Energy and Power Engineering, 2026, 18(5), 265-288
https://www.scirp.org/journal/epe
ISSN Online: 1947-3818
ISSN Print: 1949-243X

Maximizing the Monetization of Natural Gas from the Búzios Field through an Offshore Hub with a SSM-FLNG

Lauron Arend[1*], Fernando Cörner da Costa[1], Daniel Prata Vieira[2], Alberto J. Fossa[1], Xuefeng Hu[3], Junkai Feng[3], Edmilson Moutinho dos Santos[1]

[1]Institute of Energy and Environment, University of São Paulo, São Paulo, Brazil
[2]Department of Naval Architecture & Ocean Engineering, Polytechnic School, University of São Paulo, São Paulo, Brazil
[3]CNOOC Petroleum Brasil Ltd., Beijing, China
Email: *lauron@usp.br, fcorner@uol.com.br, daniel.prata@usp.br, afossa@usp.br, huxf@cnoocbrasil.com, fengjk@cnoocbrasil.com, edsantos@iee.usp.br

How to cite this paper: Arend, L., da Costa, F.C., Vieira, D.P., Fossa, A.J., Hu, X.F., Feng, J.K. and dos Santos, E.M. (2026) Maximizing the Monetization of Natural Gas from the Búzios Field through an Offshore Hub with a SSM-FLNG. *Energy and Power Engineering*, **18**, 265-288.
https://doi.org/10.4236/epe.2026.185014

Received: September 19, 2025
Accepted: May 15, 2026
Published: May 18, 2026

Abstract

Brazil's pre-salt fields, particularly the Búzios Field, represent one of the most prolific oil and gas producing regions in the world. However, the large volumes of associated natural gas generated in these operations present a significant strategic challenge: how to economically and sustainably monetize this resource. Currently, a substantial portion of this gas is reinjected into reservoirs, a practice driven by technical obstacles such as high carbon dioxide (CO_2) concentration and the absence of adequate transportation and processing infrastructure. This article proposes an innovative and integrated offshore solution aimed not only at mitigating this reinjection practice but also at transforming Brazil into a competitive exporter of liquefied natural gas (LNG), thereby adding substantial value to the national energy industry. The core of the proposal is the creation of a strategically located offshore natural gas hub designed to centralize the collection and processing of raw gas from multiple Floating Production, Storage, and Offloading (FPSO) units operating in the Búzios Field. Rather than requiring each FPSO to independently manage its own gas treatment, the hub serves as a unified processing point, optimizing impurity removal, including CO_2, to produce a clean, high-quality natural gas stream. This centralization simplifies logistics, reduces the individual capital expenditure (CAPEX) burden on each FPSO by enabling shared infrastructure, and represents a logical advancement of the guidelines set forth by the Brazilian Ministry of Mines and Energy under the "Gás para Empregar" program. Importantly, this approach offers a more flexible and cost-effective alternative to conventional pipeline-based solutions. Once treated in the hub platform, the natural gas is transferred from the hub to a Floating Liquefied Natural Gas (FLNG) platform, also located offshore. The FLNG is responsible for the liquefaction process, cooling the gas to approximately −162˚C and converting it into LNG, a liquid form with significantly reduced volume that is well-suited for transport via LNG carriers. Producing LNG offshore, in close proximity to the source, enables direct commercialization on international markets where pricing conditions are more favorable, while also allowing supply to domestic coastal terminals. The most significant innovation put forward in this study is the proposal to deploy a small-scale, mobile FLNG (SSM-FLNG) structure connected to the centralized hub, rather than to individual FPSOs. This configuration, described as having no known global precedent, optimizes both logistics and operational costs, and is the defining feature that makes the integrated project economically viable. To assess financial feasibility, the study develops a flexible Excel-based modeling and simulation tool that allows users to input key assumptions, including CAPEX, operating costs, and gas prices, and generate scenario-based financial outputs. Key metrics evaluated include Net Present Value (NPV) and EBITDA. The results confirm the solution's viability: a positive NPV demonstrates surplus value generation for investors, while a positive EBITDA reflects strong operational efficiency. In conclusion, this work contributes an engineering, logistical, and financial framework that transforms a longstanding technical and environmental challenge into a compelling economic opportunity. By combining a centralized offshore processing hub with an innovative SSM-FLNG configuration, the proposed solution positions Brazil to capture greater value from its pre-salt gas resources and to assert a stronger presence in the global LNG market.

Keywords

Liquefied Natural Gas (LNG), Floating Liquefied Natural Gas (FLNG), Brazilian Energy Transition, Monetization of Brazilian Natural Gas, Offshore HUB NG

1. The Current Brazilian Gas Market

The increase in LNG operations by Brazilian companies has made LNG a relevant component of the Brazilian natural gas (NG) matrix, integrating the country more deeply into the global energy market. As a result, Brazil becomes increasingly exposed to international price dynamics and supply fluctuations in global energy commodities such as NG [1]. Although Brazil does not depend directly on Russian gas supply, it remains indirectly affected by global disruptions in NG availability and pricing [2].

In 2022, Europe's efforts to reduce dependence on Russian gas led to an increase in long-term LNG contracts. In response to the global tightening of the NG and LNG markets, suppliers began increasing the weight of oil indexation in new contracts to guarantee price stability, creating a more challenging scenario for the development and liberalization of the Brazilian LNG market [3]. At the same time, the growth of LNG imports by Brazilian companies contributed to aligning domestic NG prices with international benchmarks [3].

Imported LNG has become an important energy source for Brazil, particularly for intermittent electricity generation in the short and medium term through projects operating under Gas-to-Wire (GtW) and Reservoir-to-Wire (RTW) models. Considering both opportunities and constraints, LNG is increasingly evaluated as a strategic alternative energy source in the Brazilian energy system [4].

Despite this potential, the expansion of LNG markets in Brazil requires substantial investments across the entire supply chain. The implementation of LNG-based transportation systems, such as LNG-powered trucks or other alternative fuel technologies, demands simultaneous development of vehicles and fueling infrastructure, which significantly increases capital requirements. According to [5], establishing LNG refueling infrastructure across Brazil's extensive highway network may become economically prohibitive, particularly under conditions of high international prices. Alternatively, compressed natural gas (CNG) trucks have already begun operating in Brazil, allowing LNG storage at refueling stations where cryogenic pumps enable high-pressure gasification and fueling operations, representing a more cost-effective solution in terms of CAPEX and operational expenditure (OPEX).

Fuel pricing for thermoelectric plants follows international market indexation rules, meaning that consumers ultimately bear the cost of fluctuations in global energy prices. In periods of market uncertainty and elevated energy prices, consumption tends to decline and industrial production slows down [6].

Brazil has experienced rising inflation in recent years, reaching levels not observed for a long time, while bank interest rates have increased significantly. These developments have contributed to higher fuel and food prices, reducing the country's economic growth prospects [2]. Because NG is a key input in the production of fertilizers imported from Russia and widely used in Brazilian agriculture, disruptions in global gas markets have significant implications for the national food supply chain and agribusiness sector. As highlighted in [6], low-income countries are particularly vulnerable to rising food prices, which are exacerbated by increases in energy and fertilizer costs.

In emerging economies such as Brazil, where food, energy, and housing expenses represent a large share of household budgets, inflation has severe social consequences. Rising energy and food prices delay economic and social progress and increase poverty among vulnerable populations [6].

Although rising commodity prices have generally harmed Brazilian imports, certain developments have produced mixed outcomes. For instance, the embargo on Russian diesel in February 2023 [7] potentially opened opportunities for Brazil, as Russia sought new markets after losing European demand. However, in September 2023 Russia announced temporary restrictions on diesel and gasoline exports, directly affecting Brazil, which had become the largest importer of Russian diesel. This measure led to price increases from approximately USD 10 per barrel to USD 40 per barrel [8]. By the end of 2023, Brazil had become the largest buyer of Russian diesel, surpassing Türkiye and France [9].

For countries that rely on energy imports, higher fuel and electricity prices negatively affect industrial output and increase production costs, weakening national macroeconomic performance. Rising energy prices also reduce household purchasing power by increasing the cost of living through inflation. Conversely, energy-exporting countries benefit from higher commodity prices through increased revenues, expanded production, and greater investment opportunities. This dynamic contributes to a redistribution of wealth within the global economy and can exacerbate inequalities between nations [10].

