standard deviation.

While the Z-score is traditionally applied in cross-country assessments to identify a country's relative position against a peer-group average in a specific year (Obadi and Korcek, 2017; Brodny and Tutak, 2023), this study adopts a longitudinal (time-series) standardisation approach (Martchamadol and Kumar, 2014). In this setting, the mean (μ) and standard deviation (σ) are calculated for each indicator over the entire analyzed period (2005–2023) for each individual country (Slovakia, Austria, Czechia, Hungary, and Poland).

Following standardisation, equal weights are assigned to all indicators. This approach, used in 38% of energy security indices (Gasser, 2020), assumes all indicators contribute equally to the composite score. The weighted values are then aggregated using a simple additive function , the most commonly used method (applied in 73% of indices), which allows for full compensability, meaning that stronger performance in some indicators can offset weaker performance in others (Gasser, 2020). This results in the energy security index score.

$$A_d = \frac{1}{n_d} \sum_{i=1}^{n_d} Z_{it}$$

where A_d is partial score of dimension *d*.

$$ESI_t = \frac{1}{4}(A_1 + A_2 + A_3 + A_4)$$

The energy security index is calculated for the five Central European countries, comprising Slovakia, Czech Republic, Hungary, Poland and Austria, for the period 2005–2023. This regional focus enables analysis of energy security dynamics in context marked by high import dependencies and exposure to geopolitical and market transformations.

Country-specific data from Eurostat form the quantitative basis for the index calculation. The chosen period 2005-2023 captures developments such as the market liberalisation, the 2009 gas crises and the energy shocks following 2022. The methodology retains equal weighting for all indicators, maintaining consistency over time, , despite differing national energy mixes and policy contexts. The index is constructed to track within-country developments over time and is not intended for direct cross-country ranking.

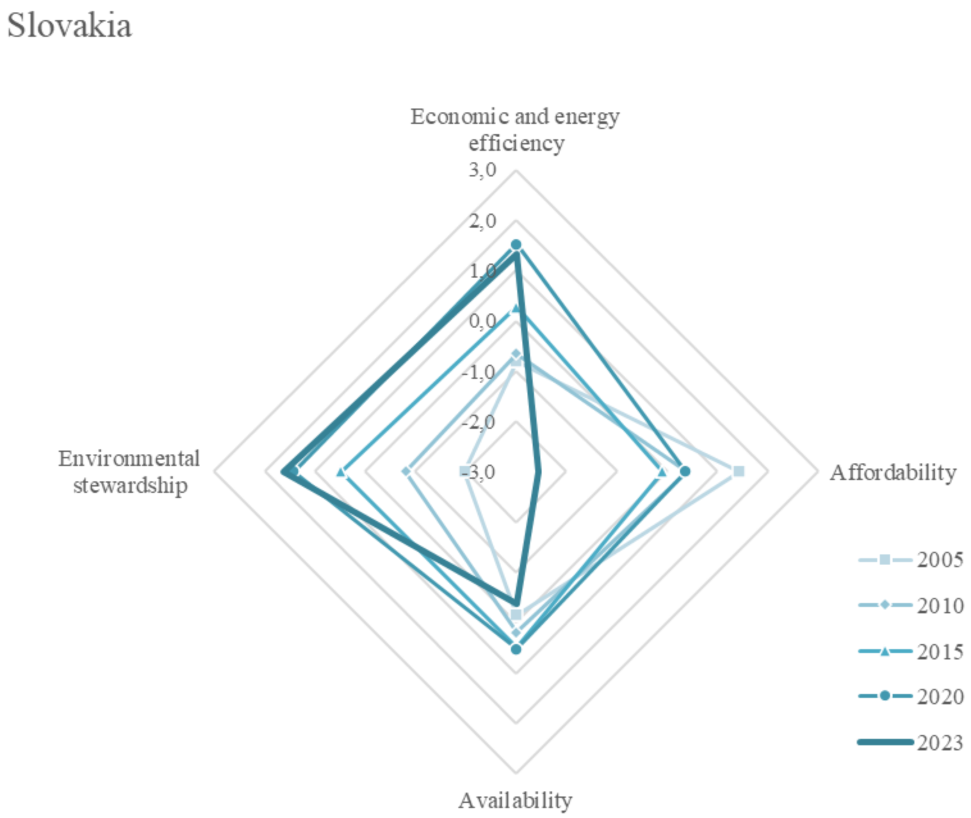
This case study illustrates temporal trends in energy security performance. By aggregating performance across multiple dimensions, the methodology enables the identification of underlying vulnerabilities and strengths within each Central European country over time. This aligns with the broader purpose of composite indices, that is to track development over time and provide decision-makers at the national, regional, and EU levels with relevant insights.

