Successful international experiences in energy security and its role in achieving economic development : The German experience

Sayah Fatima

University of Relizane, Algeria, fatima.sayah@univ-relizane.dz

https://orcid.org/0000-0002-1333-3045

Received: 10/01/2026 **Accepted: 13/02/2026** **Published:20/10/2026**

Abstract

This research paper investigates the critical relationship between energy security and sustainable economic development through a multidimensional analysis of global best practices, with particular emphasis on Germany's Energiewende strategy. Energy security, defined as the uninterrupted availability of energy sources at an affordable price, has emerged as a fundamental prerequisite for economic stability and growth in an increasingly volatile geopolitical landscape. The study employs a comparative methodology to examine successful international models of energy diversification and transition, while conducting an in-depth examination of Germany's comprehensive approach to reducing fossil fuel dependency through technological innovation, policy integration, and renewable energy expansion. Findings reveal that strategic diversification of energy sources, coupled with technological advancement and robust policy frameworks, significantly enhances energy security while driving economic competitiveness, job creation, and environmental sustainability. The German case demonstrates that even industrialized economies with high energy dependency can successfully transition toward more secure and sustainable energy systems, though not without facing significant challenges in implementation. The paper concludes with policy recommendations for nations seeking to strengthen their energy security while pursuing sustainable economic development goals.

Keywords: Energy security, Economic Development, sustainability, Germany .

Ce(tte) œuvre est mise à disposition selon les termes de la Licence Creative Commons Attribution - Pas d'Utilisation Commerciale 4.0 International

Introduction

Energy security serves as a foundation for sustained economic development by ensuring reliable access to affordable energy resources that power industrial production, transportation, and technological innovation. Countries with robust energy security frameworks typically experience enhanced economic competitiveness through reduced energy costs, increased foreign investment, and improved industrial productivity (Model-Generated). The relationship works both ways - economic development provides the financial resources and technological capabilities needed to build resilient energy infrastructure and diversify energy sources. Energy independence reduces vulnerability to external price shocks and supply disruptions, which can destabilize economic growth and create uncertainty for businesses and investors. Modern economies increasingly recognize that transitioning to renewable energy sources not only enhances long-term energy security but also creates new economic opportunities through green technology industries, job creation, and export potential. Strategic energy planning that balances security, sustainability, and affordability has become essential for maintaining economic competitiveness in the global marketplace.

The interdependent relationship between energy security and economic development has become increasingly prominent in contemporary global discourse, particularly following geopolitical disruptions that have exposed vulnerabilities in national energy systems. Energy security, traditionally conceptualized as the reliable supply of affordable energy, has evolved into a multifaceted concept encompassing availability, accessibility, affordability, and sustainability dimensions. This evolution reflects growing recognition that long-term economic prosperity cannot be sustained through dependence on volatile fossil fuel markets or geopolitically sensitive supply chains. The problematic reality facing many nations today is how to balance immediate energy needs with long-term strategic imperatives of sustainability, resilience, and economic competitiveness.

The central research problem examined in this paper concerns how nations can effectively structure their energy security strategies to simultaneously achieve sustainable economic development objectives. This investigation is particularly timely given the geopolitical upheavals of recent years—most notably Russia's 2022 invasion of Ukraine—which have dramatically reshaped European energy dynamics and forced rapid reconsideration of long-standing energy partnerships and dependencies. Germany's experience serves as a particularly instructive case, given its position as Europe's largest economy with historically deep energy ties to Russia, and its ambitious Energiewende (energy transition) program initiated well before recent crises.

Therefore, we raise the following main problem :

What is the role of energy security in achieving economic development?

This paper addresses several subsidiary questions:

- How do different national approaches to energy security impact economic development outcomes?
- What policy frameworks most effectively balance short-term energy security needs with long-term sustainable development goals?

- To what extent has Germany attained a position in achieving economic development by virtue of its energy security strategy?

To guide this investigation, the research operates from several **working hypotheses**: that diversified energy portfolios positively correlate with economic resilience; that integrated technological and policy approaches yield superior energy security outcomes; that geopolitical shocks accelerate energy transition processes; and that renewable energy expansion, while initially capital-intensive, generates long-term economic benefits.
In this academic research, we adopt a descriptive approach in order to answer the above.

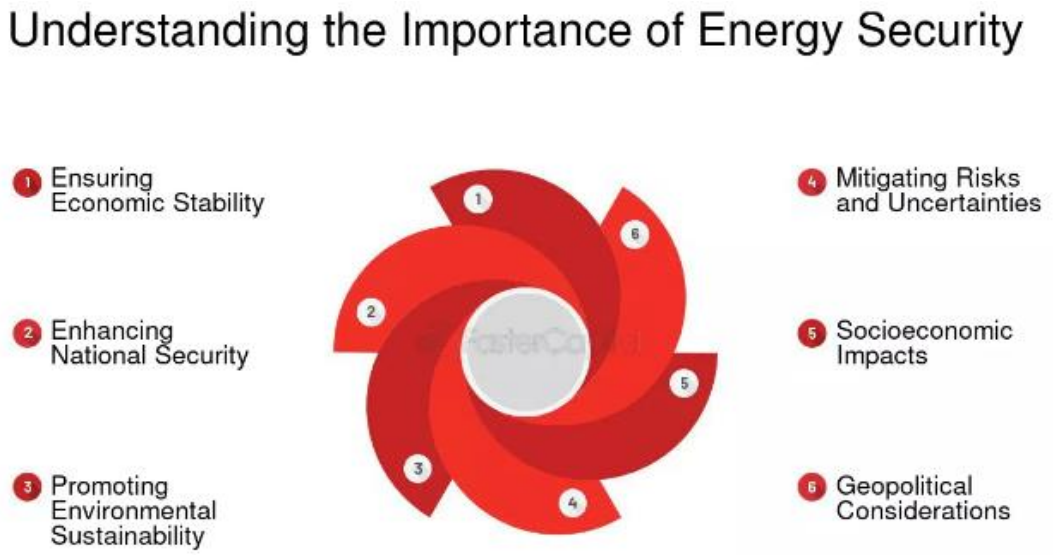
I – Theoretical Framework: Energy Security and Sustainable Economic Development

