Opportunities and Challenges of Natural Gas and Liquefied Natural Gas in Brazil

Edmilson Moutinho dos Santos
Drielli Peyerl
Anna Luisa Abreu Netto
Editors

LETRA CAPITAL

The organization of the book "Opportunities and Challenges of Natural Gas and Liquefied Natural Gas in Brazil" presents several topics related to this energy source, whose perspective of use is expanding in Brazil. This book is the result of the knowledge acquired, during December 2015 to November 2020, by researchers and collaborators of Project 26, entitled "Evaluation of small LNG and CNG supply options for transportation to off-grid locations; and planning expansion and operation of multimodal integrated networks", developed at the Research Centre for Gas Innovation (RCGI), which is based at the University of São Paulo.

The reader will find in this book subjects that surround the theme of natural gas, such as: logistics, small-scale transportation, geopolitical relations, technological characterization, regulation, and energy transition, among others.

The purpose of this production is to disseminate the research results of numerous researchers interested in academic production related to the opportunities and challenges of natural gas and liquefied natural gas in Brazil, as the book's title points out. Thus, seeking to address this title, the chapters of the book present several difficulties to be overcome and paths to be traveled, inserting or not natural gas as an element of energy transition in Brazil.

Thus, after extensive research, collection and analysis of various data, the book provides a new look at the use of NG and LNG in the country. This discussion is contained within the lines of this book and it is up to readers to take advantage of all this data and adopt their opinion, thus breaking paradigms embedded in the use of natural gas in the country.

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LETRA CAPITAL EDITORA
Telefax: (21) 3553-2236/2215-3781
letracapital@letracapital.com.br

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Contents

Preface

A timely and welcome contribution

The shale revolution in the US and the massification of the use of Liquefied Natural Gas (LNG) have transformed the reality of natural gas in the last few years. Transportation by ships has become a flexible substitute for large pipelines. The increase in supply has driven prices down and usage up. Abundant LNG has become a price reference in different markets. The transition to a lower-carbon economy was already driving the consumption of gas, the so-called transition fuel, when the COVID-19 pandemic emerged. Consequently, behavioral changes could be accelerated. Large companies in the sector have anticipated adjustments in strategy and are seeking the status of carbon neutral emitters by 2050. In this scenario, natural gas plays a central role.

The phenomenon of gas appreciation had also arrived in Brazil. Petrobras invested over decades to develop the market. And gas began to gain relevance in the Brazilian energy mix from the construction of the Bolivia-Brazil gas pipeline in the 1990s. However, the boundary conditions changed with the end of the monopoly. Now, it is necessary to have an open and competitive market in which many companies can invest and compete.

As a result, in the recent past a series of energy policy and regulatory actions have been adopted. In 2018, the National Agency of Petroleum, Natural Gas, and Biofuels (ANP), more than twenty years after the end of the state oil monopoly, sent the Administrative Council for Economic Defense (CADE) a technical note suggesting a set of measures to encourage competition in the natural gas sector. It also opened a series of Public Takes of Contribution (TPCs), resuming the discussion on the regulation applicable to natural gas.

In December of that year, the government published a decree with the same objective. In 2019, the National Energy Policy Council (CNPE) approved a resolution that establishes guidelines for improving current energy policies, promoting free competition and modernization of the Brazilian gas market. It had previously established the Committee for the Promotion of Competition in the Natural Gas Market in Brazil. The ANP approved additional actions. The CNPE resolutions and the measures adopted by the ANP faced, in a structured manner, for the first time since the monopoly was extinguished in Brazil, the reality of the gas market in which Petrobras exercised strong dominance.

These initiatives culminated in Petrobras signing a Cease and Desist Agreement (TCC) with CADE. As a result of this agreement, Petrobras is adopting a series of measures that are enabling the opening of the sector.

To complete the consolidation process of a new natural gas market in Brazil, the new Gas Law was approved by the House of Representatives and is soon to be considered by the Federal Senate.

In this scenario, a publication dealing with the Opportunities and Challenges of Natural Gas and Liquefied Natural Gas in Brazil is timely and welcome. The ideas presented here will be part of the necessary debate on the future of the sector in Brazil.

Décio Oddone
Rio de Janeiro, September, 2020.

Chapter I

Introductory remarks on the opportunities and challenges of natural gas and liquefied natural gas in Brazil

Drielli Peyerl
Anna Luisa Abreu Netto
Edmilson Moutinho dos Santos

In 1922, a new fossil fuel was discovered in Brazilian territory: natural gas (NG). However, the lack of technology, qualified personnel and the difficulty of inserting the use of gas into the energy mix caused the absence of investment in this sector for a long time outside the search and research for oil (PEYERL, 2019). Only in the 1960s did Brazil inaugurate a new phase, both in the process of industrialization and in investment in the continental platform through Petrobras, a state company established in 1953. The discovery of the first offshore well in the Guaricema (Sergipe) field, in 1968, and the first field with commercial volume in Garoupa (Campos Basin), in 1974, led Brazil to rethink its potential for using oil and natural gas (MOUTINHO DOS SANTOS; PEYERL, 2019).

On the international level, the global crisis generated by the two oil crises of the 1970s mainly affected economies characterized by dependence on imported foreign resources. These crises affected Brazil's energy security and forced fuel rationing for a certain period (LIMA, 1977; YERGIN, 2014). In this period, oil became an important instrument of exchange in international political relations (LIMA, 1977). Despite the crisis, NG continued to be restricted to a secondary role, due to efforts almost entirely focused on the pursuit and exploration of oil in the onshore and mainly offshore areas of the country (MOUTINHO DOS SANTOS; PEYERL, 2019).

Since the 1980s, interest in the use of NG has gradually increased (MOUTINHO DOS SANTOS, 2002). One of the main examples is the National Plan for Natural Gas (*Plano Nacional do Gás Natural*) known as PLANGÁS, an initiative configured by the Ministry of Mines and Energy. The PLANGÁS, launched in 1987 and implemented in 1989, had as its main objective the use of NG as a substitute for diesel in the collective transportation of passengers and in the transportation of cargo (DIÁRIO OFICIAL DA UNIÃO, 1989). PLANGÁS, with secondary goals, directly impacted the public transportation sector such as cabs and buses, which generated effects in the reduction of vehicular emission levels as a result of its use in substitution of diesel (DIÁRIO OFICIAL DA UNIÃO, 1989). The first initiative formed by PLANGÁS did not obtain conclusive results (FGV, 2014).

The second phase of the PLANGÁS began in 1991, with broader objectives than the first phase, aimed at the production, distribution, and use of NG, with a focus on the transportation sector, but also aimed at expanding the use of NG to other sectors (DIÁRIO OFICIAL DA UNIÃO, 1991). One of the focuses of this second phase was to expand the participation of NG from 2% to 12% by the end of 2010 (FGV, 2014). Phase two of the PLANGÁS also made Petrobras more active with regard to NG, for distribution purposes, and implementation of gas pipelines with neighboring countries (DIÁRIO OFICIAL DA UNIÃO, 1991).

In 2006, Petrobras launched another PLANGÁS, called Plan for the Anticipation of Natural Gas Production (Plano de Antecipação da Produção de Gás Natural), “contemplating projects in exploration and production, processing and transportation of natural gas, with the objective of increasing the supply of natural gas to 55 million cubic meters per day (MMm^3/day) by the end of 2010” (FGV, 2014, p. 8). The plan was directly associated to the expansion of its facilities and gas processing capacity (DIÁRIO OFICIAL DA UNIÃO, 2007).

As a result of this historical process of expanding the participation of NG in the Brazilian energy mix, the expansion of the use of NG has focused on two important milestones that will be addressed in this book: the construction of the Bolivia-Brazil Gas Pipeline (GASBOL), having started its operation in 1999, and the discovery of the reserves in the pre-salt, which began to be explored in 2011. The construction of GASBOL, starting in 1996, was the result of years of negotiation between Brazil and Bolivia, resulting in NG supply contracts, which guaranteed a secure energy supply to Brazil for over 20 years (PIEDRAS, 2008). In turn, the exploitation of the pre-salt reserves has gradually increased the national production of NG, but still faces several challenges to make NG economically more attractive, such as the difficulty of flow and the presence of large concentrations of CO_2 (MOUTINHO DOS SANTOS; PEYERL, 2019).

Although there has been a significant expansion in the use of NG in the last 40 years, Brazil does not have a culture of NG use, with the exception of some states such as São Paulo and Rio de Janeiro (MOUTINHO DOS SANTOS et al., 2007). The question of investments in infrastructure, such as the construction of gas pipelines, and the lack of regulation directed at this sector make it difficult to use NG in this energy transition process, which Brazil and the world have been experiencing.

NG is currently seen as a source of energy for the transition from oil to renewable energies due to the low emission of greenhouse gases (GHG) in relation to other fossil fuels. Since the 1980s, its insertion in the Brazilian energy mix and the debate on its use have been the subject of numerous discussions in the country, including economic and political ones. According to Moutinho dos Santos (2002, p. 93 and 94), NG "has a significant environmental advantage in terms of the greenhouse effect problem. In substitution to the other fossil fuels, the gas provokes a great reduction of CO_2 emissions." In other words, NG is a strategic alternative for the energy transition for two reasons: its abundance, mainly with the discovery of pre-salt (2006), and environmental advantages.

The use of NG as an element for the energy transition has been the target of public policy in several countries, such as Japan (METI, 2018) and the Netherlands (KERN; SMITH, 2008). Although there are international agreements for the reduction of GHG emissions, fossil fuels will remain predominant primary energy sources for a long time, and among them, NG will have the highest annual growth rate, that of 2% (MOUTINHO DOS SANTOS et al., 2007). Therefore, NG will continue its path of growing participation in the global energy mix, also as a substitute for more GHG emitting fossil fuels like coal and oil. It should also be noted that in 1980 the use of NG represented 17% and it is expected that global energy consumption and its participation will reach 22.6% in 2030 (MOUTINHO DOS SANTOS et al., 2007).

Despite the discoveries of large NG reserves in recent years in the Southeast, Brazil still needs strong investments in the transportation sector of this energy source, such as the construction of gas pipelines. Moreover, “natural gas, unlike oil, is a safer product in terms of guaranteeing international commercialization. The fact that its transportation requires the construction of gas pipelines creates firm commitments between the supplier and the consumer” (GOLDEMBERG; MOREIRA, 2005, p. 224). In the case of gas pipelines for bilateral relations between countries, we have as examples, in addition to the Bolivia-Brazil pipeline, the pipeline connecting Canada to the United States and the pipeline connecting Russia to Germany (BP, 2020).

In turn, the transportation of NG in its liquefied form has transformed the international NG market scenario. The international transportation of liquefied natural gas (LNG) is mainly carried out by ships, thus increasing export options to producing countries and enabling the entry of the energy source in countries that do not have NG reserves or have no neighboring producing countries (FGV, 2014). Thus, the export of NG from producing countries to consuming countries occurs mainly in two ways: through the construction of gas pipelines and through transportation via LNG, as mentioned above.

Over the past twenty-five years, LNG has played a central role as one of the elements ensuring security of energy supply, with the lowest and cleanest GHG emissions among fossil sources (WOOD, 2012). Currently, LNG trade has grown significantly globally, mainly due to the supply of NG and its liquefaction process linked to the development of new technologies. Some Latin American countries, such as Argentina, Chile, and Brazil, have been investing in LNG infrastructure, bypassing some aspects that involve dependence on Bolivian NG, and aiming at competitive offers of natural gas imported from other countries (CNO, 2016).

Besides its importance to the international market, LNG can also be an alternative for the internal flow of NG, mainly to supply locations that do not have a pipeline structure. In the Brazilian case, the focus of this book, the announcement of the discovery of the pre-salt opened a new space for the insertion of NG in the Brazilian market, although still surrounded by political and regulatory problems. In this context, LNG in Brazil could play an important and significant role as an alternative mainly for supplying this gas produced in the pre-salt to the domestic market, which includes thermal power plants and the industrial market, still adding the option of transportation fuel, with savings of 20% to the final consumer (CONFEDERATION, 2016; MOUETTE et al. 2019).

LNG transportation by land can be done by trucks or trains, with the use, for example, of containers (CNI, 2016). Small-scale transportation of LNG by containers can bring significant logistical flexibility to LNG, allowing the use of multi-modal systems to supply consumers. In the case of LNG transportation by truck, using the road modality, it is possible to flow the gas to numerous destinations, facilitating the monetization of LNG. On the other hand, the transportation of LNG by trains, with Japan as the first country to develop the technology, has an advantage over the road modality in long distances, and can be an interesting opportunity to use the idle rail structure that already exists in the country (FGV, 2014; CNI, 2016).

However, LNG in Brazil faces some problems related to physical and regulatory barriers, in which the control of gas pipelines and terminals by Petrobras stands out. In 2016, actions under the Gas for Growth initiative (*Gás para Crescer*), coordinated by the Ministry of Mines and Energy, together with the Energy Research Company (*Empresa de Pesquisa Energética* - EPE) and the National Agency of Petroleum, Natural Gas, and Biofuels (*Agência Nacional do Petróleo, Gás Natural e Biocombustíveis* - ANP), aimed to propose concrete measures to improve the regulatory framework of the NG sector, intending to reduce Petrobras' participation in the sector (GAS ..., 2016). In this way, the Brazilian LNG market may be marked, in the next few years, by the diversification of players and the decentralization of fuel supply. With this, LNG may have the function of helping in the introduction and diffusion of NG in this market (MOUTINHO DOS SANTOS, 2002; MOUTINHO DOS SANTOS et al., 2007).

Thus, this book aims to elucidate the opportunities and challenges of the insertion of natural gas and liquefied gas in Brazil, unfolding them through an in-depth analysis of some topics that surround the theme, such as: energy transition, logistics, small-scale transportation, geopolitical relations, technological characterization, and regulation, among others.

Each chapter of this book presents aspects that encompass the role of NG in Brazil, regarding the following topics: the importance of natural gas for Brazil's current energy transition; the process of decentralization of energy generation associated with the use of NG; discussions on the possible renewal of the Bolivian natural gas supply contract for Brazil; characterization of compressed natural gas and liquefied natural gas on small scales; the small-scale supply of natural gas through the railroad network; and finally, a vision of the regulatory process of LNG in Brazil, focusing on the Federal Supreme Court (STF) decision on the Gemini project.

All the themes mentioned above will be thought through and analyzed, with examples in maps and data collection through extensive research, which offers a new look at the use of NG and LNG in the country. This discussion is contained in the lines below, and it is up to the readers to take advantage of all this data and adopt their own opinions, thus breaking paradigms embedded in the use of natural gas in the country.

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Chapter II

Natural gas associated with the energy transition and the decentralization of energy generation in Brazil

Mariana Oliveira Barbosa
Drielli Peyerl

1. Introduction

Natural gas (NG) is a mixture of several hydrocarbons that includes methane (70-90%), ethane, propane, butane, pentane, and carbon dioxide, nitrogen, and hydrogen sulfide. This composition may vary due to the NG reservoir condition. This fossil fuel origin is the decomposition of buried organic matter, which is stored in the pores of the reservoirs' rocks and trapped by cap rocks that do not permit the hydrocarbon transit from reservoir to surface. NG presents a wide range of uses in the different economic sectors – industrial, residential, commercial, transportation – to compose processes as raw material or as an energy source.

Some advantages of NG utilization are: the lowest environmental impact among fossil fuels, i.e., almost zero particulate and low CO_2 emissions; in many cases, it may present an economic advantage compared to the price of other fuels; it does not require storage places; and there is great energy security throughout its continuous distribution. Due to these factors, there is a growing NG demand in the world, which has intensified in recent years due to the possibility of transporting this fuel in the liquid state (BP, 2019a). Another reason for the growing demand is the concerns with climate change and the use of fuels with lower concentration of emissions (VAN FOREEST, 2010).

The use of NG corresponded to about 12.5% of the energy supply in Brazil in 2018 (EPE, 2019). This amount is mainly absorbed by the industrial and power sectors, which correspond to 47 and 37% of total NG supply, respectively. In industry, NG works as raw material and as an energy source for thermal processes. The most consuming areas are steel, ceramics, and food. On the other hand, the demand for electricity generation presents a seasonality. In the second semester, there are periods of rainfall absence in water reservoirs – the main source of the electricity mix in the country. Therefore, there is a need to mobilize thermal plants, with those based on NG being the first in demand due to the order of priorities for greater efficiency of the financial system. The other sectors (automotive, residential, and commercial) represent only 11% of the total consumption because of the lack in infrastructure and greater competitiveness of other fuels (MME, 2019).

Thus, the growing production and demand for NG in Brazil have shown that this fossil fuel will tend to have a greater participation within the energy mix in the following years. This chapter aims to explore the paths taken for the use and insertion of natural gas and how the technologies and availability of resources have shaped its process in the Brazilian energy mix. In addition, this chapter shows the current discussion about the role of NG within energy transition and decentralization in the generation of electricity.

2. Brief history of natural gas in Brazil

The beginning of gas consumption in Brazil was in 1851 in the city of Rio de Janeiro (RJ). Baron of Mauá (1813-1889) - an important name in economy and industrialization in Brazil during the Imperial period (1822-1889) – signed a contract for gas supply for public lighting. In addition, this contract established the construction of a plant for the production of gas from coal and pipelines. In 1854, the first company in the sector was created: The Gas Lighting Company (MORAES, 2003).

In 1865, an English company purchased the Gas Lighting Company and modified the company's name to Rio de Janeiro Gas Company Limited. In 1876, gas distribution services were passed on to the Belgian company *Société Anonyme du Gaz* (SAG) and, in 1910, the Rio de Janeiro Tramway Light and Power Company came to control the distributor's capital. During this period, there had been an important exchange in the raw material for gas production, when chemical processes with naphtha took the place of coal. In May 1969, the Guanabara State Gas Company (CEG – GB) was founded, which was renamed the State Gas Company of Rio de Janeiro (CEG) in 1974, when the State of Guanabara was extinguished.

In the state of São Paulo, the use of gas was associated mainly with the development of the city of São Paulo due to the growing coffee trade around the end of the 19th century and the beginning of industrialization through private initiatives. In this context, public services showed a growing trend with the use of gas in sectors such as lighting, transportation, and home supply (BARBOSA et al., 2008).

In 1872, the first coal gasification plant was inaugurated in the city of São Paulo by the London *San Paulo Gas Company Ltda*, which had become responsible for the city's public lighting. This type of gas production process starts with the coal burning followed by steam release and purification (tar removal). The gas manufactured from coal was sent to an infrastructure known as a gasometer to maintain the pressure in distribution pipelines (BARBOSA et al., 2008). Nonetheless, popular claims, governmental decisions, and a rise in coal prices due to World War I (1914-1918) impacted the public lighting sector and the electricity began its domain on that. For this reason, the San Paulo Gas Company modified its strategy market by targeting gas supply in the residential sector (BARBOSA et al., 2008).

João Luiz Máximo da Silva - the author of the book "Cozinha Modelo" - identifies the main changes in gas utilization in residential stoves once firewood started to be scarcer near the city of São Paulo with the beginning of urbanization (ABRAHÃO, 2009). In 1912, the São Paulo Tramway Light and Power Company Limited (Light) incorporated to gas distributor and then advertised new gas stove technologies. The focus was on high and middle income families, since firewood was still economically competitive (ABRAHÃO, 2009; BARBOSA et al., 2008).

The San Paulo Gas Company - which is currently known as COMGAS (Companhia de Gás de São Paulo) - had distributed gas derived from naphtha, olive oil, carbonated hydrogen gas, coal, and others from the beginning of distribution until 1988 (COMGAS, 2014; MORAES, 2003). Since 1988, the gas from COMGAS has arisen from geological reservoir exploitation.

However, the NG Discovery in Brazil occurred before this, in 1922, in the city of Marechal Mallet, Paraná due to the search for oil in Brazilian territory (PEYERL, 2019). Moreover, only the discovery and exploration of O&G in the Reconcavo Baiano, Bahia, stimulated the beginning of the commercial use of NG in Brazil in 1939 (MORAES, 2003). The oil crisis in the 1970s and new NG exploration reserves (e.g. Campos Basin) triggered Brazil's concrete investment for a greater share of NG in its energy mix (EPE, 2019).

