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How Small-Scale Mobile LNG Defeats Contractual Lock-In in Deepwater Energy Projects

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Abstract

The global Liquefied Natural Gas (LNG) market is experiencing profound transformations, driven by shifts in energy governance, the imperatives of the energy transition, and increasing demands for energy security. This research analyzes the structure and evolution of LNG contracts through the lens of Transaction Cost Theory (TCT), emphasizing the economic rationale behind the use of long-term contractual structures. TCT, originating with Ronald Coase and formalized by Oliver Williamson, provides a powerful framework to explain how core transactional attributes, such as asset specificity, bounded rationality, opportunism, uncertainty, and transaction frequency, determine the most efficient governance choices for economic agents. In the high-stakes LNG sector, contracts transcend simple legal agreements; they function as sophisticated governance structures designed to mitigate the substantial risks inherent in large, capital-intensive investments and volatile market conditions. The study initially highlights that high asset specificity, evident in facilities like liquefaction plants and specialized tankers, establishes mutual dependency, increasing vulnerability to opportunism. Consequently, clauses such as take-or-pay, ship-or-pay, and price reopeners are interpreted as economically rational safeguards that balance contractual stability with necessary flexibility for long-term relational contracting. While the market has seen a diversification of governance models, including the rise of Floating Storage and Regasification Units (FSRUs) and greater spot liquidity, recent geopolitical shocks have reasserted the crucial insurance value of long-term contracts. For Brazil, with its renewable-dominated yet hydrologically vulnerable energy matrix, LNG is a strategic tool for enhancing system stability. The country's recent commitment to long-term LNG supply contracts signals an alignment with the TCT-predicted governance logic, addressing chronic challenges like infrastructure bottlenecks and import dependency. This analysis is augmented by a dedicated Case Study on the Búzios Field, which examines the monetization challenge of Brazil's colossal associated gas reserves through the innovative Small-Scale Mobile FLNG (ssm-FLNG) solution. The case study concludes that this ssm-FLNG approach provides a sophisticated hybrid governance solution that successfully addresses the TCT dimensions. Specifically, the mobile unit strategically mitigates the high asset specificity risk (or lock-in) inherent in building permanent pipelines by ensuring CAPEX recovery across multiple projects; it manages demand uncertainty through its flexible scale and export optionality; and it aligns the interests of consortium partners, thereby acting as a structural safeguard against opportunism to ensure the monetization of gas that would otherwise be underutilized. By integrating this empirical case, this research advances theoretical knowledge by expanding the application of TCT to encompass regulatory, geopolitical, and technological risks in the LNG sector. Practically, it offers valuable insights for policymakers, investors, and firms by mapping contractual risks and advocating for diversified portfolio strategies that combine the security of long-term contracts with the agility of spot transactions.

Keywords

LNG Contracts, Transaction Cost Theory, Brazil Presalt Búzios Field, Long-Term Contracts, Governance Structures

1. Introduction

1.1. Global Context: The Energy Transition and the Growing Role of LNG

The global energy landscape is in a transitional phase, driven by two major challenges: decarbonization and energy security. Decarbonization involves the progressive reduction of greenhouse gas (GHG) emissions, primarily carbon dioxide (CO_2), which is essential to limit the increase in global average temperature to 1.5˚C above pre-industrial levels, as established in the Paris Agreement (IPCC, 2022). The transition to renewable energy sources, such as solar and wind, which accounted for more than 80% of the new electricity generation capacity added in 2022 (IRENA, 2023), is a fundamental pillar of this process, along with increased energy efficiency.

However, decarbonization faces significant obstacles. Investments in clean energy need to reach US$4 trillion per year by 2030 to achieve carbon neutrality by 2050 (IEA, 2021). Furthermore, the intermittency of renewable sources requires investment in storage technologies, such as batteries, whose average global cost fell 77% between 2013 and 2022 (BloombergNEF, 2023), but which still represent a challenge. In Brazil, the EPE states that regulatory barriers and the lack of technological solutions adapted to the country's reality hinder the transition (EPE, 2022b).

At the same time, energy security has emerged as a central concern, especially after recent geopolitical events. According to (Planapp, 2022), Russia's invasion of Ukraine in 2022 had a profound impact on global energy markets, resulting in significant increases in natural gas prices in Europe.

In March 2022, natural gas prices soared by 51% in a single day, temporarily reaching an all-time high of €345 per megawatt-hour. The situation worsened in January 2025, when the gas transit contract between Russia and Ukraine expired, resulting in the blockage of Russian gas supplies to Europe via Ukraine. This disruption led to gas prices reaching their highest level in over a year, with benchmark prices rising by as much as 4.3% in a single day. This situation reinforced the urgent need for diversification of energy sources and infrastructure investment (The Guardian, 2025).

1.2. Global LNG Market Expansion: Future Trends and Projections

The geographic expansion of this market has occurred asymmetrically, with North America, particularly the United States, expanding its export capacity to 13.9 billion cubic feet per day by 2026, while demand grows sharply in Asia, where China surpassed Japan in 2020 as the world's largest importer.

At the same time, there has been an increase in investment in liquefaction, regasification, and transportation infrastructure at various scales, including emerging technologies such as Floating Liquefied Natural Gas (FLNG) and small-scale applications. Furthermore, there is growing adoption of this fuel in the maritime transportation sector in response to the International Maritime Organization's stricter regulations on sulfur emissions.

Shell and other major energy corporations view LNG as a key element in the future energy mix for emerging markets, which are seeking to balance economic growth with environmental sustainability. This has resulted in substantial investments in new facilities in the United States, Qatar, and Australia. This ensures a competitive supply beyond 2025 (Shell Global, 2024).

Regarding its physical and chemical characteristics, the process of cooling natural gas to approximately −162˚C, transforming it into a liquid state, reduces its volume by about 600 times, enabling economic transportation and storage over long distances without the need for pipelines. These characteristics have enabled the globalization of the natural gas market, previously restricted by geographic limitations, creating an international trade that, according to the International Energy Agency (IEA), is expected to grow by more than 4% annually over the next decade (IEA, 2023).

The recent evolution of the LNG market has been marked by significant structural transformations. First, there is a growing diversification of both suppliers and consumers. While traditionally dominant countries such as Qatar and Australia maintain significant positions, the United States has emerged as the leading exporter, revolutionizing global dynamics with the increase in shale gas extraction (unconventional gas). At the same time, the profile of importers has expanded beyond the traditional Japanese and South Korean markets, with imports also expanding to include China, India, Pakistan, and several European countries (IEEFA, 2024).