III. Results

The results of the energy security index for the selected countries (Slovakia, Czech Republic, Austria, Hungary and Poland) over the period 2005–2023 reveal temporal shifts in energy security performance. In the following analysis, a score of zero corresponds to the country-specific historical mean over the 2005–2023 period. Positive values indicate years in which a country performs above its long-term average, while negative values indicate performance below this historical baseline.

Slovakia's energy security improved overall during the period 2005 and 2023. The progress came from better economic and energy efficiency and lower GHG emissions on the back of worsened affordability and availability in the context of energy commodity price instability and energy crisis due to war in Ukraine.

Chart 1: Energy security dimensions in Slovakia



Source: author's calculations

Economic and energy efficiency dimension improved during the period 2005 and 2023. Due to ongoing decoupling of economic growth from energy use, the energy intensity consistently declined. CO_2 emissions from new cars decreased as well upon efficiency improvements across the vehicle fleet. This coincides with the period when CO_2 emissions from new cars switch from NEDC-based to WLTP-based reporting and are adjusted using the conversion procedure described in the methodology. By 2023, Slovakia's scores in this dimension were relatively high compared with the other four countries, yet this cross-country comparison needs cautious interpretation, as the index is standardised to each country's own historical mean. The improvement in the dimension after 2017 is partly influenced by methodological factors and only partly by underlying physical changes.

Environmental stewardship improves continuously over almost the entire horizon, aligned with the EU climate and energy policies. Greenhouse gas emissions per capita figures fell steadily and total emissions from energy consumption dropped sharply after 2020 in the context of pandemic-related reductions in economic activity and travel, and in line with transition in Horná Nitra and the closure of the coal power plant in Nováky.

Affordability deteriorated in 2022 and 2023, as natural gas prices surged during the energy crisis and the Russian war in Ukraine, reversing the earlier long-term stability. Energy has become unaffordable for industry in that period, impact on households have been softened by government measures, including subsidies covering up to 80 % of eligible energy expenses. This exposed the country's vulnerability to external price shocks, increasing the energy poverty of vulnerable households and negatively affecting the large consumers in industry.

Availability was volatile for the most of the period, but increased in later years. Oil and gas import dependency stayed high, yet the country started to diversify imports from one supplier in 2020 onwards (HHI for natural gas almost halved from 10000). Meanwhile, the share of renewables in transport doubled over the period.

Across the four neighbouring countries (Czechia, Austria, Hungary and Poland), the energy security index follows a broadly similar trajectory over 2005–2023 as in Slovakia. The index improved slightly between 2005 and 2010, despite the effects of the global financial crisis, which disrupted energy demand and investment, as well as the gas import crises in 2006 and 2009. Performance improved between 2010 and 2015, in line with gains in energy efficiency and declining emissions. In some cases, increased renewable energy use in transport and diversification of energy sources also contributed to improvements, though unevenly. A sharper and more widespread decline followed during the 2021–2023 energy crisis, when energy affordability decreased as natural gas prices rose sharply and volatility heightened. Despite this, environmental performance, particularly pandemic-related reductions in GHG emissions, helped softening the overall index decline by 2023.

Four major trends emerged across all five countries during this period:

- Affordability significantly deteriorated, particularly in 2022 and 2023, in all five countries. The energy prices for both households and industry spiked due to the energy crisis and the Russian invasion of Ukraine.
- Energy and economic efficiency indicators improved steadily. The main underlying indicators, the energy intensity, the CO_2 emissions from new cars and the electricity consumption per capita, jointly support a long-term improvement, particularly in Czechia, Slovakia and Austria.
- Environmental stewardship improves in every country over 2005–2023. Environmental performance strengthened after 2020, with pandemic-related decreases in total and per capita greenhouse gas emissions.
- Availability remained the most volatile in all five countries during the observed period. High oil and gas import dependency and uneven progress in renewables in transport are reflected in these oscillations.

Czechia made strong gains in energy efficiency between 2005 and 2023. Energy intensity fell and emissions from new cars improved steadily. Its environmental score rose sharply after 2020 as total and per capita emissions dropped. But affordability became a serious problem in 2022 and 2023, as it collapsed amid energy crises. Oil and gas import dependency remained high throughout the period, with no consistent improvement in renewable transport. By 2023, the overall index was positive, because emissions and efficiency gains were large enough to offset the affordability dimension.