Another source that stimulated this upward tendency was the start of NG supply from Bolivia to Brazil. Both countries agreed to build a gas pipeline and trade the NG supply in 1996[1]. In 1999, this pipeline operation began with the following objectives: the stimulus to an industrialization of inland areas of Brazil; the mitigation of environmental impacts (mainly with the replacement of high level pollution fuels by NG); the supply of NG power plants; and the diversification of the Bolivian NG consumer market (GOSMANN, 2011; ROMITELLI, 2000).

In 2006, the announcement of the discovery of geological pre-salt on the southeastern coast of Brazil and the existence of large amounts of natural gas in this area modified the direction and participation of NG in several sectors in Brazil. However, its exploration is still considered a challenge because it presents some limitations, such as the distance from the coast and high concentrations of carbon dioxide (NUNES et al., 2017).

According to the National Energy Balance, NG corresponded to 12.5% of the total domestic energy supply in Brazil in 2018 (EPE, 2019). However, an increasing trend in total NG consumption and its participation in the Brazilian energy mix has been seen since the 1970s. In 1970, NG consumption was over 100 TEP and represented less than 1% of the energy mix, and in 2018, this value had grown to 32,616 TEP, which corresponded to 12% of the energy consumed[2] (EPE, 2019). As shown in Figure 1, the increasing consumption of NG in the period from 1970 to 2018 is sustained by national production and imported gas. However, imported gas only became fundamental to the country's supply in 1999 (See Figure 1).

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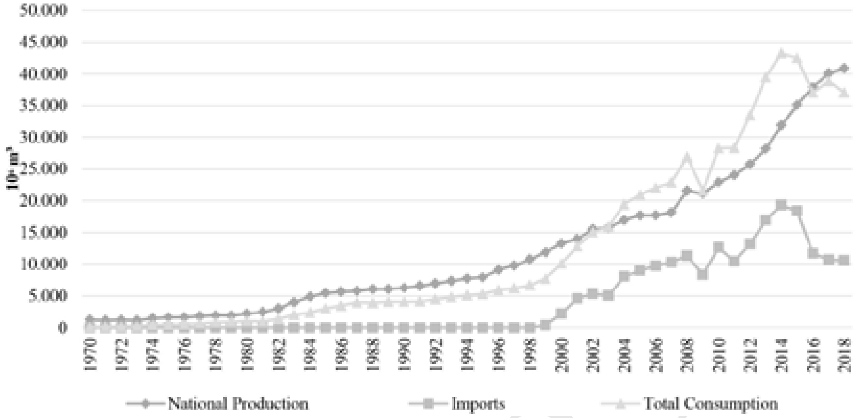
[1] Brazil-Bolivia contract for NG supply issues is discussed in detail in Chapter IV.

[2] The conversion factor from m^3 to TEP to dry Natural Gas taken from "Table VIII.10 - Conversion Factors for average Tep" of the National Energy Balance, 2019.

Figure 1: NG total consumption, national production and imports (by pipeline or LNG) between 1970 and 2018

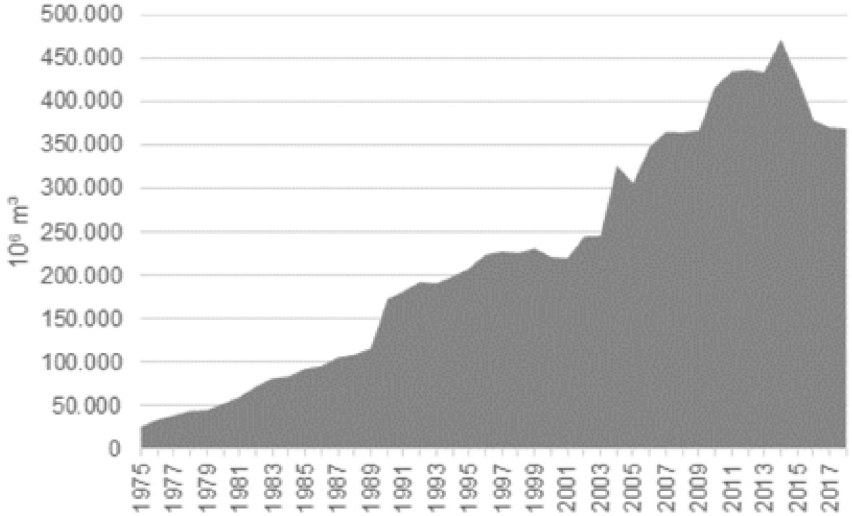


Source: Elaborated by authors based on EPE (2019a).

There are three periods of the growth of NG consumption in Brazil. The first moment refers to the early 1980s, when exploration of natural gas from the Campos Basin began, as mentioned earlier. The second period is related to the beginning of the NG importation from the Bolivia-Brazil gas pipeline in 1999. Finally, the last growth impulse of NG consumption and relative proportion in the Brazilian energy mix occurred in 2011, when the exploration of the Brazilian geological pre-salt and the operation of the flow pipelines began.

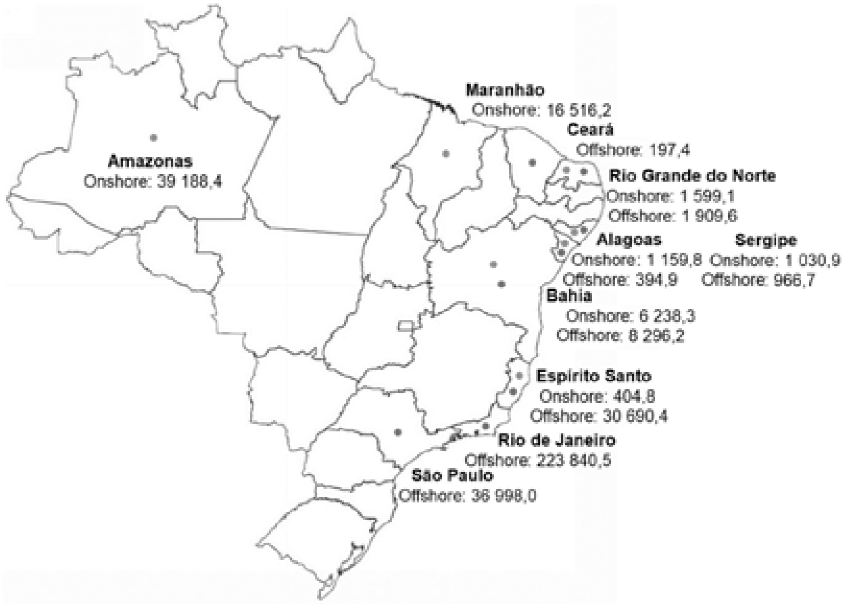
In addition, the increase in national production had been directly linked to the increase in the number of proven reserves during the period of 1975 to 2018, as noted in the following graph (Figure 2). In 2017, the Brazilian states that had the largest proven reserves were Rio de Janeiro (offshore), São Paulo (offshore), Amazonas (onshore), Espírito Santo (offshore), and Maranhão (onshore). The same states cited also have the largest production (Figure 3) (ANP, 2018). In June 2019, national media channels announced that Petrobras had discovered large reservoirs of natural gas between the states of Sergipe and Alagoas with an estimated production of 20 million cubic meters per day.

Figure 2: Proven reserves of natural gas between 1975 and 2018



Source: Elaborated by the authors with data from the history of the National Energy Balance available in the digital collection of the Energy Research Company (EPE).

Figure 3: Proven reserves of natural gas in 2017 by state in Brazil



Source: Elaborated by authors based on ANP (2018).

Note: The lightest indicators represent the offshore proven reserves and the darkest indicators represent the onshore proven reserves. The figure represents the amounts of NG (millions of m³) and their locations (onshore or offshore) by state.

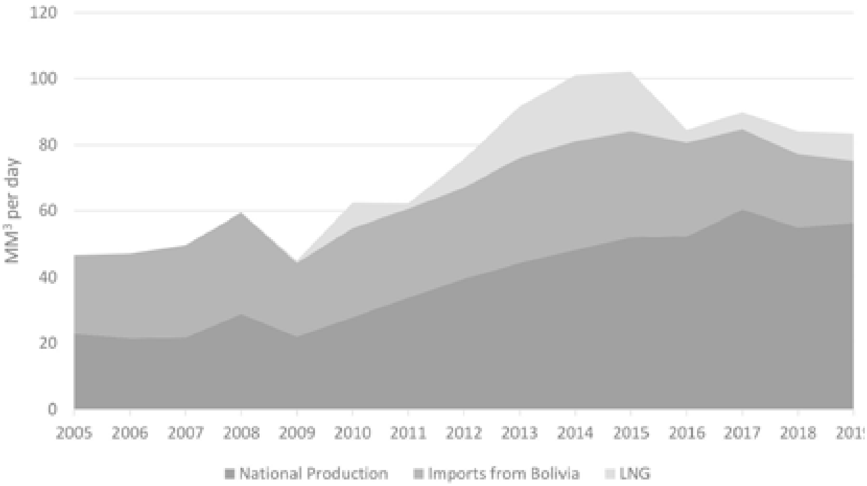
However, the transportation network is a limiting factor for the expansion of NG in Brazil, which is reduced compared to the great potential that could be achieved (Figure 4). According to Moraes, Brazil did not develop a robust natural gas transportation network because it was not thought of along with the industrialization phases (MORAES, 2003). In addition, other reasons are the low public interest in this issue and a great price competitiveness of other fuels, especially electricity. In 2019, the transportation pipelines had an extension of 9409.0 km (MME, 2019).

Figure 4: Natural gas transportation infrastructure in Brazil in 2020

Source: Elaborated by authors.
Note: This figure shows the transportation pipelines in operation and in planning. In addition, it presents Natural Gas processing units (according to recent data from the ANP Statistical Yearbook, 2018 the number is 14) and liquefied natural gas terminals (number is 4).

From this context, the transportation of small and medium scale liquefied natural gas (LNG) by trucks and trains has become a relevant NG supply source in the country. This is an option, unlike pipelines, without high amortized costs, although it is associated with higher operating costs. The following figure presents the role of LNG in the total supply of NG in the country between 2007 and 2018. It has become a fundamental portion for the supply of national demand since 2011, using the three LNG terminals on the Brazilian coast in operation until 2018 (See Figure 5).

Figure 5: Importance of imported Liquefied Natural Gas (lighter tone) to supply the total national supply during the period of 2007 to 2018



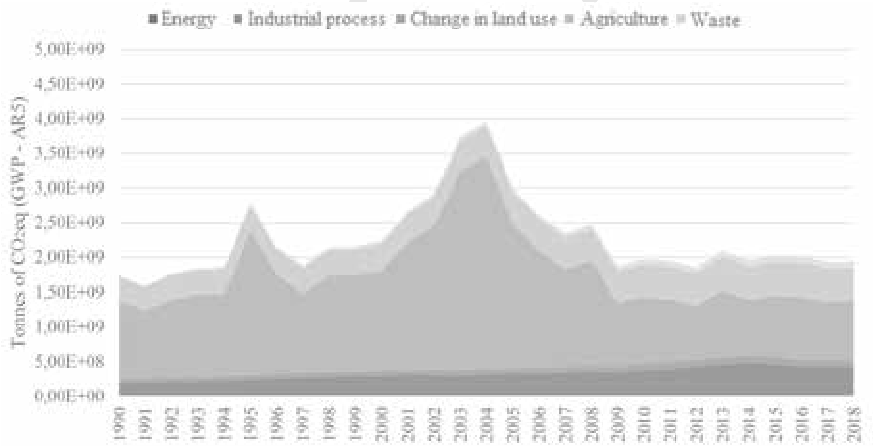
Source: Elaborated by the authors based on the data of the Monthly Bulletins for Monitoring the Natural Gas Industry of the period already mentioned produced by the Ministry of Mines and Energy (MME).

3. The role of NG in Brazilian energy transition

A large percentage of renewable resources (about 43%) makes up the Brazilian energy mix (EPE, 2019), differently to what happens on the world stage, where the percentage of fossil fuels reaches 81.0% (ENERDATA, 2018; IEA, 2019). However, Brazil remains one of the fifteen countries that emit the most greenhouse gases (GHG) (RITCHIE; ROSER, 2017). Moreover, this large representation in relation to carbon dioxide and equivalent gas emissions goes against the seventeen sustainable development goals (SDG) set by the United Nations (UN), which are expected to be implemented by all countries by 2030. In addition, it is against the climate change agreements that have been signed over the past few years since the establishment of the Intergovernmental Panel on Climate Change (IPCC), in 1988.

Unlike most countries in the world, the influence of change in land use (deforestation, for example) is much more relevant to total emissions than any other source in Brazil (SEEG, 2019). However, this contribution has shown a downward trend since 2005 (see Figure 6). Furthermore, the other sources (agriculture, energy, industrial processes, and waste) have had a growth rate of CO_2 emissions in recent years, especially in the energy sector (transportation and electricity generation, among others).

Figure 6: Contribution of different sources in total equivalent carbon dioxide emissions (Mt) in Brazil between 1990 and 2017



Source: Elaborated by the authors based on SEEG (2018).

In light of the arising impacts of climate change, the importance of measures to reduce GHG emissions in different sectors (industrial, transportation, power generation) is evident. The energy transition to a matrix that emits fewer GHGs is one of the measures that lead to climate change mitigation and this is a global trend.

The concept of energy transition involves the change from an economic, social, and environmental system dependent on one or a series of energy sources and technologies to another

(FOUQUET; PEARSON, 2012). This process is associated with (i) the reduction of GHGs emitted by the burning of fossil fuels and the effects of climate change, (ii) improvement of the population's health due to the reduction of air pollution, and (iii) energy security to ensure the growing demands for energy in different sectors of the economy.

The definitions mentioned above may have different interpretations according to other authors. O'Connor defines energy transition as a set of changes in a society's energy consumption, the impacts on resource availability, and the entire energy supply chain of a society (O'CONNOR, 2010).

This process can vary in speed depending on the level (world, national, regional) and intensity of the proposed and necessary changes (SOVACOOL, 2016). Overall, the transition covers a large number of changes in different aspects such as changing energy primary sources, technologies and their barriers, regulatory policies, pricing and tariffs, and environmental impacts (O'CONNOR, 2010).

Another important point on energy transition is associated with the motivations that lead to a change in behavior of the use of primary energy sources. In certain moments in history, the scarcity of fuel was the predominant motive for a transition, such as in a greater use of ethanol beginning in 1975 through the Proálcool program. This public policy occurred in response to the oil crisis of 1973 and the high prices that Brazil had been paying for fuel, since it was importing 80% of the oil consumed (LEITE; LEAL, 2007). Sovacool also cites the development and use of flex cars by Brazilians as an energy transition process, which was motivated by reducing taxes and fees on the price of alcohol from the Brazilian government (SOVACOOL, 2016).

Unlike the reasons already mentioned, one of the major drivers of the change in the global energy mix has been to achieve a low-carbon economy according to global agreements and climate concerns (GIELEN et al., 2019; KERN; SMITH, 2008; SHELL, 2018). Several countries have awareness about the decrease in the GHG emissions since these were on the agendas for meetings of different nations, such as the Paris Agreement (UNFCCC, 2015).

With the need to reduce GHG emissions, NG can be understood as an element of Brazilian energy transition. NG emits less GHG than oil and coal, produces the same amount of energy, contributes to the mitigation of environmental issues, and also provides energy and economic security for the country. In some Brazilian regions, the cultural factor also contributes to the use of this source as an element of transition (MOUTINHO DOS SANTOS, 2008).

Moreover, NG has acted as a source of electrical production that ensures supply, since all renewable sources present intermittence as a negative factor to their uses. In other words, natural gas safely allows a greater entry of renewable sources into the various economic sectors.

4. Decentralization in power generation

The decentralization of an energy system involves its autonomy of information management, decisions, and independent implementation of other systems (PALENSKY, 2001 *apud* ALANNE; SAARI, 2006). Therefore, the supply concentrates on small generation plants geographically distributed closer to the consumption centers instead of large power plants. The responsibilities move from a central location to the various regions, as well as human resource needs, development of local technology, automation for the operation of this system, and issues related to the financing of these facilities. The systems present levels of decentralization since, in general, they usually occur in parallel to a centralized system (ALANNE; SAARI, 2006).

Distributed Generation (DG) has some divergences in its definition, especially in aspects of installed capacity, the location of the generation structure, and where this amount of energy generated will be delivered (transmission lines, distribution, or directly to the consumer), among others aspects (SEVERINO; CAMARGO; OLIVEIRA, 2014). Thus, the generic definition proposed by Ackermann is "Distributed generation is an electrical power source connected directly to distribution lines or alongside the consumer" (ACKERMANN; ANDERSSON; SÖDER, 2001, p. 203).

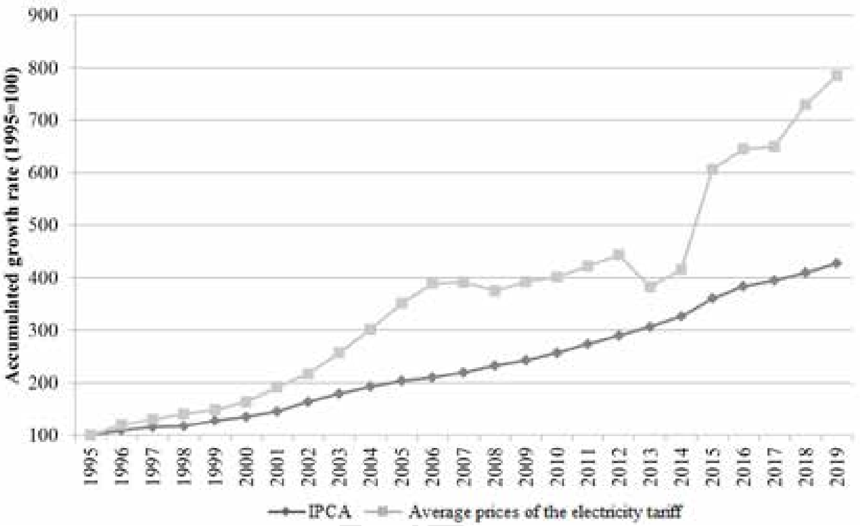
DG requires lower costs for high-voltage electricity transmission lines, while generation centers connected to distribution networks or the consumer become timelier. Therefore, the complexity of the transmission lines will be reduced, as well as the centralization of technical, political, and economic decisions in large centers (DI SILVESTRE et al., 2018).

Some other advantages of this format are: reduction of losses occurred during transmission processes; increased use of renewable resources or cleaner fossil fuels (e.g. natural gas) for power generation; consequently, reduction in GHG emissions into the atmosphere; better management in production to meet local needs, including providing energy security for companies that manage their own energy with small production stations; and stimulus for the development and dissemination of the concept of energy efficiency in the population to drive more rational attitudes of all (WADE, 2006). Finally, it also allows isolated communities to have access to electricity.

Distributed generation is also an important mechanism for supplying electricity at a time when its consumption has grown. The growth of electricity production in the world during the period of 2007 to 2017 was 2.5% per year. In Brazil, the rate in the same period already mentioned is 2.8% (BP, 2019b). The Ten-Year Energy Plan for 2029 estimates an increase in 2029 compared to 2019, from 18% of the 263 MToe consumed in 2019 to 20.3% of the 336 MToe expected for consumption in 2029, mainly due to the resumption of industry and the commercial sector (EPE, 2019a).

Finally, the graph below presents the growth of average prices of the electricity tariff at the national level and the growth of IPCA (Consumer Price Index) values - which is one of the most representative indicators of inflation – in the last years (See Figure 7). While the IPCA rate had a growth of 6.2% per year during the period of 1995 to 2019, the growth rate of the average electricity tariff had been approximately 9.0% per year.

Figure 7: Relationship between the growth rates of the IPCA (inflation) and the average electricity tariff sold in the country with the associated taxes



Source: Elaborated by the authors based on ANEEL (2019a), IBGE (2020) e Sousa (2005).

In 2013, there was a drop in the price of the tariff due to a federal government interim measure. It aimed the electricity tariff reduction at the final consumer, a greater guarantee to access and greater competitiveness of the productive sector helping to improve the economy. Therefore, two charges that make up the electricity tariff were eliminated: CCC (Fuel Consumption Account) that subsidized electricity generation in isolated systems, and RGR (General Reversal Reserve), which assisted in the reversal of assets to the granting power at the end of concession contracts and in expansion and improvement programs of the electric system. There was also a reduction in the tax known as the Energy Development Account (CDE) that finances the development of the energy sector in different states, access to energy to those of low income, and development of many technologies (DIEESE, 2015).