As energy prices continue to rise, industrial supply chains become increasingly dependent on energy costs. This situation may trigger the relocation of industrial production from high-cost countries to regions with lower energy prices, encouraging investors to favor energy-advantaged economies [6]. Additionally, global uncertainty often drives investors toward safer assets such as US equities, the US dollar, and gold. This shift can negatively affect investment prospects in Brazilian industries and influence stock market performance both domestically and internationally [2].

Global trade flows are also undergoing structural adjustments. Importing countries are increasingly prioritizing domestic energy resources to reduce exposure to volatile international markets and improve energy security [6]. Nevertheless, importing countries remain vulnerable to supply strategies adopted by exporting nations. Therefore, strengthening domestic energy production, whether renewable or fossil-based, remains essential for long-term energy security.

Brazil's energy matrix is largely based on domestic production, particularly renewable sources, along with oil and NG production from pre-salt and post-salt fields. However, LNG imports play an important role in supporting electricity generation, particularly during periods of reduced hydropower output. Petrobras has developed regasification terminals to receive imported LNG and supply thermoelectric plants during drought periods affecting hydroelectric generation [11]. Studies evaluating a decade of LNG regasification operations in Brazil confirm the importance of NG as a complementary energy source to hydropower, a trend expected to continue in the coming years [11]-[13].

Brazil has also followed the global trend of increasing electricity generation from natural gas-fired power plants. This transition contributes to reducing greenhouse gas emissions compared with coal-based generation while providing dispatchable and controllable electricity, which is more reliable than intermittent renewable sources such as wind and solar [14].

Although the Brazilian NG market is evolving gradually, state gas distributors have intensified efforts to diversify their supply sources and reduce dependence on Petrobras [15]. According to studies conducted by the consultancy Gas Energy based on contracts disclosed by the Brazilian National Petroleum Agency (ANP), new suppliers have offered gas at prices below those historically charged by Petrobras, providing evidence of increasing market competition [15].

For example, in 2022 the private producer 3R sold NG to the state distributor Bahiagás at prices between USD 6 and USD 7/MMBtu, based on Brent oil prices ranging from USD 75 to USD 125 per barrel. During the same period, Petrobras sold gas to distributors at prices above USD 14/MMBtu [15]. Such contractual disputes are common during the early stages of market liberalization, as traditional supply models coexist with new competitive arrangements.

Despite these changes, Petrobras remained the dominant supplier of NG to state distributors in 2023. Its pricing formula continues to be indexed to Brent crude oil prices and exchange rate fluctuations between the US dollar and the Brazilian real [15].

With the progressive opening of the Brazilian gas market, supply risks have increased for market participants, reinforcing the strategic importance of LNG. LNG provides flexibility and the ability to supply large volumes of gas to regions not connected to pipeline networks, particularly in southern and northeastern Brazil [1] and [11]. Several new LNG terminals are planned in these regions to support industrial consumption and electricity generation [1]. Some projects are already well advanced, including a terminal planned in the state of Paraná by the company Nimofast, representing a practical example of market liberalization [3].

In addition to LNG imports, Brazil relies on the Bolivia–Brazil gas pipeline (Gasbol) for NG supply. However, Bolivian gas production has been declining since 2015 due to limited discoveries and aging fields, raising concerns about the long-term reliability of this supply source [16]. If new discoveries are not made, Bolivia may eventually become a gas importer, affecting Brazil and Argentina, the largest consumers of Bolivian gas [15].

In response to these challenges, Brazil has renewed its efforts to strengthen energy cooperation with Argentina. The development of unconventional gas resources in the Vaca Muerta formation could enable Argentina to become self-sufficient and potentially export gas to Brazil in the future [15]. Increased production from Vaca Muerta may also allow Bolivian gas currently exported to Argentina to be redirected to Brazil later in the decade [17] and [18].

These evolving regional dynamics, combined with global LNG market volatility, are reshaping Brazil's energy strategy. Buyers around the world are reevaluating long-term LNG contracts in response to price fluctuations and supply risks, while new infrastructure projects aim to expand LNG distribution networks and improve energy security [17]-[21].

2. Brazil as an LNG Exporter

The increase in LNG prices has had a significant impact on Brazil, causing a shift in its energy model towards this product, as well as the possibility of becoming an LNG exporter. The rise in prices justifies the investment in LNG production, which comes from offshore platforms exploring and producing from Brazil's pre-salt reserves. At this point, another conclusion drawn from the study is the use of small-scale structures for LNG production offshore, such as SSM-FLNG, which fit the dimensions of NG production from pre-salt basins, as well as the size of specific demand from Brazilian consumer markets. This could also generate financial viability by taking advantage of high LNG prices, enabling Brazil to export LNG and thereby position the country among the world's leading LNG producers and exporters.

Currently, Brazil's NG matrix depends on Bolivian gas and LNG imports to balance its energy needs. However, there could be a surplus of NG from the pre-salt reserves once an economically viable solution is developed. Alternatively, a hybrid scenario could be explored, where, even with LNG imports, Brazil becomes an LNG exporter from its pre-salt reserves. This is possible because the production is offshore, far from the coast, as seen on pre-salt platforms. In this scenario, the offshore production could be transformed from NG into LNG, transported to the coast, and then reprocessed into NG again for consumption.

Brazil's energy strategy, as detailed in the Ten-Year Energy Plan 2031, aims to double the share of NG in the national energy mix from 7% to 14%. While renewables dominate the grid, NG is expected to account for over 50% of new power capacity additions this decade, serving as a flexible, dispatchable complement to intermittent sources.

3. The Innovation of LNG for Brazil

LNG is emerging as a critical alternative to diversify Brazil's supply due to main factors such as the lack of centralized coordination for cross-border or interstate pipelines, which makes LNG a more flexible option for regional diversification, and shifts in global gas dynamics, exacerbated by the Russia-Ukraine conflict, have created a unique opportunity for Brazil to turn its abundant offshore reserves into exportable products.

- Challenges in Pre-Salt Monetization: Despite high gas-to-oil ratios in the pre-salt layers, monetization remains difficult due to extreme water depths (3000 m), rock depths (7000 m), and distances from the coast exceeding 300 km. Historically, operators have prioritized gas reinjection to maintain reservoir pressure, but long-term recirculation threatens field profitability. Furthermore, high CO_2 levels in these fields necessitate advanced decarbonization solutions rather than simple venting.
- Floating Liquefied Natural Gas (FLNG) Solutions: This research identifies FLNG platforms as an innovative solution for outflowing offshore gas, particularly because they can be relocated as wells deplete. Large-scale projects like Shell's Prelude (3.6 MTPA) and Petronas' PFLNG serve as benchmarks, though Prelude initially faced significant cost overruns and delays. This study argues that massive projects like Prelude are incompatible with Brazil's economic reality; instead, it proposes unprecedented, smaller-scale FLNG solutions tailored to domestic market growth and potential international insertion.
- Current Pipeline Infrastructure: Existing infrastructure for utilizing pre-salt gas is currently limited to three primary routes. Estimates suggest that the ex-

isting and under-construction pipeline capacity will reach its limit by 2026, making alternative monetization options like LNG technically and economically essential for future production volumes.

4. Case Study: Búzios Field

According to [22], the Búzios Field holds the largest volume of oil and gas in deep waters globally, spanning 852 km^2 and located approximately 200 km off the coast of Rio de Janeiro, at water depths ranging from 1600 m to 2100 m. Pré-Sal Petróleo S.A. (PPSA), Brazil's state-owned company managing pre-salt reserves, announced on April 15, 2024, that the field had produced 1 billion barrels of oil. Petrobras operates the field through a consortium with CNOOC and CNODC, while PPSA manages the contract. Production has been ongoing since 2018 from five operational units of the FPSOs P-74, P-75, P-76, P-77, and Almirante Barroso [23].

The Búzios field is expected to operate at its maximum with twelve FPSO-type platforms. Currently, five platforms (P-74, P-75, P-76, P-77, and FPSO Almirante Barroso) are already installed and operational. Another six were in the design or implementation phase (FPSO Almirante Tamandáré, P-78, P-79, P-80, P-82, and P-83).