Hungary shows a similar pattern of gradual improvement followed by a post-2020 decline. Energy efficiency and environmental dimensions improved. Its environmental score rose steadily from 2010. Affordability dropped sharply after 2021, in line with higher energy prices. Unlike others, Hungary had already been struggling with affordability before the energy crisis. Import dependency stayed high and renewables in transport remained limited. The overall index remained positive at the end of the period, but gains were moderate and uneven.

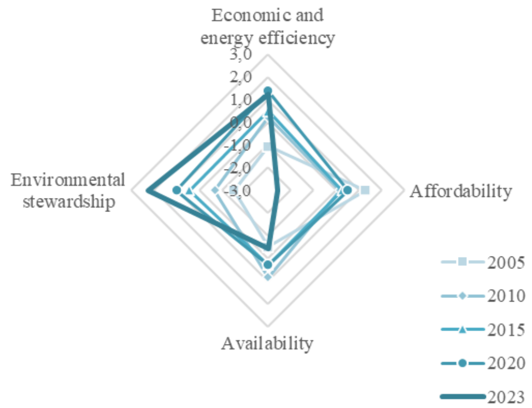
Austria recorded comparatively strong scores in the energy efficiency dimension by 2023. Its energy use per GDP was the lowest among the five countries and emissions from new vehicles declined over time. Environmental performance was also strong, with steady GHG emissions reductions. But, like in other countries, affordability fell significantly in 2022 and 2023. Gas prices rose more sharply than in any of the other countries. Despite excellent results in energy efficiency and environmental stewardship, the affordability crisis weighed down Austria's overall score in the final years.

Poland differs slightly from the others in its starting position but ultimately follows the same general pattern. The energy security index improved owing to economic and energy efficiency, but the country remained the highest emitter of greenhouse gases in absolute terms. Emissions per capita and total emissions were still high in 2020, then dropped sharply in the next three years. Affordability followed the same path as elsewhere, stable until 2021, then a steep fall. Import dependency remained high and renewables in transport were slow to expand. The final index in 2023 was positive, but built mostly on a sudden drop in GHG emissions.

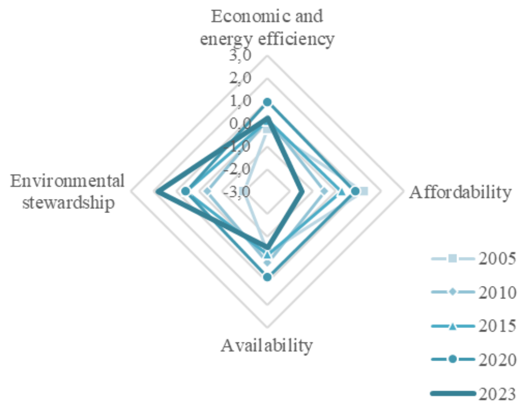
When compared with its neighbours, Slovakia follows the same energy security trend as Czechia, Austria, Hungary and Poland. Across the dimensions, Slovakia aligns with the regional pattern of increasing environmental stewardship and a sharp decline in affordability. The main difference is that Slovakia's weakening in availability after 2020 is more pronounced than in Czechia and Austria but comparable to Hungary and Poland.

Chart 2: Energy security dimensions in Slovakia, Czechia, Hungary, Austria and Poland

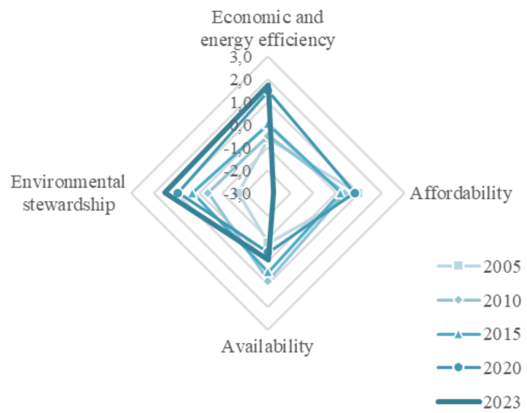
Czech Republic



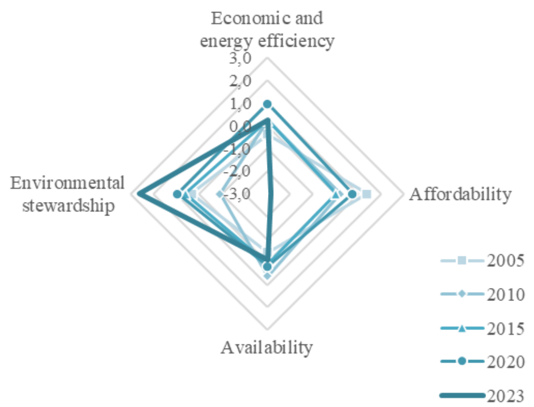
Hungary



Austria



Poland



Source: author's calculations

Note: Dimension scores are relative to each country's 2005–2023 mean; values above/below zero indicate above/below-average performance within that country.

