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Clean Base

The Role of Nuclear Energy for a Secure, Low-Carbon European Future

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DEMOCRACY

This report presents the 2026 edition of the *Energy and Climate Security Risk Index* (ECSRI), a comprehensive, data-driven tool assessing systemic risks across EU member states. Europe's energy and climate security entered a new phase in 2026, as global tensions exposed the continent's continuing vulnerability to fossil fuel supply shocks and chokepoints. While the EU has significantly reduced its dependence on Russian energy, the Gulf crisis demonstrated that diversification alone is not enough when the overreliance on fossil fuel imports represents a systemic risk, undermining the continent's affordability and competitiveness.

The Index evaluates energy security through four interconnected dimensions: geopolitical risk, affordability, reliability, and sustainability. It shows that Europe's strongest energy systems combine renewable deployment, firm low-carbon generation, modern grids, and industrial strategy rooted in secure supply chains. The report calls for a shift from crisis response to system design, placing nuclear energy and renewables at the center of a more secure, affordable, and competitive European energy model.

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EXECUTIVE SUMMARY

Europe's energy and climate security entered a new phase in 2026. The immediate shock created by Russia's invasion of Ukraine has eased, but the **structural vulnerabilities of the European energy system** persist. The disruption of LNG flows through the Strait of Hormuz exposed how dependent Europe remains on volatile global fossil fuel markets and maritime supply chokepoints. The resulting surge in natural gas and electricity prices demonstrated that Europe's energy security is a key element of its competitiveness strategy.

The 2026 *Energy and Climate Security Risk Index* (ECSRI), developed by the Center for the Study of Democracy, shows that Europe has reduced some of its most acute geopolitical risks since 2022, particularly those linked to Russian fossil fuel dependence. EU reliance on Russian oil imports fell from around 25% before the invasion of Ukraine to below 5% in 2026, while Russian gas imports declined from approximately 40% to below 10%. LNG import infrastructure expanded rapidly to meet growing demand for imports from the global market. The EU introduced mandatory gas storage obligations and alternative supplies from Norway, Algeria, Qatar, and the United States increased substantially to cover the Russian gas shortfall. Yet the March 2026 Hormuz crisis revealed **the limits of route diversification** alone. Europe has reduced dependence on Russian pipeline gas only to become more **exposed to volatile LNG markets** shaped by shipping chokepoints, geopolitical fragmentation, and direct competition with Asian buyers.

The ECSRI evaluates energy and climate security across four interconnected risk dimensions: geopolitics, affordability, reliability, and sustainability. The results reveal a widening divide between member states that have accelerated structural transformation and those still constrained by carbon-intensive energy systems, ageing infrastructure, and high import dependence.

Ranked Risk Values for 2025

The ECSRI uses 21 indicators across four dimensions to calculate a country's risk score. As these indicators are measured in different units, each one is standardized by converting it into a z-score, with the EU average and standard deviation from 2015 serving as the reference values. Using 2015 as a benchmark enables the index to capture changes in risk levels over time. Positive scores imply that risks are higher than the EU average in 2015, while negative scores imply lower risks.

Energy & Climate Security Risk (overall)	Geopolitics	Affordability	Reliability	Sustainability
1. Netherlands (-166.5)	1. Netherlands (-535.5)	1. Luxembourg (-57.9)	1. Slovakia (-169.3)	1. Netherlands (-105.6)
2. France (-44)	2. Finland (-93.1)	2. Finland (-33.6)	2. Latvia (-106.8)	2. France (-105)
3. Austria (-36)	3. Denmark (-88)	3. Sweden (-26.5)	3. Austria (-105.4)	3. Belgium (-94.8)
4. Sweden (-34.2)	4. Estonia (-82.1)	4. France (1.4)	4. Slovenia (-95)	4. Italy (-86.9)
5. Slovakia (-24.7)	5. Sweden (-68.1)	5. Ireland (8.7)	5. Bulgaria (-58.9)	5. Austria (-76)
6. Denmark (-20.3)	6. France (-60.3)	6. Austria (11)	6. Czechia (-54.2)	6. Spain (-61.3)
7. Luxembourg (-13.7)	7. Germany (-43.2)	7. Netherlands (11.5)	7. Germany (-29.5)	7. Germany (-60.2)
8. Latvia (-13.5)	8. Romania (-29.9)	8. Denmark (15.6)	8. Netherlands (-26.9)	8. Slovakia (-55.9)
9. Finland (-13.2)	9. Poland (-27.7)	9. Belgium (36.8)	9. Spain (-26.2)	9. Portugal (-52.1)
10. Belgium (-13)	10. Luxembourg (-16.7)	10. Spain (44.8)	10. Italy (-24)	10. Sweden (-48.5)
11. Germany (-11.8)	11. Croatia (-13)	11. Portugal (53.9)	11. Belgium (-12.3)	11. Slovenia (-37.9)
12. Spain (-5.7)	12. Latvia (-12.6)	12. Estonia (75.3)	12. France (-11.8)	12. Croatia (-36.6)
13. Slovenia (-4.1)	13. Portugal (-4.7)	13. Lithuania (80.5)	13. Hungary (-1)	13. Latvia (-34.4)
14. Portugal (0.8)	14. Slovenia (0.6)	14. Slovakia (83.5)	14. Romania (2.2)	14. Denmark (-28.9)
15. Italy (11.9)	15. Czechia (7.3)	15. Germany (86.4)	15. Greece (5.6)	15. Luxembourg (-27.6)
16. Ireland (16.5)	16. Lithuania (15.3)	16. Latvia (100.7)	16. Sweden (6.4)	16. Greece (-24.5)
17. Lithuania (25.2)	17. Ireland (16.7)	17. Italy (112.7)	17. Portugal (6.6)	17. Czechia (-22.8)
18. Estonia (28.6)	18. Belgium (18.4)	18. Hungary (112.8)	18. Lithuania (8.8)	18. Ireland (-5.2)
19. Croatia (37.5)	19. Spain (20.3)	19. Slovenia (117.1)	19. Poland (14.8)	19. Lithuania (-3.4)
20. Hungary (38.3)	20. Austria (26.9)	20. Greece (135.2)	20. Finland (20.4)	20. Hungary (11.2)
21. Czechia (38.9)	21. Hungary (30.7)	21. Croatia (143)	21. Denmark (20.5)	21. Poland (24.3)
22. Romania (42.4)	22. Slovakia (44.8)	22. Romania (165.8)	22. Ireland (45.8)	22. Estonia (27.4)
23. Greece (56)	23. Italy (46.9)	23. Bulgaria (193.2)	23. Luxembourg (47.6)	23. Romania (32.6)
24. Bulgaria (60.4)	24. Bulgaria (60.8)	24. Czechia (227.7)	24. Croatia (57.6)	24. Bulgaria (48.3)
25. Poland (81.7)	25. Greece (108.6)	25. Poland (319.2)	25. Estonia (94.6)	25. Finland (54.2)

Legend: very low risk; low risk; moderate risk; high risk; very high risk.

Source: CSD based on ECSRI data.

Affordability remains the largest source of risk for many European economies. Although average natural gas and electricity prices declined in 2025 by 34% and 14% respectively compared to the peak of the 2022 crisis, they remained approximately 50% and 38% above pre-war levels. European industrial electricity prices also continue to exceed those in both the United States and China, **undermining industrial competitiveness and investment attractiveness**. Between 2019 and 2023, Europe lost more than one million industrial jobs, while Germany alone shed an additional 143,000 industrial jobs in 2025. This **competitiveness gap** is increasingly affecting industrial production and investment decisions across Europe. **Emissions-intensive economies consistently face higher affordability risks** because they remain more exposed to fossil fuel volatility and carbon costs. Poland, Bulgaria, Romania, and Greece continue to rank among the highest-risk countries in the EU due to the combined impact of high energy intensity, expensive electricity, and persistent fossil fuel dependence. The outdated grid infrastructure, the high average cost of capital and political interference in energy markets have all slowed down the energy transition in Central and Eastern Europe. The result has been higher affordability risks weighing down on regional energy security and augmenting wealth disparities with the rest of the EU.

Electricity systems with **high levels of baseload low-carbon generation and electrification** are significantly more resilient to price shocks. Sweden and Finland, where electricity accounts for around 30% of final energy consumption and natural gas sets wholesale electricity prices in only a very small number of hours, exhibit among the lowest affordability risks in Europe. During the March 2026 gas shock, average wholesale electricity prices in Finland and Sweden remained respectively EUR 61/MWh and EUR 33/MWh lower than in Germany. France and Spain have also achieved lower industrial electricity prices by **combining nuclear baseload generation with rapidly expanding renewable energy-based power plant fleet**. In contrast, systems heavily **dependent on gas-fired generation**, such as Italy and Greece, remain structurally exposed to volatile global gas prices, which drives their electricity prices to some of the highest level in the EU.

Reliability risks have also changed significantly. The expansion of renewable energy accelerated rapidly after 2022, with **wind and solar generation overtaking fossil fuels** in EU electricity production for the first time in 2025. Installed solar PV capacity in several Central and Eastern European countries nearly quadrupled between 2021 and 2025, while EU **battery storage capacity** increased tenfold during the same period. Germany and Italy now each operate approximately 6 GWh of utility-scale battery capacity, while Bulgaria has rapidly emerged as one of **Europe's fastest-growing storage markets** with around 2.5 GWh already deployed and plans for up to 10 GWh by the end of 2026.

Yet the rapid growth of intermittent renewable generation has increased pressure on electricity grids, balancing systems and interconnections. The Iberian blackout of 2025 highlighted the emerging system integration challenges associated with maintaining stability in increasingly complex power systems. ENTSO-E concluded that the outage resulted from a combination of voltage instability, insufficient reactive power support, and cascading generation disconnections during a period of system stress.

Countries with stronger interconnections, a diversified generation mix, and higher investment in grid infrastructure tend to achieve more resilient reliability outcomes.

Energy policy sits at the center of **industrial competitiveness and economic security**. The ability to abundant, affordable, and reliable low-carbon electricity increasingly determines industrial investment choices, technological development, and long-term economic resilience. At the same time, Europe's energy transition is creating new **strategic dependencies linked to critical raw materials**, clean technology manufacturing, battery supply chains, semiconductors, and nuclear fuel services. While overall fossil fuel-related geopolitical risks have declined, Europe's dependence on imported wind, solar, batteries and critical raw materials has increased sharply. The geopolitical risk associated with solar panel imports, for example, increased thirteenfold between 2008 and 2025 as deployment accelerated and manufacturing concentration in China deepened. These vulnerabilities increasingly shape the geopolitical dimension of the energy transition.

To strengthen Europe's economic security, the energy transition requires **a system-level approach**. Renewable energy provides low marginal-cost electricity and can be deployed rapidly at scale. At the same time, dispatchable and firm low-carbon generation – including nuclear, hydropower, and sustainable biomass – can support industrial electrification, reduce dependence on imported fossil fuels, and help maintain system stability during periods of low renewable output. Energy systems that successfully integrate these complementary resources tend to achieve stronger long-term security, affordability and decarbonization outcomes than power systems characterized by structural imbalances or continued reliance on fossil fuel imports.

Against this backdrop, the report examines the strategic role of nuclear energy in Europe's future energy architecture. Several EU member states view nuclear power as an important component of long-term energy security and industrial resilience. However, the **deployment of new nuclear capacity continues to face major barriers**, including fragmented regulatory frameworks, financing constraints, supply chain dependencies, and outdated electricity market structures that disadvantage capital-intensive investments. There is a need for a shift toward deployment programs on EU level, built around standardized legal templates, procurement structures, financing models, and contractor ecosystems capable of accelerating replication and simultaneously **reducing financing costs** across multiple projects.

Europe's next energy policy phase must **focus on structural system optimization** rather than short-term crisis management. This requires accelerated investment in electricity grids, storage, interconnections, clean industrial capacity, and the near-and-friendshoring of technology supply chains. A secure energy system also requires electricity market reforms capable of supporting long-term investment in both renewable and nuclear energy infrastructures.

There are **six strategic priorities** for strengthening Europe's long-term energy and climate security:

1. Reduce **structural dependence on imported fossil fuels** through accelerated electrification and expansion of domestic low-carbon generation.

2. Integrate nuclear energy and renewables within a **coherent long-term electricity system** strategy focused on affordability, reliability, and industrial competitiveness.

3. Reform electricity market and financing frameworks to **support capital-intensive low-carbon infrastructure projects**.

4. Expand **investment in grids, storage**, interconnections, and flexibility technologies to strengthen system reliability.

5. Strengthen European and allied **supply chains for critical raw materials**, nuclear fuel, clean energy technologies and skilled workforce.

6. Embed energy policy within **a broader European industrial and economic security strategy** aimed at reducing the competitiveness gap with the United States and China.

Europe's energy transition has become a central economic security challenge. The **AI race** with the scramble for ever greater compute power linked to surging energy demand, has further underlined the urgency of this challenge. The countries best positioned for long-term competitiveness will be those capable of combining low-carbon electricity generation, industrial strategy and infrastructure resilience within a coherent energy system design.

ENERGY SECURITY AT A TURNING POINT: FROM CRISIS TO SYSTEM DESIGN

Europe entered 2026 believing that the worst phase of its energy crisis was over. Russian pipeline gas imports had collapsed, LNG infrastructure had expanded rapidly, storage levels had stabilized, and wholesale gas prices had retreated from the historic highs of 2022 and 2023.

The disruption of LNG flows through the Strait of Hormuz and the subsequent surge in natural gas prices demonstrated that **Europe remains deeply exposed to geopolitical instability** far beyond its borders. While the European Union succeeded in reducing its dependence on Russian fossil fuels, it simultaneously became more integrated into volatile global LNG markets increasingly vulnerable to supply disruptions in maritime chokepoints, geopolitical fragmentation, and intensifying competition for flexible gas supplies. Europe's energy crisis is increasingly the result of the **structural fossil fuel dependency** within an unstable global geopolitical environment, which drives up energy prices and hurts the sustainability of the economic development model..

Structural Redesign

The new equilibrium marks a turning point for European energy policy. The immediate crisis-management phase that dominated the years after Russia's invasion of Ukraine is coming to an end. The next phase will be defined by **long-term system redesign** even as short-term risks from external shocks will pressure policymakers into seeking quick fixes that may slow down the transition process. Even so, Europe's central challenge is building an energy system capable of simultaneously delivering **affordability, reliability, sustainability, and economic sovereignty** despite the geoeconomic fragmentation[1].

This challenge is becoming more urgent because Europe's energy demand is undergoing a profound transformation. Electrification of transport, heating, industry, hydrogen production, artificial intelligence infrastructure, and data centers is expected to drive **sustained growth in electricity consumption** over the next two decades. At the same time, European industry faces **mounting competitive pressure** from both the United States and China, where energy prices remain substantially lower and industrial policy increasingly revolves around sustaining abundant domestic energy supply and **strategic technological dominance**. The energy transition has therefore become inseparable from industrial competitiveness.

[1] Vladimirov, M., Köppen, M., and Rickles, M., *Energy and Climate Security in Europe: From Crisis Response to Structural Transformation*, Sofia: Center for the Study of Democracy, 2025.

The New Energy Security Paradigm

In this new environment, energy policy has become the **foundation of industrial strategy**. The countries capable of securing abundant, affordable, and reliable low-carbon electricity will shape the next phase of technological innovation, and economic growth. Conversely, economies unable to reduce structural exposure to volatile fossil fuel markets **risk prolonged industrial decline**, and the inability to gain strategic autonomy.

The concept of energy security itself is therefore evolving. For decades, European energy security was understood primarily through the lens of fossil fuel supply diversification. Today, security increasingly encompasses **technology supply chains**, critical raw materials, and electricity system stability.

The *Energy and Climate Security Risk Index* (ECSRI), developed by the Center for the Study of Democracy, reflects this broader transformation of the energy security paradigm. The 2026 edition evaluates the extent to which different energy system structures enhance or undermine **long-term economic resilience**. The findings reveal a growing divergence across the continent. While some countries have used the crisis to accelerate the **structural transformation of their economies and energy systems**, others remain trapped between high fossil fuel dependence and weak infrastructure that leads to lower industrial competitiveness.

The Nuclear-Renewables Nexus

A central conclusion emerging from the 2026 ECSRI is that the strongest-performing energy systems are those built around **multiple technological pathways**. These systems are capable of combining **different forms of low-carbon generation**, infrastructure flexibility, and long-term industrial planning. This insight is particularly important in the increasingly polarized debate surrounding nuclear energy and renewables.

The future of Europe's energy security will depend on **integrating nuclear and renewable energy solutions into a coherent system architecture**. Nuclear energy provides firm, low-carbon baseload generation, which stabilizes electricity systems, reduces the dependence on imported fossil fuels, and **supports industrial electrification**. Renewable energy, meanwhile, offers **low marginal-cost electricity**, rapid scalability, and declining deployment costs. Systems that successfully combine both tend to achieve **lower long-term price volatility**, lower emissions intensity, stronger reliability outcomes, and reduced geopolitical exposure.

The ECSRI findings strongly support this hypothesis. France, Sweden, and Finland, which combine substantial nuclear and hydropower capacity with rapidly expanding solar and wind power generation, consistently **rank among the best-performing energy systems in Europe** across multiple risk dimensions. Their electricity systems are **less exposed to fossil fuel price shocks**, carbon cost escalation, and better positioned to **support industrial competitiveness in an increasingly electrified economy**.

MEASURING ENERGY AND CLIMATE SECURITY IN 2026

Fragmented national energy policies and uneven implementation within the EU have long hindered the progress towards **a coherent and resilient European energy and climate security strategy**. ECSRI offers a comparative framework for the evaluation of the performance of different states across four interconnected dimensions of energy and climate security risk: geopolitical exposure, affordability, reliability and sustainability. By tracking these dimensions over time, the ECSRI identifies common vulnerabilities and structural dependencies, providing governments with **a toolbox for choosing the right policy mix** that will strengthen the resilience of the energy system.

Box 1. The Methodology

The ECSRI uses 21 indicators across 4 dimensions to measure the countries' risk score.

Each indicator's score is standardized using the EU average and standard deviation from 2015 as reference values. The standardization follows these steps:

1. The z-score is calculated as: (value in year t – EU-average in 2015) / EU-2015 standard deviation.

2. The resulting z-value is multiplied by 100 to express the score on a comparable scale.

A risk score of 0 indicates that a country's value for a given year equals the EU-average in 2015. A score of +100 means the risk level is one standard deviation higher than the EU-average in 2015, while a score of -100 indicates it is one standard deviation lower. Positive/negative scores therefore represent a higher/lower exposure to energy and climate security risks than what EU countries were facing on average in 2015. This way, the risk scores reflect countries' performance relative to EU developments both over time and between countries.

To calculate the dimensional risk scores and the overall ECSRI score, the individual indicator scores are aggregated using the geometric mean, with each indicator weighted equally.

The index comprises thousands of data points, which cover the period from 2008 to 2024 for all the indicators, and 2008 to 2025 for ten of them, allowing for a preliminary analysis of 2025 risks. These indicators form a holistic dataset capable of illustrating national vulnerabilities to supply disruptions, affordability of energy consumption, impact on industrial competitiveness and fossil fuel dependence. While assigned to specific dimensions, these indicators are highly interconnected. For example, high levels of oil and gas consumption not only increase energy expenditures (hence affordability risks) and emissions (sustainability risks) but also deepen geopolitical exposure.

To ensure comparability across countries and time, all indicators are benchmarked against the EU-27 average in 2015, a year that marked a critical strategic inflection point following Russia's annexation of Crimea, when energy prices were low but Europe largely failed to diversify away from Russian fossil fuel imports. The ECSRI therefore measures changes in risk levels, as well as the long-term consequences of strategic policy decisions and missed opportunities.

