

EU STRATEGIC AUTONOMY: COMPARING GERMAN OFFSHORE WIND AND PORTUGUESE HYDROPOWER

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ABSTRACT

This research investigates the mechanisms through which the European Union (EU) pursues strategic autonomy in the energy sector by examining the contrasting renewable energy trajectories of Germany and Portugal. The central research question explores how specific national strategies in offshore wind and hydropower influence the broader geopolitical leverage and energy security of the EU. Utilising the Renewable Energy Leadership Model, this study evaluates the transition through the three analytical pillars of policy enablers, infrastructure modernization, and industrial innovation. The paper employs a qualitative comparative case study design. The findings indicate that Germany represents a scale-focused pathway characterized by the rapid expansion of frontier offshore wind technology. Conversely, Portugal exemplifies a stability-focused pathway that leverages the modernisation of mature hydropower assets for grid flexibility and storage. The analysis suggests a conceptual complementarity between the German generation and Portuguese pumped storage capabilities. However, the study identifies critical structural barriers, most notably the lack of cross-border interconnections and persistent regulatory fragmentation. This comparative analysis concludes that individual national advancements are insufficient to achieve collective strategic autonomy without significant investment in trans-European infrastructure.

KEYWORDS: Renewable Energy Leadership, Offshore Wind, Hydropower Innovation, EU Energy Transition, Germany-Portugal Synergies.

INTRODUCTION

The European Union has set ambitious long-term goals for climate neutrality and greenhouse gas emission reductions. The REPowerEU strategy, which gained momentum after the geopolitical shifts of 2022, significantly increased the bloc's renewable energy targets for the end of this decade. This policy transformation is not merely an environmental measure. It is fundamentally a geopolitical response to reduce dependence on fossil fuel imports from external suppliers, particularly following disruptions to traditional energy trade routes. Renewable energy has therefore become central to what the EU defines as strategic autonomy, meaning the capacity to act independently in critical

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sectors such as energy supply and infrastructure. However, the energy transition requires member states to deploy very different renewable assets based on their natural endowments and industrial capabilities. This paper will discuss: How do contrasting national renewable energy strategies in Germany and Portugal shape the EU's geopolitical leverage and energy security?

Existing scholarship has extensively examined national energy transitions across Europe, yet most studies focus either on single renewable technologies or on broad EU governance mechanisms. Researchers have analysed energy sovereignty, policy fragmentation, and the limits of European integration in the energy sector. Other authors assess offshore wind development in Northern Europe or hydropower systems in the Iberian Peninsula as separate topics. Few comparative studies systematically link specific member state innovations to the concept of EU strategic autonomy from a geopolitical perspective. The analytical gap this paper fills is a systematic comparison of two contrasting but complementary renewable leadership models. These models are German offshore wind and Portuguese hydropower. They are examined within a unified framework that connects technical innovation to geopolitical leverage, energy diversification, and reduced external dependence.

Germany and Portugal illustrate two pivotal, distinct pathways toward this shared European objective. Germany has positioned itself as a primary driver of frontier technology by scaling massive offshore wind capacity through aggressive industrial policy and regulatory expansion. Conversely, Portugal exemplifies a strategy focused on the modernization of mature hydropower infrastructure, particularly through advanced pumped storage facilities that provide essential grid stability and flexibility. The Tâmega hydropower complex represents a notable example of this strategy. These two nations offer a valuable comparative study: one focuses on the rapid expansion of generation capacity, while the other emphasizes the infrastructure required to manage intermittency and storage. Together, they illustrate how diverse domestic specializations can converge to form a more resilient and autonomous European energy system.

This research employs the Renewable Energy Leadership Model to evaluate these two cases systematically across three pillars. These pillars are policy enablers, infrastructure modernisation, and industrial innovation. The study uses a qualitative comparative case study design. It draws on peer-reviewed articles, official European statistical data, and European Commission policy documents. The following sections analyse Germany's offshore wind policies and Portugal's hydropower modernisation. They then compare their complementarities and geopolitical implications. Ultimately, this paper contributes a methodologically grounded assessment of how diverse renewable assets can be integrated into a coherent framework for European strategic autonomy in the renewable energy transition. The findings aim to inform policy discussions on energy security and cross-border cooperation within the EU.