In 2014, disturbances occurred in the supplies of reservoirs used by Brazilian hydroelectric plants, especially in state of São Paulo. Therefore, the National Electric System Operator (ONS) limited the dispatch of hydroelectric plants as a precaution to water reservoirs and obtained electricity from thermal power plants, which are more expensive compared to hydroelectric plants.

Finally, in 2015 there was a great increase in the electricity tariff, since the federal government allowed the additional costs of generating electricity through the thermal power plants to be passed on to the final consumer with the adoption of the tariff flag policy and a tariff review to restore the economic and financial order of electricity distributors. Consequently, it is possible to notice an indirect potential incentive of decentralization practices since the electricity tariff has grown greater than IPCA.

In June 2019, the micro and minigeneration distributed reached the level of 1GW of installed power. About 87% of these are associated with photovoltaic panels and 8% with hydraulic generating plants (CGHs) (ANEEL, 2019b). Micro and minigeneration are facilities where the customer uses small capacity generators in their consumer unit. By definition, distributed microgeneration is the electric power generating plant whose installed power is up to 75kW and includes generation by renewable sources and qualified cogeneration (defined by normative resolution in ANEEL No. 235 of 2006) and distributed minigeneration are installations where the installed power is greater than 75 kW and less than or equal to 3MW (when the source is water) or 5MW (when the source is renewable or from qualified cogeneration) (ANEEL, 2017).

According to the Energy Research Company (EPE, 2019a), the advantages that will assist investments in distributed generation for the coming years are the decrease in the cost of technologies and the regulation of this sector, in addition to the already exposed factor of high value of average electricity tariffs. However, the existing barrier is the necessary pricing on the generation distributed fairly to society and distributors - for this, some public consultations were done by the National Electric Energy Agency (ANEEL)

According to the projection carried out by the Energy Research Company (EPE) in the 2029 Ten-Year Energy Expansion Plan (PDE 2029), micro and minigeneration projections - taking into account a binomial tariff that is projected to be applied from the year 2022 – are higher than that observed in the 2027 Ten-Year Energy Expansion Plan (PDE 2027) in the period of 2019 to 2022. The explanation for this tendency is due to a path to escape from the binomial tariff. However, after the tax implementation, installed generation will be slowed and will only recover again in the final years of the estimated period due to the decrease in the prices of technology and dissemination of this practice by society (EPE, 2019a).

Also mentioned in the PDE 2029, the installed capacity will be 11.4 GW and it will require an investment of R$ 5 billion and generate about 2.3% of the national load. Most of the installed capacity will be associated with photovoltaic panels (86%), but the energy generated has a greater division in which photovoltaics correspond to 63%, small hydroelectric plants to 19%, thermoelectric to natural gas and biomass to 16% and wind sources to 2% (EPE, 2019a).

Therefore, distributed generation is an option that has been on the rise in Brazil since the installed capacity presents increasing values. This choice brings several advantages to the consumer, especially through better management of supply and demand, in addition to avoiding losses due to long transmissions. Although the photovoltaic source obtains the highest installed capacity, natural gas can also contribute to this opportunity, especially because it does not present an inherent intermittence, which would encourage demand from commercial and industrial establishments, for example, as they have a greater accuracy demand.

5. Conclusions

The use of gas in Brazil started at the end of the 19th century and it came from some raw materials such as coal, olive oil, and naphtha, among others. This allowed the start of the creation of a distribution infrastructure to accommodate the larger offerings that would come from geological reservoirs in the following years. Around the 1980s, production and exploration of the Campos Basin began because of the insecurity of supply caused by the oil crisis. In addition, other sources of great potential for supply have been incorporated: the Bolivia-Brazil gas pipeline, with which Bolivia has supplied Brazilian demand, and the discovery of geological pre-salt. Finally, the LNG market and transportation by ships and other unconventional modalities have assisted a greater insertion of NG in the energy mix.

The flow of NG from pre-salt reservoirs and the use of LNG from other locations in the world (E.g., Nigeria, The Netherlands, Trinidad and Tobago, Norway, Angola, and the United States) as seen in chapter charts (Figures 1 and 5) have been important sources of NG supply for Brazil. However, investment in more infrastructure is needed in the country, be it for flow pipelines, regasification terminals or even unconventional modalities of transportation to the interior of the country.

In addition, the energy transition and DG are two of the global trends to achieve the SDG created by the UN, in addition to the global agreements to reduce the impacts of anthropogenic practices on climate change that directly impact Brazil. Therefore, NG is an important agent as it has a security of supply and a guarantee of a lower emission of GHG than oil derivates and coal. In Brazil, the beginning of a greater NG use can already be perceived in the electricity sector - whether in thermal plants of large installed capacities or in still-incipient distributed generation - as well as in the industrial sector.

This chapter shows the importance of Brazil's NG and how this fuel can help the country to approach the objectives defined for a more sustainable context in the coming years. The following chapters address other topics related to NG, including the discussion on opportunities for further development of natural gas transportation infrastructure in different models and assistance in improving supply assurance for the consumer market.

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Chapter III

Brazilian gas Market regulation: thermoelectric use and use of pre-salt gas

Vinicius Oliveira da Silva
Stefania Gomes Relva
Marcella Mondragon
Drielli Peyerl
André Luiz Veiga Gimenes
Miguel Edgar Morales Udaeta

1. Introduction

The need for dispatchable electricity generation in the mix of an energy generation portfolio due to the increase of variable renewable resource use in several countries (IEA, 2017a) makes the combination of the gas and electricity industries a path to sustainable development (UDAETA et al., 2010). A balanced combination of electricity generated from sources such as natural gas (NG) and renewables can adjust generation operation based on the continuous optimization of resource availability, fuel costs, and emission requirements (VAHL; FILHO, 2015). However, it is necessary to implement a market design that defines how the fuel, the transportation, and the auxiliary services will be marketed (VAZQUEZ; HALLACK; GLACHANT, 2012a). Therefore, it is essential to implement an institutional arrangement that promotes the transportation and loading of NG and that, in turn, impacts the gas market as a whole (VAZQUEZ; HALLACK, 2015).

In the Brazilian context, the largest reserves and production of NG are found in offshore, post-salt and pre-salt areas (ANP, 2020). The flow of gas from the pre-salt occurs through two offshore gas pipelines, called Route 1 and Route 2, concurrent with the implementation of a third gas pipeline, Route 3. Even with the operation of these two routes, the reinjection of NG has tripled in the period from 2010 to 2016 (IBP-UFRJ, 2017) due to the technical need of the oil extraction and production process and due to the economic conditions that have been reducing the NG demand (ANP, 2020; EPE; MME, 2019). This reduction impacts the financial viability of the production chain, which is capital intensive, that is, the investment only occurs if there is a signal of long-term demand, and sufficient legal and regulatory security, so that the investors' perception of risk is such that they conclude that the enterprise is economically viable. In this sense, the electricity sector can be seen as a demand anchor for the gas market, making it feasible in the long term, since the lifespan of combined-cycle gas thermal plants is around 30 years (SPATH; MANN, 2000).

Currently, thermal power plants are responsible for 33% of the final energy consumption of NG and the industrial sector, the main consumer in the country, is responsible for 54% (EPE; MME, 2019). However, the viability of new gas thermal plants faces challenges related to: (i) the expansion of the gas transportation network; (ii) the lack of consolidated regulation of the NG chain; (iii) the problems of logistics and transportation infrastructure of NG; (iv) the need to prove fuel availability to obtain the power plant qualification to participate in energy auctions (RELVA et al., 2020).

Several discussions on the reform of the gas and electricity sectors have taken place in the country throughout 2019 and 2020, among them: (i) the Senate Bill No. 232 of 2016, which deals with a new regulatory framework for the electricity sector and opens the way to a free energy market with the possible portability of the energy bill between distributors and the separation in the sale of ballast and energy (SENADO FEDERAL, 2020); (ii) the recent Bill No. 3,975 of 2019 approved by the Senate, which deals with the renegotiation of the hydrological risk, the GSF[1], and the destination of the revenue from the sale of oil, NG, and other hydrocarbons destined for the Union (SENADO FEDERAL, 2019a); and (iii) Bill No. 5,878 of 2019, which deals with the incentives and limits of distributed generation (CÂMARA DOS DEPUTADOS, 2019).

Also noteworthy is the Senate Bill No 3,178 of 2019, which revokes Petrobras'[2] preemptive right to tenders in the oil, gas, and liquid hydrocarbon production sharing regime and guarantees to

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[1] Generation Scaling Factor

[2] Brazilian Oil and Gas Enterprise

the CNPE,[3] assisted by the ANP,[4] the decision on the legal regime exploration and production (E&P) of oil and NG to be adopted in the pre-salt auctions (SENADO FEDERAL, 2019b). A new text version for the Brazilian Electricity Code is also in the rapporteur's report (CÂMARA DO DEPUTADOS, 2020a). And finally, approved on September 1, 2020 by the Chamber of Deputies, Bill No. 6,407 of 2013, which deals with the new regulatory framework for the NG market in Brazil (CÂMARA DOS DEPUTADOS, 2020b).

The effects of these bills on the electricity and gas sectors will depend on the final approval of these bills, with the possible vetoes that may occur, and on how they will be regulated in the future. Thus, the focus of this chapter is on systematizing the history of regulation of the gas market in Brazil and on the discussion of what the possible impacts and benefits are in the relationship between the electricity sector and the gas sector based on the new gas market model that should be formed in the next years in the country due to the advances of Bill No. 6407 of 2013. For this, this Chapter is divided into 5 sections, being this the first one. In the second, the history of regulation of the NG sector in Brazil and its relationship with thermoelectricity are systematized. In the third, we discuss the main legal changes in the regulation of the gas sector from 2013. In the fourth, we present a comparative table of the main legal frameworks for regulation of the gas sector in Brazil, discussing how the dynamics between the gas and electricity sectors should take place for the next years. Finally, the last section presents the final considerations.

2. Regulation of the NG sector in Brazil and thermoelectric generation

The beginning of the NG industry was structured exclusively by Petrobras' expansion plans, which at times act based on business strategies, at times as agents of public policies (SANTOS, 2016). The recent institutional changes in the Brazilian NG industry have occurred in the last three decades (MATHIAS; SZKLO, 2007). The first, with Law No. 9,478 of 1997 (Petroleum Law), which was created

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[3] Brazilian National Energy Policy Council.

[4] Brazilian National Agency of Petroleum, Natural Gas and Biofuels

with GASBOL (Bolivia-Brazil gas pipeline), bringing economic openness to the NG sector. The second, with Law No. 11,909 of 2009 (Gas Law), whose main objective was to increase competition both in the transportation stage and in the treatment, processing, storage, liquefaction, regasification, and commercialization of NG.

The Petroleum Law culminated in major pipeline expansion projects, such as the PLANGÁS Project (Gas Production Anticipation Plan) (FGV, 2014), which was directed towards offshore gas outlets (COLOMER, 2014). However, even today the network is a monopoly of Petrobras, which holds 96% of the national production of NG (ANP, 2020), participating in three of the four Brazilian liquefied natural gas (LNG) terminals, holding the Brazilian branch of TBG - gas pipeline Bolivia-Brazil (GASBOL) and, finally, holding a stake in 19 of the 27 gas distributors in Brazil (ABEGÁS, 2020a).

In this sense, the Gas Law of 2009 did not guarantee the entry of new actors, mainly in the Brazilian NG transportation sector (FERRARO; HALLACK, 2012). This Law did not mandate third-party access to the infrastructures of flow, treatment, and LNG terminals and, in addition, established the concession regime for the expansion of the sector's infrastructure. However, all the existing NG transportation infrastructures, even those built after 2009, were built under an authorization regime established by the Petroleum Law.

Despite the obstacles created by the Gas Law, in the last decades there was an expansion of the transportation network from 4,001 to 9,409 km between 1999 and 2017. Of this total, 2,593 km are linked to the Brazilian section of GASBOL and more than 2,400 km were built after 2009 (MME, 2017a). In addition, the period from 2009 to 2016 accounted for: (i) reduction of losses and burns in production by 48% (MME, 2010, 2018) due to increased flow capacity and technical improvements and compressor redundancy, required by ANP regulation and also due to the increased reinjection in production (COSTA JUNIOR, 2018); (ii) 18% of increase in the total supply to the domestic market; (iii) increase in imports, mainly of LNG from 0.72 MMm^3/day to 17 MMm^3/day, linked to the start of operation of the LNG terminals; and (iv) increase in direct consumption at the power plants of 5.31 MMm^3/day to 29.6 MMm^3/day, mainly due to moments of water scarcity (MME, 2010, 2018).

Another initiative that impacted the development of the gas sector in Brazil was the Thermoelectric Priority Program (PPT), established by Decree No. 3,371 of 2000, whose goal was to increase the installed capacity in the country by more than 17 GW (SOUSA, 2009). The PPT established a series of conditions to stimulate private investments in thermoelectric plants, such as: special prices for fuel, guarantees for the purchase of energy by the distributors and a special line of credit by the BNDES, however, private investment did not occur. Among the reasons, we can mention the difficulty in obtaining environmental licensing for some plants and a stalemate regarding the price of imported gas for the thermoelectric plants that was fixed in dollars. Petrobras wished to receive in dollars because of the Bolivian gas purchase contract, while electricity distributors argued that electricity tariffs were fixed in reais (SOUSA, 2009). Petrobras had to play an important role for the investments to take place, participating as an independent investor and producer of electric energy and as a result 9.2 GW out of the 17 planned GW were added to the system (SOUSA, 2009).

The development of a gas thermoelectric park was seen as a vector for the development of the gas sector. Thus, the infrastructure would be justified for the supply of the electricity sector and, from it, would become more capillary to supply the industry and smaller consumers. However, the fact that the thermoelectric plants do not operate at the base of the system resulted in an infrequent gas consumption by the thermal power plants, mainly in humid periods, not stimulating the adequate remuneration of the gas infrastructure (D'ANGELO, 2020).

The resumption of the increase in gas consumption by thermal plants occurred in 2004, with the creation of the new model for the electricity sector (Law No. 10,848 of 2004). In the energy auctions of the new model, thermal plants have been contracted in the Regulated Contracting Environment (ACR) following an availability contract, with a fixed portion of remuneration, related to the plant's inflexibility index and a variable portion, related to the dispatch defined by ONS[5]. Currently, the inflexibility index is the mechanism that guarantees the minimum dispatch of thermal

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[5] Brazilian National System Operator of the electricity sector.

plants, reducing the risks of the gas supplying agent. At a minimum, the power plant's inflexibility factor should be dispatched month by month, ensuring a minimum purchase of NG. In this case, the winner of the auction wins the concession and the long-term energy purchase and sale contract, providing predictability of cash flow and facilitating the attainment of financing (SOUSA, 2009).

However, through a test carried out in 2006 by ANEEL[6], ONS simultaneously dispatched all contracted gas thermal power plants and it was found that the available gas could supply only half of the installed capacity (CERI, 2017). Thus, it started to demand from thermoelectric proponents the proof of sufficient reserve for full dispatch throughout the contractual period, within the scope of the New Energy Auctions (LEN) (CNI, 2018).

The Gas Law determined that contracts for the purchase and sale of NG must be registered at ANP, which, in turn, must inform the origin of reserves that will support the transaction (CERI, 2017) [7]. This proof was required for all projects participating in the auction, regardless of the contractors. In the case of NG, Petrobras, in the impossibility of providing proof to all, does not provide it to any party. The company argues that there is a shortage of gas to fulfill new supply contracts (RELVA et al., 2020). However, part of the inquiries established by CADE[8] against Petrobras for alleged anti-competitive practices in the gas market, concerns precisely the indications that Petrobras has created more favorable conditions for the supply of gas to its own thermoelectric power plants (CADE, 2018).

Given this context, since 2013, a bill is being discussed to establish a new design for the gas market, Bill No. 6,407 of 2013. In 2015, Petrobras initiated the process of divestments of some assets in the NG sector and this represented the opportunity to review the sector's legal and regulatory framework (MME, [sd]). Therefore, in June 2016, MME launched the "Gas to Grow" initiative with the objective of proposing concrete measures for regulatory

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[6] Brazilian National Electric Energy Agency.

[7] Since the approval of the Gas Law, the requirements for proof of fuel for thermoelectric generation have undergone several changes through various ordinances of the Ministry of Mines and Energy (MME), details can be verified in CERI (2017).

[8] Brazilian Administrative Council for Economic Defense.

improvement in the NG sector, based on the reduction of Petrobras' participation in this segment. Reflections of this initiative were noticeable throughout 2017 and 2018. A Bill was also formulated, replacing Bill No. 6,407 of 2013, with proposals for sector reform. However, the lack of sector consensus on the proposals and the lack of a favorable political environment made the approval of the Bill unfeasible. Thus, the Gas to Grow initiative resulted in the Presidential Decree No. 9,616 of 2018, which amends Decree No. 7,382 of 2010, which regulates the Gas Law - Law No. 11,909 of 2009, bringing some specific changes to the sector.

In 2019, the publication of CNPE Resolution No. 16 represented a new milestone for the regulation of the gas sector. This resolution established the "New Gas Market Program" which was launched with the aim of discussing the Gas Law in Brazil again. According to CNPE Resolution No.16 of 2019 guidelines, Petrobras and CADE entered into a Cessation Commitment Term (TCC), in which Petrobras committed itself to negotiate third-party access to the flow systems and to the Natural Gas Processing Units (UPGN), in addition, the enterprise also committed itself to ceasing its participation in gas transportation and distribution activities. Also, in 2019, a new text replacing the one in Bill No. 6,407 of 2013 was written. This PL was voted and approved in the Chamber of Deputies on September 1, 2020 and awaits the appreciation of the Federal Senate (CÂMARA DOS DEPUTADOS, 2020b).

3. Proposals for a new regulatory framework for the NG sector in Brazil

According to data from the Technical Committee for the Development of the NG Industry (CT-GN), responsible, together with the government, for the study and proposal of the new model of the NG sector in the context of the Gas to Grow program, indiscriminate access was expected to the transportation infrastructure, with the creation of criteria for the access of new agents. The transportation tariff would be made by the person in charge of the network and approved by the ANP, this calculation should consider the costs associated with the market area and the transportation system, also including efficiency criteria (MME, 2017b). For access to the LNG terminals, the conditions established by the terminal owners should be in accordance with ANP regulations. The owners would define the services to be provided at the terminal, as well as the remuneration. If there were any differences, the ANP would be responsible for mediating the conflict. In this way, the role of the ANP would be strengthened as a regulator of the gas market.

The main objectives of the bill resulting from the program were focused on: (i) improving tax rules; (ii) allowing greater integration between the electricity and NG sectors; and (iii) formalizing the new design of the NG market, to increase the flow of contracts and commercialization of NG on the Brazilian market.

In 2018, with no vote and approval of the Bill No. 6,407 of 2013, the Decree No. 9,616 of 2018 amended the Decree No. 7,382 of 2010, which regulated the Gas Law, highlighting: (i) the independence of the transportation activity; (ii) the articulation between the Union and the states to harmonize and improve state regulation, in particular with regard to treatment for free consumers; (iii) regulation aimed at the transportation system and no longer on individual pipelines; (iv) the introduction of the entry-exit tariff model for the transportation system; (v) the preservation of the current transportation service contracts, with permission for the ANP to create incentives for adapting the current contracts to the new form of charging for entry-exit; and (vi) the creation of negotiated access by third parties to the infrastructures of outflow pipelines, UPGN and regasification facilities, with ANP regulation, which should establish guidelines for access (ALMEIDA, 2019; ODDONE, 2019).

The decree also extinguished the Ten-Year Plan for Expansion of the Pipeline Transport Network (PEMAT). Until 2019, the expansion of the gas pipeline network depended on PEMAT, which was based on the Ten-Year Energy Expansion Plan (PDE) prepared by EPE[9]. Thus, future pipeline bidding should be included in the PEMAT (EPE, 2014). The projects could be suggested by third parties, but they should be approved and inserted in PEMAT. This

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[9] Brazilian Energy Research Company.

approval considered the projections of supply and demand for NG based only on the NG plants in operation or LEN winners, without considering the potential projects that have not yet been auctioned. Only Petrobras offers were accepted (EPE; MME, 2017) reinforcing the monopoly position in the transportation segment (SANTOS, 2016). This action increased the investor's risk, especially in areas far from the existing network, hindering its expansion and maintaining the sector's monopoly, especially due to regulatory uncertainties and inadequacies in key chain posts such as pipeline classification (transfer, transportation, and distribution), definition of free consumers, third-party access to the pipelines, and exclusivity period, thus reducing the sector's investments, which are very high (CAMPOS et al., 2017).