Figure 1. Dimensions and Key Indicators of the Energy and Climate Security Risk Index

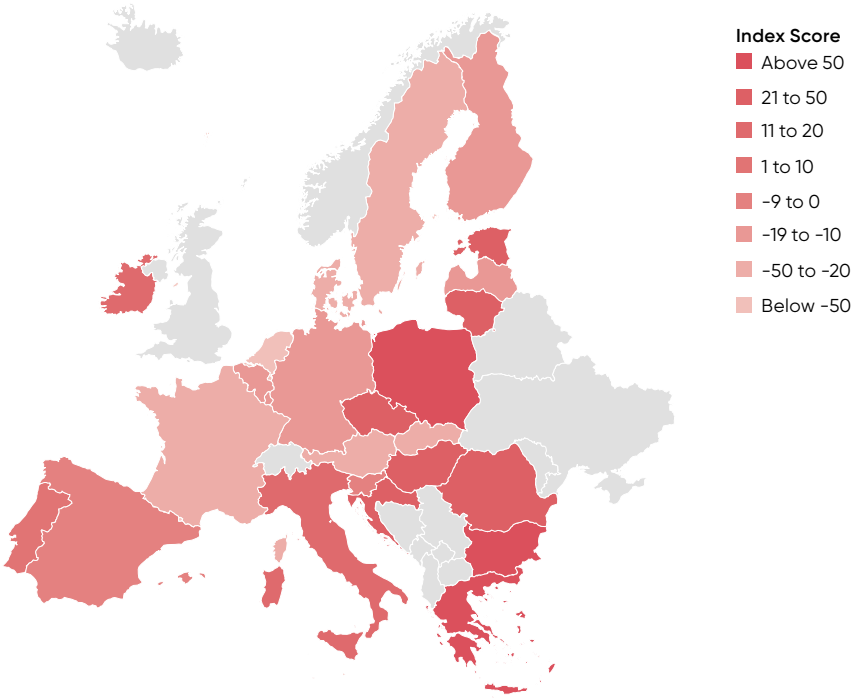
Energy and Climate Security Risk Index

Geopolitical Risk	Affordability Risk	Reliability Risk	Sustainability Risk
• Security of Petroleum Imports • Security of Natural Gas Imports • Security of Raw Materials and RES Imports	• Oil & Natural Gas Import Expenditures per GDP • Energy Expenditures per GDP • Retail Electricity Prices (Household) • CO_2 Costs per GDP • Retail Natural Gas Prices (Businesses) • Retail Electricity Prices (Businesses)	• Electricity Capacity Margins • Electricity Capacity Diversity • Gas Stocks • Gas Infrastructure Reliability • Household Energy Efficiency • Transmission and Distribution Losses	• Energy Intensity • Emissions Intensity • Low-carbon technology share in electricity generation • Waste per Capita • Circular Material Use Rate • Material Footprint

Source: CSD.

The overall picture emerging from the results is one of **partial recovery from the acute energy crisis** of 2022 and 2023. While Europe has significantly reduced some of its most immediate security of supply risks, particularly those linked to its dependence on Russian fossil fuels, many of the more structural drivers of insecurity remain unresolved.

Figure 2. The Overall Energy and Climate Security Risk Across the EU Has Declined Marginally Year-on-Year in 2025

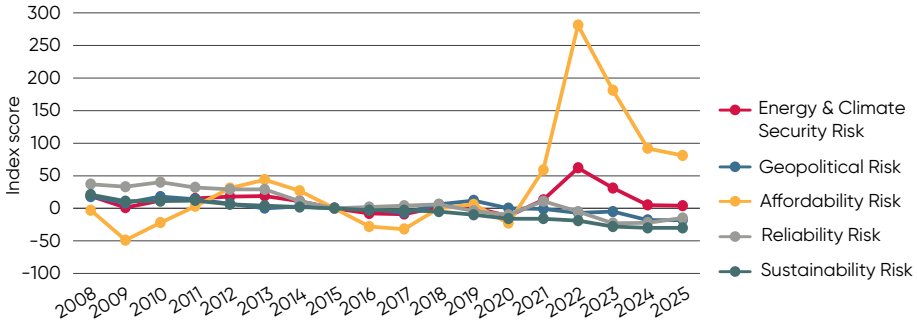


Note: For some indicators 2025 data is still not available.

Source: CSD based on ECSRI data.

The EU's dependence on Russian fossil fuels fell substantially from around 25% in oil and 40% in natural gas before the invasion of Ukraine to below 5% and 10%, respectively, in 2026. The result is a **17-point reduction in the EU geopolitical risk Index** in 2025 in comparison to 2022. The energy security improvement came on the back of a significant expansion of the number of new LNG regasification terminals, the introduction by the European Commission of minimum mandatory gas storage targets, and the surge of **supply from other, more reliable suppliers to the EU** such as Norway, Algeria, Qatar and the United States.

Figure 3. Affordability Risks Have Fallen by 13% Year-on-Year in 2025 but Still Remain Much Higher than in 2021



Source: CSD based on ECSRI data.

As the share of seaborne LNG expanded relative to that of pipeline imports, supply flexibility improved, as did the **resilience to disruptions of a single import route**. Yet, at the same time, the diversification process has also **integrated the EU energy system more deeply into the global LNG market**, thereby exposing it to international price volatility and direct competition with Asian buyers for LNG cargoes coming from both the U.S. and Qatar, the world's two largest LNG exporters. This structural gas supply vulnerability became apparent again in March 2026, when Iran closed the Strait of Hormuz, triggering another sharp rise in energy prices across Europe just three years after the Russian gas supply cuts led to the surge of average European prices to above EUR 200/MWh. The successive disruption to crude oil, petroleum products and gas deliveries have **solidified the notion that the European energy insecurity stems from the continent's persistent dependence on the use of imported fossil fuels**.

While fossil fuel imports remain the primary source of geopolitical risk for Europe's energy system, China's **dominance across critical raw materials (CRMs) and low-carbon technology (LCT) supply chains** is creating a new and increasingly important layer of strategic vulnerability. China has already demonstrated its willingness to use export restrictions as instruments of geopolitical leverage in disputes with Western economies. Against the backdrop of rising tensions in the South China Sea and around Taiwan, the risk that these dependencies could be **weaponized in a manner similar to Russia's unilateral cut of fossil fuel exports** in 2022 can no longer be dismissed. The ECSRI data suggests that the overall security of CRM and LCT imports has remained relatively stable in recent years. However, a closer look at individual sub-indicators reveals **a sharp increase in the EU's**

dependence (and thus insecurity) on the imports of lithium cells and solar panels as deployment of these technologies accelerates. Excessive reliance on clean technology supply chains is becoming a structural challenge for the energy transition. Strengthening Europe's energy and climate security will therefore require **the development of strategic partnerships with alternative suppliers** from friendly states, expanding domestic CRM processing capacity, and **scaling up European manufacturing of low-carbon technologies**.

Affordability risks declined substantially in 2025 after reaching their peak in 2022 and 2023, with alternative gas supplies and weaker industrial demand pushing natural gas prices down. Compared to 2022, the average price of natural gas and electricity in 2025 declined by 34% and 14%, respectively. Nevertheless, they have remained 50% and 38% higher, respectively, than before the Russian invasion of Ukraine. The fall in gas prices drove down power prices as well because gas-fired power plants still predominantly clear the day-ahead electricity market.

Still prices in Europe for both electricity and gas have remained significantly higher than in the United States and China, which is contributing to **a growing competitiveness gap for European industry**. The negative consequences for Europe's industrial base have become hard to ignore. Between 2019 and 2023, more than one million industrial jobs disappeared across Europe,[2] and another 143,000 jobs were lost in German industry in 2025 alone.[3] Although Europe's emissions intensity has also declined during this period, the trend was driven not only by the decarbonization of the grid, but also by weaker industrial output, and energy **demand destruction**. The average emissions intensity of EU economies was 14% lower in 2024 than in 2021. As one energy executive put it, 'Europe is not decarbonizing, it is deindustrializing.'[4]

The energy crisis has also **accelerated important structural changes** in Europe's energy system. Deployment of renewable energy, particularly solar photovoltaics (PV), on-and offshore wind energy and battery storage, expanded rapidly after 2022 as low-carbon technologies became cheaper, while **fossil fuels were seen as costlier and more unreliable**. In Central and Eastern European countries, where energy systems have long been dominated by coal, gas and nuclear, installed solar PV capacity almost quadrupled between 2021 and 2025. Wind and solar power generated more electricity than fossil fuels for the first time in 2025.[5]

As a result, the level of **sustainability risks** continued its long-term downward trajectory, declining by an average of 2.82 index points per year until 2025 (the largest annual improvement occurred in 2023, when sustainability risk

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[2] European Trade Union Confederation, "EU action not words needed over industry job losses", May 12, 2025.

[3] Federal Statistical Office, "Employment figures largely unchanged in 2025", Destatis, January 2, 2026.

[4] Hanke Vela, J., "Energie: 'Es gibt keine stabile Grundlage für Investitionen'", *Handelsblatt*, November 14, 2025.

[5] Ember, "Wind and solar generated more power than fossil fuels in the EU for the first time in 2025", January 22, 2026.

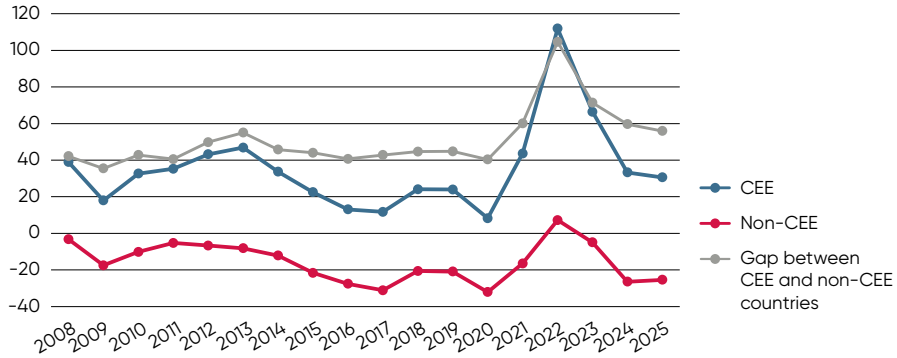
fell by 9 index points – the sharpest decline since the global financial crisis of 2008-2009 that shrank emissions due to the collapse of production). The strengthening of the sustainability indicators reflects the effectiveness of policies aimed at reducing emissions and energy intensity in line with the EU's climate neutrality objective for 2050.

Reliability risks have also declined in 2023 thanks to new LNG terminals, increased interconnector capacity and investment in gas storage and electricity infrastructure. However, these risks have jumped again in 2024 and 2025, primarily due to declining gas storage filling levels across the EU. The results also reveal significant differences between member states in terms of the **quality, resilience and adaptability of their energy infrastructure**.

In 2025, the **best energy security performers have** remained the Netherlands, France, Austria, Sweden, and Denmark as they have generally strengthened their grid infrastructure, deployed low-carbon technologies, and implemented long-term industrial strategies linked to decarbonization. The climate policy of these countries is now firmly embedded in the broader industrial and economic competitiveness strategies.

In contrast, most **Central and Eastern European states** have so far lagged behind the process of overcoming their **structural energy system vulnerabilities** related to energy intensity, ageing infrastructure, and greater historical dependence on fossil fuels that drives their energy prices much higher compared to these of many Western European countries.[6] There are some exceptions nonetheless. Due to the combination of reducing dependence on Russian fossil fuels, commissioning alternative import infrastructure, and rapidly expanding renewable generation, **total energy and climate security risk declined** by 64 index points in Bulgaria, 43 in Lithuania, 27 in Poland, and 13 in Latvia, compared to an average reduction of just 9 index points across the EU.

Figure 4. The Gap in Energy and Climate Security Between CEE and Non-CEE Countries Has Widened in 2024 and 2025



Note: CEE countries include Bulgaria, Romania, Croatia, Czechia, Estonia, Latvia, Lithuania, Hungary, Poland, Slovenia, and Slovakia.

Source: CSD based on ECSRI data.

[6] Vladimirov, M., Gantcheva, N., and Köppen, M., *Beyond Diversification: Energy Security through Structural Change in Central and Eastern Europe*, Sofia: Center for the Study of Democracy, 2026.

Both CEE and non-CEE countries have exhibited a similar downward trend prior to 2021, reducing their total energy and climate security risk by around 30 index points since 2008 (Figure 3). However, this **pace of improvement was insufficient for CEE countries** to converge with the rest of the EU. Russia's invasion of Ukraine caused a clear rupture, with **CEE member states being disproportionately more affected by the resulting energy crisis**. Consequently, the gap between CEE and non-CEE countries have widened significantly in 2024 and 2025.

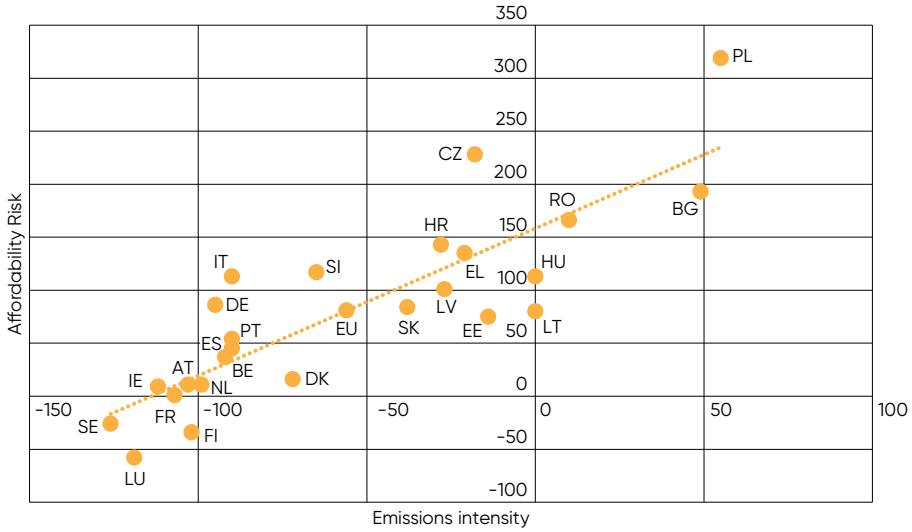
The Baltic states and Slovakia stand out in particular. Between 2021 and 2025, Lithuania and Slovakia climbed six and five positions, respectively, in the ECSRI country ranking. **Lithuania**'s significant progress was primarily driven by the **restructuring of its gas and electricity systems** after the cessation of Russian energy imports. The permanent acquisition and increased use of the Klaipėda LNG terminal, in conjunction with the Poland–Lithuania gas interconnector (GIPL), has integrated Lithuania more deeply into the wider EU gas market, significantly improving supply diversification and system redundancy. Meanwhile, investments in grid modernization, interconnection capacity and digital system management **reduced electricity transmission losses and improved overall system resilience**. Most importantly, synchronization with the continental European electricity system marked a decisive strategic decoupling from the Soviet-era BRELL (Belarus, Russia, Estonia, Latvia, Lithuania) system, thereby strengthening system stability and frequency control.[7]

Meanwhile, **Slovakia**'s improved performance was driven by stronger reliability and sustainability outcomes. Its highly **diversified electricity mix**, combining nuclear, hydro, solar, biomass and gas with only limited coal use, provides high capacity diversity and reduces exposure to disruptions affecting any single technology or fuel source. Slovakia also benefits from extensive gas transmission and storage infrastructure, inherited from its historical role as a major Russian gas transit corridor. Large storage volumes and large-scale cross-border interconnections continue to provide significant flexibility and buffering capacity relative to domestic demand. Nonetheless, Slovakia remains one of the most geopolitically exposed countries in the EU due to its continued dependence on Russian gas imports.

Countries with more **electrified economies and low-carbon electricity systems perform consistently better** across several dimensions. In particular, France, Sweden and Finland stand out because they combine large volumes of firm, low-carbon generation, primarily from nuclear and hydropower, and expanding solar and wind capacity. This reduces their exposure to fossil fuel imports, carbon costs and electricity price volatility. These countries' long-term low-carbon energy strategies have remained **stable across political cycles**, providing the necessary policy certainty for long-term investment in infrastructure, electrification, energy efficiency, and industrial decarbonization.

[7] European Commission, "Baltic States join the European continental electricity grid after fully disconnecting from Russian and Belarussian networks", *Press Release*, 9 February, 2025.

Figure 5. The Correlation Between Emissions Intensity and Affordability Risk in 2025



Note: For some affordability indicators 2025 data is still not available.

Source: CSD based on ECSRI data.

Emissions intensity remains one of the strongest predictors of affordability risk. Poland, Bulgaria and Romania are the most emissions-intensive economies in the EU and simultaneously rank among the countries with the highest energy costs. As a result, these economies have some of the highest retail electricity and natural gas prices for businesses, total energy expenditure relative to GDP and carbon costs in the Union. As affordability has remained the single most important driver of overall energy and climate security risk in 2025, Poland, Bulgaria, Greece and Romania are still among the four countries with the **highest overall energy security risk profile**.

Europe's energy security is increasingly about ensuring fast decarbonization at a low cost for the economy. The countries performing best are those combining diversified low-carbon electricity generation, modern infrastructure, flexibility systems such as batteries and demand response mechanisms, large power and gas interconnections, and a long-term industrial strategy that aims to reduce emissions intensity, and thus **strengthen the cost competitiveness of large energy consumers**. The latter will determine whether Europe will be able to catch up in the fierce geoeconomic race with the U.S. and China.

LOCKED IN THE ENERGY SECURITY TRILEMMA

Geopolitical Risks

The Geopolitical dimension assesses a country's exposure to external geopolitical shocks based on its dependency on imported energy and raw materials. It captures vulnerabilities in oil, gas, and critical raw material supply chains, which are increasingly influenced by global market volatility and strategic competition. Indicators include the security of petroleum imports, natural gas imports, and imports of raw materials and renewable energy sources (RES) components. Countries can reduce their geopolitical risk by reducing the share of oil and gas in gross inland consumption, reducing the dependence on imports, diversifying imports or switching to supplying countries that are considered as more democratic. The underlying assumption is that more democratic countries are less likely to weaponize energy supplies to put geopolitical pressure on the EU[8] and are similarly less likely to experience armed conflicts on their territories that could damage energy export infrastructure. While expanding low-carbon energy capacity helps reduce fossil fuel dependence, it also introduces new risks tied to the availability of critical materials for low-carbon technologies. As the green transition advances, securing stable, diversified, and geopolitically resilient supply chains for these inputs is becoming a central challenge to national energy security.

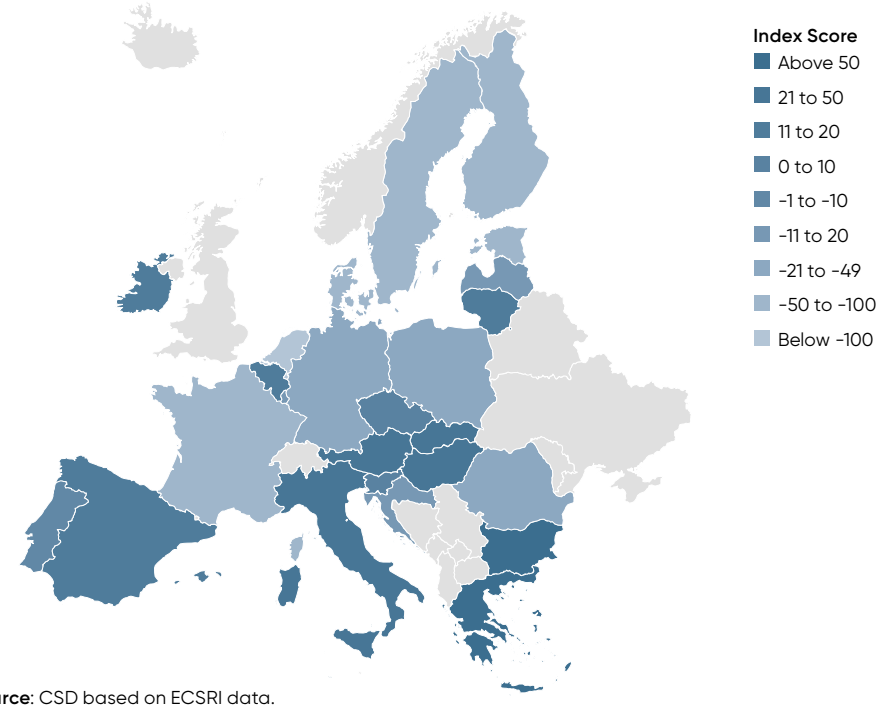
Dependence on imported fossil fuels – from politically unstable or authoritarian suppliers – has historically been the primary channel through which geopolitical risk materializes in Europe. Such dependencies **expose energy systems to supply disruptions**, price manipulation, and strategic coercion. The effects are transmitted rapidly across the system: supply shocks translate into price spikes, undermining affordability; import disruptions threaten system adequacy, weakening reliability; and continued fossil dependence delays decarbonization, exacerbating sustainability risks. Europe's experience over the past decade has made these dynamics explicit. The continent's reliance on Russian fossil fuels culminated **in a systemic shock** following the Russian invasion of Ukraine that triggered the sudden halt in gas deliveries from the East. In the years preceding the crisis, several member states, most notably Germany and Italy, increased both the volume and share of Russian gas imports, amplifying their exposure.

The subsequent policy response – **sanctions, rapid diversification, and the deployment of a number of new LNG import facilities – has significantly reduced geopolitical risk**. 2023 marked the largest recorded decline in geopolitical risk related to oil and gas imports. In Germany, the fall in geopolitical risks was four times higher than the EU average, illustrating both the scale of prior exposure and the **impact of strategically decoupling from Russian oil and gas**. Although the shift from pipeline-based imports from Russia to globally traded LNG has increased supplier diversification

[8] Starr, H., "Democracy and Integration: Why Democracies Don't Fight Each Other", *Journal of Peace Research*, Vol. 34, Issue 2, May 1997, pp. 153–162.

and reduced single-route vulnerabilities, this has come at the cost of **greater exposure to global gas price volatility**.