LNG pricing has been changing, with regional markets becoming more interconnected. Mutsau (2018) conducted a study that demonstrates the correlation between the Asian JKM index and European gas, which reached a coefficient of determination of 0.88, higher than the correlation with Japanese LNG (0.44), highlighting the growing integration of global markets. This integration may have been driven by increased liquidity in spot markets and the flexibility of long-term contracts.

Several factors have driven the growth of the LNG market, reflecting structural changes in the global energy mix. Growing environmental concerns are a key driver, given natural gas's advantage over other fossil fuels in terms of emissions. Coal, which still accounts for about 40% of the global fossil fuel mix (and fossil fuels, combined, account for approximately 70% of the global energy mix), is the main target for replacement due to its high carbon intensity and impact on air quality.

In this scenario, countries like China have been accelerating policies to shift from coal to natural gas, seeking to reduce pollution and meet climate targets. LNG producers are expanding supply not only to meet demand but also to anticipate environmental restrictions and respond to geopolitical pressures, solidifying LNG as a strategic element in the energy transition (Rechelo, 2024).

The pursuit of energy security and supplier diversification represents another determining factor, particularly in regions like Europe, where dependence on Russian gas has driven investment in LNG import terminals. Thus, the growing competitiveness of LNG, driven by technological advances and economies of scale, has made this source increasingly accessible to emerging markets (Rechelo, 2024).

Continuous technological development has also catalyzed market growth. Innovations in liquefaction processes, such as modular trains and mixed-fuel refrigeration systems, have reduced operating costs and increased the viability of projects previously considered marginal (McKinsey & Company, 2019). At the same time, solutions such as FLNG have enabled the monetization of remote offshore reserves, while small-scale technologies democratize access to LNG for smaller markets (Shell Global, 2025).

The regional dynamics of the LNG market present distinct patterns that deserve further analysis. From a supply perspective, the United States is consolidating its position as an exporting powerhouse, with projections indicating an export capacity of 13.9 billion cubic feet per day by 2026, as mentioned above (IEA, 2025). Qatar, traditionally the market leader, is implementing significant expansions of its production capacity to maintain its competitive position. Australia, Russia, and several African countries, such as Mozambique, round out the list of the main current and prospective suppliers.

On the demand side, Asia remains the main destination for global LNG exports, accounting for approximately two-thirds of global trade. China surpassed Japan as the world's largest importer in 2020, reflecting its aggressive policy of coal substitution and expansion of gas infrastructure. India represents another Asian market with projected exponential growth, driven by accelerated industrialization and urbanization.

Europe has increased its LNG imports as a strategy to reduce its dependence on Russian gas, particularly following the geopolitical tensions of recent years. Emerging markets in Latin America, the Middle East, and Africa also demonstrate significant potential for absorbing increasing volumes of LNG, driven by economic development and the desire for access to cleaner, more reliable energy sources.

Quantitative projections for the LNG market indicate consistent expansion over the coming decades. According to analyses by Verified Market Reports, the market, valued at US$65.22 billion in 2023, is expected to reach US$146.65 billion by 2030, with an annual growth rate of 12.56%. Estimates point to a market of US$150 billion by 2030, up from US$90 billion in 2022, with an annual growth rate of 7.5%. These projections reflect a consensus regarding an upward trajectory, albeit with methodological differences in the final calculation (Verified Market Reports, 2025).

The expansion of import infrastructure in consumer markets and the development of diverse applications for LNG are expected to contribute to growing demand. However, several challenges loom over this growth horizon. The energy transition to renewable sources, while benefiting LNG as an intermediate solution, raises questions about the long-term sustainability of this industry. Pressure to reduce methane emissions throughout the production chain and to develop carbon neutralization solutions is essential to maintain LNG's competitiveness in scenarios of decarbonization of global energy sources.

Price volatility poses another significant challenge, as evidenced by the extreme fluctuations observed in recent years. A study published in the journal Energy Policy investigated the impacts of various uncertainties on future natural gas prices in the United States. According to Wang et al. (2024), natural gas price volatility is strongly related to economic and political uncertainties, as demonstrated by the application of the GARCH-MIDAS model, commonly used to measure daily asset volatility.

Heavy-duty land transportation represents another frontier of expansion, with fleets of LNG-powered trucks gradually being deployed in several regions. Small-scale infrastructure, including fueling stations and decentralized distribution solutions, is developing in parallel to meet these new demands. Heavy industry sectors that are difficult to decarbonize, such as steelmaking and cement production, also have the potential to expand LNG use. These sectors are facing increasing pressure to reduce emissions and are finding natural gas to be a cleaner alternative to traditionally used fuels.

The Brazilian natural gas market has undergone significant transformations over the past ten years, driven both by the quest for diversification of the energy matrix and by regulatory and technological changes. Liquefied natural gas is emerging as a strategic component in this scenario, offering operational flexibility and expansion opportunities to regions not served by the conventional pipeline network (EPE, 2023). The next section of this chapter will analyze the main aspects related to the Brazilian energy matrix, the growing demand for natural gas, and the infrastructure challenges that condition the development of the LNG sector in Brazil.

1.3. The Promise of LNG for Brazilian Gas Monetization

Despite renewable energy accounting for less than 50% of Brazil's energy mix, the government's Ten-Year Energy Plan (EPE, 2022a) projects that NG will double its share, from the current 7% to about 14% by 2031. In 2022, 46% of Brazil's gas consumption was used for electricity generation, while direct non-energy uses accounted for only 5.5% of the total domestic supply, a fraction suggesting vast potential for expansion. Due to the lack of robust, centralized planning for large pipeline construction across Brazil and Latin America, LNG is poised to become the most viable alternative for diversifying and expanding Brazil's NG supply.

Global NG prices, sensitive to geopolitical and seasonal factors, are shifting as the U.S. emerges as a major LNG exporter, spurring international demand for diversification and security. Brazil mirrors this trend, building LNG Regasification Terminals along its coast to secure new supply sources. Domestically, LNG will drive the creation of "blue corridors" for compressed and liquefied NG use in heavy transportation (road, rail, maritime), offering a cost-compatible solution for reducing GHG emissions and other pollutants (like SOX and NOX) without disrupting the national energy system. The geopolitical landscape, heightened by the Russia-Ukraine conflict, has created a unique opportunity for the Brazilian NG industry to transform its abundant pre-salt reserves into an export product, leveraging the global search for new trading partners.

