

# Journal of Engineering Research

ISSN 2764-1317

vol. 6, n. 2, 2026

## ... ARTICLE 3

Acceptance date: 24/02/2026

# OPTIMIZING LIQUEFIED NATURAL GAS TRANSPORTATION TO ISOLATED COMMUNITIES IN THE AMAZON REGION: A DISCRETE SIMULATION APPROACH USING PLANT SIMULATION

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**Abstract:** The text presents a comprehensive analysis of the logistical challenges and opportunities surrounding liquefied natural gas (LNG) transportation to meet the energy needs of isolated communities in the Amazon region. It begins by outlining the characteristics of the Amazon, emphasizing its vastness, remote geography, and diverse population. It then delves into the description of thermoelectric power plants in the region and explores the potential use of LNG as a transitional fuel, considering both environmental and economic factors. The proposal of a supply model for the isolated systems of Amazonas is discussed, highlighting the complexities of sourcing LNG from local production basins or through importation. The text also introduces the application of discrete simulation tools like Plant Simulation software for logistics system analysis, particularly in fluid-based modeling for LNG transportation. It further examines the simulation model applied to isolated localities in Amazonas, detailing the variables involved and proposing a scheduling scheme for efficient LNG delivery. Ultimately, the analysis underscores the importance of strategic planning, technological innovation, and environmental considerations in ensuring reliable, efficient, and sustainable energy supply to remote communities in the Amazon region.

**Keywords:** Amazon Region, LNG Transportation, Discrete Simulation, Plant Simulation, Isolated Communities.

## Introduction

Brazil's Amazon region holds significant reserves of natural gas, with exploration activities ongoing to tap into this valuable resource. While the primary fo-

cus of Brazil's oil and gas industry has historically been on offshore fields, attention has increasingly turned to the potential of onshore reserves, including those located in the Amazon.

Exploration efforts in the Amazon have revealed promising gas reserves, primarily concentrated in sedimentary basins such as the Solimões Basin. This region is believed to hold substantial untapped reserves, which could potentially alleviate Brazil's reliance on imported natural gas and bolster domestic energy security.

Several companies, including both domestic and international players, have been actively exploring and developing gas fields in the Amazon. These efforts involve drilling exploratory wells to assess the size and quality of gas deposits and conducting seismic surveys to better understand the geological characteristics of the area.

One notable project is the Urucu natural gas field, located in the Solimões Basin in the heart of the Amazon rainforest. Operated by Petrobras, Brazil's state-owned oil company, Urucu has been a focal point of gas production in the region. The field has significant reserves of natural gas and condensate, with ongoing development activities aimed at maximizing production and expanding its capacity.

In addition to Urucu, other exploration and production projects are underway across various parts of the Amazon region, with companies exploring new prospects and expanding their footprint in pursuit of additional gas reserves.

However, the exploration and production of natural gas in the Amazon also raise environmental concerns, given the

sensitivity of the region's ecosystems. Sustainable development practices and stringent environmental regulations are essential to ensure that gas extraction activities minimize their impact on the Amazon's biodiversity and indigenous communities.

Overall, the exploration and development of natural gas reserves in the Brazilian Amazon hold promise for boosting domestic energy supply and contributing to economic development. However, it is crucial to balance these benefits with environmental conservation efforts and the protection of local communities and ecosystems.

Azulão is an important natural gas field located in the Amazon region of Brazil, specifically in the state of Amazonas. This field has gained attention for its significant reserves and its potential to contribute to Brazil's domestic energy supply.

Operated by Eneva, a Brazilian energy company, Azulão has been the focus of exploration and development efforts aimed at unlocking its vast natural gas resources. The field is situated in the Amazon Basin, within the Coari municipality, and is part of the larger Solimões Basin, known for its hydrocarbon reserves.

Azulão's natural gas reserves are estimated to be substantial, making it a strategically significant asset for Brazil's energy sector. The field's development involves drilling wells to extract the gas and establishing infrastructure for its processing and transportation.

One notable aspect of Azulão is its proximity to demand centers, including industrial hubs and urban areas in the Amazon region. This geographic advantage reduces the need for extensive pipeline

infrastructure and facilitates the distribution of natural gas to consumers.

Furthermore, the development of Azulão aligns with Brazil's efforts to diversify its energy mix and reduce dependence on imported fuels. By tapping into its domestic natural gas resources, Brazil aims to enhance energy security, reduce greenhouse gas emissions, and support economic growth.

However, like other natural resource projects in the Amazon, the development of Azulão raises environmental considerations. Eneva and other stakeholders in the project are expected to adhere to strict environmental regulations and implement measures to minimize the impact on the region's biodiversity and indigenous communities.

Overall, Azulão represents a valuable asset in Brazil's quest for energy self-sufficiency and economic development. Its development underscores the potential of the Amazon region as a significant contributor to the country's energy landscape while highlighting the importance of responsible resource management and sustainable practices.

