Institut européen
European Institute

LUISS
School of Government

Joint Master in EU Trade and Climate Diplomacy

On Energy and Security: Analysis of the Effectiveness of EU Policies in Reducing Energy Vulnerability in the Aftermath of the 2022 Energy Crisis

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July 2025

Thesis Pitch

This link leads to the thesis pitch: https://youtu.be/KdXTzX9mO6k

Statutory Declaration

I hereby declare that I have composed the present thesis autonomously and without use of any other than the cited sources or means. I have indicated parts that were taken out of published or unpublished work correctly and in a verifiable manner through a quotation. I further assure that I have not presented this thesis to any other institute or university for evaluation and that it has not been published before.

In Nice, France, on July 26th, 2025

Laura Llussà i Rosell

Acknowledgements

Als meus estimats avis,
que em van ensenyar a pensar fent-me preguntes.
Tot el que entenc té arrels en ells.

To my dear grandparents,
Who opened my eyes to words and my mind to ideas.
All that I understand is rooted in them.

Abstract

The 2022 energy crisis, triggered by Russia's invasion of Ukraine, exposed major vulnerabilities in the European Union's energy systems, including high import dependency, price volatility, and limited institutional preparedness. This thesis introduces the Annual Energy Vulnerability Index (AEVI), a composite indicator that combines supply diversification, price stability, and institutional response capacity in a single framework for cross-country and temporal comparison. By incorporating an institutional dimension, the AEVI provides a more comprehensive tool for assessing energy vulnerability than conventional metrics.

The AEVI was computed for 27 EU Member States for 2021–2024 and used together with an exploratory regression to illustrate how the index can be applied to study potential drivers of change. Descriptive results show a general improvement in 2022, coinciding with emergency measures such as gas storage compliance and voluntary demand reductions, followed by more heterogeneous trajectories in 2023–2024. The regression did not yield statistically significant coefficients due to the limited dataset, but the exercise demonstrates how the AEVI can be operationalized to investigate the role of policy and structural factors in shaping vulnerability trends.

The thesis's primary contribution is methodological. Rather than aiming for definitive empirical findings, it focuses on the design and application of the AEVI as a transparent and adaptable tool for monitoring energy vulnerability. The index provides a basis for future research and policy evaluation and can be extended with longer time series, richer policy indicators, and variables capturing fiscal and institutional capacity to enable more robust and comprehensive assessments.

Keywords: Energy vulnerability; Energy security; European Union; Energy policy; Supply diversification; Price volatility; Institutional capacity; Composite index; Renewable energy; REPowerEU.

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Acronyms

AEVI – Annual Energy Vulnerability Index

CBAM – Carbon Border Adjustment Mechanism

CfD / CfDs – Contract for Difference / Contracts for Difference

CPI – Climate Policy Integration

GDP – Gross Domestic Product

FSRUs – Floating Storage and Regasification Units

GATT – General Agreement on Tariffs and Trade

HHI – Herfindahl-Hirschman Index

IEA – International Energy Agency

LNG – Liquefied Natural Gas

OLS – Ordinary Least Squares

PCI – Projects of Common Interest

PPA / PPAs – Power Purchase Agreement(s)

RED III – Renewable Energy Directive III

RRF – Recovery and Resilience Facility

TEN-E – Trans European Network for Energy

TTF – Title Transfer Facility

VIF – Variance Inflation Factor

WTO – World Trade Organization

1. Introduction

From the late 1970s until the early 2020s, energy security had been sidelined from European strategic agendas. However, since 2022, following Russia's invasion of Ukraine and its impact on gas supplies, this concept has re-emerged with force, shaking both the European Union's economy and its political priorities.

The concept of energy vulnerability refers to the degree of exposure of an economic and social system to risks arising from sudden changes in energy supply or prices. Unlike isolated disruptions, such as technical failures or logistical interruptions, this is a structural and ongoing exposure to exogenous shocks that are difficult to predict and even harder to mitigate using traditional public policy instruments (IEA, 2024).

The 1970s served as the first major geopolitical testing ground for this concept. The dual shocks of the Arab oil embargo in 1973 and the Iranian revolution in 1979 demonstrated how oil could become a strategic weapon capable of destabilizing the international economic order. The 1973 embargo, imposed by Arab countries in response to Western support for Israel during the Yom Kippur War, caused the price of oil to surge by 300%, triggering an inflationary crisis across the West and contributing to the collapse of several governments (Yergin, 2023). The 1979 crisis, driven by the halt in Iranian production, doubled crude oil prices and pushed inflation in the United States to 13%, leading to the most severe recession since the Great Depression (Graefe, 2013).

These crises catalyzed the creation of the International Energy Agency (IEA) and the institutionalization of strategic reserves. At the same time, they introduced for the first time the idea of energy volatility as a systemic threat.

However, between the mid-1980s and 2021, energy markets appeared relatively stable. Production diversified, mainly due to the expansion of fracking in the United States and the development of Liquefied Natural Gas (LNG), and European consumption stabilized due to greater efficiency and deindustrialization. A relatively predictable global pricing system took shape. Within this context, the European Union adopted a strategy based on interdependence and market liberalization, under the assumption that economic openness would discourage the strategic use of energy. But that assumption collapsed on February 24, 2022.

Russia's invasion of Ukraine reopened a question that many believed to be settled: can an energy supplier use its position as a tool of political pressure? The answer was a resounding yes. Within a few months, the flow of Russian gas to the EU had dropped by over 80%, while the price of gas at the Title Transfer Facility[1] (TTF) hub surpassed €320/MWh in August 2022, a historic record, ten times higher than the usual level (IEA, 2024).

This shock has not been temporary; rather, it has generated a series of structural vulnerabilities that continue to shape the European energy agenda today:

- **Volatility has become chronic:** despite the decline in prices after the 2022 peak, average volatility in the European gas market remains 34% higher than during the 2010–2021 period, based on data from January to September 2024 (IEA, 2024)

- **Logistical instability has worsened:** the partial blockade of the Suez Canal by the Houthis and the ongoing drought in the Panama Canal have placed severe strain on the global LNG supply chain, significantly increasing both transport times and costs (IEA, 2024)

- **New geopolitical risk hotspots:** the escalation of hostilities between Iran and Israel in June 2025 triggered a 15% rise in diesel prices, highlighting Europe's remaining dependence on Gulf-region refineries, especially those in Kuwait and Saudi Arabia (Bousso, 2025).

[1] The Title Transfer Facility (TTF) is a gas trading platform where contracts for physical or financial delivery are exchanged. It serves as the main price benchmark for natural gas in Europe, with prices quoted in €/MWh reflecting supply and demand dynamics.

This environment underscores the need to rethink energy security, not merely as resilience to isolated crises, but as a structural capacity to adapt to a global energy system that is increasingly unstable, fragmented, and politicized.

1.1 Why volatility matters today

Volatility has returned to the public and academic agenda as one of the main economic and political risks of our time. Energy price instability is not only a problem for market operators or for governments planning the energy transition, it has immediate consequences for households, businesses, and the political stability of states. In this context, it is crucial to understand how abrupt price fluctuations and the associated uncertainty generate macroeconomic, distributive, and strategic costs that justify a renewed focus on energy vulnerability as both an analytical and political category.

From a macroeconomic perspective, several studies have shown that sudden increases in energy prices have contractionary effects on economic growth and fuel inflationary pressures. For instance, Papapetrou's study (2001) demonstrated that oil price shocks have a significant negative impact on economic activity and the labor market in Greece, a finding later confirmed by multiple European studies (Creti, Joëts, & Mignon, 2013). At the European level, rising gas and oil prices have been shown to directly contribute to a slowdown in industrial output and a decline in business confidence (Gabrielli, Wüthrich, Blume & Sansavini, 2022).

However, energy volatility does not affect everyone equally. While large corporations can hedge against risks through futures markets or bilateral contracts, low-income households and small businesses have limited capacity to absorb price shocks. This creates a regressive impact and often amplifies pre-existing inequalities.

Buscha, Christensen & Nielsen (2011) analyze how rising energy prices affect household consumption across income quintiles, concluding that lower-income groups spend a much higher share of their total expenditure on energy, making them more vulnerable to the effects of energy inflation. Similarly, Enescu & Szeles (2023) show how the war in Ukraine has exacerbated energy inequalities within the EU, especially in Eastern and Southern European countries, where dependency on Russian natural gas was highest.

Volatility also acts as a brake on investment: when prices are highly uncertain, companies tend to delay strategic decisions, particularly in energy-intensive sectors such as chemicals or steel. This may create spillover effects into other sectors and hamper medium-term growth (West, 1996). This dynamic is especially concerning at a time when Europe urgently needs a wave of investment to modernize its energy infrastructure and move toward decarbonization.

Energy volatility has eroded one of the pillars of the European model: stability. The 2022 sudden surge in gas prices triggered a chain reaction of political responses: price controls, massive subsidies, emergency measures, and a rapid reassessment of the internal energy market framework. Within the REPowerEU plan, the European Commission acknowledged that the vulnerability stemming from dependence on Russian gas had been underestimated for decades and proposed structural measures to diversify sources and supply routes (European Commission, 2022).

Moreover, the geopolitical impact of volatility has been direct. As Min (2022) documents, Russia's use of energy supply as a weapon exposed the fragility of the interdependence model as a guarantee of peace. At the same time, this volatility has forced the EU to redefine its foreign policy strategy, balancing climate goals with pragmatic alliances with new energy partners (such as Qatar, Algeria, and the United States).

One of the defining features of current volatility is its systemic nature. As shown by Creti, Joëts, & Mignon (2013), energy and financial markets have become highly correlated, particularly since the 2008 crisis. This "financialization" of commodities means that energy price shocks are rapidly transmitted to other assets, amplifying overall systemic uncertainty.

In addition, the interconnection of European markets means that shocks in one country or region quickly spread across the continent. The study by Sikorska-Pastuszka & Papież (2023) shows that electricity market volatility in Europe has significantly increased since 2021, with rising spillover effects between regional markets and high sensitivity to factors such as gas prices and geopolitical tensions.

Finally, the re-emergence of volatility as a structural problem has triggered a reorientation of public policy. It is no longer simply a matter of ensuring supply or reducing emissions, but also of managing systemic risks associated with a volatile, financially interconnected, and geopolitically unstable global environment. Energy has once again become a matter of national security and macroeconomic stability.

This new centrality demands new indicators of vulnerability and better integration between energy policy, fiscal policy, and social protection. In this context, developing tools to measure the structural exposure of European states to energy volatility can help strengthen response capacity and improve strategic planning (Gabrielli et al., 2022).

1.2 Research objectives and structure

This thesis begins with a core observation: the energy crisis triggered in 2022 has starkly exposed the structural vulnerabilities of Europe's energy systems. Despite market integration efforts and progress in renewable deployment, the region's dependence on fossil fuel imports and its limited capacity for coordinated response have cast serious doubt on the robustness of the European energy model. In response, the European Union implemented an ambitious package of emergency measures between 2022 and 2024 aimed at reducing exposure to price shocks, supply risks, and institutional constraints.

Hence, the research aims to investigate the actual effectiveness of this European emergency package with the following research question:

To what extent, and through which combinations of instruments, have the measures adopted by the European Union between 2022 and 2024 reduced the energy vulnerability of the Member States?

This overarching question unfolds into two operational sub-questions:

- What has been the evolution of energy vulnerability before (2021) and after (2024) the implementation of the EU emergency package? → This first component offers a quantitative, cross-country analysis using the Annual Energy Vulnerability Index (AEVI), an indicator developed for this thesis, which integrates three core dimensions: supply diversification, exposure to energy prices, and institutional response capacity.

- What are the main factors explaining the differences across countries in the reduction of energy vulnerability? → The second component adopts an explanatory approach to identify key drivers of change, drawing on variables such as energy mix composition, cross-border interconnection, speed of strategic storage deployment, participation in instruments like Contracts for Difference (CfDs) and Power Purchase Agreements (PPAs), and demand reduction policies.

To carry out this analysis, the topic is first introduced through the historical and theoretical context of energy vulnerability, from the first oil shocks of the 1970s to the recent crisis. This is followed by a literature review on main definitions, indicators, and mitigation strategies, which also identifies the main research gap. The methodology chapter outlines the empirical strategy and research hypotheses. The following chapters first examine the new geopolitical risk landscape and policy narratives, and then present the quantitative analysis, including the construction and validation of the AEVI. The final sections discuss the results, policy implications, and limitations, and conclude with the main findings and avenues for future research.

2. Literature Review

2.1 Conceptual framework of energy security and its metrics

Energy security has become a central concept in global economic and environmental policy. However, its definition, traditionally linked to the assurance of a stable oil supply in the context of the shocks of the 1970s, has expanded and become more sophisticated over time. Cherp & Jewell (2014) argue that the concept should be understood as a specific variant of the broader idea of security, and therefore must address three essential questions: security for whom, from what, and how. Winzer (2012) contends that energy security should be understood as the ability of an energy system to withstand disruptions and uncertainties without losing essential functionality, and emphasizes the need to differentiate between physical, economic, institutional, and geopolitical risks. This definition allows for a distinction between risk (a combination of probability and impact) and vulnerability (the degree of a system's exposure to that risk), a distinction also highlighted by Ang, Choong & Ng (2014) in their analysis of over 100 studies published between 2001 and 2014.

The International Energy Agency (IEA), for its part, defines energy security "as the uninterrupted availability of energy sources at an affordable price" although it acknowledges that this definition must be adapted for both the short and long term. In the short term, it implies resilience to sudden supply disruptions, while in the long term it includes the capacity to ensure a transition toward sustainable, robust, and efficient systems (Cherp & Jewell, 2014).