1- Defining Energy Security in Contemporary Context

Energy security represents a complex multidimensional concept that has evolved significantly beyond its traditional focus on supply reliability. The International Energy Agency defines it as "the uninterrupted availability of energy sources at an affordable price," while the United Nations expands this to include availability "in all times, in various forms, in sufficient quantities, at suitable and reasonable prices". This broader conceptualization acknowledges that true energy security must address multiple dimensions simultaneously: physical availability of diverse energy sources; economic affordability for consumers and industries; technological capacity to integrate different energy forms; and environmental sustainability of energy systems. The European Commission has further operationalized this concept through four key pillars: diversification of energy sources; demand management through efficiency; strengthening external supply partnerships; and crisis prevention through market regulation.

The relationship between energy security and economic development operates through multiple transmission channels. Reliable and affordable energy supplies directly reduce production costs across economic sectors, enhancing industrial competitiveness. Energy security also minimizes macroeconomic vulnerabilities to price shocks and supply disruptions, which can cause inflationary pressures, trade imbalances, and growth volatility. Furthermore, strategic investments in energy infrastructure and technology stimulate economic activity through job creation, research and development spillovers, and development of new industrial sectors. Perhaps most significantly in the long term, transitioning toward sustainable energy systems mitigates climate-related risks that increasingly threaten economic stability and growth prospects.

Fig. 1



Source : https://fastercapital.com/topics/what-is-energy-security.html/2

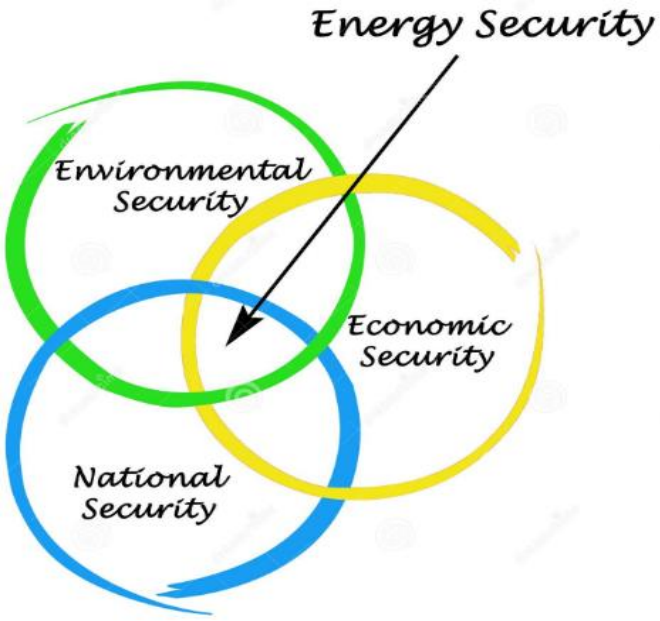
2.2 The Energy-Economy-Environment Nexus

Contemporary understanding of energy security is inextricably linked to the triple nexus of energy, economy, and environment—sometimes described as the "three-dimensional impact of energy on development". This framework recognizes that energy systems simultaneously influence and are influenced by economic development patterns and environmental constraints. The traditional model of fossil fuel-dependent development has demonstrated serious limitations, creating what some scholars term the "energy development paradox"—where short-term economic gains from fossil fuel exploitation undermine long-term sustainability through environmental degradation and climate change. Renewable energy sources offer a potential resolution to this paradox by decoupling economic growth from greenhouse gas emissions and fossil fuel dependency. However, this transition presents its own challenges, particularly regarding the intermittency of solar and wind resources and the substantial upfront investments required. The integrated approach to energy security recognizes these interdependencies and seeks policy solutions that simultaneously address energy, economic, and environmental objectives. This often involves "co-benefit strategies" where investments in renewable energy or efficiency measures simultaneously enhance energy security, stimulate economic activity through green job creation, and reduce environmental impacts.

Energy security constitutes a fundamental pillar of national security, directly underpinning economic security and serving as an indispensable prerequisite for environmental security. This interconnected framework reveals that energy security transcends the mere guarantee of uninterrupted energy supplies; it is intrinsically linked to a nation's economic stability, geopolitical sovereignty, and long-term ecological resilience. A secure, affordable, and reliable energy system mitigates macroeconomic vulnerabilities to price shocks and supply disruptions, thereby strengthening economic security by ensuring industrial competitiveness, maintaining employment, and fostering sustainable growth. Simultaneously, a strategic transition towards diversified and renewable energy sources is

essential for achieving environmental security, as it reduces the ecological footprint, mitigates climate-related risks, and promotes the sustainable management of natural resources. Consequently, nations must adopt integrated policies that address this energy-economic-environmental nexus holistically, recognizing that true national security in the 21st century is contingent upon the synergistic achievement of energy, economic, and environmental imperatives. As shown in the following figure :

Fig. 2 The fundamental interplay between energy security, the economy, and the environment



