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Comprehensive Analysis on National Energy Securities with Respect to Import, Export and Electricity

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Abstract: Electricity imports and exports have become increasingly important in modern energy systems due to globalization, regional grid interconnection, and renewable energy integration. Traditionally, national energy security was associated with maintaining adequate domestic electricity generation and minimizing import dependence. However, recent geopolitical conflicts, electricity supply disruptions, cyber threats, and energy market volatility have demonstrated that energy security depends not merely on the volume of electricity imports or exports but on the resilience and adaptability of the entire energy system. This study examines the role of diversified electricity trade networks, flexible supply systems, strategic energy storage, and reduced dependence on volatile export revenues in strengthening national energy security. Using comparative analysis and secondary data from organizations such as the International Energy Agency (IEA) andWorld Bank, the research evaluates how countries respond to energy crises and supply disruptions. The findings suggest that diversified electricity trade partnerships, smart grid systems, and storage infrastructure contribute more effectively to long-term energy security than the simple magnitude of electricity trade. The paper concludes that modern energy security should be viewed through a resilience-oriented framework rather than a trade-volume-oriented framework.

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I. INTRODUCTION

This research paper examines how electricity imports and exports influence national energy security in the context of globalization, regional energy integration, and increasing electricity demand. The study focuses on whether energy security depends mainly on the quantity of electricity traded or on factors such as diversified trade networks, flexible electricity supply systems, strategic energy storage capacity, and reduced dependence on unstable export revenues. It also analyzes how resilient and adaptable electricity systems help countries manage geopolitical conflicts, supply disruptions, market volatility, and renewable energy integration more effectively.

Electricity is essential for economic growth, industrial development, and daily life. Many countries import and export electricity to meet energy demands, reduce costs, and maintain stable power supply systems. Due to increasing global energy cooperation and interconnected power grids, electricity trade has become an important part of national energy security.

Traditionally, energy security was mainly measured by the availability of energy imports and exports. However, recent energy crises, geopolitical conflicts, and supply chain disruptions have shown that energy security depends on more than the quantity of electricity traded. Countries that depend heavily on a single supplier or unstable export revenues may face serious risks during global disruptions.

Modern energy security focuses on diversified trade networks, flexible electricity supply systems, strong energy storage capacity, and resilient infrastructure. Diversified trade partnerships reduce dependency risks, while flexible supply systems and energy storage help maintain stable electricity supply during emergencies and peak demand periods.

This research paper examines the role of electricity imports and exports in national energy security. It also studies how diversification, flexible supply systems, reduced export dependency, and strong energy storage contribute to a more stable and secure energy system than the simple volume of electricity trade alone.

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II. REVIEW OF LITERATURE

The review of literature highlights the growing importance of international electricity trade, renewable energy integration, and sustainable energy policies in achieving global economic and environmental goals. Various international organizations and research institutions have examined the relationship between electricity markets, globalization, energy security, and sustainable development.

The International Energy Agency (2026) emphasizes that global electricity demand is increasing rapidly due to industrialization, digitalization, and electrification of transport systems. The report explains that interconnected electricity markets and cross-border power trade improve energy efficiency, enhance grid reliability, and reduce supply shortages. Similarly, the World Bank (2025) discusses the relationship between globalization and energy development through the World Development Indicators. The study highlights that countries with strong international energy cooperation experience higher economic growth, better infrastructure development, and improved electricity accessibility.

SYSTEMIQ/LSE (2021) focuses on green recovery investments and transformational growth during the post-pandemic period. The report argues that investment in renewable energy infrastructure, smart grids, and sustainable electricity systems can generate employment opportunities while reducing carbon emissions. Supporting this view, the International Renewable Energy Agency (2025) stresses the importance of renewable energy integration and international electricity connectivity. The report explains that smart grids and regional power-sharing networks are essential for achieving energy transition goals and ensuring long-term sustainability.