CONCEPTUAL FRAMEWORK: RENEWABLE ENERGY LEADERSHIP MODEL (RELM)

The Renewable Energy Leadership Model (RELM) is a theoretical framework developed for this study to analyse how individual member states can translate domestic renewable energy projects into a collective asset that enhances the European Union's strategic autonomy. It is not a pre-existing model from the literature but an original analytical construct synthesized from core principles of energy governance, geopolitical studies, and innovation theory. The model is built on the understanding that energy leadership in the 21st century is not defined solely by a nation's installed capacity or technological sophistication. Instead, leadership is conceptualized as the capacity to create self-sustaining ecosystems where regulatory foresight, industrial advancement, and grid modernization converge to generate not only environmental benefits but also tangible geopolitical leverage. This involves reducing external energy dependencies, diversifying supply chains, and enhancing the bloc's resilience against coercive diplomacy from third countries (Elmastini & Abdessamad, 2024). By operationalizing three interdependent pillars, policy enablers, infrastructure modernisation, and technological innovation, the RELM provides a structured lens to assess and compare the contributions of different national energy strategies to the overarching goal of EU strategic autonomy. This framework is cemented through the European Union's binding climate targets and policy instruments. The pursuit of a 55 percent reduction in greenhouse gas emissions by 2030 and climate neutrality by 2050 provides the operational context for the RELM. These goals are reinforced through the REPowerEU strategy and its renewable energy target of 45% in the EU's final energy consumption by 2030, with an ambition to reach 50%, as part of accelerating the clean energy transition in response to the energy crisis following Russia's invasion of Ukraine (EESC, 2022).

The first pillar, policy enablers, examines the regulatory environments that facilitate rapid technological deployment within the Union. In the context of established European strategies, this includes the creation of specialized zones and streamlined permitting processes intended to bypass administrative bottlenecks. Scholarly discourse suggests that the velocity of such regulatory shifts is a primary determinant of a nation's ability to project leadership within the climate governance architecture of the bloc. This pillar is not merely an administrative exercise; it represents a strategic tool used to set transnational standards that minimize market fragmentation and harmonize cross-border energy flows. By establishing a clear legal pathway, member states ensure their domestic transitions contribute to collective security.

Simultaneously, the infrastructure modernisation pillar advances initiatives like the Trans-European Networks for Energy (TEN-E), which build the interconnections critical to balancing the inherent intermittency of renewables. This pillar addresses the physical and technical requirements of a resilient energy system, including the integration of high-capacity storage solutions and the expansion of cross-border transmission networks. In geopolitical terms, infrastructure integration functions as a "security of supply" mechanism. By building a redundant and interconnected grid, the EU can mitigate the risks of localized energy shortages, thereby decreasing the bloc's vulnerability to external supply disruptions or coercive energy diplomacy. The third pillar, technological innovation,

focuses on the scaling of frontier technologies from laboratory research to commercial dominance on a global scale. This pillar evaluates how public and private investments foster competitive advantages in the green technology market, ensuring that the transition does not trade one form of external dependency for another (Olugboyega et al., 2024). Despite the proliferation of literature on the European Green Deal, a significant analytical gap remains regarding how specific national infrastructure archetypes link to the broader geopolitical goal of autonomy. This paper fills that gap by utilizing the RELM to synthesize technical, regulatory, and geopolitical variables. By examining the synergy between different energy profiles, the study contributes a systematic framework that moves beyond isolated technology assessments toward a geopolitically informed analysis of energy diversification.