Figure 6. Geopolitical Risks Across the EU Have Fallen in 2025, but Regional Disparities Have Not Narrowed



Source: CSD based on ECSRI data.

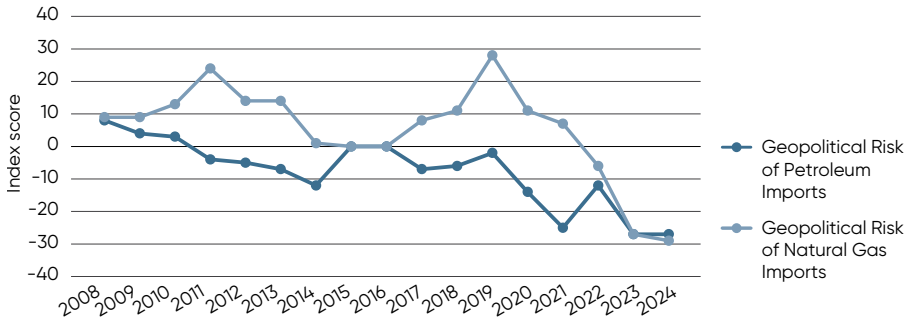
However, the improvement in the EU's energy security profile masks the significant structural differences between member states, reflecting the different composition of their energy mix, the lack of infrastructure preparedness of some and the **energy policy incoherence** of others.

The **Netherlands, Finland, Denmark, Estonia, Sweden and France**, for example, rank among the lowest-risk systems due to a combination of factors, including diversified energy import portfolios, strong access to seaborne deliveries, and lower structural fossil fuel dependence. Domestic production of oil, gas and nuclear or a high proportion of low-carbon electricity generation eliminates the import exposure entirely. Additionally, some of these countries benefit from stronger positions in critical raw materials (CRMs), which further mitigates supply chain risk.

By contrast, geopolitical exposure remains high in Greece, Italy, Slovakia and Hungary. In these energy markets, a high share of fossil fuels in energy consumption coincides with the dependence on a few suppliers. The result is systemic vulnerability: **disruptions affecting a single supplier or route can propagate across the entire energy system**. Continued reliance on gas-fired power generation, which accounted for around 40% of electricity production in both Greece and Italy in 2025, further amplifies this exposure by linking electricity prices directly to global gas market volatility. It is not surprising that European electricity prices have been among the highest in the European countries, which power systems are most reliant on gas-fired production.

Hungary and Slovakia are distinct cases where geopolitical risk is sustained by both structural factors and deliberate policy choices. Despite having access to viable alternative supply routes, both countries continue to rely heavily on Russian oil and gas imports.[9] The reliance is not due to technical limitations or pricing advantages, but rather a result of long-term contracts and entrenched commercial interests embedded in the two countries' political oligarchies. The supply of discounted Russian oil by the U.S.-sanctioned company Lukoil has enabled the dominance of the Hungarian oil major MOL of the Central European refining and distribution business, which has generating enormous profits for company and the cronies of ex-Prime Minister Orban without lowering fuel prices for consumers.[10]

Figure 7. Rapid Diversification of Oil and Gas Imports Has Led to a Steep Fall in Geopolitical Risks



Source: CSD based on ECSRI data.

The reliance on Russian crude in Hungary increased **from around 60% of imports in 2021 to over 90% by 2025**,[11] effectively locking the country into near-total dependence on a single supplier. Russian oil dependence in Slovakia is also close to 100%. Existing infrastructure, including the Adria pipeline, has sufficient capacity to replace Russian supplies entirely, and regional examples such as **Bulgaria and the Czechia** demonstrate that a rapid phase-out is feasible and would not lead to higher domestic prices.[12]

Central Europe is also more than 75% dependent on the supply of Russian natural gas via the European extension of the TurkStream gas pipeline, which passes through Bulgaria, Serbia before reaching its main markets in Central Europe. In 2024-2026, Gazprom has maximized supply volumes via TurkStream at times even exceeding the nominal technical capacity of the gas transmission infrastructure despite the EU's decision to ban Russian oil and gas imports by the end of 2027. The effectiveness of the regulation on Russian gas phaseout, passed in the beginning of 2026, will depend on **closing the**

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9 Vladimirov, M. et al., *The Last Mile: Phasing Out Russian Oil and Gas in Central Europe*, Sofia: Center for the Study of Democracy, 2025.

10 Vladimirov, M. et al., *Cutting the Cord: Russian Oil Supply to Central Europe Is Not Indispensable*, Sofia: Center for the Study of Democracy, 2026.

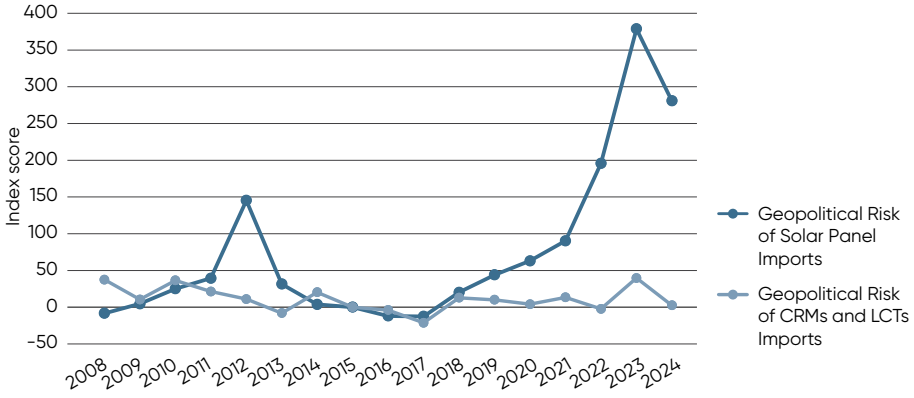
11 Eurostat, Imports of Natural Gas by Partner Country, dataset code: nrg_ti_gas, European Commission, 2026.

12 Vladimirov, M. et al., *The Last Stronghold: Hungary Can Complete Europe's Energy Decoupling from Russia*, Sofia: Center for the Study of Democracy, 2026.

remaining exemptions and preventing circumvention through regional infrastructure and intermediary markets.

As Europe reduces its dependence on fossil fuels, a new layer of geopolitical risk is emerging within the supply chains of the energy transition, i.e. the EU's **reliance on critical raw materials and low-carbon technologies**, such as batteries, solar panels and wind turbines. After reaching the highest levels of CRM and LCT dependence in 2023, there hasn't been a clear upward trend in the risk levels in 2024-2025, most likely due to two conflicting trends. Even as EU's material footprint, which measures the total amount of raw materials extracted globally to meet a country's final consumption (including materials embodied in imports and excluding those embodied in exports), has declined by 26% since 2008, reflecting efficiency gains and economic restructuring, the actual imports of CRMs, such as aluminum, copper and zinc, have surged, making Europe ever more dependent.[13]

Figure 8. The Average Geopolitical Risk of Solar Panel Imports in the EU has Increased Drastically Compared to that of CRMs and LCTs Imports in General



Source: CSD based on ECSRI data.

Despite the supply chain risks involved, shifting from **fossil fuel-based consumption** to energy production from **low-carbon technologies** would represent a significant improvement in energy security. Unlike fossil fuels, which require continuous replenishment and are immediately impacted by supply disruptions, **low-carbon technologies create a long-term assets base**. Once deployed, solar panels and wind turbines generate electricity for decades at minimal marginal cost and with no exposure to geopolitical shocks. For example, a single shipment of solar panels can **generate electricity equivalent to around 50 LNG cargoes over its lifetime**, thereby reducing exposure to recurrent supply shocks.[14] The potential for recycling and the circular use of materials provides also an opportunity **to reduce the long-term reliance on primary imports**. Realizing this potential requires deliberate policy action, including expanding domestic extraction and processing capacity, **developing strategic partnerships** and strengthening circular economy frameworks.

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[13] Center for the Study of Democracy, *Economic Security and Strategic Autonomy*, Policy Brief No. 156, March 2025.

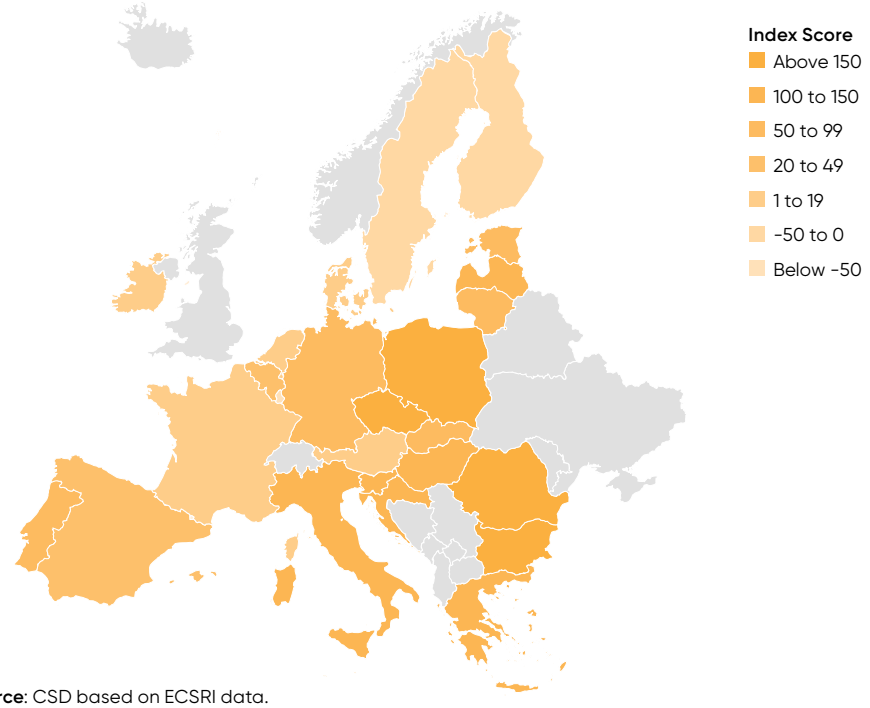
[14] International Energy Agency, *Energy Technology Perspectives 2024*, Paris: IEA, 2024.

Affordability Risks

The affordability risk pillar of the Index evaluates the financial strain that energy systems place on national economies, businesses, and households. It captures both direct and indirect vulnerabilities by assessing energy prices, import expenditures, and the broader macroeconomic burden of energy consumption. Indicators include retail electricity and natural gas prices, oil and gas import expenditures, carbon costs and overall energy expenditures relative to GDP. Affordability also reflects how fuel mix choices, energy efficiency, and consumer behavior influence total energy costs. Together, these factors reveal how vulnerable countries are to energy-driven inflation, energy poverty, and competitiveness pressures.

Affordability risks in the EU have declined markedly in 2024-2025 from their peak of the 2022–2023 energy crisis, but remain structurally elevated compared to pre-crisis levels. A closer look at the underlying indicators relative to the 2015 baseline suggests that the composition of **affordability risk has fundamentally shifted**. During the 2022 peak, risks were primarily driven by a simultaneous surge in natural gas and EU ETS carbon prices. The gas price shock triggered by Russia's invasion of Ukraine coincided with **a robust post-pandemic recovery**, leading to increased industrial output and demand for emissions allowances. Given the well-documented link between gas and carbon prices, driven by fuel-switching dynamics in the power sector, this resulted in historically **high carbon costs across the economy**.

Figure 9. Affordability Risks Are Much Greater in Fossil-fuel Dependent Countries



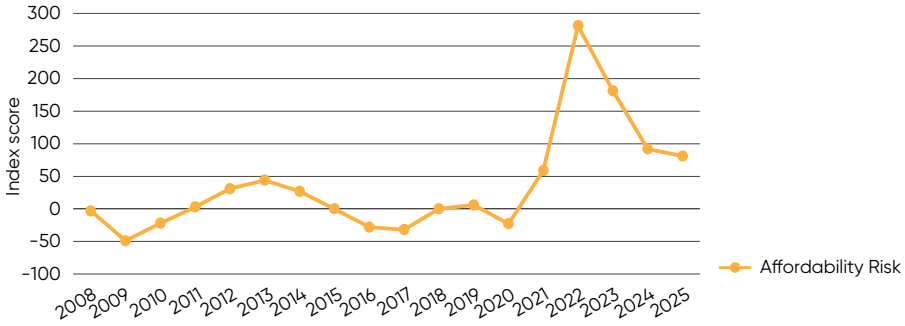
Source: CSD based on ECSRI data.

In 2025, carbon costs declined as the price of EU allowances (EUAs) moderated and the emissions intensity decreased based on **behavioral adjustments and structural responses** to the crisis. Retail electricity and natural gas prices for non-household consumers became the main drivers of affordability risk.

While the EU ETS contributed to short-term cost increases, it also accelerated efficiency improvements and reduced fossil fuel consumption, thereby demonstrating its effectiveness as a decarbonization instrument. With ETS costs accounting for only a relatively small proportion of final electricity prices – typically around 10% at most[15] – the main drivers of retail prices remain wholesale electricity costs, network charges and taxation.

The extent to which **electricity prices remain exposed to natural gas prices is a central determinant of affordability** outcomes across member states. Countries with the lowest affordability risks, most notably **Sweden and Finland**, have effectively reduced this exposure through high levels of electrification and a diverse, low-carbon energy mix. Electricity there accounts for around 30% of final energy consumption thanks to the widespread electrification of transport and industry. In 2024, 35% of new cars sold in Sweden were EVs and 30% in Finland, compared to 14% in Germany and just 3% in Poland.[16] Their power systems combine **baseload low-carbon capacity (hydropower and nuclear) with a high proportion of wind generation**, enabling them to meet demand without relying on gas-fired generation, even during peak periods. Consequently, natural gas only sets the marginal electricity price in a very small proportion of hours – estimated at around 1% in Sweden and 3% in Finland[17] – **insulating these markets from fossil fuel price shocks** such as closure of the Strait of Hormuz. In March 2026, average wholesale electricity prices in Finland and Sweden were 61 EUR/MWh and 33 EUR/MWh lower than in Germany, respectively.[18]

Figure 10. Average Affordability Risks in the EU Have Continued Falling in 2025 but Remain Much Higher than in 2021



Note: Some data indicators for 2025 are missing.

Source: CSD based on ECSRI data.

France and Spain, where a combination of nuclear baseload and rapidly expanding renewable energy-based power generation, have squeezed the role of natural gas in setting electricity prices, **resulting in lower industrial consumer prices in 2025**. In contrast, electricity prices remain structurally

[15] Rosslowe, Ch., and Petrovich, B., "Latest energy shock reminds Europe of its risky gas reliance", *Ember*, March 13, 2026.

[16] Bekker, H., "2024 (Full Year) Europe: Electric Car Sales per EU, UK, and EFTA Country", *Best-Selling Cars*, January 31, 2025.

[17] Zakeri, B. et al., "The role of natural gas in setting electricity prices in Europe", *Energy Reports*, Vol. 10, November 2023, pp. 2778-2792.

[18] Center for the Study of Democracy calculations based on ENTSO-E.

higher and more volatile in systems where fossil fuels continue to dominate marginal price setting, such as in Italy, where natural gas sets the wholesale price for around 80% of hours, and in coal-reliant markets in Central and Eastern Europe.

System flexibility will be crucial for mitigating affordability risks. In the short to medium term, battery storage will be increasingly capable of reducing peak price spikes by shifting renewable energy production to periods of high demand. In Australia, for instance, batteries set prices 36% of the time during peak-demand evening hours, up from 18% in 2024, cutting spot prices in half during those hours.[19] Similar dynamics are already evolving in European markets such as Germany, Bulgaria and Greece, which have been leading the wave of battery storage capacity expansions.

Box 2. Comparative Development of Battery Storage Uptake in Europe and the Impact on Prices

The build-out of battery storage is changing European power prices through the daily shift between renewable output and peak demand, mainly in markets where solar generation already creates low-price hours before evening consumption rises. EU battery capacity recorded a tenfold increase from 2021 to 2025, with utility-scale projects accounting for 55% of new capacity.[20] Large-scale storage investment remains concentrated in a limited group of markets, with Germany and Italy leading at around 6 GWh each and Bulgaria emerging as the third-largest market with around 2.5 GWh (Bulgaria plans to actually deploy 10 GWh of batteries until the end of 2026).[21] This concentration explains why the price effect is visible in some systems but still uneven across the EU.

Germany is furthest along the storage development curve, as the share of solar PV in power demand has risen to 15.2%. Hence, negative-price hours increased by around 31%, from 440 in 2024 to 576 in 2025.[22] This allows **power traders to achieve price arbitrage by discharging the accumulated electricity in the batteries on the market during peak demand**. The German power system profile point toward the need for longer-duration batteries rather than only short balancing services. Germany's average daily price swing reached around €125/MWh, while the net-load ramp from midday into the evening reached 23.8 GW in spring and 22.7 GW in summer.

In Bulgaria, the battery build-out has moved from marginal capacity to a system-relevant trend in one year, supported by the EU-financed RESTORE program that subsidised 30% of the costs of 6 GWh worth of storage systems. Installed battery storage power reached 1,382 MW,

[19] Fulghum, N. et al., Global Electricity Review 2026, *Ember*, April 21, 2026.

[20] Hemetsberger, W., Acke, D., and Schmela, M., *EU Battery Storage Market Review 2025*, SolarPower Europe, 2026.

[21] CSD analysis based on ENTSO-E.

[22] Ibid.

equal to 7.4% of total installed power capacity in 2025 on the back of a 1500% increase from 2024.[23] Batteries are already **changing the regional electricity flows in the SEE region** as Bulgaria has increasingly become a major net exporter to Greece and Romania during the peak hours, reducing the commercial viability of gas-fired power plants. The storage systems depend on the deployment of large amounts of solar PV facilities. Solar accounted for 32.7% of installed power capacity in 2025, which contributed to the increase in negative-price hours from 55 in 2024 to 164 in 2025, as the average daily price swing reached €166/MWh.[24]

The main effect of the massive introduction of battery storage systems has been **to shift part of the daytime surplus toward the evening peak** rather than to compress the overall wholesale price structure, which is still often determined by the coal power plants that have been receiving lavish state subsidies to remain part of the country's electricity market even if they have been technically insolvent.[25] The evening price premium will be harder to reduce until storage duration, renewable saturation and flexible demand grow together. Bulgaria has an evening net-load ramp of around 1.5 GW and similar seasonal pressure across the year as Germany. Four-hour batteries fit this profile because they **move surplus wind and solar from low-price hours into the peak window**, reduce the need for fossil generation at the margin and make better use of domestic renewable output.

Batteries could help Italy reduce its excessive dependence on gas-fired power generation (reflected in the absence of negative-price hours) and lower the overall market prices. In 2025, gas-fired plants produced around 52% of domestic electricity generation, while covering about 43% of electricity consumed in the country once cross-border flows are considered. Gas remained the dominant domestic source of dispatchable generation, while its contribution to actual consumption was moderated by regional electricity trade. This role was particularly visible in the summer profile, when the net-load ramp reached 32.9 GW and the system required substantial flexible generation as solar output declined into the evening. Batteries can reduce part of the evening call on gas-fired plants, but the wholesale price effect remains narrower when the system has less low-cost renewable electricity to shift.

The three EU case studies show that batteries should be **planned after the shape of the power system**, not as a standalone capacity target. Their price effect is strongest where wind and solar already create recurring low-price hours and where storage duration can move that electricity into the evening peak. In gas-exposed systems, **batteries add flexibility and improve security of supply**, but the larger price effect depends on deeper renewable and low-carbon build-out that reduces the role of gas in the marginal mix.

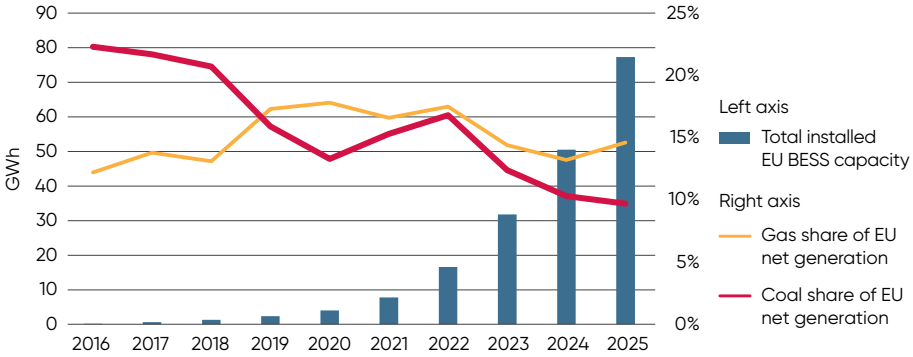
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[23] Electricity System Operator EAD (ESO), Statistical Booklet 2025, May 2026.

