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Barriers to Integration in the Global Natural Gas Market: Insights from Regional Price Trends and Volatility Analysis

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ABSTRACT: This study examines natural gas price dynamics across the United States, Europe, and Japan from 2022 to 2025 to evaluate global market integration. Using World Bank Commodity Markets Outlook data and statistical methods including coefficient of variation, price spread analysis, and volatility modeling, the study finds that despite LNG trade expansion, significant regional price differentials persist. Europe experienced sharp price spikes due to the Russia-Ukraine conflict, Japan was buffered by long-term contracts, while the US maintained the lowest and most stable prices owing to strong domestic production. In 2025, seasonal trends and storage capacity continued to shape regional pricing. The study concludes that global natural gas markets remain only partially integrated, constrained by regulatory heterogeneity, contractual rigidity, and uneven infrastructure development. Policy recommendations include establishing regional trading hubs, standardizing contracts, and investing in flexible infrastructure to enhance energy security and market resilience.

Keywords: Natural Gas, LNG Trade, Price Volatility, Market Integration, Regional Disparity, Energy Security.

INTRODUCTION

The global natural gas market has experienced considerable transformation in recent years, particularly in the wake of rising energy demand, geopolitical developments, and the ongoing global energy transition. Among fossil fuels, natural gas has emerged as a crucial transitional energy source, serving as a bridge between high-carbon sources such as coal and more sustainable, low-carbon alternatives. This relevance is heightened by the increasing integration of renewable energy sources, where natural gas continues to offer grid stability and flexibility. Within this global shift, the dynamics of regional natural gas markets have become a focal point, with significant attention directed towards price behavior across major consumption and production regions including the United States, Europe, and Japan.

Recent trends in global LNG trade reveal a surge in demand, especially in Asia and Europe, driven by the need for cleaner energy alternatives and the reduction of carbon emissions. This growing demand has been matched by supply diversification efforts, notably the expansion of U.S. LNG

exports, which have enabled countries to reduce reliance on traditional suppliers such as Russia (Farag et al., 2025; Nikhalat-Jahromi et al., 2017). The onset of the Russia-Ukraine conflict in February 2022 was a pivotal event that disrupted European gas markets, causing price surges and prompting a reassessment of regional energy security frameworks. In the six months following the invasion, natural gas prices increased globally by an estimated 78.65%, underlining the geopolitical sensitivity of energy markets (Xiao-mei et al., 2025).

In response to these shocks, European countries intensified efforts to diversify supply routes and reduce their dependency on Russian gas. This included expanding LNG import capacities and forming new trade agreements with exporters such as the United States and Qatar (Albrizio et al., 2025; Pye et al., 2025). These measures not only altered the sourcing strategies of European nations but also triggered broader integration initiatives, focusing on enhancing interconnection infrastructure and streamlining regulatory frameworks (Bilgin, 2025; Hudak et al., 2025). Simultaneously, Asia, led by China, continued to scale up its LNG infrastructure, while Southeast Asia, particularly within ASEAN, explored regional integration to strengthen market connectivity (Muzychenko, 2024; Shi et al., 2019).

As part of the global energy transition, natural gas occupies a strategic role due to its lower carbon intensity relative to coal and oil. Its adaptability and relatively lower emissions make it an optimal candidate for facilitating a smoother shift to renewable energy systems. In particular, power generation systems have incorporated natural gas to enhance efficiency and balance the intermittency associated with renewables (L. Chen et al., 2024). Furthermore, as energy policies increasingly focus on emissions reductions and the sustainable transformation of energy systems, the demand for natural gas remains robust, reinforcing its role as both a substitute and a complement to renewable technologies (Alzate-Ortega et al., 2024).

Natural gas pricing mechanisms differ considerably across regions. These mechanisms can be broadly classified into hub-based, contract-based, and hybrid models. In the U.S., hub-based pricing dominates, where markets such as the Henry Hub determine prices based on real-time supply and demand fluctuations. This structure allows for price transparency, enhanced liquidity, and competitive market behavior (Chiappini et al., 2019; Wang et al., 2020). In contrast, Japan primarily operates under contract-based pricing, typically indexed to crude oil benchmarks. These long-term contracts offer price stability and revenue predictability but limit responsiveness to short-term market changes. Europe exhibits a hybrid pricing model that incorporates both spot market influences and contractual pricing. This hybridization allows for flexibility and hedging against volatility while accommodating market shifts (Bilgin, 2025).