Most of Brazil's hydrocarbon reservoirs are in ultra-deep waters, with oil reserves in the pre-salt layers already accounting for over 60% of national production and exhibiting high Gas-to-Oil Ratios (GORs). Monetizing this domestic gas is challenging due to the near absence of infrastructure; the production areas are over 300 km from the coast. For the first fifteen years, pre-salt operators primarily reinjected the gas into reservoirs to maintain pressure and boost oil recovery. However, this practice will soon lead to gas recirculation, reducing profitability and making alternative markets necessary to ensure sustainable production and prevent the unacceptable practice of gas-flaring. Furthermore, many pre-salt fields have high CO_2 levels, which must be managed through reinjection or Carbon Capture and Storage (CCS), not venting.

The domestic supply of natural gas (NG) in Brazil relies almost exclusively on pipelines (MIT Energy Initiative, 2014). However, the expense of submarine pipelines and the risk of wells depleting over time (rendering the pipeline useless) have stalled major government pipeline plans (EPE, 2019, 2021). This research posits that Floating Liquefied Natural Gas (FLNG) platforms are an innovative, flexible solution for outflowing offshore NG. An FLNG platform can be relocated to another FPSO when gas production declines, ensuring maximum asset lifespan.

While large-scale FLNG solutions, such as Shell's Prelude (3.6 MTPA, 488 m) (Shell, 2013), demonstrated technical complexity, enormous cost overruns (US$17 billion), and limited local benefits in Australia, they are deemed incompatible with the Brazilian economic reality. Large-scale FLNG is therefore discarded in this project.

The proposed innovation focuses on unprecedented, smaller-scale FLNG solutions better suited to Brazil's economic and technical realities. These solutions aim to monetize the pre-salt gas for both domestic markets (matching growing consumption) and international exports. The PDE 2031 reference scenario shows that NG-fired power generation is expected to account for over 50% of new capacity added yearly, making it Brazil's primary NG consumption vector (Lee et al., 2014). As intermittent renewables dominate the grid, NG will increasingly serve as the ultimate complementary source to manage supply intermittency, requiring flexible, dispatchable power plants. This strategic need reinforces the viability of a flexible FLNG solution.

1.4. The Proposed Solution: Small-Scale Mobile FLNG

As suggested by the authors (Arend et al., 2025a), the intrinsic modularity and versatility of FSRUs, especially regarding rapid deployment, limited territorial footprint, and suitability for diverse market capacities, naturally harmonize with the shifting requirements of Brazil's energy industry. This opens an avenue for implementing small-scale FLNG systems, which possess comparable mobility and adjustability. Furthermore, these small-scale platforms offer the distinct benefit of facilitating localized LNG fabrication, specifically engineered for the nation's unique offshore gas reserves and demand profiles. Through the deployment of these small-scale mobile FLNG units, Brazil is positioned to tackle the irregular consumption tendencies and infrastructural bottlenecks within its NG market, concurrently leveraging the enhanced operational effectiveness and redeployment potential characteristic of FSRU technology.

Table 1 presents a comparison of the advantages and disadvantages of using a small-scale FLNG versus the traditional approach.

Given that the system is engineered for swift positional adjustments, we can augment the small-scale liquefaction design by highlighting its mobility feature, branding it as ssm-FLNG. This methodology represents a comparatively recent notion within the offshore and LNG sectors. Nevertheless, conventional large-scale FLNG units are already established and extensively utilized globally. For instance, Shell inaugurated its inaugural FLNG venture, Prelude, in 2011 to harness gas fields in the Browse Basin off Western Australia, commencing gas processing in 2018. Other notable endeavors include ENI's Coral South FLNG in Mozambique and Petronas' DUA and SATU FLNG initiatives in Malaysia, which are acknowledged as substantial operations (Shell, 2013; Eurasia Review, 2025).

Table 1. Advantages and disadvantages of the two FLNG models.

	FNLG traditional	Smal-scale FLNG
Production	From 2 to 4 MTPA	From 0.1 to 1 MTPA
Dimensions	Lengths range from 350 m to 450 m	Lengths of up to 320 m
CAPEX	Higher	Lower
Economies of scale	Higher	Lower
Development time	Higher	Lower
Mobility	Lower	Higher

Source: Prepared by the authors.

Conversely, smaller-capacity projects are experiencing swift growth across nascent LNG markets worldwide, catering to the needs of power generation facilities and small-to-medium enterprises. These solutions also present a viable prospect for delivering LNG to isolated locales inaccessible by pipelines, particularly where navigable inland waters or archipelagos complicate traditional pipeline construction7. Moreover, these developments prove advantageous in regions where conventional fuels are expensive relative to LNG, where mandates for reducing CO_2 emissions exist, and where the supply of natural gas is sporadic due to seasonal fluctuations.

2. Complexity and Risks Inherent in LNG Contracts: A TCT Perspective

LNG purchase and sale contracts, particularly the long-term contracts that characterize the international market, represent legal and economic instruments of considerable complexity. They involve significant capital expenditures, long terms (often decades), and a dynamic and uncertain market environment. These contracts are inherently exposed to a variety of risks that can compromise their execution, economic viability, and the objectives of the parties involved (Tordo, 2010).

Transaction Cost Theory, conceived by Coase (1937) and expanded upon by Williamson (1975), Williamson (1985), and Williamson (1996), offers a theoretical framework for analyzing the structure and risks of LNG contracts. By assessing transaction costs arising from agents' limited rationality, opportunism, asset specificity, and unpredictability, TCT provides an analytical lens for understanding the level of contractual governance requirements and risk mitigation measures in markets such as LNG (Shelanski & Klein, 1995).

In the specific context of LNG contracts, TCT is relevant due to market characteristics such as high asset specificity, uncertainty, and significant transaction costs. Investments in LNG infrastructure, both in liquefaction and regasification, constitute highly specific assets with limited use value in this context (Joskow, 1987). This asset characteristic establishes mutual dependence between the contracting parties and intensifies the risks of lock-in and individual advantage (Williamson, 1985).

This uncertainty compromises long-term planning and increases the risk of unforeseen events, potentially directly affecting contract performance (Hart, 1995). The transaction costs associated with LNG contracts, including negotiation, drafting, monitoring, oversight, and eventual renegotiation, are substantial due to the depth of the contracts, the need for specialized information, and the potential for disputes and litigation (Milgrom & Roberts, 1992).