The utilization of liquefied natural gas (LNG) in the Brazilian Amazon region presents a promising opportunity with significant potential benefits. With the growing demand for energy in remote areas of the Amazon, LNG can serve as a cleaner and more efficient alternative compared to traditional fuels like diesel or heavy oil.

Firstly, LNG offers environmental advantages, emitting fewer pollutants such as sulfur dioxide and particulate matter, which can help mitigate the im-

impact of energy production on the sensitive ecosystems of the Amazon rainforest. Additionally, LNG combustion produces lower greenhouse gas emissions compared to conventional fuels, aligning with global efforts to combat climate change.

Moreover, the transportability and versatility of LNG make it particularly suitable for the unique logistical challenges of the Amazon region. Its liquefied form allows for easier transportation via ships, trucks, or even small-scale barges along the region's rivers, circumventing the need for extensive pipeline infrastructure. This flexibility facilitates the provision of energy to remote communities and industrial facilities located far from traditional energy grids.

Furthermore, the use of LNG can contribute to local economic development by creating opportunities for investment in infrastructure and fostering job creation. The establishment of LNG facilities, such as liquefaction plants or regasification terminals, could stimulate economic activity and attract investment to the region, potentially enhancing its overall development.

However, it's essential to consider the environmental and social impacts associated with LNG infrastructure development and operation in the Amazon. Responsible planning and implementation, including thorough environmental assessments and community engagement, are crucial to ensure that LNG projects in the region are sustainable and beneficial in the long term.

The utilization of LNG in the Brazilian Amazon offers a promising opportunity to meet the region's energy needs while promoting environmental sustainability

and economic development. With careful planning and consideration of environmental and social factors, LNG can play a significant role in powering the Amazon's future growth and prosperity.

This work aims to develop a discrete event simulation model using the Plant Simulation tool to enable analysis of liquefied natural gas distribution to the thermoelectric power plants in the municipalities of the interior of the state of Amazonas.

## **The energy market in the state of Amazonas: the case of isolated municipalities**

The state of Amazonas, located in the northern region of Brazil, is characterized by its vast expanse of tropical rainforest, encompassing a significant portion of the Amazon Basin. It is the largest state in Brazil by land area, covering approximately 1.57 million square kilometers (IBGE, 2022a).

Amazonas is renowned for its rich biodiversity, including a multitude of plant and animal species found nowhere else on Earth. The Amazon Rainforest, often referred to as the "lungs of the Earth," plays a crucial role in global climate regulation and is considered one of the world's most important natural resources.

The state is home to a diverse population, including indigenous communities with distinct cultures and languages, as well as urban centers such as the capital city, Manaus. Manaus is a major industrial and economic hub, known for its Free Economic Zone which attracts investment and manufacturing activities.

Despite its natural wealth, Amazonas faces challenges related to environmental conservation, sustainable development, and social inequality. Efforts are underway to promote responsible management of the region's resources, support local communities, and preserve the Amazon rainforest for future generations.

Overall, Amazonas is a region of immense ecological significance and cultural diversity, with both opportunities and challenges for its sustainable development.

In the inside of the state of Amazonas, there are numerous municipalities and a significant population. This region is characterized by its vast expanses of dense rainforest, rivers, and diverse ecosystems. While the exact number of municipalities may vary over time due to administrative changes, as of [current year]. The population of the interior of Amazonas is estimated to be around 1.5 million people, based on the latest available census data (IBGE, 2022b).

The population of the interior of Amazonas is also notable, although it tends to be less densely populated compared to urban areas. People living in the interior are often spread across remote communities, indigenous villages, and rural settlements. Access to basic services such as healthcare, education, and infrastructure can be limited in these areas due to the challenges of transportation and communication in such remote environments.

Overall, while the interior of Amazonas may have fewer municipalities and a lower population density compared to urban centers, it is still home to a significant number of people who rely on the region's natural resources for their livelihoods and

sustenance. Efforts to improve infrastructure, healthcare, education, and economic opportunities in the interior are crucial for the well-being and development of its inhabitants.

## Description of the thermoelectric power plants in the remote municipalities of the state of Amazonas

### General configuration of the energy supply in the Amazon

Providing electricity to the population in the Amazon region poses significant challenges due to its vast and remote geography, environmental considerations, and socioeconomic factors. The Amazon region spans over 6.7 million square kilometers, encompassing dense forests, rivers, and isolated communities (INPE, 2022). The vast and often inaccessible terrain makes it difficult and costly to extend electricity infrastructure to remote areas.

Environmental regulations and conservation efforts in the Amazon region impose restrictions on infrastructure development to minimize ecological impacts (WWF, 2022). Balancing the need for electricity access with environmental preservation presents a challenge for policymakers and energy planners.

Many communities in the Amazon region are characterized by low population density, poverty, and limited access to basic services (IBGE, 2021). Economic constraints and social inequalities hinder investment in electricity infrastructure and affect the affordability of electricity services for residents.