The characteristics of each pricing model significantly affect market behavior and integration. Hub-based models encourage fluid market operations, while contract-based models promote stability and predictability. Hybrid systems attempt to harness the benefits of both, enhancing resilience and competitiveness. As natural gas markets evolve, the trend towards hybrid pricing structures has been reinforced by advancements in infrastructure and market liberalization, which promote a cohesive pricing environment (Bublyk et al., 2022).

Since 2020, there has been a marked acceleration in global natural gas market integration, driven by LNG trade expansion and infrastructure investments. Enhanced interregional connectivity and increased LNG flows have facilitated cross-border trade and improved market liquidity. The United States has played a pivotal role in this process by shifting its focus to LNG exports, thereby contributing to the alignment of gas prices between North America, Europe, and Asia (Farag et al., 2025; Chiappini et al., 2019). Additionally, global integration efforts have been supported by regulatory reforms and investments in interoperable gas networks, which have improved the ability of markets to respond to supply shocks and adjust to global pricing dynamics (Bublyk et al., 2022; Albrizio et al., 2025).

Nevertheless, despite these strides toward market unification, considerable regional price disparities persist. These are influenced not only by supply-demand imbalances and infrastructure constraints but also by localized market mechanisms and geopolitical considerations. The observed divergence in prices among the U.S., Europe, and Japan over the 2022 to 2025 period exemplifies this phenomenon. While short-term convergence has occurred during specific periods, particularly when global market conditions aligned, such instances remain exceptions rather than the norm. Thus, a comprehensive understanding of natural gas price trends in different regions is essential to evaluate the depth and resilience of market integration.

This study seeks to investigate the regional dynamics of natural gas pricing by analyzing data from the United States, Europe, and Japan between 2022 and 2025. It aims to determine whether global LNG trade and enhanced infrastructure have contributed to market convergence or whether persistent regional differences suggest continued fragmentation. By examining price trends, volatility, and regional spreads, the research intends to contribute to the broader discourse on energy market integration. The novelty of this study lies in its comparative approach across multiple time horizons (annual, quarterly, monthly) and the focus on three distinct pricing systems, offering insight into how structural, contractual, and geopolitical factors collectively shape global gas pricing. Ultimately, the findings will have implications for policymakers and stakeholders aiming to enhance global energy security and market efficiency.

METHOD

Research Design and Scope

This study employs a quantitative research design aimed at analyzing the pricing dynamics of natural gas across three major regions: the United States, Europe, and Japan. The research focuses on the time period from 2022 to 2025 and uses secondary data obtained from the World Bank's Commodity Markets Outlook (Pink Sheet), which provides standardized and publicly available historical pricing data in USD per million British thermal units (mmbtu). By comparing trends across time and region, the study seeks to assess the degree of convergence or divergence in natural gas markets, thereby evaluating the extent of global market integration.

Data Collection and Sources

The primary dataset used in this study is drawn from the World Bank's Pink Sheet, which offers monthly, quarterly, and annual price data for various energy commodities. This includes:

- Annual average prices for 2022 to 2024.
- Quarterly price averages for Q1 to Q4 of 2025.
- Monthly price data for September through November 2025.

Additional context for methodology development and volatility modeling was informed by authoritative energy data providers such as the U.S. Energy Information Administration (EIA), the International Energy Agency (IEA), Bloomberg, Reuters, and academic journals, which are widely recognized for their accuracy and historical depth in tracking energy market behavior.

Variables and Indicators

The core variable analyzed is the price of natural gas ($/mmbtu) in three regions:

- United States (hub-based pricing)
- Europe (hybrid pricing)
- Japan (contract-based LNG pricing)

To evaluate volatility and convergence, several indicators were employed:

- Average price per period
- Standard deviation and coefficient of variation
- Price spread between regions
- Trend visualization across time intervals

Statistical Methods for Analyzing Price Volatility

The complex nature of natural gas pricing necessitates the use of sophisticated statistical tools. Among the most robust are Generalized Autoregressive Conditional Heteroskedasticity (GARCH) models, which are well suited to modeling financial time series data characterized by volatility clustering. The GARCH(1,1) model is particularly common in energy economics due to its ability to reflect periods of intense price fluctuation followed by relative calm (Chan & Grant, 2016; Goldman & Shen, 2017; Rahman et al., 2023).