CASE STUDY ONE: GERMAN OFFSHORE WIND

➤ NATIONAL CONTEXT AND STRATEGIC AMBITION

Germany has positioned itself as a leading actor in European offshore wind through progressively ambitious capacity targets. The Offshore Wind Energy Act legally defines expansion targets of 30 gigawatts by 2030, 40 gigawatts by 2035, and 70 gigawatts by 2045 (Lehneis, Manske, & Thrän, 2021). As of 2024, installed offshore wind capacity stood at approximately 9 gigawatts, meaning that achieving the 2030 target would require an additional 21 gigawatts to be connected within a few years. This expansion forms a cornerstone of Germany's *Energiewende*, which legally mandates at least a 65 percent reduction in greenhouse gas emissions by 2030 and climate neutrality by 2045 (Schreiber, Zapp, Wulf, & Reitz, 2025). Within the broader EU framework, Germany's offshore wind ambitions directly support REPowerEU's goal of reducing external fossil fuel dependence. Table 1.1 below outlines Germany's offshore wind capacity targets from 2024 to 2045, highlighting key milestones including installed capacity, projected growth, and its role in meeting national energy demand. It emphasizes the country's strategic commitment to scale offshore wind as a core pillar of its *Energiewende*.

Year	Target Capacity	Key Milestones
2024	9.2 GW	1,639 turbines operational
2030	30 GW	Quadrupling current capacity
2035	40 GW	45% of national power demand
2045	70 GW	82 GW technical potential in German waters

Table 1.1: Germany's Offshore Wind Expansion Targets (Deutsche WindGuard GmbH, 2024).

➤ RELM ANALYSIS: POLICY ENABLERS

The RELM framework's policy enablers pillar evaluates regulatory support using measurable criteria such as auction outcomes, permitting timelines, and subsidy mechanisms. Germany's Offshore Wind Energy Act (WindSeeG), enacted in 2017 and amended in 2022, mandates site planning and competitive auctions for development rights. This legislation has driven market maturity, with 2023-2024 auctions allocating 4 gigawatts at average bids below 5-euro cents per kilowatt-hour, reflecting cost reductions from 130 euros per megawatt-hour in 2017 to under 50 euros by 2024 (Fehling, 2025).

The zero-subsidy model, introduced in 2021, encourages developers to bid for low strike prices without direct support, aligning with EU state aid rules. However, recent tenders highlight challenges.

In June 2025, the N-9.4 site auction for up to 1.2 gigawatts drew only two zero-subsidy bids, with TotalEnergies winning at 180 million euros, or 180,000 euros per megawatt, down from 1.3 million euros per megawatt in 2024. The August 2025 tender for N-10.1 and N-10.2 sites, totaling 2.5 gigawatts, received no bids due to rising costs, supply chain issues, and market volatility (Wojtaszek et al., 2025). Debates favor shifting to two-sided contracts for difference, as in other European nations, to stabilize revenues and lower financing costs amid price fluctuations. Permitting acceleration under REPowerEU has shortened environmental reviews to under 12 months via digital processes, approving 7 gigawatts by late 2024 and achieving tender success rates above 90 percent (Al-Dabbas, 2024). These measures demonstrate policy alignment with EU targets, though adaptations are needed to sustain investor confidence.

➤ **RELM ANALYSIS: INFRASTRUCTURE MODERNISATION**

Infrastructure modernisation in the RELM framework assesses grid expansion and curtailment mitigation through metrics like interconnection capacity and loss rates. Germany's North Sea and Baltic Sea connections provide a core structure, with high-voltage direct current lines such as BorWin and DolWin operational since 2020, enabling up to 2.8 gigawatts of export. Planned extensions target 10 gigawatts by 2025, linking to EU interconnectors via the North Sea Energy Cooperation (Fliegner et al., 2025). A key challenge is the north-south transmission bottleneck, where northern offshore wind meets southern demand centers. The SuedLink project, a 700-kilometer line adding 4 gigawatts, addresses this but faces delays from opposition and approvals, with completion now set for 2028 and average project lags of 3.2 years per a 2025 study. Curtailment rates for offshore output stand at 2 to 5 percent, reduced from 10 percent in 2020 via meshed grids, though cabling delays persist. REPowerEU's 20 billion euros in funding aims for zero net curtailment by 2030 using smart technologies (Pavlenko & Cherp, 2026).