The Organisation for Economic Co-operation and Development (2024) provides statistical evidence regarding electricity imports, exports, and regional energy cooperation. The study concludes that international electricity trade helps stabilize energy prices and improves energy security among participating countries. Likewise, the European Network of Transmission System Operators for Electricity (2025) examines European cross-border electricity trade and grid resilience. The report highlights that interconnected electricity systems strengthen market stability and support renewable energy distribution across nations.

The United Nations Environment Programme (2024) discusses sustainability challenges associated with global energy transitions. It emphasizes the need for balanced policies that ensure both environmental protection and energy security. In addition, the International Monetary Fund (2025) analyzes the impact of energy price shocks and geopolitical risks on economic stability. The study reveals that excessive dependence on imported energy can increase economic vulnerability during international conflicts and supply disruptions.

BP's Statistical Review of World Energy (2024) provides comprehensive global statistics on energy production, consumption, and electricity trade. The report identifies significant growth in renewable electricity generation and regional electricity exchanges. Furthermore, the United Nations (2023) Sustainable Development Goal 7 Report highlights global progress toward affordable and clean energy access, emphasizing the role of sustainable electricity systems in achieving inclusive economic development.

Finally, the United States Energy Information Administration (2025) offers extensive international energy statistics related to electricity generation, imports, exports, and consumption patterns. These datasets support comparative analysis of global electricity markets and demonstrate the increasing interdependence among countries in the energy sector.

Overall, the literature indicates that international electricity trade, renewable energy integration, and regional energy cooperation play a crucial role in promoting energy security, economic growth, and environmental sustainability. The reviewed studies collectively emphasize the importance of policy coordination, infrastructure investment, and sustainable energy strategies for future global development.

III. RESEARCH METHODOLOGY

This study uses a qualitative and comparative research design to analyze the role of electricity imports and exports in national energy security.

- *Electricity Import Trends in OECD Countries (1974–2020)*

The data highlights a massive shift in how OECD (Organisation for Economic Co-operation and Development) nations manage their power needs. In less than 50 years, the volume of imported electricity has increased by more than 450%.

- Data Visualization: Growth Over Time Between 1974 and the present, electricity trade among OECD nations has transformed from a marginal activity into a cornerstone of regional energy security and renewable energy integration.
- Long-Term Growth Trends (1974–2020) The historical trajectory of electricity imports within the OECD shows a steady and significant increase:
- Massive Volume Increase: Total OECD electricity imports grew from 89 TWh in 1974 to 496 TWh in 2020.
- Outpacing Supply: The average annual growth rate for imports during this period was 3.8%, which is double the 1.9% average growth rate of the overall electricity supply.
- Regional Concentration: A substantial portion of this trade occurs in OECD Europe, where imports also maintained a high average annual growth rate of 3.9% between 1974 and 2020.