Further refinement in modeling is achieved through extensions such as the Exponential GARCH (EGARCH), which captures asymmetric market reactions to positive and negative price shocks (Y. Chen & Fan, 2024). Some studies have also explored hybrid models combining GARCH with machine learning algorithms like Long Short-Term Memory (LSTM) networks, improving

forecasting accuracy by capturing nonlinear dependencies in energy price movements (Zeng et al., 2022).

Copula and Multivariate Analysis

To explore dependencies between regional gas markets, copula-based models are incorporated. These models enable researchers to examine how price shocks in one market may spill over to others. Multivariate GARCH models allow for simultaneous modeling of multiple regional price series, revealing the strength and nature of their interdependencies (Sadraoui et al., 2021).

Coefficient of Variation (CV) for Comparative Volatility

The coefficient of variation (CV) is used as a normalized measure of price volatility. Defined as the ratio of the standard deviation to the mean, the CV facilitates the comparison of variability across datasets with different scales or units. In energy economics, this statistic is crucial for assessing risk and instability in fuel pricing(Saghaian et al., 2017). A high CV in natural gas prices, for example, may suggest increased uncertainty, affecting procurement planning, risk mitigation strategies, and policy formulation.

Price Spread Analysis and Trend Visualization

Interregional price spreads are calculated to assess convergence or divergence trends. The spread is defined as the absolute difference between the maximum and minimum prices across the three regions in each time period. This analysis is supported by visual tools including:

- Line charts for temporal price comparisons
- Bar charts for interregional price spread visualization
- Volatility graphs showing CoV across time

Limitations and Scope Constraints

The study acknowledges certain limitations. First, it does not use proprietary or real-time trading data, which may include more granular details. Second, while the GARCH and CV approaches are statistically robust, they may not capture all market fundamentals such as regulatory shifts or sudden geopolitical disruptions. Additionally, while price trends are assessed through descriptive and inferential tools, the research does not construct a forecasting model, focusing instead on comparative historical and near-future patterns.

RESULT AND DISCUSSION

Annual and Regional Price Trends.

Natural gas markets across the United States, Europe, and Japan experienced notable price volatility in the aftermath of the COVID-19 pandemic. In the United States, prices remained relatively stable but increased modestly due to a strong post-pandemic industrial rebound. The Henry Hub price averaged approximately $6.00 per million British thermal units (MMBtu), reflecting growing domestic demand and emerging supply constraints (Saad, 2023).

Europe, in contrast, witnessed dramatic price spikes, especially in 2022. Average natural gas prices exceeded €190 per MWh as a consequence of heightened concerns over supply disruptions following the Russian invasion of Ukraine. This geopolitical event triggered panic buying, sharp increases in LNG import demand, and a reorientation of energy sourcing strategies (Saad, 2023). The closure of Nord Stream pipelines significantly exacerbated these concerns, further destabilizing market prices (Saad, 2023).

Japan, heavily reliant on LNG imports, also experienced price increases. Although less volatile than Europe, Japanese LNG prices ranged between $15 and $20 per MMBtu during this period, driven by higher import costs and international competition for LNG cargoes (Saad, 2023).

Long-term LNG contracts played a crucial role in Japan's market stability during this time. Typically indexed to crude oil, these contracts shielded Japan from extreme spot market volatility. While providing predictability, they limited the country's ability to benefit from occasional spot market price declines (Amoako et al., 2022). Nevertheless, amid global energy market turbulence, these agreements offered vital price stability.

Key supply-side factors contributing to price trends included reduced Russian gas flows, maintenance delays at LNG facilities, and logistical challenges in global supply chains. Demand-side drivers included rapid industrial recovery, electricity generation needs, and increased reliance on natural gas as a transitional energy source in the shift toward low-carbon alternatives (Saad, 2023).

Table 1. Annual Average Natural Gas Prices by Region (2022–2024)

Year	US ($/mmbtu)	Europe ($/mmbtu)	Japan LNG ($/mmbtu)
2022	6.45	40.73	24.11
2023	2.57	13.04	14.43
2024	2.30	10.73	11.85

Quarterly and Monthly Trends

Analysis of 2025 data reveals continued seasonal trends and region-specific market dynamics. LNG demand remained higher during winter months, particularly in Japan and Europe, where heating needs peaked. Japan experienced a significant demand surge in Q1 and Q4, aligned with seasonal heating cycles, while Europe increased imports during shoulder seasons to build strategic storage (Saad, 2023).