In remote areas where grid extension is not feasible, isolated energy systems such as diesel generators or small-scale renewable energy installations are often used (EPE, 2021). However, these systems can be expensive to operate and maintain, impacting the reliability and affordability of electricity supply.

### Isolated systems of the municipalities of Amazonas

Thermoelectric power plants in the isolated systems of the Amazon are crucial for providing electricity to remote communities that are not connected to the main electricity grid. These power plants typically rely on diesel as the primary fuel source due to its availability and ease of transport to remote areas (EPE, 2021).

The operation of these power plants involves diesel engines driving generators to produce electricity. The generated electricity is then distributed to local consumers through distribution networks, meeting the minimum electricity requirements of the community (EPE, 2021).

Maintenance and monitoring of these power plants are essential to ensure their reliability and efficiency. However, challenges such as remote locations and limited access to technical expertise and spare parts make this task particularly demanding (EPE, 2021).

While diesel-fired thermoelectric power plants provide a reliable source of electricity to isolated communities, they also have environmental implications. Emissions from these plants, including carbon dioxide (CO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), sulfur dioxide (SO<sub>2</sub>), and particulate matter (PM), can contribute to air

pollution and impact the delicate ecosystems of the Amazon (EPE, 2021).

Efforts to integrate renewable energy sources, such as solar and biomass, into isolated power systems in the Amazon are underway. Hybrid systems that combine diesel generators with renewable energy sources offer opportunities to reduce fuel consumption, greenhouse gas emissions, and environmental impact while improving energy reliability and sustainability (EPE, 2021).

Overall, thermoelectric power plants play a vital role in providing electricity to remote communities in the Amazon, but efforts to improve their efficiency, reliability, and environmental performance are crucial for sustainable energy development in the region.

Electric power generation in isolated systems in the municipalities of the inside of the state of Amazonas is essential for providing electricity to remote communities that are not connected to the main electricity grid. These isolated systems typically rely on thermoelectric power generation.

In many isolated systems, diesel generators are the primary source of thermoelectric power generation. Diesel fuel is readily available and can be transported to remote areas, making it a practical choice for electricity generation in isolated communities. Diesel generators are often used to provide baseload power, supplying a constant level of electricity to meet the community's minimum demand.

## The opportunity to use LNG in the Amazon: The case of isolated systems in the state of Amazonas

### Description of the production basins in the region

In the state of Amazonas, there are 2 large active oil basins that are potential sources to meet the energy needs of isolated thermoelectric systems in the Amazon, namely Urucu and Azulão.

The Urucu Basin, located in the state of Amazonas, Brazil, is a significant area for natural gas exploration and production. The basin is home to the Urucu Gas and Condensate Field, which contains substantial reserves of natural gas. Exploration and production activities in the Urucu Basin are primarily conducted by Petrobras, the state-owned oil company, through various gas fields (Petrobras, 2021). With the development of LNG facilities in the region, Urucu Basin's natural gas can be liquefied and transported for export or domestic use. This infrastructure serves as a vital link for the utilization of LNG as a transitional fuel (Petrobras, 2021).

The Azulão Basin, also situated in Amazonas, Brazil, is another area of interest for natural gas exploration. Companies like Eneva have been actively exploring and developing gas resources in the Azulão Basin. With the development of gas fields and associated infrastructure, Azulão Basin contributes to the supply of natural gas for the region (Eneva, 2021). Investment in LNG facilities in the Azulão Basin allows for the liquefaction and transportation of natural gas. This enables the utilization of LNG as a transitional

fuel to pave the way for future hydrogen integration in the energy matrix of Amazonas (Eneva, 2021).

### Benefit and opportunities

Liquefied natural gas (LNG) offers significant environmental and transportation safety advantages over diesel oil when used as a fuel for barges and other marine vessels.

LNG combustion produces lower levels of greenhouse gases (GHGs) and air pollutants compared to diesel oil, resulting in decreased emissions of carbon dioxide (CO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), sulfur oxides (SO<sub>x</sub>), particulate matter (PM), and other pollutants (EIA, 2021a).

The use of LNG as a marine fuel can help improve local air quality in port areas and along shipping routes, reducing the health risks associated with air pollution (EIA, 2021a).

By lowering GHG emissions, the widespread adoption of LNG as a marine fuel contributes to global efforts to mitigate climate change and reduce the environmental footprint of maritime transportation (EIA, 2021a).

LNG is stored and transported in a liquid state at cryogenic temperatures, significantly reducing the risk of spills compared to liquid fuels like diesel oil. In the event of a spill, LNG evaporates quickly without leaving a residue, minimizing environmental impact (DNV GL, 2019).

LNG has a higher ignition temperature and narrower flammability range than diesel oil, making it safer to handle and transport. The risk of fire and explosion accidents associated with LNG is

lower compared to traditional liquid fuels (DNV GL, 2019).