[24] CSD analysis based on ENTSO-E data.

[25] Center for the Study of Democracy, *Ending the State Central Planning Model in the Electricity Sector*, Policy Brief No. 158, April 2025.

Figure 11. EU Battery Storage Expansion and Declining Fossil Generation Shares, 2016–2025



Source: CSD based on Entsoe and SolarPower Europe data.

In the longer term, affordability gains will depend on the combination of clean firm capacity and flexible renewable generation. **Nuclear power**, in particular, can provide stable, low-carbon electricity for continuous, high-load consumers such as heavy industry, hydrogen production and data centers, potentially under long-term contracts that reduce exposure to market volatility. At the same time, wind and solar generation – supported by massive storage deployment, the expansion of **power interconnections and demand response measures** – can increasingly serve more flexible consumption segments.

A key factor enabling demand response is the deployment of **smart meters and time-dynamic pricing**. Several member states, including Sweden and Finland, have already introduced hourly pricing for households, allowing consumers to respond to real-time market signals. Germany and the Netherlands are also implementing similar models following recent regulatory reforms. Households can thus become **flexible demand resources**, capable of **absorbing variable renewable energy generation** and **reducing system costs**.

Box 3. Price Regulation and the Limits of Subsidy-led Energy Affordability

Against this backdrop, **Hungary**'s retail electricity price structure in 2025 is an example of an ineffective approach to mitigating affordability risks, reflecting the government's decision to artificially suppress household tariffs while shifting costs elsewhere in the system. In 2025, regulated retail prices and extensive subsidies kept household electricity prices the lowest in Europe (including taxes and levies, and at purchasing power parity), while retail prices for businesses were the highest in the EU and stood at around 2.15 times the household level.

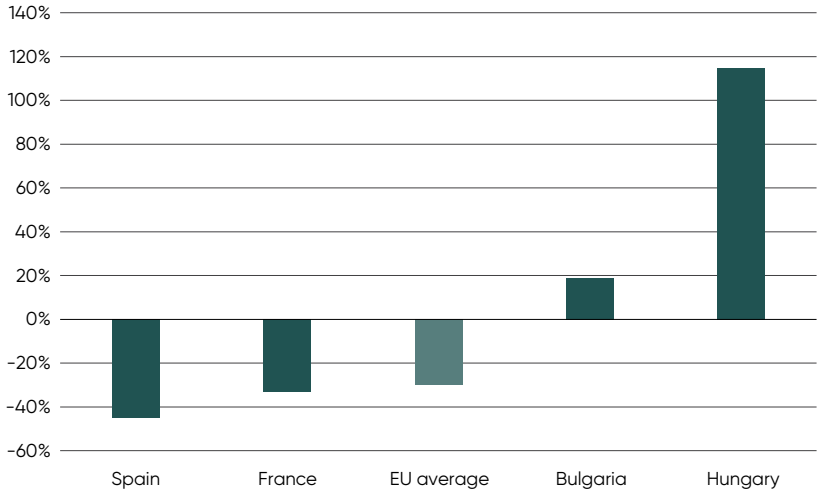
This divergence is largely driven by the long-standing 'utility cost reduction' scheme, under which the Hungarian government earmarks roughly HUF 800–880 billion (€2–2.3 billion, around 1% of GDP[26])

[26] D&T, "Gov't to Maintain Regulated Utilities Price Scheme", *Diplomacy & Trade*, December 29, 2025.

annually to maintain regulated household prices. While this approach delivers short-term affordability gains, it distorts price signals, **weakens incentives for energy efficiency** and demand-side flexibility, and increases fiscal pressure.

The contrast with France and Spain shows the scale of the distortion more clearly, because business electricity prices there were 0.67 and 0.55 times below household tariffs[27]. In Hungary, firms absorb a much larger share of the visible electricity cost, even though the underlying system cost has not changed. Such a design diverts substantial public resources away from strengthening the overall electricity system. **Redirecting these funds towards decarbonizing the power mix** and enhancing flexibility on both the supply and demand sides would lower wholesale prices over time, providing a more economically efficient and resilient pathway to affordable electricity.

Figure 12. The Business Electricity Price Burden Relative to Household Tariffs, 2025



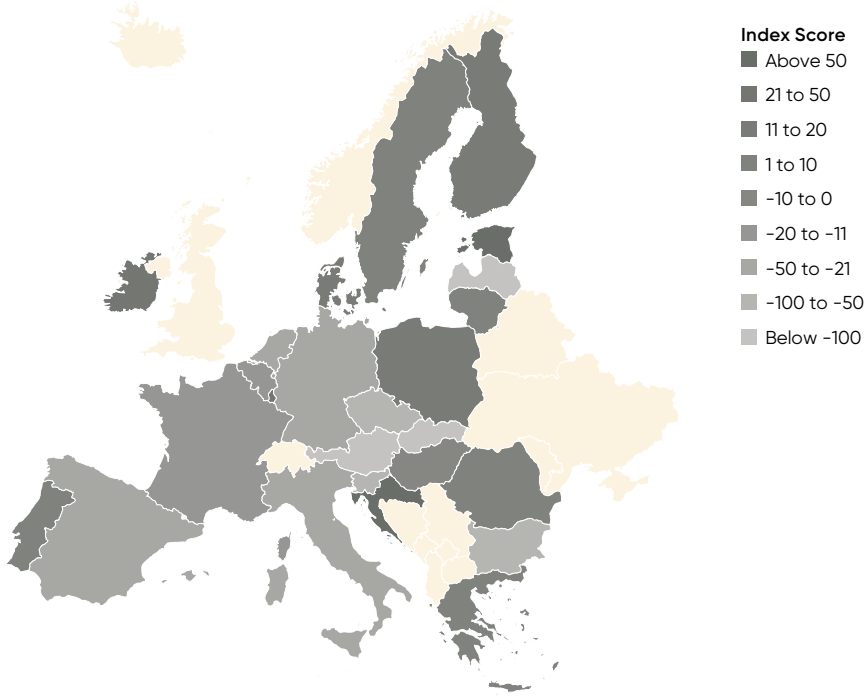
Source: CSD based on Eurostat data

Reliability Risks

This pillar assesses a country's resilience to energy supply disruptions and its capacity to **maintain stable energy flows** during crises. It evaluates infrastructure robustness (e.g., gas storage, electricity capacity margins, and gas infrastructure reliability), demand-side adaptability (household energy efficiency), and risks from over-reliance on single technologies, suppliers or vulnerable trade routes. The risks to the electricity and gas system are particularly relevant in the context of increasing electrification, high volatility in the supply and price of natural gas, and more frequent extreme weather events.

[27] CSD analysis based on Eurostat data.

Figure 13. Reliability Risks in the EU Have Remained High in Countries with Limited Gas and Power Interconnection Capacity



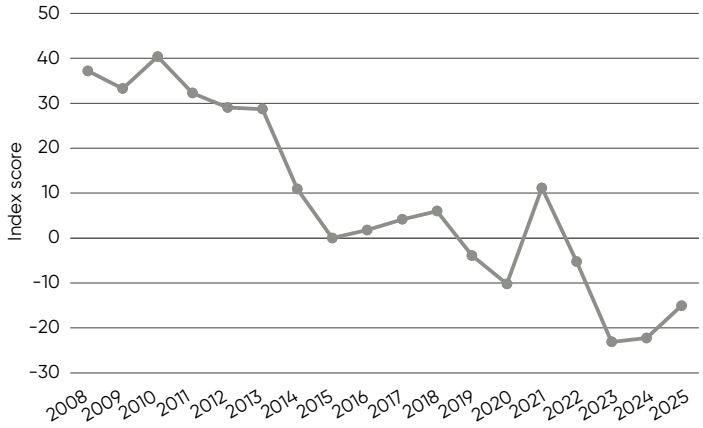
Note: Some data indicators for 2025 are missing.

Source: CSD based on ECSRI data.

EU reliability risks improved substantially between 2022 and 2025 thanks to **expanded gas infrastructure, strengthened interconnections and the partial replacement of former Russian pipeline dependencies** with access to diversified LNG supplies. However, these vulnerabilities worsened somewhat again in 2024 and 2025, mainly due to lower gas storage levels and growing pressure on electricity grids from expanding intermittent renewable energy supply.

In gas, Slovakia, Latvia, Austria and Slovenia performed well due to high levels of regional integration, large storage capacities relative to demand and infrastructure redundancy. Slovakia, Latvia and Austria all serve as crucial transit and storage hubs in their region with gas storage and import capacity well exceeding their national needs, which is a historical legacy of their role in the transport and storage of Russian natural gas. In the aftermath of Russia's invasion of Ukraine, this infrastructure has proven **crucial in the diversification of natural gas imports**. Latvia can access a diversified global portfolio through LNG terminals in Poland, Lithuania and Finland, providing storage services to the entire Baltic region independently of Russian gas. Similarly, Austria can access LNG and Norwegian pipeline imports via Germany, providing storage and diversification services to neighboring countries.

Figure 14. EU Reliability Risks Improved Substantially Between 2022 and 2025 Thanks to Expanded LNG Import Infrastructure and Strengthened Power and Gas Interconnections



Source: CSD based on ECSRI data.

At the other end of the spectrum are **Estonia, Croatia and Ireland**, which recorded the highest reliability risk in the EU in 2025. Estonia, for instance, is highly vulnerable to disruptions of single pipelines or transmission lines due to its heavy reliance on Latvia for natural gas supplies and on Finland for electricity imports. Its domestic power mix still consists largely of shale oil-fired power plants, with smaller contributions from solar, wind, and biomass. Imports from Finland frequently cover 50% or more of its electricity demand. As the case study on the role of Finnish nuclear energy in Baltic energy security below demonstrates, disruptions to imports via the two Estlink 1 and 2 interconnectors have had severe consequences for electricity prices in Estonia. At the same time, transmission and distribution losses remain high, compounding already low overall efficiency levels.

Box 4. Data Centers as the Next Test for Europe's Power System

The rapid expansion of artificial intelligence is **turning data centers into one of the fastest growing sources of electricity demand**. The IEA expects global data-center electricity consumption to roughly double from 485 TWh in 2025 to around 950 TWh in 2030, while electricity use by AI-focused hyperscalers is projected to triple over the same period[28]. Although Europe will not be the main driver of this growth, the impact on its power system could still be substantial. McKinsey estimates that European data-center power consumption could rise from around 62 TWh today to more than 150 TWh by 2030, increasing its share of total electricity consumption from about 2% to around 5%.[29]

AI workloads require not only electricity for computing, but also cooling, power electronics, transformers, batteries and advanced control

[28] International Energy Agency, Energy and AI, Paris: IEA, 2025.

[29] International Energy Agency, "Executive Summary", – In: Key Questions on Energy and AI, Paris: IEA, 2026.

systems. The European Commission warns that the environmental impact of data centers will **depend heavily on whether their power supply is decarbonized**, while the European Parliament notes that data centers already account for around 3% of EU electricity demand, with much higher shares in countries such as Ireland.[30]

Data centers can **support the deployment of clean electricity** by signing long-term power purchase agreements and anchoring investments in renewables, storage and baseload low-carbon capacity such as nuclear energy. However, if **grid expansion lags behind demand**, **data centers can also intensify congestion**, **raise local system costs** and create pressure for **behind-the-meter fossil generation**. Slow grid connections are pushing some developers towards on-site gas-fired power, even though most data centers still prefer to source their electricity directly from the grid.[31]

Investment decisions are therefore increasingly shaped by energy-system fundamentals. The most attractive locations will be those offering fast and predictable grid connections, reliable low-carbon electricity, competitive power prices, access to storage and flexibility, and transparent permitting. This is already changing the geography of data-center investment in Europe, as congestion and long connection queues in traditional hubs push developers towards markets with available grid capacity and shorter delivery timelines. Countries such as Bulgaria with large, untapped low-carbon energy potential and a growing nuclear energy fleet could benefit from this shift because of its renewable potential, existing nuclear base, storage pipeline and strengths in copper processing, electrical equipment, cables, control systems and power-management components.[32]

If connected to clean power, storage, flexible demand and modern grids, **data centers can reinforce Europe's competitiveness** and **accelerate investment in low-carbon infrastructure**. If they are added to weak and congested systems, they risk increasing affordability pressures and prolonging fossil-fuel dependence.

Gas storage levels across the EU were lower in 2025 and 2026 than in 2023 and 2024– reflecting a clear shift away from the exceptionally high precautionary inventories maintained during the peak crisis period – and that, paradoxically, countries with robust gas infrastructure reliability often fail to leverage it to reduce import risks, while states with weaker systems achieve greater supply diversification. **Slovakia and Hungary**, historically central hubs in Russian gas transit networks, exemplify this disconnect. Despite their **low gas infrastructure reliability risks** (stemming from extensive pipeline networks

[30] Widuto, A., AI and the Energy Sector, European Parliamentary Research Service, Briefing, July 4, 2025.

[31] International Energy Agency, "Executive Summary", – In: Key Questions on Energy and AI, Paris: IEA, 2026.

[32] Center for the Study of Democracy, *A Roadmap for the Development of the Bulgarian Electricity Sector within the EU Until 2050*, Policy Brief No. 70, October 2017.

and storage facilities), they retain **some of the highest security of natural gas imports risks** because they continue sourcing most of their gas from Russia via alternative routes like TurkStream. This reliance persists as alternatives – e.g. Norwegian pipeline gas via Germany, LNG from Italy's Adriatic terminals, or Croatia's Krk LNG facility – remain underutilised.

By contrast, by reversing flow directions on pipelines previously used for imports from Russia, Czechia now imports most of its gas from Norway via Germany which has slashed its import security risk compared to 2022. This model proves that even infrastructure originally designed for Russian gas can be **repurposed to enhance resilience**, a lesson yet to be embraced by Hungary and Slovakia, where geopolitical alignment continues to outweigh energy security pragmatism.

The central challenge to ensuring the reliability of the next phase of the transition is the **disparity between the deployment of renewable energy sources and the readiness of the system**. While wind and solar power are essential for reducing dependence on fossil fuels and lowering wholesale prices, their variability alters the operational logic of the power system. A **higher proportion of inverter-based generation reduces the traditional role of synchronous coal, gas, hydroelectric and nuclear power stations** in providing inertia, short-circuit strength and voltage support.[33]

Digital grids are becoming a bottleneck for the secure transition to clean energy.[34] This does not mean that renewables are inherently unreliable. Rather, it suggests that systems with a high proportion of renewables require **a different infrastructure backbone**, including stronger transmission and distribution networks, grid-forming inverters, batteries, synchronous condensers, demand response, interconnectors and more granular system operation. The blackout that affected the Iberian Peninsula on 28 April 2025 provided a stark illustration of these emerging system integration challenges. ENTSO-E concluded that the outage was not caused by renewable energy generation itself, but by a combination of voltage instability, insufficient reactive power support and cascading generation disconnections during a period of system stress. The deeper vulnerability lays in **inadequate voltage control and system management capabilities in a power system** with a growing share of inverter-based generation. Hence, as renewable penetration and electrification accelerate, reliability increasingly depends on whether grids, storage, flexibility resources and operational frameworks evolve quickly enough to maintain stability under rapidly changing conditions.[35]

Policymakers need to accelerate the deployment of the technologies and market rules that enable a high level of renewable energy integration. Priority actions include **upgrading key electricity transmission lines with neighboring countries**, reinforcing domestic corridors and key substations. Achieving real system flexibility requires a nationwide smart-meter roll-out under a unified

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[33] ENTSO-E, "Recovering Power System Resilience in Case of System Splits for a Future-Ready Decarbonised System", *Position Paper*, January 2025.

[34] International Energy Agency, "Executive Summary", – In: Electricity Grids and Secure Energy Transitions, Paris: IEA, 2023.

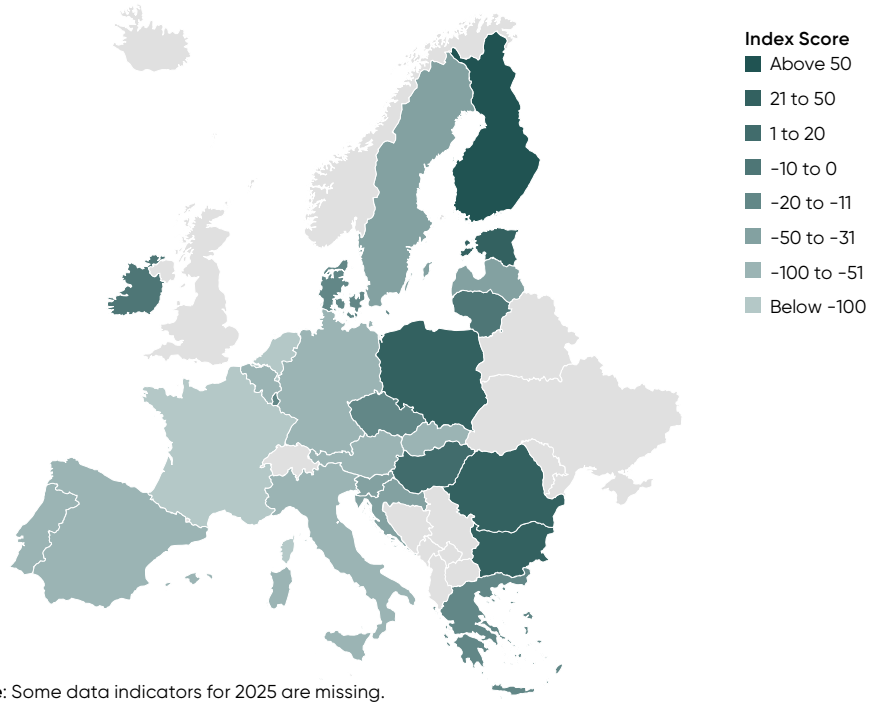
[35] ENTSO-E, "Expert Panel Final Report on 28 April 2025 Blackout in Spain and Portugal", March 20, 2026.

technical standard and deployment of digital grid management, AI-based forecasting, and data-sharing frameworks.[36]

Sustainability Risks

The sustainability risk pillar evaluates the environmental sustainability of national economies by assessing their carbon intensity, resource efficiency, and progress toward circularity. It captures both climate-related and material-based risks that affect long-term economic resilience and alignment with EU climate goals. The indicators span energy use and emissions, as well as environmental pressures from consumption and waste. These factors signal the degree to which economies are decoupling growth from environmental degradation. The Index does not consider the broader socio-economic and environmental risks linked to climate change impacts. However, sustainability risks are closely intertwined with geopolitical and affordability risks, as higher shares of renewables and more efficient material use tend to reduce exposure to imported fossil fuels and mitigate carbon-related cost pressures.

Figure 15. Sustainability Risks in the EU in 2025 Are Significantly Higher in Fossil-Fuel Dependent Countries in Central and Eastern Europe



Note: Some data indicators for 2025 are missing.

Source: CSD based on ECSRI data.

Although in 2025, the EU's sustainability risk position has improved, the energy transition has entered a more challenging phase. Europe is on track to **reduce emissions by more than 50%** by 2030 compared to 1990 levels.[37] However, Europe's decarbonization efforts thus far have been predominantly

[36] Vladimirov, M. et al., *Future Resilience: Building Bulgaria's Path to Clean Growth, Industrial Competitiveness and Economic Security*, Sofia: Center for the Study of Democracy, 2025.

[37] European Commission, "EU closing in on the 2030 climate and energy targets, according to national plans", *Press Release*, Brussels, May 28, 2025.

driven by the power sector. Between 2008 and 2024, the emissions intensity of EU electricity generation fell by 46%, whereas the emissions intensity of the EU economy as a whole decreased by just 36%.[38] This divergence highlights a key challenge for the next stage of the transition: decarbonizing electricity generation has been much easier than decarbonizing heavy industry, transport, buildings, and consumption patterns across the wider economy.

Electrification is becoming an increasingly important bridge between sustainability, affordability and competitiveness. Countries with abundant low-carbon electricity are better placed to reduce emissions in transport, heating and industrial production while maintaining economic competitiveness. This helps to explain why Sweden, Finland and France continue to perform well across several energy security dimensions. Their electricity systems combine nuclear and hydro baseload generation with expanding renewable capacity, enabling them to decarbonize while reducing their reliance on volatile fossil fuel imports.

Despite the significant EU progress in decarbonizing its economy, the sustainability performance of a country cannot be defined solely in terms of emissions. Several member states excel in power-sector decarbonization but exhibit **poor resource-efficiency** and **low circularity** in their broader economic structure. Finland and Luxembourg illustrate this tension particularly clearly. Both have some of the lowest-carbon electricity systems in Europe and perform exceptionally well on emissions-related indicators. However, they also consume significantly larger quantities of raw materials per capita, generate more waste, and have lower rates of circular material use than many other member states. Conversely, **Slovakia and the Czechia** remain among the most energy- and emissions-intensive economies in the EU, primarily due to their industrial structure and historical dependence on fossil fuels. However, they perform comparatively well on material efficiency and circularity indicators relative to many wealthier Western European economies.