➤ **RELM ANALYSIS: INDUSTRIAL INNOVATION**

Industrial innovation in the RELM framework measures progress through domestic content ratios, research and development spending, and employment generation. Turbine production hubs in Cuxhaven and Bremerhaven produce 12 to 15 megawatt units, with Siemens Energy and Vestas leading in deep-sea applications. Port upgrades at Wilhelmshaven since 2023 support vessels for 20 gigawatts of annual capacity. A 2025 industry study reports 14.6 billion euros in gross value added, sustaining 31,530 full-time equivalent jobs and 49,000 positions nationwide, concentrated in North Rhine-Westphalia and Baden-Württemberg. Supply chain risks loom large, with China providing 80 to 90 percent of rare earth magnets. Initiatives include recycling 20 percent of neodymium from retired turbines by 2025 and the EU Critical Raw Materials Act to curb 40 percent non-EU component reliance. An August 2025 resilience roadmap targets 30 percent alternative magnet sources by 2030 and 50 percent by 2035. Research investments hit 1.5 billion euros in 2024, emphasising floating platforms (Deutsche WindGuard GmbH, 2025).

➤ **GEOPOLITICAL CONTRIBUTION OF GERMAN OFFSHORE WIND**

Germany's offshore wind expansion contributes to EU strategic autonomy through two mechanisms. First, large-scale domestic renewable generation directly reduces reliance on imported natural gas, lowering the EU's vulnerability to external supply disruptions. Second, Germany's industrial leadership in turbine manufacturing and project development strengthens the EU's competitive position in the global renewable energy market. However, this contribution faces clear limits. Without adequate cross-border interconnection capacity, German offshore wind cannot reliably supply other EU member states. The absence of sufficient north-south transmission within Germany also means that even domestic industrial consumers in southern regions may not receive wind-generated electricity. Furthermore, the high dependence on Chinese rare earth magnets for turbine production creates a new form of external dependency. As German offshore wind capacity expands, this dependency is expected to grow unless alternative supply chains are developed.

Germany's case demonstrates that achieving EU strategic autonomy through renewable energy requires more than technological ambition and large-scale targets. The country has successfully established offshore wind as a major industrial sector with significant economic value and employment. However, regulatory instability in auction design, persistent infrastructure bottlenecks, and supply chain vulnerabilities all constrain the geopolitical contribution of German offshore wind. The failure of the August 2025 tender to attract any bids signals that even a market leader with world-leading targets can struggle to maintain momentum. For Germany to fully realise its potential as a scale-focused pathway to EU energy security, coordinated reforms are needed across policy frameworks, grid infrastructure, and industrial supply chains.

CASE STUDY TWO: PORTUGUESE HYDROPOWER

➤ **NATIONAL CONTEXT AND STRATEGIC AMBITION**

Portugal has emerged as a European leader in renewable electricity generation, with hydropower playing a central and enduring role. According to study data, renewable sources consistently account for more than 70 percent of Portugal's annual electricity production, placing the country among the top performers in the European Union (Koroleva, 2025). Hydropower remains the backbone of this system, providing flexible, dispatchable generation that complements variable wind and solar capacity. The Portuguese National Energy and Climate Plan for 2030 targets 80 percent renewable electricity and a 55 percent reduction in greenhouse gas emissions from 2005 levels, with carbon neutrality to be achieved by 2045 (Silva et al., 2024). Energy storage, particularly pumped hydropower, is explicitly prioritised as the primary technology for grid stabilisation. Within the REPowerEU framework, Portugal's strategy contributes to reducing natural gas dependence on the Iberian Peninsula, though its isolation from central European markets limits broader geopolitical impact.