Switching from diesel oil to LNG for electricity generation in isolated systems can result in significant cost savings. LNG generally has a lower cost per unit of energy compared to diesel oil, reducing the operating expenses associated with power generation (EIA, 2021b).

LNG prices tend to be more stable and less volatile than diesel oil prices. By using LNG as a fuel source, electricity producers in isolated systems can better predict and manage their fuel costs, reducing the financial risks associated with fluctuations in fuel prices (EIA, 2021b).

Investing in LNG infrastructure, such as liquefaction plants and regasification terminals, enables long-term access to a reliable and cost-effective fuel supply. This long-term investment provides stability and certainty for electricity generation in isolated systems, supporting economic growth and development in the region (EIA, 2021b).

While not strictly economic, the use of LNG for electricity generation offers environmental benefits such as reduced greenhouse gas emissions and improved air quality. These environmental benefits can lead to indirect economic advantages, including potential cost savings related to environmental compliance and public health improvements (EIA, 2021b).

### Isolated systems in Amazonas

There is complexity in obtaining and validating data to be used in modeling. The complexity transcends the natural dispersion condition of the potential LNG supply points. Figure 1 represents the map

of the state of Amazonas with the identification of the locations of isolated thermo-electric power plants, which are potential recipients of LNG.

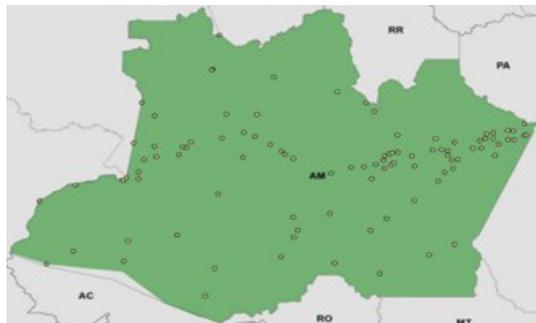


Figure 1. Location of isolated system thermoelectric plants in Amazonas

Source: EPE (2022)

According to EPE (2022), there are 97 isolated power systems in Amazonas, as depicted in Figure 1, scattered across the territory. Almost all of these systems operate using diesel oil as fuel. However, exceptions are found in the municipalities of Anamá, Anori, Caapiranga, Codajás, and Coari, where thermoelectric power plants consume natural gas from the Coari/Manaus pipeline's city gates. Another exception is the isolated system of Itacoatiara, where part of its generation comes from the supply of the MIL-BK Energia Biomass Thermoelectric Plant, which uses wood chips as fuel, with a contract expected to last until the interconnection of this locality to the National Interconnected System - SIN.

It was found that on April 30, 2021, the National Electric Energy Agency - ANEEL conducted an auction to define energy suppliers for isolated systems. In Lot 2, the Novo Remanso system, located

in the municipality of Itacoatiara, was included, with natural gas generation under the responsibility of the company Usina Xavantes. The project team, in dialogue with local stakeholders, managed to gather additional information to enhance the future simulation model. It was discovered that the natural gas supply for the Novo Remanso plant will be through compressed natural gas (CNG) obtained from the natural gas distribution network in the city of Manaus. Interestingly, the option of supplying natural gas for the Novo Remanso plant with LNG from the ENEVA plant in Azulão, municipality of Silves, located next to Itacoatiara, was not defined. It is worth noting that CNG reduces the gas volume at STP by 270 times, while LNG reduces it by 600 times. Therefore, from a logistical point of view, the advantage of transportation is much greater for LNG than for CNG, disregarding the costs of these chains' components, as well as market, strategic, and regulatory variables. Apparently, the decision to use CNG for the Novo Remanso UTE resulted from the need to meet deadlines for presenting an effective solution at the time of the agreement made in the ANEEL auction.

The previous episode highlights the complexity involved in adjusting information to compose the database to be used for the development of the LNG distribution network simulation model. It is important to emphasize that the objective is to serve the set of isolated thermoelectric plants in Amazonas, as well as fleets of vessels interested in and potentially able to convert engines to consume natural gas. Additionally, there is also the prospect that some locations will be interconnected with the National Interconnected System - SIN,

thus foreseeing the potential decommissioning of some of the plants in isolated systems.

Considering the accessibility conditions by waterway transport, in which isolated systems with potential for receiving LNG through the region's waterways are identified, in addition to considering the aforementioned exceptions, it can be inferred that out of the universe of 97 isolated systems in Amazonas, 43 have attributes to be included in the LNG supply chain modeling.

In the analysis conducted in this study, it is considered that the energy efficiency of natural gas generators is 35%, and the calorific value of the gas is 9.47 kWh/m<sup>3</sup> at Normal Temperature and Pressure Conditions (CNTP), as per ANP Resolution No. 16/2008 - Natural Gas Specification Table for the Northern Region. The total estimated consumption for all 43 locations results in a volume of 272,964,060 m<sup>3</sup>/year or 747,846.73 m<sup>3</sup>/day of natural gas. Considering that the liquefaction process reduces the volume of natural gas by 600 times, the volume of LNG required for the year 2024 would be approximately 454,940.10 m<sup>3</sup>, corresponding to approximately 37,911.67 m<sup>3</sup> monthly or 1,263.72 m<sup>3</sup>/day.