3. Expansions and Criticisms of TCT: Alternative and Complementary Approaches

Transaction Cost Theory (TCT), although established as one of the pillars of New Institutional Economics since the seminal works (Williamson, 1975; Williamson, 1985), has not remained static and has continued to evolve over the decades, undergoing significant expansions, theoretical refinements, and constructive criticism that have driven its development and dialogue with other schools of thought. A complementary theoretical strand of great relevance is Agency Theory, which emerged strongly in the mid-1970s, notably from the work of Jensen and Meckling (1976). Agency Theory focuses on the complex contractual relationship established between a "principal" (the one who delegates a task) and an "agent" (the one who executes the task), a relationship often characterized by information asymmetry and potential conflicts of interest. Jensen and Meckling (1976) pioneered the study of agency costs when ownership and control of a company are separated, as in the classic case of shareholders and managers. These costs arise from divergences in objectives between the parties and the possibility of opportunistic behavior on the part of the agent. Although Agency Theory shares with TCT the assumption that individuals pursue their self-interest, it places particular emphasis on issues of imperfect information and risk allocation. For instance, the principal often cannot fully observe the agent's actions, giving rise to the problem of moral hazard. The governance mechanisms investigated by Agency Theory involve structuring contracts with incentives and monitoring systems to align the interests of the principal and the agent. In contrast, TCT is more concerned with choosing the most efficient governance structure (market, hybrid contract, or hierarchy/vertical integration) to minimize transaction costs in different contexts. The two theories are complementary: TCT operates at a more macro level, analyzing governance structures, while Agency Theory operates at a more micro level, focusing on contract design and incentive mechanisms within a given organizational structure.

In this theoretical debate, the Economic Analysis of Law, associated with Posner

(2014), adds a relevant dimension by proposing that legal institutions and contracts be examined based on their economic efficiency. This approach allows for a clearer understanding of how legal rules, contractual structures, and property regimes shape behavior and help reduce market failures. Another related approach that offers important counterpoints and complements to TCT is Property Rights Theory and the theory of incomplete contracts, developed from the work of authors such as Grossman & Hart (1986) and Hart & Moore (1990). Property Rights Theory, also known as the Hart-Moore approach, recognizes, like TCT, that contracts are invariably incomplete. However, its distinctive focus lies in the allocation of residual control rights over assets as a mechanism that determines ex ante investment incentives. Granovetter (1985), in their seminal model, argued that vertical integration can be beneficial when it avoids underinvestment problems caused by the fear of hold-up in the context of incomplete contracts. Unlike TCT's focus on ex post transaction costs (e.g., adaptation difficulties and disputes), the theory of Grossman & Hart (1986) and Hart & Moore (1990) focuses on the ex-ante effects of property distribution, arguing that ownership of the critical asset provides greater bargaining power and a stronger incentive to make specific investments. This theory complements TCT by providing a formal treatment of hold-up problems and investment incentives. The approach of Grossman & Hart (1986) and Hart & Moore (1990) fills an analytical gap, analyzing how the ownership structure affects incentives and economic efficiency in the presence of incomplete contracts, thereby building a bridge between Agency Theory and TCT. Although the predictions of TCT and Hart's theory often coincide, they start from different assumptions, and scholars generally recognize that these theories should be seen as complementary rather than mutually exclusive.

TCT has also faced direct criticism regarding its fundamental assumptions. One notable criticism concerns the assumption of universal opportunism. Authors such as Grossman & Hart (1986) and Hart & Moore (1990) argued that TCT's emphasis on self-interested behavior tends to adopt an overly pessimistic perspective on human nature, potentially inhibiting spontaneous cooperation and mutual trust that could, in fact, improve performance and reduce transaction costs. Additionally, economic sociologists such as Granovetter (1985) criticized TCT for allegedly \"under socializing\" its analysis, neglecting the fact that economic agents are deeply embedded in social networks and informal institutions (such as reputation and trust) that often mitigate opportunistic behavior. Granovetter (1985) argued that long-term relationships can generate trust and shared norms of conduct. Another criticism concerns an analytical limitation regarding the consideration of dynamic and technological aspects. Some authors suggest that the theory's emphasis on minimizing transaction costs in each specific \"make or buy\" decision can lead to ignoring long-term strategic considerations, such as organizational learning and the development of distinctive capabilities. The resource-based view emphasizes that firms internalize activities to protect and develop strategic knowledge and capabilities to drive sustainable competitive advantage. Williamson (1999) and Williamson (2002) responded to some of these criticisms by incorporating concepts such as \"contractual atmosphere\" and recognizing the role of trust in hybrid arrangements, though without abandoning the central hypothesis of opportunism as a non-zero possibility.

Despite criticism, TCT has expanded beyond its original domain, with subsequent research integrating it with other approaches. For example, the combination of TCT and Resource Dependence Theory has been used to analyze the formation of strategic alliances and joint ventures, where cooperation involves both transaction costs and the need for access to critical resources. Similarly, more recent studies have formally incorporated factors such as reputation and trust into the TCT model, recognizing that these function as informal governance mechanisms that reduce the likelihood of opportunistic behavior and expected transaction costs. TCT has proven to be a consistent and adaptable analytical framework, applied and tested across a wide range of industrial sectors. Classic studies on coal supply contracts confirm that greater asset specificity leads to longer contract durations and vertical integration. In the oil and natural gas sector, the presence of complex contractual clauses and joint ventures is explained by the need to protect specific investments and deal with inherent uncertainties. The theory has been used to understand diverse phenomena such as public sector contracts and the organization of digital platforms. TCT maintains its fundamental core: the idea that the frictions inherent in economic interaction (transaction costs) exert a decisive influence on how productive activities are organized and coordinated, whether through the market price mechanism, complex contracts, or within the hierarchical boundaries of organizations.

A hybrid governance solution is an intermediate organizational arrangement within the TCT governance spectrum, positioned between pure market transactions (characterized by short contracts and impersonal relations) and hierarchical or vertical integration (characterized by internal coordination within firm boundaries, such as total asset ownership). Hybrid structures utilize complex long-term contracts to establish a continuous cooperative relationship between legally independent parties, incorporating sophisticated safeguard mechanisms like renegotiation and monitoring clauses. Such solutions are chosen when transactions involve a significant degree of asset specificity and uncertainty (factors that would make the market risky), but without reaching the level necessary to justify the cost and complexity of vertical integration, thus offering the optimal balance for minimizing total transaction costs (Williamson, 1985).