Flexible LNG contracting and diversified sourcing reduced the extremity of seasonal peaks compared to prior years. As European markets transitioned toward a more liquid and diversified LNG supply structure, the magnitude of seasonal demand swings appeared less pronounced.

Geopolitical developments continued to influence prices in 2025. The persistence of sanctions against Russia, OPEC supply interventions, and global energy trade negotiations added uncertainty and price volatility. Furthermore, ongoing renewable energy integration shaped regional pricing, as gas remained vital for grid stability.

In Q4 2025, regional divergence persisted. European prices remained elevated due to diminished storage entering winter and limited Russian supply. The U.S., with strong domestic production and expanded LNG infrastructure, maintained more stable prices. This contrast illustrates continued fragmentation in global pricing despite infrastructure improvements.

Storage levels played a pivotal role in pricing dynamics. Sufficient storage in Europe during summer helped mitigate winter spikes, while lower reserves in subsequent periods reignited volatility. The strategic use of LNG inventories emerged as a key tool for price stabilization and risk mitigation.

Table 2. Quarterly and Selected Monthly Natural Gas Prices (2025)

Period	US ($/mmbtu)	Europe ($/mmbtu)	Japan LNG ($/mmbtu)
Q1 2025	3.18	13.01	13.99
Q2 2025	3.44	10.93	12.07
Q3 2025	2.61	10.90	11.91
Q4 2025(f)	2.62	10.49	11.24
Sep 2025	2.16	11.07	12.25
Oct 2025	2.49	11.48	12.69
Nov 2025	2.98	11.29	12.50

Figure 1. Quarterly Price Trends for Natural Gas by Region (2025)

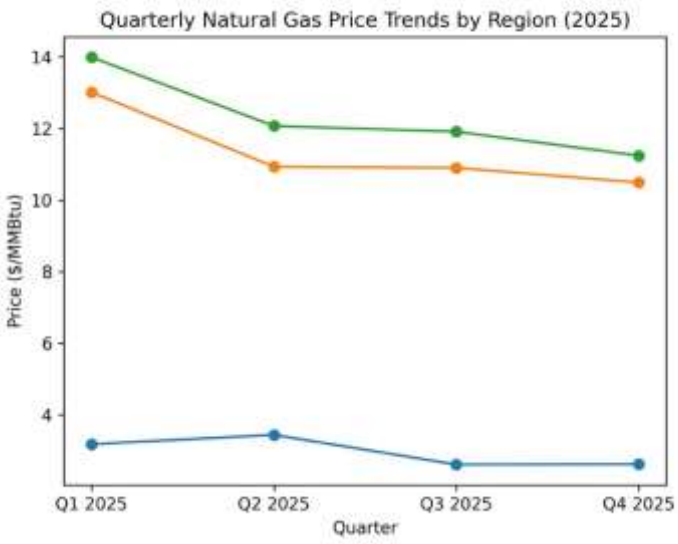
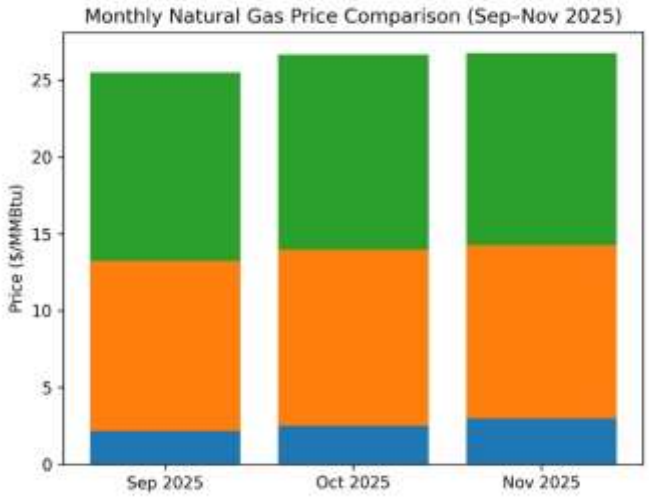


Figure 2. Monthly Price Comparison (Sep–Nov 2025)



Volatility and Price Spread Analysis

Market volatility was assessed using several key indicators, including GARCH model outputs, standard deviation calculations, and rolling historical volatility. These measures captured the dynamic nature of natural gas markets and revealed underlying shifts in market sentiment and expectations (Dhifaoui et al., 2023).