## Proposal of a supply model for the isolated systems of Amazonas

Regionally, there are two possibilities to meet the LNG demand indicated in the previous section. The first one could be the Coari/Manaus pipeline (initially under PETROBRAS responsibility), which currently has a transportation capacity of

4,670,000 m<sup>3</sup>/day, with the potential to reach 6,850,000 m<sup>3</sup>/day through the installation of new compression stations in Juaruna and Coari. However, according to information from the Amazonas State Gas Company - CIGAS, as of February 2022, the average volume marketed by this concessionaire is 4,500,000 m<sup>3</sup>/day, with percentages allocated to the following sectors: thermal power generation (96.77%), industrial (2.52%), vehicular (1.67%), commercial (0.34%), and residential (0.16%). The second possibility arises from the availability of LNG produced in the Azulão field in Silves/AM by the company ENEVA. Despite the conception of the LNG production system and supply for the Jaguatirica II thermoelectric plant in Boa Vista/RR, focused on the use of cryogenic trailers of 50 m<sup>3</sup> for transportation from Silves to Boa Vista. The initially planned transportation is 20 trailers/day, indicating a production capacity of at least 600,000 m<sup>3</sup>/day at CNTP.

ENEVA has announced and highlighted the agreement to maintain a reserve of 3.6 billion m<sup>3</sup> of natural gas exclusively for the Jaguatirica UTE consumption. At the same time, it indicated a 60% increase in its reserves. Considering the current production dedicated to supplying 20 cryogenic trailers to the Jaguatirica UTE, the dedicated reserve would last approximately 16.5 years. However, the ongoing installation of the transmission line that will connect the National Interconnected System - SIN, linking Manaus with the isolated system of Roraima, represents a potential decommissioning of the Jaguatirica UTE. Probably, such a scenario may have motivated ENEVA to include the installation of a new UTE in Silves/AM

in its planning, confirmed by ANEEL's reserve auction at the end of 2021, named UTE Azulão, with a planned capacity of 295 MW, expected to start operating in 2026.

Considering the forecasted demand of the 43 isolated systems to be approximately 747,846.73 m<sup>3</sup>/day of natural gas, as indicated in Table 01, it is noted that such demand surpasses the current demand of 600,000 m<sup>3</sup>/day from the Jaguatirica UTE in Boa Vista/RR. In the event of no additional volumes available from the Azulão field, there is a relative difficulty in opening up prospects for the destination of Azulão LNG for the thermal supply of the Amazonas isolated systems.

A similar analysis can be considered for the case of the Coari/Manaus pipeline, as previously mentioned, CIGÁS reports that almost all of the current capacity of the pipeline is committed, possibly leaving a fraction of approximately 170,000 m<sup>3</sup>/day, which would not be enough to meet the total forecasted demand of 747,846.73 m<sup>3</sup>/day for the 43 isolated systems. However, it is also possible that the national generation system planning review may reassess the need for the Manaus UTEs, which consume over 96.77% of the gas available in the pipeline. Another alternative would be the possibility of increasing the pipeline's capacity, but as previously indicated, it would require some investments in compression stations along the pipeline, as well as the need to increase reserves in the Urucu region, which is possible considering the availability of Juruá reserves.

Considering the discussed elements, there are justifications for the interest of different organizations and companies in offering natural gas supply alternatives in

the North region of the country. In such an environment, proposals have emerged, such as that of the company Amazônica Energy. This company is proposing the importation of LNG from international suppliers, in the project entitled Uirapuru Gas & Energy, with an expected start of operation in July 2023. Figure 2 illustrates the flow proposition of this project. Thus, LNG tankers would import LNG to the North region, specifically to meet the demand of Manaus and other markets concentrated in the vicinity, such as Porto Velho, aiming to supply fertilizer production, industrial operation, naval propulsion, power generation, among others. It is worth mentioning that there are already concrete initiatives for LNG importation to the North region, such as the LNG terminal in Barcarena/PA, authorized by the National Petroleum Agency - ANP on 12/29/2020, aiming to supply the Barcarena UTE, under the responsibility of Centrais Elétricas Barcarena.



Figure 2. Representation of the flow of LNG imported by the Uirapuru project

Source: Amazonica Energy (2022)

Following Amazônica Energy's proposition of LNG importation, the second stage will involve regional distribution. Amazônica Energy has been promoting some proposals for transportation systems, for example, there is the indication of developing LNG barges with a capacity of 1,200 m<sup>3</sup>, as shown in Figure 3.