IV. Discussion

The energy security index offers consistent analytical framework and can serve as a descriptive analytical tool reflecting historical trends. However, it faces methodological and conceptual limitations.

As outlined in the methodology section, the dataset includes several methodological breaks in 2007, 2017, and 2020–2021 in data for gas prices, car emissions and share of renewables in transport. These revisions introduce uncertainty and limit indicators suitability for uninterrupted long-term trend analysis. In this sense, the index is used as a descriptive tool that summarises patterns across indicators over time rather than as a model for identifying causal effects of specific policies or shocks.

The data are normalised using Z-score standardisation and indicators are aggregated using equal weights across dimensions through linear aggregation. Equal weighting simplifies interpretation and reflects a normative choice to treat all dimensions as equally important, but may ignore that their relative importance changes over time and is shaped by political priorities in specific national contexts. The use of equal weights, Z-score standardisation and additive aggregation prioritises transparency, simplicity and consistency with earlier studies. In line with the original methodological approach advanced techniques such as the principal component analysis or uncertainty testing were not applied. The absence of sensitivity testing, dynamic weighting or qualitative validation may moderately limit the robustness of results. This approach is common in energy security research focused on long-term or cross-country comparison, but it reduces the model's flexibility and does not reflect changes in how different dimensions of energy security are prioritised politically, as illustrated by the renewed focus on affordability after the 2022 energy crisis. When the index is used as a basis for forward-looking scenario analysis, it can therefore be complemented by qualitative, policy-based assessment to capture such changes in political prioritisation alongside the numerical results.

This study forms part of the process of identifying a suitable methodological basis for future integration of the energy security index with scenario-based analysis toward carbon neutrality in 2050. The current results test the consistency and interpretative capacity of the existing index under changing system conditions. The aim is not to finalise a model but to define its limits before joining energy security and long-term decarbonisation pathways. In this sense, the paper identifies which parts of the current, fossil-based 4A framework can be retained and where additional dimensions and indicators will be needed for a decarbonised, electrified and more digital energy system. Understanding these limits is essential for selecting frameworks linking energy security assessment with transition scenarios to show how different pathways affect country's resilience.

The dimensions and indicators from Obadi & Korček (2017) were selected because their framework specifically incorporated Slovakia, providing regional consistency and a starting point for an expanded timeseries analysis assuming accessible national data. However, this selection also highlights a fundamental challenge in energy security research: the choice of indicators is frequently dictated not only by the evolving energy situation but also by the practical constraints of data availability (Gasser, 2020). Even with this targeted selection, data gaps for indicators and specific dimension coverage remain an issue.

For continuity, the current version of energy security index construction follows the original 2017 indicator selection. Import dependency indicators were retained. While the Herfindahl–Hirschman index may better reflect supplier concentration and is widely used in current energy security assessments, but may not be relevant for a carbon neutral landscape. Electricity price were excluded due to inconsistent data, but future iterations need to include electricity prices to reflect the rising importance of electrification as a core decarbonisation strategy.Furthermore, the new indicators may need to be introduced and the complexity of the energy security index may need to be expanded. The four-dimensional framework reflects the logic of fossil-based systems. It focuses on physical supply, access, affordability and environmental stewardship. These dimensions remain relevant but capture only part of today's risks. The framework assumes stable infrastructures and predictable markets. In a system driven by electrification, variable renewables, interdependent grids and prosumer economy, this assumption no longer holds. Energy security today and in the future depends on flexibility, storage capacity, data integrity and system governance, which current framework does not measure.

Although the framework is adequate for identifying key outcomes of the energy security index, decarbonisation needs introduction of new dimensions. The transition to low-carbon technologies creates exposure to critical raw materials and battery supply chains and new low-carbon technologies. Electrification increases reliance on flexibility and stable grid operation. Digitalisation adds another dependency layer through data infrastructure, monitoring systems, communication networks and automated control. Energy systems affect energy poverty, social justice, climate adaptation and health of citizens. These links multiply potential failure points, the volume of affected citizens and businesses, and reshape what security means. Traditional indicators focused on fuel imports and prices cannot reflect this systemic complexity.

Expanding the index to include governance, resilience, social equity, cybersecurity, material dependence and other dimensions would improve its explanatory value and policy relevance. These additions would align with Sovacool & Mukherjee, 2011, or Azzuni & Breyer, 2017, frameworks and form the basis for a multidimensional framework that captures both security and transition resilience.