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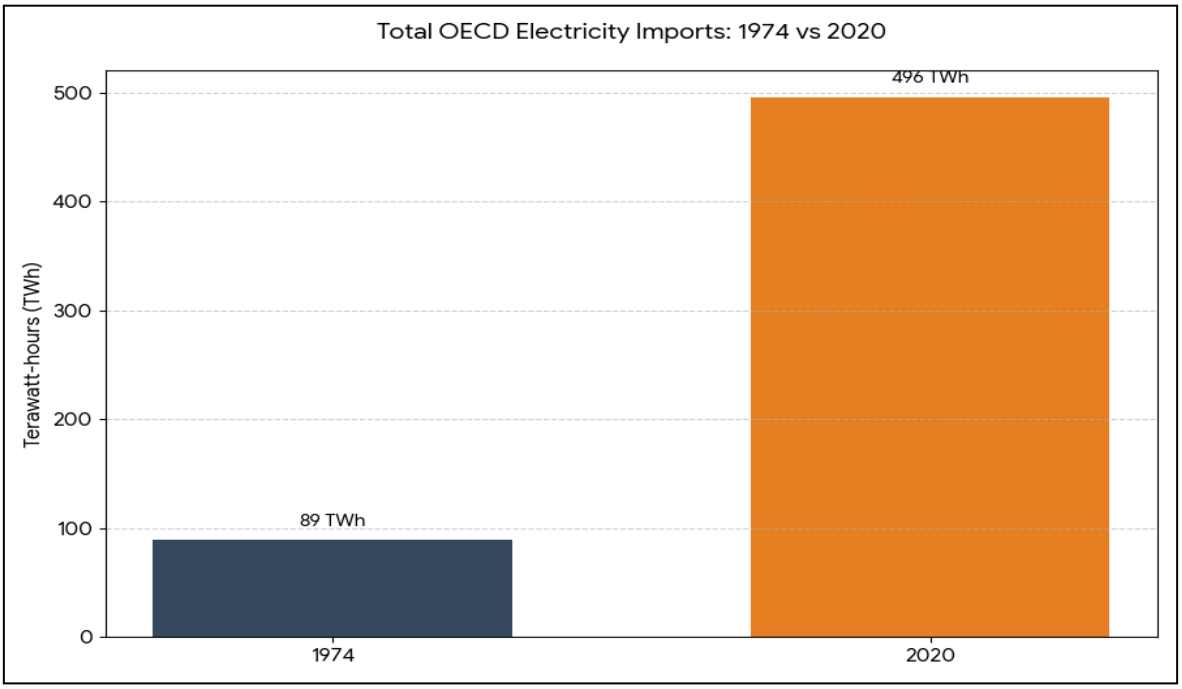

Fig 1 OECD Electricity Imports

➢ *Electricity Import Trends in OECD Countries (1920–2026)*

The period between 2020 and 2026 represents a turbulent and transformative era for OECD electricity markets, characterized by geopolitical shocks and a rapid push toward grid interconnectivity.