As threats have expanded, more integrative frameworks have been proposed. The paradigm of the "4 A's" (availability, accessibility, affordability, and acceptability) has been widely adopted by the Asia Pacific Energy Research Centre (APERC, 2007) and replicated in various later works (Kruyt, van Vuuren, de Vries & Groenenberg, 2009), although some authors have criticized this approach for its lack of explanatory and operational power in real crisis contexts (Cherp & Jewell, 2014; Chester, 2009). Moreover, the application of this framework tends to be fragmented, and often each study reinterprets it using different criteria.

Regarding metrics, early empirical approaches focused on import dependency as a basic indicator of vulnerability. The Herfindahl-Hirschman Index (HHI), used by the IEA and multiple empirical studies, measures the concentration of energy supply by origin. A high HHI indicates excessive reliance on a small number of suppliers, as was the case with Russian gas in the EU before 2022. However, this approach is incomplete: it fails to capture price volatility, the system's absorptive capacity, or the territorial distribution of the shock's impact (Kruyt et al., 2009; Ang, Choong, and Ng, 2014).

In response to these limitations, composite indexes have been developed, such as MOSES (Model Of Short-term Energy Security), which combines risk elements (import share, volatility, storage capacity) and resilience components (infrastructure, regulation, demand flexibility). Other indexes, such as those by USAID (for Europe and Central Asia), attempt to integrate criteria such as environmental sustainability or institutional governance, although their application is often limited by the lack of homogeneous data across countries (Kruyt et al., 2009; Ang, Choong, and Ng, 2014).

With the outbreak of the war in Ukraine in 2022, the literature has shifted toward more dynamic approaches that combine concentration metrics with indicators of price volatility and sectoral exposure. Studies such as those by Boeck & Zörner (2024) or Casoli, Manela & Virenti (2024) show how gas price shocks have had uneven effects across sectors and countries, and that the degree of impact has been more closely related to the rigidity of energy demand and the lack of contractual alternatives than to total consumption volume.

This shift has also translated into the regulatory framework. Regulation (EU) 2024/1747, adopted as an institutional response to the 2022 price crisis, explicitly acknowledges that market volatility was mainly due to the increase in gas prices and that the system’s response capacity must be reinforced through instruments such as contracts for difference (CfDs) and long-term PPAs. This reform represents regulatory recognition that energy security cannot be measured solely in physical terms, but must also include the economic, regulatory, and financial capacity to cope with disruptions.

Thus, four structural limitations in the current design of energy security metrics have been highlighted:

1. **Temporality**: Most indexes are annual and cannot capture short-duration, high-intensity crises (e.g., summer 2022).
2. **Aggregation**: Many indicators operate at the country level and conceal critical sectoral vulnerabilities (e.g., energy-intensive industries or household heating systems).
3. **Regulatory Disconnection**: Metrics are not aligned with public policy instruments (like CfDs or Green Deal targets).
4. **Abstract Geopolitics**: Although source dependency is recognized, few indexes integrate variables such as political coercion risk, institutional reliability of suppliers, or vulnerability to international sanctions (Giuli & Oberthür, 2023).

2.2 Mitigation policies for energy risk in the European Union (2022-2024)

The outbreak of the energy crisis following Russia's invasion of Ukraine accelerated a wave of measures that, for the first time, attempt to reconcile supply security with decarbonization. Giuli & Oberthür show that the 2022 response reflects an unprecedented level of integration of climate policy into the EU's external energy policy, surpassing the precedents of 2009 and 2014 thanks to the convergence of material threats and stricter institutional climate frameworks (Giuli & Oberthür, 2023). This perspective is key to understanding why risk mitigation strategies are being deployed along three major thematic axes: diversification of supply sources, reform of market design, and demand management.

<u>Diversification of Supply and Strengthening Physical Resilience</u>

The immediate priority, right after Russia's invasion of Ukraine in 2022, was to reduce dependence on Russian gas and ensure sufficient reserves for the winter of 2022–23. Regulation (EU) 2022/1032 on gas storage requires Member States to fill at least 80% of their storage capacity in 2022 and 90% from 2023 onwards, making strategic stockpiling an essential requirement to mitigate the risk of supply cuts. Giuli & Oberthür (2023) interpret this measure as an example of "strong" Climate Policy Integration (CPI), as replacing Russian gas with U.S. LNG or domestically produced EU biomethane links supply security with the goal of climate neutrality (Giuli & Oberthür, 2023).

Empirically, Cevik (2024) shows, using a panel of 27 states, that increasing the share of renewables reduces both price volatility and the weight of energy imports: each additional percentage point of non-hydrocarbon energy is associated with a statistically significant decrease in the import component (average coefficient –0.006). These findings reinforce Giuli and Oberthür's argument that diversification toward low-carbon sources is currently the safest path to strengthen European energy resilience. However, the structural shift toward low-carbon energy sources is a gradual process that requires major infrastructural investment. In an acute crisis, swift measures such as gas storage targets, joint procurement, and demand-reduction schemes are essential to provide short-term relief. These instruments cannot substitute the long-term goal of decarbonization but serve as complementary tools to stabilize markets while the transition progresses.

Reform of the Electricity Market: Stabilizing Expectations and Catalyzing Investment

The literature agrees that the short-term pricing mechanisms of the "energy-only market" amplify vulnerability during scarcity episodes (Honkapuro & Jaanto, 2023). Their systematic review notes that, despite the crisis, few radical changes have been proposed, focusing instead on integration and liquidity while avoiding the core incentives of the day-ahead market.

This regulatory gap explains the relevance of Regulation (EU) 2024/1747, which amends Regulations (EU) 2019/942 and (EU) 2019/943: it mandates grid operators to publish information facilitating long-term Power Purchase Agreements (PPAs) and creates a European framework for green Contracts for Difference (CfDs), defined as contracts likely to reduce the final bill when the market price exceeds the fixed strike price. It also requires that excess revenues be reinvested in consumer protection (Honkapuro & Jaanto, 2023). From an academic standpoint, Poplavskaya, Lago & de Vries (2020) use strategic game simulations to show that CfDs reduce opportunities for speculative bidding and, consequently, the systemic risk of price spikes during demand peaks.

Demand Management and Efficiency

Regulation (EU) 2022/1369 introduced a voluntary target, later extended, of reducing gas consumption by 15%. Kim, Jaumotte, Panton & Schwerhoff (2025) calculate a dynamic energy risk index that combines import intensity and demand elasticity; their modeling indicates that saving 10% of gas is equivalent, in terms of risk mitigation, to adding 15

GW of distributed solar capacity, but at a significantly lower marginal cost (Kim et al., 2025). This confirms the relative effectiveness of "demand-side flexibility" policies incorporated into REPowerEU.

Emergency Mechanisms to Cushion Price Shocks

In response to the 2022 price spiral, Regulation (EU) 2022/1854 imposed a temporary cap of €180/MWh on "inframarginal" revenues and introduced a solidarity contribution on windfall profits. Honkapuro & Jaanto (2023) warn that while such caps help correct short-term risk perceptions, they may suppress renewable investment signals if extended without a clear exit timeline. Meanwhile, the "Market Correction Mechanism" (Reg. 2023/2578) has never been activated, which, according to Wang and Tian (2025), reflects a sufficiently dissuasive effect in itself, although their time-series analysis detected a drop in the depth of the futures market immediately after the announcement.

* * *

So, overall, post-2022 literature converges on three main findings:

First of all, the existence of a security–climate symbiosis: Diversifying toward renewables and energy savings is not just climate policy, it reduces exposure to supply shocks and improves the trade balance. This convergence is documented in both qualitative analyses of CPI (Giuli & Oberthür, 2023) and econometric estimates of the EU Regulation 2024/1747.

Second, the need for long-term price frameworks: The strong emphasis of Regulation 2024/1747 on PPAs and CfDs addresses a gap identified by market design research, which calls for stable signals to mobilize large-scale capital and reduce systemic risks in electricity markets.

And thirdly, still understudied demand governance: Despite promising evidence on the impact of coordinated consumption reduction (Kim et al., 2025), there is a lack of empirical research comparing the relative effectiveness of flexibility instruments, dynamic pricing, and behavioral measures.

Overall, the 2022–2024 arc reveals a shift toward hybrid instruments that combine regulatory intervention with market mechanisms. However, the review also highlights analytical gaps regarding the distributive effects and long-term durability of these mechanisms under normalized price conditions.

2.3 Geopolitics of Energy Trade

Several scholars have identified the 2022 energy crisis as a turning point in the European Union's energy security paradigm. Giuli & Oberthür (2023), citing estimates by Zachmann, Sgaravatti, & McWilliams (2022), highlight that Russian gas supplies fell drastically, from accounting for 40% of EU imports prior to the invasion to just 9% by the end of 2022. This dramatic collapse is widely interpreted as the result of Russia's weaponization of energy, the EU's emergency response measures, and the immediate restructuring of supply chains. Moreover, this decline represents the culmination of a longer-term trend, which Giuli & Oberthür trace through successive crises (in 2009, 2014, and 2022) that each accelerated both the recognition of structural vulnerabilities and the adoption of legislative responses, such as enhanced supply security regulations and the screening of intergovernmental agreements.

The push for diversification has first materialized through major projects under the Trans-European Network for Energy (TEN-E) and the lists of Projects of Common Interest (PCI). Unlike the two previous crises, in 2022 the new import capacity planned (51 Mtoe) was outweighed by the decommissioning of 205 Mtoe of Russian pipelines, resulting in a negative net balance, thus more consistent with climate neutrality than in the past (Giuli & Oberthür, 2023). In the short term, priority was given to the installation of rental Floating Storage and Regasification Units (FSRUs) and "hydrogen-ready" pipelines, a decision that minimizes the risk of stranded assets.

In parallel, the geography of gas pipelines has shifted toward the Caucasus and Eastern Mediterranean. The Southern Gas Corridor (Azerbaijan–TAP) is being reinforced, while the EastMed–Poseidon axis and Turkey's position as a pivot between Russia, the Middle East, and the EU have acquired strategic significance (Olier, 2023). This North–South pivot also aligns with U.S. policy: the 2022 U.S.–EU Task Force made Europe the top destination for U.S. LNG (52% of exports) (Olier, 2023).

In terms of diversification versus trade governance, Marhold (2023) argues that the EU's attempt to discriminate against high-risk suppliers clashes with the rigidity of WTO rules, as illustrated by the *EU Energy Package* case (DS476). However, the same authors suggest that in the post-invasion context, the security exception (Article XXI of the GATT) could gain more weight. This opens a debate on whether selective protection of critical infrastructure can be compatible with trade multilateralism.

In regard to measuring the political risk and diversification, the new quantitative studies are introducing new metrics:

- **Portfolio Theory**: Kim et al. (2025) show that declining energy security stems mainly from insufficient diversification; expanding the range of suppliers with different risk levels reduces overall exposure.
- **Infrastructure as a Hidden Variable**: The same authors warn that current diversification indicators overlook pipeline and terminal dependency and call for indexes that incorporate fuel substitution elasticity.
- **Green Transition and Risk**: Wang & Tian's evidence (2025) suggests that each additional percentage point of renewables reduces long-term security risk by 0.155%, though it introduces intermittency challenges that require interconnected grids and storage.
- **Climate-Policy Integration (CPI)**: Giuli & Oberthür (2023) develop a framework that asses whether diversification routes are consistent with emission pathways aligned with the Paris Agreement climate targets. Their analysis shows that, while the EU made some improvements in 2022, its gas infrastructure still reflected "weak CPI".

Hence, there is academic consensus on the need to shorten unipolar dependency chains, especially on Russian fossil fuels, and to expand sources and routes. However, diagnoses diverge:

Author	Diagnosis
Marhold (2023)	A “security-centred” transition, though more interventionist, is essential to reduce vulnerabilities.
Giuli & Oberthür (2023)	Physical diversification can clash with climate goals if the expansion of gas capacity is not limited.
Kim et al. (2025)	Concentration of transition metals could create new dependencies (less critical than fossil ones) but that the key factor will be the flexibility of the electricity system.

At the same time, the literature converges on three ideas: firstly, that geographical diversification remains the most effective buffer against political risk. Secondly, that without methodologies that integrate infrastructure and renewable interdependencies, current indexes underestimate real risk. And thirdly, that the multilateral trade framework may need reforms to accommodate proactive security policies.

2.4 Identified Research Gap

Although the post-2022 literature has produced valuable insights on the EU’s response to the energy crisis, there is still a lack of integrated assessments that evaluate the actual effectiveness of the emergency measures adopted between 2022 and 2024. Existing studies tend to focus either on broad indicators such as import dependency or price levels, or on individual instruments like Regulation 2022/1032, Contracts for Difference (CfDs), or Power Purchase Agreements (PPAs). However, few attempts have been made to assess how these instruments have functioned in combination, and how their effects have varied across countries with different energy mixes, governance capacities, and levels of market integration.

This fragmented approach limits our understanding of whether vulnerability has truly been reduced, which countries remain most exposed, and which policy tools have made the greatest difference. Moreover, current evaluations often overlook institutional response capacity as a key dimension of energy vulnerability, despite its growing relevance in the management of systemic risks.

This study addresses these gaps by developing the Annual Energy Vulnerability Index (AEVI), a composite indicator that combines supply diversification, price stability, and institutional response capacity into a single framework. Using the AEVI, it conducts a comparative analysis of the evolution of energy vulnerability across the 27 EU Member States from 2021 to 2024. While the thesis delivers preliminary empirical results based on the available data, its primary contribution is methodological: to design and test a transparent and adaptable tool that can serve as a foundation for future research and more robust policy evaluation.

3. Research Methodology

3.1 Empirical Strategy

The empirical analysis follows a two-step approach to assess whether the emergency package adopted by the European Union between 2021 and 2024 effectively reduced Member States' energy vulnerability.

First, a composite indicator, the Annual Energy Vulnerability Index (AEVI), was developed to capture three core dimensions of vulnerability: exposure to supply concentration, exposure to price volatility, and institutional response capacity. The AEVI enables both cross-country and temporal comparisons, offering a synthetic yet transparent measure of energy security.