➤ **RELM ANALYSIS: POLICY ENABLERS (PORTUGAL)**

Portugal's regulatory environment has been characterised by long-term stability and broad political consensus on renewable energy development. The country introduced feed-in tariffs for hydropower and other renewables in the early 2000s, typically offering

15 to 20-year power purchase agreements that provided revenue certainty for investors. This stable framework allowed Portugal to attract consistent investment in hydropower modernisation and expansion over two decades. More recently, Decree Law 15/2022 streamlined licensing procedures for hybrid projects and storage facilities, setting shorter deadlines for environmental assessments. (Díaz-Cuevas et al., 2025). However, the feed-in-tariff system is now maturing, and a transition towards competitive market arrangements is underway. This shift introduces new financing challenges for repowering decisions on existing hydropower assets.

➤ **RELM ANALYSIS: INFRASTRUCTURE MODERNISATION (PORTUGAL)**

The centrepiece of Portugal's hydropower modernisation is the Tâmega hydropower complex. Located in northern Portugal, this facility has a total installed capacity of 1,158 megawatts across three plants, including 880 megawatts of new pumped storage capacity (Giorgi, 2025). The Gouvães plant houses reversible turbines that can switch between pumping and generating modes within minutes. The complex stores up to 40 gigawatt-hours of energy, sufficient to supply approximately 2 million Portuguese households for a full day. Total investment exceeded 1.5 billion euros. This infrastructure enables Portugal to store surplus wind and solar generation during low-demand periods and release it during peak hours, effectively functioning as a large-scale battery for the national grid. The critical weakness of Portugal's infrastructure is its low interconnection capacity with the rest of the European Union. The Iberian Peninsula currently has cross-border transmission capacity of only 2.5 gigawatts connecting Spain and France, far below the EU target of at least 15 percent of installed production capacity by 2030. The European Investment Bank has committed 1.6 billion euros to finance the Bay of Biscay interconnection, which will increase exchange capacity to 5 gigawatts (Iglesias et al., 2025). This project is scheduled for completion in 2028. However, even the improved capacity will remain well below the level needed for Portugal to reliably export stored hydropower to central European markets such as Germany. Until this bottleneck is resolved, Portugal's infrastructure modernisation will primarily benefit the domestic and Iberian market rather than EU-wide strategic autonomy.

➤ **RELM ANALYSIS: INDUSTRIAL INNOVATION (PORTUGAL)**

Portugal's approach to industrial innovation focuses on modernising mature hydropower assets rather than developing frontier technologies. Key innovations include digitalisation of reservoir management using artificial intelligence for predictive maintenance and real-time optimisation. Retrofitting existing plants with adjustable speed turbines has improved efficiency across variable flow conditions. Hybrid projects that integrate solar photovoltaic panels into hydropower reservoirs leverage existing grid connections. A notable example is the Alqueva plant, which added solar capacity alongside its hydroelectric generation (Felgueiras et al., 2026). These innovations allow Portugal to extract maximum value from its existing hydropower fleet while maintaining grid stability as wind and solar shares continue to rise. The complementarity between pumped storage and variable renewables is the central contribution of Portuguese industrial innovation to the energy transition.

➤ **GEOPOLITICAL CONTRIBUTION OF PORTUGUESE HYDROPOWER**

Portuguese hydropower contributes to EU strategic autonomy through two mechanisms. First, the flexibility provided by pumped storage enables higher penetration of variable renewables on the Iberian Peninsula, reducing the need for natural gas-fired backup generation and thereby lowering fossil fuel import dependence. Second, the Tâmega complex demonstrates a replicable model for integrating large-scale storage into a high-renewable-electricity system, offering lessons for other member states. The principal limitation is geographic and infrastructural. Without adequate cross-border interconnection capacity, the stored energy in Portuguese hydropower cannot be reliably delivered to central European markets where it could backstop intermittent generation from sources such as German offshore wind. The hoped-for synergy between Portuguese storage and German scale generation remains conditional on future investment in transmission links across the Pyrenees. Pending such investment, Portugal's geopolitical contribution will remain largely regional rather than EU-wide. Portugal exemplifies a stability and storage-focused pathway to renewable energy integration. The country has successfully modernised its hydropower fleet, with the Tâmega complex providing large-scale, fast-response storage that stabilises the grid and enables higher shares of wind and solar generation. A stable policy environment and long-term planning have supported consistent investment. However, Portugal's contribution to EU-level strategic autonomy is constrained by low cross-border interconnection capacity. The geopolitical value of Portuguese hydropower for Germany and other central European markets can only be realised with new and expanded transmission links across the Iberian border. Portugal, therefore, represents a pathway that requires complementary EU investment in cross-border infrastructure to achieve its full geopolitical potential.