Therefore, PEMAT frustrated the gas market, since there is no new demand, there are no eligible projects and due to the absence of gas pipelines, new demands were not created (COLOMER, 2014). PEMAT was replaced by the Transport Gas Pipeline Indicative Plan (PIG), first published in October 2019 (EPE, 2019). PIG is also the responsibility of EPE, however it is based on the carriers' investment plans and information market share (PRESIDENCY OF THE REPUBLIC, 2010).

In addition to Decree No. 9,616 of 2018, the Gas to Grow discussions also highlighted the need for a balanced allocation of risks between the electricity and NG sectors, which must take place through integrated gas-electricity planning, in which a single agent must carry out a consolidated planning with precision for expanding the gas pipeline network, as is the case with transmission lines. New guidelines were considered in LEN A-4[10] and A-6[11] that occurred in 2017[12] (MME, 2017c): (i) adoption of a mobile horizon for gas purchase contracts, the GSA[13]; (ii) redefinition of

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[10] New Energy Auctions with projects expected to start operating in 4 years

[11] New Energy Auctions with projects expected to start operating in 6 years

[12] The period of NG availability proof had already been relaxed in the 3rd Reserve Energy Auction in 2015 and in the LEN A-5 in 2016. The rule adopted for both events was that of a minimum initial proof of 15 years, renewed only once time to meet the remaining 20-year term of the contract. In the 2017 rules, this period became 10 years, maintaining a minimum advance of 5 years for renewal and a total duration of 25 years (CERI, 2017).

[13] Gas Sales Agreement.

the inflexibility limit and the possibility of seasonal declaration of the future generation, allowing the agent to dispatch constantly during a certain period of time; (iii) monthly readjustments in fuel prices of the Variable Unit Cost (CVU) and Fixed Revenue linked to fuel consumption (RFcomb), considering the revision of the formula and readjustment indexes; (iv) dissociation of the CVU and RFcomb parameters declared in the auction (flexibility of the declaration); and (v) ANEEL changed the penal clause for lack of fuel. The A-6 auction resulted in the contracting of two NG thermal power plants, totaling 1,870.9 average MW (ANEEL, 2017), which corresponded to the largest projects contracted at the auction.

In the same period, the ANP, through several technical notes and carrying out the Public Contribution Making process, collaborated mainly with (ALMEIDA, 2019): (i) discussions on the application of independence models (complete separation of ownership or independent carrier and independent system operator); (ii) discussions on the rules and guidelines for formalizing access to drainage pipelines, UPGN, and LNG regasification terminals; (iii) discussions on the creation of a "National Pact" between the union and the states, to harmonize the rules for regulating NG, such as tariff criteria and the separation between the activities of commercialization and movement of NG; (iv) technical note in defense of the unbundling of the industry; the total separation for new transporters, that is, the transportation company cannot act or participate in the commercialization of NG; (v) the complete separation of ownership for existing carriers, or the definition of the system independent operator (ISO) or the independent carrier - ITO; (vi) technical note with diagnosis of the main barriers to competition in the gas market; (vii) technical note addressing the promotion of competition in the gas industry, defending the promotion of a gas release program (Gas Release), the role of competition-defense bodies in conjunction with sectoral regulation for the entry of new providers on the market and the need for additional measures to unbundle transportation and distribution links.

Although the Gas to Grow initiative did not effectively result in a new regulatory framework for the gas sector, the initiative sparked the discussions about the necessary reforms in the sector.

It should also be noted that the Gas Law was also amended by Laws No. 12,351 and No. 12,276 of 2010 in addition to Decree No. 9,616 of 2018, which amended Decree No. 7,382 of 2010, which in turn regulated the Gas Law. Law No. 12,351 of 2010 created the production-sharing regime in parallel with the concession regime, which applies to the pre-salt areas and areas that may be considered strategic,[14] while Law No. 12,276 of 2010 authorized the Federal Government to transfer Petrobras oil and NG and other fluid hydrocarbon exploration and mining activities in non-concession areas located in the pre-salt, with extraction of up to five billion barrels of oil equivalent (FORMAN, 2019). Thus, it is observed that Brazil comes from a long period of attempts and adaptations of the Gas Law, a movement that gained strength, mainly from Gas to Grow.

From 2019, new effective actions for opening and restructuring the gas market occurred again. The TCC affirmed between CADE and Petrobras, with the approval of the ANP, was established in the context of investigations of alleged anti-competitive conduct from Petrobras on the Brazilian NG market, including abuse of a dominant position and discrimination against competitors through differentiated pricing (CADE, 2019). Under the TCC, Petrobras is committed to negotiating third-party access to the flow systems and the UPGNs, to make space in the transportation pipelines, allowing the offer of this capacity on the market, in addition to selling its shares in the gas carries and selling its indirect shareholding in distributors, among other obligations. Currently, three investigations against Petrobras are underway at CADE, which will be closed as soon as CADE attests to the fulfillment of all obligations provided for in the TCC by Petrobras. These measures are intended to favor third-party access to the infrastructure of the gas sector and to stimulate a non-monopolized market in the sector.

The TCC was one of the guidelines established in the New Gas Market Program (CNPE Resolution No. 16 of 2019). While the TCC was the first concrete sign to the market of the end of Petrobras' monopoly in the gas sector, the New Gas Market Program had the

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[14] Law No. 12.351 of 2010 was later amended by Law No. 13.365 of 2016 to modify Petrobras' obligation to hold at least 30% of any sharing contract and to be the operator.

role of returning the discussions established in Gas to Grow and strengthening the political environment for approval of Bill No. 6704 of 2013 with a substitute text.

In addition to establishing guidelines and improving energy policies to promote free competition in the NG market, CNPE Resolution No. 016/2019 highlights the need for a coordinated regulatory transition process. The gas sector in Brazil today has numerous facilities and long-term contracts. Thus, there must be an articulation between different institutions, such as MME, EPE, CADE, and ANP, to monitor the implementation of the actions necessary to open the NG market. Unlike what happened in the past, at this moment of regulatory change in the sector, there is a commitment by Petrobras to end its monopoly, allowing the entry of new agents. In this sense, it is important to think not only about the role of Petrobras in the sector, but also of the other agents. Today, Petrobras not only holds a monopoly and operates the system, but also assumes the risks inherent in this role (CECCHI; MATHIAS, 2018).

One of the Gas to Grow proposals advocated the creation of an independent transportation system manager, which would have a role analogous to that of ONS, however, while ONS guides its performance by seeking the lowest cost of service, an operator of the gas system can seek some reduction of the logistical cost, but very little can be done for a reduction of the global cost of supply (ARENTZ, 2019). The solution established was the creation of three market zones, one per carrier, with the establishment of companies as those responsible for the operational coordination of the network, based on the network codes that will be prepared by them and approved by ANP. Some gas distributors have expressed concerns about the model's transition process. For these agents, the construction of a network code would be a time-consuming process, being essential to guarantee that there will be no interruptions in supply or any other type of discrimination in the offer (BNDES, 2020). Therefore, although one of the focuses of the New Gas Law is the separation in the links of the value chain (production, transportation, distribution), establishing the total independence of the transportation agents, it is important to consider Petrobras' actions for this transition.

4. Evolution of the NG regulatory framework and the future of thermoelectricity in Brazil

Board 1 systematizes the aspects dealt with in the evolution of the regulatory framework for the gas sector in Brazil.

Board 1: Comparison between regulatory frameworks for the gas sector in Brazil

Aspects	**Petroleum Law Law 9,478/1997**	**Gas Law Law 11,909/2009**	**Decree 9,616/2018**	**New Gas Law Bill 6407 of 2013**
Drainage pipelines	No approach	Authorized by the ANP. Third-party access is not mandatory.	Third-party access is not mandatory. Denial of access that constitutes anti-competitive conduct will subject agents to penalties. Third-party access established by ANP normative act.	Non-discriminatory and negotiated access from interested third parties is ensured. Preference of use by the owner, under ANP regulation.
Processing Units	Authorized by the ANP	Third-party access is not mandatory.	Third-party access is not mandatory. Denial of access that constitutes anti-competitive conduct will subject agents to penalties. Third-party access established by ANP normative act.	Non-discriminatory and negotiated access from interested third parties is ensured. Preference of use by the owner, under ANP regulation.
LNG Terminals	Authorized by the ANP	Third-party access is not mandatory.	Third-party access is not mandatory. Denial of access that constitutes anti-competitive conduct will subject agents to penalties. Third-party access established by ANP normative act.	Non-discriminatory and negotiated access from interested third parties is ensured. Preference of use by the owner, under ANP regulation.
Commercialization	Authorized by the ANP, within the Union's jurisdiction	Authorized by the ANP, within the Union's jurisdiction, upon registration of the contract. The selling agent must inform the origin of the NG reserves.	Authorized by the ANP, within the Union's jurisdiction, upon registration of the contract. The selling agent must inform the origin of the NG reserves.	Authorized by the ANP, within the Union's jurisdiction, upon registration of the contract at ANP or in an entity authorized by ANP.
Storage	Authorization regime	Concession regime. Third-party access is not mandatory.	Concession regime.	Authorization regime. Third-party access is mandatory under the terms of the ANP regulation.

Aspects		**Petroleum Law Law 9,478/1997**	**Gas Law Law 11,909/2009**	**Decree 9,616/2018**	**New Gas Law Bill 6407 of 2013**
Transportation	Construction, expansion, and operation of gas pipelines	Authorization regime	Concession regime preceded by bidding process promoted by ANP. Concession duration of 30 years, renewable for an equal period.	Concession regime preceded by bidding process promoted by ANP. Concession duration of 30 years, renewable for an equal period. Criteria for autonomy and independence regulated by the ANP.	Authorization regime, without duration. If there is more than one interested carrier, the ANP must promote a public selection process to choose the most advantageous project. ANP may, at any time, conduct a public selection process to identify the existence of an interested carrier.
	Transportation service	Tariff according to criteria established by the ANP	Access by public call for hiring transportation capacity, promoted by the ANP. Tariff according to criteria established by the ANP.	Access by public call for hiring transportation capacity, promoted by the ANP. Capacity contracting regime for entry and exit for new contracts, in which entry and exit may be contracted independently. The tariffs will be proposed by the carrier and approved by the ANP.	Capacity hiring regime by entry and exit, in which the entry and exit can be contracted independently, through the capacity allocation process. The tariffs will be proposed by the carrier and approved by the ANP, after public consultation, according to criteria previously established by ANP.

Aspects	**Petroleum Law Law 9,478/1997**	**Gas Law Law 11,909/2009**	**Decree 9,616/2018**	**New Gas Law Bill 6407 of 2013**
Distribution	Activity explored exclusively by the states, directly or through concession, under the terms of § 2 of art. 25 of the Federal Constitution.	Activity explored exclusively by the states, directly or through concession, under the terms of § 2 of art. 25 of the Federal Constitution.	Activity explored exclusively by the states, directly or through concession, under the terms of § 2 of art. 25 of the Federal Constitution. Articulation between the Union and the states for the harmonization and improvement of norms for the NG industry, including the regulation of the free consumer.	Activity explored exclusively by the states, directly or through concession, under the terms of § 2 of art. 25 of the Federal Constitution. Articulation between the Union and the states for the harmonization and improvement of norms for the NG industry, including the regulation of the free consumer.
Expansion Plan	Proposed by market agents.	Proposed by MME, via EPE, through PEMAT.	Proposed by MME, via EPE, but considering the investment plans of the carriers.	Proposed by MME, via EPE, but considering the investment plans of the carriers.

Source: Elaborated by the authors.

Along the process of regulatory change in the gas market, in addition to the regulatory frameworks set out in Board 1, there are a number of other laws, provisional measures and ordinances of regulatory bodies and the MME in an attempt to expand the access of agents to the gas sector and to establish a better distribution of risks between agents in the electricity sector and the gas sector. The New Gas Law will solidify a market model for the sector, with guaranteed access to third parties in the gas transportation infrastructure and with a pricing model for entrances and exits. In this sense, the model that has been designed for the gas market is similar to the European one.

The European gas market, in search of greater liquidity in the commercialization of the hydrocarbon molecule, has implemented a pricing model for entrances and exits for the transportation of NG. In this model, just as it has been established in Brazil, a gas-selling agent, in order to have the right to inject the molecule into the transportation system, only needs to contract an entry point. Those interested in removing gas at another point, need only perform the contracting at an exit point. Thus, there is no need for a seller to inform the destination of the gas, just as the buyer does not need to inform the origin of the gas. Thus, there is a separation between the physical environment, that is, the transportation of gas, and the contractual environment, the commercialization of gas. The commercialization of NG is no longer tied to the physical path that the gas molecule will take in the transportation pipelines.

The separation between the physical and contractual environment poses a dilemma for the operation of the gas transportation network, which is its balance. Balancing is the mechanism that guarantees that the differences between the physical and the contractual environment will be adequate, and that the transportation will be done efficiently, guaranteeing the best use of the network. As sellers can inject gas at any contracted entry point and buyers can withdraw gas at any contracted exit point, so that it is possible for the entire contracted amount to be used according to the contractor's need, the capacity to be offered to a player will always be less than the total capacity the transportation pipeline can offer. Thus, for the operator to ensure that the contracted capacity is met without congestion in the network, commercial allocation is limited, which can make transportation on the pipelines inefficient, using less than the available capacity (VAZQUEZ; HALLACK; GLACHANT, 2012b).

Although the entry and exit model can increase liquidity in the sale of gas, the market design for balancing the system is crucial for its proper functioning. In view of the loss of Petrobras' monopoly in the gas transportation sector, the dynamics of the charging of inputs and outputs can be better analyzed based on ANP regulations and the real functioning of the model with several agents.

In addition to the formulation of all necessary regulations - by the ANP - from a New Gas Law, the next challenge for the sector is to guarantee a safe demand that enables the expansion of investments in transportation and processing structures. In this sense, ABEGÁS has been defending the need to establish inflexible thermals in the electricity sector and the universalization and interiorization of NG (ABEGÁS, 2020b). However, the participation of NG thermal power plants in the electricity sector and the interiorization of the gas pipeline network is something that goes beyond the gas sector and encompasses a broad discussion on the energy development policy, in a context of energy transition to a low-carbon economy.

Regarding the interiorization of the gas network, unlike the USA, which developed a robust and extensive network of gas pipelines due to the wide and intense use of residential heating, has a decentralized profile market with more than 23,000 producers, and a deregulated gas transportation sector, in Brazil, the use of NG is concentrated on the coast and the internalization of the network would entail intensive investments.

The current context of energy transition is characterized, among other aspects, by the trend of (i) expansion of the use of LNG and biofuels in the transportation sector, (ii) use of industrial cogeneration to shift the electricity demand, (iii) decentralization of power generation and (iv) increased use of variable renewable sources. Given this context, it is important to assess whether a large capital investment in physical and fixed gas structures would not be counterproductive at a time when the trend is towards decentralization of the energy sector and the use of dispatchable sources to meet demand along the duck curve that tends to be formed from the increased penetration of solar energy into the system.

In addition, the current environment of reforms in the electricity and gas sectors is favorable to the use of gas thermal power plants as a source of support for variable renewables, which are likely to be anchored in the use of LNG. The use of thermal power plants as a resource for contracting power for the sector does not create the necessary gas demand to justify investments in the interior of the transportation network.

Considering the pre-salt gas resources, it is not foreseen, at this moment, that the electricity sector can assimilate this offer in the coming years, since this gas has a higher price than the NG imported from Bolivia and the post-salt reservoirs. Besides that, the flow of this NG is already in decline, given the country's economic conditions in recent years and the current health crisis (COVID-19). In addition to this, a third stretch of gas flow from the pre-salt will start operating at a time of continuous decline in national demand.

In this case, the establishment of a favorable regulatory condition may imply in directing the national capacity for exports. Within the international context, the conditions are present, given the increase in imports and the implementation of new LNG regasification terminals in European and Asian countries. This movement for NG importation occurs for many reasons: the increase of domestic supply; the replacement of generation in nuclear power plants; the reduction in energy generation by sources that pollute more than NG; the diversification of suppliers, aiming for security of supply; and mainly to meet the growing and consistent Chinese demand (IEA, 2017b, 2019; US EIA, 2019).

Therefore, it is evident that there is a long-term signal for the increase in demand for LNG in several countries and that the export of Brazilian NG may become attractive to investors. However, it is exalted that this scenario of international commercialization falls on realpolitik, in which national interests prevail, with transnational agreements between the largest importers and exporters.

5. Final considerations

Through the systematization of the history of regulation of the Brazilian gas sector, through the lense of its relationship with the electricity sector, it appears that in addition to the regulatory frameworks established from the Petroleum Law (1997), passing through the Gas Law (2009) until the New Gas Law project (2019), there were a series of laws, provisional measures and ordinances from the regulatory bodies and the MME in an attempt to expand the access of agents to the gas sector and establish a better distribution of risks among the agents in the electricity and gas sectors.

In the long period of attempts and adaptations, the Gas Law was changed, mainly due to the impulse given by Gas to Grow. It is also noted that several aspects linked to the gas production chain present in the current text of Bill No. 6,407 of 2013 had already been addressed in the Gas to Grow initiative. The Gas Law created barriers to the sector in the last decade; it was observed that the expansion of the transportation network took place within the authorization rule, which preceded this law, with the implantation of transportation pipelines within the concession rule in force in that period. Another important point is the expansion of direct consumption in NG thermoelectric plants as a result of water scarcity and not the improvement of the market.

The new market environment is favorable to the use of NG thermal power plants as a complementary source to variable renewables, to meet some periods of demand along the duck curve and periods of water scarcity, but it does not create the gas demand necessary for expansion of the installed capacity of thermal plants and the transportation network, given the characteristic of power contraction of these thermal plants. However, the New Gas Law solidifies a market model in which non-discriminatory and negotiated access of third parties with preference for use by the owner is ensured, in the form of ANP regulation, to the transportation infrastructure, UPGN, and LNG terminals, with a pricing model for entrances and exits with sellers being able to inject gas at any hired entry point and buyers being able to withdraw gas at any hired exit point. In addition, shared use allows multiple agents to use the terminal's storage capacity and aggregate their demands, giving greater negotiating power to LNG suppliers.

Still in relation to the internal supply of NG, this tends to be supplied by the idle capacity of the existing LNG terminals, by the NG imported by GASBOL and by the post-salt reservoirs. Pre-salt NG, if a favorable regulatory condition is established, could enter the international market via LNG exports to supply the diversification of European demand and the increase in long-term demand from Asian countries, mainly by China, but considering the realpolitik practiced in this international trade.

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Chapter IV

Renewal of the contract for the supply of Bolivian natural gas to Brazil in the context of increased Brazilian gas production

Dorival Suriano dos Santos Júnior
Anna Luisa Abreu Netto
Drielli Peyerl
Edmilson Moutinho dos Santos

1. Introduction

The participation of natural gas (NG) in the Brazilian energy matrix has grown exponentially over the last 30 years and currently presents itself as an important energy alternative for industry, commerce, households, and electricity generation. According to the National Energy Balance (EPE, 2019a), in 2018, natural gas accounted for 13% of all available primary energy sources in Brazil, behind only oil derivatives and sugarcane derivatives.

In 2018, thermoelectric plants and the industrial sector were responsible for approximately 70% of all NG demand in Brazil, followed by the use in the reinjection process in oil production wells, in NGV (natural gas vehicle) and in consumption in the Natural Gas Processing Units themselves. To meet all this demand, the total supply of NG in Brazil is composed of domestic production and fuel imports. In 2018, the net domestic NG supply reached about 55 MMm3/day (approximately 66% of the national consumption in 2018), and 70% of this volume was supplied by fields associated with oil production (MME, 2019a).

Regarding imports, Brazil acquires international NG by two means: importing it from Bolivia, through the GASBOL pipeline, and from other countries via LNG, using three existing regasification terminals. The Bolivian imported gas has been responsible for an average of 27% of all gas supply to the Brazilian market in the last 5 years and, in 2018, corresponded to 80% of all imported gas volume (MME, 2019a).