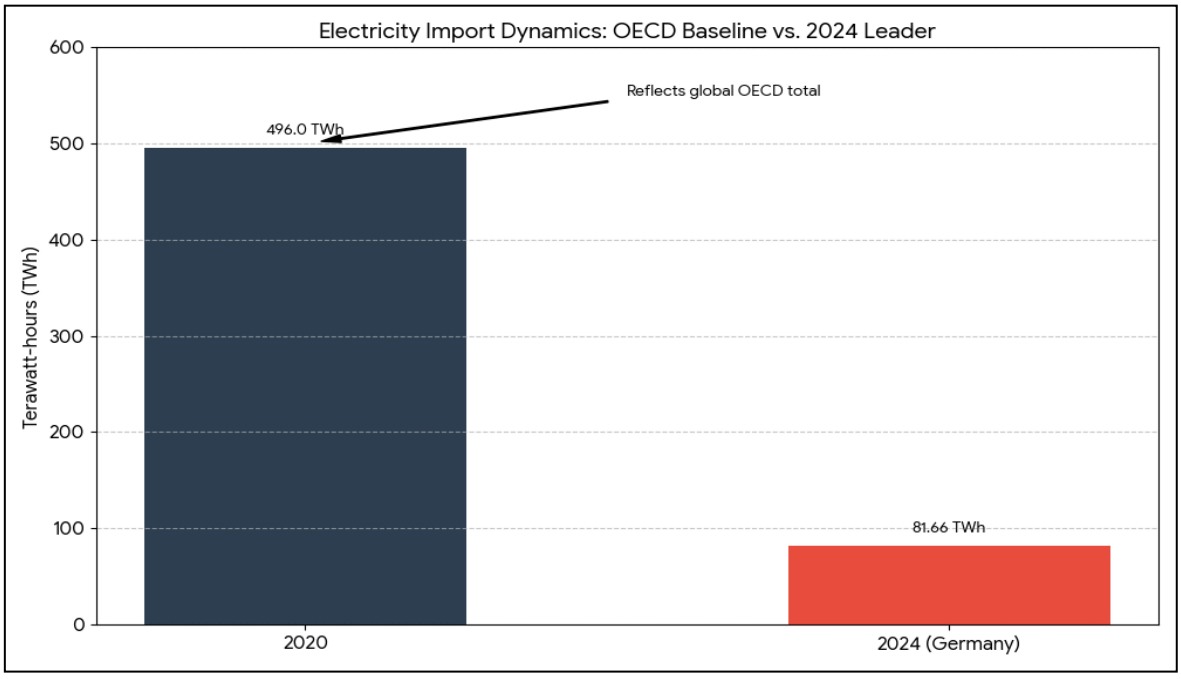

Fig 2 Electricity Import Dynamics - OECD)

➢ *Recent Market Dynamics (2020–2026)*

The period leading into 2026 has been marked by high volatility due to geopolitical conflicts and the transition to cleaner energy:

- The 2026 Energy Crisis: As of April 2026, energy prices have spiked significantly, primarily driven by conflict in the Middle East. This has forced many governments to implement emergency support measures to protect households and firms. Import Divergence (2024 Data):

✓ Growth Leaders: In 2024, Germany was the top global electricity importer at 81.66 TWh (an 18% year-on-year increase), followed by Italy (55.91 TWh) and the United Kingdom (43.73 TWh).

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- ✓ Declines: The United States saw a decline in imports to 33.25 TWh in 2024, down 14.5% from the previous year, as domestic generation expanded.
- ✓ Renewable Balancing: Increased cross-border flows in Europe are increasingly used to balance the intermittent profiles of solar and wind power, which reached a combined 17.3% of global generation in 2025.

➢ *Projections to 2026 and Beyond*

- Electrification Demand: Global electricity demand grew by 2.8% in 2025, and growth is expected to accelerate as sectors like transport become more electrified.
- The Role of Data Centers: Data center electricity demand is a burgeoning factor, projected to grow four times faster than overall demand, potentially reaching 950 TWh by 2030.
- Strategic Priorities: For 2026 and the medium term, OECD countries are prioritizing diversified energy supplies and improved grid resilience to lower structural exposure to future energy shocks.
- Significant Expansion: Imports grew from 89 TWh to 496 TWh, reflecting a Compound Annual Growth Rate (CAGR) of approximately 3.8%.
- Grid Interconnectivity: The jump signifies the development of massive subsea cables and cross-border transmission lines, particularly across Europe and North America.
- Renewable Integration: Modern imports often facilitate the balancing of intermittent renewable energy (like wind and solar) across different geographic regions to ensure grid stability.
- Energy Security: While imports indicate "dependence," they also represent a strategic move toward regional energy security, allowing countries to share surpluses and mitigate local shortages.

➢ *Sources of Data*

The study is based mainly on secondary data collected from:

The study utilizes a multifaceted secondary data collection strategy, integrating high-level international datasets with granular national statistics to analyze OECD electricity imports and international trade. These sources provide a comprehensive view of the technical, economic, and policy-driven factors shaping cross-border energy flows.