The Búzios FPSOs are among the most prominent production units in operation in Brazil. Búzios concentrates the most productive wells in the country. The field had already broken records in July 2023, with 680,000 barrels/day of oil and 30 million m^3/day of NG.

The last unit to begin operations was the FPSO Almirante Barroso, which started in May 2023. This unit can produce up to 150,000 barrels/day of oil and 6 million m^3/day of NG. The FPSO Almirante Tamandáré will be the largest producer on the Brazilian coast, with a planned capacity of 225,000 barrels/day of oil and 12 million m^3/day of NG.

When the FPSO supplies NG to the FLNG, it is assumed that all necessary processing of the raw gas into primarily methane (CH_4), free of impurities and other components such as gas liquids, has already been completed by the FPSO. Currently, only some FPSOs in the Búzios field have these characteristics, known as Theoretical Type 1 FPSOs [24]. For the P-80, P-82, P-83, and the future Búzios 12 FPSOs, the Theoretical Type 1 FPSO configuration will be used to enable gas export and provide access to the natural gas consumer market, as they are expected to connect to the existing gas pipeline network.

5. The Concept of an Offshore Gas Hub Connected to a Small-Scale FLNG

The proposal for an offshore gas hub is conceived as a central point for the aggregation and processing of natural gas, aiming to improve interconnection and increase flexibility in the gas evacuation network. Its main objectives include optimizing the utilization of existing and planned gas processing and transportation capacities, as well as offering a competitive alternative to gas reinjection or to the individual processing that would otherwise be carried out on each FPSO.

The implementation of a new platform in the Búzios field, which would be an additional FPSO unit in pre-salt field, has been mentioned by Petrobras as specifically intended for the creation of a new gas hub in the pre-salt region [25] and [26]. This hub would be responsible for processing gas produced by surrounding platforms, centralizing a function that was previously distributed among individual production units [27] and [28]. This conceptual solution can be better understood through **Figure 1**.

The shared hub model represents a significant operational and economic shift. Instead of each FPSO requiring its own complex gas treatment and evacuation systems, multiple FPSOs could focus primarily on oil production, while only the hub platform would be dedicated to centralized gas processing. This approach, according to studies by EPE, could result in approximately a 35% reduction in CAPEX for individual production platforms since gas specification systems would be concentrated at the hub [29].

Gas processing with high CO_2 content is a well-known challenge in the pre-salt region [30], and the development of Petrobras' HISEP technology for subsea CO_2 reinjection demonstrates both the complexity of the issue and the need for efficient treatment solutions. This hub could overcome the inherent limitations of individual FPSOs, particularly those that were not initially designed for extensive gas exports, as well as those already connected to the evacuation network that is currently operating near its capacity limit [26]. The hub concept represents a viable alternative for monetizing potential gas volumes, highlighting its applicability to large pre-salt fields such as Búzios [29]. It offers a flexible, faster, and often more environmentally conscious alternative for monetizing remote, smaller, or isolated gas reserves when compared with traditional pipeline infrastructure.

Source: Prepared by the authors with the help of AI technology, 2026.

Figure 1. Representation of the hub platform receiving natural gas from various FPSOs and delivering it to SSM-FLNG.

Small-scale floating units offer several attractive economic advantages, including faster time-to-market, inherent scalability for phased expansion, and reduced dependence on fixed infrastructure. Furthermore, the ability to redeploy FLNG units to new gas fields enhances asset utilization and value. However, challenges remain, notably the substantial initial capital investment required, the inherent complexity of offshore projects, and the operational difficulties associated with offloading operations in challenging offshore environments.

The transition from a paradigm in which individual FPSOs manage their own associated gas (often resulting in reinjection due to localized constraints) to a shared offshore gas hub model [31] represents a fundamental shift toward systemic optimization across the entire Brazilian gas value chain.

6. Financial Assessments

This study uses the case of Búzios field, in the Brazilian pre-salt, which is the largest oil and gas field in Brazil, with production projections of up to 2 million barrels per day (bpd) and colossal volumes of associated natural gas [32]. The efficient monetization of this gas is a strategic imperative, especially given the potential saturation of existing and planned pipeline infrastructure.

For the development of this study, the studies prepared by [33]-[35] use an economic-financial model, implemented in spreadsheets, to evaluate the feasibility of an offshore SSM-FLNG unit focused on gas monetization. This model served as the basis for the present work, which advances the analysis by incorporating an offshore natural gas hub solution into the modeling framework in order to obtain the results explored in this study.

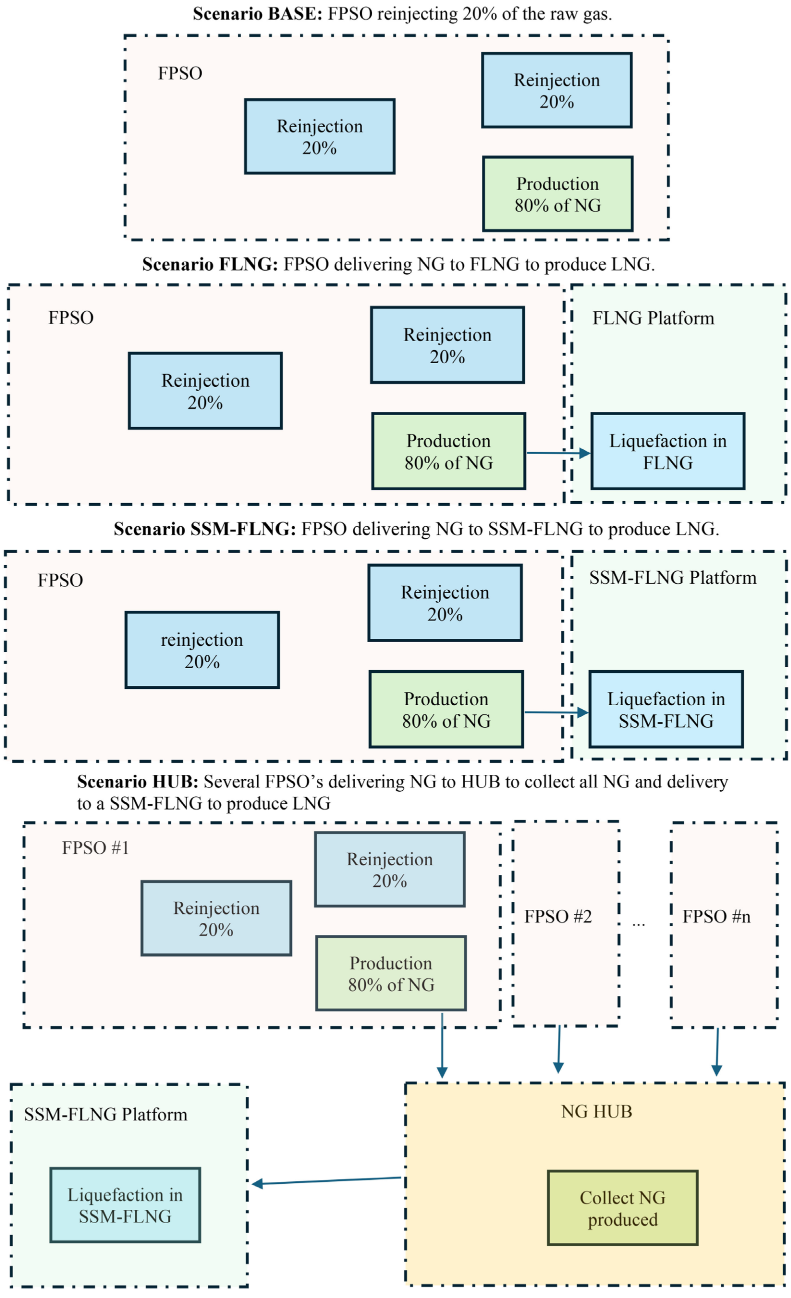
This tool enables the economic and financial evaluation of the proposed SSM-FLNG, a small-scale, modular floating platform for natural gas processing and LNG generation. The modeling assumes that this FLNG will receive natural gas with a purity level suitable for liquefaction, with all pre-processing performed by an adjacent FPSO. The oil and gas production data for the Búzios FPSOs used in this modeling are obtained from the Environmental Impact Study/Environmental Impact Report (EIA/RIMA) prepared by Petrobras for [24] [36]-[39], ensuring a robust and regulatorily validated database, as well as from actual production data available on the ANP's production dashboard [40].