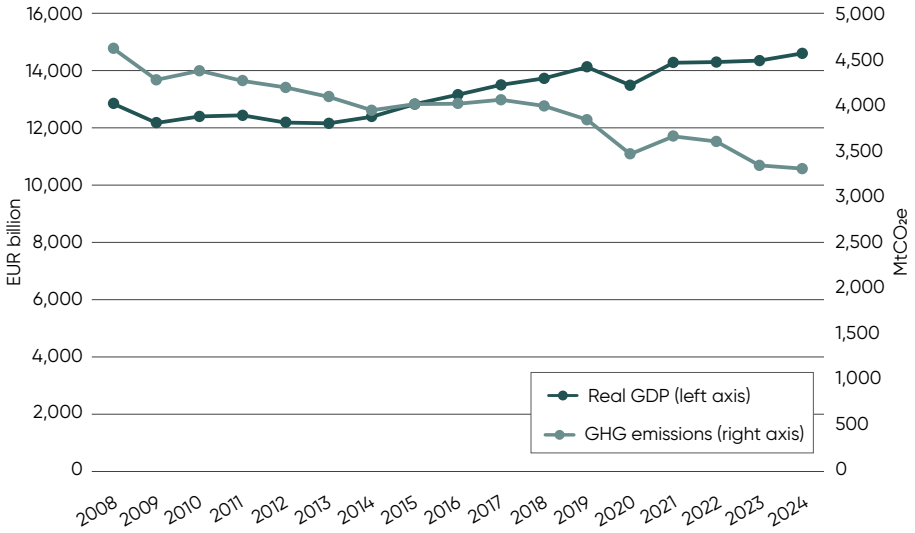
This distinction is becoming increasingly important because the clean transition itself is materially intensive. Wind turbines, solar panels, batteries, grids, electrolysers and electric vehicles all require large quantities of metals and minerals, while nuclear energy depends on uranium supply chains, specialised fuel-cycle services and long-term waste infrastructure. Therefore, sustainability increasingly depends on **how efficiently economies use energy and materials overall**.

The Netherlands, France, Belgium, Italy and Austria perform particularly well because they combine relatively low emissions intensity with the efficient use of energy and raw materials, generating lower levels of waste and embedding circularity more deeply into industrial systems. Many Central and Eastern European economies face the dual challenge of expanding economic output and living standards while reducing energy and material intensity. This tension is evident in ECSRI trends relating to the material footprint. While the sustainability risk associated with the EU's overall material footprint declined by 67 index points between 2008 and 2025, the corresponding risk

[38] European Environment Agency, "Total net greenhouse gas emission trends and projections in Europe", EEA Indicators, November 6, 2025.

increased by 10 index points in Hungary, 31 in Bulgaria, and an alarming 119 in Romania. This highlights the growing pressure that industrial convergence and infrastructure expansion can place on resource consumption.

Figure 16. EU Real GDP and GHG Emissions Have Decoupled Over Time



Source: CSD based on ECSRI data.

NUCLEAR AS A STABILITY ANCHOR IN LOW-CARBON SYSTEMS

Nuclear power can play a distinct role in ensuring the reliability of the new energy landscape. As a synchronous, baseload, low-carbon source of electricity generation, nuclear power provides a continuous output while also contributing inertia and voltage support through large rotating generators. Inertia from the generators of fossil fuel, nuclear and hydroelectric power stations provides stored kinetic energy that helps the grid respond within the first few seconds of a disturbance. This makes nuclear power particularly valuable in systems where coal is being phased out and hydropower potential is limited.

An energy transition process involving less nuclear power is more challenging and expensive, and the EU electricity market design should recognize the value of dispatchable, low-emission capacity.[39] This is particularly relevant for Central and Eastern European countries seeking to replace ageing coal fleets while avoiding becoming dependent on gas-fired backup generation.

Nuclear power can provide the firm, low-carbon backbone of the power system but cannot replace investments in renewables, storage systems and grid upgrades. Batteries and demand response can cover short-duration flexibility, interconnections can smooth regional imbalances, and grid-forming technologies can maintain stability in systems with high shares of inverter-based resources.[40]

The policy implication is that reliability should be treated as a system-design challenge, and not as a technology contest. A fossil-heavy system may appear reliable because dispatchable plants are available, but it remains exposed to fuel-price shocks, import disruptions and carbon costs. A renewables-heavy system may be low-cost and low-carbon, but reliability risks increase if grids, storage, inertia and flexibility lag behind generation growth. The most **resilient European power systems are those that combine firm, clean capacity with rapid renewable energy deployment and a modern grid**.

Nuclear energy will also play a particularly important role for achieving industrial decarbonization. Large volumes of reliable, low-carbon electricity are required by the heavy industry, hydrogen production, district heating, data centers and electrified manufacturing. Although wind and solar generate electricity at a very low cost, industrial consumers also require a reliable supply, long-term price visibility and grid stability. Nuclear power can fulfil these needs by **providing continuous low-carbon generation and long-term supply contracts** that mitigate the impact of fossil fuel price volatility.

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[39] International Energy Agency, *Nuclear Power and Secure Energy Transitions*, Paris: IEA, 2022.

[40] International Atomic Energy Agency, Nuclear–Renewable Hybrid Energy Systems, *IAEA Nuclear Energy Series* No. NR-T-1.24, Vienna: IAEA, 2022.

Nuclear energy uptake, however, involves significant trade-offs. Although the lifecycle emissions of nuclear power stations are among the lowest of all electricity generation technologies, nuclear projects are capital-intensive, demanding in terms of institutional requirements and often slow to deploy. Recent European projects have demonstrated how delays and cost overruns can undermine the contribution of nuclear energy to short-term decarbonization goals. Long-term radioactive waste management also remains a governance challenge, requiring stable institutions, public trust, and credible disposal strategies.

THE NUCLEAR ENERGY PARADIGM ACROSS EUROPE

Nuclear energy occupies very different roles across European energy systems and therefore faces different combinations of opportunities, constraints and risks. In some countries, existing nuclear fleets already **function as a central pillar of electricity supply**, supporting the upscaling of low-carbon generation, limiting exposure to fossil fuel imports and reducing gas and carbon markets volatility. Elsewhere, nuclear power plays a strategically important role in stabilizing power systems and supporting the **gradual replacement of coal-fired generation**. The nuclear energy contribution depends heavily on national circumstances, including the condition of existing reactors, the structure of electricity markets, the pace of electrification, and the ability to **manage high upfront investment costs, long construction timelines and fuel-cycle dependencies**.

The case studies in the following section illustrate how these dynamics unfold across different European contexts. In particular, the section zooms in on the impact from the commissioning of Finland's Olkiluoto 3 reactor (OL3), one of the few large-scale nuclear projects completed in Europe in the past decade. The Finnish case **provides a rare opportunity to assess empirically how new nuclear capacity can influence electricity prices**, emissions intensity, regional trade flows and broader energy security outcomes during a period of significant stress on European energy markets.

The Impact on Energy Security of a New Nuclear Plant

In April 2023, at a time when Europe was still grappling with the worst shocks of the energy crisis caused by Russia's invasion of Ukraine, Finland commissioned the third unit of its Olkiluoto Nuclear Power Plant (OL3) which increased Finland's total installed nuclear capacity from 2,794 MW to 4,364 MW. The new nuclear addition coincided with the decision of the Baltic states to decouple their power grids from the Russian system and synchronize them with the continental European grid. Hence, OL3 represents a unique case which allows for a data-based analysis of the real impacts of additional nuclear capacity on energy security during a time of an acute energy supply crisis.

Box 5. Impact Assessment of the Role of Nuclear Energy in the Baltic Region

To evaluate the effect that the commissioning of Finland's Olkiluoto 3 (OL3) nuclear reactor has had on electricity prices and carbon intensity in Finland and the Baltic states, the analysis combined a descriptive market study with a number of additional econometric methods. Monthly panel datasets covering EU member states were constructed using data on electricity prices, demand, renewable generation, fuel prices, interconnector availability, and carbon intensity.

First, autoregressive distributed lag (ARDL) models were employed to analyse the evolution of Finnish electricity prices relative to regional benchmark prices, while accounting for changes in electricity demand, renewable generation, natural gas prices, and EU ETS prices. These models distinguish between short-term market reactions and longer-term structural relationships in electricity price formation.

Secondly, panel event-study difference-in-differences (DiD) frameworks were applied to examine whether the commissioning of OL3 in 2023 coincided with statistically significant changes in electricity prices and carbon intensity in Finland, Estonia, Latvia and Lithuania, compared to other EU countries. In practical terms, this approach compares developments in the countries under study before and after OL3's commissioning against a broader control group, while also tracing the monthly evolution of the effects over time. By estimating separate coefficients for each month relative to the commissioning date, the methodology enables the identification of anticipatory market effects and delayed responses, rather than assuming an immediate, one-off structural break.

The analysis also considered the impact of outages of the EstLink 2 interconnector between Finland and Estonia. Separate event-study specifications were estimated for the major outage periods from 25 January to 4 September 2024 and 25 December 2024 to 19 June 2025, in order to evaluate the impact of cross-border transmission disruptions on Baltic electricity prices in comparison to other Central and Eastern European markets.

Finally, an hourly regression analysis was conducted to determine whether an increase in Finnish low-carbon electricity generation displaces carbon-intensive oil shale generation in Estonia. The model linked Estonian oil shale output on an hourly basis to Finnish nuclear and renewable generation, while controlling for electricity demand, Estonian and Latvian renewable output, and interconnector availability. This allowed the analysis to determine the impact of Finnish electricity exports and regional market integration on reducing fossil-based generation in the Baltic power system.

The analysis covers the time period from 1 January 2022 to 31 December 2025, during which Finland added 1,600 MW of nuclear, 4,200 MW of wind and roughly 1,500 MW of solar capacity. Between 2022 and 2023, Finland experienced the largest drop in the carbon intensity of its consumed electricity (from 133 gCO2e/KWh to 84 gCO2e/KWh) and coal generation dropped 43% down to 4.21 TWh (-43%). Before 2023, nuclear generated around 22-24 TWh per year and provided around 25-29% of electricity used in Finland. Since 2023, nuclear has generated around 32 TWh per year and its share expanded to between 34-39% of electricity. At the same time, wind generation went from 11 TWh (13.3%) in 2022 to 21.6 TWh (23.6%) in 2025.

Over the same time, 377 MW of onshore wind and 721 MW of solar was commissioned in Estonia, 100 MW of solar in Latvia and 1,700 MW of onshore wind and 2,440 MW of solar in Lithuania. Estonia experienced the largest drop in its carbon-intensity of consumed electricity between 2022 and 2023 (from 426 gCO2e/KWh to 287 gCO2e/KWh). Imports from Finland did not increase significantly in volume after 2023, probably because of interconnection constraints, but the carbon-intensity of Finnish imports declined from 124 gCO2e/KWh in 2022 to an average of 75 gCO2e/KWh in the years after. Estonian fossil oil shale-based generation dropped from 4.16 TWh (29.3%) to 2 TWh (16.7%) between 2022 and 2023, likely the main reason for the decline in carbon intensity.

Table 1. Energy System Developments in Finland and the Baltics Between 2022 and 2025

	Added nuclear capacity (MW)	Added wind capacity (MW)	Added PV capacity (MW)	Electricity carbon intensity (2022)	Electricity carbon intensity (2025)	Coal/ oil shale generation (2022)	Coal/ oil shale generation (2025)
Finland	1,600	4,200	1,500	133 gCO2e/KWh	68 gCO2e/Kwh	9%	2%
Estonia	0	377	721	426 gCO2e/KWh	243 gCO2e/KWh	29%	14%
Latvia	0	0	100	285 gCO2e/KWh	156 gCO2e/KWh	0%	0%
Lithuania	0	1,700	2,440	226 gCO2e/KWh	135 gCO2e/KWh	0%	0%

Source: CSD analysis using partial data inputs from Electricitymaps.com.

A simple descriptive analysis of trends in carbon intensity and prices over time is insufficient to assess the full set of impact the commissioning of OL3 and Finnish nuclear generation in general had on the regional power system. As a result, the current analysis runs different regression models to answer the following three main questions about the project's impact on the Baltic energy system in comparison to a CEE regional benchmark:

- How does the Finnish nuclear generation **replace fossil-fuel-based generation**?
- Does the OL3 **lower electricity prices** and carbon intensity?
- Does the outage of the key power interconnection EstLink2 **affect electricity price spreads**?

The first set of regressions examines the relationship between Finnish low-carbon generation and Estonia's oil shale-based electricity output. The results show **a strong and statistically robust substitution effect between Finnish nuclear generation and Estonian fossil-fuel generation**. A 1 MW increase in Finnish nuclear output is associated with a reduction in Estonian oil shale generation of roughly 0.04 MW during periods when EstLink2 is unavailable, increasing to around 0.07 MW when the interconnector is operational. By

comparison, Finnish renewable generation has a significantly smaller effect, reducing oil shale output by approximately 0.01–0.02 MW per additional MW generated.

Nuclear generation provides **stable baseload electricity** that competes directly with oil shale generation in the regional merit order and consistently lowers the need for carbon-intensive dispatchable generation. Renewable generation also contributes to fossil fuel displacement, but its impact is more variable because output depends on weather conditions and seasonal patterns. The results suggest that firm low-carbon generation plays a particularly important role in reducing reliance on fossil-based balancing and baseload generation during periods of system stress.

The analysis also highlights **the importance of regional market integration and cross-border demand dynamics**. Higher electricity demand in Estonia increases oil shale generation, reflecting its continued role as a marginal domestic supply source. Higher Finnish electricity demand similarly exerts upward pressure on Estonian fossil-fuel generation by tightening regional supply conditions. At the same time, greater renewable generation in Latvia, primarily hydropower, is associated with lower oil shale output in Estonia, demonstrating how wider Baltic integration increasingly contributes to reducing carbon-intensive generation across the region.

A second set of regressions applies a panel event-study difference-in-differences (DiD) framework to estimate whether the commissioning of OL3 created a structural break in electricity prices and carbon intensity in Finland and the Baltics relative to a Central and Eastern European benchmark (see Box 2).

The results show that **carbon intensity in Finland and the Baltics declined substantially relative to the benchmark group** over the sample period, but the downward trend began well before OL3's formal commissioning in April 2023. This suggests that OL3 reinforced an already ongoing regional decarbonisation process driven by growing renewable deployment, falling coal and oil shale generation, and structural changes in the Nordic-Baltic power system. The analysis therefore does not identify a sharp discrete structural break in carbon intensity directly attributable to OL3 alone. Instead, OL3 appears to have strengthened and accelerated an existing transition toward lower-carbon electricity generation.

The impact on electricity prices is more pronounced. The results indicate that price spreads between Finland, the Baltics, and the CEE benchmark started to decline already in early 2023 during the phased ramp-up of OL3 generation, several months before full commercial commissioning. As additional low-cost nuclear generation entered the Nordic market, electricity prices and price volatility declined significantly across Finland and, through interconnections, in the Baltics. The estimates also become more stable and statistically precise after early 2023, indicating that increasing nuclear output improved market predictability and dampened scarcity-driven price fluctuations during the peak energy crisis period. However, the price-reducing effect gradually weakened over time as the market absorbed the additional generation capacity and broader regional demand and supply conditions evolved.

The final part of the analysis examines the effect of EstLink2 outages on electricity price spreads between the Baltics and the CEE benchmark. The January 2024 outage is associated with **a substantial increase in Baltic electricity price spreads** – approximately €15/MWh – highlighting the critical role of Finnish imports and cross-border interconnection capacity for regional price convergence and market stability. The results confirm that the **Baltics remain highly exposed to disruptions affecting Nordic electricity imports** even when average price levels remain relatively competitive under normal market conditions.

By contrast, the December 2024–January 2025 outage had a materially smaller effect on regional price spreads despite similar technical disruptions. This reflects the significant increase in Baltic system resilience ahead of synchronization with the continental European electricity grid in February 2025. Prior to synchronization, the Baltic states relied on the Russian-controlled IPS/UPS system for frequency management and balancing. The transition to the ENTSO-E framework required major investments in reserve capacity, balancing infrastructure, grid modernization, and operational preparedness. As these adjustments were gradually implemented throughout 2024, the Baltic power system became **better equipped to absorb external shocks and interconnection disruptions**.

Nuclear Energy and the Restructuring of Electricity-System Risk in Central and Eastern Europe

After two decades in which many European countries treated nuclear power primarily as a legacy technology, the 2022-2023 energy crisis and the deterioration of the geopolitical environment have pushed nuclear back into the center of the energy security debate. The key question is whether European electricity systems can provide stable and affordable low-carbon power during periods of high demand, weak renewable output, and volatile fossil fuel markets. The evidence from the Index suggests that nuclear energy matters most through its ability to reduce exposure to expensive and carbon-intensive residual-load hours.

The global 2050 commitment assumes a threefold expansion of nuclear power, even as the European trajectory keeps the fleet close to its current size even after a large investment cycle aiming to add 60 GW of new capacity. Policymakers have directed their attention first to preserving firm low-carbon output from ageing reactors, with only a limited financial room left for capacity additions in a more electrified economy. The slow project implementation would reduce the available clean firm output at the same time as electricity demand surges. The period of electricity scarcity would be then covered more often through fossil-fuel-based generation, turning the delay in nuclear energy uptake into a reliability risk for the wider electricity system.[41]

Wind and solar reduce electricity prices and emissions during periods of high output, but they also increase the importance of dispatchable capacity during periods of low renewable generation.[42] In this respect, the value of nuclear

[41] European Commission, Nuclear Illustrative Programme presented under Article 40 of the Euratom Treaty – Final *(after the opinion of the EESC)*, COM(2026) 120 final, Brussels, March 10, 2026.

[42] Vladimirov et al., *Future Resilience*, Sofia: CSD, 2025.

energy lies in **maintaining stable low-carbon supply during winter demand peaks**, evening ramps, and low-wind periods when electricity systems would otherwise depend on expensive and carbon-intensive balancing services.

The key to unlocking Europe's nuclear energy potential is to develop a long-term, bankable deployment program for multiple projects. Without commitments to develop a pipeline of projects, design approval slows down, suppliers cannot guarantee equipment delivery deadlines, offtake agreements face an uncertain supply mix (hence prices), and lenders are hesitant to support projects as they price each reactor as a stand-alone construction and political risk.[43]

The lack of a long-term program for a nuclear build-out may undermine the growth of the AI sector in Europe. The surge in AI-related power consumption can deepen locational grid congestion for additional connections for consumers. Data centres concentrate continuous, high-availability load in nodes where cloud infrastructure, fibre routes, cooling conditions and spare substation capacity overlap, often competing with demand from the industry, which wants to electrify production and connect additional renewables. The development of large-scale, firm low-carbon generation such as nuclear can alleviate these constraints by reducing the need for the additions of hundreds of dispersed intermittent generation units that raise the costs for the balancing and expansion of the grid. The misalignment between the connection of consumption and production units throughout the grid raises the needs for fossil-fuel-based generation to provide balancing services.[44]

Box 6. France: Europe's Nuclear Core with A Russia Problem

France has maximized the system value of an existing nuclear fleet. Nuclear accounts for around 66-68% of French electricity production and the French power mix has become more than 95% low-carbon. France's electricity generation remains among the least carbon-intensive in Europe, at around 20 gCO_2e/kWh in 2025, compared with roughly 175 gCO_2e/kWh across Europe.[45] At this level of nuclear concentration, the critical variable is the operational resilience of the fleet. A large nuclear base reduces the structural exposure to fossil fuel prices and carbon costs only when the availability of the reactors remains high, maintenance cycles are well sequenced and reinvestment is sufficient to prevent ageing assets from becoming a source of generation volatility (as France experienced in 2022).[46] The almost 70% share of nuclear in the mix reduces significantly affordability and security of supply risks as well but reliability risks may increase disproportionately due to lack of a diversified power mix if nuclear operators fail to implement effectively their reactor maintenance and modernization plans.

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[43] Virone, A. et al., "A Vision for the EU Net-Zero Transition: Transforming EU economy for climate neutrality – policy recommendations", *Clean Air Task Force*, April 2024, pp. 39-43.

[44] Schneider Electric Sustainability Research Institute, AI & Energy in Europe: From Scenarios to National Trajectories, 2025.

[45] RTE, 2025 Electricity Review: Full Report, 2025.

[46] Ibid.