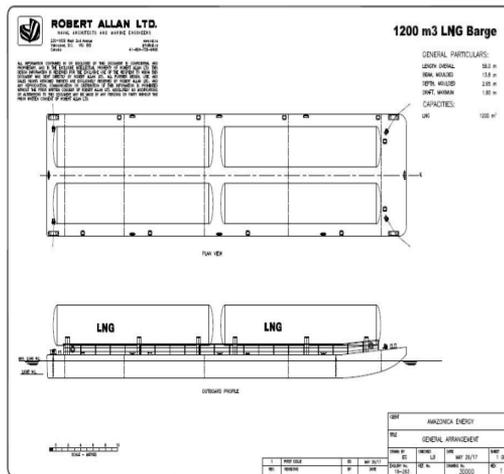


Figure 3. Amazônica Energy's LNG transport ferry model proposal

Source: SINDINAVAL (2019).

And finally, it is worth highlighting a new component in this discussion about international LNG supply. The onset of the international conflict between Russia and Ukraine since February 2022 has resulted in a reduction in the use of Russian natural gas in Europe. Pipelines from Russia to European countries are experiencing operational disruptions due to embargo issues. If this scenario persists, the LNG market is expected to pose challenges for smaller global demanders, such as in the

case of demand from the Northern Region of Brazil.

The possibility of using natural gas from the Pre-Salt reserves in Brazil to meet the demand of the Northern Region has not been discussed in this study. There are also various variables that currently prevent the identification of possible scenarios to be explored among the set of information and occurrences observed in the sector under discussion. However, this serves as a warning and reminder to consider these points for the modeling to be developed in the next stages.

Lastly, although not addressed throughout the text, considering it would require considerable discussion space, the environmental issue stands as a strong influencing factor in the decisions of the energy and transportation sectors, given their impact on climate change. The trend for these segments is to reduce the use of fossil sources, although natural gas, being one of these sources, indeed has a lower potential for generating adverse environmental impacts than other petroleum derivatives. Therefore, in the current scenario of the Amazon, which shows a high dependence on diesel for thermal generation in isolated systems and naval propulsion, it is seen as more environmentally advantageous and desirable for these segments to transition to natural gas, in the event that there are no other renewable alternatives available.

## **Use of discrete simulation tool for logistics system: The case of Plant Simulation Software**

Discrete event simulation (DES) is a powerful tool for modeling and analyzing complex logistic systems. It enables the study of system behavior under different scenarios, facilitating decision-making processes and optimizing system performance. Siemens PLM Software's Plant Simulation is a widely used tool for conducting DES in various industries, including logistics (Rossetti et al., 2015).

Plant Simulation is a software solution developed by Siemens PLM Software for modeling, simulating, and analyzing production and logistic systems. It offers a user-friendly interface coupled with powerful simulation capabilities, making it suitable for a wide range of applications, including warehouse management, material flow analysis, and supply chain optimization.

Plant Simulation is extensively used in logistic systems to model and simulate various processes such as inventory management, order fulfillment, and transportation. By accurately representing the flow of materials and resources within a logistic system, Plant Simulation enables stakeholders to identify bottlenecks, assess system performance, and explore optimization strategies.

According to SDIS (2024) the utilization of Plant Simulation software in logistic systems offers several benefits, including: a) Visualization: Plant Simulation provides visual representations of the logistic system, allowing stakeholders to

gain insights into system dynamics and interactions; b) Scenario Analysis: Users can simulate different scenarios to evaluate the impact of changes in system parameters, such as resource allocation and workflow configurations; c) Optimization: Plant Simulation facilitates the optimization of logistic systems by identifying inefficiencies and proposing improvements to enhance productivity and reduce costs; e d) Risk Mitigation: By simulating various scenarios, stakeholders can proactively identify potential risks and develop mitigation strategies to minimize their impact on the logistic operations. So, Plant Simulation software provides an effective platform for conducting discrete event simulations in logistic systems. By leveraging its simulation capabilities, stakeholders can gain valuable insights into system behavior, optimize operations, and make informed decisions to enhance the efficiency and performance of logistic processes.

## Simulations components in fluid systems

Fluid-based modeling is a technique used in logistic systems to simulate the flow of materials, resources, and entities within a system. In Plant Simulation software, this approach is implemented through various components designed to represent fluid-like behavior, facilitating the modeling and analysis of complex logistic processes. The components of Fluid-Based Modeling in Plant Simulation, may contain:

### 1) Fluid objects:

Plant Simulation provides specialized objects, such as tanks, pipes, and conveyors, to model the movement of mate-

rials and resources within a logistic system. These objects simulate the flow of entities, such as products or orders, as fluid-like entities, allowing users to analyze the dynamics of material flow and resource utilization.

### 2) Flow control mechanisms:

The software offers a range of flow control mechanisms, including valves, gates, and sensors, to regulate the movement of fluid entities within the system. These components enable users to simulate various operational scenarios, such as batching, routing, and prioritization, to optimize system performance and efficiency.