Second, the annual change in AEVI (ΔAEVI) was computed for each Member State to analyze year-on-year variations in vulnerability. Descriptive statistics illustrate how vulnerability evolved before and after the introduction of the emergency measures, while a regression model was used to identify which policy instruments and structural factors were associated with reductions in vulnerability.

Given the small sample size (27 countries * 3 years) and the limited variability of some policy measures, a pooled OLS specification was used as the main model. An alternative version including country and year dummies was tested but could not be fully estimated due to the lack of degrees of freedom. The regression includes three institutional variables (storage target compliance, demand reduction, and PPAs) and four structural controls (renewables share, GDP per capita, industry share, and interconnection index).

This design enables an exploratory assessment of the potential drivers of change in energy security, complementing the descriptive analysis and providing the basis for future research with longer time series and richer policy datasets.

3.2 Hypothesis

The central hypothesis is that both institutional measures and structural factors contribute to reducing energy vulnerability across EU Member States after the implementation of the emergency package, from 2022 on.

Formally:

- H1 (Institutional measures): Compliance with the gas storage target ($\beta_1 < 0$), achieving the 15% gas demand reduction ($\beta_2 < 0$), and signing at least one green PPA ($\beta_3 < 0$) are each expected to be associated with a decrease in energy vulnerability.

- H2 (Structural factors): A higher share of renewables ($\beta_4 < 0$) and higher GDP per capita ($\beta_5 < 0$) are expected to correlate with lower vulnerability, whereas a larger industrial share ($\beta_6 > 0$) is expected to increase vulnerability due to greater exposure to energy shocks.

- H3 (Interconnection): The interconnection index is expected to have a negative coefficient ($\beta_7 < 0$), reflecting the role of cross-border integration in improving resilience.

4. The new geopolitical risk landscape

4.1 Russia’s supply cliff and EU sanctions

The EU’s response to Russia’s invasion was accompanied by a profound restructuring of its gas supply portfolio. According to the European Council (2025), Russia’s share of EU pipeline gas imports dropped from over 40% in 2021 to approximately 11% in 2024. When considering both pipeline and LNG, Russia still accounted for less than 19% of the EU’s total gas imports in 2024 (European Council, 2025).

While this reduction is substantial, it also reveals a degree of residual dependence, particularly through Russian LNG rerouted via intermediary countries. This shift can be attributed to three main developments:

1. **Pipeline disruptions**: Nord Stream ceased operations following the explosions in the summer of 2022, and the Yamal-Europe pipeline was permanently halted after Poland refused to pay in rubles (Smid, 2024).

2. **Sanctions and contractual tensions**: Russia’s demand for ruble-denominated payments was rejected by many EU countries, prompting further unilateral supply cuts.

3. **Termination of the Ukraine transit contract**: In January 2025, Ukraine halted the transit of Russian gas through its territory, effectively closing the last major physical delivery route to the EU.

In absolute terms, this represents a loss of over 100 bcm/year (billion cubic meters) of supply. This gap has been largely filled through increased LNG imports, primarily from the United States, and higher volumes from alternative suppliers such as Norway, Algeria, and Azerbaijan (McWilliams, Sgaravatti, Tagliapietra, & Zachmann, 2024).

Despite these shocks, Europe continued paying for Russian gas throughout 2022 – 2024. A report by Ember (2025), an energy think tank, estimated that in 2024 Russian gas imports rose by 18%, despite a 2027 phase-out plan. Moreover, the report also pointed out that, during the third year of the invasion, the EU paid €21.9 billion for Russian gas and oil, more than it sent in military and humanitarian aid to Ukraine (€18.7 billion) (Czyzak, Nolan, & Mindekova, 2025)

This situation creates a dangerous paradox: financing, through our imports, the very war effort Europe claims to be sanctioning. This effect is known as the "funding-the-enemy" paradox: paying Russia for part of the energy Europe consumes means directly supplying resources that sustain its war.

Hence, faced with the paradox of continuing to finance the very conflict it aimed to contain, the European Union launched a set of measures to structurally reduce its dependence on Russian gas. These actions fall within the framework of the REPowerEU plan, adopted in 2022 and subsequently reinforced (European Commission, 2022). In particular, regarding gas, the main measures adopted up to mid-2025 are as follows:

- **Ban on new Russian gas contracts** (from January 1, 2026): The European Commission has proposed a ban on signing new contracts for the import of Russian natural gas and LNG starting in early 2026. This measure applies both to commercial agreements and bilateral supply contracts between European companies and Gazprom or its intermediaries (European Commission, 2025).

- **Progressive termination of existing contracts**: Short-term contracts signed before June 17, 2025, must expire before June 17, 2026; and long-term contracts (e.g., take-or-pay) must end no later than December 31, 2027 (European Commission, 2025).

- **Application of "force majeure" clauses**: To facilitate the exit from these contracts without litigation, the Commission has declared that the legal ban constitutes a force majeure condition that exempts contracting parties from penalties for non-compliance. This allows companies to cancel or renegotiate existing agreements without severe economic consequences (Reuters, 2025).

- **Gas origin tracking and transparency systems**: The EU has announced the implementation of a Gas Transaction Register, which will require importers to report the precise origin of the gas purchased. The aim is to prevent covert imports of Russian gas through indirect routes, particularly in the form of LNG re-exported from third countries (European Commission, 2025).

This set of measures responds not only to geopolitical coherence, ending the indirect financing of Russian aggression, but also to an explicit commitment to strengthening Europe’s strategic autonomy, in line with the REPowerEU plan. Thus, these initiatives represent a structural rupture in the energy relationship between Europe and Russia. What had long been framed as mutual economic interdependence was ultimately exposed as a strategic vulnerability of the first order. And the European response, though uneven, complex, and still incomplete, has been significant.

Yet beyond the institutional ambition, the disconnection process has proven far from neutral. It entails costs, internal tensions, and new forms of dependency. On one hand, the crisis has catalyzed a reinforcement of Europe’s energy sovereignty and showcased the EU’s capacity to coordinate strategic action under pressure. On the other hand, it has increased exposure to global LNG markets, required urgent infrastructure investments, and severely impacted the social and productive fabric through a historic spike in prices.

This rebalancing has also strained internal political cohesion. Countries such as Hungary, Slovakia, and Austria have voiced concerns about the pace of the transition, citing risks to their energy security, particularly due to their dependence on the TurkStream pipeline (Czyzak, Nolan, & Mindekova, 2025). These divergences have reignited the debate between values and imports: to what extent can the EU uphold a foreign policy consistent with its principles without compromising the viability of its energy supply?

4.2 Emerging flashpoints

The EU’s efforts to reduce dependency on Russian energy have exposed new vulnerabilities, particularly in the context of escalating geopolitical tensions. Recent developments in the Middle East, disruptions in key maritime routes, and challenges in securing critical minerals have underscored the fragility of Europe's energy and resource security.

Middle East instability

The ongoing conflict between Israel and Iran has significantly impacted global energy markets. The Strait of Hormuz, a vital passageway for oil and liquefied natural gas (LNG) shipments, has been a focal point of concern. Approximately 20% of global LNG trade passes through this strait. Recent tensions have led to a dramatic increase in shipping costs, with leasing rates for large crude carriers from the Gulf to China rising from $18,600 to $78,000 daily. A complete closure of the Strait could cut off about 86 billion cubic meters of gas annually, potentially pushing European gas prices from $11 to $29 per million British thermal units (mmbtu), reminiscent of the 2022 energy crisis (Moore, 2025).

The conflict has also disrupted global shipping, with Iran's parliament approving a blockade of the Strait, amplifying risks for shipping companies. This has led to increased war risk insurance costs, which are passed on to customers, further escalating energy prices (Saul & Jones, 2025)

Red Sea Chokepoints and Maritime Disruptions

Beyond the Strait of Hormuz, the Red Sea has emerged as another critical area of concern. Yemen's Houthi rebels have attacked international shipping passing through the Red Sea, majorly disrupting one of the world's busiest maritime routes. Since November 2023, maritime traffic has decreased by 55%, with over 190 attacks reported by October 2024. These disruptions have forced many shipping companies to reroute vessels via the Cape of Good Hope, leading to longer journey times and increased costs. (European Council on Foreign Relations, 2025; Atlas Institute of International Affairs, 2025).

The Suez Canal and the Bab el-Mandeb Strait are strategic routes for Persian Gulf oil and natural gas shipments to Europe and North America (EIA, 2023). Any disruption in these chokepoints can have significant implications for global energy flows. The instability in the Red Sea has prompted European countries to reassess their LNG supply strategies, focusing on diversifying sources and investing in storage infrastructure to buffer against potential disruptions (Maritime LNG, 2025).

Critical Minerals and Supply Chain Vulnerabilities

The EU's transition to a green economy has increased its reliance on critical minerals such as lithium, cobalt, and rare earth elements. However, the supply of these minerals is heavily concentrated in a few countries, particularly China, which accounts for about 70% of global refining capacity for 19 out of 20 strategic minerals. This concentration poses risks to energy security and economic stability (Birol, 2025).

In response, the EU has urged member states to establish joint strategic reserves of rare earth elements to protect against potential supply chain disruptions. Plans have been announced to launch additional tenders to promote alternative sources of raw materials. This initiative aligns with the EU's broader strategic effort to support new raw material projects outside the bloc, aimed at securing vital metals and minerals essential for the energy transition, defense, and aerospace sectors (Reuters, 2025).

However, efforts to develop domestic sources of critical minerals have faced challenges. In Portugal, for example, villagers have resisted the development of lithium mines near their homes, fearing environmental degradation and disruption of their traditional way of life. This highlights the broader dilemma of balancing green energy development with social and environmental costs (Niranjan, 2025).

4.3 Policy narratives

4.3.1 Strategic autonomy as a new European narrative

The Russian invasion of Ukraine in February 2022 triggered a profound shift in the political narrative of the European Union (EU), placing strategic autonomy at the center of the energy and geopolitical agenda. This concept, which until then had been vague and fragmented, was consolidated as a response to the vulnerability exposed by dependence on Russian fossil fuels. However, its implementation has revealed internal tensions and contradictions that cast doubt on the coherence and effectiveness of this new direction.

Before the conflict, the EU imported approximately 45% of its natural gas from Russia, with countries like Germany and Italy as the main consumers (European Commission, 2025). The war exposed the fragility of this dependence, especially in light of Russia's use of energy as a tool of political coercion. In response, the EU launched the

REPowerEU plan in May 2022, with the goal of drastically reducing reliance on Russian fossil fuels before 2027. This plan is based on three pillars: save energy, diversify energy sources, and accelerate clean energy transition (European Commission, 2025).

This shift was accompanied by a new political narrative centered on "energy sovereignty" and industrial autonomy. The Versailles Declaration of March 2022 reflected this change, highlighting the need for the EU to take greater responsibility for its own security and to strengthen its capacity to act independently (Puka, 2024).

Nevertheless, despite the apparent consensus on the need to reduce energy dependence on Russia, the implementation of this strategy has revealed significant divisions among member states. Countries like Hungary and Slovakia have openly expressed their opposition to proposed energy sanctions, arguing that such measures could severely harm their economies and jeopardize their energy security (Reuters, 2025). These countries have used their veto power to block sanction packages, demanding concessions and exemptions to protect their national interests.

Moreover, the continued dependence of these countries on Russian gas and oil has generated tensions with other EU members, who view these exemptions as a threat to the cohesion and effectiveness of common policy. This situation highlights the challenges of implementing a strategy of strategic autonomy in a context of diverse interests and dependencies among member states.

<u>Emerging Dependence on U.S. LNG: Substitution or Perpetuation of Vulnerability?</u>

The reduction of Russian energy imports has led the EU to significantly increase its imports of liquefied natural gas (LNG) from the United States. In 2024, the U.S. supplied 45% of the EU's LNG imports, becoming its main supplier (Hancock, 2025). While this diversification has helped mitigate the immediate energy crisis, it has raised concerns about a new dependency, this time on the United States.

Trade tensions between the EU and the U.S., particularly under the administration of Donald Trump, have highlighted the risks of this new dependency. Trump threatened to impose tariffs on European imports if the EU did not increase its purchases of American energy, using energy supply as a tool of political pressure. This situation raises the question of whether the EU is simply replacing one dependency with another, rather than achieving true energy autonomy.

Dilemma Between Resilience and Market Efficiency

The strategy of strategic autonomy has also sparked debate over the balance between resilience and market efficiency. Measures to ensure energy security, such as diversification of supply and increased strategic reserves, can entail significant economic costs and challenges to the competitiveness of European industry. Furthermore, the implementation of mechanisms like the Carbon Border Adjustment Mechanism (CBAM) has sparked controversy, with critics arguing that it constitutes a form of green protectionism that could trigger international trade disputes.

This dilemma is further complicated by the need to maintain the EU's leadership in combating climate change, while also ensuring energy security and economic competitiveness. The transition to a decarbonized economy requires massive investments and effective coordination among member states, as well as careful management of geopolitical and trade tensions.

4.3.2 Values vs. Imports: CBAM and Article XXI of the GATT

Policies like the CBAM have generated tensions with trading partners, especially developing countries, who perceive them as protectionist measures disguised as climate objectives.

The Article XXI of the General Agreement on Tariffs and Trade (GATT) allows members of the World Trade Organization (WTO) to adopt measures they consider necessary to protect their essential security interests. Although this article remained ambiguous for decades, a key WTO decision in 2019 in the case *Russia – Measures Concerning Traffic in Transit* (DS512) established an important precedent.

In that case, Ukraine challenged the restrictions imposed by Russia on the transit of Ukrainian goods, but the WTO panel accepted that, in the context of an "international emergency" stemming from the conflict, Russia could invoke Article XXI. However, the ruling also clarified that the application of the article is not entirely discretionary: it must be linked to a genuine threat and is subject to panel review, which may assess whether the state is acting in good faith (WTO, 2019).