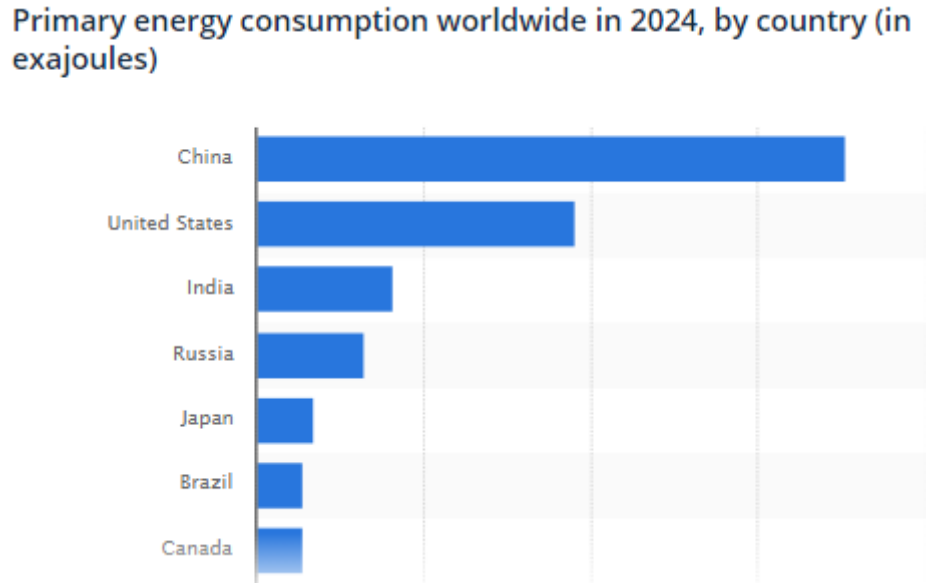
Source : https://www.dreamstime.com/stock-photo-diagram-energy-security-what-provide-image85677804

2.3 Measuring Energy Security Outcomes

Assessing energy security effectiveness requires consideration of both quantitative indicators (such as import dependency ratios, diversity indices, price volatility measures, and reserve capacities) and qualitative factors (including regulatory frameworks, market structures, innovation ecosystems, and geopolitical relationships). Economic development impacts can be measured through traditional metrics like GDP growth, employment rates, and industrial productivity, but should also incorporate broader measures of sustainable development including environmental quality, social equity in energy access, and resilience to external shocks. This comprehensive assessment framework guides the analysis of national case studies in subsequent sections.

Since the beginning of the century, global energy production and consumption have declined just twice: in the year following the Great Recession (2009) and during the first year of the coronavirus pandemic (2020). China is the world's largest producer and consumer of primary energy. As the second leading economy and home to over 1.4 billion people, it requires far more fuel to power households and industry than any other country.

Fig. 3



Source :https://www.statista.com/markets/408/topic/436/energy/?srsltid=AfmBOooHIBqWj5eHxzi0by1022vo3bSPjPefyuN4F25ngeh4quMJj6PQ#overview

3 Global Case Studies of Successful Energy Security Strategies

3.1 Denmark: Wind Energy Leadership and System Integration

Denmark's energy transition represents one of the world's most successful transformations from fossil fuel dependency to renewable energy leadership. Beginning in response to the 1970s oil crises, Denmark implemented a long-term strategy focused on wind energy development, combined heat and power systems, and energy efficiency measures. The results have been remarkable: wind power accounted for over 50% of Denmark's electricity consumption in 2020, with targets reaching 84% by 2035. This transition has been achieved while maintaining economic competitiveness and high living standards, demonstrating that ambitious renewable energy goals can align with prosperous economic development.

The Danish model emphasizes several key success factors: consistent long-term policy frameworks that provide investor certainty; integration of energy planning with spatial and industrial policies; significant investment in research and development; and innovative approaches to community ownership of renewable energy projects. Particularly noteworthy is Denmark's approach to system integration, addressing the intermittency challenge through grid interconnections with neighboring countries, flexible demand response systems, and strategic use of biomass and waste-to-energy as controllable renewable sources. Economically, Denmark has cultivated a world-leading wind industry employing approximately 33,000 people and generating substantial export revenues, illustrating how energy security strategies can simultaneously create new economic opportunities.

3.2 Iceland: Geothermal Innovation and Economic Diversification

Iceland provides a compelling case of how **resource-specific advantages** can be leveraged to achieve exceptional energy security and economic transformation. Historically

dependent on imported fossil fuels, Iceland now generates nearly 100% of its electricity from renewable sources—primarily hydro (70%) and geothermal (30%)—and uses geothermal energy directly for heating 90% of its buildings. This comprehensive transition has positioned Iceland with among the lowest energy costs in Europe, providing competitive advantages for energy-intensive industries while eliminating fossil fuel import dependency.

The Icelandic experience highlights several important principles: the value of adapting energy strategies to local resource endowments; the economic benefits of transitioning from energy import costs to domestic investment and job creation; and the potential for renewable energy to enable entirely new industries. Iceland's development of energy-intensive sectors like aluminum smelting and data centers demonstrates how abundant renewable energy can drive industrial diversification beyond traditional economic activities. Additionally, Iceland has developed significant geothermal expertise that it now exports internationally, creating a specialized services sector that contributes to economic development while spreading renewable energy technologies globally.

3.3 China: Strategic Investment and Manufacturing Scale

China's approach to energy security illustrates a different model centered on strategic state investment, manufacturing scale, and technology acquisition. Despite remaining the world's largest coal consumer and importer of oil and gas, China has simultaneously become the global leader in renewable energy investment, manufacturing, and deployment. In 2022, China accounted for nearly half of worldwide renewable energy capacity additions, demonstrating an unparalleled capacity for rapid scaling of clean energy technologies.

China's strategy combines several distinct elements: massive domestic deployment creating economies of scale; targeted industrial policies fostering globally competitive manufacturers; aggressive technology acquisition and adaptation; and increasing international engagement in energy infrastructure development. This approach has significantly enhanced China's energy security by reducing growth in fossil fuel imports relative to economic expansion, while positioning Chinese firms as dominant players in global solar, wind, and battery supply chains. The economic development implications are substantial, with millions employed in renewable energy sectors and Chinese companies increasingly setting global technology standards. However, this model also raises questions about technology dependencies and the environmental impacts of rapid manufacturing expansion, highlighting inevitable trade-offs in energy security strategies.