France's six EPR2 reactors at Penly, Gravelines and Bugey, approved in 2026 adds around 10 GW of replacement capacity on established nuclear sites. The lost availability of nuclear generation capacity would increase the need for gas-fired generation, more imports and balancing services raising industrial tariffs. The timely serial deployment will protect the ability of the French nuclear fleet to support affordable prices, industrial electrification and the potential for cheap and low-carbon exports to neighboring markets in times of low renewable energy output.

France's ECSRI profile is largely the result on this cornerstone role of nuclear energy. France was not insulated from the 2022-2023 price shock and faced surging affordability risks, but the recovery of the nuclear production following a slump in 2022 reduced the role of gas in securing the domestic demand, thereby weakening the transmission of fossil geopolitical risk into the security of the electricity system. Even when hydro output fell in 2025 after the exceptional rainfall of 2024, the system did not revert to fossil generation because nuclear availability stabilized the system and solar output expanded to cover the gap.[47] Nuclear provides the emissions floor of the system, while **renewables reduce marginal fuel use above that floor**. In fact, the lower costs and predictability of the French nuclear energy fleet **strengthened Europe's overall energy security and helped stabilize EU power prices at a lower level in 2024-2025**.[48] This is not to say that France is entirely insulated from affordability risks. Nuclear energy reduces the number of hours, in which gas and carbon costs determine market outcomes, but prices still respond to peak demand periods, outages, interconnection constraints, wholesale-market rules and the cost of maintaining an ageing fleet.

Affordability concerns are visible in the **decline of electrification of the economy**. The increase in power prices has hurt badly industrial demand. Weather-adjusted electricity consumption in 2025 is still 6% below the 2014–2019 average, while large industrial consumers connected to the transmission grid are around 13% below pre-crisis levels. Within manufacturing, chemicals fell by more than 9% and steel by more than 2% in 2025.[49] Although France has one of Europe's cleanest electricity systems, the economy is not yet converting that advantage into a proportional reduction of fossil fuel use in heating, industrial production and transportation. The energy security value of nuclear can be maximized only when low-carbon electricity substitutes imported fossil fuels in final energy demand. That requires nuclear-backed electricity to be linked to long-term industrial contracts, grid-access planning and electrification projects rather than absorbed mainly through short-term consumer relief.

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[47] Vladimirov, Koeppen, and Rickles, *Energy and Climate Security in Europe*, Sofia: CSD, 2025.

[48] Schneider, M. et al. *The World Nuclear Industry Status Report 2025*, Paris: Mycle Schneider Consulting Project, 2025.

[49] Ibid.

Reliability is the internal constraint that defines the limits of the French model. The same concentration of nuclear capacity that delivers low emissions also concentrates operational risk. The 2022 crisis showed this clearly, when corrosion issues, maintenance backlogs and outages coincided, reducing the stabilising role normally played by the French fleet and increasing dependence on imports. A nuclear-heavy system is secure only when firm low-carbon capacity is available during winter peaks and residual-demand stress. Reliability therefore depends less on the grid capacity and the overall installed generation capacity but on inspection cycles, outage coordination, corrosion monitoring, spare-part availability, workforce depth and reinvestment discipline.[50]

The nuclear backbone of the French energy system also does not eliminate entirely some of the external dependencies. The energy security risks shift from continuous fossil fuel procurement toward guaranteeing the uranium supply, conversion, enrichment, fuel fabrication, reactor services and maintenance capability.

The external constraint on the French model sits **in the fuel cycle rather than in the performance of the domestic reactor fleet**. Nuclear generation lowers France's exposure to imported fossil fuels, but the system still depends on fuel-cycle services where Russia retains market power and technical depth. Converted and enriched uranium, qualified fuel designs and reactor-specific licensing are not interchangeable commodities. They depend on certification, safety validation and operating experience, which gives Rosatom a form of leverage that is slower-moving than gas dependence but more difficult to unwind once embedded in reactor operation.[51] This leverage is durable because nuclear fuel is not only a tradable input but part of the licensed operating basis of a reactor. Once a fuel design has been accepted for a specific core, replacement requires proof that an alternative design can preserve the same safety margins under real operating conditions and secure regulatory approval before it can be used at scale. Dependence therefore persists through the qualification pathway itself, making supplier diversification a technical and regulatory transition.

Framatome is central to this exposure because it links France's nuclear industrial base to the fuel needs of Russian-designed reactors elsewhere in Europe. The company is positioning itself as an alternative supplier for VVER operators that want to reduce direct purchases from TVEL, Rosatom's fuel subsidiary. That role could strengthen European resilience if it creates an autonomous Western fuel route. It becomes more ambiguous when the alternative still relies on Russian design parameters, components, licensing arrangements or technical validation inherited from TVEL.[52]

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[50] RTE, 2022 Electricity Review: Full Report, 2023.

[51] Forum Energii, "Anatomy of Dependence: How to Eliminate Rosatom from Europe", July 2024.

[52] Lehner, J., and Camut, N., "France enlists Russian state-owned company to help make nuclear fuel in Germany", *POLITICO*, December 17, 2025.

The controversy around Lingen captures this ambiguity. Framatome's German subsidiary, Advanced Nuclear Fuels, seeks to produce fuel assemblies for Russian-designed reactors using cooperation with TVEL as the technical basis for the project. The objective is presented as faster diversification away from direct Russian fuel deliveries, yet the manufacturing route **risks preserving Rosatom's role inside the qualification and design process**. For utilities operating VVER reactors in Central and Eastern Europe, the supplier may become European, while part of the technical dependency remains Russian.[53]

This creates a second-order dependence that is harder to see than a direct fuel contract with Moscow. The commercial relationship with Rosatom becomes less visible, but the reactor operator still depends on a fuel product shaped by Russian technology and validated through a Russian-linked pathway. Over time, this can normalize Rosatom's continued role in Europe's nuclear fuel ecosystem under the language of diversification, especially if national regulators and utilities treat European fabrication as sufficient proof of independence.[54]

The strategic test for Framatome is whether it can separate the nuclear fuel production from Rosatom-controlled intellectual property, component supply and licensing constraints. If it cannot, the French nuclear industry risks turning direct dependence on Russian fuel into mediated dependence on Russian technology. That would reduce the political visibility of the problem without removing the underlying security exposure.[55]

France represents a very similar system model. Its nuclear fleet reduces the role of fossil fuels across a large share of the residual-load curve and helps stabilize prices during periods of regional stress. Germany moved in the opposite direction. The nuclear phaseout removed domestic firm low-carbon generation before storage, grids, and balancing infrastructure had fully matured, increasing reliance on imports and flexibility mechanisms during residual-load hours.

Central and Eastern European countries need to decide how different technologies can jointly reduce the fossil-based dependence of their electricity systems. Poland, Romania, and Bulgaria each face different versions of this challenge.

Poland is trying to build out a fleet of nuclear power plants to reduce its structural coal dependence and avoid a long-term gas lock-in. Coal still dominates the Polish electricity system, accounting for more than half of generation in 2025, while growing electricity demand and rising carbon costs

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[53] Kunert, M., "Despite sanctions: German company wants to build fuel elements with Putin's nuclear group", *Euronews*, March 26, 2026.

[54] Greenpeace Ukraine, "How Framatome and Siemens support Russia", July 18, 2023.

[55] Mouterde, P., and Pécout, A., "France is still trading uranium with Russia, nearly four years after Ukraine invasion", *Le Monde*, January 28, 2026.

continue to increase affordability pressures across the economy.[56] Despite the rapid growth in wind and solar capacity, Poland still faces high electricity prices during periods of low renewable output, particularly during winter and evening demand peaks. The planned deployment of Westinghouse AP1000 reactors, however, illustrates the central financing challenge facing European nuclear expansion. Cost estimates for the first Polish plant have risen sharply, **requiring substantial public guarantees, state-backed financing, and long-term contracts for difference**. Nuclear can lower long-term system costs only if **new reactors replace fossil-fuel generation** during high-value residual-load hours without creating unsustainable financing burdens for consumers and public finances. The viability of Poland's nuclear energy strategy will depend on the successful grid expansion, system flexibility, and industrial electrification capable of absorbing large volumes of firm low-carbon electricity.[57]

Romania is expanding nuclear within an already diversified low-carbon system to **strengthen reliability and support electrification.** Nuclear energy supplies around one fifth of electricity generation, while hydro, wind, solar, and bioenergy together account for a growing share of the mix. However, fossil-fuel generation still plays a critical balancing role during periods of weak renewable output, and Romania remains vulnerable to electricity-price volatility and rising import dependence during system stress.[58] The expansion of Cernavodă Units 3 and 4 would substantially increase the share of firm low-carbon generation before rapid electrification and growing system complexity tighten residual-load pressures further. Unlike Poland, Romania is not trying to replace a coal-dominated system from scratch. Instead, it is attempting to reinforce an already diversified low-carbon system before balancing costs and infrastructure constraints intensify. The country's SMR strategy at Doicești also represents one of the most advanced attempts in Europe to integrate modular nuclear technology into coal-region redevelopment and industrial decarbonization. However, financing, licensing, and technology-maturity risks are substantial, particularly given the absence of fully operational commercial SMR projects globally.[59]

Bulgaria already possesses a strong nuclear base but faces the challenge of timing the replacement of its existing two reactors with newer technological solutions, without locking itself in excessive baseload capacity or jeopardizing its fiscal discipline. Nuclear energy already supplies close to 40% of electricity generation and acts as the main low-carbon anchor of the Bulgarian power system. Combined with rapidly growing solar and storage capacity, this has significantly reduced the carbon intensity of the electricity sector and strengthened Bulgaria's position as key exporter in Southeast Europe.[60] The central policy challenge for Bulgaria's nuclear energy sector development is the timing of additional nuclear expansion. Two new AP1000 reactors

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[56] Kacper Kwidziński, K., and Dusiło, M., *Energy Transition in Poland. Edition 2025*, Forum Energii, 2026.

[57] European Commission, "Commission Approves Polish State Aid for the Construction and Operation of the First Nuclear Power Plant," December 8, 2025.

[58] Nuclearelectrica, *Cernavodă NPP Units 3 and 4 Project,* 2025.

[59] Schneider et al., *The World Nuclear Industry Status Report 2025*, Paris: Mycle Schneider Consulting Project, 2025.

[60] Vladimirov, Gantcheva, and Köppen, *Beyond Diversification*, Sofia: CSD, 2026.

at Kozloduy could strengthen long-term energy security and eventually **replace ageing existing reactors due to be decommissioned by mid-century**. However, expanding baseload capacity too early – before coal retirements, demand growth, storage deployment, and grid modernization are sufficiently advanced risks increasing system costs and **crowding out more commercially viable flexibility investments**.

The success of the nuclear energy expansion will also depend on managing the widespread governance risks linked to the implementation of large-scale energy projects. The now-canceled Belene NPP project, which aimed to install two Rosatom-built VVER-1000 reactors, became a huge fiscal blackhole that sucked more than EUR 2 billion in public resources that were siphoned off by well-placed subcontractors and consultancies through corrupt public procurement tenders.[61] The project lacked a clear commercial logic, and was justified by unrealistic power demand projections developed by the same institutions that were benefitting from the implementation of the project. The lesson for the current project for deploying two AP-1000 reactors at the Kozloduy NPP is that if it is to be implemented successfully, energy policymakers and the project company need to align the procurement, financing and construction commitments to a clear timeline for replacing the existing reactors, off-take agreements securing the demand for huge expansion of electricity generation, and a transparent governance structure that prevents cost overruns, raising the LCOE of the generated electricity far above the average market prices.[62] Bulgaria should also avoid signing a CfD at a strike price that is not justified by demand conditions and long-term EU energy pathways.

Slovakia, Czechia, and **Hungary** face structural nuclear energy dependence on Russia, rooted in a reactor fleet built entirely around Soviet VVER technology. Historically, these nations have relied completely on Russian fuel, specialized spare parts, and technical support from Rosatom. Breaking this dependence requires a **deliberate strategy to eliminate operational links across the entire nuclear fuel cycle**, maintenance chain, and reactor-service ecosystem. While Slovakia and Czechia have initiated tangible steps toward Western supply routes, the process remains gradual due to the rigorous safety testing, complex regulatory licensing, and supplier qualification schedules required to safely replace VVER fuel assemblies.[63]

Slovakia maintains heavy Russian legacy inside its nuclear sector although it has officially embarked on a Western path to mitigate this exposure. The country has signed long-term contracts with the U.S. firm Westinghouse to supply alternative VVER-440 reactor fuel for its Bohunice and Mochovce nuclear power plants. Concurrently, Bratislava is exploring an SMR track in cooperation with the U.S. to diversify its technology base, opening a strategic route for new capacity and regional industrial development.[64]

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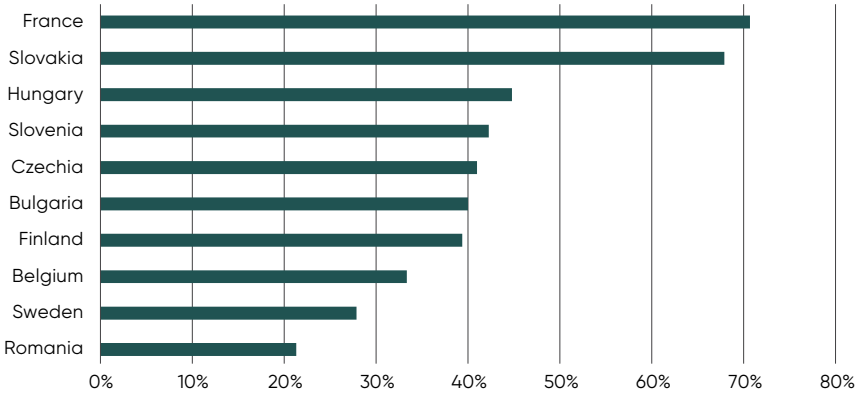
[61] Stefanov, R. et al., *Energy and Good Governance in Bulgaria: Trends and Policy Options*, Sofia: Center for the Study of Democracy, 2011.

[62] Stefanov. R. et al., *Energy Sector Governance and Energy (In)Security in Bulgaria*, Sofia: Center for the Study of Democracy, 2014.

[63] Vladimirov et al., *The Last Mile*, Sofia: CSD, 2025.

[64] Ogrodnik, Ł., and Pastucha, T., "Slovakia Remains Dependent on Russian Energy", *Polish Institute of International Affairs*, March 14, 2025.

Figure 17. Share (%) of Nuclear Energy in Electricity Generation Across Europe (2025)



Source: CSD based on ENTSO-E data.

Czechia has advanced the furthest in the region **toward full nuclear fuel independence**. The country successfully terminated its reliance on Russian nuclear supply chains early on and transitioned its fuel procurement entirely. For the VVER-1000 units at the Temelín NPP, Czechia has moved completely away from Russian fuel. Furthermore, Prague has secured **fuel delivery contracts with Westinghouse to begin a phased transition for the older VVER-440** reactors at the Dukovany NPP. To support coal phase-out and industrial competitiveness, Czechia is also pursuing the expansion of large-scale capacity at Dukovany and launching an SMR track at Temelín, though these projects rely on strict mitigation of financial and regulatory risks to prevent new dependencies.[65]

In sharp contrast to its neighbors, Hungary remains the most structurally exposed country to Russian nuclear energy leverage and has actively dragged its feet on meaningful diversification.[66] Instead of cutting ties, Budapest has doubled down on its relationship with Rosatom. Under the Paks II expansion project, Hungary is adding two new VVER-1200 reactors. This initiative deeply locks the state into Russian influence across multiple dimensions:

- **Financing Architecture:** The cost of the project has expanded from EUR 12.5 billion to EUR 15 billion. It is funded via an opaque, non-competitive intergovernmental agreement backed by a Russian state loan covering 80% of the capital. This shifts the financial and macroeconomic risk directly onto the Hungarian state budget as a long-term sovereign liability.

- **Fuel Supply Countermeasures:** While the existing Paks I plant quadrupled its imports of Russian nuclear fuel to EUR 172 million by the end of 2025 to build up protective inventories, Hungary's attempts at "diversification" lack full strategic autonomy. The operator signed a VVER-440 fuel supply agreement with the French company Framatome. However, Framatome relies on joint industrial arrangements and

[65] Vladimirov et al., *The Last Mile*, Sofia: CSD, 2025.

[66] Vladimirov et al., *The Last Stronghold*, Sofia: CSD, 2026.

manufacturing cooperation with Rosatom's fuel subsidiary, TVEL, meaning the technological link to the Russian nuclear ecosystem remains partially embedded.

Box 7. Germany's Nuclear Phaseout and the Changing Structure of European *Energy Security*

Germany's nuclear phaseout **altered the structure of electricity-system risk across Europe** by removing a large source of firm low-carbon generation at the same time as renewable energy became the dominant source of new electricity supply. The main effect was not a simple return to fossil fuels, but a growing dependence on flexibility, imports, storage, and cross-border balancing to cover periods when wind and solar output are insufficient. This shifted part of the burden of system stability onto neighboring markets and regional interconnections. The contrast with Finland is particularly instructive. While the commissioning of OL3 added stable low-carbon capacity to the Nordic-Baltic system during the peak of the energy crisis, Germany removed domestic low-carbon baseload before flexibility infrastructure, storage, and grid expansion had fully matured. The result is a more coordination-dependent electricity system that performs well during renewable-rich hours but faces greater stress during periods of low wind, weak solar output, and high demand.

This shift is increasingly visible in the widening divergence between periods of surplus renewable generation and residual-load hours. Germany has experienced **a sharp increase in negative-price hours as wind and solar output expanded**, rising from around 457 hours in 2024 to 573 hours in 2025. At the same time, average electricity prices remained elevated because the system still depends on gas, imports, and flexible dispatchable generation during periods when renewable output falls. Nuclear generation would not have **eliminated volatility or removed the need for flexibility**, but it would have reduced the size of the fossil-based residual system by providing stable low-carbon electricity during evening, winter, and low-wind periods. Without nuclear generation, the value of storage, interconnections, demand response, and balancing infrastructure becomes substantially more important for maintaining affordability and reliability.

Germany's post-nuclear adjustment also changed the role of regional market integration within the European electricity system. Imports increasingly help **reduce the carbon intensity of German electricity consumption** during periods of domestic renewable shortfall. In 2025, Germany's consumption-based electricity carbon intensity remained lower than its production-based intensity, indicating that imported electricity from neighboring lower-carbon systems partially compensated for the loss of domestic nuclear generation. However, this also creates greater exposure to regional correlation risks. Interconnection-based security functions efficiently under

normal market conditions, but its resilience weakens during periods of simultaneous cold weather, low wind generation, or regional scarcity across interconnected markets. Germany therefore **replaced part of its domestic low-carbon firmness with conditional access to neighboring low-carbon supply**.

The broader European implications are significant. Germany's model can remain viable, but only if renewable deployment is matched by equally rapid expansion of grids, storage, demand-side flexibility, and clean dispatchable capacity. Otherwise, the system could risk accumulating large volumes of cheap renewable electricity without proportionally reducing expensive and carbon-intensive residual-load hours. This challenge is particularly important for industrial competitiveness. Energy-intensive industries require **stable access to affordable low-carbon electricity across full production schedules** rather than occasional periods of very low prices. Germany's phaseout therefore illustrates a broader strategic lesson for Europe's energy transition: replacing firm low-carbon generation with variable renewables increases the importance of flexibility and market integration, but it also raises the cost and complexity of maintaining affordability, reliability, and industrial competitiveness during periods of system stress.

BARRIERS TO SCALING NUCLEAR IN EUROPE

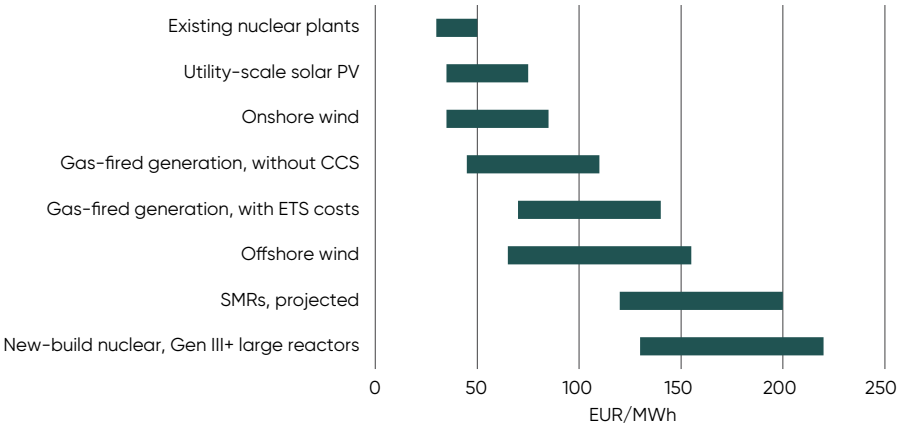
Financing and Market Design

Nuclear power creates system value because it supplies firm low-carbon electricity at scale, over long operating lifetimes, and during the residual-load hours when coal, gas, imports, or flexibility constraints often determine prices. This makes nuclear strategically attractive in electricity systems trying to **reduce fossil fuel exposure while supporting industrial electrification**. The core barrier is that this value appears only after the plant is commissioned, while most of the financial risk is concentrated years earlier, during licensing, design finalization, site preparation, procurement, construction, and regulatory approval.