This has important implications for the EU: while it could argue that eliminating Russian imports is a response to a security threat, it could not invoke this article to justify, for example, the CBAM, which is a measure aimed at climate goals rather than security ones. In this sense, the abuse or overextension of Article XXI, which other actors such as the U.S. have also invoked in trade disputes, risks undermining the EU's legal credibility as a guardian of a rules-based multilateral system. It could also open the door to covert trade retaliation by other countries that likewise invoke "national security" as an arbitrary pretext (WTO, 2019).

More in detail, the CBAM, imposes a carbon cost on imports of emission-intensive products such as steel, cement, and aluminum, in order to prevent carbon leakage and protect European industries that are already subject to the EU Emissions Trading System. Although the EU argues that the CBAM is a necessary environmental measure, many developing countries see it as a trade barrier that unfairly penalizes their exports. For example, India has criticized the CBAM as an arbitrary measure that harms developing countries (Reed, Kay, Findlay & Bounds, 2024).

Moreover, the CBAM could have a significant economic impact on these countries, especially those that rely heavily on exports of carbon-intensive goods. A study by the Foundation for European Progressive Studies highlights that the CBAM could negatively affect developing economies, creating trade tensions and hindering their efforts toward sustainable development (Tandon & Le Merle, 2024).

Therefore, some might argue that the implementation of the CBAM and the potential use of Article XXI of the GATT to justify it pose risks to the EU's credibility as a multilateral actor committed to international trade norms. If other countries perceive these measures as protectionist or discriminatory, they could respond with similar actions, weakening the multilateral trading system.

In addition, the perception that the EU is imposing its environmental standards on other countries without considering their specific circumstances could erode trust in its foreign policy and its capacity to lead global initiatives. To avoid these risks, the EU should work collaboratively with its trading partners, particularly developing countries, to ensure that its climate policies are fair and compatible with international standards.

4.3.3 Policies adopted

In policy terms, the European Union has adopted a range of measures aimed at enhancing its energy security, accelerating the green transition, and reinforcing its strategic autonomy. Depending on their ultimate objectives, these policies can be grouped into five distinct categories.

4.3.3.1 Demand Coordination: REPowerEU and Savings Measures

One of the main pillars of the EU's initial response to the energy crisis was reducing gas demand across Member States. Regulation (EU) 2022/1369 introduced a voluntary 15% reduction target for gas consumption between August 2022 and March 2023, later extended through Regulation (EU) 2023/435 until 2025. This objective yielded measurable results: EU gas demand fell by 17.7% during the first implementation phase (Eurostat, 2023).

Nevertheless, the social and economic consequences varied considerably. Industrialized Member States achieved the target through rapid sectoral adaptations, while others like Spain faced challenges due to rigid energy structures and limited fiscal room, with concerns over increased energy poverty and regressive social impacts (Eurostat, 2023).

The REPowerEU Plan allocated an additional €20 billion from the Recovery and Resilience Facility (RRF) to support energy savings, building renovation, and heat pump deployment. However, by the end of 2023 (midway through the 2021–2026 RRF timeframe) only a third of these funds had been disbursed. Less than 30% of pre-defined milestones had been reached, mainly due to inflationary pressures, material shortages, political instability, and administrative bottlenecks. Notably, seven Member States, including the Netherlands, Sweden, and Poland, had not received any funding at all (Reuters, 2024; European Court of Auditors, 2024).

The framework's voluntary nature has also limited its long-term effectiveness. The absence of binding burden-sharing obligations or enforcement mechanisms resulted in uneven implementation across Member States. Public communication initiatives such as the campaign "Save gas for a safe winter" (COM(2022) 361 final) contributed to behavioral change, but without structural instruments, the effort remains fragile (European Commission, 2022).

In summary, while short-term reductions in demand were achieved, the sustainability of these efforts depends on the EU's ability to institutionalize energy savings into binding, equitable, and long-lasting policy instruments.

4.3.3.2 Substitution of Supplies: Gas Storage and Joint Procurement

To mitigate dependence on Russian fossil fuels, the EU pursued strategies focused on replacing disrupted supply channels. These included the introduction of mandatory gas storage levels and the creation of a joint procurement mechanism to consolidate European demand.

<u>Gas Storage: Mandatory Targets and Recent Flexibility</u>

Regulation (EU) 2022/1032, adopted in June 2022, required Member States to fill underground gas storage facilities to at least 90% of capacity by 1 November each year. This measure aimed to guarantee sufficient supply during winter heating seasons and avoid energy rationing.

In 2023, the EU reached the 90% storage threshold by August, well ahead of schedule, and in 2024, this target was achieved ten weeks before the deadline (European Commission, 2024). However, the speed and scale of refilling created upward pressure on summer gas prices, increasing procurement costs for households and industry (Moore and Hancock, 2025). In response, the EU adopted a more flexible framework in June 2023, allowing the 90% target to be met at any point between 1 October and 1 December, with leeway for minor deviations under exceptional market conditions (Reuters, 2025).

Joint Procurement: The EU Energy Platform and the AggregateEU Mechanism

The EU Energy Platform, launched in 2022, was established to coordinate the joint purchase of natural gas, LNG, and eventually hydrogen. The aim is to consolidate European demand in order to increase bargaining power with global suppliers and reduce price fluctuations.

The AggregateEU mechanism, operational since April 2023, enables EU-based companies to register their gas purchasing needs, which are then aggregated and presented to international sellers (European Commission, 2023). The first tendering round exceeded expectations: offers were received for over 13.4 bcm of gas, surpassing the combined demand of 11.6 bcm (European Commission, 2023).

Despite its promising launch, participation in the mechanism is only partially compulsory. Member States are obligated to use AggregateEU for at least 15% of their required gas storage volumes; the rest remains voluntary (Dulian & Klochko, 2023). This limited obligation could weaken the EU's collective bargaining position and reduce the platform's strategic impact in achieving supplier diversification and price stability.

4.3.3.3 Price Containment and Energy Measures

In response to soaring energy prices in 2022, the EU adopted emergency market interventions to limit excessive price spikes and redistribute unexpected profits.

Market Correction Mechanism (MCM)

Regulation (EU) 2022/2578 established a temporary gas price cap mechanism, activated if TTF prices exceeded €180/MWh for three consecutive days and were at least €35/MWh above LNG benchmarks (Council of the European Union, 2022). Although the Market Correction Mechanism (MCM) was never formally triggered, its adoption appears to have influenced market participants' behavior and contributed to stabilizing expectations. According to the European Union Agency for the Cooperation of Energy Regulators, some trading adjustments were observed in anticipation of the mechanism's activation, suggesting a preventive effect even in the absence of direct intervention (ACER, 2023).

Electricity Emergency Regulation

Regulation (EU) 2022/1854 introduced three tools to address the electricity price crisis (Council of the European Union, 2022):

- A binding obligation to cut electricity consumption during peak hours by at least 5%.
- A revenue cap of €180/MWh on inframarginal electricity producers (e.g. renewables and nuclear), to fund measures for vulnerable consumers.
- A 33% "solidarity contribution" on the windfall profits of fossil fuel companies, calculated on the basis of a 20% surplus over the 2018–2021 average.

These measures allowed Member States to generate revenue to alleviate consumer energy costs. By Q2 2023, EU gas prices had dropped sharply from their August 2022 peak above €200/MWh, reaching an average of €35.2/MWh (European Commission, 2023). However, the ACER warned that energy markets remained vulnerable to supply shocks and regulatory fragmentation due to inconsistent national implementations (ACER, 2023).

4.3.3.4 Structural Push for Renewables: RED III and Permitting Form

Beyond immediate crisis management, the EU has pursued structural reforms to accelerate the deployment of renewable energy and reduce long-term dependence on fossil fuels. A central pillar of this effort is the revision of the Renewable Energy Directive, known as RED III, adopted in October 2023.

RED III raised the EU's binding renewable energy target from 32% to 42.5% by 2030, with a non-binding aspirational target of 45%. It also introduced sector-specific sub targets, including minimum shares of renewables in buildings (49%) and industry (1.6% annual increase in renewable fuels use), as well as a reinforced 2.2 percentage point annual target for transport via advanced biofuels or renewable electricity (Directive (EU) 2023/2413, 2023).

To ensure implementation, RED III mandates accelerated permitting procedures, designating renewables as projects of overriding public interest. It introduces "go-to areas" where environmental assessments are streamlined, and deadlines are capped at 12 months for new projects and 6 months for repowering existing ones (Directive (EU) 2023/2413, 2023).

In parallel, the Regulation on Accelerating Permitting for Renewable Energy Projects, adopted as part of the emergency energy package in December 2022, introduced temporary derogations from environmental directives for solar and heat pump deployment (Council Regulation (EU) 2022/2577, 2022). These emergency measures served as a blueprint for the permanent reforms embedded in RED III.

Despite the improved legislative framework, implementation challenges persist. Hence, RED III and the permitting reforms mark a significant structural shift towards a more resilient and autonomous energy system, but their effectiveness will ultimately depend on Member States' ability to translate streamlined rules into practice and address administrative inertia on the ground.

4.3.3.5 Roadmap to Phase Out Russian Gas, Oil and Nuclear Imports by 2027

In June 2025, the European Commission unveiled a roadmap to fully end the EU's reliance on Russian energy sources, including natural gas, crude oil, and nuclear materials. Building on the foundations of the REPowerEU plan, the roadmap sets out concrete actions to complete the decoupling from Russian fossil and nuclear fuels by strengthening transparency, enforcing market rules, and enhancing long-term energy security.

- Natural Gas: The roadmap outlines the phasing out of all remaining Russian gas imports, with an emphasis on preventing circumvention through short-term spot purchases. The EU will also introduce stricter traceability measures to monitor the origin of imported gas and avoid backdoor Russian supplies.

- Oil: To prevent Russia from bypassing sanctions, the EU plans targeted measures against the so-called "shadow fleet", vessels operating under opaque ownership structures used to transport Russian oil covertly. These measures aim to reinforce the oil embargo already in place and close enforcement loopholes, particularly in maritime logistics.

- Nuclear: The Commission proposes limiting future supply agreements with Russian entities for nuclear fuels and enrichment services, including a revision of procedures within the Euratom Supply Agency. This is intended to progressively shift EU nuclear dependencies toward trusted alternative partners.

This roadmap is part of a broader economic and industrial strategy that aligns with the Green Deal, the Net-Zero Industry Act, and the EU's competitiveness agenda. The objective is not only geopolitical (cutting energy ties with Russia) but also structural: to strengthen the EU's clean energy economy and ensure affordable, secure, and sustainable energy for the future (European Commission, 2025).

* * *

To guide the analytical framework of this thesis, the following table classifies the EU policy instruments adopted between 2022 and 2024 according to the three core dimensions of energy vulnerability assessed in this study: price exposure, supply diversification, and governance capacity. Each measure is further grouped under a specific strategic category reflecting the objectives previously described, such as demand coordination, supply substitution, price containment, structural support for renewables, or geopolitical decoupling.

This classification is intended to clarify how different instruments correspond to distinct facets of vulnerability and will serve as a foundation for the comparative and explanatory analysis developed in the following chapters.

Price Exposure	1. Demand Coordination	- REPowerEU Plan - Regulation (EU) 2022/1369 (15% gas reduction)
	3. Price Containment	- Regulation (EU) 2022/2578 (Market Correction Mechanism) - Regulation (EU) 2022/1854 (electricity price measures)
Supply Diversification	2. Supply substitution	- Regulation (EU) 2022/1032 (90% gas storage target) - EU Energy Platform - Aggregate EU joint procurement mechanism
	4. Structural support for renewables	- RED III (Directive (EU) 2023/2413): 42.5% renewable target - Council Regulation (EU) 2022/2577 (permitting acceleration) - Go-to areas and streamlined permitting
Governance Dimensions	5. Phase out of Russian energy by 2027	- EU Roadmap to phase out Russian gas and oil imports (June 2025): complete fossil and nuclear decoupling - Measures to eliminate Russian gas, oil (shadow fleet), and nuclear imports

5. Quantitative analysis: building the Annual Energy Vulnerability Index

This section describes the methodological steps followed to construct the Annual Energy Vulnerability Index (AEVI) and the subsequent empirical strategy used to analyze its evolution and the drivers of change across EU Member States. The AEVI is designed as a composite indicator capturing three complementary dimensions of energy risk: supply diversification, price stability, and institutional response capacity. These dimensions reflect the exposure of each country to supply disruptions, market volatility, and its ability to effectively implement EU-level emergency measures.

The AEVI is calculated annually for each Member State over the period 2021–2024, allowing for both cross-country comparisons and temporal analysis of changes in vulnerability. Once the AEVI is computed, its year-on-year variation (ΔAEVI) is derived as the absolute difference in the index between consecutive years. This change is subsequently used as the dependent variable in the regression analysis to identify the drivers of change.

5.1 Construction of variables (sources, methodology, R scripts)

5.1.1 Supply diversification (Inverse HHI)

The first component of the AEVI measures each Member State's exposure to physical supply risks through the concentration of natural-gas imports by supplier country. The Herfindahl-Hirschman Index (HHI), widely used in the literature as a measure of market concentration (Cohen et al., 2011; Kim et al., 2025), is computed for each Member State based on the shares of extra-EU natural-gas imports by origin.

To capture diversification, the inverse of the HHI is used so that higher values correspond to a more diversified import structure (and thus lower vulnerability). The index is normalized on a 0–100 scale to facilitate interpretability and aggregation with the other AEVI components.

Formula: $$HHI_i = \sum_{j=1}^{n} s_{ij}^2$$

Where s_{ij} represents the share of imports from supplier *j* to country *i*.

The diversification score is calculated as the inverse HHI, rescaled between 0 and 100:

$$\text{Diversification}_i = 100 \times \left(1 - \frac{HHI_i - \min(HHI)}{\max(HHI) - \min(HHI)}\right)$$

- Data source: Eurostat database *Imports of natural gas by partner country* (dataset: nrg_ti_gas) (Eurostat, 2025).