Many factors encouraged the development of a purchase and sale agreement for Bolivian gas and the construction of a gas pipeline linking Bolivian reserves to the Brazilian consumer market, such as the Brazilian need to diversify its electricity mix in the early 1990s (until then almost exclusively from water sources), the opportunity to replace other fossil fuels considered more polluting and more dependent on the world's oil supply, and the existence of large NG reserves in the neighboring country of Bolivia (MOUTINHO DOS SANTOS; MAZAFERRO; OXILIA, 2004).

Inaugurated in 1999 and starting gas supply through a 20-year contract, GASBOL represents an important energy integration project in Latin America and was the initial and fundamental milestone for the expansion of the gas market in Brazil, until then quite restricted. For Brazil, the importation of Bolivian gas made the diversification of sources possible and, therefore, it was a positive initiative to increase energy security in the country (FUSER, 2011). The area covered by GASBOL, in Brazilian territory, represents approximately 50% of the country's GDP, supplying thermoelectric plants, oil refineries and gas distributors which, together, serve more than one million residential consumers and thousands of commercial and industrial consumers, thanks to the availability of Bolivian gas (MME, 2018).

For Bolivia, the sale of gas to Brazil allowed the entry of foreign investments and revenues that encouraged the economy and enabled an improvement in the quality of life of its population (EPE, 2017). In 2018, the sale of NG to Brazil represented 4% of Bolivia's entire GDP, injecting USD 1.6 billion in revenue into the Bolivian economy that year from the sale of gas alone (IBCE, 2019).

After almost 20 years of uninterrupted supply, the gas supply contract between Brazil and Bolivia officially ended in December 2019. With the end of this contract, the two countries must decide whether or not to renew the gas supply contract from Bolivia to Brazil. However, consideration must be given to the profound structural changes that have occurred in the domestic NG markets on both sides of the border.

Thus, in this chapter, the main factors that must be analyzed in order to be able to decide on an eventual renewal (or not) of the gas supply and purchase agreement between the two countries will be evaluated, in the context of the expectation of the increase in Brazilian domestic gas production and in function of the commercial and geopolitical relations between Brazil and Bolivia.

2. The Gas Imported from Bolivia and the Importance of GASBOL to Brazil

In the early 1990s, with Brazil's need to diversify its energy mix, it became important to consider gas imported from Bolivia in national policy guidelines, not only for strategic and energy-security issues, but also for environmental issues, which were beginning to gain ground in governmental and social discussions at that time. Because it is less polluting, NG was seen as a potential substitute for fuel oil, especially in the industrial sector (MOUTINHO DOS SANTOS, 2002).

In addition to consumption in industry, Holanda (2001) also states that in the 1990s, the Brazilian government began to consider a larger share of NG for electricity generation as a result of the decrease in hydroelectric potential in the South and Southeastern regions, the country's main center of load. Moreover, advantages such as shorter construction time in relation to hydroelectric plants of the same size, the possibility of being located close to the consumer centers, and the use of a cleaner fuel than fuel oil and coal, were all additional motivators for the beginning of the implementation of a broad program of natural gas thermoelectric plants in Brazil (HOLANDA, 2001).

Since Brazil had not yet developed a solid internal production of NG in this period, the option of importing the fuel from Bolivia, a neighboring country that was beginning to announce discoveries of enormous NG reserves, was consolidated in the 1990s. Bolivian gas emerged then as the main supply option for Brazil (FUSER, 2011).

In this context, after periods of negotiations between the Brazilian and Bolivian governments, initially without much progress, a contract for the purchase and sale of NG from Bolivia to Brazil, called GSA (Gas Supply Agreement), was signed in February 1993, conditional on obtaining financing that would make the construction of a gas pipeline interconnecting the productive areas of Bolivia to the Brazilian consumer market possible (MOUTINHO DOS SANTOS, 2002). This gas pipeline was named GASBOL: Gasoduto Bolivia Brasil.

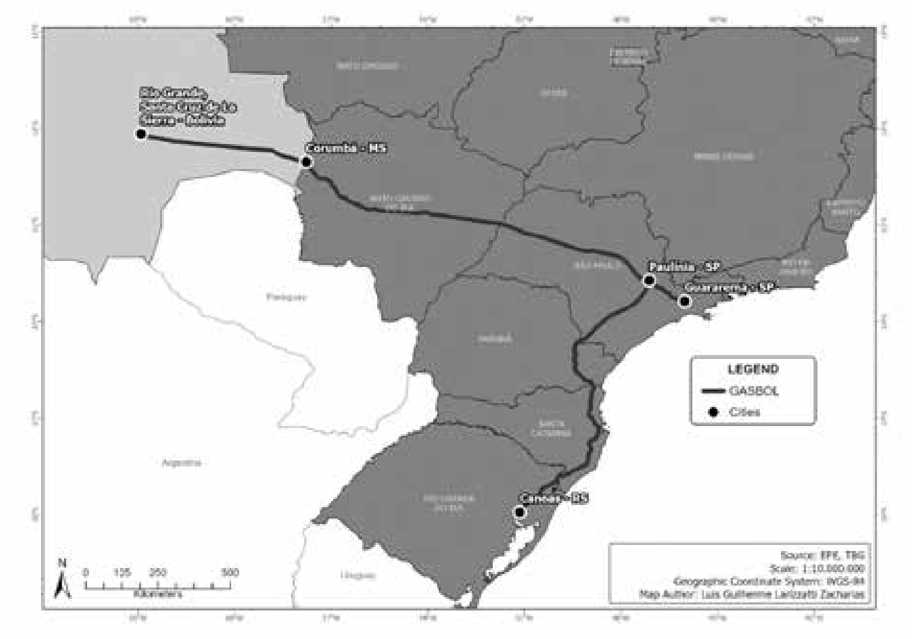
Under the agreement for the purchase and sale of NG, it was decided that, on the Bolivian side, the state-owned company Yacimientos Petrolíferos Fiscales Bolivianos (YPFB) would be exclusively responsible for the exportation of NG produced in the country. On the Brazilian side, the execution of the importation contract and the construction of GASBOL would be under the responsibility of Petrobras, then holder of the monopoly on exploration, production, exportation, importation and transportation of oil and natural gas in the country (EPE, 2017).

For Brazil, the GASBOL project represented a definitive step towards the diversification of its energy mix through gas consumption. For Bolivia, the importance of developing this project extended well beyond the simple commercialization of its gas. GASBOL represented the materialization of a great national development project, with impacts that affect different generations.

GASBOL construction work began in 1997 and was completed in 1999. With a nominal transportation capacity of 31 MMm3/day, GASBOL is 3,150 km long, 557 km inside Bolivia and 2,593 km inside Brazil (MOUTINHO DOS SANTOS; MAZAFERRO; OXILIA, 2004).

Within the Bolivian territory, GASBOL originates in the Rio Grande Natural Gas Plant, owned by YPFB, located 40 km from Santa Cruz de La Sierra and, when entering Brazil, the pipeline crosses 136 municipalities in six states of the federation and ends at the Alberto Pasqualini refinery (REFAP) of Petrobras, located in the city of Canoas/RS (PETROBRAS, 2016). The most detailed layout of GASBOL is shown in Figure 1.

Figura 1: GASBOL route



Source: EPE, TBG
Scale: 1:10.000.000
Geographic Coordinate System: WGS-84
Map Author: Luis Guilherme Larizzatti Zacharias

The cost of the GASBOL project was equivalent to USD 2.1 billion, of which 20% (USD 435 million) corresponded to investments on the Bolivian side and the remaining USD 1.7 billion was spent on the Brazilian side. Of the total resources, 82% were obtained by Petrobras, through long-term loans from multilateral agencies and export credit, and through a significant participation of BNDES (TORRES, 2002).

Regarding GSA contractual terms, it was established that Bolivia would supply NG to Brazil for a contract period of 20 years, therefore, in principle, until December 2019. As for the established amounts, the GSA foresaw the beginning of a supply of 8 MMm3/day of gas, increasing to 16 MMm3/day after 8 years of contract term. Ten years after the beginning of the contract until the final period, Brazil would import an average of 30 MMm^3/day from Bolivia (MOUTINHO DOS SANTOS; MAZAFERRO; OXILIA, 2004).

Regarding the price, a base value was set at the entrance of the pipeline and both parties agreed that the price of the NG sold to Brazil would be readjusted periodically from the prices of a combination of three types of fuel oil on the international market. Of the maximum contractual volume, 80% corresponds to a take-or-pay clause, in which Petrobras pays, whether the imported NG is used or not (PINTO JUNIOR et al., 2016).

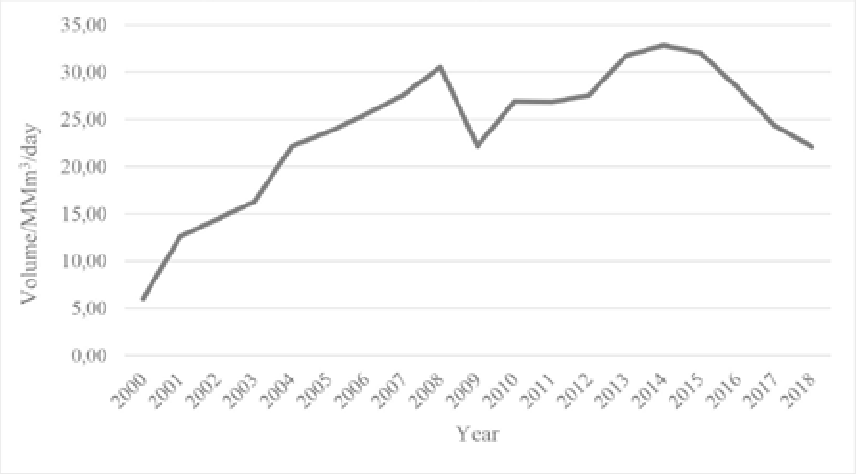
To manage the operation and maintenance of GASBOL, Petrobras and YPFB created, in 1997, two companies. TBG (Transportadora Brasileira Gasoduto Bolivia-Brasil S/A) was created to manage the Brazilian stretch, a privately held company with the following groups as partners, with their respective business shares: Petrobras (51%), BBPP Holdings (29%), YPFB Transporte do Brasil (12%) and GTB-TBG Holdings (8%) (TBG, 2017). On the Bolivian side, GTB (Gas TransBoliviano S.A) was created.

Almost 20 years after the start of uninterrupted NG transportation through GASBOL, Bolivian gas was essential for the expansion of a gas market on a scale that had not existed until then in Brazil. In the early 1990s, the share of gas in Brazil's primary energy mix was only 2% (LAW; DE FRANCO, 1998). Since then, Brazil's growing demand for energy and the possibility of purchasing Bolivian gas have been important contributors to the share of NG in Brazil's total primary energy supply reaching 13% in 2018 (EPE, 2019a).

According to Hage (2008), after the implementation of GASBOL, Brazil has largely encouraged the consumption of NG in the industry, electricity generation, and transportation sectors without the immediate need to increase domestic production offshore, considered of higher cost. In addition, from the point of view of Petrobras, which became the largest NG producer agent in Bolivia, it was a matter of promoting effective internationalization policy of Exploration and Production (E&P) activities, as well as adding relevant productive capacity in onshore assets (important diversification for a company that was increasingly dependent on offshore operations) (HAGE, 2008).

Figure 2 shows the evolution of the volume of gas imported from Bolivia from the beginning of the GASBOL operation until 2018. It can be seen that imports from Bolivia had a compound annual growth rate (CAGR) of 17% between 2000 and 2010.

Figure 2: Volume of NG imported from Bolivia



Source: Elaborated by the authors based on MME (2019a).

In 2000, one year after the start of GSA's commercial operation, Bolivian gas already accounted for 26% of Brazil's total NG supply. In 2008, GASBOL's nominal capacity was reached for the first time and the Bolivian gas represented 50% of the Brazilian liquid NG supply[1].

After the sudden drop in consumption as a result of the global financial crisis of 2008/2009, the economy and energy consumption recovered in the country at the end of 2009. Imports through GASBOL were again expanding consistently (although with a lower CAGR of 6% between 2009 and 2015).

In 2014, Brazil imported a record NG volume from Bolivia of 33 MMm3/day, that is, above the nominal capacity of the pipeline and imports accounted for 33% of all Brazilian NG supply that year. However, since that year, Bolivian gas imports have been decreasing, trying to match the much less vigorous needs of a consumer market stagnant for a long period of economic recession, as well as the arrival of more domestic gas to that same market of

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[1] Curiously, as of 2005, and over the next 3 years, Brazilian (and also Bolivian) geopolitical feelings toward GASBOL were beginning to suffer setbacks, fed by growing nationalist feelings in both countries. The mutual advantages of integration were beginning to leave room for mutual distrust and growing fears of excessive mutual dependency.

little vigor. In 2018, Bolivian gas accounted for 28% of Brazil's net gas supply (MME, 2019a).

The area served by GASBOL in the national territory represents approximately 50% of the Brazilian GDP for 2018, supplies four thermoelectric plants and is delivered to seven distributors which, together, serve more than 1.2 million residential consumers, 18 thousand commercial consumers, 2 thousand industrial consumers and 590 NGV service stations (ANP, 2018).

Besides supplying the Brazilian consumer market with approximately 30% of the NG supply, GASBOL is considered one of the largest energy integration projects in South America and this integration built by GASBOL has enabled gains for both countries. For Bolivia, the exportation of gas to Brazil allowed the country to monetize its reserves, increase investments in the country and the relevance of the natural gas industry in this country. For Brazil, the availability of Bolivian gas contributed to the development of a consumer market that was practically non-existent before, which contributed to the diversification of the Brazilian energy matrix and, consequently, to an increase in Brazil's security of energy supply (EPE, 2017).

3. The importance of GASBOL to the Bolivian economy

According to data from the World Bank (2018b), the Gross Domestic Product (GDP) of South American countries recorded a CAGR of approximately 3.18% in the period between 2007 and 2017. Among the Latin American economies, the Bolivian economy was the one with the highest GDP growth rate compared to the other South American countries. In the ten-year period analyzed, Bolivia's GDP showed a CAGR of 4.49%, a very relevant figure when compared to the other countries of the South American continent and the average world growth, which had an average expansion of 2.18% per year. As will be seen below, much of this economic dynamism is due to its reserves, production, and sale of NG to the external market, mainly to Brazil.

As stated by the International Monetary Fund (IMF, 2017), the increase in gas prices on the international market in the last 10 years (and the consequent direct increase in the country's revenues) has allowed Bolivia significant public investments and social spending. These, in turn, contributed to the improvement of the country's Human Development Index (HDI)[2], with the Bolivian HDI rising from 0.608 in 2000 to 0.693 in 2017, representing an increase of 14% (UNDP, 2018).

With regard to the country's poverty, it decreased considerably from 2000 to 2015: in the year 2000, 42% of the population lived on less than USD 3.20 per day and by the year 2015, this rate had decreased to 12.9% (STATISTA, 2019).

At the same time that poverty decreased, the Bolivian government saved part of the resources provided by its exports and built a considerable financial reserve, about USD 20 billion, which allowed the government, for example, to absorb the economic impacts of the fall in commodity prices during the decade of 2010 (IMF, 2017).

The relative success of Bolivia's economy and social development over the period of 2007 to 2017 is a complex phenomenon whose complete analysis goes beyond the dimensions and scope of this chapter. However, one can estimate the role of Brazil and NG in the Bolivian economy from the figures related to NG exports to Brazil. In 2018, Bolivia's GDP corresponded to USD 40.3 billion and approximately USD 9.0 billion (22%) was exclusively related to exportation activity (WORLD BANK, 2019). The most exported products by Bolivia in 2018 were Manufactured Goods (33.6%), Natural Gas (33.1%), and Minerals (26.7%) (IBCE, 2019). In other words, the sale of NG to the external market alone was responsible for 7% of the value of all goods and services produced by Bolivia in 2018.

Regarding the destination of NG sales, Bolivia exports this fuel to only two countries: Brazil, which absorbed, in 2018, about 55% of the volume sold, and Argentina, which acquired the remaining 45% in the same year (IBCE, 2019). Since NG is Bolivia's main individual export product and Brazil is its largest consumer

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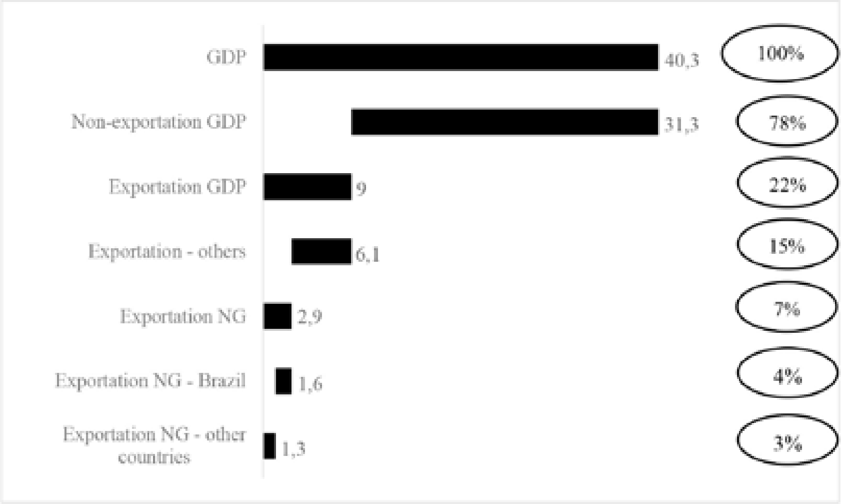
[2] The HDI correlates information on life expectancy of the population, education level and per capita income.

market, Figure 3 was elaborated with the objective of showing the current weight that gas sales to Brazil have in Bolivia's economy.

Figure 3: Composition of Bolivia's GDP in 2018: Gross Value (USD billion) and percentage in relation to the total GDP



Source: Elaborated by the authors based on IBCE (2019) and World Bank (2019).

It is possible to observe in Figure 5 that Brazil plays a very important role in the revenue inflow to the Andean country, being responsible for injecting USD 1.6 billion in 2018 (or 4.0% of all Bolivian GDP) through the NG trade by GASBOL.

According to Cadena et al. (2017), the inflow of financial resources in Bolivia, through NG exports to Brazil, contributed in a relevant way to local social policies and the economic development of this nation. Thus, it is possible to say that Brazil had a direct participation in the rates of quality improvement for the Bolivian people. In this dimension, bilateral gas trade has had a fundamental redistributive role in Bolivia. Meanwhile, it is an item with very limited participation in the Brazilian importation agenda and with an almost insignificant weight in the GDP in Brazil (CADENA et al., 2017).

According to data from the Bolivian Foreign Trade Institute (IBCE, 2019) and the MME (2019a), between 2000 and 2017, total Bolivian exports jumped from USD 1.2 billion to USD 8.0

billion and the volume of NG exported to Brazil increased from 6.0 MMm3/day to 25 MMm3/day in the same period. Thus, NG exports to Brazil have played the role of defining the volatility curve of total Bolivian exports. Therefore, one can infer that a sudden reduction of NG imports by Brazil could generate important instabilities in the commercial balance and in the GDP evolution capacity of Bolivia.

Here, the only objective is to demonstrate that an apparently simple Brazilian gas policy decision should consider complex geopolitical dimensions vis-à-vis Bolivia and Brazil's role as regional leader with much less favorable neighboring countries. It should also be remembered that unstable borders pose constant threats to national order and security.

4. Possible effects in Bolivia in a scenario of non-renewal of the gas supply contract

Considering that exports are responsible for a 22% share of Bolivia's GDP and that NG sent to Brazil has a majority share in the exported product mix, a first possible negative effect, in a scenario of termination of the NG supply contract, would be a certain economic disorganization in Bolivia's current account balance with likely serious consequences for the Bolivian economy in the short and long terms (IRONS, 2009).

Irons (2009) describes that a fall in a country's GDP could have the effect of reducing public and private investment, increasing the number of people without jobs, and decreasing household income, generating a vicious cycle of loss of economic activity. Other effects pointed out by the author include the area of education, especially for children and youth, since the loss of income discourages families from providing a more adequate educational environment, including not only insertion in good schools and leisure activities, but also health care and food, leading to a delay, or even abandonment, in the plans of young people to enter university. In addition to the effects on families, another consequence of the fall in GDP is the reduction in the level of private investment, which can lead to a fall in the country's production capacity over a long period. Slowing investment may also reduce the capacity to innovate and develop new technologies.