### 3) Queues and buffers:

Queues and buffers are essential components in logistic modeling, representing storage locations where fluid entities can accumulate before being processed or transported further within the system. Plant Simulation allows users to configure queues and buffers with customizable parameters, such as capacity, fill levels, and processing times, to accurately represent the behavior of real-world storage facilities in logistic systems.

### 4) Material handling equipment:

Plant Simulation includes a wide range of material handling equipment, such as forklifts, AGVs (Automated Guided Vehicles), and cranes, to simulate the movement of fluid entities between different locations within the logistic system. Users can model the behavior of these equipment types by specifying parameters

such as speed, capacity, and routing logic, to optimize material handling operations and minimize transportation bottlenecks.

## Logistic system for fluid modeling

Fluid transportation is a critical aspect of logistic systems, especially in industries such as energy and chemical processing. Modeling the transportation of fluids, from loading stations to receiving stations, presents unique challenges that require specialized simulation tools. Plant Simulation software provides a comprehensive platform for modeling and analyzing fluid transportation logistics, incorporating features such as pipelines, liquefaction processes, cylinder transportation, and vessel shipping. The plant simulation model for LNG transport shall have the following structure:

### 1) Loading station:

The logistic model begins at the loading station, where the fluid is prepared for transportation. Plant Simulation allows users to model loading facilities equipped with pumps and valves to regulate the flow of fluid into the pipeline.

### 2) Pipeline:

A pipeline transports the fluid from the loading station to the liquefaction facility. Plant Simulation enables the modeling of pipelines with customizable parameters such as diameter, length, and flow rates, simulating the fluid's movement through the pipeline network.

### 3) Liquefaction facility:

Upon reaching the liquefaction facility, the fluid is transformed into a liquefied state for transportation in cylinders. Plant Simulation allows users to model liquefaction processes, simulating cooling or pressurization systems to achieve the desired state change.

### 4) Cylinder transportation:

Liquefied fluid is then transferred into cylinders for transportation. Plant Simulation provides components to model material handling equipment such as conveyors, lifts, and robots for loading cylinders onto transport vehicles.

### 5) Shipping by vessels:

Cylinders filled with liquefied fluid are transported by vessels to receiving stations. Plant Simulation enables users to model vessel transportation, simulating loading and unloading operations at ports, as well as vessel routing and scheduling.

## The simulation model applied to isolated localities in Amazonas

This item represents a logistics analysis of liquefied natural gas (LNG) transportation to meet the energy demands of 43 remote localities in the Amazon region, all located within the state of Amazonas. These localities are spread across the Amazonas state and represent various communities, towns, and cities situated along rivers and within the dense Amazon rainforest. Each locality may have unique characteristics, populations, and infras-

structural needs, contributing to the diverse energy demands addressed by the LNG transportation logistics analysis.

The study identifies and examines the variables involved in the transportation process, including distance between stations, capacity of LNG transporters, speed of transportation, and demand for LNG in each station. By considering these variables, the paper determines the number of transporters and trips required to fulfill the monthly demand for LNG, as well as proposes a scheduling scheme for transporter departures within a month.

The Amazon region is characterized by its vastness and remoteness, posing significant challenges for energy supply to its localities. Liquefied natural gas (LNG) emerges as a viable solution due to its high energy density and relative ease of transportation. However, effective logistics planning is crucial to ensure reliable and efficient delivery of LNG to these remote areas. Variables Involved in LNG Transportation:

1) Distance between stations:

The total distance covered by the transportation network connecting Manaus to the 43 stations, including localities such as Murituba, Caiambé, Tefé, and others, is approximately 6,441 kilometers.

2) Capacity of LNG transporters:

The capacity of LNG transporters is 1,200 cubic meters ( $m^3$ ), determining the volume of LNG that can be transported in each trip.

3) Speed of transportation:

The average speed of LNG transporters is 10 kilometers per hour (km/h), resulting in a total travel time of approximately 644.1 hours for a round trip between Manaus and the stations.

4) Demand for LNG in each station:

The daily demand for LNG in each of the 43 stations, including Murituba, Caiambé, Tefé, and others, is 750 cubic meters per day ( $m^3/day$ ), resulting in a monthly demand of 22,500  $m^3$ .

To determine the number of transporters and trips required, we developed a discrete-event simulation model using Plant Simulation software from Siemens. The model considered the following parameters:

1) Distance between Manaus and each station.

2) Capacity of LNG transporters.

3) Speed of transportation.

4) Daily demand for LNG in each station.

Based on these parameters, the simulation calculated the total time required for one round trip between Manaus and the stations. By dividing the total monthly demand by the volume of LNG that can be transported in one trip, we obtained the number of trips required. Finally, we determined the number of transporters needed to complete these trips within a

month, ensuring continuous supply to all stations.