- Data limitations:
    - Estonia (2022-2023), Cyprus (2021-2023) and Latvia (2023) report no extra-EU natural-gas imports. These cases were treated as having HHI = 1 (full concentration) and hence diversification = 0.
    - Data for 2024 are not available yet, as Eurostat releases gas-import statistics with a significant lag due to reporting, validation and harmonization processes. Eurostat has been contacted and confirmed that 2024 data will be published during 2025.

5.1.2 Price Stability

The second component of the AEVI captures a country's exposure to price volatility, which reflects the economic dimension of energy vulnerability. It is measured as the inverse of the standard deviation of natural-gas and electricity prices for household consumers, expressed in €/kWh (all taxes and levies included).

For each Member State and year:

- The standard deviation of monthly natural-gas and monthly electricity prices is calculated separately.
- The two standard deviations are averaged, giving equal weight to gas and electricity.
- The resulting value is normalized on a 0-100 scale, where higher values correspond to more stable prices (lower volatility.

$$\text{Price Stability}_i = 100 \times \left(1 - \frac{\sigma_{i,\text{avg}} - \min(\sigma_{\text{avg}})}{\max(\sigma_{\text{avg}}) - \min(\sigma_{\text{avg}})}\right)$$

Formula:

Where $\sigma_{i,avg}$ is the average of the standard deviations of gas and electricity prices for country *i*.

- Data sources:
  - Gas prices: Eurostat, dataset nrg_pc_202, *Gas prices for household consumers* (bi-annual data, all taxes and levies included, energy band U: 120-199 GJ) (Eurostat, 2025).
  - Electricity prices: Eurostat, dataset nrg_pc_204, *Electricity prices for household consumers* (bi-annual data, all taxes and levies included, consumption band D: 2,500 – 5,00 kWh) (Eurostat, 2025).

- Treatment of missing data: for Cyprus, Finland, and Malta, Eurostat does not report on natural-gas prices. In these cases, the electricity price standard deviation alone is used to compute the volatility indicator.

5.1.3 Institutional Response

The third component of the AEVI captures the institutional capacity of the Member States to implement the emergency measures adopted at the EU level after the 2022 energy crisis. Three binary variables (0/1) have been designed to represent key instruments from the REPowerEU package:

Storage_target_met

The variable storage_target_met equals 1 if a country met the EU gas storage target in the given year (80% in 2022; 90% in 2023 and 2024), 0 otherwise; Regulation (EU) 2022/1032.

Only the countries listed in COM(2024) 89 final (European Commission, 2024) were considered, as they are the only Member States with underground gas storage infrastructure in their territory. The following countries do not have domestic gas storage facilities, and were therefore assigned a value of 0 for this variable in all years: Cyprus, Estonia, Finland, Greece, Ireland, Lithuania, Luxembourg, Malta and Slovenia. For the countries that do have gas storage infrastructure in their territory, the data source was the Gas Infrastructure Europe – Aggregate Gas Storage Inventory (GIE – AGSI) for the years 2022-2024 (GIE – AGSI, 2025).

Demand_reduction_15

The variable demand_reduction_15 measures whether a Member State achieved at least a 15% reduction in natural gas consumption compared with the average consumption of the same period in previous years. It is based on the Regulation (EU) 2022/1369 and its extensions, which established voluntary gas demand reduction targets in response to the 2022 energy crisis.

This variable captures the capacity of each Member State to voluntarily reduce has demand, a key emergency measure in the REPowerEU plan. Achieving this reduction requires significant coordination of industry, households and energy systems, reflecting both institutional effectiveness and societal adaptability.

The calculation method has been: for each year, the actual national gas consumption during the relevant period is compared to the average consumption for the same months over the reference years (five preceding years). The variable takes value 1 if the reduction is ≥ 15%, and 0 otherwise.

Time periods assessed:

- 1 august 2022 – 31 March 2023: it was the first official period defined by Regulation (EU) 2022/1369. The comparison is done with the average of the same 8 months (Aug – Mar) over 2017 - 2022.
- 1 April 2023 – 31 March 2024: extension period decided by the European Council in March 2023 (European Council, 2023). The comparison is done with the average of the same 12 months (Apr – Mar) over 2017 - 2022.
- 1 April 2024 – 24 March 2025: third consecutive period, approved as part of the REPowerEU Plan. Comparison with the average of the same 12 months (Apr – Mar) over 2018 - 2023

The data source has been the *Supply, transformation and consumption of gas - monthly data* from Eurostat (dataset nrg_cb_gasm) (Eurostat, 2025).

Cfds_or_ppas

Originally intended to capture whether a country implemented at least one green Contract for Difference (CdF) or Power Purchase Agreement (PPA) in the given year. Upon reviewing the available data and regulatory context, only green PPAs were ultimately considered. CfD data at the country level are not systematically publicly reported or harmonized across Member States, whereas data for PPA was available. The variable name Cfds_or_ppas was retained to reflect the original design of the indicator, even though, as mentioned, only PPAs were ultimately used due to data availability constraints.

Data were compiled from ACER's *Contractual Arrangements in Electricity Markets (CAAR) 2024 Report* and the ACER *Assessment on the Needed for Voluntary PPA Templates*.

*   *   *

These three variables were given equal weights (33.3 points each) to construct the Institutional Response Capacity component of the AEVI. The equal weighting approach ensures that meeting any of the three measures contributes proportionally to the country's institutional preparedness score.

5.1.4 Control variables

In addition to the three main components of the AEVI, a set of structural control variables was included to account for cross-country differences that may influence energy vulnerability but are not directly captured by the index components. These variables provide a broader view of each Member State's energy system characteristics, economic structure, and integration within the European electricity market.

Renewables share % (renewables_share)

- Definition: Share of renewable energy in the national electricity mix, expressed as a percentage of total final electricity consumption.
- Rationale: Countries with higher renewable penetration are generally less exposed to fossil fuel price volatility and supply risks.

- Source: Eurostat database *Share of energy from renewable sources* (dataset: nrg_ind_ren) (Eurostat, 2025).
- Limitation: At the time of analysis, 2024 data were not yet published. Thus, no data was considered for 2024.

GDP per capita (gdp_per_capita)

- Definition: Gross Domestic Product per capita, expressed in euros at current prices.
- Rationale: Higher-income countries may have greater fiscal and institutional capacity to respond to energy shocks.
- Source: Eurostat database *GDP and main components per capita* (dataset: nama_10_pc) (Eurostat, 2025)
- Treatment: All values were numeric and expressed in euros.

Industry share (industry_share)

- Definition: Share of industry in national GDP (%).
- Rationale: Economies with a larger industrial sector are typically more energy-intensive and therefore more vulnerable to supply and price shocks.
- Source: Eurostat database *Gross value added and income by main industry – NACE Rev.2* (dataset: namq_10_a10) (Eurostat, 2025).

Interconnection index % (interconnection_index)

- Definition: Share of a country's electricity demand that could be simultaneously met through cross-border interconnections if operated at full capacity, expressed as a percentage (Import Potential).
- Rationale: Greater interconnection capacity can enhance energy security by allowing countries to import electricity during supply shocks.
- Source: ENTSO-E, Med-TSO, Ember Europe Interconnection Data Tool, and the document *Ember Europe Interconnection Data Tool – Sources and Methodology* (Ember, 2025).
- Limitation: Since comparable annual data were not available for the full period, the 2024 Import Potential value was used as a proxy for all three years (2022–2024), assuming short-term structural stability.

5.1.5 Computation of the AEVI

The Annual Energy Vulnerability Index (AEVI) aggregates the three main dimensions (import diversification, price stability, and institutional response capacity) into a single composite indicator for each Member State and year. The final score is computed as a weighted sum, following the scheme:

AEVIit = $0.4 * Divers_{it} + 0.3 * Price_{it} + 0.3 * Response_{it}$

Where $AEVI_{it}$ represents the energy vulnerability score for country *i* in year *t*.

The rationale for the weighting scheme is explained in section 5.2, Index Validation.

5.1.6 Construction of ΔAEVI

To analyze changes in energy vulnerability over time, the year-on-year variation in the AEVI was computed for each Member State. The change in vulnerability for country *i* between year *t-1* and year *t* is defined as:

$\Delta AEVI_{it} = AEVI_{it} - AEVI_{i(t-1)}$

The absolute difference captures whether energy vulnerability increased (positive ΔAEVI) or decreased (negative ΔAEVI) from one year to the next.

The absolute difference was preferred over a relative change (%) to do the regression, for two reasons:

- Comparability across countries: A relative change would disproportionately magnify changes in countries with very low baseline AEVI values, even if the actual improvement is minor.
- Consistency with policy interpretation: The EU targets (storage, demand reduction, PPAs) are binary measures, making an absolute scale more meaningful for evaluating changes in vulnerability.

5.1.7 Implementation in R

Once the AEVI index was computed for each Member State and year in Microsoft Excel, the dataset was imported into R version 4.5.1 (R Core Team, 2024) using RStudio version 2025.05.1-514 as the integrated development environment, to estimate the regression model exploring the drivers of change.

The workflow in R consisted of:

1. Importing the final dataset containing the AEVI values and relevant control variables.
2. Cleaning and harmonizing variable names, converting categorical variables (country, year) to factors, and filtering out rows with missing data.
3. Estimating two models:
    a. A pooled OLS regression without country fixed effects (baseline specification).
    b. An extended model with country and year dummies, which could not be fully estimated due to the limited degrees of freedom.
4. Checking for multicollinearity using Variance Inflation Factor (VIF).

All scripts were written in R, using the packages readxl, dplyr, and car. The full R script is provided in Annex 1.

5.2 Index Validation

The validation process involved assessing the weighting scheme, checking the robustness of results, and identifying potential limitations.

<u>Weighting scheme justification</u>

The AEVI combines three components:

- Import diversification (40%): measures each Member State's exposure to supply concentration, based on the inverse Herfindahl-Hirschman Index (HHI), a widely used concentration metric in economics.

- Price stability (30%): captures a country's exposure to price volatility resulting from price shocks.
- Response capacity (30%): reflects the institutional ability to implement main EU emergency measures after the 2022 crisis. It is computed as a checklist of three binary variables: meeting the gas storage target, achieving the voluntary gas demand reduction and signing at least one green PPA. Each measure contributes equally (33.3 points) to the final component score.

This thesis assigns greater importance to diversification (40%) following evidence from Cohen et al. (2011) and Kim et al. (2025), who identify supplier concentration as the main determinant of supply risk. Price stability and response capacity are each given a weight of 30%, ensuring that the index captures both structural exposure and institutional resilience without overemphasizing any single dimension. This 40/30/30 structure reflects existing literature while explicitly integrating an institutional dimension that is often omitted in traditional energy security metrics.

Robustness checks

- Alternative weighting scenarios: sensitivity tests were conducted by modifying the weights to 33/33/33 and 50/25/25. The ranking of Member States by AEVI showed only minor variations. Countries with very high or low diversification remained at the extremes regardless of weights.
- Correlation between components: pairwise correlations showed that the three components capture complementary dimensions: diversification and price stability are weakly correlated, while response capacity is largely independent.
- Year-to-year consistency: the AEVI scores evolved in line with major policy events:
    - 2022: widespread increase in AEVI values after storage filling and demand reduction.
    - 2023: more heterogeneous changes, reflecting the unequal implementation of CfDs/PPAs and varying price dynamics.

Main limitations

- Short time period (2021–2024): The index captures only three post-crisis years, limiting long-term trend analysis.

- Incomplete data for some variables:
    - 2024 data for gas import diversification and renewables share are not yet published by Eurostat.
    - Gas price data are missing for some countries (e.g., Cyprus, Malta, Finland), requiring partial computation based only on electricity prices.

Despite these limitations, there is no evidence contradicting the idea that the AEVI constitutes a transparent and conceptually consistent measure of energy vulnerability. The index effectively bridges the gap between structural exposure (diversification, prices) and institutional response capacity.

6. Results and discussion

6.1 Descriptive results: evolution of AEVI (2021-2024)

Table 1 and Figure 1 show the evolution of the Annual Energy Vulnerability Index (AEVI) for each Member State between 2021 and 2024, thereby addressing the first research subquestion. The table includes absolute AEVI values, year-on-year percentage changes, and the cumulative change over the entire period.