With these considerations, the future research may focus on linking energy security assessment with long-term decarbonisation planning. Scenario-based analysis would then use an updated version of the index to compare alternative pathways and examine how different strategies affect the energy security and resilience over time. This approach can help define pathways that reinforce Slovakia's energy security alongside climate neutrality objectives. The present study therefore contributes to clarifying the methodological direction, not to completing it.

V. Conclusion

This study analysed the evolution of Slovakia's energy security between 2005 and 2023 and assessed the adequacy of the current analytical framework for future planning scenarios. The results show a structural change: efficiency and environmental indicators improved, while affordability and availability remained weak.

The energy security index shows that Slovakia achieved progress in energy efficiency and environmental performance. Energy intensity declined consistently, indicating decoupling of economic growth from energy use. Total and per capita greenhouse gas emissions fell sharply after 2020. These achievements align with EU energy and climate targets and reflect the impact of the Emissions Trading System, REPowerEU and the Clean Energy Package (EC, 2023a; EC, 2022; EC, 2019).

Yet, affordability deteriorated. While energy prices remained stable for much of the observed period, they spiked in 2021 - 2023. This increase was driven by the energy crisis and the Russian invasion of Ukraine, elevating fossil fuel price volatility, incurring other costs and increasing national vulnerability (Colgan et al., 2023). Energy has become unaffordable for industry in that period, impact on households have been softened by government measures. Slovak government introduced compensation schemes, including subsidies covering up to 80 % of eligible energy expenses. It also introduced a windfall tax on companies processing cheaper Russian oil to finance household support (Mišík & Oravcová, 2024).

Around 16 % of households in Slovakia were energy poor in 2023, with affordability losses concentrated among low-income and rural groups (Dokupilová & Gerbery, 2023; Dokupilová, 2024; 2025). However, the government subsidies did not address underlying causes such as outdated housing stock and limited access to energy-efficiency financing (Dokupilová, 2024; 2025). These findings suggest that the affordability crisis extends beyond temporary price volatility and points to structural fragility within the social dimension of energy security.

Energy availability was volatile for the most of the period, but increased in later years. The country is dependent on imported oil and gas, until 2020 completely on Russian natural gas. Reverse natural gas flows from Austria and the Czech Republic, established after the 2009 gas crisis, improved short-term stability rather than long-term resilience (Mišík & Oravcová, 2024). Diversification under the EU's REPowerEU plan has reduced supplier concentration since 2022. Slovakia's gas import Herfindahl–Hirschman index halved between 2019 and 2023 (Eurostat, 2025; European Commission, 2022). LNG and pipeline imports from other EU member states substitute Russian gas. Oil imports stay concentrated in transport sector. Renewables in transport grow irregularly and remain below the EU average. Electrification of transport is slow. Battery electric vehicles reached 2.4% share in new car registrations in 2024 (SEVA, 2025).

Slovakia remains exposed to price volatility and supply shocks in natural gas and crude oil. Without structural changes in the national energy mix this risk persists. Slovakia needs faster deployment of renewables and demand-side flexibility measures such as smart grids, storage and responsive demand systems. Political and financial support for nuclear power has created a nuclear lock-in that limits diversification of the power mix and slows the deployment of more flexible, renewable-based generation (Mišík & Oravcová, 2024).

EU policy drives technological and environmental progress via climate neutrality goals. Slovakia's core energy strategy relies on nuclear energy (nearly 60% of electricity generation in 2022) and on natural gas as a flexible complement. Coal has been phased out, but renewable energy adoption was weak, driven mainly by photovoltaic installations. Given high structural import dependency, single supplier history and economic vulnerability sustained investment in infrastructure modernisation, diversification (e.g., reverse flows and new pipeline connections) and price-risk management is needed to stabilize supplies and mitigate concentration risks (Brodny & Tutak, 2023; Mišík & Oravcová, 2024).

Improving affordability is essential. Policies should address energy and transport poverty, especially among vulnerable groups, including through the use of the Social Climate Fund, that aims to mitigate social impacts of extending carbon pricing to buildings and road transport (EC, 2023b). In addition, regional cooperation and alignment with EU strategies such as the Green Deal and REPowerEU remain key to achieving both national and EU goals.

Acknowledgements

I would like to thank my supervisor RNDr. Dušana Dokupilová, PhD. for her mentorship, guidance and constructive comments on earlier drafts of this paper.