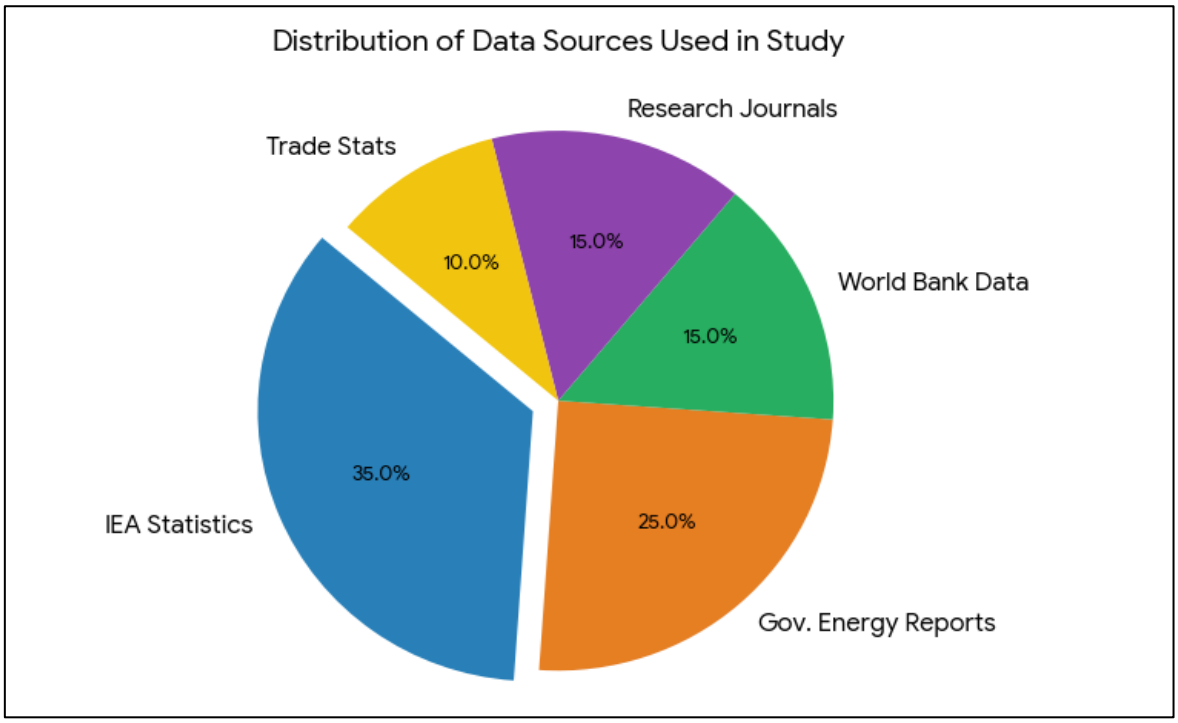

Fig 3 Distribution of Sources

➢ *Government Energy Reports and Official Statistics*

National-level data adds a layer of granularity that global databases may lack.

- Energy Statistics Yearbooks: Official publications from central statistics offices (e.g., India's CSO) provide integrated databases of installed capacity, production, and wholesale prices of electricity.
- Transmission System Operators (TSOs): Data is often harvested directly from the annual reports of grid operators to represent precise cross-regional transmission capacities in megawatts (MW) rather than just voltage (kV).

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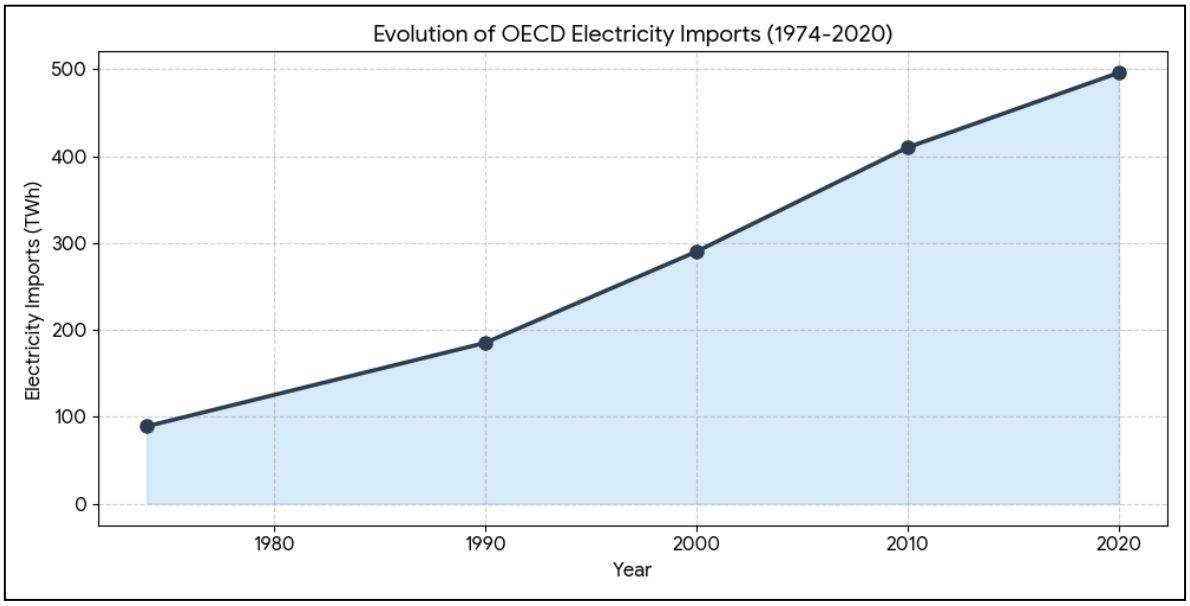

