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Digital infrastructure as a market institution: Coordination, resilience, and governance in Transatlantic LNG trade

Igoche Godwin *[1] and Lana Musulin[2]

[1 2]Independent Author, Germany

Email: lana.musulin@gmail.com[2]; ORCID: 0009-0009-4188-37982

*Correspondence: ellahscholar@gmail.com; ORCID: 0009-0004-1906-9101

Abstract

Transatlantic liquefied natural gas (LNG) trade between the United States and the European Union has expanded substantially since 2022, driven by the restructuring of European energy supply following the curtailment of Russian pipeline gas. This paper examines the role of digital infrastructure in strengthening this trade across three analytical dimensions: operational coordination, supply chain resilience, and sustainability governance. Applying a qualitative systems-based analysis over the period 2021–2025, and drawing on official statistics, regulatory guidance, industry reports, and documented operational and cyber disruptions, the study evaluates how digital tools including real-time vessel tracking, smart terminal systems, predictive maintenance platforms, and regulatory reporting mechanisms, reduce coordination frictions and improve market transparency. The analysis treats digital infrastructure not merely as a technical enhancement but as an evolving market institution that shapes how LNG is traded, verified, and regulated across jurisdictions. The findings indicate that while digital systems have become operationally indispensable, the current infrastructure remains transitional: fragmented data standards, persistent paper-based documentation, limited interoperability, and cybersecurity vulnerabilities constrain full market coordination. The study concludes that interoperable, secure, and standardised digital infrastructure is a prerequisite, not merely an efficiency gain, for a resilient and transparent transatlantic LNG market, particularly as environmental accountability and automated market interaction become increasingly central to trade governance.

Keywords**:** Liquefied Natural Gas (LNG), Digital Infrastructure, Transatlantic Energy Trade, Supply Chain Resilience, Cybersecurity, Market Coordination, Energy Governance, Methane Regulation

JEL Classification: Q40, Q48, F18

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1. Introduction

The disruption of Russian pipeline gas supplies following the 2022 Ukraine conflict fundamentally restructured European energy markets and elevated transatlantic liquefied natural gas (LNG) trade to a position of strategic centrality. The European Union (EU), confronted with urgent supply security requirements, moved rapidly to increase LNG import capacity and redirect procurement toward flexible spot markets. The United States, with expanding liquefaction infrastructure, contract flexibility, and export surplus, emerged as Europe's dominant LNG supplier, accounting for approximately 48% of EU LNG imports in 2023 and rising to nearly 60% by the third quarter of 2025 (EIA, 2024; Eurostat, 2025). This shift was not merely quantitative but structural: it entailed a transition from long-term, pipeline-dependent supply relationships to a dynamic, multi-actor, cross-jurisdictional trade system requiring coordination across vast distances and regulatory boundaries. The operational complexity of this system extends well beyond physical infrastructure. While liquefaction plants, LNG carriers, floating storage and regasification units (FSRUs), and onshore terminals constitute the tangible backbone of transatlantic LNG trade, their effective functioning increasingly depends on a layer of digital infrastructure that enables real-time coordination, market transparency, regulatory compliance, and risk management. Vessel tracking systems, smart port controls, predictive maintenance platforms, trading analytics, and digital reporting mechanisms now form an integrated operational architecture without which the flexibility and scale of modern LNG trade would not be achievable (IEA, 2017). Yet this digital infrastructure is rarely treated as an analytical object in its own right. Studies of LNG market dynamics have predominantly focused on pricing mechanisms, contract structures, liquefaction capacity, and geopolitical drivers (Talus, 2025; Jao, 2023). Where digitalisation is addressed, it tends to be characterised as a technical enhancement, a means of improving efficiency at specific operational nodes. rather than as an evolving institutional structure that shapes how LNG markets function, how regulatory obligations are fulfilled, and how resilience is constructed at the system level. This framing understates both the current significance and the future trajectory of digital infrastructure in energy trade.

This paper addresses that gap by examining digital infrastructure as a multi-layered market institution rather than a collection of isolated tools. Drawing on transaction-cost theory and information economics, the analysis frames digitalisation as a mechanism for reducing coordination frictions, mitigating information asymmetries, and building operational resilience across geographically and jurisdictionally dispersed supply chains (Williamson, 1985; Akerlof, 1970). This perspective is consistent with recent scholarship on digital transformation in energy systems, which emphasises that the governance of data, interoperability standards, and cybersecurity frameworks is as consequential as the underlying technology itself (IEA, 2017; OECD, 2025).