Country	2021	Δ 2021 - 2022	Δ% 2021 - 2022	2022	Δ 2021 - 2022	Δ% 2022 - 2023	2023	Δ 2023 - 2024	Δ% 2023 - 2024	2024	Δ 2021 - 2024	Δ% 2021 - 2024
Belgium	47,811	20,573	43,030%	68,384	11,261	16,470%	79,645	-3,860	-4,850%	75,784	27,973	58,510%
Bulgaria	25,945	50,848	195,980%	76,794	-0,055	-0,070%	76,739	-10,895	-14,200%	65,844	39,899	153,780%
Czechia	37,820	8,754	23,150%	46,574	12,141	26,070%	58,716	-18,060	-30,760%	40,656	2,835	7,500%
Denmark	15,722	14,289	90,880%	30,011	18,401	61,310%	48,411	-14,732	-30,430%	33,679	17,957	114,220%
Germany	58,384	25,580	43,810%	83,964	-12,172	-14,500%	71,792	-14,894	-20,750%	56,898	-1,487	-2,550%
Estonia	4,905											
Ireland	24,387	-9,641	-39,540%	14,745	4,422	29,990%	19,168					
Greece	47,023	17,831	37,920%	64,854	-0,193	-0,300%	64,661	-13,328	-20,610%	51,334	4,311	9,170%
Spain	45,685	21,611	47,310%	67,296	11,653	17,320%	78,949	-0,134	-0,170%	78,816	33,131	72,520%
France	64,779	23,001	35,510%	87,780	-4,887	-5,570%	82,893	-13,783	-16,630%	69,110	4,331	6,690%
Croatia	50,904	18,625	36,590%	69,529	15,793	22,710%	85,322	21,826	25,580%	107,148	56,244	110,490%
Italy	58,093	20,353	35,030%	78,446	-2,136	-2,720%	76,310	-28,100	-36,820%	48,209	-9,884	-17,010%
Cyprus												
Latvia	13,406	-3,324	-24,790%	10,082								
Lithuania	51,115	-17,633	-34,500%	33,482	21,931	65,500%	55,413	-4,978	-8,980%	50,435	-0,680	-1,330%
Luxembourg	46,732	13,080	27,990%	59,812	-4,278	-7,150%	55,534	-19,754	-35,570%	35,780	-10,952	-23,440%
Hungary	33,800	25,622	75,800%	59,422	8,927	15,020%	68,349	-16,160	-23,640%	52,189	18,389	54,400%
Malta	17,797	-0,334	-1,880%	17,463	-6,412	-36,720%	11,051	-4,058	-36,720%	6,993	-10,804	-60,710%
Netherlands	59,802	6,234	10,420%	66,036	-8,979	-13,600%	57,057	-22,213	-38,930%	34,844	-24,958	-41,740%
Austria	26,757	24,556	91,770%	51,314	5,881	11,460%	57,195					
Poland	55,357	20,868	37,700%	76,225	-7,862	-10,310%	68,363	-13,204	-19,310%	55,159	-0,198	-0,360%
Portugal	52,148	15,506	29,740%	67,654	12,772	18,880%	80,426	-13,435	-16,710%	66,990	14,843	28,460%
Romania	24,142	16,029	66,400%	40,171	19,590	48,770%	59,761	-11,750	-19,660%	48,010	23,869	98,870%
Slovenia	33,359	11,214	33,620%	44,573	-10,012	-22,460%	34,561	-0,683	-1,980%	33,878	0,519	1,560%
Slovakia	45,857	22,458	48,970%	68,315	-1,182	-1,730%	67,133	-10,705	-15,950%	56,428	10,570	23,050%
Finland	10,003	12,239	122,350%	22,242	3,207	14,420%	25,450	7,797	30,635%	33,246	23,243	232,350%
Sweden	26,379	39,498	149,740%	65,877	1,188	1,800%	67,065	-13,282	-19,800%	53,783	27,404	103,890%

Table 1: Annual Energy Vulnerability Index (AEVI) values (orange column), year-on-year changes, and cumulative variation (2021–2024). This table is an own elaboration based on calculations using the AEVI methodology developed in this thesis. For full details of the data sources and calculations, see Annex 2.

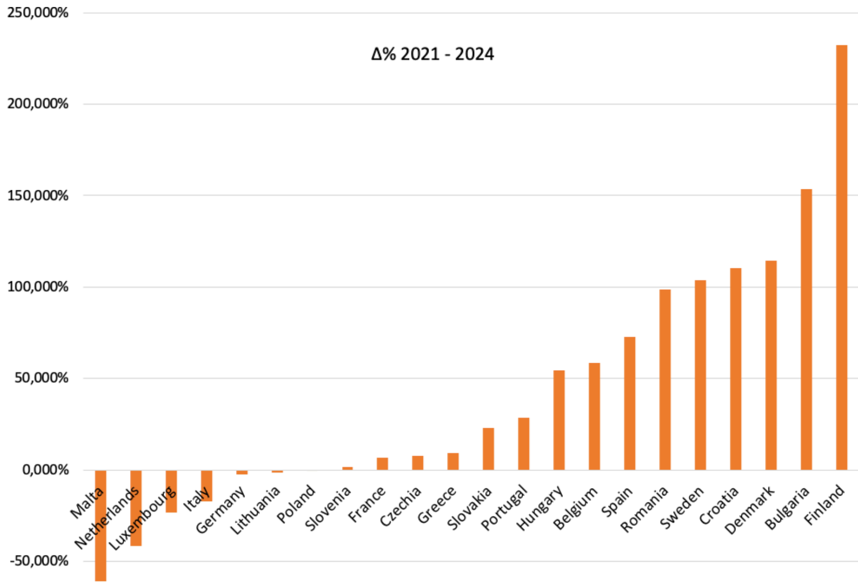

Figure 1: Cumulative change in AEVI by Member State (2021–2024). The figure is an own elaboration displaying the cumulative percentage change in AEVI between 2021 and 2024 for each Member State, sorted from highest to lowest.

The descriptive statistics provide a first overview of how energy vulnerability evolved before and after the implementation of the EU emergency package (2022–2024).

Overall trends:

- From 2021 to 2022, AEVI values rose in most Member States, indicating an improvement in energy security.
- In 2023, results became more mixed: while some countries (e.g. Denmark, Czechia, Croatia) continued to improve, others (e.g. Germany, Italy, Netherlands) saw AEVI decline, suggesting that earlier gains were partly reversed.
- In 2024, the largest and only increases were recorded in Finland and Croatia, while several countries such as Germany, Netherlands, Malta, and Luxembourg experienced further declines.

Cumulative change 2021 – 2024:

The overall change over the period reveals sharp contrasts. Finland, Bulgaria, Sweden, Denmark and Romania achieved the largest overall improvements, whereas Malta, Netherlands, Luxembourg, Italy, Germany, Lithuania and Poland experienced deterioration. These divergent trajectories often reflect structural factors such as a high share of energy-intensive industry or limited institutional capacity to implement emergency measures effectively.

Preliminary interpretation

As a response to the first sub-question of this study, "*What has been the evolution of energy vulnerability before (2021) and after (2024) the implementation of the EU emergency package?*", the data indicate that right after the crisis there was a general strengthening of energy security, followed by a more uneven trajectory in 2023. Countries showing the greatest improvements combined rapid diversification of gas imports with progress in renewable energy, whereas those with stagnant or declining AEVI scores typically relied more heavily on fossil fuels and exhibited lower institutional responsiveness.

Although it may seem counter-intuitive that AEVI values first increase and then decline, this pattern can be explained by the multi-dimensional nature of the index. The initial rise mainly reflects short-term diversification efforts and emergency actions taken immediately after the supply shock, together with the exceptional price surge of 2022, which temporarily reduced relative volatility. In the following years, as markets stabilized, and prices fell, relative volatility increased again while progress on storage and demand-reduction measures reached a plateau. As a result, some of the initial gains in energy security were not sustained once the immediate crisis had passed.

6.2 Regression results: drivers of change

The following table presents the results of the regression analysis examining the factors associated with annual changes in the AEVI (ΔAEVI) across EU Member States between 2022 and 2024. The model includes three institutional variables (Storage, Demand15, and PPA), four structural controls (Renewables share, GDP per capita, Industry share, and Interconnection index).

Metric	Value
Residual Std. Error	10.11
Degrees of Freedom	9
R^2	0.4038
Adjusted R^2	-0.05991
F-statistic	0.8708
p-value	0.5625

Table 2: Summary statistics of the OLS regression model for ΔAEVI. Own elaboration based on the R results. The full R output of the model estimation is provided in Annex 3.

The model explains approximately 40% of the variation in ΔAEVI ($R^2 = 0.4038$), while the adjusted R^2 is slightly negative (–0.05991) due to the limited number of observations relative to the number of predictors. The overall F-statistic is not significant ($F = 0.8708$, $p = 0.5625$), which is expected given the small sample size and short time frame.

Variable by variable interpretation

Variable	Estimate	p-value
Intercept	35.8595	0.3873
Storage	-26.3503	0.2779
Demand15	-2.1146	0.8164
Cdf/PPA	8.7244	0.4757
Renewables share	0.1979	0.3864
GDP per capita	-0.0002	0.3901
Industry share	-82.5468	0.3207
Interconnection	11.9783	0.1742

Table 3: Estimated coefficients of the OLS regression model for ΔAEVI (2022-2024). Own elaboration based on the R results. The full R output of the model estimation is provided in Annex 3.

Among the institutional measures, storage (β = –26.35) and demand reduction (β = –2.11) have negative coefficients, consistent with the hypothesis that these policies reduce energy vulnerability. In contrast, CfDs/PPA (β = +8.72) shows a positive coefficient, opposite to the expected sign.

For the structural factors, GDP per capita (β = –0.0002) is slightly negative, in line with theoretical expectations. However, renewables share (β = +0.20), industry share (β = –82.55), and interconnection (β = +11.98) display signs that contradict the expected relationships. Nevertheless, none of the coefficients are fully statistically significant, which was expected, and is largely due to the small sample size and limited variation in the dataset.

What are the main factors explaining the differences across countries in the reduction of energy vulnerability?

Based on the results of this model, none of the estimated coefficients reaches conventional levels of statistical significance, which is largely due to the small sample size and short time horizon. However, the direction of some coefficients provides indicative patterns. Among the institutional measures, meeting gas storage targets (β = –26.3503) and reducing gas demand by 15% (β = –2.1146) are associated with lower energy vulnerability, consistent with theoretical expectations. Higher GDP per capita (β = –0.0002) also shows a slight negative relationship with vulnerability.

Conversely, CfDs/PPA (+8.7244), renewables share (+0.1979), industry share (–82.5468), and interconnection (+11.9783) display signs that are not in line with the expected effects. For example, renewables share, which would theoretically reduce vulnerability, appears with a positive sign, whereas industry share, expected to increase risk, shows a negative coefficient.

These results indicate that, in this specific dataset, storage compliance, demand reduction, and GDP per capita are the factors most consistently associated with lower vulnerability, while other variables do not align with theoretical predictions.

Interpretation and limitations

The absence of statistically significant results is mainly due to the small number of observations and the short time series (2022–2024), which limit the statistical power of the analysis. In addition, some policy variables show little variation across Member States, as many measures were implemented simultaneously at EU level, further reducing the ability to detect individual effects.

Despite these limitations, the analysis provides an exploratory application of the AEVI as an analytical tool, showing that it can be operationalized to investigate changes in energy vulnerability and potential drivers of resilience. The findings should be interpreted as indicative rather than conclusive.

Future research should extend the time horizon, include more granular policy indicators, and use larger samples with panel-data techniques to strengthen statistical power and assess the robustness of these preliminary patterns.

6.3 Discussion: interpretation and policy implications

The regression analysis sought to identify which policy instruments and structural factors most strongly influenced the reduction of energy vulnerability (ΔAEVI) across EU

Member States between 2022 and 2024. None of the estimated coefficients is statistically significant ($p > 0.05$), mainly due to the short time series and small number of observations, which limit the statistical power of the model. Nevertheless, the signs of some coefficients provide indicative patterns that help interpret how recent EU measures may have influenced vulnerability trends.

Among the institutional measures, both gas storage compliance (Regulation (EU) 2022/1032) and gas demand reduction (Regulation (EU) 2022/1369) display negative coefficients, consistent with their intended purpose as emergency tools to stabilize supply and prices. These results suggest that countries meeting storage targets and reducing demand were, on average, less vulnerable during the crisis period, even if the effects cannot be statistically confirmed. In contrast, green Power Purchase Agreements (PPAs) (Regulation (EU) 2024/1747) show a positive coefficient. This likely reflects their long-term nature: these instruments are designed to encourage renewable investment and provide price stability over time, but they cannot deliver immediate reductions in vulnerability within the short 2022–2024 horizon.

Regarding structural factors, GDP per capita shows a small negative coefficient, in line with the idea that wealthier countries are better equipped to implement mitigation measures and diversify supply. However, renewables share (RED III Directive 2023/2413) unexpectedly appears with a positive sign, contrary to the assumption that greater renewable penetration reduces exposure to fossil fuel volatility. Likewise, industry share is negative, opposite to the expectation that economies with larger energy-intensive sectors would be more vulnerable. Interconnection shows a positive sign, suggesting that highly integrated electricity markets may have been more exposed to price volatility during the crisis, particularly in Central and Western Europe.

6.3.1 Policy implications

The results, although not fully statistically significant, offer several insights for policy evaluation:

1. Short-term crisis measures worked in the expected direction. Gas storage compliance and demand reduction appear to reduce vulnerability, reinforcing the

relevance of Regulations (EU) 2022/1032 and 2022/1369 as effective emergency instruments.

2. Long-term investment tools have not yet delivered measurable impacts. The positive coefficient for PPAs highlights that these instruments, established under Regulation (EU) 2024/1747, are still in an early phase. Their benefits are likely to materialize gradually as new renewable capacity comes online and price-stabilizing contracts accumulate.

3. The unexpected sign for renewables shares underlines the limits of the dataset. Despite robust evidence in the literature that renewable deployment strengthens energy security, the short time frame and limited cross-country variation may explain why the estimated coefficient is inconsistent with theory.

4. Industrial structure requires further analysis. The negative coefficient for industry share could reflect temporary demand reductions or targeted mitigation measures in highly industrialized economies during the crisis. Longer datasets are needed to confirm whether industrial dependence structurally increases vulnerability.

5. Interconnection alone is not sufficient. The positive coefficient for interconnection suggests that cross-border market integration, while beneficial for efficiency, can amplify exposure to price volatility if not combined with diversification, storage capacity, and demand-side flexibility.

Overall, these findings provide exploratory evidence that the AEVI can be operationalized to study the drivers of energy vulnerability. They indicate that gas storage compliance, demand reduction, and higher GDP per capita are the factors most consistently associated with lower vulnerability, whereas other variables behave differently from theoretical predictions.

6.4 Limitations of the analysis

While the analysis provides useful initial insights into the drivers of changes in the Annual Energy Vulnerability Index (AEVI), several limitations must be acknowledged.

First, the study period (2022–2024) is very short, covering only two annual variations in AEVI. This restricted timeframe limits the statistical power of the regression and reduces the ability to detect significant effects of policy measures.

Second, several variables show limited variation across countries and years, as many institutional measures were implemented almost simultaneously across Member States as part of a coordinated EU-level response. This lack of cross-country variability, although expected, constrains the model's ability to identify their individual impacts.

Third, the model does not include fixed effects due to the limited degrees of freedom, meaning that unobserved country-specific factors (e.g. historical energy mix, geography) are not fully controlled for.