4 The German Experience: Energiewende in Theory and Practice

4.1 Historical Context and Strategic Foundations

Germany's energy security strategy, encapsulated in the **Energiewende** (energy transition) policy, represents one of the world's most comprehensive efforts to reconcile industrial economic power with environmental sustainability and energy independence. The conceptual foundations emerged in the 1970s, influenced by environmental movements and concerns about nuclear safety following the Chernobyl disaster, but gained substantial

political momentum with the Renewable Energy Sources Act (EEG) of 2000. This legislation established Germany's innovative **feed-in tariff system**, guaranteeing renewable energy producers fixed payments for their electricity and catalyzing rapid expansion of wind and solar capacity.

The Energiewende initially focused on three pillars: accelerated deployment of renewable energy (particularly wind and solar), improved energy efficiency across all sectors, and gradual phase-out of nuclear power by 2022 and coal by 2038. This strategy reflected Germany's particular circumstances as Europe's largest economy with limited domestic fossil fuel resources—importing approximately 60% of its total energy needs, including 94-100% of its oil, natural gas, and hard coal prior to the recent energy crisis. The policy framework evolved through successive amendments, incorporating mechanisms such as competitive auctions and grid expansion mandates to address integration challenges as renewable shares increased.

Table 1: Germany's Energy Transition Targets and Progress

Indicator	2022 Status	2030 Target	2045 Target
Renewable share in gross electricity consumption	46%	80%	Near 100%
Greenhouse gas reduction (vs. 1990)	41%	At least 65%	Net zero
Primary energy consumption reduction (vs. 2008)	17%	30%	50%
Coal phase-out	33% of electricity	Complete by 2030	Complete
Annual renewable capacity addition	Approximately 10 GW	At least 20 GW	Not specified

Source : Author

4.2 Post-2022 Adaptation: The Geopolitical Turning Point

Russia's 2022 invasion of Ukraine triggered what German Chancellor Olaf Scholz termed a "Zeitenwende" (turning point) in Germany's energy security strategy, exposing critical vulnerabilities in the country's energy system. Prior to the invasion, Germany imported approximately 35% of its natural gas from Russia, which played a crucial balancing role in the energy transition by providing flexible generation to complement intermittent renewables -3. The sudden disruption of these supplies forced immediate crisis responses—including temporary reactivation of coal plants, acceleration of liquefied natural gas (LNG) terminal construction, and implementation of emergency conservation measures—alongside strategic recalibration of long-term energy security approaches.

Germany's adaptation strategy has emphasized several key elements: unprecedented acceleration of renewable energy expansion, with targets increased to reach 80% renewable electricity by 2030; diversification of gas supplies through new partnerships with Norway, the United States, and Qatar; substantial investment in hydrogen infrastructure and international partnerships; and enhanced focus on energy efficiency and demand reduction. The crisis also prompted important policy innovations, including the "Gas Storage Law" ensuring minimum storage levels, emergency price caps to protect consumers and businesses, and streamlined permitting procedures for renewable energy projects. These measures have produced tangible results: by 2023, Russian gas imports had fallen to below 10% of total imports, while renewable energy generation reached record levels despite supply challenges.

4.3 Technological Integration: AI-Driven Energy Systems

A distinctive aspect of Germany's recent energy security strategy has been the systematic integration of artificial intelligence (AI) technologies to optimize energy systems and reduce dependency on Russian gas. Research indicates that "AI and environmental policy stringency (EPS) significantly reduce Germany's dependency on Russian gas in both the short and long run, with stronger effects observed over the long term". AI applications in Germany's energy sector include demand forecasting, grid management, predictive maintenance of infrastructure, optimization of renewable energy integration, and enhancement of energy trading and market operations. The transformative potential of AI in energy security stems from several capabilities: processing vast datasets from smart meters, weather forecasts, and market signals to optimize energy flows; enabling more efficient operation of complex systems with high renewable penetration; and facilitating dynamic pricing and demand response mechanisms. The German Energy Agency (dena) reports that most energy companies recognize AI's positive effects for the energy transition, though implementation challenges remain, particularly regarding expertise gaps and upfront investment requirements. The interaction between AI technologies and geopolitical risks reveals "compounded benefits of integrated technological advancement and policy strategies in mitigating energy dependency in times of turmoil".

4.4 Economic Development Implications

Germany's energy security strategy has generated significant economic impacts, both positive and negative. On the positive side, the Energiewende has fostered substantial growth in renewable energy industries, creating approximately 300,000 jobs in the sector. Germany has developed world-leading expertise in several green technologies, particularly wind turbine manufacturing, solar technology, and energy efficiency solutions, contributing to export revenues and technological innovation. The transition has also stimulated investment in energy infrastructure, with estimates suggesting €400-€500 billion will be needed by 2045 to achieve climate targets.

However, the transition has also presented economic challenges. Energy prices in Germany remain among Europe's highest, creating competitive pressures for energy-intensive industries. The phase-out of coal has necessitated substantial structural adjustment support for affected regions, with €40 billion allocated to support economic diversification in coal-

dependent areas like North Rhine-Westphalia. Supply chain vulnerabilities have been exposed, particularly dependence on Chinese solar components and critical minerals for batteries and renewable technologies. Nevertheless, research suggests that the long-term economic benefits of enhanced energy security—reduced exposure to fossil fuel price volatility, avoided climate damages, technological leadership positions, and improved trade balances—substantially outweigh transition costs.