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The paper addresses two research questions. First, which layers of digital infrastructure most significantly reduce coordination frictions in transatlantic LNG trade? Second, through which operational, market, and governance mechanisms do digital systems enhance resilience and transparency? These questions are examined through a qualitative systems-based analysis of the 2021–2025 period, corresponding to the post-2022 restructuring of European gas supply, drawing on official statistics, regulatory documents, industry reports, and documented operational and cyber disruptions. The contribution of this study is threefold. First, it provides a systems-level synthesis linking specific layers of digital infrastructure to concrete coordination functions across the LNG supply chain, a level of analytical granularity that sector-level energy studies have not consistently applied. Second, it identifies the governance gaps, fragmented data standards, limited interoperability, legal uncertainty around electronic documentation, and uneven cybersecurity frameworks that prevent the current digital system from functioning at full capacity. Third, it traces the developmental trajectory from digital infrastructure as administrative support, through its present role as operational coordination mechanism, to its emerging function in environmental accountability and automated market interaction.

The remainder of this paper is organised as follows. Section 2 provides background on the growth of transatlantic LNG trade and the digital transformation of the energy sector. Section 3 describes the methodological approach. Section 4 examines the main layers of digital infrastructure in LNG operations and their current limitations. Section 5 analyses how digital systems contribute to supply chain resilience, with reference to documented disruptions. Section 6 concludes by outlining future directions for digital infrastructure development in the transatlantic LNG market.

2. Background on Transatlantic LNG Trade and Digitalisation

This section provides the analytical and empirical context for the study by examining the evolution of transatlantic LNG trade and the parallel digital transformation of the energy sector. It first outlines the growth and structural importance of U.S.–EU LNG flows in the context of energy security, and then discusses how digitalisation has reshaped coordination, monitoring, and governance mechanisms in modern energy systems.

2.1 Growth and Geographical Structure pf US–EU LNG Trade

Following the reduction of Russian pipeline gas supplies, the EU significantly increased LNG imports to manage price volatility and ensure security of supply. The United States remained the largest supplier of LNG to Europe in 2023, accounting for 48% of total LNG imports (EIA, 2024). Eurostat data show that in Q3 2025, US LNG accounted for 59.9% of EU LNG imports, demonstrating sustained reliance on transatlantic LNG flows (Eurostat, 2025).

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Table 1. EU LNG imports by main supplier (Q3 2025)

Supplier	Share of EU LNG imports [%]
United States	59.9
Qatar	15.3
Algeria	9.2
Nigeria	6.8
Others	8.8

Source: Eurostat, 2025

Table 1 illustrates the dominant role of the United States in the EU LNG supply mix. The high share of US LNG reflects Europe's strategic shift toward flexible but more expensive transatlantic imports following reduced pipeline gas availability.

Table 2. U.S. LNG exports by destination (selected regions and major markets, 2025)

Destination (region/country)	Approximate share of U.S. LNG exports [%]	Comments
Europe (EU+UK)	~66-68	Dominant destination for U.S. LNG exports (EIA, 2024; Eurostat, 2025).
Asia	~20-22	Includes Japan, South Korea and China (EIA, 2024).
Africa	~15	Notably Egypt, reflecting regional balancing needs (Eurostat, 2025).
Latin America & Others	<5	Smaller spot-market deliveries (EIA, 2024).

Source: EIA (2024); Eurostat (2025).

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Table 2 highlights the strong geographical concentration of U.S. LNG exports towards Europe in 2025, with roughly two-thirds of total shipments directed to EU and UK markets. This reinforces the strategic importance of digital coordination across transatlantic LNG logistics, trading platforms, and regulatory reporting systems.

2.2 Digital Transformation of the Energy Sector

In this paper, digital infrastructure is understood as a layered system comprising: (i) connectivity and sensors, (ii) data collection and storage, (iii) applications and analytics, (iv) interoperability standards and documentation systems, (v) governance and cybersecurity frameworks and (vi) systems that enhance trade (buying and selling). This distinction allows digital infrastructure to be analytically separated from individual applications and linked to specific outcomes. Digitalisation in the energy sector has accelerated through the adoption of sensors, cloud computing, data analytics, and automation (IEA, 2017). In LNG operations, digital tools support asset monitoring, logistics optimisation, predictive maintenance of ports and ships, and emissions tracking. Digital infrastructure also includes data standards, communication networks, cybersecurity systems, and governance frameworks that enable secure information exchange across borders.