For these reasons, the results should be interpreted as indicative rather than conclusive. Future research extending the time horizon, incorporating more granular indicators of policy implementation, and using panel-data techniques would help improve the robustness and explanatory power of the analysis.

7. Conclusions and future research

This thesis set out to explore how energy vulnerability evolved across the European Union in the wake of the 2022 energy crisis, a period characterized by unprecedented price volatility, supply disruptions, and rapid institutional responses. The research addressed a clear gap in the existing literature: while numerous studies have examined individual policy instruments or aggregate indicators such as import dependency, few have attempted to evaluate vulnerability in a way that integrates structural exposure with institutional capacity. To fill this gap, the study developed the Annual Energy Vulnerability Index (AEVI), a composite indicator that combines three dimensions (supply diversification, price stability, and institutional response capacity) into a single framework that allows for both cross-country comparisons and temporal analysis.

The AEVI is the central methodological contribution of this thesis. Unlike conventional measures of energy security, it explicitly accounts for governments' ability to implement coordinated emergency measures, thereby recognizing that resilience depends not only on structural characteristics but also on institutional effectiveness. This dual focus makes the AEVI both analytically robust and policy-relevant, providing a tool that can inform future research and practical decision-making.

Main empirical insights

The descriptive analysis based on the AEVI revealed a two-phase trajectory. In 2022, the first year after the onset of the crisis, most Member States recorded increases in their AEVI scores, indicating an overall improvement in energy security. This progress coincided with the roll-out of emergency measures such as compliance with the EU gas storage target and voluntary reductions in gas demand. These actions likely helped stabilise supply and prices during the acute phase of the shock.

From 2023 onwards, the evolution became more heterogeneous. While several countries (including Denmark, Croatia, and Finland) continued to improve, others such as Germany, Italy, Luxembourg, and the Netherlands experienced stagnation or declines in their AEVI scores. By 2024, the largest increases were observed in Finland, Croatia, and Bulgaria, whereas countries like Germany, the Netherlands, Malta, and Luxembourg recorded further decreases.

This divergence suggests that short-term emergency measures alone were not sufficient to ensure sustained improvements. Countries that maintained or enhanced their AEVI scores were typically those that complemented immediate crisis tools with more structural adjustments, such as diversified supply portfolios or stronger institutional capacity. By contrast, some Member States with higher industrial dependence or limited policy responsiveness struggled to consolidate earlier gains.

Exploratory regression findings

The regression analysis provided an initial exploration of the factors associated with annual changes in the AEVI. As expected given the short time series, small sample size, and limited variation in several measures, none of the coefficients is statistically significant. However, the signs of some estimates offer indicative patterns.

Among the institutional measures, gas storage compliance and gas demand reduction show negative coefficients, consistent with their intended purpose of reducing energy vulnerability. By contrast, green PPAs display a positive coefficient, which is likely due to the fact that these instruments have only recently been introduced and are designed to provide long-term investment signals rather than immediate relief.

For the structural factors, GDP per capita has a small negative coefficient, in line with the idea that wealthier countries are marginally less vulnerable. However, both renewables share and industry share show signs opposite to theoretical expectations: renewable deployment would normally be expected to reduce vulnerability, while economies with a larger industrial base are typically assumed to be more exposed. Finally, interconnection has a positive coefficient, suggesting that highly integrated markets may have been more exposed to price volatility during the crisis period.

These results should be interpreted with caution. They indicate that storage compliance, demand reduction, and higher GDP per capita are the factors most consistent with lower vulnerability, while other variables behave differently from what theory would predict.

Main contributions

The primary value of this thesis lies not in producing conclusive empirical results but in the creation and validation of the AEVI as an analytical framework. The empirical component functions as a proof of concept, illustrating how the index can be operationalized to track changes in vulnerability and to explore the potential contribution of different policy instruments. By explicitly integrating an institutional dimension alongside structural exposure, the AEVI addresses a significant gap in existing energy security metrics and provides a foundation for future, more statistically powerful studies.

Policy relevance

The results provide exploratory evidence that short-term crisis tools, such as the EU's gas storage and demand-reduction regulations, likely helped contain energy vulnerability in 2022. However, the uneven trends observed in later years show that emergency measures alone cannot deliver lasting resilience. Ensuring sustained progress requires structural reforms, including diversified supply portfolios, accelerated renewable deployment, and targeted support for industrial decarbonization.

The limited and sometimes counter-intuitive coefficients for PPAs, renewables share, industry share, and interconnection mainly reflect the short time frame and restricted dataset rather than contradicting existing evidence. Nevertheless, they underline the need to combine long-term investment policies with short-term preparedness measures.

Overall, the findings reinforce that a balanced approach is required: emergency tools can stabilize markets in times of crisis, but structural policies, especially those supporting renewables and diversification, are essential for long-term energy security. At the same time, the heterogeneous performance across Member States highlights the importance of EU-level solidarity and tailored support for the most vulnerable economies.

Limitations and future potential

This thesis acknowledges several limitations that restrict the scope and statistical power of the analysis. First of all, the study period (2022–2024) is very short, covering only two annual changes in the AEVI. This limited timeframe prevents the assessment of the longer-term effects of structural policies such as green PPAs, which are expected to influence energy security over several years rather than immediately.

Data availability also constrained the analysis. For example, renewables share and gas import diversification for 2024 were not yet published at the time of writing, resulting in gaps for the final year. Several institutional measures displayed very limited cross-country variation, as they were implemented almost simultaneously across Member States as part of the EU emergency package, reducing the model's ability to isolate their individual effects.

The regression does not include variables for fiscal capacity or institutional quality, which likely affect countries' ability to respond to energy shocks. Adding indicators of fiscal space or governance would improve the understanding of institutional resilience.

Final reflection

Ultimately, this work should be viewed as the beginning of a research agenda rather than a final assessment. Its primary achievement is the creation of a tool that captures the multidimensional nature of energy vulnerability and offers a structured way to track how policy actions and structural factors shape resilience over time. By focusing on the design and validation of the AEVI rather than on generating statistically strong results, the thesis provides a foundation for future studies that will benefit from longer datasets and more detailed information.

In an era defined by volatility, uncertainty, and geopolitical fragmentation, tools such as the Annual Energy Vulnerability Index are essential to bridge the gap between academic research and policy evaluation. The index enables a more nuanced understanding of how short-term emergency measures interact with long-term structural changes, providing valuable insights for the design of resilient and equitable energy strategies in the European Union and beyond.

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Annex 1: R code for AEVI regression analysis

```
# ----------------------------------------------------------
# STEP 1: Load packages and import dataset
# ----------------------------------------------------------
install.packages(c("readxl", "dplyr", "car"))  # only if not installed

library(readxl)
library(dplyr)
library(car)

# Import Excel file containing AEVI values and control variables
data <- read_excel("C:/Users/ASUS/Documents/Regression.xlsx")

# ----------------------------------------------------------
# STEP 2: Clean and prepare dataset
# ----------------------------------------------------------
# Rename columns to avoid special characters
colnames(data) <- c("country","year","aevi","inversed_hhi","price_stability",
                    "storage","demand15","cfds_ppa","renewables_share",
                    "gdp_per_capita","industry_share","interconnection_index")

# Convert country and year to factors
data$country <- as.factor(data$country)
data$year <- as.factor(data$year)

# Convert all other columns to numeric
numeric_cols <- setdiff(colnames(data), c("country","year"))
data[numeric_cols] <- lapply(data[numeric_cols], as.numeric)

# Remove rows where all numeric values are NA
data <- data %>% filter(!if_all(all_of(numeric_cols), is.na))

# ----------------------------------------------------------
# STEP 3: Compute ΔAEVI (year-on-year change)
# ----------------------------------------------------------
data <- data %>%
  group_by(country) %>%
  arrange(year, .by_group = TRUE) %>%
  mutate(delta_aevi = aevi - lag(aevi)) %>%
  ungroup()

# ----------------------------------------------------------
# STEP 4: Remove constant variables (if any)
# ----------------------------------------------------------
```

```
# Calculate standard deviation for numeric columns
sd_values <- sapply(data[numeric_cols], sd, na.rm = TRUE)

# Keep only variables with variation
vars_ok <- names(which(sd_values > 0))

# Create cleaned dataset
data_clean <- data[, c("country","year","delta_aevi", vars_ok)]

# ---------------------------------------------------------
# STEP 5: Baseline regression (pooled OLS, no fixed effects)
# ---------------------------------------------------------
model_simple <- lm(delta_aevi ~ storage + demand15 + cfds_ppa +
                     renewables_share + gdp_per_capita +
                     industry_share + interconnection_index,
                   data = data_clean)

summary(model_simple)

# ---------------------------------------------------------
# STEP 6: Extended model (adding country and year dummies)
# ---------------------------------------------------------
# Prepare dataset for fixed-effects approximation
data_reg <- data_clean %>% filter(!is.na(delta_aevi))
data_reg$year2024 <- ifelse(data_reg$year == "2024", 1, 0)

model_fixed <- lm(delta_aevi ~ storage + demand15 + cfds_ppa +
                    renewables_share + gdp_per_capita +
                    industry_share + interconnection_index +
                    country + year2024,
                  data = data_reg)

summary(model_fixed)

# ---------------------------------------------------------
# STEP 7: Multicollinearity check (Variance Inflation Factor)
# ---------------------------------------------------------
vars_to_check <- c("storage","demand15","cfds_ppa",
                   "renewables_share","gdp_per_capita",
                   "industry_share","interconnection_index","year2024")

# Keep variables with variation
vars_vary <- names(which(sapply(data_reg[, vars_to_check], sd, na.rm = TRUE) >
0))
```

```r
# Fit model only with variables that vary
formula_vif <- as.formula(paste("delta_aevi ~", paste(vars_vary, collapse = "
+ ")))
model_vif <- lm(formula_vif, data = data_reg)

# Calculate VIF
vif(model_vif)

# ---------------------------------------------------------
# STEP 8: Final results (summary and coefficients)
# ---------------------------------------------------------
summary(model_fixed)
coef(summary(model_fixed))

summary(model_simple)
coef(summary(model_simple))
```

Annex 2: Dataset and variable construction for the AEVI

(next page)

YEAR: 2021

#	Country	Year	HHI	Price Stability	Storage_target_met (0/1)	Demand_reduction_15 (0/1)	Cfds_or_ppas (0/1)	% variables activated	AEVI	Renewables_share (%)	Gdp_per_capita	Industry_share	Interconnection_index
1	Belgium	2021	52,97466694	55,4042			1	33,333	47,81112018	13,0760	43.680,00	14,7074%	26,53%
2	Bulgaria	2021	16,97522788	63,8510			0	0,000	25,9454045	19,4450	10.970,00	19,7340%	62,49%
3	Czechia	2021	0	92,7339			1	33,333	37,82016349	17,6140	23.430,00	25,8417%	41,27%
4	Denmark	2021	0	19,0736			1	33,333	15,72207084	41,8130	58.640,00	16,9112%	85,21%
5	Germany	2021	51,20624418	93,0064			1	33,333	58,38440503	19,3000	44.190,00	23,3362%	19,99%
6	Estonia	2021	0	16,3488			0	0,000	4,904632153	37,3420	23.650,00	19,3431%	130,28%
7	Ireland	2021	0	47,9564			1	33,333	24,38692098	12,9960	88.070,00	37,9726%	12,32%
8	Greece	2021	75,45859423	22,7975			1	33,333	47,02267475	22,0010	17.350,00	15,0533%	22,87%
9	Spain	2021	73,81633783	20,5268			1	33,333	45,68457328	20,5500	26.090,00	16,5799%	12,17%
10	France	2021	73,1190321	85,1045			1	33,333	64,77894799	19,3160	36.920,00	12,5411%	12,69%
11	Croatia	2021	54,78089644	96,6394			0	0,000	50,90418419	31,2850	14.890,00	17,8196%	156,87%
12	Italy	2021	72,07216495	64,2144			1	33,333	58,09317116	18,8830	31.160,00	20,0904%	17,35%
13	Cyprus	2021		0,0000			0	0,000		19,0690	27.850,00	7,4006%	0,00%
14	Latvia	2021	0	44,6866			0	0,000	13,40599455	42,0960	17.130,00	18,7330%	168,57%
15	Lithuania	2021	69,8853523	77,2025			0	0,000	51,11490386	28,1660	20.180,00	20,7988%	90,69%
16	Luxembourg	2021	54,97667656	82,4705			0	0,000	46,73181504	11,7260	113.920,00	6,3877%	176,47%
17	Hungary	2021	9,50120336	100,0000			0	0,000	33,80048134	14,1340	16.090,00	22,0683%	65,66%
18	Malta	2021	44,49339507	0,0000			0	0,000	17,79735803	12,6310	32.190,00	8,4597%	29,47%
19	Netherlands	2021	69,60046676	73,2062			1	33,333	59,80203957	13,1160	50.850,00	14,7180%	29,42%
20	Austria	2021	0	89,1916			0	0,000	26,75749319	34,7920	45.380,00	22,0624%	55,68%
21	Poland	2021	46,15872215	89,6458			1	33,333	55,35722183	15,6040	15.770,00	25,6606%	9,07%
22	Portugal	2021	61,02311149	92,4614			0	0,000	52,14766422	33,9820	20.800,00	17,6746%	41,12%
23	Romania	2021	0	80,4723			0	0,000	24,14168937	23,8710	12.660,00	21,7552%	28,64%
24	Slovenia	2021	13,84593307	92,7339			0	0,000	33,35853672	25,0000	24.680,00	26,1096%	152,72%
25	Slovakia	2021	42,84487796	95,7312			0	0,000	45,85729723	17,4190	18.740,00	21,9321%	94,43%
26	Finland	2021	0,008198601	0,0000			1	33,333	10,00327944	42,8190	44.890,00	21,0667%	20,21%
27	Sweden	2021	40,94713206	0,0000			1	33,333	26,37885282	62,5270	51.260,00	18,8538%	34,62%