To evaluate attractive ranges that yield positive results, this study simulated the extreme limits of certain variables while maintaining the evaluated indicators at a level attractive enough to justify the use of SSM-FLNG platforms.

6.1. Process Steps and Modelation Explanation

This chapter presents and analyzes the results of the economic evaluation of the solution of a hub with the SSM-FLNG configuration, obtained through a simulation model. The analysis highlights the positive results in terms of revenue, NPV, and EBITDA, and examines the impact of the input assumptions. The in-depth analysis of the financial indicators provides a robust understanding of the hub with the SSM-FLNG configuration's economic performance.

The graphs presented in the report illustrate each indicator's contribution to the outcome, highlighting the key factors driving the economic viability of the hub with the SSM-FLNG project. Analyzing these graphs identified how various components, such as CAPEX, OPEX, and revenues from gas, affected the positive NPV and EBITDA results. To understand the results, it is essential to comprehend the impact of the assumptions on each scenario, as detailed below. The flow at each scenario is described, with the contribution of Figure 2.



Source: Prepared by the author (2026).

Figure 2. Process divided into scenarios from raw gas processing to transformation into LNG.

This study adopts a modeling approach applied to the 12 FPSO units of the Búzios field collectively, where their NG production is summed and aggregated. Within this set of 12 platforms, six are currently configured to process NG, as they are already connected to the national export pipeline network. The remaining six platforms, which do not currently perform gas separation and treatment, were modeled under the assumption that they can deliver processed NG ready for liquefaction.

In the base case scenario, a reinjection rate of 20% of the raw gas produced was adopted, while the remaining 80%, consisting of processed, separated, and filtered gas, was utilized as the feed gas ready for the liquefaction process. Following the study of Borges (2021) [41].

While CO_2 management is a critical factor in offshore operations, providing a comprehensive analysis of its removal and sequestration was outside the primary scope of this research. Due to the high CO_2 content characteristic of the Brazilian pre-salt reservoirs, a detailed treatment of this subject would require an extensive technical and economic framework. Consequently, the intricate modeling of CO_2 capture, its impact on the cryogenic process, and the associated carbon credit potential are suggested as high-priority topics for future studies.

6.2. Scenarios Studied

6.2.1. Scenario BASE: FPSO Processing Crude Oil and Gas, Reinjecting 20%

In this scenario, we evaluated the sale of processed natural gas directly from the FPSO, prior to liquefaction, without incorporating transportation costs to the mainland. Raw gas is subject to a 20% reinjection rate before separation, meaning it still contains CO_2 and other extraction contaminants. The specific assumptions for this scenario are as follows:

- Gas Processing and Yield: A processing rate of 80% for raw gas is assumed, with deductions for CO_2 content (calculated specifically for each FPSO) and internal fuel consumption for production, estimated at 33%.
- Purity Standards: The FPSO is responsible for processing the raw gas to reach the purity levels required for subsequent liquefaction in the FLNG unit.
- Operational Losses: Natural gas process losses are estimated at a fixed rate of 5%.
- CAPEX: Dedicated CAPEX for NG processing is estimated at 10% of the FPSO's total investment, totaling the six platforms in the Búzios field that lack the "Theoretical Type 1" configuration; the remaining six Type 1 platforms are already equipped with the necessary processing infrastructure as per IBAMA (2012) [36] standards.
- Revenue Generation: Revenue is based solely on aggregated NG priced at global market rates of USD 3.31/MMBtu (NYMEX May/25 benchmark), adjusted annually by an estimated 2% U.S. inflation rate.
- Wellhead Cost Deduction: The price paid for natural gas at the wellhead (at the FPSO) is deducted at a rate of USD 2/MMBtu [42], which is also adjusted

annually by a 2% U.S. inflation rate.

6.2.2. Scenario FLNG: FPSO Processing Crude Oil and Gas, Reinjecting 20%, and Delivering the Resulting NG to the FLNG

In this scenario, deductions were applied for reinjection, fuel consumption, and CO_2 content. The presence of Natural Gas Liquids (NGL) was excluded from the model as they typically represent less than 1% to 3% of the volume, and other impurities were similarly discounted. The gas delivered to the FLNG is assumed to be ready for liquefaction and is priced at the wellhead value as defined in the assumptions table, having already undergone processing and associated cost allocations in the preceding scenario.

The large-scale FLNG model is based on 0.2 MTPA modules with a minimum utilization factor of 33.33% and a maximum of 87%. Under these parameters, the 12 FPSOs reach a peak utilization of 20 modules during 2029 and 2030, resulting in a maximum output of 4.0 MTPA on a single platform [43] and [44]. Specific assumptions for this scenario include:

- Energy and Process Loss: Fuel use for the liquefaction process is set at 32%, with an additional 15% estimated loss during liquefaction.
- Operational Losses: Standard losses within the liquefaction process are estimated at 5%.
- CAPEX: Dedicated CAPEX is set at US$900 per ton of LNG, aligned with the Gimi project benchmarks, totaling US$7.2 billion for the 12 Búzios FPSOs [41].
- Revenue Projections: Revenue is derived from LNG priced at global market rates of US$8.88/MMBtu, adjusted annually by a 2% U.S. inflation rate, excluding international transport costs.

6.2.3. Scenario SSM-FLNG: Transforming FLNG into SSM-FLNG

In this scenario, the study evaluates the SSM-FLNG configuration, utilizing modular units with a capacity of 0.07 MTPA each. These modules operate with a minimum utilization factor of 33.33% and a maximum of 87%. Under these parameters, the 12 FPSOs reach a peak utilization of 64 modules during 2029 and 2030, achieving a collective capacity of 4.48 MTPA.

The comparative analysis indicates that this modular parallel array outperforms conventional FLNG designs, which typically employ fewer, larger units (e.g., 20 units for 4.0 MTPA). By reaching 4.48 MTPA, the SSM-FLNG model delivers a 12% increase in total throughput, demonstrating higher volumetric efficiency that directly enhances the project's Net Present Value (NPV) and overall financial attractiveness. Specific technical and economic assumptions for this scenario include:

- Fuel and Process Dynamics: Gas consumption for liquefaction fuel is set at 32%, with an additional 15% estimated loss during the liquefaction process.
- Operational Efficiency: Standard losses within the liquefaction process were estimated at a 5% rate (reflecting a 95% yield).

- CAPEX: Dedicated CAPEX for the processing structure is set at US$600 per ton of LNG based on the Gimi project benchmark, resulting in a total investment of US$2.688 billion to serve the 12 Búzios FPSOs.
- Revenue Projections: Revenue is based on LNG sales at global market prices of US$8.88/MMBtu, adjusted by an annual U.S. inflation rate of 2%, excluding international transport costs.

6.2.4. Scenario HUB: Several FPSOs Delivering NG to HUB to Collect All NG and Deliver to a SSM-FLNG to Produce LNG

In this final scenario, we integrated the Natural Gas Hub concept as a centralized infrastructure to consolidate the gas produced by all 12 FPSOs within the Búzios field. This hub functions as a primary gathering and treatment point, ensuring the natural gas reaches liquefaction quality before being transferred to the SSM-FLNG modular array. The economic and technical parameters for the liquefaction stage remain consistent with the previously established SSM-FLNG assumptions. The specific assumptions for this integrated Hub-to-SSM-FLNG scenario are as follows:

- Centralized Consolidation: The Hub is designed to collect the total natural gas output from the 12 active FPSOs, neutralizing individual platform constraints and optimizing the flow for large-scale monetization.
- Hub Processing and Efficiency: The centralized facility manages the primary separation and treatment; internal consumption and processing yields are maintained in line with the modular SSM-FLNG efficiency standards (including the 32% fuel use and 15% process loss).
- Infrastructure Synergy: By utilizing a shared Hub, the individual CAPEX requirements for gas treatment on each FPSO are redistributed. The Hub investment is amortized across the collective production, enhancing the financial viability of the individual E&P projects.
- SSM-FLNG Integration: After processing at the Hub, the gas is liquefied via the 64-module SSM-FLNG array, maintaining the peak capacity of 4.48 MTPA and a maximum utilization factor of 87%.
- CAPEX: The CAPEX for the liquefaction structure continues to be benchmarked at US$600 per ton of LNG, while the Hub infrastructure is treated as a shared asset, aligning with the goal of reducing the overall cost of gas delivered to the SSM-FLNG.
- Revenue and Pricing: Revenue projections remain tied to the global market price of US$8.88/MMBtu, adjusted annually by the 2% U.S. inflation rate.