Regional price spreads offered critical insights into the state of market integration. Narrowing spreads between U.S. and European prices in late 2024 and early 2025 suggested improved market linkages, likely driven by increased LNG trade. However, price disparities with Japan remained due to long-term contract structures and limited spot exposure (Dhifaoui et al., 2023).

Key determinants of volatility included geopolitical tensions, supply disruptions, seasonal demand shifts, and oil price dynamics. Interdependencies with crude oil were particularly influential, given historical substitution patterns and indexed contract structures (Dhifaoui et al., 2023). Additional factors such as transportation bottlenecks, weather anomalies, and policy changes further contributed to market uncertainty.

Policy interventions and international trade agreements significantly shaped interregional pricing. Carbon pricing, tariffs, and energy sanctions altered competitive dynamics, influencing pricing strategies and regional energy strategies. For example, European initiatives to diversify supply and introduce regulatory reforms helped moderate volatility over time, despite initial disruption from Russian supply losses (Dhifaoui et al., 2023; Saad, 2023).

In conclusion, the analysis of natural gas prices from 2022 to 2025 highlights persistent regional disparities and dynamic volatility. While some convergence was observed during specific periods, structural and geopolitical factors continued to shape differentiated pricing outcomes. These findings support the assertion that global natural gas markets, though increasingly interconnected, remain only partially integrated.

The findings of this study indicate that despite the increased interconnectedness of global energy markets, the natural gas sector continues to experience significant regional disparities. Several structural and policy-related factors contribute to the fragmented nature of the market, limiting the potential for full integration. These barriers are deeply rooted in regulatory heterogeneity, infrastructure disparities, long-term contractual arrangements, and geopolitical dynamics.

One of the foremost impediments to global market integration lies in the variation of regulatory frameworks across regions. Differences in how countries regulate the pricing, trading, and transportation of natural gas create operational friction, hindering the establishment of unified market mechanisms. For example, East Asian countries such as Japan and South Korea maintain strict import regulations that constrain the evolution of more dynamic and flexible LNG trading systems (Shi & Variam, 2016). Without regulatory alignment, market participants face substantial uncertainty, thereby reducing incentives for cross-border investment and integration.

Infrastructure limitations also present a substantial challenge. Although there have been significant investments in LNG terminals and pipeline networks, disparities in infrastructure development persist between and within regions. In many cases, the lack of adequate regasification capacity, storage facilities, or interconnection points restricts the efficient flow of gas and contributes to local price spikes and supply imbalances (Kim et al., 2020). These physical constraints are particularly pronounced in developing markets, where infrastructure investments have not kept pace with rising demand.

Long-term contracts represent another major structural feature influencing market integration. While these agreements offer stability and revenue certainty for suppliers, their rigidity often limits market responsiveness. Most long-term LNG contracts are indexed to crude oil, and their fixed terms reduce the flexibility of buyers to shift procurement strategies in response to real-time market signals (Agerton, 2017; Xia et al., 2023). This lock-in effect inhibits price convergence, especially when market conditions change rapidly, such as during geopolitical crises. During the European energy crisis triggered by the Russia-Ukraine conflict, countries locked into inflexible contracts were unable to fully benefit from emerging spot market opportunities, highlighting the need for more adaptive contracting models (Agerton, 2017).

The role of geopolitical factors cannot be overstated. Political tensions, trade sanctions, and conflicts such as the Russia-Ukraine war have had profound effects on energy supply chains and market confidence. These disruptions not only shift supply routes and pricing strategies but also exacerbate the risk perceptions of investors and policymakers, further complicating integration efforts (Emiliozzi et al., 2024). Uncertainty over energy availability and security leads to fragmented procurement policies and reinforces regional isolation.