During the preparation of this article, I used Undermind.ai, Litmaps.ai and Perplexity.ai for relevant literature discovery, Google NotebookLM to generate preliminary summaries and organise references, and Grammarly for minor language editing of final draft. I reviewed and edited all AI-assisted content and take full responsibility for the accuracy of final version of the paper.

VI. References

Ang, B.W., Choong, W.L. and Ng, T.S. (2015). Energy security: Definitions, dimensions and indexes. Renewable and Sustainable Energy Reviews, 42, pp. 1077–1093. https://doi.org/10.1016/j.rser.2014.10.064

APERC (2007). Asia Pacific Energy Research Centre: A quest for energy security in the 21st century: Resources and constraints. Institute of Energy Economics, Japan. https://www.ieej.or.jp/aperc/2007pdf/ES_2007.pdf

Augutis, J., Krikštolaitis, R., Martišauskas, L., Pečiulytė, S. & Žutautaitė, I. (2017). Integrated energy security assessment. Energy, 2017, vol. 138, issue C, 890-901. doi: 10.1016/j.energy.2017.07.113

Augutis, J., Krikštolaitis, R., Martišauskas, L., Urbonienė, S., Urbonas, R. & Užspurienė, A. (2020). Analysis of energy security level in the Baltic States based on indicator approach. Energy, 199:117427. doi: 10.1016/j.energy.2020.117427

Azzuni, A. and Breyer, C. (2018) 'Definitions and dimensions of energy security: a literature review', Wiley Interdisciplinary Reviews: Energy and Environment, 7. doi: 10.1002/wene.268. https://wires.onlinelibrary.wiley.com/doi/10.1002/wene.268

Bompard, E., Carpignano, A., Erriquez, M., Grosso, D., Pession, M. & Profumo, F. (2017). National energy security assessment in a geopolitical perspective. Energy, 130, pp. 144–154. doi: 10.1016/j.energy.2017.04.108

Brodny, J. & Tutak, M. (2021). The comparative assessment of sustainable energy security in the Visegrad countries. A 10-year perspective. Journal of Cleaner Production, 317, 128427. doi: 10.1016/j.jclepro.2021.128427

Brodny, J. & Tutak, M. (2023). Assessing the energy security of European Union countries from two perspectives – A new integrated approach based on MCDM methods. Applied Energy, 347, 121443. doi: 10.1016/j.apenergy.2023.121443

Brown, M.A., Wang, Y., Sovacool, B.K. & D'Agostino, A.L. (2014). Forty years of energy security trends: A comparative assessment of 22 industrialized countries. Energy Research & Social Science, 4, pp. 64–77. doi: 10.1016/j.erss.2014.08.008

Carmon, O. et al. (2025). Evaluating energy security in decentralized systems. Energy Strategy Reviews, 60, 101754. doi: 10.1016/j.esr.2025.101754

Chalvatzis, K.J. & Ioannidis, A. (2017). Energy supply security in the EU: Benchmarking diversity and dependence of primary energy. Applied Energy, 207, pp. 465–476. doi: 10.1016/j.apenergy.2017.07.010

Cherp, A. & Jewell, J. (2011). The three perspectives on energy security: intellectual history, disciplinary roots and the potential for integration, Current Opinion in Environmental Sustainability 2011, 3:202–212, doi: 10.1016/j.cosust.2011.07.001

Cherp, A. & Jewell, J. (2014) The concept of energy security: beyond the four As, Energy Policy, 75, pp. 415-421. doi: 10.1016/j.enpol.2014.09.005.

Chester L. (2010). Conceptualising Energy Security and Making Explicit Its Polysemic Nature, Energy Policy, Vol. 38, pp. 887–895. doi: https://doi.org/10.1016/j.enpol.2009.10.039

Colgan, J.D. (2023). Quantifying the value of energy security: How Russia's invasion of Ukraine exploded Europe's fossil fuel costs. Energy Research & Social Science, 103, 103201. doi: 10.1016/j.erss.2023.103201

Demir, C. & Cergibozan, R. (2025). Energy security Risk across EU. Politická ekonomie, 73(3), Forthcoming articles. doi: 10.18267/j.polek.1454

Dokupilová, D. (2024) Energetická chudoba 2024. Bratislava: Prognostický ústav SAV. Retrieved from: https://www.prog.sav.sk/wp-content/uploads/Energeticka-chudoba_2024.pdf

Dokupilová, D. (2025) Energetická chudoba 2025. Bratislava: Prognostický ústav SAV. Retrieved from: https://www.prog.sav.sk/wp-content/uploads/Energeticka-chudoba2025-.pdf

Dokupilová, D. and Gerbery, D. (2023) Energetická chudoba na Slovensku: Analytická štúdia a index rizika domácností. Bratislava: Prognostický ústav SAV. Retrieved from: https://www.prog.sav.sk/wp-content/uploads/Energeticka-Chudoba.pdf

European Commission (2025). European Commission’s Weekly oil Bulletin, retrieved from (EU_price_with_tax_euro95), https://energy.ec.europa.eu/data-and-analysis/weekly-oil-bulletin_en#price-developments

European Commission (2023a). EU Emissions Trading System (EU ETS). Retrieved from https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets_en.