Some countries neighboring Brazil and Bolivia have already had experiences of how the loss of revenues from exports can compromise the country's economy. Here, it is worth mentioning the example of Venezuela. In relation to Venezuela, the example should be cited not to present the internal effects that the economic and political crisis has been causing to the country, but to exemplify how an economic recession in a neighboring country can have important negative effects also in Brazil, including population issues associated with the mass flight of Venezuelans to the Brazilian border.

Venezuela has one of the world's largest oil reserves and energy is practically the country's only source of external revenue, accounting for 96% of the country's total exports. That is, the inflow of money into the Venezuelan economy is almost exclusively dependent on oil exports, subject to variations in price and demand on a global scale (MESQUITA; CORAZZA, 2019). The fall in oil prices in 2014 and the fall in Chinese demand for Venezuelan heavy oil led Venezuela to a sharp drop in revenues, which was one of the additional factors in the economic crisis that took hold of the nation after the death of President Hugo Chaves. According to Mesquita and Corazza (2019), the country is experiencing the biggest recession in its history, with 12 consecutive quarters of economic retraction and a 37% drop in GDP between 2013 and 2017.

Due to the serious economic situation, basic food and medicine are in short supply in most cities of the country, leading thousands of Venezuelans to take refuge in Colombia and Brazil, generating a regional humanitarian crisis that could last for many years.

Brazil borders Venezuela for a total length of 2,200 km. In Roraima, the state that owns most of this extension, the recent entry of Venezuelans, who left their country in search of better opportunities in Brazil, has brought serious consequences for the state. Cambricoli (2018) states that in the capital of the state of Roraima, Boa Vista, the entry of approximately 40,000 Venezuelans between 2017 and 2018 has increased the city's population by 10%.

Without the guarantee of getting a job in Boa Vista and in the absence of capacity of the municipal and state governments to receive the Venezuelan immigrants, they start to live in the public squares of Boa Vista, or even on sidewalks, without any access to bathrooms or drinking water, living on charity in the streets and in rows of restaurants.

There was also an increase in the number of Venezuelan women who became prostitutes as a means of obtaining income while remaining in the city between 2017 and 2018. According to Cambricoli (2018), as direct consequences of this migratory wave in Boa Vista, there has been an increase in the level of degradation observed in the city and an increase in the level of insecurity felt by local residents.

The situation in Venezuela is not only linked to dependence on oil exports. The lack of diversification of its economy, strong dependence on imports, chaotic policies of exchange control and domestic prices, as well as a history of populist, interventionist, and corrupt governments are other factors that have led Venezuela to the present situation.

Unlike Venezuela, Bolivia has diversified its exported products and does not depend exclusively on gas, which, as we have seen, currently accounts for 33% of exported products. However, in a scenario of falling gas exports to its main market, Brazil, and a consequent fall in its industrial activity and eventual economic recession, one can see new migratory humanitarian issues, this time from Bolivians to Brazil, in search of jobs and better living conditions, especially to the state of Mato Grosso do Sul, which holds the largest border with the neighboring country.

5. Resumption of prioritization of bilateral relations

The gas trade partnership between Bolivia and Brazil is characterized as a bilateral relationship whose main characteristic is to provide each other with financial, fiscal, political, and social benefits.

Lopes and Carvalho (2011) state that the construction of bilateral agreements has been motivated by the size of the challenge involved in the relationship involving several nations, such as the slow progress of multilateral negotiations and the frequent impasses that have arisen between nations on some important issues, including the application of non-tariff barriers, differentiated treatment for certain products and many other issues aimed at promoting values such as human rights, full democracy, or sustainability.

In relation to Brazil and its international trade, data from the MDIC (2019b) show that Brazil maintains trade agreements (directly or via Mercosur) only with neighboring countries in South America, with Mexico, Cuba, India, Israel, Egypt, and some countries in Africa. For the small amount of official agreements, Kalout et al. (2018), affirm that Brazil is one of the most closed economies in the world, with very reduced gains in international trade. As a solution, the authors suggest a greater trade opening for the country, reduction of import tariffs, modernization of the regulatory regime, and qualification of labor.

Other literature found (OECD, 2018; WORLD BANK, 2018a) also points out that the gains from greater international integration are related to greater access to capital goods and inputs, at more competitive prices and with modern technologies. The greater openness also enables companies to participate in global value chains, thus increasing their competitiveness and providing substantial gains in job creation and increasing the country's productivity, including more innovation, competitiveness, improved quality of labor, and goods and services offered. The focus on bilateral trade is reaffirmed by the Director-General of the World Trade Organization (WTO), Roberto Azevedo, who also states: "I have said with great frequency that the bilateral path has to be followed and is more effective especially in tariff negotiations and market access" (AZEVEDO, 2019).

Therefore, a renewal of the gas supply and purchase contract between Brazil and Bolivia seems to be in line with the recent propensities to bilateral agreements. The renewal of the GSA would help Brazil not to isolate itself on the world market in the gas industry because of the country's historic vocation for energy self-sufficiency.

6. Trade Balance between Brazil and Bolivia

The commercial partnership relations between Brazil and Bolivia began in the first half of the 20th century, when the Brazilian economy ceased to be fundamentally agrarian and started in an industrial direction. However, despite some attempts at cooperation between the two countries in the past, it was only through GASBOL that cooperation, in fact, materialized.

Data from IBCE (2019) indicate that with the construction of GASBOL and the development of NG exports from Bolivia to Brazil, this became the main destination for Bolivian exports. In 2018, Brazil absorbed 19% of all products that the Andean country exports, followed by Argentina (13%), India (8%), and Japan (7.5%).

On the other hand, data from the Ministry of Economy, Industry, Foreign Trade and Services of Brazil (MDIC, 2019a) indicate that the commercial volume exchanged between Brazil and Bolivia is still much lower than the other countries with which Brazil has commercial relations. As shown in Table 1, Bolivia, in 2018, was not even among the first 30 countries to trade most with Brazil.

Table 1: Ranking of the countries that exported the most products to Brazil in 2018

Ranking	Country	Value (USD MM)	Participation
1st	China	63930	26.7
2nd	United States	28697	12
3rd	Argentina	14913	6.2
4th	Netherlands	13060	5.5
5th	Chile	6693	2.7
...	...	...	...
37th	Bolivia	1453	0.6

Source: Elaborated by the authors based on MDIC (2019a).

When comparing the values of bilateral relations between Brazil and Bolivia, it can be seen that NG exports practically finance Bolivian imports of Brazilian goods and this has been done with a certain commercial surplus for Bolivia. Among the items exported by Brazil to Bolivia, the highlights are manufactured or semimanufactured products, especially iron ingots, refined bitumen, electric conductors, tractors, locomotives, wooden furniture, rice, shoes, and fungicides (MDIC, 2019a).

The Brazilian trade balance with Bolivia is sometimes in surplus and other times in deficit. In 2016 and 2017, with the reduction in volumes and price of gas imported from Bolivia, the trade balance became a surplus. In 2018, the balance was again negative for Brazil, although with a much smaller margin than those seen in years prior to 2016 (ITAMARATY, 2019).

However, even these deficits recorded against Brazil in bilateral trade relations with Bolivia must be analyzed with a more positive and strategic bias. First, these are amounts that pose no threat to Brazil's trade balance aggregate. Second, it must be agreed that this represents a certain natural order in trade relations between two economies with such distinct patterns of development, that is, Bolivia as a nation that exports natural resources and Brazil in search of energy sources that promote its plans for growth and industrial modernization, especially in its South and Southeastern regions.

In this sense, it must be emphasized that NG is the only element that permits a certain irradiation of Brazilian economic strength beyond the frontier, promoting the inclusion of Bolivia in a regional economy under construction. With this perspective, it is only to be regretted that the commercial agenda between Brazil and Bolivia is still quite timid, and therefore there is room for new strategies that could increase bilateral commercial transactions.

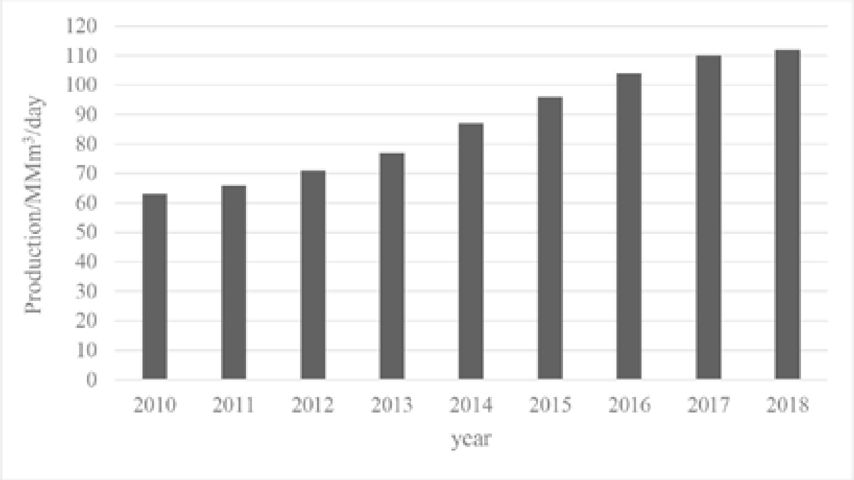
7. The prospect of increasing national production: The pre-salt gas

The year 2006 represented a historic milestone for Petrobras' offshore exploration activities in Brazil in relation to its investments in new oil fields in the country. That year, below the thick layer of salt in the Tupi Field (currently Lula's field), the existence of an extensive oil system with great capacity to generate high quality hydrocarbons was confirmed, revealing a new exploratory frontier with significant volumes of oil and NG (PEDROSA; CORRÊA, 2016).

From this field, the exploratory activities did not stop, and then other systems were identified, always below the salt layer, mainly in the Santos, Campos, and Espírito Santo basins. According to Guedes (2016), this new geological frontier, called pre-salt, corresponds to an area of approximately 800 km long and 200 km wide in the oceanic area of the states of Santa Catarina, Paraná, São Paulo, Rio de Janeiro, and Espírito Santo.

After overcoming technological challenges for the extraction of hydrocarbons from the pre-salt layer, domestic production of both oil and associated NG (given the gas-oil ratio of the reservoirs) grew systematically between 2010 and 2018 (ALMEIDA; COLOMER; VITTO, 2017). Almost ten years after the first discoveries in the pre-salt, Brazil produced, in 2018, an unprecedented volume of NG equivalent to 112 MMm^3/day, of which 45% (50 MMm^3/day) corresponded to the volume of gas extracted from the pre-salt reserves (MME, 2019a). Figure 4 shows the evolution of Brazilian domestic NG production between 2010 and 2018.

Figure 4: Evolution of the national gross NG production



Source: Elaborated by the authors based on MME (2019a).

The average gross national NG production has grown 77% in the last eight years, rising from 63 MMm3/day in 2010 to 112 MMm3/day in 2018. This strong expansion can be attributed to the recent technological innovations that made NG exploration in the pre-salt region possible (TOLMASQUIM, 2016).

Regarding the transportation of NG from the pre-salt to the Brazilian market, this gas is flowed through two large submarine pipelines: the Route 1 pipeline, in operation since 2011, with a flow capacity of 20 MMm³/day and the Route 2, which started operating in 2016 and has a flow capacity of 13 MMm³/day. With 401 kilometers of extension, Route 2 is the longest submarine pipeline in operation in Brazil (GUEDES, 2016).

In addition to the two pipelines already in operation, Petrobras has begun the construction of a third pipeline, called Route 3, which will drain the NG from the pre-salt region of the Santos Basin to the Petrochemical Complex of the State of Rio de Janeiro (Comperj). The Route 3 gas pipeline project is 355 km long and has a transportation capacity of 18 MMm³/day (MESQUITA; GUIMARÃES; VERGARA, 2018).

On the private side, the private company COSAN has been developing the project of a fourth route for the pre-salt NG flow, connecting the Santos Basin to the coast of the state of São Paulo, with a capacity of 15 MMm³/day. The objective of this pipeline is to supply gas to the municipalities of Baixada Santista and others that are under concession from the distributor Comgás (ZANARDO, 2015).

Regarding the future planning of an internal NG supply, the Brazilian government, through its Decennial Plan for Energy Expansion (PDE 2027), signals an average daily production of 220 MMm3/day for the year 2027 (EPE, 2018). This will correspond to a growth of 97% in relation to the 2017 production.

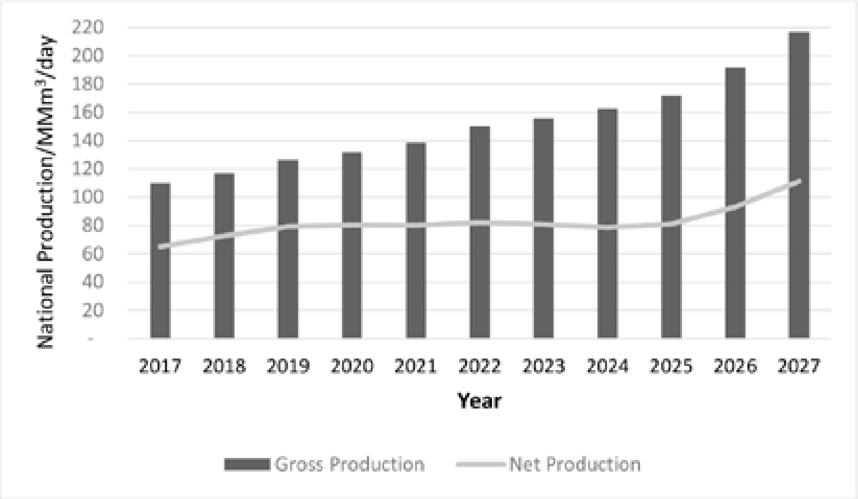
According to the PDE 2027 (EPE, 2018), the domestic production related to the pre-salt fields will have a very significant share in the increase of NG volume, reaching a share of 78% of the total Brazilian production volume forecasted for the end of 2027. The government still plans that the Campos and Santos basins, together, will correspond to approximately 92% of the total NG production forecasted for 2027.

Thus, recent evolutions and future expectations of internal NG production in Brazil impose a reflection on the Brazilian potential to become self-sufficient in NG production in the future, thus eliminating the need for fuel importation, mainly from Bolivia. However, as will be seen below, the consolidation of this increase in the Brazilian internal production and the way for such volume to reach the Brazilian domestic market are faced with some challenges that public and private agents must consider.

7.1 Challenges to the production of Natural Gas from the pre-salt

When one analyzes the Brazilian government's planning regarding the net NG production, that is, the volume of gas available in the NG Processing Units after discounting from the gross production the volumes referring to injection processes in the reservoirs, losses or flaring and proper consumption in the exploration and production processes, one can see that the net production does not follow the estimated gross production, as shown in Figure 5.

Figure 5: Indicative of the expansion of gross and net national NG production in Brazil



Source: Elaborated by the authors based on EPE (2018).

According to the PDE 2027 (EPE, 2018), the projected net NG production growth for the next ten years corresponds to 70%, rising from 65 MMm³/day in 2017 to 111 MMm³/day by the end of

2027. The difference observed between gross production and net production occurs mainly due to the high rates of gas reinjection to increase oil recovery that are considered for the ten-year period in question.

Bernardes (2018) points out that the alternative of gas reinjection in the offshore oil fields can be adopted whenever there is need. However, according to the author, once the reinjection of the gas becomes technically unfeasible and the commercial use of the gas is not possible, the producing companies will not be able to exploit the pre-salt oil fields.

In order to adopt a better management of the production fields and, eventually, restrict (or contain) the high volumes of NG expected to be reinjected in the wells, Almeida, Colomer and Vitto (2017) emphasize that the economic viability of using the pre-salt gas and, therefore, the increase in domestic Brazilian production, will depend on the necessary investments for the treatment, flow, and processing of NG for sale to the domestic market. The authors emphasize that this gas has certain technical particularities in relation to traditional Brazilian reserves and that they result in high production costs.

The first challenge regarding the future increase of NG production in the pre-salt layer is the considerable presence of contaminant concentrations in some regions, particularly carbon dioxide (CO_2). According to Beltrão et al. (2009), the occurrence of CO_2 in NG may make it impossible to transport crude NG to the Brazilian coast, since this “contaminant,” in the presence of traces of water, produces carbonic acid (H_2CO_3) which causes a tendency of greater corrosion in the NG transportation pipes.

According to D’Almeida et al. (2018), the CO_2 concentration in the pre-salt fields that are already in production in the Campos and Santos Basins corresponds to an average value of 0.5% in volume. However, in some of the most recent prospecting areas, CO_2 concentrations are quite high, ranging from 5% to 80%, values well above the limits imposed by the ANP for the commercialization of gas, defined by a maximum value of 3% in volume (ANP, 2008). Therefore, the conversion of these gross gases with high CO_2 concentrations into a specified NG for the domestic market requires important additional investments from producers for

CO_2 removal. Currently, the removal of CO_2 is performed through physical or chemical processes, such as chemical absorption, membrane permeation, absorption, cryogenic distillation, and even hybrid processes, whose selection of technology depends on the flow and composition of the NG to be treated (EPE, 2019b).

Regardless of the unitary operation used, its implementation will require investment costs and the feasibility of logistic space for its installation on offshore NG extraction platforms, and these costs should be reflected in the final price of NG sales. Rochedo et al. (2016) and Almeida Colomer and Vitto (2017) state that the available technologies for CO_2 removal, due to their high implementation and operation costs, require the treatment of large volumes of "contaminated" NG. However, eventual economies of scale end up being limited by logistical constraints, since large separation units take up a lot of space on extraction platforms, especially when expansion of existing separators is required. Thus, the producer needs to do trade-off studies whose results may make the production and commercialization of this gas technically/economically unviable.

A second challenge to be mitigated refers to the cost of transporting gas from pre-salt wells to an NG processing plant located on the Brazilian coast. According to Albert et al. (2011), the costs embedded in a pipeline project are a function of several variables, such as the volume and composition of the gas to be transported, pipeline depth, water temperature, topography at which the pipelines will be installed, and the length of the pipeline. In relation to the pre-salt fields, the costs of runoff are impacted by two main factors: the location of the fields in deep water, which demands a greater thickness of the transportation pipes to withstand high pressures, and the enormous distance between the pre-salt areas and the Brazilian coast, which corresponds to an average value of 300 km (EPE, 2019b).

According to Subero, Sun and Deshpande (2004), the estimated CAPEX for the deployment of offshore gas pipelines is between 313 million USD/km and 625 million USD/km. That is, considering the distance of 300 km between the pre-salt fields and the Brazilian coast, the cost for the construction of future pipelines may vary from USD 94 billion to USD 188 billion. The amounts involved require relevant sources of financing, with high maturation terms. For offshore producers, the cost of opportunities must be considered, since these same investments may make two to four new pre-salt producing wells viable, with returns that tend to be much higher, given the associated additional oil production (MOUTINHO DOS SANTOS, 2019).

In addition, such required investments demand significant volumes of transportation which, on the other side of the pipeline, need to find access to markets for the sale of NG in order to justify and amortize such investments. However, both domestic production and access to transportation infrastructure, as well as sales to distributors are activities that practically belong to a single company, Petrobras.

Even with the regularization of the sector through Law 11,909/2009, known as the "Gas Law," Petrobras continued with the monopoly on the supply of NG to the Brazilian market. According to Sales and Hochstetler (2016), Petrobras is still responsible for 92% of the internal production of NG in Brazil, controls more than 95% of the entire pipeline network in the country, has ownership interest in 19 of the 27 gas distribution concessionaires present in Brazilian territory and is still responsible for 52% of all the installed power of thermoelectric plants powered by NG in the country.

This monopoly of the Brazilian state-owned company on the transportation infrastructure and its participation in the distributors does not encourage the entry of new producing agents that could contribute to the increase of the Brazilian domestic production and to a greater competitiveness of the NG sector in Brazil. Despite the Brazilian government's plans to extinguish the Petrobras monopoly in the gas value chain within a market-opening program, this situation of exclusivity of the Brazilian state-owned company still persists in the country.

8. The price of Bolivian gas as a competitive factor for Brazil

Besides the geopolitical and commercial aspects between Brazil and Bolivia, another relevant factor to be considered in discussions regarding the maintenance (or not) of Bolivian gas supply to Brazil refers to the price charged for this imported resource. Negotiations regarding the price to be charged for the gas to be consumed by Brazil were discussed between the governments of both countries.