COMPARATIVE ANALYSIS: GERMANY AND PORTUGAL UNDER RELM

➤ **DIRECT COMPARISON ACROSS THREE PILLARS**

The Renewable Energy Leadership Model provides a structured framework for comparing how Germany and Portugal contribute to EU strategic autonomy. Each country exhibits distinct strengths and weaknesses across the three pillars of policy enablers, infrastructure modernisation, and industrial innovation. A comparative assessment of the policy enablers pillar reveals a significant contrast in regulatory stability. Germany's approach is characterized by highly ambitious capacity targets, aiming for 70 GW by 2045. The Offshore Wind Energy Act set legally binding capacity goals, yet it suffers from an unstable auction design that led to a total absence of bids in the August 2025 offshore wind tenders. In contrast, Portugal exemplifies a leadership model built on long-term policy stability and cross-party political consensus, which has fostered a predictable investment climate for over two decades through consistent licensing frameworks and stable revenue mechanisms. Regarding infrastructure modernization, the two nations face different physical constraints. Germany demonstrates the capacity for large-scale renewable generation, particularly through its high-voltage North Sea and Baltic Sea connections. However, its contribution to collective energy security is hampered by severe domestic north-south grid bottlenecks, leading to notable curtailment rates. Portugal has successfully modernized its infrastructure to provide massive domestic storage through the Tâmega complex, which functions as a regional stabilizer. Nevertheless, its contribution remains

localized due to critically low interconnection capacity with the rest of the European Union, an "energy island" effect that limits its ability to support central European markets.

In the pillar of industrial innovation, Germany leads in the development of frontier technologies, such as massive 15 MW offshore turbines. However, this leadership is challenged by a high dependency of approximately 80 to 90 percent of rare earth magnets being sourced from China. Portugal's innovation strategy differs by focusing on the digitalization and hybridization of mature technology. By integrating AI-driven management and floating solar into existing hydroelectric reservoirs, Portugal extracts maximum value and grid flexibility from its established assets. This comparison reveals that neither country alone can deliver EU-wide strategic autonomy. Germany provides scale but struggles with internal transmission and supply chain vulnerabilities. Portugal offers stability and storage but lacks the interconnection needed to export its flexibility to central Europe.

➤ **COMPLEMENTARITY ASSESSMENT**

The conceptual synergy between Germany and Portugal lies in their functional complementarity. Germany specialises in large-scale renewable generation from offshore wind, producing variable electricity that requires balancing. Portugal specialises in pumped storage hydropower, providing flexible capacity that can absorb surplus generation and release it when demand rises. In theory, Portuguese storage could backstop German wind intermittency, reducing the need for fossil fuel backup across the EU. However, several conditions are required for this synergy to be realised. New cross-border interconnectors between the Iberian Peninsula and France are necessary. The current transmission capacity of approximately 2.5 gigawatts is far below the level needed to transfer stored Portuguese hydropower to German markets. The Bay of Biscay interconnection, scheduled for completion in 2028, will increase capacity to 5 gigawatts, but this remains insufficient for large-scale balancing. Additional transmission lines and harmonised market rules would also be required. The current absence of adequate physical interconnection limits the geopolitical value of this complementarity. Without the ability to move electricity across borders, Portuguese pumped storage primarily benefits the domestic and Iberian market. German offshore wind cannot reliably receive balancing services from Portugal. Therefore, the complementarity remains conceptual rather than operational.