Table 2: Economic Impacts of Germany's Energy Security Strategy

Economic Dimension	Positive Impacts	Challenges and Costs
Employment	~300,000 jobs in renewable energy sector; New "green" occupations	Job losses in conventional energy sectors; Structural unemployment in transition regions
Industrial Competitiveness	Leadership in renewable technology exports; First-mover advantages	High energy prices affecting energy-intensive industries; International competitive pressures
Investment	Stimulates infrastructure investment; Attracts green technology R&D	Substantial upfront capital requirements; Stranded asset risks in conventional energy
Innovation	Strong renewable energy patent activity; Development of integrated energy solutions	Implementation gaps between innovation and deployment; Skills shortages in emerging technologies
Macroeconomic Stability	Reduced exposure to fossil fuel price volatility; Improved trade balance through import substitution	Transition costs contributing to public debt; Inflationary pressures from energy system restructuring

Source : Author

4.5 Germany's Energiewende : Comprehensive energy transition strategy

Germany's Energiewende stands as a comprehensive long-term project requiring strong state intervention to replace conventional energy sources with renewables while increasing energy efficiency (Baran, 2015). This ambitious strategy goes beyond simple energy policy to represent a broader plan for transitioning to green capitalism and positioning Germany as a global leader in renewable energy technology (Reis, 2017). The transition encompasses three major targets: environmental goals including climate change response and nuclear phase-out, economic objectives of creating new industries and job

opportunities, and security aims of reducing energy imports while achieving diversified energy supply (Li, 2021).

The policy framework has evolved through distinct phases, with Germany's energy focus historically shifting from coal to oil and gas, then nuclear energy, and finally to renewable sources (Shen et al., 2021). The core policy innovation driving this transformation is the feed-in tariff (FIT) system, which guarantees grid connection for renewable energy producers and provides long-term price guarantees typically lasting 20 years (DeWit, 2010). This mechanism ensures that funding comes from consumers rather than public budgets, while digression rates encourage technical innovation and cost reduction across renewable sectors (DeWit, 2010).

The Energiewende has established increasingly ambitious targets, with recent legislation aiming for 80 percent of electricity demand to be met by renewables by 2030, up from 42 percent in 2021 (Sher et al., 2022). The program projects Germany to become a low-carbon, nuclear-free energy system by mid-century, supported by widespread public belief in sustainability objectives (Savio et al., 2022). Economic policies including financial subsidies, green finance, bidding systems, and environmental taxes have played crucial roles in promoting renewable energy development (Shen et al., 2021). The comprehensive nature of this transformation includes technological innovations in wind and solar power, energy system integration, electric transport infrastructure modernization, and enhanced energy efficiency measures (Synianskyi, 2024).

-Economic Development Impacts of Germany's Energy Transition

Germany's Energiewende has delivered substantial economic development benefits, with the country creating almost 300,000 jobs in renewable energy sectors by 2007, of which 60% were directly attributable to the Renewable Energy Sources Act (DeWit, 2010). The energy transition represents more than two decades of sustained investment that now benefits the economy through a growing number of new jobs and exports of high-tech products (Baran, 2015). This job creation has been particularly significant in rural regions with abundant wind and solar energy resources, providing economic opportunities in areas that previously had limited industrial development (Kouhihabibi et al., 2023).

The transition has positioned Germany as a global leader in green technology exports and industrial competitiveness. Through massive public and private R&D investments in renewable energy, Germany has strengthened its capacity to export products and services for manufacturing solar and wind devices, transforming itself from a fossil fuels importer into a green energy technology powerhouse (Reis, 2017). Energy efficiency has become a key competitive advantage for strategic German export industries including transportation, logistics, building technologies, mechanical engineering, and IT services (Nyga-Lukaszewska et al., 2017), (Bilan et al., 2017).

The economic framework supporting this transformation has been carefully designed to minimize public budget impact while maximizing private investment. The feed-in tariff system ensures funding comes from consumers rather than government budgets, while digression rates encourage technical innovation and cost reduction across renewable sectors

(DeWit, 2010). Market-based instruments, innovative capacity planning approaches, and strong social support have driven sustainable development of the renewable energy sector beyond government subsidies alone (Khanova, 2025).

However, the transition faces ongoing economic challenges that require careful policy management. While producer rents have been significantly reduced, renewable energy subsidies have led to sharp increases in end-user electricity prices, creating tensions for energy-intensive industries (Schiffer et al., 2018). German policymakers recognize that maintaining international competitiveness requires support programs for industrial decarbonization and reliable policy frameworks to harvest the business opportunities that come with energy transition (Schiffer et al., 2018). The correlation between renewable energy generation, energy prices, investment activity, and economic growth demonstrates the complex interconnections that must be managed for continued success (Khanova, 2025).

-Energy Security achievements and Resillence

Germany has achieved the highest energy security level in the world according to aggregated energy security indices, attributed to its coordinated approach across multiple dimensions of energy policy (Azzuni et al., 2020). The country excels particularly in the resilience dimension, demonstrating the highest adaptive capacity to cope with changes and shocks in the energy system to ensure continuity of functioning society and economic systems (Azzuni et al., 2020). This resilience performance works together with Germany's advanced political system and energy regulations, proving that lacking natural resources should not hinder energy security if political will exists to advance resilience and regulatory frameworks (Azzuni et al., 2020).

The practical benefits of Germany's energy security achievements became evident during recent geopolitical crises. Germany would have been in a much more difficult situation with the Ukraine crisis if it were not for the country's strong renewable energy market, which provided energy independence and reduced exposure to volatile input prices in traditional power systems (Bashynska, 2015). European nations, including Germany, successfully managed energy supply disruptions by diversifying gas supplies, coordinating demand reduction, and accelerating renewable energy development, with renewables now representing the primary source of electricity generation in Europe (Tocci, 2023).

Research across economically strong EU countries demonstrates that increasing renewable energy share in the energy balance can compensate for growing demand for fossil fuel imports and enhance overall energy security (Sotnyk et al., 2021). Germany's model has proven that renewable energy transitions present substantial opportunities for enhanced energy security alongside economic growth and job creation (Kouhihabibi et al., 2023). The country ranks among five OECD nations that have successfully balanced energy security with environmental protection, achieving both secure energy supplies and decoupling economic growth from carbon emissions (Bartha, 2025).

The correlation between renewable energy generation, energy prices, investment activity, and economic growth reveals strong interlinkages that support long-term energy security, with domestic production factors playing decisive roles in stabilizing investment dynamics during crisis periods (Khanova, 2025). However, the integration of variable renewable sources like solar and wind power requires careful grid management to address gaps in energy availability and maintain system reliability (Alagoz, 2025).