6.3. Modeling and Simulation Assumptions

Certain constraints within this study involve the exclusion of cost simulations for LNG vessel chartering, insurance requirements, and regasification fees at destination FSRUs, whether in Brazil or international markets. Consequently, the current scope is restricted to the delivery of LNG within international waters, with future research proposed to evaluate the logistics of reaching specific consumer end-markets.

Furthermore, the economic analysis is limited to operational results prior to the application of taxes and royalty payments. This boundary was established to maintain focus on the proposed technical solution and avoid the intricate complexities of the Brazilian tax system. Detailed tax assessments and fiscal modeling are therefore recommended as a priority for subsequent studies.

6.4. CAPEX, Abandonment, and Decommissioning (ABEX) for Small-Scale Modular FLNG

Natural gas liquefaction has faced a significant increase in costs over the last decade, with projects recording surges of 30% to 50% compared to initial estimates due to construction delays and regulatory requirements. Data from the International Gas Union indicate that average unit costs jumped from US$404/ton in the 2000-2008 period to US$1005/ton between 2009 and 2017. Several factors determine these values, including geographic location, the complexity of gas processing—which is more expensive in the Brazilian pre-salt due to the high presence of CO_2—and the technological choice between new builds or vessel conversions [45].

In the scenario of floating units, ship conversions are typically more competitive than new platforms, with costs ranging between US$550 and US$600 per ton of annual capacity, as exemplified by the Gimi FLNG. In contrast, new builds can reach US$750 per ton, while the industry average for integrated projects is around US$1400 per ton. For simulation purposes in this study, a benchmark of US$600 per ton of processed LNG was adopted, excluding abandonment costs (ABEX) for the FLNG and SSM-FLNG structures, as these are considered generic assets that can be redeployed in other global projects.

For the purpose of this study's simulations, a CAPEX benchmark of US$600 per ton of processed LNG was adopted, consistent with the Gimi FLNG project. While abandonment costs (ABEX) for the FPSO platform were calculated at 7% of its total CAPEX, distributed over the final decade of operation, such costs were excluded for the FLNG and SSM-FLNG structures. This exclusion is justified by the generic nature of these mobile platforms, which allows them to be redeployed to other projects worldwide rather than being decommissioned at the end of a specific field's life.

6.5. OPEX of an FLNG Structure

The OPEX of an FLNG unit covers daily expenses such as maintenance, personnel, fuel, and insurance, which are often higher than onshore facilities due to the complexities of maritime logistics and remote environments. While typical operating costs for FLNGs and FPSOs range from 3% to 5% of the total CAPEX, this study adopts a conservative premise of 3% per year. Specialized technologies, such as those used for membrane-based CO_2 removal, require an even higher annual allocation of approximately 5% of their associated CAPEX [46].

Operational efficiency is further impacted by availability, as FLNG facilities typically reach about 90% uptime compared to the 98% seen in onshore plants. This discrepancy, combined with the need for highly skilled labor, specialized logistics like helicopter transportation, and significant energy consumption during liquefaction, creates a demanding financial landscape. Furthermore, broader studies by the EPE suggest that combined OPEX and ABEX can reach 6% and 7% of total CAPEX, respectively, underscoring the necessity of cost transparency to maintain a competitive and fair remuneration model for offshore infrastructure [28].

6.6. Comparison of FLNG and SSM-FLNG Modular Configurations

The primary distinction between the large-scale liquefaction modeling (FLNG) and the small-scale approach (SSM-FLNG) lies in the nominal capacity assigned to the individual liquefaction modules. The FLNG model employs modules with a unit capacity of 0.2 MTPA arranged in parallel, whereas the SSM-FLNG model utilizes 0.07 MTPA modules. In practice, both models are designed to accommodate the annual volume of available NG.

The 33.33% Limit (Technical or Turndown Minimum): The 33% value refers to the operational flexibility of the liquefaction compressor while still being able to maintain operation without shutting down. The PRICO® technology, developed by Black & Veatch, is widely recognized in the LNG industry for its operational flexibility, especially in offshore units such as the Gimi FLNG and the Hilli Episeyo [43]. The maximum rate of 87% is justified by the high OPEX in an offshore environment and the logic of maintenance/operational availability [44].

The comparative analysis indicates that the SSM-FLNG architecture, characterized by a modular parallel array (64 units), outperforms the conventional FLNG design (20 units) in terms of total throughput. Although each SSM module is smaller in scale, the collective processing capacity reaches 4.48 MTPA, representing a 12% increase over the 4.0 MTPA produced by the standard FLNG unit. Consequently, the SSM-FLNG model exhibits higher volumetric efficiency, directly correlating to enhanced project NPV and overall financial attractiveness.

While working with monthly or even daily data would be the ideal approach for this analysis, such granular information is frequently difficult to obtain. Since this study focuses on a conceptual analysis to validate the fundamental logic of the SSM-FLNG and offshore hub proposal, the current data set effectively demonstrates that the concept is sound.

7. Results

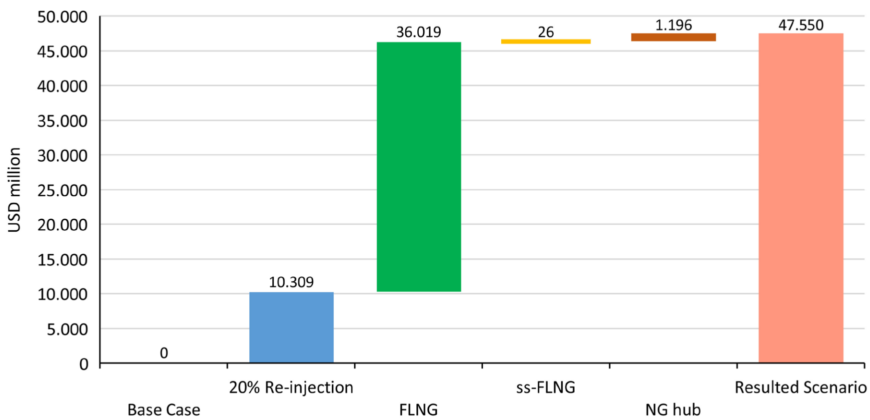
This section presents and analyzes the results of the economic evaluation of hub NG with the SSM-FLNG configuration, obtained through a simulation model. The analysis highlights the positive results in terms of revenue, NPV, and EBITDA, and examines the impact of the input assumptions. Given the empirical nature of the research, presenting the data and elucidating the connections between them are crucial to offer a concise overview of the findings.

The simulation results demonstrate that the SSM-FLNG configuration added positive economic value, as evidenced by the economic viability indicators. The NPV and EBITDA were favorable, indicating the project's attractiveness under the adopted assumptions. The resulting graphs below illustrate the contribution of each analyzed component to the overall revenue, NPV, and EBITDA, providing an aggregated view of their effect. This is presented as an additional contribution to the habitual oil production of the Búzios Field platforms during the production years from 2016 to 2055, covering 40 years of field production. Taxes and royalties on the calculated EBITDA were not considered.

It is worth noting that the results without the inclusion of the NG hub modeling are identical to those presented in the studies developed by [33]-[35], with the gains modeled with the NG hub solution being included here.

7.1. Revenue Added by LNG

Figure 3 illustrates the revenue contribution when considering FPSOs producing 80% of raw gas as NG, after CO_2 has been accounted for. This NG is then sold at the wellhead, where it is delivered to a hypothetical export pipeline or another transportation solution to a point where it can be commercialized. At this point, the solution proposed in this article would be applied via unification through a NG hub, connecting to a SSM-FLNG unit to be transformed into LNG and then commercialized by LNG carriers, both for the Brazilian market and the global LNG market, at global prices.



Source: Author, 2026.

Figure 3. Analysis of revenue increase considering all Búzios Fields over 40 years of operation.

Analyzing Figure 3, the use of the FLNG platform to liquefy NG and sell it as LNG at global market prices generates a total revenue (across the 12 Búzios FPSOs) of US$36.019 billion (over 40 years of operation). Using the small-scale model, it generates a total revenue of US$36.05 billion, an additional US$0.026 billion (or US$26 million). And finally, the use of the GN hub solution generated an additional US$1.1 billion.