European Commission (2023b). Regulation (EU) 2023/955 of the European Parliament and of the Council of 10 May 2023 establishing a Social Climate Fund and amending Regulation (EU) 2021/1060. Retrieved from https://eur-lex.europa.eu/eli/reg/2023/955/oj/eng

European Commission (2022). Communication from the Commission to the European parliament, the European Council, the Council, the European economic and social committee and the Committee of the regions REpowerEU Plan, COM/2022/230 final. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52022DC0230

European Commission (2021). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality. COM/2021/550 final. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550

European Commission. (2019). Communication from the Commission to the European Parliament, the European Council, the European Economic and Social Committee, and the Committee of the Regions: The European Green Deal. COM(2019) 640 final. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52019DC0640

European Commission (2015) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy, COM/2015/080 final. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52015DC0080

European Commission (2007), Commission Decision 2007/394/EC: Commission Decision of 7 June 2007 amending Council Directive 90/377/EEC with regard to the methodology to be applied for the collection of gas and electricity prices charged to industrial end-users. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32007D0394

European Commission (2006). GREEN PAPER A European Strategy for Sustainable, Competitive and Secure Energy, SEC(2006) 317, retrieved from https://europa.eu/documents/comm/green_papers/pdf/com2006_105_en.pdf

Erker, S. et al. (2017). Resilience in the light of energy crises: framework to conceptualise regional energy resilience. Journal of Cleaner Production, 164, pp. 420–433. doi: 10.1016/j.jclepro.2017.06.163

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

IEA (2007). Energy Security and Climate Policy: Assessing Interactions. Paris, retrieved from https://www.iea.org/reports/energy-security-and-climate-policy-assessing-interactions

Jones, O; Dodds, P; (2017) Definitions of energy security. In: Steinberger-Wilckens, R and Dodds, PE and Kurban, Z and Velazquez Abad, A and Radcliffe, J, (eds.) The role of hydrogen and fuel cells in delivering energy security for the UK. (pp. 32-45). H2FC Hub: London, UK. https://discovery.ucl.ac.uk/id/eprint/10087004

Kisel, E. et al. (2016). Concept for Energy Security Matrix. Energy Policy, 95, pp. 1–9. doi: 10.1016/j.enpol.2016.04.034

Kruyt B., van Vuuren D.P., de vries H.J.M, Groenenberg H. (2009). Indicators for energy security, Energy Policy 37 (2009) 2166–2181, doi:10.1016/j.enpol.2009.02.006

Labelle, M. (2024). Breaking the era of energy interdependence in Europe. Energy Strategy Reviews, 52, 101314. doi: 10.1016/j.esr.2024.101314

Månsson, A., Johansson, B. & Nilsson, L.J. (2014). Assessing energy security: An overview of commonly used methodologies. Energy, 73, pp. 1–14. doi: 10.1016/j.energy.2014.06.073

Martchamadol, J. and Kumar, S. (2014) 'The aggregated energy security performance indicator (AESPI) at national and provincial level', Applied Energy, 127, pp. 219–238. doi: 10.1016/j.apenergy.2014.04.045

Martišauskas, L., Augutis J., Krikštolaitis R. (2018). Methodology for energy security assessments considering energy system resilience to disruptions. Energy Strategy Reviews, 22, pp. 106–118. doi: 10.1016/j.esr.2018.08.007

Mišík, M. & Nosko, J. (2023). Exploring the energy security paradox of the European Union. Energy Research & Social Science, 99, 103074. doi: 10.1016/j.erss.2023.103074

Mišík, M. (2022). The EU needs to improve its external energy security. Energy Policy, 165, 112930. doi: https://doi.org/10.1016/j.enpol.2022.112930

Mišík, M. and Oravcová, V. (2024) Policy persistence vis-à-vis a crisis: the curious case of Slovak energy policy after the Russian invasion of Ukraine. Energy Efficiency 17 (33). doi: 10.1007/s12053-024-10216-x

Muñoz, B., García-Verdugo, J., & San-Martín, E. (2015). Quantifying the geopolitical dimension of energy risks: A tool for energy modelling and planning. Energy, 82, 479–500, doi: 10.1016/j.energy.2015.01.058.