In any case, this figure should be compared to other gas supply alternatives for Brazil. According to Filgueiras (2009), because gas does not have a captive market, the sensitivity of its demand is relatively high due to price, that is, consumers are always aware of the costs of this energy source in an attempt to preserve its competitiveness. Once it is not competitive, consumers may have the option of replacing it with other supply alternatives or even with other energy sources. Thus, price policy among competitors that offer NG is an important variable to guarantee a consumer market.

In Brazil, the pricing of LNG is indexed, mainly, to the basket price of oil on the international market and is practiced in three main pricing modalities (MME; ANP; EPE, 2016; INSTITUTO ACENDE BRASIL, 2016):

i) TCQ Tariffs (Transportation, Capacity, and Quantity)

A mode initially adopted by Petrobras, whose pricing is separated between the value of the molecule, whose value is differentiated between the national offer and the imported offer, and the value of transportation, which is a function of the distance transported. The price of the molecule is indexed to the international prices of petroleum, while the portion referring to transportation depends on the origin of the natural gas: in the case of the national, the value of transportation is indexed to the General Market Price Index (IGPM); and in relation to the Bolivian imported gas, the transportation tariff is readjusted, annually, by 0.5% plus the exchange variation of the period (CECCHI, 2002).

ii) Tariffs for thermoelectric generation

An exclusive tariff for the supply of gas to thermoelectric plants and established by the Priority Thermoelectric Program (PPT), implemented in 2000.

iii) NPP Tariffs (New Price Policy)

A mode that was introduced by Petrobras in 2007. As in TCQ, there are two parcels in the NPP Tariff, one referring to the molecule and the other to transportation. The main difference, however, is that in NPP, the transportation parcel became uniform throughout the country, regardless of the origin of the gas and the point of its withdrawal. The portion related to the molecule continued to be indexed to international oil prices. However, in 2011, Petrobras adopted a policy of discretionary discounts in the NPP that changed the dynamics of pricing. This was called the New Policy Renegotiated Firm Modality (*Nova Política Modalidade Firme Renegociado*).

The NPP modality without discount made the national gas more expensive than the product imported from Bolivia and also less attractive than fuel oil. To respond to the sharp drop in industrial activity that began in 2010, industrial consumers were trying to regain competitiveness by migrating their energy mix to fuel oil and biomass.

Data from the period of June 2012 to December 2018 (MME, 2019a) shows that until the end of 2015, the price of Bolivian gas was lower than the price of Brazilian domestic gas of the NPP modality without discount and higher than NPP with discount. However, since the end of 2015, when the price of oil reacted again in global markets, the discount is no longer applied on prices contracted under the NPP mode. Once again, Bolivian imported gas has regained competitiveness in relation to Brazilian domestic gas. The biggest difference between domestic and Bolivian gas in this period is in 2017, when the average price of Bolivian gas was sold at 6.0 USD/MMBtu and the price of domestic gas sold at 8.0 USD/MMBtu.

According to data from the Ministry of Mines and Energy (MME, 2019a), the average price of gas imported from Bolivia in 2018 was USD 5.35/MMBtu at the entrance of Brazil. When adding the transportation cost of the GASBOL pipeline, the Brazilian distributors paid an average price of USD 7.34/MMBtu. Still in 2018, the average value paid for the gas produced in Brazil, together with transportation, corresponded to 7.79 USD/MMBtu (Firm Mode) and 8.87 USD/MMBtu (Renegotiated Firm Mode), thus registering, on average, a difference of 0.45 to 1.53 USD/ MMBtu in favor of Bolivian gas.

In more current values, Table 1 presents the average price of NG practiced by Petrobras for the local distributors referring to the month of February/2019, released by the MME (2019a).

Table 1: Average Petrobras Price for Distributors in February 2019[3]

	Imported Gas			**New Policy Firm Modality**			**New Policy Renegotiated Firm Modality**		
Average Price Brazil (USD/ MMBTU)	Transport	Molecule	**Total**	Transport	Molecule	**Total**	Transport	Molecule	**Total**
	1.99	6.75	**8.75**	2.12	7.55	**9.67**	1.64	9.08	**10.72**

Source: Elaborated by the authors based on MME (2019a).

At the end of February 2019, the average price difference between Bolivian and national gas was even greater than the 2018 average. Each MMBtu of gas produced domestically in Brazil has a price higher than Bolivian gas of USD 0.91 (10.5%) to USD 1.97 (22.5%), in relation to the firm modality without discount and renegotiated, respectively.

Only as a demonstrative effect, assuming the latter price disclosure, and considering a hypothetical transaction of acquisition of 20 MMm^3/day of domestic gas, such a purchase option would represent an additional annual cost for the Brazilian consumer of USD 240 million to USD 513 million due to the non-discounted and renegotiated modality, respectively.

For the Brazilian industries consuming natural gas, such as the chemical and fertilizer sector, which uses gas as raw material, the cost of fuel can represent up to 30% of all productive operational costs (TOLMASQUIM, 2016). Therefore, the price factor becomes an important item when analyzing a new supply policy that

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[3] Simple regional averages (not weighted by volume). Prices free of taxes and charges. Four Distributors have a contract of the type New Policy Firm Modality (Algás, Cegás, Copergás and Sulgás); 13 Distributors have a contract of the type New Policy Renegotiated Firm Modality (Bahiagás, BR distribuidora-ES, Ceg, Ceg Rio, PBgás, Potigás, Sergás, Comgás, Gasmig, São Paulo Sul, Gasbrasilia-no, Compagás, Msgás); 5 distributors have a contract of the type Imported Gas (Bolivian) (Msgás, Comgás, Compagás, Scgás and Sulgás).

eventually privileges the substitution of Bolivian gas importation by Brazilian domestic production.

Considering a new Bolivian gas supply contract from its expiration date, since all GASBOL infrastructure will be ready with its construction cost fully amortized, the prices practiced by the Bolivian gas and the supply terms for the consumers may become quite competitive in relation to other supply options.

Regarding the national gas originating from the pre-salt, its price to the final consumer still seems to be unknown. The presence of high concentrations of CO_2 and the need to install and operate plants to separate this impurity, combined with the construction of new pipelines to transport the NG at an average distance of 300 km from the Brazilian coast, will reflect on the production and logistics costs and, consequently, reflect on the selling price.

Although the scenario is of greater incentive to NG, this source will hardly reign alone in a country that boasts the presence of a diversified energy mix with high participation of renewable energy sources. Political forces in pro-gas Brazil have always had underlying roles, and integrated resource planning has never exalted gas to the detriment of other established sources.

About the future of this domestic political context, there are still many uncertainties. On the one hand, there is a commitment by the federal government to propose a New Gas Market that is more attractive to investments. On the other hand, it must be questioned whether the absence of Petrobras as a leading company with developmentalist characteristics is not detrimental to anchoring a new cycle of expansion of the gas industry in Brazil.

9. New Natural Gas Market in Brazil and the Public Call GASBOL

As already discussed in this chapter, Petrobras holds the monopoly on gas production and transportation, which has been maintained since the 1950s. However, in the second half of 2019, the federal government announced a program to open the gas sector in Brazil that is unprecedented in the country (MME, 2019b). Called the New Gas Market program, this opening process is composed of a series of actions to increase NG investments in Brazil, through the diversification of the number of companies operating in this segment and the increase of NG supply from the pre-salt. Among the actions foreseen in this program is the withdrawal of Petrobras' monopoly in the gas value chain, including the sale of assets and the opening of the fuel transportation infrastructure to other gas supply companies.

In addition to Petrobras' departure as the sole agent in the NG sector, the program also includes the revision of the sector's tax model, actions to encourage gas consumption and a new legal framework to support the greater insertion of free consumers, who can negotiate the acquisition of gas without the intermediation of the product's distributors. MME agents believe that these market opening actions will provide a reduction in the final price of NG of up to 40% by 2022 (MME, 2019b).

The New Gas Market program, despite being in its initial phase of development, shows, a priori, a clear vision of the Brazilian government regarding the intention of increasing the participation of gas in the Brazilian energy mix. The entry of new producing agents and a possible drop in prices could have positive consequences on the national economy, such as a reduction in the industry's energy costs.

According to Wagner (2019), the high costs embedded in the production processes, including energy costs, have undermined the level of competitiveness of domestic manufacturers in the last ten years, which in turn have lost space to imports. According to the MME (2019b), this "cheap energy shock" in the industry could collaborate with 8.5% growth in the country's industrial GDP.

The foreseen plan to break the monopoly of Petrobras includes the sale of the participation of the Brazilian state-owned company TBG, owner of GASBOL, and also the loss of the exclusivity to contract the Bolivian gas, as will be discussed below.

Although the official date of termination of the gas-supply agreement by GASBOL is at the end of 2019, the Brazilian government foresees the maintenance of the maximum contractual quantity (30 MMm3/day) until the year 2021, due to the existence of a compensatory volume, called make-up, due to the withdrawal of gas inferior to that contracted in the take-or-pay clause in certain periods, which allows the extension of the contract automatically until the end of the complete withdrawal of the remaining volumes, which should occur at the end of 2021 (EPE, 2018).

In compliance with these deadlines and a joint request from the distributors present in five Brazilian states, which are served exclusively by gas transported via GASBOL (Compagas/PR, GásBrasiliano/SP, MSGás/MS, SCGás/SC, and Sulgás/RS), TBG launched in 2017 a public call to contract a GASBOL capacity of 18 MMm3/day, starting in 2020, thus opening an opportunity for the winners to sign new NG transportation contracts with TBG (ANP, 2018).

In addition, the Bolivian company YBPF started to consider a direct negotiation with current consumers and new gas clients in Brazil. The initial volume considered by YBPF is equivalent to an excess of at least 4 MMm³/day referring to the reduction of the volume imported by Petrobras, which has been taking place since 2017 (MME, 2019a).

In addition to the interest in the distributors served by GASBOL, TBG's public call may involve private energy companies operating in Brazil. At the end of 2018, the energy company, Shell, signed a memorandum of understanding with YPFB for the acquisition of 4 MMm³/day, until the end of 2022, and 10 MMm³/day after 2022. The interest materializes as GASBOL's capacity becomes available in the context of the end of GSA. According to the company, the objective of this agreement is to expand its position as an energy supplier in Brazil (OPETRÓLEO, 2019).

Both the public call and the Shell memorandum are milestones that are part of the first steps towards the imminent opening of the gas market in Brazil. After 20 years of contract between YPBF and Petrobras, where tariffs remained locked between the two companies, direct agreements with Bolivian producers can give more flexibility to energy prices (EPBR, 2019).

10. Conclusion

After 20 years of execution, the contract for the supply of natural gas from Bolivia to Brazil officially ended in December 2019. This chapter presents some elements for discussion on the renewal of the Bolivian natural gas supply contract, in the context of a possible increase in domestic NG production with the new pre-salt reserves. It should be noted that this chapter was not intended to give an answer about the renewal of the contract, but to provide subsidies for reflection on the subject.

Brazil's relationship with Bolivia is important for both countries in the field of energy and cross-border cooperation. Of course, the added value of the trade carried out is much more relevant from a Bolivian perspective. This bilateral relationship gains geostrategic importance when considering the extensive dry border between the two countries (3,423 km), the largest border in Brazil, and the potentials that can still be jointly explored in industry, commerce, and the fight against international crime areas.

The prospect of economic growth in any nation is directly related to an energy supply to serve the transportation and production sectors. In this sense, South America has an abundance and diversity of energy resources and both Bolivia and Brazil have a privileged geographic location for a broad energy integration in the continent.

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Chapter V

Small-scale compressed and liquefied natural gas distribution systems

Denis Martins Fraga
Drielli Peyerl
Edmilson Moutinho dos Santos

1. Introduction

The first natural gas transportation pipeline infrastructure system in Brazil is dated back to 1974 with the Atalaia – Santiago/Catu system, aiming at the coastal areas of northeastern states, totaling 230 km in extension (EPE, 2016). However, in the following 20 years, the whole pipeline system did not experience a significant increase in extension.

In the years 1999/2000, with the commissioning of the natural gas transportation pipeline connecting Bolivia and Brazil (GASBOL), the system observed an addition of 2,593 km of pipelines (30 MMm^3/day capacity). It is worth mentioning that this project also encompassed 557 km of pipelines within Bolivia. Due to this significant project, the natural gas sector experienced a substantial increase in investments and supply. Following that, another stagnation period is observed between 2001 and 2006, along with not as robust of an increase in extension, when compared with GASBOL, as a result of the Massification Use of Natural Gas Plan from Petrobras (PENHA, 2014).

It is also worth highlighting the construction of the GASENE system, composed of 1,315 km of pipelines, which connect the Southeastern and Northeastern regions of the country. This system has a section from Cabiunas (RJ) to Vitória (ES), from Vitória (ES) to Cacimbas (ES) and from Cacimbas (ES) to Catu (BA) (GASNET, 2006). Currently, Brazil has 9,244 km of transportation pipelines in which 8,582.8 are interconnected (EPE,2016) and had provided average daily flowrates, up to April 2018, of 79.77 M m^3/day (MME, 2018).

As no significant expansion of the transportation pipeline systems is predicted (EPE; MME, 2014), the dilemma of the lack of infrastructure for the transportation and distribution of NG towards the indigenous market off the grid is observed. Due to that dilemma, one can think of alternatives to the conventional transportation pipeline system to meet the off-grid regions. Small-Scale Compressed (CNG) and Liquefied (LNG) NG distribution systems are two of those alternatives.

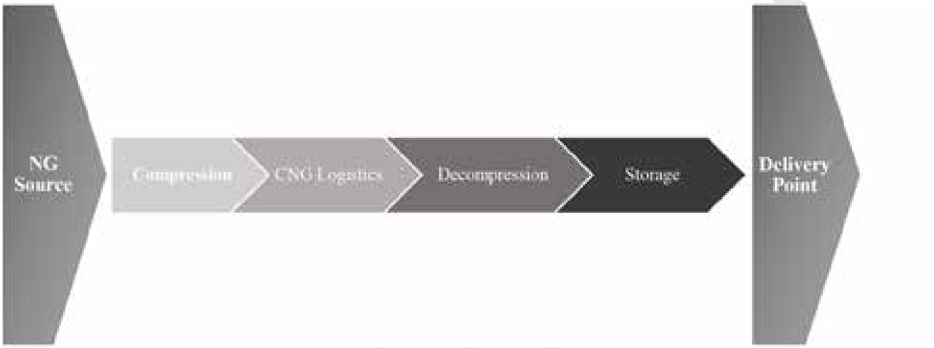
The distinct volumetric ratio of NG in small-scale CNG and LNG, respectively 200:1 m^3 and 600:1 m^3, along with the particular pressure and temperature related to each transportation mode allow different levels of NG distribution. For instance, CNG operations in Ivory Coast are around 2,000 to 6,000 m^3/day (POULALLION, 2016), whereas the low boundary of small-scale LNG is 0.1MTPA, which is equivalent to approximately 320,000 m^3/day.

This chapter presents the key elements of the transportation chain of natural gas via compressed natural gas (CNG) or small-scale liquefied natural gas (LNG), with literature values, as well as with market agents, training in planning and management of batchwise NG systems (CNG and LNG) and last but not least, technical visits to two LNG importation terminals located in both Portugal and Spain. It is also envisaged to review the state-of-the-art technologies and methods of this alternative transportation of NG studied and define the main elements of investments, operational expenditures, maintenance, and operational capacities.

2. CNG definition and characteristics

In a technical procedure issued by the national regulator (ANP), the CNG operations are defined by the elements of acquisition, reception, compression, loading, transportation, unloading, trade and quality control (ANP, 2007). It is assumed that this procedure proposed by ANP encompasses absolutely all the activities related to NG from acquisition to trade in the compressed way. Therefore, and also as suggested by López Bendezú (2008) and Poulallion (2016), one can characterize the CNG value chain as compression, logistics, storage, and decompression, which is a sensible composition for the cost assessments and projection. Figure 1 describes these elements and their connections. Also, throughout this chapter, the technologies available, cost figures, both investments and operational, are presented.

Figure 1: Value Chain CNG



Source: Elaborated by the author based on López Bendezú (2008), Poulallion (2016) and ANP (2007).

2.1. Compression Technology for CNG systems

The compression process is formed by the reception of the NG, treatment and compression from 200 up to 250 bars, which results in 1m^3 of CNG being equivalent to approximately 268 m^3 (under normal condition of pressure and temperature) (LÓPEZ BENDEZÚ, 2008; POULALLION, 2016). This NG is acquired compressed within either transportation pipelines, with high pressures ranging from 80 to 100 bars, or distribution pipelines, with low to medium pressures, ranging from less than 1 to 30+ bars. The compression costs are a function of the volumes to be compressed and the pressure gradient to be performed. In this chapter it is assumed the CNG is provided from low to medium pressures.

In order to perform the compression work, there are compressors that can be arranged in a modular way, turning the logistic and fixed facilities less complex and less costly. Those elements are usually composed of entry filters, control valves, electric controls, fire prevention, metering, cooling, condensate recovery systems, and lastly, the compression unit (LÓPEZ BENDEZÚ, 2008).

López Bendezú's (2008) research identified capital expenditures around 1,600 USD/kW, which, adjusted for US inflation to 2018, results in approximately 1,850 USD/kW for a compressor unit with outlet pressure of 250 bars and power of 440kW/h and which has operating pressures of 0.5 to 60 bars. The daily volume output is 100,000 m^3/day. Therefore, the total cost for a compressor unit is estimated at USD 814,154.

In the Ivory Coast case, presented by Poulallion (2016), the capital cost figures were composed of a fixed element of 17,000 Euros and a variable element related to the load and production of the system. Adopting the same currency conversion as stated above, the compression unit capital cost, with daily outlet volume of 100,000 m^3/day, is USD 815,809. Therefore, these two independent studies present compression unit costs of similar values.

Other than those compression unit costs, there are other elements to compose capital cost of the whole system. For López Bendezú (2008), those other elements are related to adaptation and plant works, which could correspond to 20% of the total compressor unit investments. Among the operation expenditures, the main element is the energy cost. This is usually obtained as a function of the power and utilization rate of the compression unit. It is assumed that these overall operational and maintenance expenditures are equivalent to 2% of the total capital expenditure from the compressor unit.

Thus, one can observe the cost matrix for compression adjusted for 2018, as per Table 1, which presents the category of the cost, either capital expenditure (CAPEX) or operational expenditure (OPEX), the description of this element, the value, and the adopted metric.

The key element for capital costs for the compression stage are the variable production costs and compression unit costs. Among the operational expenditure, the energy costs and energy consumption during the compression process are the key variables in terms of impact on the total cost.

Table 1: Investment and operational costs for NG compression

Cost category	Description	Value in 2018 (USD)	Metric
CAPEX	Compression plant fixed cost	18.68	USD/plant
	Compression plant variable cost	11	USD/m^3
	Compressor cost	275	USD/m^3h
	Consumables	3	USD/m^3h
	Load system	21,926	USD
OPEX	Energy Cost	0.18	USD/kWh
	Energy consumption at the Compressor	0.207	kWh/m^3

Source: Elaborated by the author based on Poulallion (2016).

2.2. Logistics and Transportation of CNG

According to information obtained in field research, the CNG logistics requires storage tanks with capacity of transporting high pressure gas, in this case 250 bars, and suitable for mounting in a truck, when this is the selected option. Those tanks are observed either in cylindrical format arranged in a modular way or in a fixed trailer. The latter is less common than the former. The key players in CNG logistics in Brazil are CDGN, IGAS, and NEOGAS, and all of them can operate in both arrangements described above.

The selection of the CNG systems for long distances might not show economic feasibility due to the number of required trailers and, as a result, the equipment that has to be installed at the consumption point. On the other hand, those facilities have to assure maintenance, continuous flow, and storage. The selection of the best arrangement will be a result of the distances and volumes to be supplied, which minimizes the total cost, including total investments and operational costs.

Modular logistics allow the truck to supply more than one consumption point as it can deliver multiple modules to different destinations, depending on the volume required. A truck can usually transport from three to eight modules, each module, as per observed in the Ivory Coast pilot project, has approximately 2,500m^3 capacity of CNG (POULALLION, 2016). The fixed arrangement requires the whole trailer to be parked at the consumption point to be connected to the decompression unit. Therefore, the delivery to multiple consumption points is not a suitable option.