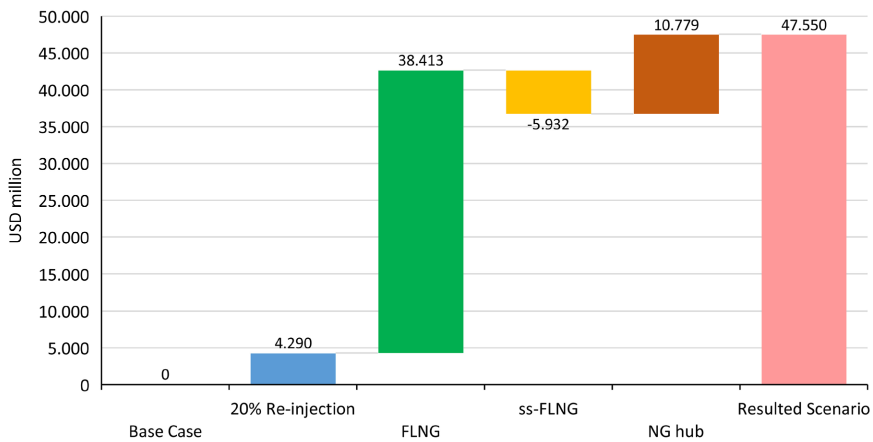
7.2. EBITDA

The EBITDA evaluation for the hub NG with the SSM-FLNG configuration yielded a positive value, as illustrated in **Figure 4**. EBITDA is an operational profitability metric that reflects a project's ability to generate cash from its core activities, before considering interest, taxes, depreciation, and amortization. A positive EBITDA indicates the project's operational efficiency and its ability to generate gross profits from its operations.

While a positive EBITDA is a strong indicator that hub NG operations are profitable, it is important to understand its role in the broader financial context. It demonstrates the operation's gross cash generation capacity, which is essential for covering operational costs and, eventually, debt service. However, it is crucial to note that EBITDA does not incorporate the impact of taxes, financing interest, or asset depreciation, which are real expenses affecting net profit and final cash flow. Therefore, for a complete and accurate financial analysis, EBITDA should be evaluated in conjunction with NPV (Net Present Value).

Evaluating **Figure 4**, the production process on the FLNG generated an EBITDA of US$38.213 billion. With the use of small-scale units, there is a reduction of US$5.932 billion, resulting in a final aggregated result of US$32.481 billion over 40 years of operation. The lower EBITDA in the SSM-FLNG scenario is justified by the high CAPEX and OPEX required to operate many modules in parallel.

However, the use of the NG hub solution generates an increase in EBITDA of approximately US$10.7 billion over the 40 years evaluated. This demonstrates a significant result to validate the financial viability of the proposed solution.



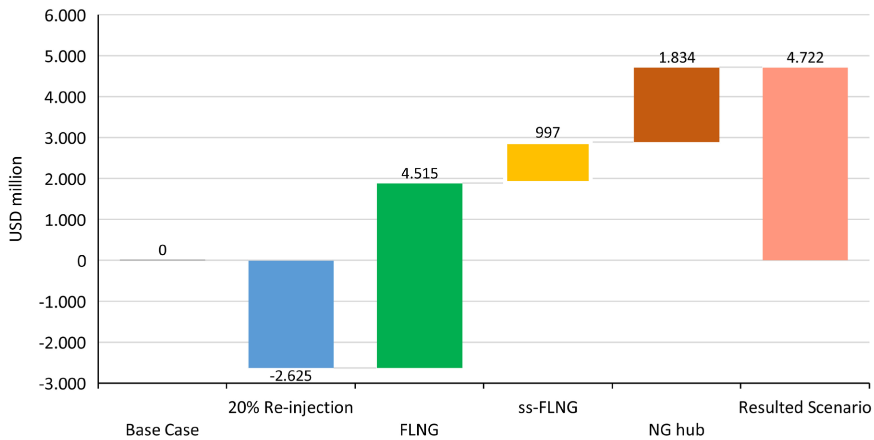
Source: Author, 2026.

Figure 4. EBITDA analysis considering all Búzios Fields.

7.3. Net Present Value (NPV)

The calculated NPV for the hub NG with the SSM-FLNG configuration yielded a positive value, as shown in **Figure 5**. This outcome is a fundamental indicator of the project's economic attractiveness, as it means the present value of expected benefits exceeds the present value of total costs, generating a surplus that adds wealth to investors. A positive NPV for the solution demonstrates that, under the study's assumptions, the project not only covers its costs and required rate of return but also creates an excess value, which is a clear sign that the investment is financially advantageous.

Evaluating **Figure 5**, with the utilization of the FLNG, there is a discounted cash flow (at a 12% annual rate) of US$4.515 billion and with the use of the SSM-FLNG, the discounted cash flow (at a 12% annual rate) results in a final value of US$5.512 billion. The SSM-FLNG solution yielded a valuation increase of USD 997 million, representing a 22% increase in NPV. Furthermore, there is an additional US$1.8 billion resulting from the use of the NG hub. This performance justifies and validates the approval of the investment in the proposed hub NG with the SSM-FLNG solution.



Source: Author, 2025/2026.

Figure 5. NPV analysis considering all Búzios Fields.

8. Conclusions

The findings of this study provide a robust validation of the SSM-FLNG architecture and the integrated offshore NG hub as a transformative solution for Brazil's pre-salt monetization. The developed economic modeling tool transcends specific case evaluations, offering a flexible methodological framework to analyze small-scale offshore structures across diverse global scenarios.

The economic simulations confirm that the SSM-FLNG configuration yields positive and robust results, outperforming conventional designs in several key metrics: the modular parallel array of 64 units achieves a total throughput of 4.48 MTPA, representing a 12% increase in collective processing capacity compared to standard 4.0 MTPA units. This higher volumetric efficiency correlates directly to an enhanced Net Present Value (NPV), as evidenced by positive IRR and EBITDA indicators. By reducing rigid infrastructure and transportation costs, the SSM-FLNG allows projects to deliver LNG at more competitive prices on the global market compared to traditional onshore sources.

A critical conclusion of this research is the necessity of the offshore NG hub platform. Currently, high CO_2 content and limited evacuation capacity force producers to rely heavily on gas reinjection. The proposed hub emerges as a promising solution to consolidate processing by: treating and processing gas from various FPSOs to reach liquefaction quality, the hub frees up critical capacity on individual production platforms; optimizing Capital Allocation so that the shared hub model redistributes CAPEX, making individual E&P projects more attractive and aligning with market liberalization objectives; and Future-Proofing Assets by avoiding the long-term costs of unnecessary reinjection, ensuring that pre-salt production remains competitive and sustainable.

In summary, the demonstrated viability of the SSM-FLNG and the integrated hub provides a promising roadmap for developing associated gas fields in remote deep waters where traditional pipelines are unfeasible. This innovation acts as a catalyst for economic efficiency, positioning Brazil to accelerate new projects and monetize gas assets previously considered marginal.

Funding

This research was funded by CNOOC Petroleum Brasil Ltd., through the Brazilian R&D levy regulation established by the Petroleum, Natural Gas and Biofuels Agency (ANP) (ANP's Resolution nº 918/2023). The Brazilian Federal Agency supported a seminal PhD Thesis related to this research, named Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

Acknowledgements

We gratefully acknowledge the support of CNOOC Petroleum Brasil Ltd., and the strategic importance of the support given by ANP (Brazil's National Oil, Natural Gas and Biofuels Agency) through the R&DI levy regulation (ANP Resolution n° 918/2023). The authors also gratefully acknowledge the seminal support from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES). The present publication reflects only the authors' views, and the scholarship's sponsors are not liable for any use of the information contained here.