Narula, K., & Reddy, B. S. (2016). A SES (sustainable energy security) index for developing countries. Energy, 94, 326–343. doi: 10.1016/j.energy.2015.10.106

Obadi, S.M. & Korček, M. (2017). EU Energy Security - Multidimensional Analysis of 2005-2014 Development. International Journal of Energy Economics and Policy, 7(72):113-120.

Obadi, S. M., & Korcek, M. (2020). Quantifying the Energy Security of Selected EU Countries. International Journal of Energy Economics and Policy, 10(2), 276–284. Retrieved from https://www.econjournals.com/index.php/ijeep/article/view/8847

Osička, J., & Černoch, F. (2022). European energy politics after Ukraine: The road ahead. Energy Research & Social Science, 91, 102757. doi: 10.1016/j.erss.2022.102757

Radovanović, M., Filipović, S. & Pavlović, D. (2017). Energy security measurement – A sustainable approach. Renewable and Sustainable Energy Reviews, 68, pp. 1020–1032. doi: 10.1016/j.rser.2016.02.010

SEVA. (2025). Number of electric cars on Slovak roads exceeded 15 thousand as of 31 December 2024, there were 15 476 battery electric vehicles on Slovak roads, published 30.1.2025. Retrieved from https://seva.sk/en/bev-sk-2024/ (25.8.2025).

Siksnelyte-Butkiene, I. et al. (2024). Comprehensive analysis of energy security indicators and measurement of their integrity. Technological Forecasting & Social Change, 200, 123167. doi: https://doi.org/10.1016/j.techfore.2023.123167

Sovacool, B.K. & Mukherjee I. (2011). Conceptualizing and measuring energy security: A synthesized approach. Energy 36 (2011) 5343e5355. doi:10.1016/j.energy.2011.06.043

Valdés, J.R. (2018). Arbitrariness in multidimensional energy security indicators. Energy Policy, 113, pp. 450–467. doi: 10.1016/j.ecolecon.2017.09.002

Wu, T.-H. et al. (2021). Evaluating global energy security performance using integrated PCA/DEA-AR technique. Sustainable Energy Technologies and Assessments, 45, 101041. doi: https://doi.org/10.1016/j.seta.2021.101041

Zhao, X. & Zhai, G. & Nasim, A. & Ma, X.. (2025). Geopolitical risks, trade openness, and energy security. Energy Economics, 127, 107147. doi: 10.1016/j.eneco.2025.108777

Data references

Eurostat, (2025):

Reference data for energy intensity (nrg_ind_ei), retrieved from https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ei__custom_18280488/default/table

Reference data for average CO2 emissions per km from new passenger cars (sdg_13_31), retrieved from https://ec.europa.eu/eurostat/cache/metadata/en/sdg_13_31_esmsip2.htm

Reference data for electricity consumption per capita (nrg_cb_e a demo_gind), retrieved from https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_e__custom_18280529/default/table, https://ec.europa.eu/eurostat/databrowser/view/demo_gind__custom_18280543/default/table

Reference data for gas price for industry, (nrg_pc_203), retrieved from https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_203__custom_18280654/default/table

Reference data for gas price for households, (nrg_pc_202), retrieved from https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_202__custom_18280662/default/table

Reference data for oil import dependency, (nrg_ind_id (Oil)), retrieved from https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_id__custom_18280745/default/table

Reference data for gas import dependency, (nrg_ind_id (Gas)), retrieved from https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_id__custom_18280745/default/table

Reference data for share of RES in transport, (nrg_ind_ren), retrieved from https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ren__custom_18280747/default/table

Reference data for GHG emissions per capita, (sdg_13_10), retrieved from https://ec.europa.eu/eurostat/databrowser/view/sdg_13_10__custom_18280754/default/table

Reference data for GHG of energy consumption, (env_air_gge), retrieved from https://ec.europa.eu/eurostat/databrowser/view/env_air_gge__custom_18280761/default/table

Reference data for gasoline prices: EC (2025), Weekly oil Bulletin, retrieved from (EU_price_with_tax_euro95), https://energy.ec.europa.eu/data-and-analysis/weekly-oil-bulletin_en#price-developments

Reference data for electricity prices - bi-annual data (from 2007 onwards) (nrg_pc_204), retrieved from https://ec.europa.eu/eurostat/cache/metadata/en/nrg_pc_204_sims.htm