4. Key Concepts of TCT and Their Applicability to Long-Term Contracts

4.1. Bounded Rationality and Opportunism: Behavioral Assumptions and Contractual Implications

At the core of TCT lie the behavioral assumptions of bounded rationality and opportunism, which fundamentally shape the governance of long-term contracts.

Bounded rationality, a concept from Simon (1957) incorporated by Williamson (1985), posits that economic agents, despite intending to be fully rational, are limited by finite cognitive capacity and the cost of processing information. This limitation makes it humanly impossible to exhaustively anticipate and stipulate every possible contingency—such as drastic energy price fluctuations, geopolitical upheavals, or unexpected regulatory changes—over the 15-to-20-year lifespan of a complex LNG contract (Cuypers et al., 2021; Joskow, 2022). Consequently, LNG contracts are inherently incomplete in their formal sense, only detailing core volumes, pricing, and basic penalties (Tirole, 2019; Williamson, 1985).

Contractual incompleteness becomes a source of significant risk due to opportunism, defined by Williamson (1985) and Williamson (1996) as the self-interested pursuit of gain with guile, exploiting contractual ambiguities to the counterparty's detriment (Cuypers et al., 2021; Joskow, 2022). In the high-risk LNG market, opportunism is a constant threat. For example, during the 2021-2022 energy crisis, when spot LNG prices soared to historic peaks, suppliers were tempted to opportunistically seek excuses (like questionable force majeure claims) to avoid contractual obligations and redirect cargoes to the open market for higher profits (IEA, 2023). Conversely, when demand collapsed, as seen during the 2020 COVID-19 pandemic, buyers might opportunistically force renegotiations to reduce take commitments and shift losses (Giles & Thompson, 2021). These scenarios illustrate how incomplete contracts invite attempts to subvert the original risk allocation.

Aware of these threats, parties develop sophisticated governance structures to mitigate opportunism. The standardized take-or-pay clause, for instance, mandates the buyer to pay for a minimum volume even if not withdrawn, securing the seller's cash flow for substantial infrastructure investments and discouraging the buyer's hold-up (Majone, 2022). Conversely, robust non-delivery penalties safeguard the buyer, dissuading the seller from engaging in opportunistic arbitrage. Crucially, price review or price reopener clauses, typically scheduled every three to seven years, function as rational "safety valves" (Majone, 2022). By preemptively establishing an orderly process for renegotiation, they adapt the contract to significant, unforeseen market changes, preventing disputes motivated by opportunistic gain and avoiding destructive termination.

The premise of opportunism does not require constant bad faith but rather recognizes that the possibility of such behavior cannot be ignored when incentives are significant. This drives firms in highly critical transactions—involving large, specific investments—to design governance that transcends mere contracts, sometimes opting for vertical integration or joint ventures (e.g., Asian importers partnering in liquefaction projects) to secure supply and align interests (Chen et al., 2023). In essence, bounded rationality explains the inherent gaps in contracts, while opportunism explains why those gaps become sources of friction. The synergistic combination generates the "transaction costs" that LNG contracts are designed to minimize through elaborate governance arrangements, such as arbitration clauses and joint contract management, ensuring the long-term relationship remains cooperative and adaptive despite market shocks (Williamson, 1996).

4.2. Asset Specificity: Types of Specificity and Impact on LNG Transaction Costs

Asset specificity is the conceptual pillar of TCT most directly linked to the prevalence of long-term contracts in the energy sector. It describes the degree to which an investment loses value if redirected to an alternative use or counterparty (Williamson, 1985). TCT identifies five categories of specificity, all highly relevant to LNG contracts, which influence transaction costs and necessitate contractual safeguards: location, physical, human capital, dedicated assets, and time specificity.

Location specificity arises when facilities are strategically interconnected to reduce transport costs, but this proximity creates bilateral dependence. For example, a regasification terminal built adjacent to a thermoelectric plant (like the Pecém terminal in Brazil) is geographically linked; if the LNG supply is interrupted, the plant's utility is severely compromised. This interdependence increases the risk of hold-up, compelling parties to establish long-term contracts ex ante to secure the relationship and avoid costly ex post renegotiations (EPE, 2022b).

Physical specificity refers to equipment customized for a transaction. In LNG, this includes specialized tankers adapted to specific port conditions or liquefaction plants adjusted for a customer's unique gas quality. These substantial capital expenditures (CAPEX) have a significantly lower value in alternative configurations, increasing the transaction cost of altering the relationship. Empirical studies confirm that contracts associated with specific assets are longer, with some research finding they averaged four years longer than others (Ruester, 2009; Chen et al., 2023).

Human capital specificity relates to specialized knowledge and training developed within the transaction (e.g., specific know-how for operating a unique liquefaction plant). While intangible, this specificity contributes to the inertia of relationships, as losing the established coordination efficiency is costly.

Dedicated assets are investments made exclusively to meet a specific counterparty's demand, such as expanding liquefaction capacity only after securing a purchase agreement. This creates an economic lock-in, and the need to amortize these billions-of-dollars investments explains why long-term contracts are often signed even before facilities are built, serving as a revenue guarantee for project financing (Ruester, 2009; Hartley, 2015).

Time specificity relates to the critical timing of delivery. In LNG, delays in meeting peak demand or supplying industrial customers can cause significant losses. Long-term contracts reduce this uncertainty compared to volatile spot purchases by establishing predictable schedules.

Historically, the LNG trade was dominated by "inflexible," integrated, 20-25-year contracts, a TCT solution to the high risks posed by these specific assets and the threat of opportunism. Although the market has evolved toward greater flexibility and spot trading (partly due to innovations like FSRUs reducing location specificity), the need for long-term contracts to finance new billion-dollar projects persists (Hartley, 2015). For Brazil, securing its first 15-year long-term LNG contract (Petrobras, 2025) to ensure the reliable availability of gas represents a TCT-advocated decision, aligning the contractual governance with the substantial and specialized investments made in thermoelectric plants and regasification terminals.