➤ **DIVERGENCE AND CONVERGENCE**

Germany and Portugal diverge most clearly in their technology pathways. Germany pursues a new frontier strategy, investing heavily in large-scale offshore wind turbines, floating platforms, and high-voltage direct current transmission. This approach requires continuous technological breakthroughs and carries higher deployment risks. Portugal pursues a mature modernisation strategy, upgrading existing hydropower assets with digital controls, adjustable speed turbines, and hybrid solar integration. This approach involves lower technological risk but offers limited potential for export to other EU markets. The two countries converge in their domestic outcomes. Both reduce national dependence on imported fossil fuels. German offshore wind displaces natural gas used for electricity generation. Portuguese hydropower and storage reduce the need for gas-fired backup during periods of low wind and solar output. However, their contributions to collective EU autonomy differ significantly. Germany provides large-scale renewable

electricity that could, with adequate transmission, supply multiple member states. Portugal provides grid stability that is currently confined to the Iberian Peninsula. Achieving convergence at the EU level requires investment in cross-border infrastructure that neither country can finance or build alone. While their contributions remain distinct, one providing scale and the other providing flexibility, they illustrate how diverse domestic specializations can, if properly interconnected, converge to form a more resilient and autonomous European energy system.

GEOPOLITICAL SYNTHESIS: PATHWAYS TO EU STRATEGIC AUTONOMY

The transition to a renewable energy architecture is a fundamental geopolitical project that redefines the European Union's capacity for independent action. By operationalizing the Renewable Energy Leadership Model (RELM), this synthesis evaluates how the distinct strategies of Germany and Portugal contribute to the broader objective of strategic autonomy. The analysis demonstrates that while national advancements in offshore wind and hydropower provide the necessary components for security, their collective geopolitical value is contingent upon the integration of these disparate assets into a unified continental system.

➤ HOW GERMANY SHAPES EU GEOPOLITICAL LEVERAGE

Germany's offshore wind expansion contributes positively to EU strategic autonomy through two mechanisms. First, large-scale domestic renewable generation directly reduces reliance on imported natural gas. Before 2022, Germany imported approximately 50-55 percent of its gas from non-EU nations. Offshore wind substitutes these imports with domestically produced electricity, enhancing national and collective energy security. Second, Germany's industrial leadership in turbine manufacturing and project development strengthens the EU's competitive position in the global renewable energy market. The sector generated 14.6 billion euros in gross value added in 2025 and supported approximately 31,500 full-time equivalent jobs. This industrial base reduces the EU's need to import renewable technology from external suppliers.

However, this contribution faces clear limits. Without adequate cross-border interconnection capacity, German offshore wind cannot reliably supply other EU member states. The absence of sufficient north-south transmission within Germany also means that even domestic industrial consumers in southern regions may not receive wind-generated electricity. Furthermore, the high dependence on Chinese rare earth magnets for turbine production creates a new form of external dependency. Approximately 80 to 90 percent of these critical materials are sourced from China. As German offshore wind capacity expands, this dependency is expected to grow unless alternative supply chains are developed. Therefore, Germany's geopolitical contribution remains primarily national rather than EU-wide.

➤ HOW PORTUGAL SHAPES EU GEOPOLITICAL LEVERAGE

Portugal's hydropower modernisation contributes positively to EU strategic autonomy through two mechanisms. First, the flexibility provided by pumped storage enables higher penetration of variable renewables on the Iberian Peninsula. This reduces the need for natural gas-fired backup generation, thereby lowering fossil fuel import

dependence. Second, the Tâmega complex demonstrates a replicable model for integrating large-scale storage into a high-renewable-electricity system. This offers lessons for other member states seeking to stabilise their grids as they transition away from fossil fuels. The principal limitation is geographic and infrastructural. Portugal's low interconnection capacity with the rest of the European Union severely constrains its geopolitical contribution. The Iberian Peninsula currently has cross-border transmission capacity of only 2.5 gigawatts connecting Spain and France, far below the EU target of 15 percent of installed production capacity. Without adequate cross-border links, the stored energy in Portuguese hydropower cannot be reliably delivered to central European markets where it could backstop intermittent generation from sources such as German offshore wind. Therefore, Portugal's geopolitical contribution remains largely regional rather than EU-wide.