Amid these challenges, some policy solutions have been proposed to promote global market integration. One approach involves the development of regional trading hubs that enhance market transparency and allow prices to reflect real-time demand-supply dynamics. These hubs can increase liquidity and facilitate the emergence of competitive pricing mechanisms (Kim et al., 2020). Additionally, efforts to standardize LNG contract structures could help reduce legal and operational complexity, enabling greater harmonization of global trading practices (Chandler, 2024; Yalamov et al., 2023). Cross-border trade agreements also play a critical role in reducing

tariffs and regulatory friction, fostering trust, and encouraging cooperation across markets (Shi & Variam, 2016).

Infrastructure investment remains a foundational element in integration strategies. Expanding regasification facilities, pipeline networks, and storage capabilities will allow for more dynamic supply responses and help mitigate local supply shocks. Investment in flexible infrastructure is particularly important in supporting the shift from rigid contractual dependence to a more hybrid and responsive market structure (Yalamov et al., 2023).

Persistent regional disparities in natural gas pricing raise serious concerns for energy security. Price volatility, especially in import-dependent regions, increases consumer and industrial energy costs, posing risks to economic stability and development. For low-income economies, the impact is even more pronounced, as a larger share of household and public expenditure is allocated to energy (Emiliozzi et al., 2024). These financial pressures reduce the fiscal space for investments in resilience and sustainability.

Moreover, dependence on a limited number of suppliers due to price disparities can undermine national energy strategies. Countries may be forced into long-term agreements with dominant suppliers during periods of high prices, thereby compromising their bargaining position and increasing vulnerability to supply disruptions. The resulting market distortions also lead to inequities in global energy access, where some countries secure energy at lower costs while others pay premiums due to regional disadvantages (Agerton, 2017; Emiliozzi et al., 2024).

In addition to economic risks, price fragmentation can hinder global cooperation on climate and energy transition goals. Disparities in energy costs create uneven competitive environments, where countries with access to cheaper gas can transition more smoothly, while others lag behind due to affordability issues. Such imbalances complicate multilateral agreements on emissions reductions and undermine collective action on sustainable energy transformation.

In summary, while LNG trade and infrastructure development have improved global connectivity, significant structural, contractual, and geopolitical barriers remain. These challenges prevent full integration and contribute to persistent pricing disparities. Addressing these issues through coordinated policy frameworks, flexible contracting, and strategic infrastructure investment is essential for building a more resilient and equitable global natural gas market.

CONCLUSION

This study set out to examine the extent of price convergence among the United States, Europe, and Japan in the natural gas market from 2022 to 2025, as a proxy for assessing global market integration. The results highlight both the progress made and the persistent barriers that continue to define regional gas markets.

Annual and quarterly price data reveal that while the global LNG trade has contributed to greater market liquidity and diversified supply, significant pricing gaps remain among regions. Europe experienced extreme price spikes in 2022 due to geopolitical tensions, especially the Russia-

Ukraine conflict, while Japan's reliance on long-term contracts ensured relative price stability. In contrast, the United States maintained the lowest and most stable prices due to its self-sufficiency and expansive production capacity.

Quarterly and monthly data from 2025 further confirm these disparities, with seasonal demand and regional storage levels influencing price movements. While some degree of convergence occurred in specific quarters, such instances were not consistent or sustained. These trends suggest that although global LNG infrastructure has improved, the natural gas market remains only partially integrated.

The volatility and price spread analyses reinforce this view, showing how regional markets still respond differently to global shocks and seasonal pressures. Variability in pricing is driven not only by supply and demand fundamentals but also by structural features such as contract rigidity and infrastructure asymmetries.

The discussion underscores the systemic challenges to integration, including regulatory differences, long-term contracts that limit flexibility, uneven infrastructure development, and geopolitical disruptions. These elements create persistent inefficiencies and hinder the natural alignment of regional markets.

However, the study also identifies pathways for improvement. Establishing regional trading hubs, harmonizing contractual standards, facilitating cross-border trade agreements, and investing in adaptable infrastructure can collectively enhance market responsiveness and integration.

Persistent price disparities have significant implications for global energy security. They expose certain regions to economic vulnerabilities and limit their capacity to participate in a fair and resilient global energy system. In this context, pursuing deeper market integration is not only a matter of economic efficiency but also a strategic imperative for global stability and equitable access to energy.

In conclusion, while globalization of the natural gas market is advancing, it remains incomplete. This research contributes to the broader understanding of how price dynamics reflect underlying structural conditions and offers a roadmap for addressing fragmentation in pursuit of a more integrated, secure, and flexible global gas market.

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