4.3. Uncertainty: Types of Uncertainty Relevant to LNG Contracts and Governance Strategies in Uncertain Environments

Uncertainty is a pivotal factor in TCT when designing long-term LNG contracts, given the volatile dynamics of demand, supply, technology, regulation, and geopolitics. Negotiators must weave unique mitigation and adaptation strategies into the contractual fabric. In Brazil, NG demand is highly sensitive to hydrological variability. Since the national electricity system relies heavily on hydroelectric power, severe droughts mandate the activation of gas-fired thermal plants, spiking demand for imported LNG. The 2021 drought, for instance, caused a 200% increase in LNG imports, while the rain in 2022 saw imports drop by 74%. This high degree of uncertainty makes rigid quantity commitments risky for both buyers (fear of paying for unused gas under take-or-pay clauses) and suppliers. TCT suggests that highly uncertain environments favor contractual arrangements that allow for flexibility and adaptation, rather than inflexible contracts. Strategies observed include incorporating a take-or-pay range and make-up clauses to allow buyers to adjust withdrawals, using the spot market to complement a stable long-term base volume, and including destination flexibility to allow the importer to redirect cargo and mitigate losses. Additionally, the global energy transition introduces long-term uncertainty; NG faces the risk of lock-in and potential underutilization if technologies like large-scale batteries become widely viable by 2040. To mitigate this risk, companies often favor 10- to-15-year contracts over the traditional 20-to-25-year terms. The U.S. LNG market itself offers flexibility, with many contracts based on take-or-pay for liquefaction capacity rather than volume, allowing the buyer to pay a fixed fee for capacity without incurring the full gas cost if they choose not to load (Ruester, 2009; Chen et al., 2023).

Another strategy is to require financial guarantees or performance bonds, whereby the seller agrees to indemnify the buyer in the event of a failed delivery. The experience of the 2021 energy crisis, when Brazil had to compete for spot cargoes at prohibitive prices (IGU, 2022), led to a strategic adjustment, with Petrobras deciding to seek long-term contracts to secure a portion of its supply (Petrobras, 2025), recognizing that supply and price uncertainty in the spot market had become an unacceptable risk. A performance bond is a guarantee that a contract will be fulfilled, issued by an insurer or bank in favor of the client. If the contracted company fails to fulfill its obligations, the insurer or bank compensates the client for losses. It is common in large projects, such as LNG, to reduce risk and encourage compliance.

Supply uncertainty requires assurance of delivery. While the robust U.S. supply mitigates physical shortages, risks persist from operational failures (e.g., the 2022 Freeport LNG plant shutdown) and potential shifts in U.S. export policies. Buyers mitigate this through portfolio diversification—as Brazil does by negotiating with the U.S., Bolivia, and aggregators like Centrica—and by incorporating robust contractual guarantees. The experience of the 2021 energy crisis, when Brazil competed for high-priced spot cargoes, demonstrated that high supply and price uncertainty in the spot market was an unacceptable risk, leading Petrobras to seek long-term contracts as a strategic adjustment. Contractual safeguards include well-defined force majeure clauses and requiring performance bonds (financial guarantees) from the seller to indemnify the buyer in case of failed deliveries. Technological uncertainty creates a risk of obsolescence over long durations, addressed by limiting contract duration and including adaptation clauses. Regulatory uncertainty from changes in domestic laws (like the 2021 Brazilian Gas Law) or international climate frameworks can profoundly affect contract performance. LNG contracts mitigate this using hardship or change-of-law clauses, which trigger renegotiation if regulatory shifts significantly burden a party.

Geopolitical uncertainty is constant in transnational energy contracts. The 2022 war in Ukraine drastically drove spot prices to record highs, prompting many importers, including Brazil, to return to long-term contracts to ensure supply security and avoid full dependence on volatile global markets. The emerging governance strategy, consistent with TCT principles, is a diversified portfolio: long-term contracts cover base demand, complemented by spot purchases for maximum flexibility. This mixed approach is a form of governance under uncertainty. Ultimately, a well-designed LNG contract acts as an "adaptive constitution" for the commercial relationship, allowing the parties to manage unforeseen events cooperatively. The 2021-2022 crisis strongly reinforced the "insurance" function of long-term contracts, which protected buyers from extreme spot price volatility (Petrobras, 2025).

4.4. Transaction Frequency and Repetition: Long-Term Contracts vs. Spot Contracts in the LNG Market

Within the conceptual framework of TCT, the regularity of exchanges, or transaction frequency, is considered a decisive factor in shaping the choice of governance structure. Frequently recurring transactions justify investments in specialized governance, such as vertical integration or long-term contracts, to achieve economies of scale in transaction costs. Conversely, isolated or rare transactions are more efficiently handled through the spot market, even if the unit transaction cost is higher, since this expenditure is not repeated frequently (Williamson, 1985).

In LNG trade, this distinction is stark: long-term contracts establish a continuous and regular flow, typically involving scheduled deliveries over a 15-year period, demanding frequent, direct interaction for logistics and payments. This recurrence fosters a long-term relationship built on mutual trust and standardized routine practices, which substantially reduces marginal transaction costs with each successive delivery. Furthermore, frequent repetition creates an "iterated game" where the knowledge that opportunistic behavior in a single instance could jeopardize the entire future relationship—a value potentially greater than the immediate gain—acts as a powerful incentive for cooperation, forming a self-enforcing contract.

In contrast, spot market transactions, historically used by Brazil, are one-off and often non-repetitive, with price and terms negotiated for that single cargo, conducting the exchange "in a vacuum" of the market. The lack of guaranteed repetition fundamentally alters the negotiation dynamics, diminishing the buyer's security and making contractual enforcement more diffuse if problems arise. Generally, spot transactions entail higher transaction costs per unit, such as market research, price negotiation (often volatile), and formalizing short adhesion contracts that must be repeated every time a shipment is needed. When an importer anticipates a regular, even if seasonal, LNG need, these recurring spot costs become a financial barrier, making the long-term contract the preferred structure for avoiding repeated negotiation.

In Brazil, while LNG imports were characterized by sporadic activity (until approximately 2010, and even during the period 2011-2013), the strategy of relying solely on the spot market or short-term contracts proved rational. The regasification terminals installed in the country (such as Pecém, Bahia, and Guanabara) were designed as contingency units, activated primarily during times of energy crisis, rather than for continuous use throughout the year (FGV Energia, 2015).