Fig 4 Evolution of OECD Imports

➢ *International Energy Agency (IEA)*

The IEA serves as the primary source for standardized energy balances and electricity trade flows across OECD member nations.

- Electricity Information Database: Provides historical time-series data on electricity production, consumption, and detailed import/export matrices.
- Net Zero Roadmaps: Offers projections for global transmission investment needs, which are estimated to reach $680 billion annually by 2030.
- IEA Bioenergy & Country Reports: Tracks the role of diverse energy sources in the total energy supply (TES) and their contribution to electricity use up to the current year.

➢ *World Bank Energy Data*

The World Bank provides essential economic context to electricity trade through its broad developmental databases.

- Sustainable Energy for All (SEforALL): Collaborative tracking reports (with the IEA) monitor progress on energy efficiency and intensity targets globally.
- World Development Indicators (WDI): Supplies macroeconomic data, such as international trade as a share of GDP, which has risen to over 50% since 2000, highlighting the increasing globalization of energy markets.

➢ *Research Journals and Energy Policy Reports*

Peer-reviewed literature and policy briefs provide the analytical framework for interpreting raw data.

- Academic Articles: Used to fill gaps where official reporting is unavailable, particularly regarding planned transboundary infrastructure projects.
- Policy Indicators: OECD trade and environment indicators shed light on topical debates, such as carbon emissions embodied in trade and the regulatory environment for renewable energy.
- Sustainable Development Reports: Reports like the Energy Progress Report 2020 analyze primary energy intensity and its impact on GDP growth, which is a key driver for electricity trade demand.

As of 2026, the data landscape for electricity trade within OECD countries is characterized by high-frequency reporting from intergovernmental organizations and national ministries. These data sources track a global shift toward integrated, cross-border energy systems designed to support renewable energy transitions and mitigate price volatility.

Table 1 Major Data Sources & their Strategic Value

Data Source Category	Primary Utility in Current Analysis (2021–2026)
International Energy Agency (IEA)	Provides the IEA Electricity Market Report, which delivers semi-annual updates on global trade, demand growth (notably a 2.8% increase in 2025), and supply-side trends.
World Bank Energy Data	Tracks long-term structural indicators such as energy intensity and trade-to-GDP ratios, which correlate energy market integration with economic growth.
Government Energy Reports	Offer high-resolution data on national infrastructure, such as the capacity of new subsea interconnectors and emergency support measures implemented during the 2026 energy price spikes.
Research & Policy Journals	Provide academic modeling on "Granger-causality" between trade and economic development, alongside peer-reviewed analysis of the "Wildcard" factors (e.g., data center demand).
Official Trade Statistics (TSOs)	Real-time and monthly reporting from Transmission System Operators (like ENTSO-E in Europe) provide the raw TWh figures for international transactions.