3. Methodological Approaches

This study applies a qualitative systems-based analysis of the transatlantic LNG supply chain. Evidence is drawn from official statistics, regulatory guidance, policy analyses, industry reports, and documented cyber and logistics disruptions. The analytical framework treats digital infrastructure as a multi-layer capability (connectivity, data, applications, standards, and governance) and evaluates how it affects coordination, resilience, and sustainability outcomes. The analysis covers the period 2021-2025, corresponding to the post-2022 restructuring of European gas supply. Sources were selected based on three criteria: (i) institutional authority (e.g. regulators, statistical agencies), (ii) peer-reviewed relevance to energy trade, market design, or logistics, and (iii) documented relevance to LNG, maritime transport, or critical energy infrastructure. Case examples of disruption were included where digital or ICT-related factors played a clear causal role and were widely documented by authoritative bodies. The analysis interprets digital infrastructure primarily through the lenses of transaction-cost reduction, information asymmetry mitigation, and operational resilience.

4. Digital Infrastructure In LNG Operations

Digital infrastructure influences LNG trade through multiple operational layers, ranging from maritime logistics and terminal management to data analytics and market information systems. These systems enable real-time coordination, improve operational efficiency, and support regulatory compliance across geographically dispersed supply chains. This section examines the

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main digital components of LNG operations and highlights both their benefits and current limitations.

4.1 Vessel Tracking and Maritime Logistics

LNG carriers are equipped with AIS transponders that provide real-time data on vessel location, speed, and route. These data are integrated into digital platforms used by traders, terminal operators, and port authorities to optimise scheduling and reduce congestion. This optimization advantage could help traders make more profits.

4.2 Smart Port and Terminal Systems

Modern LNG terminals use digital control systems for berth allocation, cargo handling, and safety management. Sensors are capable of monitoring temperature, pressure, and flow rates in real time, enabling predictive maintenance and rapid response to anomalies thereby preventing accidents or force majeure situations.

4.3 Predictive Maintenance and Asset Management

Machine-learning models and digital twins are increasingly used in liquefaction plants and terminals to predict equipment failures, reduce downtime and improve supply reliability.

4.4 Trading Platforms and Price Transparency

LNG markets rely on digital information services for price assessments, cargo tracking, and analytics. However, LNG pricing remains more complex than pipeline gas due to destination flexibility and contractual diversity. The Agency for the Cooperation of Energy Regulators (ACER) has expanded its guidance on reporting LNG market data under the Regulation on Energy Market Integrity and Transparency (REMIT) to improve transparency (ACER, 2024).

4.5 Limitations in Contract Execution and Documentation

Despite pilot projects, LNG trade documentation remains heavily paper based. McKinsey describes global trade documentation as a "multi-billion-dollar paper jam" (McKinsey & Company, 2022) while the OECD identifies paper dependence as a major barrier to efficient cross-border trade (OECD, 2025)

Key limitations include:

1. Limited interoperability between systems
2. Legal uncertainty around electronic bills of lading
3. Manual reconciliation of cargo changes
4. Fragmented data standards

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The EU Methane Regulation (European Union, 2024) requires enhanced monitoring, reporting, and verification (MRV) for methane emissions, including import-related data. Legal analysis confirms that the regulation affects LNG imports (Talus, 2025). However, gas blending complicates emissions attribution, prompting the EU to explore digital "trace-and-claim" approaches (Reuters, 2025). Trace-and-claim refers to digital supply-chain accounting that makes invisible methane emissions legally traceable across international gas markets. Instead of trying to physically follow each methane molecule (which is basically impossible), the system follows the commercial transaction trail and certified emissions data. Blockchain-style bookkeeping may be used to solve the limitation caused by gas blending.

The limitations identified can be grouped into technical barriers (interoperability, data standards, system integration) and institutional barriers (legal acceptance of digital documents, liability allocation, and regulatory alignment). Addressing both dimensions is necessary for digital market coordination to reach a state-of-the-art level.

5. Strengthening Supply Chain Resilience

In addition to enhancing efficiency and transparency, digital infrastructure plays a critical role in strengthening the resilience of transatlantic LNG supply chains. By enabling real-time risk monitoring, supporting adaptive decision-making, and reinforcing cybersecurity frameworks, digital systems help mitigate disruptions in a complex and interconnected energy market. This section analyses key mechanisms through which digitalisation contributes to supply chain resilience.

5.1 Real-time Risk Monitoring

Digital platforms integrate data on weather, port congestion, and geopolitical events to enable proactive rerouting of LNG shipments. This information provides traders and market participants with actionable insights that support improved decision-making and risk management. Data-driven analysis supports portfolio management and supplier diversification.

5.2 Cybersecurity Considerations

Energy infrastructure is a critical cyber target, requiring robust digital security frameworks. Cybersecurity is a prerequisite for digitalisation rather than a secondary consideration, particularly in LNG maritime transport and storage systems where digital vulnerabilities can directly affect operational safety and supply continuity (Jao, 2023). For example, manipulation of cargo scheduling data could result in artificial congestion or increased demurrage costs, while interference with emissions monitoring datasets could undermine methane regulatory reporting obligations. The growing role of digital certification and trace-and-claim mechanisms further increases the importance of data integrity, since regulatory compliance increasingly depends on trustworthy digital records rather than purely physical verification.