-International cooperation and knowledge transfer

Germany has developed a comprehensive approach to international energy cooperation that extends beyond traditional trade relationships to encompass technology transfer and knowledge sharing across diverse partnerships. The country actively develops collaboration in clean energy technologies, energy efficiency, and renewable energy sources with both large energy consumers like China and India, and major producers such as Russia, creating opportunities for German companies to export energy-efficient products and innovative energy installations (Molo, 2019). This externalization strategy involves transferring energy transition experience and technological solutions to partner countries in renewable energy, energy saving, and energy efficiency improvement (Molo, 2019).

The German government has systematically integrated Energiewende experiences into its foreign and international development policies, with experts and politicians promoting the energy transition as an "export hit" to other countries (Hernandez, 2022), (Hernandez_1, 2022). The reform strategy "BMZ 2030" implemented by the German Federal Ministry for Economic Cooperation and Development incorporates elements and experiences from the Energiewende, identifying "green people's energy" as one of ten initiative areas that focuses development policy on energy transition in partner countries (Hernandez, 2022), (Hernandez_1, 2022).

Practical cooperation takes multiple forms, including partnerships and energy dialogues through which the federal government shares energy transition experiences via business trips, expert exchanges, working groups, and jointly organized events (Molo, 2019). Specific examples include the Korean-German Energy Partnership's Energy Transition working group, the German-New Zealand hydrogen partnership, and the EnerPhil project with the Philippines (Hernandez, 2022). Germany's approach particularly benefits partnerships with developing countries, where the nation's superior economic and political capacity enables provision of social security nets, technology, and knowledge for just energy transitions (Hagele et al., 2022).

The international influence extends to policy mechanisms, with Germany's Feed-in Tariff programs being replicated successfully in countries like Spain, demonstrating how guaranteed premium prices for renewable electricity can attract investments, spur innovation, and facilitate renewable energy grid integration (Oluwadamilare et al., 2023). Germany's experience also contributes to broader European frameworks, including the EU's Renewable Energy Directive (RED II) and the development of Renewable Energy Communities that can unlock private investment while providing social benefits (Bisht et al., 2024), (Hoicka et al., 2020).

-Comparative International Experiences in Energy Security

International experiences in energy security reveal diverse pathways to success, with European countries emerging as recognized leaders in both regional cooperation and innovative policy approaches. The European integration model began in 1951 with the European Coal and Steel Community Treaty, establishing common markets for essential energy resources among France, Germany, Italy, Netherlands, Belgium and Luxembourg to support post-war economic reconstruction (Udaeta et al., 2015). This foundation evolved through the 1957 Treaties of Rome creating the European Economic Community and European Atomic Energy Community, with member states seeking nuclear energy as a means to ensure energy security and independence when traditional energy investments exceeded individual state capabilities (Udaeta et al., 2015).

The effectiveness of coordinated European approaches became evident during recent energy crises, with European nations successfully managing supply disruptions by diversifying gas supplies from Norway, the US, Qatar, Azerbaijan, Algeria, Angola, Mozambique and the Republic of Congo while coordinating demand reduction and accelerating renewable energy development (Tocci, 2023). European countries are now recognized leaders in using public-private partnerships for large-scale infrastructure projects that contribute to energy efficiency across economic sectors (Chupryna et al., 2021).

Beyond Europe, successful international experiences demonstrate common patterns in achieving energy security through renewable energy integration. Leading countries including Germany, China, Denmark, and the USA actively invest in solar and wind energy development, reducing dependence on traditional energy resources while improving environmental conditions and creating new employment opportunities (Shpatakova et al., 2024). Research identifying countries that successfully balance the "3E trilemma" of energy security, economic development, and environmental protection reveals that Australia, Switzerland, Germany, Denmark, and Sweden have achieved both strong energy security and successful decoupling of economic growth from carbon emissions (Bartha, 2025).

The success patterns across these diverse international experiences highlight several key factors. Economically developed countries predominate among nations with high energy security indices, with 35 EU or OECD countries ranking among the top performers due to strong environmental awareness and long-term focus on energy efficiency, renewable energy, and sustainable development (Hu et al., 2022). Effective energy transitions require integrated approaches combining government support, international cooperation, and innovation, with intelligent decarbonization strategies helping countries save significant amounts through enhanced productivity and reduced energy import costs (Kravchenko et al., 2024). Economic freedom plays a critical role by encouraging market competition and private investment in clean energy technologies, attracting international investment in energy infrastructure that helps diversify energy supplies and build resilience against energy shocks (Hou et al., 2025)(Yang et al., 2024).

5 Results and Discussion

5.1 Comparative Analysis of Energy Security Approaches

The examination of international case studies alongside Germany's experience reveals several common principles underlying successful energy security strategies. First, diversification emerges as a universal imperative—whether across energy sources (as in Denmark's wind-dominated system), supply partners (as in Germany's post-2022 gas strategy), or technological approaches (as in China's simultaneous pursuit of multiple renewable pathways). Second, policy consistency and predictability prove crucial for attracting the substantial long-term investments required for energy infrastructure. Third, technological innovation—particularly in system integration, storage, and digital management—plays an increasingly central role in enabling high shares of renewable energy while maintaining reliability.

However, important contextual variations shape national approaches. Resource endowments significantly influence strategy options, as demonstrated by Iceland's geothermal specialization versus Denmark's wind focus. Economic structures also matter: Germany's industrial base creates different imperatives than China's manufacturing-focused economy or Denmark's services orientation. Political systems shape implementation capacity, with China's centralized approach enabling more rapid infrastructure deployment than Germany's federal system with stronger participatory elements. These variations suggest that while general principles can be identified, effective energy security strategies must be tailored to national circumstances rather than copied as blueprints.