YEAR 2022

#	Country	Year	HHI	Price Stability	Storage_target_met (0/1)	Demand_reduction_15 (0/1)	Cfds_or_ppas (0/1)	% variables activated	AEVI	Renewables_share (%)	Gdp_per_capita	Industry_share	Interconnection_index
1	Belgium	2022	78,9236393	22,7148	1	1	1	100,000	68,38390564	13,8160	48.260,00	16,2909%	26,53%
2	Bulgaria	2022	58,52818128	77,9420	1	1	1	100,000	76,79386693	19,0440	13.310,00	24,6651%	62,49%
3	Czechia	2022	33,88240113	43,4045	n/a	1	1	66,667	46,57430692	18,1230	26.670,00	26,6242%	41,27%
4	Denmark	2022	0,02653145	0,0000	1	1	1	100,000	30,01061258	42,3830	64.430,00	18,4208%	85,21%
5	Germany	2022	66,19144493	91,6256	1	1	1	100,000	83,9642627	20,8140	47.180,00	23,6246%	19,99%
6	Estonia	2022		69,8413	n/a	1	0	33,333		38,5420	27.360,00	20,0437%	130,28%
7	Ireland	2022	0	15,8183	0	0	1	33,333	14,7454844	13,0680	100.140,00	40,2400%	12,32%
8	Greece	2022	80,44316559	42,2551	n/a	1	1	66,667	64,85378512	22,6710	19.650,00	17,0006%	22,87%
9	Spain	2022	80,02148847	50,9579	1	0	1	66,667	67,29595171	21,8960	28.750,00	17,1162%	12,17%
10	France	2022	77,70211003	88,9984	1	1	1	100,000	87,7803514	20,4450	38.920,00	12,1414%	12,69%
11	Croatia	2022	28,05067344	94,3623	1	1	1	100,000	69,52897217	28,0880	17.260,00	18,1475%	156,87%
12	Italy	2022	78,54443609	56,7597	1	1	1	100,000	78,44568905	19,1310	33.860,00	20,2366%	17,35%
13	Cyprus	2022		0,0000	n/a	n/a	0	0,000		19,4270	31.270,00	6,7124%	0,00%
14	Latvia	2022	0	0,2737	0	1	0	33,333	10,08210181	43,7200	19.140,00	17,9710%	168,57%
15	Lithuania	2022	48,27886688	13,9026	n/a	1	0	33,333	33,48231851	29,5990	23.820,00	21,4196%	90,69%
16	Luxembourg	2022	49,52977979	100,0000	n/a	1	0	33,333	59,81191192	14,2620	117.100,00	5,5163%	176,47%
17	Hungary	2022	29,05675253	92,6656	1	1	0	66,667	59,42237261	15,1280	17.600,00	22,1348%	65,66%
18	Malta	2022	43,65832377	0,0000	n/a	0	0	0,000	17,46332951	13,9690	34.350,00	8,2842%	29,47%
19	Netherlands	2022	77,48775977	16,8035	1	1	1	100,000	66,03615481	15,1340	56.140,00	15,9237%	29,42%
20	Austria	2022	0	71,0454	1	1	1	100,000	51,3136289	34,0750	49.490,00	21,3720%	55,68%
21	Poland	2022	69,01189148	95,4023	1	0	1	66,667	76,22544625	16,6290	17.520,00	26,1615%	9,07%
22	Portugal	2022	60,67856495	77,9420	1	1	0	66,667	67,6540204	34,6750	23.300,00	16,5133%	41,12%
23	Romania	2022	17,87362859	10,0712	1	1	1	100,000	40,17079791	24,2290	14.790,00	22,3775%	28,64%
24	Slovenia	2022	42,5075512	58,5660	n/a	1	0	33,333	44,57280701	25,0020	26.980,00	25,1420%	152,72%
25	Slovakia	2022	47,38807155	97,8654	1	1	0	66,667	68,31483453	17,4810	20.170,00	21,1719%	94,43%
26	Finland	2022	5,605425519	0,0000	n/a	1	1	66,667	22,24217021	47,7400	47.890,00	22,4125%	20,21%
27	Sweden	2022	53,1577856	48,7137	1	1	1	100,000	65,87723575	66,2870	51.980,00	20,0723%	34,62%

YEAR: 2023

#	Country	Year	HHI	Price Stability	Storage_target_met (0/1)	Demand_reduction_15 (0/1)	Cfds_or_ppas (0/1)	% variablles activated	AEVI	Renewables_share (%)	Gdp_per_capita	Industry_share	Interconnection_index
1	Belgium	2023	79,47111619	59,5211	1	1	1	100,000	79,645	14,7410	50.610,00	15,1162%	26,53%
2	Bulgaria	2023	51,08332676	87,6853	1	1	1	100,000	76,739	22,5490	14.690,00	21,4271%	62,49%
3	Czechia	2023	23,41379604	97,8335	n/a	1	1	66,667	58,716	18,5860	29.330,00	27,0977%	41,27%
4	Denmark	2023	0,019308735	61,3455	1	1	1	100,000	48,411	44,3960	62.910,00	21,2367%	85,21%
5	Germany	2023	37,00540316	89,9658	1	1	1	100,000	71,792	21,5620	49.520,00	24,5872%	19,99%
6	Estonia	2023		73,0331	n/a	1	0	33,333		40,9500	27.960,00	18,3992%	130,28%
7	Ireland	2023	0	30,5587	0	0	1	33,333	19,168	15,2530	99.080,00	33,0207%	12,32%
8	Greece	2023	72,98412538	84,8917	n/a	0	1	33,333	64,661	25,2690	21.350,00	15,3879%	22,87%
9	Spain	2023	79,21512022	90,8780	1	0	1	66,667	78,949	24,8520	30.970,00	16,1301%	12,17%
10	France	2023	74,93457313	76,3968	1	1	1	100,000	82,893	22,2830	41.340,00	14,5071%	12,69%
11	Croatia	2023	63,30548749	100,0000	1	1	1	100,000	85,322	28,0510	19.800,00	18,2754%	156,87%
12	Italy	2023	74,42600627	55,1311	1	1	1	100,000	76,31	19,5940	36.130,00	19,8818%	17,35%
13	Cyprus	2023		0,0000	n/a	n/a	0	0,000		20,2130	32.720,00	6,8485%	0,00%
14	Latvia	2023		73,2041	0	1	0	33,333		43,2230	20.930,00	17,6189%	168,57%
15	Lithuania	2023	55,35093699	44,2417	n/a	1	1	66,667	55,413	31,9260	25.700,00	19,5767%	90,69%
16	Luxembourg	2023	39,60470249	98,9738	n/a	1	0	33,333	55,534	14,3550	121.290,00	6,1029%	176,47%
17	Hungary	2023	21,429586	99,2588	1	1	1	100,000	68,349	17,1170	20.630,00	23,3538%	65,66%
18	Malta	2023	27,62725165	0,0000	n/a		0	0,000	11,051	15,0770	37.110,00	8,3831%	29,47%
19	Netherlands	2023	67,6423109	0,0000	1	1	1	100,000	57,057	17,4200	58.740,00	15,0574%	29,42%
20	Austria	2023	0	90,6499	1	1	1	100,000	57,195	40,8440	51.830,00	21,4443%	55,68%
21	Poland	2023	64,12345149	75,7127	1	0	1	66,667	68,363	16,5640	19.980,00	25,6291%	9,07%
22	Portugal	2023	61,58317089	85,9749	1	1	1	100,000	80,426	35,1630	25.330,00	16,0479%	41,12%
23	Romania	2023	0	99,2018	1	1	1	100,000	59,761	25,7820	17.010,00	20,9174%	28,64%
24	Slovenia	2023	0	81,8700	n/a	0	1	33,333	34,561	25,0660	30.160,00	26,4267%	152,72%
25	Slovakia	2023	46,12515691	95,6100	1	1	0	66,667	67,133	16,9900	22.690,00	23,3395%	94,43%
26	Finland	2023	13,62456747	0,0000	n/a	1	1	66,667	25,45	50,7500	48.920,00	20,5573%	20,21%
27	Sweden	2023	42,71897875	66,5906	1	1	1	100,000	67,065	66,3930	50.490,00	18,8544%	34,62%

YEAR: 2024

#	Country	Year	HHI	Price Stability	Storage_target_met (0/1)	Demand_reduction_15 (0/1)	Cfds_or_ppas (0/1)	% variablles activated	AEVI	Renewables_share (%)	Gdp_per_capita	Industry_share	Interconnection_index
1	Belgium	2024	80,0223908	79,2517	1	0	1	66,667	75,784		51.810,00	14,1697%	26,53%
2	Bulgaria	2024	44,58546662	93,3673	1	0	1	66,667	65,844		16.110,00	21,3181%	62,49%
3	Czechia	2024	16,17966339	80,6122	n/a	0	1	33,333	40,656		29.440,00	26,4350%	41,27%
4	Denmark	2024	0,014052275	78,9116	0	0	1	33,333	33,679		65.650,00	22,4176%	85,21%
5	Germany	2024	20,68847213	95,4082	1	0	1	66,667	56,898		50.830,00	23,1240%	19,99%
6	Estonia	2024		72,4490	n/a	1	0	33,333			28.740,00	17,3388%	130,28%
7	Ireland	2024		53,4014	0	0	1	33,333			104.510,00	32,6512%	12,32%
8	Greece	2024	66,21671982	49,4898	n/a	0	1	33,333	51,334		22.560,00	15,5448%	22,87%
9	Spain	2024	78,41687765	91,4966	1	0	1	66,667	78,816		32.590,00	15,5735%	12,17%
10	France	2024	72,26560834	67,3469	1	0	1	66,667	69,11		42.590,00	13,6543%	12,69%
11	Croatia	2024	142,8694664	100,0000	1	0	1	66,667	107,15		21.740,00	16,1606%	156,87%
12	Italy	2024	70,52352382	0,0000	1	0	1	66,667	48,209		37.180,00	18,6115%	17,35%
13	Cyprus	2024		0,0000	n/a	n/a	0	0,000			34.490,00	6,5822%	0,00%
14	Latvia	2024		50,8503	0	1	0	33,333			21.610,00	15,9331%	168,57%
15	Lithuania	2024	63,45895053	50,1701	n/a	0	1	33,333	50,435		27.150,00	18,6856%	90,69%
16	Luxembourg	2024	31,66847229	77,0408	n/a	0	0	0,000	35,78		126.910,00	5,4214%	176,47%
17	Hungary	2024	15,80449004	86,2245	1	0	1	66,667	52,189		21.570,00	21,7896%	65,66%
18	Malta	2024	17,48269213	0,0000	n/a	0	0	0,000	6,9931		39.330,00	8,1531%	29,47%
19	Netherlands	2024	59,04780623	4,0816	0	0	1	33,333	34,844		62.380,00	14,2348%	29,42%
20	Austria	2024		14,7959	1	0	1	66,667			52.760,00	19,1402%	55,68%
21	Poland	2024	59,58128291	37,7551	1	0	1	66,667	55,159		22.560,00	22,9400%	9,07%
22	Portugal	2024	62,50126284	39,9660	1	1	1	100,000	66,99		26.700,00	16,2043%	41,12%
23	Romania	2024	0	93,3673	1	0	1	66,667	48,01		18.560,00	19,3257%	28,64%
24	Slovenia	2024	0	79,5918	n/a	0	1	33,333	33,878		31.490,00	25,7169%	152,72%
25	Slovakia	2024	44,89589955	94,8980	1	0	0	33,333	56,428		24.000,00	22,8297%	94,43%
26	Finland	2024	33,11592282	0,0000	n/a	1	1	66,667	33,246		49.100,00	20,3502%	20,21%
27	Sweden	2024	34,33008213	66,8367		1	1	66,667	53,783		52.600,00	18,0394%	34,62%

Annex 3: R output of the AEVI regression model

```
> summary(model_simple)

Call:
lm(formula = delta_aevi ~ storage + demand15 + cfds_ppa + renewables_share +
    gdp_per_capita + industry_share + interconnection_index +
    year2024, data = data_reg)

Residuals:
   Min     1Q Median     3Q    Max
-9.326 -6.106  0.000  4.456 15.191

Coefficients: (1 not defined because of singularities)
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)           3.586e+01  3.947e+01   0.909    0.387
storage              -2.635e+01  2.282e+01  -1.155    0.278
demand15             -2.115e+00  8.843e+00  -0.239    0.816
cfds_ppa              8.724e+00  1.172e+01   0.744    0.476
renewables_share      1.979e-01  2.174e-01   0.910    0.386
gdp_per_capita       -1.756e-04  1.945e-04  -0.903    0.390
industry_share       -8.255e+01  7.854e+01  -1.051    0.321
interconnection_index 1.198e+01  8.118e+00   1.475    0.174
year2024                     NA         NA      NA       NA

Residual standard error: 10.11 on 9 degrees of freedom
  (29 observations deleted due to missingness)
Multiple R-squared:  0.4038,    Adjusted R-squared:  -0.05991
F-statistic: 0.8708 on 7 and 9 DF,  p-value: 0.5625
```

```
> coef(summary(model_simple))
                           Estimate   Std. Error    t value  Pr(>|t|)
(Intercept)            3.585954e+01 3.946882e+01  0.9085536 0.3872679
storage               -2.635027e+01 2.281840e+01 -1.1547813 0.2779191
demand15              -2.114585e+00 8.843435e+00 -0.2391135 0.8163738
cfds_ppa               8.724371e+00 1.172171e+01  0.7442918 0.4756833
renewables_share       1.979372e-01 2.174452e-01  0.9102858 0.3864017
gdp_per_capita        -1.756072e-04 1.944795e-04 -0.9029597 0.3900745
industry_share        -8.254679e+01 7.854253e+01 -1.0509820 0.3206666
interconnection_index  1.197834e+01 8.118211e+00  1.4754905 0.1741861
```