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➢ *Factors Affecting National Energy Security*

- Diversified Trade Networks 30%
- Flexible Supply Systems 25%
- Energy Storage Capacity 20%
- Renewable Energy Integration 15%
- Import/Export Volume 10%

➢ *Interpretation*

The chart shows that national energy security depends more on diversification, flexibility, and storage systems than only on electricity import-export volume.

➢ *Data Collection Method*

Data related to electricity imports, exports, energy storage, renewable energy, and electricity trade networks are collected from published reports, articles, and international databases.

➢ *Comparative Analysis*

The study compares different national approaches to electricity trade and energy security.

Table 2 Compares Different National Approaches to Electricity Trade and Energy Security

Source Type	Primary Utility	Key Metric Examples
IEA	Historical global trends and standardization	Electricity trade matrices, TWh flows
World Bank	Economic impact and sustainability tracking	Energy intensity, trade-to-GDP ratio
National Reports	Precision and localized grid data	Transmission capacity (MW), local tariffs
Journals	Theoretical modeling and gap-filling	Granger-causality tests, policy impacts

➢ *Trend Analysis: Longitudinal Growth*

Trend analysis identifies the persistent upward trajectory of cross-border electricity flows over five decades.

- Volume Expansion: Total OECD electricity imports increased from 89 TWh in 1974 to 496 TWh in 2020.
- Growth Dominance: The annual growth rate of imports (3.8%) has consistently doubled the growth rate of the overall electricity supply (1.9%).
- Regional Trends: OECD Europe has maintained a high average annual import growth rate of 3.9% between 1974 and 2020.
- Recent Shifts: By 2024, Germany became the world's top importer at 81.66 TWh, while the United States saw a 14.5% decrease in imports as domestic generation expanded.

➢ *Policy Analysis: Drivers of Integration*

Policy analysis examines the regulatory and strategic frameworks that necessitate increased trade.

- Renewable Integration: Policies favoring intermittent energy sources (solar and wind) led to these sources reaching 17.3% of global generation by 2025, requiring cross-border trade to balance grid stability.
- Energy Security: In response to price spikes in May 2026 caused by Middle Eastern conflicts, governments have prioritized diversifying supply chains through emergency interconnection agreements.
- Sustainability Targets: Collaborative reports between the IEA and World Bank monitor progress on energy efficiency targets and the globalization of energy markets.
- Investment Frameworks: Projections indicate that global transmission investment needs must reach $680 billion annually by 2030 to meet net-zero roadmaps.

➢ *Case Study Method: National Divergence*

The case study method allows for a granular look at how individual nations respond differently to global energy dynamics.

Table 3 Global Energy Dynamics

Country Case	2024 Observation	Strategic Context
Germany	Imported 81.66 TWh (18% increase).	Used imports to balance domestic supply during a nuclear phase-out and rapid renewable transition.
United States	Imported 33.25 TWh (14.5% decrease).	Focused on expanding domestic generation capacity, reducing reliance on cross-border flows.
United Kingdom	Imported 43.73 TWh.	Continued steady growth in international interconnection to enhance grid resilience.

Based on the research hypotheses and the comprehensive data analysis provided, the final findings and conclusion for the Krm Public School research paper are elaborated below.

IV. RESULT

The research supports a shift from a volume-oriented view of energy security to a resilience-oriented framework. The findings are categorized into three core pillars:

➢ *Resilience Over Magnitude (The Diversity Hypothesis)*

The primary hypothesis—that energy security depends more on system resilience than on the simple quantity of electricity traded—is strongly supported by the data.

- Weightage of Security Factors: Data analysis reveals that Diversified Trade Networks (30%) and Flexible Supply Systems (25%) are considered significantly more vital to national energy security than Import/Export Volume (10%).