➤ **COLLECTIVE CONTRIBUTION AND THE INTERCONNECTION IMPERATIVE**

The Renewable Energy Leadership Model reveals that individual national strengths cannot achieve EU-wide strategic autonomy without cross-border infrastructure. Germany provides scale but cannot export its wind power beyond its borders. Portugal provides stability but cannot share its storage capacity with Central Europe. The conceptual synergy between the German generation and Portuguese storage remains conditional on physical transmission links that do not currently exist at sufficient capacity. The policy recommendation emerging from this analysis is clear. The EU must prioritise funding for new cross-border interconnectors between the Iberian Peninsula and France. The Bay of Biscay interconnection, scheduled for completion in 2028, will increase capacity to 5 gigawatts, but this remains insufficient for large-scale balancing. Additional transmission lines and harmonised market rules are required. Without these investments, the complementary assets of Germany and Portugal cannot be integrated into a coherent EU-wide energy security strategy. The RELM framework highlights that strategic autonomy is not achieved through national accumulation of renewable capacity alone. It requires supranational coordination and infrastructure spending.

➤ **LIMITATIONS OF THE ANALYSIS**

This research has several limitations that readers should consider. First, the paper does not provide transmission level modelling, interconnector constraint analysis, dispatch analysis, or temporal balancing evidence. The claim that Portuguese hydropower could backstop German offshore wind remains conceptual rather than empirically validated. Full verification of this synergy would require engineering and grid-level analysis beyond the scope of this comparative policy study. Second, the research relies on existing peer-reviewed articles, official European statistical data, and European Commission policy documents. While these sources are credible, the analysis does not generate primary data or conduct original modelling. Third, the geopolitical analysis is qualitative and scenario-based. It identifies potential pathways to EU strategic autonomy but does not quantify the precise impact of different policy choices. The findings should therefore be interpreted as a conceptual synthesis rather than an empirical breakthrough.

CONCLUSION

This research has argued that the European Union stands at a pivotal geopolitical juncture where energy and security paradigms are converging. The core finding is that Germany's offshore wind strategy and Portugal's hydropower innovation are not merely national climate projects. They are critical security assets for the entire bloc. Together, they form the backbone of a Renewable Energy Leadership Model that delivers geopolitical dividends by reducing coercive dependencies, enhancing economic competitiveness, and strengthening EU strategic autonomy. The analysis demonstrates that Germany provides the scale needed to power its industry and displace imported fossil fuels. Portugal offers the grid stability and storage that allow variable renewables to flourish.

This synergy between scalable and stable assets, located in different geographic theatres, creates a diversified European energy system less vulnerable to external political pressure or synchronised shocks. However, neither country alone can achieve EU-wide autonomy. Germany needs export routes for its wind power. Portugal needs an interconnection to send stored energy to Central Europe. The contribution of this paper is a systematic comparative framework linking national renewable assets to EU strategic autonomy. Moving beyond isolated technology assessments, the study provides a geopolitically informed analysis of energy diversification and reduced external dependence. Several policy implications follow. The EU must prioritise funding for cross-border interconnectors between the Iberian Peninsula and France. Germany should stabilise its auction design by shifting to two-sided contracts for difference.

The EU must diversify clean tech supply chains to reduce dependence on non-EU sources for rare earth magnets and other critical components. Future research should pursue transmission-level modelling to validate the proposed complementarity between German wind and Portuguese storage. Additional member states should be included in the comparative analysis to test the RELM framework more broadly. Analysis of critical raw material dependencies would further illuminate geopolitical risks. The lesson of recent years is clear. Renewable energy is Europe's new national security frontier. The turbines in the North Sea and the hydropower plants in the Iberian mountains are as vital to the continent's future sovereignty as any traditional security infrastructure. By championing this leadership model, the EU can secure a future that is cleaner, more prosperous, resilient, and strategically independent. The transition to a renewable-based system is the definitive project for safeguarding European security in the 21st century.

DISCLOSURE STATEMENT

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