Conflicts of Interest

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

References

[1] Arend, L., da Silva, Y.F.M., Pereira, C.A.A., dos Santos, E.M. and Peyerl, D. (2022) Prospects and Challenges of the Liquefied Natural Gas Market in Brazil. *Research, Society and Development*, **11**, e11811225527. https://doi.org/10.33448/rsd-v11i2.25527

[2] Velleda, I. (2022) Como a guerra entre Rússia e Ucrânia afeta o Brasil? [How the War between Russia and Ukraine Affects Brazil?]. *Forbes*. (In Portuguese) https://forbes.com.br/forbes-money/2022/02/como-a-guerra-entre-russia-e-ucrania-afeta-a-economia-brasileira/

[3] Ramalho, A. (2022) O que está em jogo nas discussões sobre gasodutos virtuais na

ANP [What Is at Stake in the Discussions about Virtual Pipelines at ANP]. EPBR. (In Portuguese)
https://epbr.com.br/o-que-esta-em-jogo-nas-discussoes-sobre-gasodutos-virtuais-na-anp/

[4] Botão, R.P., Costa, H.K.d.M., Miranda, M.F. and Santos, E.M.d. (2022) Analysis of a Power Generation Project in the Face of Increased Demand for Liquefied Natural Gas (LNG) in the Context of the New Gas Market. *Research*, *Society and Development*, **11**, e567111032100. https://doi.org/10.33448/rsd-v11i10.32100

[5] Rodrigues Teixeira, A.C., Machado, P.G., Borges, R.R., Felipe Brito, T.L., Moutinho dos Santos, E. and Mouette, D. (2021) The Use of Liquefied Natural Gas as an Alternative Fuel in Freight Transport—Evidence from a Driver's Point of View. *Energy Policy*, **149**, Article ID: 112106. https://doi.org/10.1016/j.enpol.2020.112106

[6] IEA (2022) World Energy Outlook 2022.
https://www.iea.org/reports/world-energy-outlook-2022

[7] Duchiade, A. (2023) União Europeia embarga derivados de petróleo russos, e medida pode afetar Brasil [European Union Imposes Embargo on Russian Petroleum Derivatives, and the Measure May Affect Brazil]. O Globo. (In Portuguese)
https://oglobo.globo.com/mundo/noticia/2023/02/uniao-europeia-embarga-derivados-de-petroleo-russos-e-medida-pode-afetar-brasil.ghtml

[8] EPBR/GasWeek (2023) Um giro pelos novos terminais de GNL do Brasil [A Tour of Brazil's New LNG Terminals]. EPBR-GasWeek Newsletter, May 5, 2023. (In Portuguese)
https://eixos.com.br/newsletters/newsletter-gas-week/um-giro-pelos-novos-terminais-de-gnl-do-brasil

[9] Harris, B. (2024) Brazil's Imports of Russian Oil Products Soar. *Financial Times*.
https://www.ft.com/content/7ebb679e-099e-49ac-a750-73ca46538dee

[10] The World Bank. RISE-Regulatory Indicators for Sustainable Energy.
https://rise.esmap.org/

[11] Estrella, L.M. (2022) Gás Natural Canalizado em Santa Catarina: Subsídios para um Novo Marco Regulatório [Piped Natural Gas in Santa Catarina: Subsidies for a New Regulatory Framework]. Master's Dissertation—Territorial Planning and Socio-Environmental Development, Universidade do Estado de Santa Catarina (UDESC). (In Portuguese)
https://www.udesc.br/arquivos/faed/id_cpmenu/7187/Dissertac_a_o_16643043553008_7187.pdf

[12] Souza, R.C., Thomé, A.M.T. and Vargas, S.A. (2019) Previsão de Demanda de Importação de Gás Natural Liquefeito (GNL) no Mercado Brasileiro [Demand Forecast for Liquefied Natural Gas (LNG) Imports in the Brazilian Market]. PUC-Rio. (In Portuguese) https://www.maxwell.vrac.puc-rio.br/49379/49379.PDF

[13] Fraga, D.M., Peyerl, D. and dos Santos, E.M. (2020) Small-Scale Compressed and Liquefied Natural Gas Distribution Systems. In: dos Santos, E.M., Peyerl, D. and Netto, A.L.A., Eds., *Opportunities and Challenges of Natural Gas and Liquefied Natural Gas in Brazil* [Oportunidades e Desafios do Gás Natural e do Gás Natural Liquefeito no Brasil], Letra Capital, 92-116. (In Portuguese)
https://letracapital.com.br/produto/oportunidades-e-desafios-do-gas-natural-e-do-gas-natural-liquefeito-no-brasil/

[14] Brito, T.L.F., Galvão, C., Fonseca, A.F., Costa, H.K.M. and Moutinho dos Santos, E. (2022) A Review of Gas-to-Wire (GtW) Projects Worldwide: State-of-Art and Developments. *Energy Policy*, **163**, Article ID: 112859.
https://doi.org/10.1016/j.enpol.2022.112859

[15] Ramalho, A. (2023) Os gargalos a serem superados no choque de oferta de gás, segundo a PUC [The Bottlenecks to Be Overcome in the Gas Supply Shock, According to PUC]. EPBR. (In Portuguese) https://epbr.com.br/os-gargalos-a-serem-superados-no-choque-de-oferta-de-gas-segundo-a-puc/

[16] Wood Mackenzie (2023) Mercado de óleo e gás continuará tumultuado em 2023, diz Wood Mackenzie [Oil and Gas Market Will Remain Turbulent in 2023, Says Wood Mackenzie]. EPBR. (In Portuguese) https://epbr.com.br/mercado-de-petroleo-e-gas-continuara-tumultuado-em-2023-diz-wood-mackenzie/

[17] Ruddy, G. (2023) Petrobras quer mudar fórmula de preço do gás natural, diz Prates [Petrobras Wants to Change the Natural Gas Pricing Formula, Says Prates]. EPBR. (In Portuguese) https://epbr.com.br/petrobras-tambem-quer-abrasileirar-preco-do-gas-natural-sinaliza-prates/

[18] Ramalho, A. (2023) EUA renovam compromisso para envio de GNL à Europa [US Renew Commitment to Send LNG to Europe]. EPBR. (In Portuguese) https://epbr.com.br/eua-renovam-compromisso-para-envio-de-gnl-a-europa/

[19] Poletti, L. and Ramalho, A. (2022) Acordo Brasil-Argentina promete gás barato e parceria em transição energética [Brazil-Argentina Agreement Promises Cheap Gas and Energy Transition Partnership]. EPBR. (In Portuguese) https://epbr.com.br/acordo-brasil-argentina-promete-gas-barato-e-parceria-em-transicao-energetica/

[20] El Ghazi, F., Lechheb, C. and Kaitouni, O.D. (2023) Midstream Supply Chain Infrastructure Facilities and Optimization Opportunities for Emerging LNG Markets. *International Journal of Energy Economics and Policy*, **13**, 175-186. https://doi.org/10.32479/ijeep.14421

[21] Chiappini, G. (2022) Dutra Azul: Governo do Rio estuda transformar via em corredor de GNV, biometano e hidrogênio [Dutra Azul: Rio Government Studies Transforming the Highway into a CNG, Biomethane and Hydrogen Corridor]. EPBR. (In Portuguese) https://epbr.com.br/dutra-azul-governo-do-rio-estuda-transformar-via-em-corredor-de-gnv-e-hidrogenio/

[22] Agência Petrobras. Petrobras Reaches 2024 Annual Production Target. https://agencia.petrobras.com.br/en/w/negocio/petrobras-atinge-meta-de-producao-anual-de-2024

[23] PPSA (2024) Campo de Búzios bate a marca de 1 bilhão de barris de óleo produzidos desde que começou a operar [Búzios Field Reaches the Milestone of 1 Billion Barrels of Oil Produced Since It Began Operating]. Pré-Sal Petróleo S.A., April 2024. (In Portuguese) https://www.presalpetroleo.gov.br/noticias/campo-de-buzios-bate-a-marca-de-1-bilhao-de-barris-de-oleo-produzidos-desde-que-comecou-a-operar/

[24] IBAMA (2014) RIMA—Atividade de Produção e Escoamento de Petróleo e Gás Natural do Polo Pré-Sal da Bacia de Santos—Etapa 2, Revisão 3 [Environmental Impact Report—Oil and Natural Gas Production and Outflow Activity at the Santos Basin Pre-Salt Cluster—Stage 2, Revision 3]. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, February 2014. Process no. 02022.002141/2011-03. (In Portuguese)

[25] Adefemi, A., *et al.* (2024) Reviewing the Development of Floating LNG Facilities and Their Global Impact. *World Journal of Advanced Research and Reviews*, **21**, 371-381.