5.2 The German Model: Strengths and Limitations

Germany's energy security strategy demonstrates particular strengths in several areas: its comprehensive, multi-sector approach; its integration of environmental and energy security objectives; its strong emphasis on technological innovation and research; and its democratic, participatory implementation process. The Energiewende has achieved substantial increases in renewable energy deployment while maintaining high levels of public support, and has positioned German firms as technology leaders in several renewable energy sectors.

However, the German approach also reveals significant limitations. Implementation has been slower than originally planned, with Germany likely to miss several interim climate targets. Costs have been substantial, contributing to Europe's highest electricity prices and creating competitive challenges for energy-intensive industries. The phase-out of nuclear power before fully replacing it with renewables increased short-term reliance on coal and gas, temporarily worsening emissions. Additionally, Germany's federal system has sometimes created coordination challenges between national targets and regional implementation. These limitations highlight the inherent tensions and trade-offs in energy security strategies, particularly between short-term affordability and long-term transformation, and between environmental ambitions and economic competitiveness.

5.3 Energy Security as Economic Development Catalyst

Across case studies, energy security strategies function not merely as protective measures against supply disruptions, but as **active catalysts** for economic development.

This occurs through multiple channels: job creation in new energy sectors; stimulation of innovation with spillover benefits across the economy; reduction of import dependencies that drain national resources; and enhancement of industrial competitiveness through stable, predictable energy costs. The German case particularly illustrates how energy transition can drive industrial modernization, with traditional manufacturing sectors adapting to produce components for renewable energy systems, and entirely new industries emerging around energy storage, grid management, and efficiency technologies.

The economic benefits appear most pronounced when energy security strategies are integrated with broader industrial and innovation policies. Germany's "Platform for the Future of Industry" and similar initiatives demonstrate conscious efforts to align energy transition with economic development objectives. Similarly, Denmark's wind industry development benefited from coordinated research funding, export promotion, and skills development programs. This integrated approach contrasts with narrower conceptions of energy security focused primarily on supply assurance, suggesting that the most effective strategies view energy security as a component of comprehensive economic development rather than a separate policy domain.

6 Conclusion and Recommendations

6.1 Summary of Findings

This investigation confirms the fundamental interconnection between energy security and sustainable economic development. Nations that have pursued deliberate, long-term energy security strategies—particularly through diversification, innovation, and renewable energy deployment—have generally strengthened both their economic resilience and their competitiveness. The German experience illustrates that even industrial economies with high existing energy dependencies can undertake substantial transitions, though the process involves significant costs, complexities, and inevitable trade-offs. Key success factors emerging from comparative analysis include policy consistency, technological adaptation to local conditions, integration of energy security with broader economic strategies, and social consensus-building around transition pathways.

The research particularly highlights the transformative impact of recent geopolitical events on energy security strategies. The 2022 energy crisis accelerated existing trends toward diversification and renewable energy expansion while revealing previously underestimated vulnerabilities in globalized energy systems. In this context, Germany's rapid reduction of Russian gas dependency—from approximately 50% of imports before 2022 to less than 10% by 2023—demonstrates the adaptive capacity of advanced economies when faced with existential energy security threats. However, this adaptation has come with substantial economic costs, highlighting the premium on proactive rather than reactive energy security planning.

6.2 Policy Recommendations

Based on comparative analysis, several **strategic recommendations** emerge for policymakers seeking to enhance energy security while promoting sustainable economic development:

1. **Develop Integrated Energy-Economic Strategies**: Energy security policies should be explicitly linked with industrial, innovation, and employment strategies to maximize economic co-benefits. This includes targeted support for green technology development, workforce retraining programs for transition regions, and strategic trade policies that enhance rather than undermine energy security objectives.
2. **Accelerate Renewable Energy Deployment Through System Integration**: Beyond capacity expansion, focus on enabling technologies—particularly energy storage, demand response, smart grids, and AI-driven optimization—to facilitate high renewable penetration while maintaining system reliability. Germany's target of 12 GW of storage capacity by 2030 provides a useful benchmark.
3. **Strengthen International Cooperation on Diversified Supply Chains**: Reduce vulnerabilities in critical mineral and technology supply chains through strategic partnerships, stockpiling, recycling initiatives, and diversification of supplier relationships. This requires moving beyond traditional energy trade relationships to encompass broader technology and materials collaborations.
4. **Implement Progressive Carbon Pricing with Social Safeguards**: Use carbon pricing mechanisms to signal transition priorities while protecting vulnerable households and industries during the transition. Revenues should be partially reinvested in energy efficiency improvements, particularly for low-income households and small businesses.
5. **Enhance Research and Development for Next-Generation Technologies**: Increase public and private investment in emerging energy technologies with high potential to transform energy systems, including advanced geothermal, next-generation solar, green hydrogen production and utilization, and advanced nuclear technologies where appropriate to national contexts.
6. **Establish Robust Monitoring and Adjustment Mechanisms**: Given the inherent uncertainties in energy transitions, implement regular assessment processes with flexibility to adjust strategies based on technological developments, economic impacts, and geopolitical changes. Germany's use of independent expert commissions to evaluate progress provides a useful model.

6.3 Future Research Directions

This investigation suggests several productive avenues for further research. First, more detailed analysis is needed on the distributional impacts of energy security strategies across different socioeconomic groups and regions. Second, comparative studies of institutional frameworks for energy governance could identify optimal structures for balancing national coordination with local implementation. Third, research on the geopolitical implications of renewable energy transitions would enhance understanding of how changing energy interdependencies reshape international relations. Finally, investigation of optimal financing mechanisms for energy security investments—

particularly in developing economies with constrained fiscal space—remains a critical priority.

In conclusion, energy security has evolved from a narrow technical concern to a central pillar of sustainable economic development strategy. The German experience, while imperfect, demonstrates that comprehensive transitions are possible even for major industrial economies, and that the economic benefits of enhanced energy security can substantially outweigh transition costs when strategies are well-designed and consistently implemented. As nations worldwide confront the intertwined challenges of energy affordability, reliability, and sustainability, the lessons from Germany and other pioneers provide valuable guidance for navigating this essential transition.