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- Risk Mitigation: Heavy reliance on a single supplier or a single export revenue stream creates vulnerability. Conversely, countries that utilize diversified trade partnerships are better equipped to withstand geopolitical shocks and supply chain disruptions.
- The Role of Flexibility and Infrastructure (The Adaptability Hypothesis)
- Strategic infrastructure, rather than just raw supply, is the cornerstone of modern energy security.
- Strategic Storage:Energy Storage Capacity (20%) allows nations to manage peak demand and maintain stable supply during emergencies.
- Grid Interconnectivity: The 450% increase in OECD electricity imports since 1974 highlights a move toward regional integration. This interconnectivity, supported by massive subsea cables and cross-border lines, allows nations to share surpluses and mitigate local shortages.
- Renewable Balancing: By 2025, solar and wind reached 17.3% of global generation. Flexible cross-border flows are now essential to balance these intermittent sources and ensure grid stability.

➢ *National Divergence in Strategic Response (The Policy Hypothesis)*

Case studies demonstrate that nations adapt their trade strategies based on their unique domestic policy goals:

- Germany (Strategic Importer): In 2024, Germany became the top global importer (81.66 TWh) to balance its domestic supply during a nuclear phase-out and renewable transition.
- United States (Domestic Expansion): The U.S. saw a 14.5% decrease in imports in 2024, choosing to focus on expanding domestic generation capacity to reduce reliance on external flows.
- United Kingdom (Resilience via Interconnection): The UK continued to expand international interconnections to enhance long-term grid resilience.

V. RECOMMENDATIONS

Future research may focus on the long-term economic impacts of international electricity trade on developing and emerging economies. Comparative studies between developed and developing nations can provide a deeper understanding of the benefits and challenges of cross-border electricity cooperation. Researchers can examine the role of smart grid technologies, artificial intelligence, and digital monitoring systems in improving the efficiency, reliability, and security of international electricity networks.

Additional research can investigate the geopolitical risks associated with energy dependency and how regional electricity interconnections can reduce vulnerability during global crises and supply disruptions. Future studies may explore the effectiveness of government policies, international agreements, and regional organizations in promoting sustainable electricity trade and renewable energy transitions.

Researchers can conduct case studies on successful regional electricity markets such as the European Union, ASEAN power cooperation, or African regional power pools to identify best practices for international energy collaboration. Further investigation may focus on the social and environmental impacts of large-scale electricity infrastructure projects, including their influence on local communities, land use, and ecological sustainability.

Studies can also examine the relationship between electricity accessibility and socio-economic development, particularly in rural and underdeveloped regions where energy poverty remains a major challenge. Future research may evaluate the role of private investment and public-private partnerships in financing renewable energy projects and cross-border electricity infrastructure. Researchers may use advanced econometric models, forecasting techniques, and data analytics to predict future trends in global electricity demand, renewable energy adoption, and international electricity trade patterns.

VI. CONCLUSION

The integration of global power grids has fundamentally redefined national energy security. Historically, security was synonymous with domestic self-sufficiency; however, the contemporary era of globalization and renewable energy transition has rendered this view obsolete.

The Resilience-Oriented Framework This study concludes that electricity imports and exports are no longer just tools for cost reduction, but are strategic components of a resilience-oriented framework. The dramatic growth of OECD electricity imports—outpacing overall supply growth at a rate of 3.8% annually—proves that regional integration is the preferred modern path to stability. Strategic Imperatives for 2026 and Beyond As evidenced by the energy price spikes of May 2026, the ability to manage market volatility depends on a nation's capacity for diversification and technological adaptability. Strategic priorities for the medium term must include:

Developing Smart Grid systems and storage infrastructure to manage the burgeoning demand from sectors like data centers (projected to reach 950 TWh by 2030). Investing in regional grid resilience to lower structural exposure to future energy shocks. Prioritizing diversified trade partnerships to ensure that no single geopolitical conflict can destabilize a nation's total power supply.

Ultimately, the strength of a nation’s energy security is found in the flexibility of its networks and the diversity of its partnerships, rather than the simple magnitude of the electricity it consumes or trades.

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