https://doi.org/10.30574/wjarr.2024.21.2.0463

[26] Reuters/CNN Brasil (2024) Petrobras buscará reduzir reinjeção de gás o "máximo possível", diz Chambriard [Petrobras Will Seek to Reduce Gas Reinjection to the "Maximum Possible Extent", Says Chambriard]. CNN Brasil. (In Portuguese) https://www.cnnbrasil.com.br/economia/macroeconomia/petrobras-buscara-reduzir-reinjecao-de-gas-o-maximo-possivel-diz-chambriard/

[27] ABEGÁS (2024) Reinjeção desnecessária de gás tende a levar a aumento de custos no futuro, defende MME [Unnecessary Gas Reinjection Tends to Lead to Higher Costs in the Future, Says MME]. Associação Brasileira das Distribuidoras de Gás Natural. (In Portuguese) https://www.abegas.org.br/arquivos/92694

[28] Hanwha (2025) How FLNG Is Expanding Global LNG Supply. https://www.hanwha.com/newsroom/news/feature-stories/how-flng-is-expanding-global-lng-supply.do

[29] MME (2024) Relatório do Grupo de Trabalho do Programa Gás para Empregar—Comitê 1 [Report of the Working Group of the Gás para Empregar Program—Committee 1: Natural Gas Availability]. Ministério de Minas e Energia. (In Portuguese) https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/gas-para-empregar/relatorio-dos-comites-tematicos/relatorio_comite_1_vf.pdf https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/gas-para-empregar/relatorio-dos-comites-tematicos

[30] EPE and MME (2021) Plano Indicativo de Processamento e Escoamento de Gás Natural—PIPE 2021 [Indicative Natural Gas Processing and Outflow Plan—PIPE 2021]. Empresa de Pesquisa Energética, November 2021. (In Portuguese) https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-640/Plano%20Indicativo%20de%20Processamento%20e%20Escoamento%20de%20G%C3%A1s%20Natural%20-%20PIPE.pdf https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/plano-indicativo-de-processamento-e-escoamento-de-gas-natural-pipe

[31] MME (2024) Relatório do Grupo de Trabalho do Programa Gás para Empregar—Comitê 2 [Report of the Working Group of the Gás para Empregar Program—Committee 2: Access to the Natural Gas Market]. Ministério de Minas e Energia. (In Portuguese) https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/gas-para-empregar/relatorio-dos-comites-tematicos/relatorio_comite_2_vf.pdf https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/gas-para-empregar/relatorio-dos-comites-tematicos

[32] Chambriard, M. (2020) A Petrobras, o Pré-Sal e o Campo de Búzios [Petrobras, the Pre-Salt and the Búzios Field]. FGV Energia. (In Portuguese) https://fgvenergia.fgv.br/opinioes/petrobras-o-pre-sal-e-o-campo-de-buzios

[33] Arend, L., Vieira, D.P., da Costa, F.C., dos Santos, E.M., Fossa, A., Castagnet, M., *et al.* (2025) Brazilian SSM-FLNG Offshore, a Conceptual Solution of a System as a New Frontier of National Production and Technological Innovations. *World Journal of Engineering and Technology*, **13**, 885-922. https://doi.org/10.4236/wjet.2025.134056

[34] Arend, L., Vieira, D.P., *et al.* (2025) Monetization of Natural Gas from the Búzios Field through an SSM-FLNG Platform: Economic and Financial Assessment. *Energy and Power Engineering*, **17**, 270-308. https://www.scirp.org/journal/paperinformation?paperid=145440

[35] Arend, L., Vieira, D.P. *et al.* (2025) SSM-FLNG in Brazil—Innovative Monetization

of Presalt Gas.
https://synergiaeditora.com.br/produto/ssm-flng-in-brazil-innovative-monetization-of-presalt-gas/

[36] IBAMA (2012) EIA/RIMA para a Atividade de Produção e Escoamento de Petróleo e Gás Natural do Polo Pré-Sal da Bacia de Santos—Etapa 1, Revisão 02 [Environmental Impact Study/Report for the Oil and Natural Gas Production and Outflow Activity at the Santos Basin Pre-Salt Cluster—Stage 1, Revision 02]. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, May 2012. Process No. 02022.002287/2009-26. (In Portuguese)

[37] IBAMA (2010) EIA/RIMA—Projetos Integrados de Produção e Escoamento de Petróleo e Gás Natural no Pólo Pré-Sal, Bacia de Santos, Revisão 00 [Environmental Impact Study/Report—Integrated Oil and Natural Gas Production and Outflow Projects at the Santos Basin Pre-Salt Cluster, Revision 00]. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, July 2010. Process No. 02022.002287/2009-26. (In Portuguese)

[38] IBAMA (2013) EIA/RIMA—Atividade de Produção e Escoamento de Petróleo e Gás Natural do Polo Pré-Sal da Bacia de Santos—Etapa 2, Revisão 00 [Environmental Impact Study/Report—Oil and Natural Gas Production and Outflow Activity at the Santos Basin Pre-Salt Cluster—Stage 2, Revision 00]. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, October 2013. Process No. 02022.002141/2011-03. (In Portuguese)

[39] IBAMA (2011) EIA/RIMA para a Atividade de Produção e Escoamento de Petróleo e Gás Natural do Polo Pré-Sal da Bacia de Santos—Etapa 1, Revisão 01 [Environmental Impact Study/Report for the Oil and Natural Gas Production and Outflow Activity at the Santos Basin Pre-Salt Cluster—Stage 1, Revision 01]. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, November 2011. Process No. 02022.002287/2009-26. (In Portuguese)

[40] ANP (n.d.) Painéis Dinâmicos de Produção de Petróleo e Gás Natural [Dynamic Dashboards for Oil and Natural Gas Production]. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis. (In Portuguese)
https://www.gov.br/anp/pt-br/centrais-de-conteudo/paineis-dinamicos-da-anp/paineis-dinamicos-sobre-exploracao-e-producao-de-petroleo-e-gas/paineis-dinamicos-de-producao-de-petroleo-e-gas-natural

[41] Borges, C.M. (2021) Avaliação de Tecnologias Integradas ao Gás Visando Alavancar os Lucros do Cluster Pré-Sal da Bacia de Santos para a Sociedade e a Indústria. Official English Title (as Published on the USP Repository): Evaluation of Gas-Integrated Technologies Aiming at Leveraging Profits of Santos Basin Pre-Salt Cluster for Society and The Industry. Ph.D. Thesis, Universidade de São Paulo (USP). (In Portuguese) https://www.iee.usp.br/producao/990/

[42] Estadão/Eixos (2025) Silveira anuncia que regulamentação sobre gás natural virá na MP que limita custos da CDE [Silveira Announces That Natural Gas Regulation Will Come in the Provisional Measure Limiting CDE Costs]. Eixos. (In Portuguese)
https://eixos.com.br/gas-natural/mercado-de-gas/silveira-anuncia-que-regulamentacao-sobre-gas-natural-vira-na-mp-que-limita-custos-da-cde/

[43] Black & Veatch (2025) FLNG Facility from Converted Carrier Features PRICO Liquefaction Technology. https://www.bv.com/projects/golar-gimi-flng

[44] EPE (2025) Plano Indicativo de Gasodutos de Transporte—PIG [Indicative Transportation Pipeline Plan—PIG]. Empresa de Pesquisa Energética. (In Portuguese)
https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/plano-indicativo-de-gasodutos-de-transporte--pig

[45] International Gas Union (2018) 2018 World LNG Report—27th World Gas Conference Edition. IGU. (In English)
https://www.igu.org/igu-reports/2018-world-lng-report-27th-world-gas-conference-edition

[46] MME, CADE, ANP and EPE (2019) Propostas para o Mercado Brasileiro de Gás Natural: Nota Técnica do Comitê de Promoção da Concorrência no Mercado de Gás Natural do Brasil [Proposals for the Brazilian Natural Gas Market: Technical Note of the Committee for the Promotion of Competition in the Brazilian Natural Gas Market]. Ministério de Minas e Energia, June 2019. (In Portuguese)
https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/novo-mercado-de-gas/documentos-relacionados-1/2.RelatrioComitdePromoodaConcorrnciavfinal10jun19.pdf
https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/novo-mercado-de-gas