The financing problem begins with capital intensity and long construction periods. Nuclear projects require **large upfront expenditure before revenue begins**, and delays quickly increase total costs through higher interest during construction, inflation, contractor claims, and additional regulatory or engineering work. Recent Western projects show how delivery risk can overwhelm the initial investment case. Vogtle Units 3 and 4 in the United States now provide firm low-carbon electricity, but their final cost rose from an original estimate of around USD 14 billion to roughly USD 30–35 billion.

Flamanville 3 in France is even more relevant for Europe: despite France's long nuclear experience, the project started up around twelve years later than planned, while costs rose from roughly USD 4.3 billion to around USD 25.6 billion. Olkiluoto 3 in Finland tells the same story from another angle. Construction lasted almost two decades from first concrete to regular production.[67]

Figure 18. 2025 Levelized Cost of Electricity (LCOE) Comparison in Europe



Source: CSD based on Lazard data.

[67] Schneider et al., *The World Nuclear Industry Status Report 2025*, Paris: Mycle Schneider Consulting Project, 2025.

These cases show that nuclear construction risk is rarely caused by one failure. Immature design, regulatory rework, weak project control, supply-chain bottlenecks, contractor disputes, and quality-control problems reinforce one another. By contrast, more successful programs, such as Barakah in the United Arab Emirates and parts of China's nuclear buildout, show that risk falls when nuclear is organized as a repeat industrial program rather than as a sequence of bespoke national projects. Standardized designs, repeated units on the same site, experienced contractors, integrated supply chains, and continuity of skills reduce the probability that delays become financially destructive.[68]

European electricity market design compounds the problem. **Short-term marginal pricing does not provide the long-term revenue certainty needed for capital-intensive assets** with operating lives of 60 years or more. Existing nuclear plants can operate in such markets because much of their capital cost has already been recovered. New nuclear faces a different challenge: investors must commit capital before knowing future wholesale prices, the frequency of negative-price hours, the value of firm low-carbon output, or the durability of policy support. As wind and solar expand, merchant revenue becomes less predictable even though the system value of firm low-carbon generation rises.

Contracts for Difference (CfDs), Regulated Asset Base (RAB) models, state-backed guarantees, and long-term industrial power contracts can reduce financing costs, but only if they allocate risk carefully. Hinkley Point C shows that CfDs can make a privately financed project bankable by stabilizing future revenues, but they do not control construction risk. Sizewell C's RAB model addresses financing costs earlier by allowing some cost recovery during construction, but it also shifts risk toward consumers before electricity is produced. The central policy challenge is bankability without moral hazard. Public support should lower the cost of capital, but it should not automatically transfer avoidable delays, overruns, or weak project execution to consumers and taxpayers.[69]

Financing support should be conditional on project readiness. Long-term contracts and regulated recovery mechanisms should be granted only after design maturity, licensing clarity, site readiness, supply-chain capacity, and construction planning have reached a credible threshold. Standardization should also be treated as a financing instrument. A nuclear program built around repeatable designs, harmonized licensing lessons, and coordinated supply chains will attract capital more cheaply than fragmented projects negotiated separately by each member state.

The next financing constraint lies in the structure of the European nuclear pipeline. If new reactors move forward as isolated national projects, Europe risks multiplying first-of-a-kind exposure instead of reducing it through repetition. The cost trend from repeat deployment is clear. In the Barakah program, capital costs fell by around 58% between the first and fourth APR1400

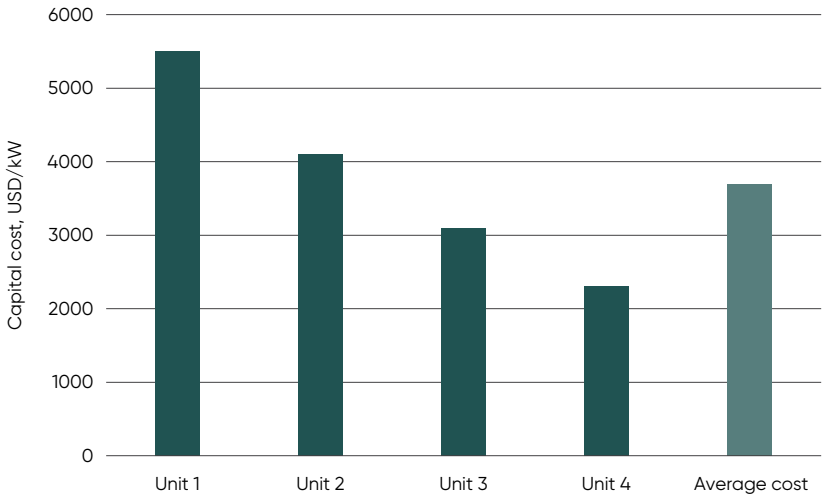
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[68] Bartak, J., and Camarcat, N., *The Challenges of Building Modern Nuclear Power Plants in the XXIst Century*, *NucAdvisor*, 2026.

[69] Mangin, J., et al., "A Robust Decision-Making Approach to Evaluating State Support for Nuclear Programmes under Uncertainty: A UK Case Study", *Energy Policy*, Volume 205, October 2025, 114653.

unit, while modelling based on **larger reactor orderbooks shows that average overnight costs fall by around 24% across three units, 31% across five units and 40% across ten units compared with the first-of-a-kind level**.[70] Nuclear costs decline when the same design, supply chain and delivery model are repeated often enough for industrial learning to accumulate across design finalization, licensing, procurement and construction.[71]

Figure 19. Capital Cost Reductions at the UAE's Barakah Units 1-4



Source: CSD based on ETI data

For Europe, this implies a coordinated procurement and delivery model built around a sequence of standardized reactors rather than separate one-off projects negotiated by each member state. Public backing would then support repeated designs, aligned licensing and supply-chain investment before costs escalate, instead of compensating for fragmented delivery after overruns appear. The financial objective would be to ensure that each additional unit becomes less risky and cheaper to deliver than the previous one.[72]

Box 8. What Europe Can Learn from Successful Projects in Asia

Asian projects provide the more constructive lesson. China's recent nuclear program and the Barakah project in the United Arab Emirates show that delivery risk can be reduced when nuclear is organized as an industrial program rather than as a bespoke project. Chinese projects have also faced delays, including with imported Generation III designs, but continuous construction and supply-chain depth have limited the scale of escalation compared with the most problematic Western

[70] Ingersoll, E. et al., *The ETI Nuclear Cost Drivers Project: Full Technical Report,* Energy Technologies Institute, 2020.

[71] Clean Air Task Force, *Nuclear Energy Orderbooks 101: Enabling Cost-Effective Nuclear Deployment in Europe*, 2025.

[72] Moniz, E., J. et al., *A Cost Stabilization Facility for Kickstarting the Commercialization of Small Modular Reactors*, EFI Foundation, 2023.

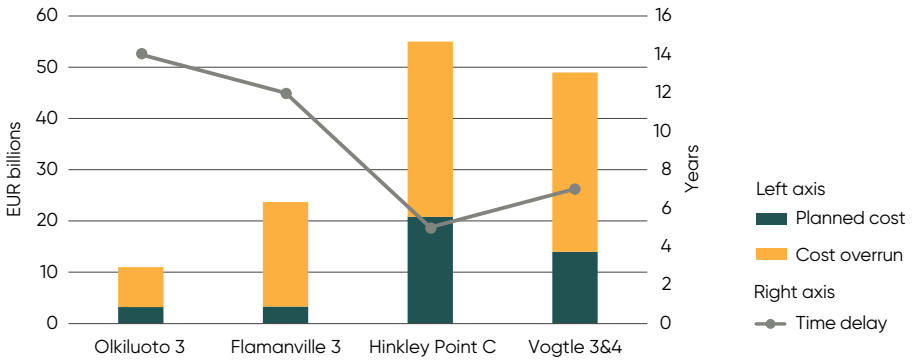
projects. Barakah's four-unit APR1400 program shows the value of building repeated units on one site with an experienced contractor, shared infrastructure and learning across construction phases. The project was not frictionless, but its program structure reduced interface risk and strengthened delivery discipline.

Europe's financing problem would be materially lower if new nuclear power plants were procured through repeatable designs, harmonized licensing lessons and coordinated supply-chain planning rather than through disconnected national projects. Bulgaria's Belene project illustrates how when policymakers ignore these lessons, new nuclear energy reactors become very costly even if they never become operational. Construction began in the late 1980s, was halted, revived, restructured and eventually terminated after decades of political and financial uncertainty. Belene accumulated sunk costs worth at least EUR 2 billion, equipment issues, legal disputes, vendor dependence and political lock-in without delivering electricity. This example is important because it widens the concept of financing risk.

Regulatory and Deployment Bottlenecks

Regulation is central to nuclear safety, but it also shapes project timing, financing exposure, and delivery risk. Nuclear projects must pass through site selection, environmental assessment, design review, construction authorization, safety-case validation, and operating licensing. **These stages cannot be compressed easily because each depends on the technical credibility of the previous one**. When unresolved design or quality problems appear late, they reopen approval cycles, extend construction schedules, and increase financing costs.[73]

Figure 20. Cost Overruns and Delays in Recent Nuclear Projects



Source: CSD calculations based on primary project data from TVO / Areva-Siemens for Olkiluoto 3, EDF and Cour des comptes for Flamanville 3, and EDF / UK Government project disclosures for Hinkley Point C.

[73] Talášek, P., "Schedule Constraints and Delay Drivers in Nuclear Power Plant Construction", *Business & IT*, no. 02/2025, Czech Technical University in Prague, 2025.

The scale of the timing effect is visible across nuclear construction history. U.S. reactor lead times had already increased from around 6–7 years to 10–11 years by the late 1970s. Delays are also widespread in most nuclear energy projects under construction around the world. As of mid-2025, 22–26 of 63 reactors under construction worldwide were delayed.[74]

The European record demonstrates the scale of this problem. OL3 and Flamanville 3 were delayed because of design immaturity, contractor responsibility and poor supply chain coordination with regulatory requirements. In nuclear projects, a technical change can require new safety analysis, regulatory review, requalification of components, and updated documentation. This is why late design change is so costly. Although EU countries share broad safety principles, approval processes remain national, with different technical requirements, regulatory interpretations, and institutional capacities. This prevents genuine serial deployment of standardized reactor designs. Even when the same technology is used, **each project becomes partly unique, requiring additional engineering adaptation and regulatory interaction**.

Project developers need to deal with a lot of technical uncertainty often on the basis of incomplete site-specific information and assumptions about future construction conditions and supply-chain bottlenecks. When discrepancies later emerge during execution, the consequences are severe. **Design changes trigger renewed regulatory review**, updated safety analysis and additional approval cycles. In nuclear projects, regulation and engineering are tightly coupled, so modifications in one domain propagate into the other. Relatively local design problems can therefore produce disproportionate schedule and cost effects.

Deployment constraints also arise from **institutional fragmentation and limited regulatory capacity**. Nuclear projects must interact not only with safety regulators, but also with environmental authorities, grid operators, energy regulators and, in many cases, state-aid review mechanisms. Where these interfaces are poorly coordinated, under-resourced or unevenly staffed, review processes become iterative and slow. This is particularly acute in countries with limited recent experience of nuclear new-build, where specialist expertise is thin and procedural caution tends to increase.[75]

Strategic Dependencies

Nuclear energy can create or preserve strategic dependencies related to fuel supply, technical designs, financing, maintenance, or digital control systems when these are concentrated in geopolitically risky supply chains. This is especially important for countries operating Russian-designed reactors. Bulgaria, Czechia, Finland, Hungary, and Slovakia have all depended to varying degrees on Russian nuclear fuel and services for Rosatom's VVER reactors. Russian reactor fuel assemblies are embedded in reactor design,

[74] Congressional Budget Office, *Nuclear Powerplant Lead Times*, Congress of the United States, 1978.

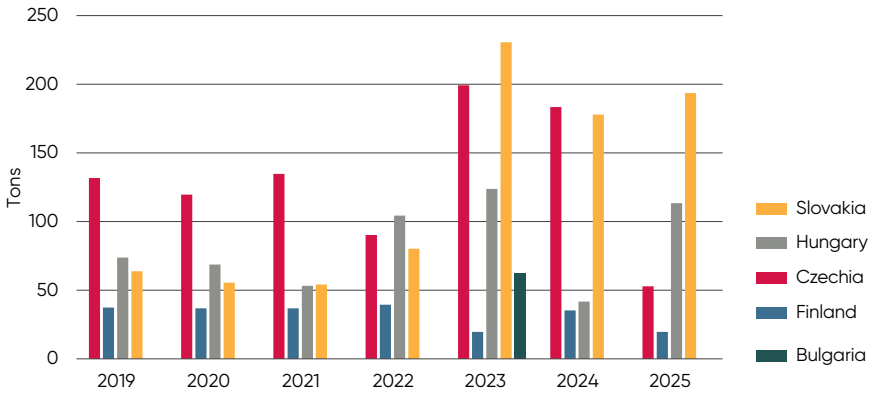
[75] Ministry of Industry and Trade of the Czech Republic, *SMR Roadmap for the Czech Republic: Applicability and Contribution to Economy*, 2025.

safety cases, reload patterns, operating procedures, transport arrangements, and regulatory approvals.[76]

The first strategic exposure concerns the fuel cycle and Russia. For European countries operating Russian-designed reactors, **dependence on Russian nuclear fuel is a technologically embedded constraint**. This is currently relevant for five EU members: Bulgaria, Czechia, Finland, Hungary and Slovakia. The exposure is not uniform. Bulgaria and Czechia's Temelín operate VVER-1000 units, where alternative Westinghouse fuel pathways are more advanced, while Finland, Hungary, Slovakia and Czechia's Dukovany operate VVER-440 units, where diversification is technically more complex and depends more heavily on European qualification efforts for non-Russian fuel. In all cases, **the dependency is embedded in a licensed fuel ecosystem built around TVEL assemblies**, core design, reload patterns, safety analysis, transport arrangements and operating procedures.

Several operators have moved to reduce this exposure. Bulgaria decided to replace the Russian nuclear fuel with supplies from Westinghouse[77] and Framatome. Czechia has also diversified the reactor fuel supply of the Temelín NPP, and Finland has begun introducing Westinghouse fuel at the Loviisa facility. Slovakia is also part of the European effort to qualify non-Russian fuel for VVER-440 reactors. Hungary remains the most exposed case because Paks continues to rely on the Russian reactor and fuel ecosystem, while Paks II would move the dependency from operational fuel supply into a new multi-decade package of Russian technology, finance, services and project governance.[78]

Figure 21. Dependence on Russian Nuclear Fuel Imports (tons), 2019–2025



Source: CSD based on Eurostat.

Switching supplier is therefore not captured by the commercial price of nuclear fuel. Alternative fuel has to be designed for the specific reactor type, tested through lead assemblies, incorporated into the safety case, reviewed

[76] Vladimirov et al., *The Last Stronghold*, Sofia: CSD, 2026.

[77] World Nuclear News, "Westinghouse Signs Agreement to Diversify Fuel Supply for Bulgarian Plant", December 23, 2024.

[78] World Nuclear News, "Framatome Signs VVER-440 Fuel Agreement with EU Utilities", April 9, 2026.

by the regulator and integrated into reload management without reducing availability. Operators also need transitional inventories, parallel supplier arrangements, additional analytical work, updated operating procedures and staff training. These costs are **front-loaded and organizationally demanding**, while the security benefit appears gradually through lower outage risk, weaker Russian leverage and greater resilience against sanctions, contract disruption or political coercion. The strategic comparison is between the near-term cost of technical diversification and the long-term cost of remaining inside a supplier ecosystem where fuel, documentation, services and licensing knowledge can be used as instruments of influence.

This dependence becomes deeper in new-build projects. Once a reactor vendor is selected, the relationship extends well beyond construction into long-term fuel supply, maintenance, spare parts, software systems, technical services and future upgrades. In projects built within the Rosatom ecosystem, fuel dependence, financing dependence and technological dependence are bundled together. The **Hungarian case** illustrates the mechanism clearly. Russian nuclear fuel imports increased sharply after 2022, while the Paks II project reinforced a multi-decade dependence on Russian reactor technology, Russian financing and the broader Russian service chain. Under such arrangements, the project embeds **a long-duration geopolitical dependency into the electricity system itself**.[79]

Apparent diversification can preserve Russian influence rather than eliminate it. **Framatome**'s role is the clearest example. In the short term, Framatome has pursued entry into the VVER fuel market through arrangements tied to TVEL, Rosatom's fuel subsidiary. Its Lingen project was designed around manufacturing Russian VVER fuel under TVEL license, and assessments of that model note that Rosatom would remain integral to the arrangement as license holder and sub-supplier. That structure does not produce a clean break from Russian dependence. It relocates part of fabrication into Europe while **preserving Russian technological leverage**, commercial influence and potential information access. Criticism in Germany has focused on that point, including concern over espionage risks, national security implications and the wider question of whether Rosatom would retain influence through board participation and voting rights on strategic decisions.

The problem is broader than fuel fabrication alone. Framatome's long-term cooperation with Rosatom extended explicitly to fuel fabrication[80] and **instrumentation and control technologies**. Assessments of that cooperation have pointed to strong mutual business interests between Framatome and Rosatom and to the possibility that Rosatom, in exchange for facilitating Framatome's entry into the VVER fuel market, could gain access to Framatome's higher-value technologies, particularly in instrumentation and control. Since instrumentation and control systems are effectively the brain and central nervous system of a nuclear plant, such cooperation matters well beyond routine industrial exchange. It creates another channel through which Russian influence can be sustained inside the European nuclear supply chain

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[79] Vladimirov et al., *The Last Stronghold*, Sofia: CSD, 2026.

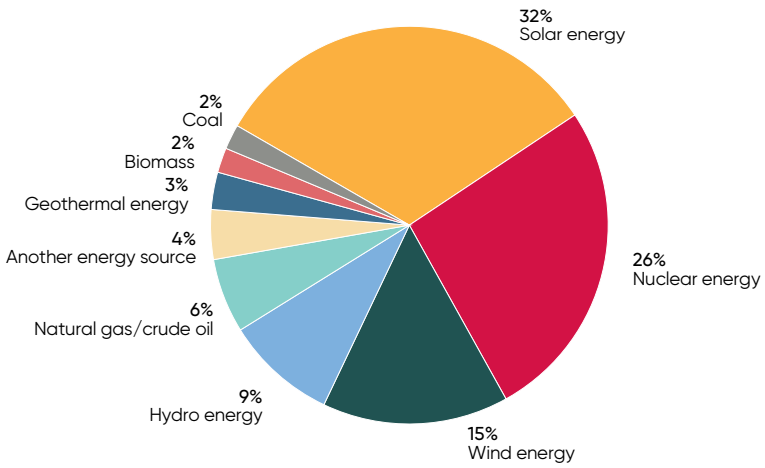
[80] European Nuclear Society, "Framatome and Rosatom Sign Strategic Cooperation Agreement", December 2, 2021.

under the label of diversification. In some parts of the VVER supply chain, Framatome is a vehicle through which Russian technological and commercial influence is preserved in European form.

The second exposure concerns **China and the wider technology supply chain**. China does not dominate Europe's nuclear reactor fleet in the way Russia dominates specific fuel and vendor ecosystems. Its leverage lies instead in manufacturing depth, materials processing and concentration across critical upstream and downstream segments of strategic technology supply chains. China supplies a large share of raw materials, processed materials, components and final assemblies across sectors central to the energy and industrial transition, including batteries, fuel cells, wind power, solar photovoltaics, electric motors, robotics and information and communication technologies. Its position is particularly **concentrated in processed materials and in downstream manufacturing**, especially in rare earth refining and permanent magnet production.[81]

For nuclear expansion, this matters because large-scale deployment depends on a broader industrial ecosystem, advanced manufacturing, electrical equipment, specialized materials, control systems, heavy engineering capacity and resilient supply chains. If Europe remains structurally dependent on China in critical materials, intermediate goods and high-value manufacturing segments, its ability to execute capital-intensive energy infrastructure at scale remains exposed to external disruption, strategic leverage and industrial bottlenecks. The issue is not only what enters the reactor core, but **whether Europe controls enough of the surrounding industrial base** to build and sustain complex low-carbon systems on its own terms.[82]

Figure 22. Public Preference for the Future Energy Mix of Europe, 2025



Source: CSD based on E.ON Foundation European Survey 2025.

[81] CSD, *Economic Security and Strategic Autonomy*, Policy Brief No. 156, March 2025.