Historically, Brazil's LNG imports were sporadic (until roughly 2013), relying on the spot market for contingency use during crises, which was a rational strategy since terminals often sat idle. However, as gas consumption for thermoelectricity increased and the intermittency of renewables demanded more frequent thermal "insurance," LNG imports transitioned from rare events to frequent, strategic necessities. The severe water crisis in 2021 exemplified this, forcing Brazil to acquire numerous monthly cargoes (0.8 - 0.9 bcfd, or six to seven monthly shipments) at extraordinarily high spot prices, sometimes exceeding US$30/MMBtu, exposing the inefficiency of relying on the spot market. This experience confirmed a TCT trade-off: as the frequency and strategic importance of LNG demand increased, a shift from pure market governance (spot purchases) to hybrid governance (long-term relational contracts) became justified to reduce high negotiation costs and increase supply reliability.

In short, the frequency of LNG transactions directly affects the choice between purchasing volumes on the spot market or establishing stable long-term contracts. When demand is not constant, the spot market offers flexibility and avoids costly financial commitments. However, as LNG imports become frequent transactions, as seen in Brazil's energy transition in recent years, economic logic and the precepts of Transaction Cost Theory point to the adoption of long-term contractual structures or even more integrated arrangements. Such structures aim to reduce the costs associated with repeated negotiations and increase supply reliability (Petrobras, 2025).

This transition is formalized by Brazil's recent 15-year contract with Centrica starting in 2027, signaling an intention to secure base supply and strategically combine procurement modalities. The increased global frequency of spot transactions fostered the development of a more liquid market with price indices (JKM, TTF), reducing some transactional friction; consequently, the spot share of global trade jumped to over 30% by 2019. However, long-term contracts still governed the majority of volume before 2020, and post-2022, importers reversed the trend, increasing long-term commitments to hedge against volatile spot markets. This indicates that the specific nature of the industry favors stable contracts for the main supply portion (IGU, 2022).

Empirical work by Ruester (2009) noted that contracts between partners with established bilateral experience sometimes trended shorter, suggesting that built-up trust (a relational mechanism) can reduce the need for excessively rigid constraints. Nevertheless, the combination of a specific asset (like the Bolivia-Brazil pipeline) and high frequency (daily deliveries) historically demanded a long-term contract with take-or-pay clauses to eliminate daily negotiation risks. Similarly, for LNG, as imports become a consistent, high-frequency requirement, TCT suggests that future steps might include forms of vertical integration or strategic partnerships, a typical solution when high frequency and asset specificity are highly combined. The current adoption of a long-term contract favors a relational contract structure that supports cooperative adaptation and joint risk management over time, essential for the complex logistical coordination required by the global LNG supply chain, thereby building sustainable, long-term partnerships.

Table 2 summarizes how the core behavioral and environmental dimensions of TCT (Asset Specificity, Uncertainty, Frequency, Limited Rationality, and Opportunism) are managed by specific governance mechanisms, such as long-term contracts, take-or-pay clauses, and arbitration, to mitigate risks inherent in LNG supply contracts.

The qualitative part of the research focuses on the analysis of multiple case studies. The choice of multiple case studies, as suggested by Eisenhardt (1989), makes it possible to identify recurring patterns and significant divergences, enabling analytical generalizations that go beyond the specifics of each individual contract.

Table 2. Dimensions of transaction cost theory (TCT) and indicators for analyzing LNG contracts.

TCT Dimension	Description	Indicators	Examples in LNG Contracts
Asset Specificity	Assets dedicated to transactions, with little alternative use.	Exclusive infrastructure, long-term contracts, and restricted locations.	Exclusive use of terminal; vessels are dedicated to the buyer.
Uncertainty	Unpredictability of market, regulatory, or operational factors.	Price volatility, regulatory changes, and force majeure.	Force majeure clauses: adjustments linked to multiple indexes.
Frequency	Regularity of transactions between the parties.	Spot vs. long-term delivery frequency.	Continuous supply for 20 years; spot operations.

Continued

Limited Rationality	Limitations to foresee all future contingencies.	Open clauses, renegotiation, and contractual gaps.	Hardship or reopening clauses for unforeseen adjustments.
Opportunism	Strategic use of contractual gaps.	Penalties, monitoring, guarantees.	Take-or-pay or ship-or-pay with high fines.
Governance	Structures to mitigate risks and align incentives	Safeguards, dispute resolution, and price indexers	International arbitration; hybrid pricing formulas.

Source: Prepared by the author, based on Williamson (1985), Williamson (1996), Hart (1995) and Riordan & Williamson (2024).

5. Case Study: Transaction Cost Theory Applied to the Búzios Field

5.1. Case Summary: The Búzios Field and Monetization Challenge

The Búzios Field, situated in Brazil's pre-salt Santos Basin, is renowned as the largest ultra-deepwater oil and gas field globally. It is operated by a consortium led by Petrobras, with participation from CNOOC and CNODC. The field's production exceeded 1 billion barrels of oil as of April 2024. A critical challenge for the field involves the efficient monetization of its significant volumes of associated natural gas.

Existing and under-construction subsea pipeline infrastructure (Routes 1, 2, and 3) used to transport pre-salt gas to the coast is estimated to reach its full capacity around 2026. This structural limitation mandates alternative solutions for flowing additional NG volumes. Historically, a substantial amount of the produced gas has been reinjected into the reservoirs to maintain pressure for enhanced oil recovery (EOR). However, this reinjection strategy is a temporary solution; as the gas-to-oil ratio (GOR) increases, it may diminish future oil recovery and is not an economically viable, long-term solution for gas monetization.

The proposed solution to this structural and economic challenge is the implementation of a Small-Scale Mobile Floating Liquefied Natural Gas (ssm-FLNG) unit. An ssm-FLNG unit would be connected to existing Floating Production Storage and Offloading (FPSO) platforms (such as the planned FPSO Almirante Tamandaré, with a capacity of 12 million NG), to receive pre-processed NG, liquefy it, and export the LNG to domestic or international markets via LNG carriers.

A financial assessment utilizing the Búzios Field data confirmed that the ssm-FLNG configuration added substantial value and was studied by Arend et al. (2025b). Liquefying NG and selling it on the global market as LNG increased the total projected revenue to \$46.3 billion over 40 years, compared to \$10.3 billion from simply selling raw NG at the wellhead. Crucially, the Net Present Value (NPV) and EBITDA for the ssm-FLNG configuration were found to be positive and robust, indicating that the investment is financially advantageous and creates wealth for the investors. The ssm-FLNG approach presents a competitive alternative to conventional methods for monetizing associated gas in remote, deep-water areas.