References

1. Alagoz, E. (2025). Power dynamics and global challenges: A critical exploration of energy, climate and industry. *International Journal of Current Research in Science, Engineering & Technology*.
2. Azzuni, A., & Breyer, C. (2020). Global energy security index and its application on national level. *Energies*.
3. Baran, B. (2015). Support for renewable energy in Germany as an example of effective public policy.
4. Bartha, Z. (2025). Top OECD performers in green growth — an FOI model analysis.
5. Bashynska, Y. (2015). Why is it reasonable to invest in renewable energy in Ukraine? *Three Seas Economic Journal*.
6. Bilan, Y., Strielkowski, W., Karbach, R., & Mentel, G. (2017). Secure development of country and competitiveness issues: Case of Germany's energy security.
7. Bisht, Y., Alzubaidi, L. H., Gulbakhor, U., Yuvaraj, S., Saravanan, T., Kumar, R. S., et al. (2024). Legal framework for energy transition: Balancing innovation and regulation. *E3S Web of Conferences*.
8. Chilimoniuk-Przeździecka, E., & Nyga-Łukaszewska, H. (2017). Modelling energy security and international competitiveness: The export perspective.
9. Chupryna, I., Tormosov, R., Chupryna, K., Oleksandr, M., & Natali, P. (2021). Systematization of international and domestic experience in project management aimed at adapting public-private partnerships to the implementation of sustainable energy development programs. *Scientific Journal of Astana IT University*.
10. DeWit, A. (2010). Get FIT: Public policy, the smart state and the energy-environmental revolution. *Asia-Pacific Journal*.
11. Hägele, R., Iacobuţă, G., & Tops, J. (2022). Addressing climate goals and the SDGs through a just energy transition? Empirical evidence from Germany and South Africa. *Journal Of Integrative Environmental Sciences*.
12. Hernandez, A. (2022). The phases model of the transformation to sustainability (T2S)—structuring through the negotiation perspective. *Sustainability*.
13. Hoicka, C., Lowitzsch, J., Brisbois, M., Kumar, A., & Camargo, L. R. (2020). Implementing a just renewable energy transition: Policy advice for transposing the

new European rules for renewable energy communities. *Social Science Research Network*.
14. Hou, X., Jin, J., & Feng, Y. (2025). Does economic freedom affect green economic growth? Analyses of mediation, moderation, and heterogeneity in EU and non-EU countries. *Frontiers in Environmental Science*.
15. Hu, G., Yang, J., & Li, J. Y. (2022). The dynamic evolution of global energy security and geopolitical games: 1995~2019. *International Journal of Environmental Research and Public Health*.
16. Khanova, O. V. (2025). The German model of renewable energy market development as a benchmark for the EU's energy security. *Economic Scope*.
17. Kouhihabibi, M., & Mohammadi, E. (2023). The future of sustainability in Germany: Areas for improvement and innovation.
18. Kravchenko, M., Trofymenko, O., Kopishynska, K., Pyshnograiev, I., Boiarynova, K., & Roshchyna, N. V. (2024). Ensuring energy security on the basis of intelligent decarbonisation and innovative economic development. *E3S Web of Conferences*.
19. Li, N. (2021). Experience and enlightenment of energy transition in Germany.
20. Molo, B. (2019). The external dimension of the European Union's energy policy and practice of German energy policy.
21. Oluwadamilare, F., Usman, A., Adewnmi, A., Andrew, K., Okoli, C. E., & Usiagu, G. S. (2023). Sustainable energy solutions and climate change: A policy review of emerging trends and global responses. *World Journal of Advanced Research and Reviews*.
22. Reis, S. (2017). Energiewende: German energy policy in times of green transition.
23. Salik uddin Ahmed et al, 2018, China Pakistan Economic Corridor and Pakistan's energy security: A meta-analytic review, Energy Policy, p. 4.
24. Savio, A., De Giovanni, L., & Guidolin, M. (2022). Modelling energy transition in Germany: An analysis through ordinary differential equations and system dynamics. *Forecasting*.
25. Schiffer, H., & Trüby, J. (2018). A review of the German energy transition: Taking stock, looking ahead, and drawing conclusions for the Middle East and North Africa. *Energy Transitions*.
26. Shen, J., Li, J., & Chen, Y. (2021). A comparative study of economic policies based on green energy transformation. *Advances in Transdisciplinary Engineering*.
27. Sher, G., Zhou, J., & Lan, T. (2022). The economic impacts on Germany of a potential Russian gas shutoff. *IMF Working Papers*.
28. Sotnyk, I., Kurbatova, T., Kubatko, O., Prokopenko, O., Prause, G., Kovalenko, Y., et al. (2021). Energy security assessment of emerging economies under global and local challenges. *Energies*.
29. Synianskyi, G. O. (2024). Green transformation of Germany's economy in the contemporary context of global challenges. *Scientific Notes of Taurida National V.I. Vernadsky University. Series: Economy and Management*.
30. Tocci, N. (2023). Europe and Russia's invasion of Ukraine: Where does the EU stand? *LSE Public Policy Review*.

31. Udaeta, M., dos Reis, A. G., Grimoni, J., & Junior, A. C. A. (2015). Energy integration in South America region and the energy sustainability of the nations.
32. Yang, X., Shafiq, M. N., Nazir, R., & Gillani, S. (2024). Unleashing the influence mechanism of technology innovation and human development for ecological sustainability in emerging countries. *Emerging Markets Finance and Trade*.
33. Shpakova, O., Zhuravel, M. O., & Slobodian, N. B. (2024). Ecological energy as a strategic direction for ensuring energy security. *Herald of Khmelnytskyi National University Economic Sciences*.