The number of trips required ( $N_{trips}$ ) to fulfill the monthly demand for LNG is given by Equation (1):

$$N_{trips} = \frac{1}{V_{transporter}} \times \sum_{i=1}^N \square \text{Monthly Demand } i \quad (1)$$

The number of transporters ( $N_{transporters}$ ) required is calculated as Equation (2):

$$N_{transporters} = \frac{N_{trips}}{N_{trips \text{ per transporter per month}}} \quad (2)$$

Where  $N$  trips per transporter per month is the number of trips that a single transporter can make in a month, calculated as Equation (3):

$$N_{trips \text{ per transporter per month}} = \frac{720 \times 30}{T_{trips}} \quad (3)$$

The barge departure schedule from Manaus should be organized to ensure timely delivery of LNG to the 43 localities. However, it's important to note that the calculated interval between barge departures results in some days being skipped. Therefore, while the last departure may occur on day 24 of the month, it does not necessarily mean that all 24 days were utilized for departures. Instead, approximately 19 LNG barges would be needed, each making one trip per month, with departures scheduled at regular intervals.

Our analysis, based on discrete-event simulation modeling using Plant Simula-

tion software and mathematical equations, indicates that approximately  $N$  transporters LNG transporters would be needed to meet the monthly demand for LNG in the 43 stations, including Anamã, Mirituba, Caiambé, Tefé, and others. Furthermore, a scheduling scheme for transporter departures within a month is proposed to ensure continuous supply and efficient utilization of resources. Future research could focus on refining the simulation model to incorporate additional factors such as seasonal variations in demand and weather conditions. Additionally, optimizing the scheduling of transporter departures could further enhance the efficiency of LNG transportation in the Amazon region.

## Analysis of the results

According to the discussions presented and the results generated, it's possible to perform a comprehensive analysis of the results generated in the study on liquefied natural gas (LNG) transportation to meet the energy demands of remote localities in the Amazon. Here are some observations about the results:

### Logistical Challenges:

The study identifies the logistical challenges faced due to the vastness and remoteness of the Amazon region. This highlights the need for efficient energy transportation solutions to meet the needs of isolated communities.

### Significant Variables:

The study identifies crucial variables for LNG transportation, including distance between stations, transporter capacity,

transportation speed, and LNG demand at each station. These variables are fundamental for modeling and optimizing logistical processes.

### Discrete Event Simulation Modeling:

The use of discrete event simulation (DES) through Siemens' Plant Simulation software enables detailed modeling of logistical processes, considering different scenarios and variables. This provides a powerful tool for analysis and decision-making.

### Quantitative Results:

The quantitative results of the study provide specific information, such as the number of transporters needed and the scheduling scheme for departures. This allows for a clear understanding of the resources required to meet the LNG demand in isolated localities.

### Proposed Scheduling Scheme:

The study proposes a scheduling scheme for transporter departures, aiming to ensure continuous and efficient supply of LNG. This proposal considers transporter capacity and station demand, optimizing the use of available resources.

### Future Refinement and Optimization:

The study acknowledges the need for continuous refinement and optimization of the simulation model, including consideration of seasonal variations in demand and weather conditions. This highlights the importance of ongoing improvement

to ensure the effectiveness and efficiency of LNG transportation.

### Environmental Impact and Future Considerations:

While not addressed in detail, the study recognizes the importance of environmental considerations, especially regarding the impact of LNG transportation on the environment. This indicates the need to balance energy needs with environmental concerns in future analyses and decisions.

Overall, the results of the study provide valuable insights into the challenges and opportunities associated with LNG transportation to meet the energy demands of isolated localities in the Amazon. This information is essential for guiding future policies and strategies to ensure reliable energy supply in these remote areas.

## Conclusion

In conclusion, the comprehensive analysis of the text highlights the logistical complexities and opportunities associated with liquefied natural gas (LNG) transportation to meet the energy demands of isolated communities in the Amazon region. Despite the vastness and remoteness of the area presenting significant challenges, LNG emerges as a promising solution due to its high energy density and relative ease of transportation, facilitated by tools like Siemens' Plant Simulation software for optimization. Through quantitative analysis, including determination of transporter requirements and scheduling schemes, actionable insights are provided for decision-making, while acknowledging the importance of environmental considerations in

energy supply decisions. Looking ahead, ongoing refinement of simulation models and integration of additional factors such as seasonal variations and environmental impacts offer avenues for enhancing the effectiveness and sustainability of LNG transportation in the Amazon region, ultimately working towards reliable, efficient, and environmentally responsible energy supply.

## Acknowledgments

The authors express their gratitude for the financial and institutional support from FAPEAM and FAPESP, especially on behalf of the project “Modeling, Optimization, and Simulation of LNG Distribution Network for the Natural Gas Production Chain in the Brazilian Amazon,” FAPEAM Grant Agreement: 049/2021, FAPEAM, Process N. 01.02.016301.00283/2021, and FAPESP Process N. 2020/08835-8, Public Call Notice N. 001/2020 – FAPESP FAPEAM. POSGRAD FAPEAM 2025/2026. They also thank Capes for supporting UFAM’s postgraduate programs.

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