[82] International Energy Agency, *Global Critical Minerals Outlook 2025,* Paris: IEA, 2025.

Another practical deployment constraint is public acceptance. Public perception and political economy matter because **nuclear development depends on the legitimacy of large, complex and highly visible decisions** taken over long-time horizons. Nuclear projects require large public commitments over several electoral cycles, and support depends on whether citizens see the project as transparent, well governed, affordable, and necessary for solving a real system problem. **Nuclear acceptance is strongest where it is linked to coal replacement**, industrial electricity security, reduced fossil fuel dependence, or firm low-carbon supply. It is weaker where nuclear is associated mainly with cost overruns, waste, opaque procurement, or political lock-in.[83]

Social acceptance depends also on whether the project implementation is seen as **transparent, competently governed and fair in the way risks and benefits are distributed**. European public opinion provides a mixed but usable mandate for nuclear. It is no longer a marginal public option, but it does not enjoy the low-friction legitimacy of solar. Nuclear ranks second among preferred future energy sources in the surveyed European countries, behind solar, which gives it a place in the public technology mix without making it the default public image of the transition.[84]

Nuclear acceptance is stronger where the technology is linked to coal replacement, industrial electricity security, firm low-carbon supply or reduced exposure to imported fuels. This explains why support is materially higher in Czechia, Bulgaria and Poland than in Germany or Spain.

Citizens may support public coordination of the transition, but they are unlikely to accept open-ended risk transfer to households or taxpayers. CfDs, RAB models, and state guarantees can strengthen legitimacy if they are presented as tools for lowering long-term costs and reducing exposure to fossil fuel volatility. They become **politically fragile when they appear to protect developers while socializing construction overruns**. Good governance, transparent procurement, clear risk allocation, and independent cost scrutiny are therefore essential to sustaining public support.

This is particularly important because nuclear projects extend across multiple electoral cycles and therefore require a degree of political continuity that many European systems struggle to sustain. This generates recurring policy uncertainty, especially when delays and cost overruns make public exposure more visible. **Procurement and governance quality become central under these conditions**. Where responsibilities between the state, developers, contractors and regulators are unclear, accountability weakens and disputes become more likely.

The workforce constraint is equally important. Nuclear expansion requires specialized engineers, safety analysts, regulators, welders, project managers, quality-control experts, operators, and supply-chain specialists. Europe still has a significant nuclear industrial base, but decades of limited new build have weakened training pipelines and practical construction experience. The sector

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[83] E.ON Foundation, *European Survey 2025: Attitudes towards the Energy Transition in Europe*, 2025.

[84] Ibid, p. 6 and p. 47.

may need up to 250,000 new recruits over the next two decades to support new build, lifetime extension, decommissioning, fuel-cycle diversification, and SMR development. France alone expects around 60,000 full-time recruitments by 2033, reflecting both retirements and growth needs.[85]

France has introduced a recruitment strategy, which focuses on a much wider industrial base: welders, pipefitters, technicians, IT specialists, project managers, product owners, safety specialists and operators. Around half of recruitment is expected to come from experienced profiles, while interns and apprentices account for a quarter of the recruitment effort. This composition matters because nuclear delivery depends on experienced personnel who can manage interfaces between engineering, regulation, procurement and construction, but also on early-career pipelines that can preserve skills over several decades. If the sector relies too heavily on experienced workers, it competes with other high-technology and infrastructure sectors. If it relies too heavily on new entrants, it increases training and supervision needs during the very period when projects require execution discipline.

In many European countries, decades of limited new-build activity weakened the educational and training infrastructure needed to reproduce nuclear expertise over time. Universities narrowed specialized programs, research ecosystems contracted and opportunities to develop project-based construction experience declined. France is responding by linking recruitment to high schools, apprenticeships, technical training centers, universities and regional partnerships, while EDF reports nearly 700 internal training program and simulator-based trainings at each nuclear power plant. A nuclear program that does not secure the training pipeline before construction begins will face higher dependence on vendors, foreign contractors and external project-management capacity.

The UK provides a useful illustrative case because it has one of the most detailed recent workforce assessments, although it is no longer an EU member state. Its nuclear workforce increased by 15% in one year, from 83,000 to 96,000, yet projected demand reaches 120,000 by 2030.[86] The relevance of the example is structural: even in a country with an established nuclear sector and active workforce planning, new build, operations, decommissioning, regulation and defense schemes draw on overlapping pools of engineers, project managers, safety specialists and qualified technicians. The UK case therefore confirms the same pattern visible in France and across Europe, which is that nuclear expansion does not draw on spare capacity, but on a workforce already required for existing operations, legacy management, regulatory oversight and long-term industrial renewal.

For the EU, the constraint appears through the interaction between ageing fleets, lifetime extension and limited construction continuity. Large nuclear countries face a retention and renewal problem, while smaller or restarting programs face a capability-building problem. France has the largest nuclear

[85] European Nuclear Society, "Projects, Innovations, Workforce and Talents – How Will the Nuclear of the Future Cope with Them? Interview with Patrick Bossaert, HR Director for New Nuclear Project at EDF", *Nuclear Focus*, 2026.

[86] Cogent Skills, *Nuclear Workforce Assessment*, March 2025.

workforce base in Europe, but must replenish skills while maintaining 56 reactors, preparing new projects and delivering a large modernization agenda. Central and Eastern European countries face a different version of the same constraint. Poland, Romania and Bulgaria are seeking to develop or expand nuclear programs while also building regulatory capacity, educating new specialists and reducing dependence on external vendors.

Limited specialist capacity slows design work, safety documentation, regulatory review, construction productivity, and project oversight. Smaller or restarting nuclear programs, such as Poland, Romania, and Bulgaria, face the additional challenge of building national regulatory and technical capacity while relying on foreign vendors. Without **a coordinated European skills strategy** linking universities, vocational training, operators, regulators, and suppliers, nuclear expansion will face higher costs, longer timelines, and deeper dependence on external industrial ecosystems.

The Future System: SMRs, Flexibility, and Hybrid Grids

Europe's electricity system is entering a new and dynamic phase. Electrification is expanding in transport, buildings, cooling, digital infrastructure and selected industrial processes. Efficiency gains, industrial restructuring, demographic decline, population ageing and shifts in the geography of production are changing where demand appears, how quickly it grows and what kind of energy service it requires. The **value of new generation depends increasingly on scale, location, operating profile, grid availability, and industrial offtake**.

That is why, the role of large baseload projects is changing because the system conditions under which that capacity is added have become more complex. Renewable penetration is creating more hours of low or negative prices, while grid congestion prevents low-cost electricity from moving easily from surplus regions to demand centers. In addition, industrial electrification is advancing unevenly, creating uncertainty about the level of demand for new generation capacity. In this environment, a large nuclear reactor can still deliver major system value where grids, demand and financing capacity are strong enough to absorb it. The difficulty is that gigawatt-scale additions **concentrate construction risk, financial exposure and system-integration requirements in a single asset**.[87]

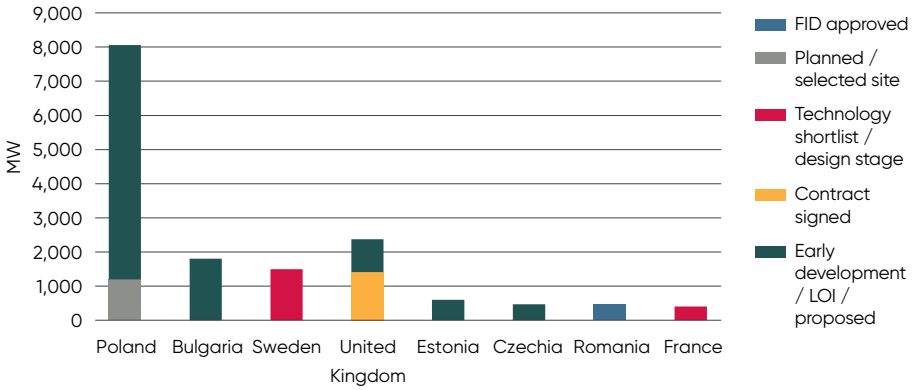
Conventional nuclear has not lost its strategic relevance, since large reactors remain important for the stability of the system. The problem, however, is scalability under current European conditions. That is why **SMRs can deliver a more efficient middle-ground pathway for nuclear energy uptake in Europe**. SMRs preserve the core function of nuclear, firm low-carbon supply across the load curve, while reducing the scale of each investment decision. Smaller units can be matched more closely to industrial clusters, district heating systems, hydrogen production, data centers, regional grids and phased electrification. This does not remove the overall nuclear risk, but **reduces the exposure created when a single large asset arrives late, over budget or ahead of demand**. SMRs also reduce that exposure by making

[87] European Commission Joint Research Centre, *Nuclear Power in the European Union: 2025 Status Report on Technology Development, Trends, Value Chains and Markets*, Publications Office of the European Union, 2026.

investment more divisible and by allowing deployment to follow system development in stages. Their advantage is the ability to reduce the cost of mistiming and to align firm low-carbon capacity with more granular system needs.

The advantage of SMRs remains conditional because they do not automatically solve the cost, delivery and licensing problems of nuclear. Smaller reactors can lose economies of scale, face higher costs per unit of capacity and require new licensing pathways, supply chains, factory capacity, fuel arrangements and operating models. If each SMR project is still designed, licensed and procured as a bespoke national project, the technology will reproduce many of the uncertainties of large nuclear at smaller scale. If designs are standardized, regulatory review becomes more repeatable, manufacturing is organized around serial production and supply chains learn across units, **smaller scale can reduce delivery uncertainty and financing premiums**. The decisive issue is whether Europe can move from project-by-project deployment to portfolio-based deployment.

Figure 23. Planned SMR Capacity (in MW) in Europe by Project Development Stage



Source: CSD based on World Nuclear Association, Small Modular Reactor (SMR) Design Database.

Existing SMR projects offer useful but limited lessons. Russia's "Akademik Lomonosov" project[88], a floating nuclear power plant operating commercially in the Arctic has shown that small reactors can provide electricity and heat where demand is difficult to serve through conventional grid expansion. SMRs have their clearest early value where **the demand case is concrete**, especially where electricity, heat and industrial supply can be combined in a system that cannot efficiently absorb or access large central generation.

China provides a second, more industrially relevant lesson through the HTR-PM at Shidaowan[89], which has moved into commercial operation, and the ACP100 Linglong One in Hainan, which is advancing as a land-based SMR project. Even in state-backed systems with deep industrial capacity, SMRs require supply-chain readiness, regulatory continuity and a program logic that allows learning to accumulate. SMRs will not become credible projects in

[88] Floating Nuclear Power Plant, Akademik Lomonosov Floating Nuclear Power Plant, FNPP.info.

[89] World Nuclear Association, Shidaowan HTR-PM 1, World Nuclear Reactor Database.

Europe only if they are embedded in an industrial model capable of repeating designs, qualifying suppliers and reducing uncertainty across successive units.

The system value of SMRs is clearer when they are part of a hybrid grid. Europe's future electricity system will combine renewables, storage, interconnection, demand-side management, hydrogen and firm low-carbon generation. Renewables provide large volumes of low-marginal-cost electricity. Storage shifts output across short periods. Demand response reduces peak stress. Hydrogen connects low-carbon electricity to industrial uses that cannot be served entirely through direct electrification. SMRs fit this architecture if they **provide stable supply at a scale that is easier to combine with industrial clusters**, district heating networks, hydrogen production and regional grids than a very large conventional unit.

SMRs will also reduce the need for fossil backup in the hours and locations where renewable output and industrial demand do not align. In a hybrid system, an SMR can supply steady electricity to an industrial cluster, provide heat or steam, support hydrogen production when electricity demand is lower and stabilize regional grids when renewable output falls. This improves the utilization of low-carbon assets because **electricity, heat and molecules can be matched to different demand profiles** rather than forcing all output through the wholesale power market.

Hence, SMRs can provide a much-needed boost to solving Europe's competitiveness problem. Chemicals, metals, hydrogen, process heat, data centres and district heating require predictable low-carbon electricity, heat or steam over long contracting horizons without being able to absorb gigawatt-scale output. SMRs could be better aligned with this demand structure because they can be located closer to industrial use, scaled to regional load, combined with renewables and storage, and integrated into heat or hydrogen systems.

SMRs still bring significant constraints including unproven commercial deployment in Europe, uncertain cost curves, licensing fragmentation, fuel-cycle questions, factory-capacity requirements and the need for serial orders before learning effects appear. Europe should avoid both overclaiming and underusing SMRs. They could become **a strategic complement if deployed through standardized designs and long-term offtake structures**.

BUILDING EUROPE'S OPTIMAL ENERGY MIX

The findings of the 2026 *Energy and Climate Security Risk Index* demonstrate that Europe's energy vulnerabilities are structural. The disruption caused by the conflict in Iran exposed how dependent the European economy remains on imported fossil fuels, volatile LNG markets, and external geopolitical developments. At the same time, persistent electricity price disparities between Europe, the United States, and China continue to undermine industrial competitiveness and investment across the continent. Europe needs to **redesign an energy system capable of delivering affordable, reliable, and low-carbon electricity at industrial scale** while reducing strategic dependencies and strengthening economic resilience.

The ECSRI results show that **the strongest-performing countries combine a diversified low-carbon generation mix**, modern infrastructure, high system flexibility, and stable long-term industrial planning. In particular, countries integrating nuclear energy alongside renewable generation consistently achieve stronger outcomes across affordability, reliability, geopolitical exposure, and sustainability.

Reforming Electricity Market Design

European electricity markets remain heavily influenced by short-term marginal pricing, where natural gas continues to determine electricity prices in a large share of hours even in increasingly decarbonized systems. This model **amplified the effects of both the Russian gas crisis and the 2026 LNG disruption linked to the Strait of Hormuz**. Europe needs a market structure capable of reducing the transmission of fossil fuel volatility into electricity prices while supporting long-term investment in low-carbon infrastructure.

Electricity market reform should **prioritize long-term price stability and investment certainty** rather than short-term spot market optimization alone. Long-term contracts, including two-way CfDs, regulated asset base models, and industrial power purchase agreements, should be expanded to support both renewable and nuclear generation. Such mechanisms would lower financing costs, stabilize industrial electricity prices, and **reduce exposure to gas market volatility**.

At the same time, electricity market design must better reflect system value rather than only marginal generation costs. Firm low-carbon generation capable of supporting system stability, industrial baseload demand, and security of supply should be **appropriately remunerated within capacity and flexibility mechanisms**. Current market structures often undervalue dispatchable low-carbon technologies, particularly nuclear energy, despite their contribution to price stability and system adequacy during periods of renewable intermittency or supply shocks.

The EU should also **accelerate regional electricity market integration**, which will improve cross-border balancing, reduce congestion costs, and optimize infrastructure utilization. Fragmented national market interventions

introduced during the energy crisis weakened investment predictability and undermined coordinated energy planning. Greater harmonization of capacity mechanisms, balancing markets, and flexibility services is necessary to **strengthen long-term reliability across the European electricity system**.

European governments should also **move from fragmented project-by-project negotiations toward program-based deployment**. Common legal templates, procurement models, financing structures, and contractor frameworks would lower transaction costs, accelerate replication, and **improve investor confidence through standardization and predictability**. Europe's future competitiveness will depend on building out clean energy technologies faster, more consistently, and at lower financing cost.

Financing Nuclear Deployment at Scale

Europe's current financing environment remains poorly suited to the deployment of capital-intensive nuclear infrastructure despite its strategic contribution to affordability, reliability, decarbonization, and industrial competitiveness. High upfront capital requirements, long construction periods, regulatory uncertainty, and fragmented national procurement structures continue to raise the cost of capital for new projects. Europe needs financing frameworks that **reduce risk without weakening construction discipline or transferring unlimited liabilities to taxpayers and consumers**.

Europe needs dedicated financing instruments capable of reducing the cost of capital for nuclear deployment, particularly for projects contributing to strategic energy security objectives. The European Investment Bank should expand eligibility for nuclear financing under strategic autonomy, decarbonization, and industrial resilience frameworks. Nuclear energy should be fully integrated into long-term energy security planning rather than treated as an exceptional or transitional technology.

CfDs remain appropriate where long-term electricity price uncertainty is the primary constraint, while Regulated Asset Base models may be justified for large-scale projects where reducing interest during construction is essential. However, financing support should be conditional on design maturity, licensing clarity, supply-chain readiness, realistic construction planning, and transparent governance. European-level guarantee facilities can significantly **reduce borrowing costs and improve investment bankability**. Without such reforms, Europe risks prolonging **dependence on volatile gas-fired generation** due to the inability to mobilize long-term capital for low-carbon baseload infrastructure.

There is a need to **expand portfolio-level financing instruments** rather than negotiating each reactor individually from zero. Pooling financing structures across multiple projects would reduce financing friction, strengthen investor confidence, and lower borrowing costs across the broader European build-out plan. Europe needs **stronger institutional learning mechanisms**. Euratom should create a special data repository containing all the necessary data from major nuclear and power-sector projects so that the EU can systematically track licensing delays, supply-chain bottlenecks, labor shortages, contractor disputes, module delivery failures, and interface-management problems.

This would help **reduce repeated execution failures and improve delivery quality across future projects**.

Particular attention should be given to supporting the development and commercialization of SMRs and advanced nuclear technologies. These technologies could improve deployment flexibility, reduce financing risk, support industrial decarbonization, and strengthen energy security in regions with constrained grid infrastructure or growing electricity demand. The EU should **accelerate regulatory harmonization and licensing cooperation for SMRs** to avoid fragmented national approaches that delay deployment and weaken industrial scalability.

At the same time, financing frameworks should **support lifetime extensions and modernization of existing nuclear fleets** where technically feasible and economically justified. Maintaining existing low-carbon generation capacity remains one of the most cost-effective ways to reduce gas demand and stabilize electricity prices during the transition period.

Strengthening Supply Chain Security

The energy transition is reducing some geopolitical vulnerabilities while creating new ones. Europe's dependence on imported fossil fuels is increasingly being replaced by dependence on critical raw materials, batteries, solar manufacturing, semiconductors, and nuclear fuel services. The concentration of many of these **supply chains in China and Russia creates a new layer of strategic exposure that directly affects Europe's industrial resilience and energy security.**

Reducing these vulnerabilities requires diversification across the full low-carbon industrial ecosystem. Europe should accelerate domestic processing of critical raw materials, strengthen recycling and circular economy capacity, and **deepen strategic partnerships with allied supplier countries**. Nuclear fuel diversification must also remain a priority for countries operating Russian-designed reactors, particularly through the accelerated qualification of non-Russian fuel assemblies and the development of independent European fuel-cycle capabilities.

Member states should **expand their domestic manufacturing capacity** across key clean technology sectors, including batteries, grid equipment, hydrogen technologies, advanced reactors, and power electronics. Europe's competitiveness challenge increasingly reflects weaker industrial scale in strategic technologies compared to the US and China. Industrial policy instruments should therefore prioritize strategic energy technologies capable of strengthening both decarbonization and economic resilience.

Accelerating System Integration and Infrastructure Modernization

The rapid expansion of renewable energy generation after 2022 exposed major weaknesses in Europe's electricity infrastructure. Grid congestion, insufficient interconnection capacity, limited storage deployment, and inadequate balancing infrastructure increasingly constrain system reliability and market efficiency.

It is crucial to **accelerate investment in transmission and distribution infrastructure at unprecedented scale**. Electrification of transport, heating, data centers, industry, and hydrogen production will substantially increase electricity demand over the coming decades, requiring a fundamental expansion of grid capacity and system flexibility. Delays in grid modernization increasingly represent one of the largest bottlenecks to both renewable deployment and industrial electrification. Europe should **accelerate permitting for transmission infrastructure**, modernise distribution networks, and improve cross-border electricity integration to strengthen resilience against both market volatility and physical disruption. Priority should be given to strengthening infrastructure integration between Central and Eastern Europe and the rest of the EU, where infrastructure fragmentation continues to increase both affordability and geopolitical risks.

There is a need to **accelerate energy storage deployment** including batteries, thermal and hydrogen systems, as well as pumped hydro power plants, which are all necessary to support high-renewable electricity systems while preserving reliability.

However, flexibility infrastructure alone will not fully eliminate system stability risks associated with weather-dependent generation. Europe should pursue a co-optimized energy system in which nuclear energy and renewables operate as complementary rather than competing technologies. Systems integrating both technologies achieve stronger resilience against fuel price volatility, lower emissions intensity, and improved long-term affordability outcomes.

Europe's long-term energy security will depend on **designing integrated electricity systems** capable of balancing affordability, reliability, sustainability, and strategic sovereignty simultaneously. The countries that succeed in building such systems will be best positioned to **maintain industrial competitiveness and economic resilience** in an increasingly fragmented global economy.