5.2. Application of Transaction Cost Theory (TCT) to the Búzios Case

The Búzios gas monetization dilemma and the selection of the ssm-FLNG solution can be directly analyzed through the critical dimensions of Transaction Cost Theory (TCT).

The decision to adopt the innovative ssm-FLNG solution is a direct response to high asset specificity and structural limitations. The pre-salt gas is located over 200 km from the coast at extreme depths. Constructing dedicated pipeline infrastructure for monetization would be an excessively expensive and high-risk undertaking, particularly given the long-term risk of gas depletion. Such a pipeline would constitute a highly specific asset for the Búzios gas, creating significant lock-in and high transaction costs if the gas supply were to deplete faster than expected, thereby becoming an unprofitable stranded asset.

The ssm-FLNG mitigates this specificity by offering high mobility and modularity. As the gas flow diminishes from one FPSO, the modular unit can be relocated to another production unit (P-80, P-82, P-83) or even another field. This mobility ensures the CAPEX payback across multiple projects, significantly reducing the sunk-cost risk associated with a dedicated pipeline. This mobile solution represents a shift from a high-specificity ex-ante investment (the pipeline) to a more flexible, hybrid governance structure (the mobile platform), in line with TCT principles.

The Brazilian energy market is characterized by high demand uncertainty, primarily caused by the hydrological variability of its power system. Thermoelectric generation, the main driver of NG consumption, is intermittent and dependent on rainfall levels. A fixed, large-scale pipeline commitment could lead to costly gas surpluses in hydrologically favorable years.

The small-scale and modular nature of the ssm-FLNG is strategically aligned with this uncertainty. Its scale allows for incremental production compatible with the moderate and fluctuating volumes the Brazilian market can absorb. Furthermore, the system provides crucial governance flexibility to manage demand volatility by allowing the operator to switch between supplying the domestic market (via small-scale LNG distribution) and the global export market (via LNG carriers), thereby reducing the risk of financial loss due to uncertain domestic demand.

The Búzios project involves a consortium of international partners (Petrobras, CNOOC, and CNODC). This structure introduces the risk of opportunism or misalignment of interests over the long term, particularly concerning the utilization of the associated gas. Without an efficient monetization mechanism, partners might prioritize maximizing oil recovery via gas reinjection, potentially sidelining the commercialization of the valuable natural gas.

By implementing the ssm-FLNG, the partners are creating a transparent and profitable revenue stream from a previously non-monetized asset. The ssm-FLNG enables the commercialization of the NG at international LNG prices, directly aligning the long-term financial incentives of all partners to monetize the gas. The contract associated with the ssm-FLNG acts as a safeguard to ensure the value of the NG is captured, which is a core function of governance structures designed under TCT to mitigate opportunism in complex partnerships.

The detailed concept of the proposed ship solution for this case study was developed by Arend et al. (2025a), utilizing an LNG carrier transformed into an SSM-FLNG platform. This study (Arend et al., 2025a) presents all the proposed and studied details and dimensions.

6. Conclusion

The analysis of Liquefied Natural Gas (LNG) contracts through the lens of Transaction Cost Theory (TCT) reveals a complex interaction between risk mitigation and economic efficiency in the global energy market. The historical preference for long-term contracts in the LNG sector is an economically rational response to the challenge of coordinating massive, specific investments in a highly uncertain global market where the risk of opportunism is high due to bounded rationality.

The market's evolution toward greater flexibility and spot trading was largely driven by technological advances and increased liquidity. However, recent geopolitical crises have underscored the critical "insurance function" of long-term contracts, which shield buyers from extreme spot price volatility, reinforcing the necessity of long-term commitment for ensuring base supply and energy security.

The ssm-FLNG solution for monetizing associated gas in Brazil's Búzios Field serves as a powerful practical application of TCT principles, specifically addressing asset specificity and uncertainty.

Mitigation of Asset Specificity Risk: The ssm-FLNG, with its modularity and high mobility, strategically mitigates the lock-in risk associated with massive, highly specific infrastructure like dedicated deep-water pipelines. This approach ensures that capital expenditure (CAPEX) can be amortized across multiple projects as gas production depletes, validating a hybrid governance structure over highly specific vertical integration (i.e., a permanent pipeline).

Management of Uncertainty and Scale: The small-scale nature of the ssm-FLNG allows the Búzios project to better match the moderate, fluctuating gas volumes that the Brazilian energy market can absorb, which is subject to high hydrological demand uncertainty. Furthermore, the system provides crucial flexibility by enabling the operator to choose between supplying the domestic market and the global export market, thereby reducing exposure to domestic demand volatility.

Alignment of Opportunistic Incentives: By creating a dedicated, profitable revenue stream from the NG (as evidenced by robust NPV and EBITDA results), the ssm-FLNG aligns the financial interests of all consortium partners to monetize gas that might otherwise be underutilized (reinjected or stranded), thereby serving as a structural safeguard against opportunism in a complex, high-stakes partnership.

For Brazil, securing a stable LNG supply, as exemplified by its move toward long-term contracts, is a pivotal strategic step that minimizes transactional exposure to global volatility. The success of capitalizing on LNG's role as a transition fuel and a tool for energy security—both through imports and through domestic projects like Búzios—hinges on two key governance requirements:

Strategic Portfolio Management: The country must continue to strategically utilize a diversified portfolio of long-term and spot contracts to balance supply security with market flexibility.

Institutional Resilience: Brazil must urgently address existing infrastructure gaps and refine its regulatory framework to provide greater legal certainty for investors.

Ultimately, the success of LNG in supporting a low-carbon future requires designing governance structures that are both economically efficient and resilient, effectively balancing the economic constraints of TCT with the strategic imperatives of national energy policy.

The ssm-FLNG solution for the Búzios Field explicitly strengthens resilience against the broader geopolitical and technological risks addressed by TCT. Geopolitically, the system's crucial flexibility to choose between supplying the domestic market or the global export market acts as a vital buffer, mitigating sovereign exposure to global volatility by providing an arbitrage option against domestic price and demand shocks, a key strategic benefit in securing energy supply. Technologically, the platform's modularity and high mobility directly address the risk of technological obsolescence and potential future market shifts toward alternatives like green hydrogen; since the unit is not permanently fixed to a single asset, it mitigates the lock-in risk of massive, dedicated infrastructure, ensuring that CAPEX can be recovered across diverse projects or fields over time.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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