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Effective protection requires a layered approach combining network segmentation, authentication protocols, encryption, continuous monitoring and incident response coordination across jurisdictions. Because transatlantic LNG trade involves operators, traders, regulators and infrastructure owners in multiple countries, cybersecurity governance must also be cooperative.

5.3 Documented Challenges Caused by Insufficient Digitalisation

Several documented incidents demonstrate how weaknesses in digital infrastructure can disrupt energy logistics and supply chains. These examples underscore the importance of secure, interoperable and reliable digital systems in global LNG trade. One notable case is the Colonial Pipeline ransomware attack in 2021, which forced the shutdown of the largest refined fuel pipeline in the United States. Although the incident targeted IT systems rather than the physical pipeline itself, the operator halted operations due to uncertainty about the integrity of operational data. The shutdown disrupted fuel distribution across the U.S. East Coast and demonstrated how cyber vulnerabilities in digital infrastructure can interrupt energy supply chains even when physical assets remain functional (CISA, 2023). A second example is the Maersk cyberattack in 2017, which resulted from the NotPetya malware and caused widespread outages across the global logistics network operated by the shipping company. Port terminals, cargo booking systems and logistics platforms were temporarily disabled, leading to delays in global maritime trade and disruptions to shipping schedules. Because LNG shipments rely heavily on the same global maritime logistics systems and port infrastructure, similar cyber incidents could significantly disrupt LNG cargo movements and supply coordination (Maersk, 2017).

In addition to cyber threats, persistent reliance on paper-based documentation remains a major structural challenge in LNG trading. Key commercial documents such as bills of lading, cargo nominations and contractual documentation are still frequently processed manually. This creates delays in cargo ownership transfers, increases administrative costs and raises the risk of errors or fraud. Studies on global trade logistics describe the continued use of paper documentation as a major barrier to efficient supply chain management and digital integration (McKinsey & Company, 2022; OECD, 2025). These examples demonstrate that insufficient digitalisation can affect the LNG supply chain in multiple ways, including operational disruption, logistical inefficiencies and increased exposure to cyber risks. As LNG trade becomes more flexible and globally interconnected, the resilience of digital infrastructure will be increasingly critical for ensuring secure and transparent energy markets.

6. Conclusion

The evolution of transatlantic LNG trade illustrates how energy systems increasingly depend not only on physical infrastructure but also on digital coordination capacity. Historically, LNG trade functioned through relatively rigid long-term contracts, manual documentation, and limited real-time information exchange. Operational decisions were slower, market transparency was lower, and risk management relied heavily on contractual buffers rather than data-driven

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optimisation. In this context, digitalisation played only a supportive administrative role. Digital infrastructure therefore became an operational necessity rather than an efficiency enhancement. Real-time vessel tracking, smart terminal systems, predictive maintenance, market reporting platforms and emerging emissions-tracking mechanisms now enable flexible cargo routing, short-term contracting and regulatory compliance in a highly volatile market environment. At the same time, the study shows that the current system remains transitional: fragmented data standards, paper-based documentation, interoperability barriers and cybersecurity vulnerabilities prevent digital coordination from attaining its peak. Looking forward, digitalisation is likely to move from operational optimisation toward fully integrated market architecture. Several developments can be anticipated. First, end-to-end digital trade documentation, including electronic bills of lading and automated contractual execution, will reduce transaction costs and shorten deal cycles. Second, trusted data environments and trace-and-claim systems will enable verifiable methane intensity tracking, allowing environmental attributes to become a tradable parameter in LNG pricing. Third, artificial intelligence and predictive analytics may support dynamic cargo allocation, demand forecasting and portfolio optimisation across Atlantic basins. Fourth, secure distributed ledgers or similar tamper-resistant registries could improve trust in cross-border data exchange while reducing verification burdens. Finally, cybersecurity governance frameworks will increasingly operate at a transnational level, reflecting the reality that LNG supply chains function as shared digital infrastructure rather than isolated national assets. In this trajectory, digital infrastructure evolves from a logistical support tool to a market-forming institution. The past phase relied on physical reliability, the present phase depends on digital coordination, and the future phase will likely integrate environmental accountability and automated market interaction. Consequently, strengthening interoperable and secure digital systems is not only a matter of efficiency but a prerequisite for maintaining both supply security and climate governance in the transatlantic LNG market.

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