In a conversation with an expert, it has been pointed out that the transfer of the CNG from the transportation modules to the storage modules, allowing the quick re-use of the transportation module, is unfeasible due to the reduction of operational efficiency as this transfer process is driven by the differential pressure between the two modules. In other words, at the moment in which the pressure equilibrium is obtained, the amount of CNG transferred from the transportation module to the storage module is lower than the total amount from the transportation module. Therefore, the volume allowed for consumption in this symbolic operation is lower than if the whole transportation module were made available at the consumption point, which is the practice of the industry. To conclude, once the transportation module reaches the low level, another module replaces the depleted module.

At the logistics stage, the main costs are related to the capital requirements for the acquisition of transportation tanks, with capacity varying from 2,000 m^3 to 10,000 m^3, depending on the system arrangement adopted, either modular or fixed (LÓPEZ BENDEZÚ, 2008). The second capital cost driver is related to the CAPEX of trucks required for the operation. Among the operational expenditures, the cost of drivers and fuel are the key elements, as highlighted in Table 2, which compiles the information from López Bendezú (2008) and Poulallion (2016).

Table 2: CAPEX for CNG Logistics by truck

Item	Description	Value (2018 USD)
Total transportation capacity CNG	from 2,150m^3 to 10,050m^3	from 4.65/m^3 to 6.14/m^3
Truck	Vehicle for module transportation	30,000/truck
Transportation Module	Cost per liter capacity of the module	27/nominal cylinder (m^3)

Source: Elaborated by the authors based on López Bendezú (2008) and Poulallion (2016).

The operational transportation cost can be composed as per presented by Poulallion (2016), including driving, maintenance, and tire replacement, in addition to fuel consumption. Table 3 describes these elements.

Table 3: OPEX for CNG logistics by truck

Item	Description	Value (2018 USD)
Operational Cost	driver, maintenance, tire replacement	0.29/km
Diesel consumption	Vehicle for module transportation	25 liters/100km
Diesel Cost	Cost by liter of diesel	1/liter

Source: Elaborated by the authors based on Poulallion (2016).

2.3. CNG storage and Decompression

The decompression stage is formed by the reduction of the NG pressure, metering, odorization, and heating of the NG, following the specification demanded by the consumption point. The sizing is dependent on the levels of demand and storage of NG (LÓPEZ BENDEZÚ, 2008).

It has been noted, in discussion with an expert of the sector, that it is crucial that the decompression system be reliable during the operations. Reliability at this stage is defined by providing a supply of NG without unexpected interruptions and with high control standards. This reliability assurance might result in the system operator having the ownership of the equipment installed at the consumption point, this arrangement always being subject to regulation obligation and the characteristics of the consumption point. The latter is often determined by the local distribution company (LDC).

The storage element is related to the number of hours of supply redundancy required by the consumption point and to the arrangement of the supply cylinders. In the case of the modular arrangement, a second module is installed at the client's property and enables operation independently of the trailers. For the fixed trailer arrangement, the trailer itself is left at the consumption point.

It is worthwhile to note that the distance between compression and delivery and hourly volume demand play a substantial role in dimensioning the size of the storage and decompression system.

The distance directly impacts the operation time estimates, resulting in more or fewer modules required. The latter is related to the number of modules that have to be left at the consumption point (POULALLION, 2016).

Table 4 compiles the capital and operational costs reported in the Ivory Coast pilot project (POULALLION, 2016) and from López Bendezú (2008) for the storage and decompression stage.

Table 4: Investment for CNG storage and decompression

Item	Description	Value (2018 USD)
Investment	Fixed at consumption point	10,000
	Metering	$10/m^3$
	Variable at consumption point	63,470
	Other (management, freight, packing, insurance, and safety)	30% of the total investment per year
Operational Cost	Maintenance	3% of investment
	Manpower	13,000/employee

Source: Elaborated by the authors based on López Bendezú (2008) and Poulallion (2016).

3. LNG definition and characteristics

The LNG is characterized by the cooling of NG up to cryogenic temperatures, around -163° Celsius, which results in a volumetric ratio of 1:600 (e.g. $1m^3$ is equivalent to $600m^3$ of NG), when compared to NG at standard temperature and pressure. Before the cooling process, the stages of purification and obtaining dehydrated NG are performed, thus avoiding the risks of generating hydrates, freezing, desulphurization, decarbonation, and the removal of mercury and helium, with the aim of reducing the risks of corrosion (due to, for example, the formation of C5+24, abrasive particles with a high potential of damaging the aluminum pipes and equipment) (MANOEL, 2006).

After the treatment steps described previously, the cooling process takes place and occurs in two steps. The first reduces the temperature of the NG to -20°C/-30°C and the second reduces the temperature even further, by using cooling refrigerants (nitrogen and condensates) thus reaching the temperature of -160ºC. This cooling process is enabled by exchange heaters, which are composed of spiral tubes with an enormous exchange surface. Usually those tubes are 4 meters in diameter and 60 meters in height (BRET-ROUZAUT et al., 2011).

The LNG industry has experienced fast development worldwide mainly due to the capability of diversifying the NG supply for one particular region along with the growing importance of NG in the energy mix amid processes of transition of energy consumption toward less carbon-intensive sources. For instance, the replacement of heavy oil and coal for electricity generation to NG-fueled power plants. This shift aims to contribute to the reduction of greenhouse gas emissions as per the 2016 Paris Agreement. The LNG supply grew at 7% annual compound growth rates (ACGR) up to 2000 and 7.8% afterwards.

Countries such as Australia, Nigeria, Trinidad and Tobago, and The United States have shown significant growth as suppliers of LNG to the global markets. Those rates might lead these countries to a greater share than the current biggest supplying country, which is Qatar. From the demand side, Asia is the main market, accounting for 70% demand. China is being positioned to be the second biggest importer, just behind Japan. In terms of trading, it is expected the total volume of LNG trade will surpass the pipeline traded amount by 2035 (DA SILVA et al., 2017).

The small-scale LNG (SSLNG) is characterized by the smaller production capacities from the liquefaction and regasification plants, with interval capacity ranging from 0.1 to 1 million tonne per annum (MTPA). There is also micro-scale LNG, which encompasses capacities lower than 0.1 MTP (IGU, 2015).

Assuming this category placement, this chapter focused only on SSLNG and defines its value chain as liquefaction, logistics, regasification, and storage. Therefore, micro-scale LNG (e.g. lower than 0.1 MTPA) and conventional LNG (greater than 1MTPA) are not considered.

According to Biscardini, Schmill, and Del Maestro (2017), the main end uses of SSLNG are ship and truck fueling and power generation for areas which are off the NG pipeline grid. The growth of SSLNG demand is dependent on the price gap between LNG and the barrel of oil. In the supply-growth scenarios proposed, one can observe a 24% growth of the SSLNG supply in the conservative version (e.g. LNG at USD 9/MMBtu; Oil at USD 50-60/Barrel) and, for the optimistic version, 100% growth (e.g. LNG at USD 3-4 MMBtu; Oil at higher than USD 90/Barrel). At the denominated realistic version, the expected growth is 75% (e.g. LNG at USD 5-8/MMBtu; oil at USD 70-80/barrel).

Figure 2 illustrates the proposed value chain composed of liquefaction, logistics, storage, and regasification. This value chain, suggested as an integrated and dedicated value chain, is the most applicable to the Brazilian reality, considering the fact that the transportation pipelines are concentrated on the coast, therefore, there are several municipalities lacking an NG pipeline infrastructure. Therefore, SSLNG could allow greater interiorization and universalization of NG uses in the country.

For instance, there is only one SSLNG plant located in the municipality of Paulínia, within the state of São Paulo, where the ownership is split between White Martins and Petrobras. This plant only performs the first two elements of the value chain, the cooling process. Trade is performed by another company, which also operates the logistics and supply mainly to off-grid industrial customers (WHITE MARTINS, 2020).

Figure 2: SSLNG Value Chain

Source: Elaborated by the authors. Adopted from IGU (2015).

The SSLNG logistics can have multiple configurations, including small-scale ships, barges, trains, and trucks. As well as being used for truck, train, and ship fueling and other end users.

One example to illustrate that logistics don't always take place from the small-scale liquefaction plant has been observed in two technical visits to LNG importation terminals in Portugal and Spain. Both terminals perform the storage and regasification on the conventional LNG scale and are connected to the NG pipeline grid. On top of that, they have facilities to perform truck loading to transport LNG to off-grid areas (FRAGA; LIAW; GALLO, 2017).

Yet in discussing the possible arrangements of the value chain, one can assume that multimodal transportation of LNG, in Brazil, could take place starting from the existing importation terminals on the coast, both floating and fixed. Penha (2014) describes the construction and commissioning phases of three of those terminals all floating at Pecém port (CE), Baía de Guanabara (RJ), and Baía de Todos os Santos (BA).

Those coastal terminals perform regasification (e.g. turning LNG back to the gaseous state) on floating vessels with the exclusive function of supplying NG to meet power generation from NG-fuelled power plants (PENHA, 2014).

One can observe in Table 5 that those terminals have been operating at high idle capacity, close to 90% from 2016, which could eventually be considered to perform SSLNG logistics (e.g. offloading the LNG to a fixed storage plant nearby the existing terminals)

Table 5: Idle analysis of Brazilian LNG importation terminals

Average import (MMm^3/day)	**2013**	**2014**	**2015**	**2016**	**2017**	**2018 up to April**
Pecém Terminal	3.59	3.65	2.96	1.75	2.15	1.88
Baia de Guanabara Terminal	10.99	10.63	5.16	0.63	0	0
Bahia Terminal		5.64	9.84	1.43	2.91	0.44
Total	14.58	19.92	17.96	3.81	5.06	2.32
Total daily capacity	21	28	28	28	28	28
Idle %	64%	51%	56%	91%	88%	94%

Source: Elaborated by the authors based on MME (2018).

In terms of future developments, all the assessed options were following the same configuration, which is a floating importation vessel connected to a power plant, either single or combined cycle fuelled by NG, and which will be tendered at the energy bidding rounds. In a technical report on LNG importation terminals, EPE (2018) highlights 17 projects in which the average distance to transportation pipelines is 80 km and where most of them demand dredging works to allow conventional LNG ship docking.

This report does not mention the possibility of logistics of LNG by off-grid markets via trucks or any alternative transportation option to the pipeline. Therefore, one can assume that it is possible to consider the SSLNG value chain in order to optimize the idle capacity of the LNG importation terminals.

After the investments required to offload LNG to the coastal area of the country, those terminals could connect local markets to competitive LNG supply options and could distribute this energy source by trucks as observed in Portugal and Spain. This could strengthen the logistics of LNG throughout the country and as a result, increase the share of NG use in the energy mix.

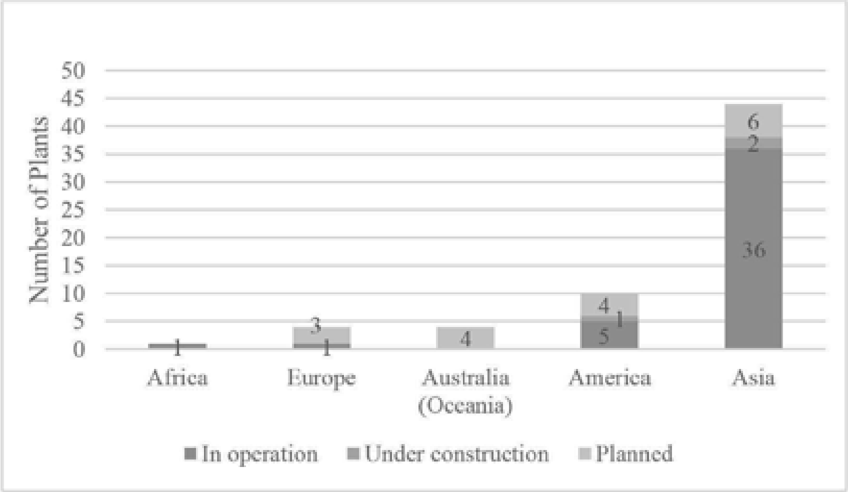
3.1. The NG small-scale liquefaction

In this section, the main characteristics of the cooling process of NG, here called small-scale liquefaction, are presented encompassing the operating units around the world, the adopted technology, and indicative cost figures based on the executed investments and operational costs. These figures were obtained from reports from industry experts and technical visits in Brazil and abroad.

In a report published in 2015, the International Gas Union (IGU) counted 43 operating liquefaction plants, totalling 10.1 MTPA capacity. Among the total, the biggest share is observed in China, with 35 plants and 8.25 MTPA capacity. The second biggest concentration, with 5 plants, was found in the Americas, specifically in the USA, totalling 0.61 MTPA liquefaction capacity. Other continents such as Africa and Europe were reported to have one single plant on each continent with 1MTPA and 0.30 MTPA capacity respectively (IGU, 2015).

In the same report, growth projection was reported for the liquefaction plants from 2014 onwards. In 2014, the expected number of additional liquefaction plants was 20, totaling an additional 11.77 MTPA of liquefaction capacity. The new plants were concentrated in China, with 8 plants and 3.37 MTPA, the Americas with 5 plants and 3.8 MTPA, Australia with 4 plants and 4 MTPA, and Europe with 3 plants and 0.59 MTPA of liquefaction capacity. Therefore, the accumulated amount of existing and expected plants is 63 with 21.93 MTPA[1]. Those expected plants did not have an expected conclusion date. Figures 4 and 5 illustrate the concentration of plants, the total liquefaction capacity and their distribution around the world.

Figure 4: Distribution of the number of small-scale liquefaction plants in the world



Source: Elaborated by the authors based on IGU (2015).

Some actors of the sector such as consultancy companies and technology providers, estimate significant demand growth of LNG, supplied from small-scale liquefaction plants, up to 2030, which could reach values between 75 and 90 MTPA (BISCARDINI; SCHMILL; DEL MAESTRO, 2017).

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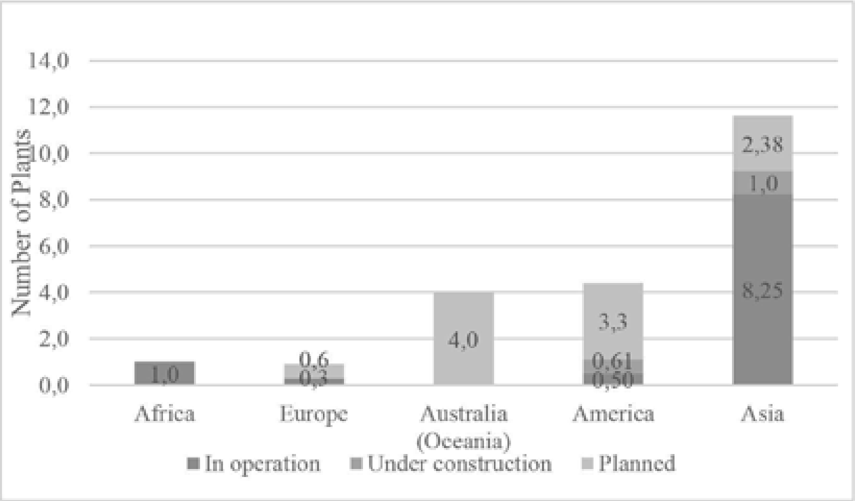
[1] In a report published in 2018, IGU (2018) reports 339.7 MTPA of worldwide liquefaction capacity, including small-scale, and which represents 10% growth when compared to 2015. The total under-construction capacity is of 114.4 MTPA. Therefore, one can conclude that small-scale liquefaction accounts for approximately 6.5% of the total liquefaction capacity in 2015.

Figure 5: Distribution of the small-scale liquefaction capacity in the world



Source: Elaborated by the authors based on Garcia-Cuerva and Sobrino (2009) and IGU (2015).

The incremental capacity of liquefaction of 21.93 MTPA allows one to estimate that the future liquefaction capacity, combined with the existing 10.1 MTPA, could reach 32.03 MTPA (IGU, 2015). This capacity is still smaller than predicted by Biscardini, Schmill, and Del Maestro (2017). Therefore, one can observe that there is still potential for growth of the liquefaction capacity.

The liquefaction of NG occurs by cooling cycles which removes the heat of treated NG (also named *feed gas).* This process can utilize refrigerant cooling gases associated to NG, in an open cycle, or independent cooling gases which feed the heat exchangers in the close cycle. The liquefaction occurs after work is auditioned via compressors and the heat is rejected to the air or water (MOKHATAB, 2013).

The selection of liquefaction technology aims to fit the best cycle or combination of cycles which result in the best fit towards the NG cooling curve, which has varying composition depending on the region, blend, and ultimately the reservoir source. The main technologies available are grouped into three elements: (i) Cascade Liquefaction Process; (ii) Cooling with mixed refrigerants and (iii) Processes based on gas expansion (MOKHATAB, 2013).

Table 6 demonstrates the main manufacturers of those technologies, their pros and cons and main end uses observed in each technology. Processes (ii) and (iii) are the main ones adopted in the operations of small-scale liquefaction (GARCIA-CUERVA; SOBRINO, 2009; MOKHATAB, 2013; IGU, 2015).

Table 6: Liquefaction technology qualitative analysis

Technology	**Pros**	**Cons**	**End-Use**
Liquefaction Process Cascade Variations: Cascade optimized from Conocco Philips and mixed fluid Cascade from Linde and Statoil	Flexible operation Small area for heat exchange and low energy demand Low technical risks and quick deployment	Capital intensive Not adaptable to the NG source Limited terminal capacity	Conventional LNG terminal with capacity higher than 1 MTPA
Single cycle of mixed refrigerants Manufacturer: Black & Veatch, APCI, Linde, Kryopak, Chart, KOGAS and LNG Limited	Operational temperature close to heat exchanger temperature Low quantity of compressor, flexible adjustment of the mixed refrigerants to fit the NG cooling curve Low cost and simple process	Low thermal efficiency High start-up and line-up times due to the mixing of the refrigerants	Small-scale (0.1 to 1 MTPA) Conventional Scale (higher than 1 MTPA)
Double cycle of mixed refrigerants or pre-cooling with single cycle of mixed Manufacturer: Kryopak and LNG Limited	Small area for heat exchange and low energy demand Higher efficiency than the Single cycle	High complexity High quantity of equipment	Small-scale (0.1 to 1 MTPA) Conventional Scale (higher than 1 MTPA)
Cycle based on expansion: Single, multiple or pre-cooling with single cycle Manufacturer: Various, Mustang, APCI, CB&I Lummus	Stable and in high gradient of operating temperature	Low efficiency when compared with the other processes	Small-scale (0.1 to 1 MTPA) Floating liquefaction Plants

Source: Elaborated by the authors after Mokhatab (2013) and IGU (2015).

For the selection of the technology, factors need to be considered, such as the required capacity of the compressors, the available area for the heat exchangers, and a temperature gradient analysis of the region. The first liquefaction plants were conceived by adopting only one technology, therefore, with improvements in technology as a result from the scaling up, the combination of technologies is often observed (MOKHATAB, 2013).

Table 7 demonstrates the information related to investment, in 2018 terms, only for the technologies adopted for liquefaction on small and medium scales, with the minimum value as 371.42 USD/TPA in China and the highest reported value in the literature is 1,591.81 USD/TPA in Australia and Europe. Table 7 also demonstrates the key elements in the operational composition of the liquefaction plants. It is worth highlighting the energy consumption of each technology, which varies from 385 kWh/ton to 557 kWh/ton[2]. The liquefaction capacity range for each technology from 0.1 to 1 MTPA is also observed.

Table 7: Investment costs, energy consumption and technology capacity

Technology	Process	CAPEX USD/ TPA (2018)	Energy Consumption (kWh/ton)	Capacity Range (MTPA)
PRICO Process	Mixed refrigerants	371.42 (China) – 1591.81(Europe and Australia)	415	0.1 – 1.0
Mustang OCX-2	Expansion based		474 - 557	0.5 - 2
LNG Limited OSMR	Single Cycle of mixed refrigerants		415	0.1 – 1.0
Kryopak	Pre-cooling and single cycle of mixed refrigerants		474 - 557	Lower than 0.1
Linde multistage	Single cycle mixed refrigerants		415	0.43 – 2.5
APCI	Single cycle mixed refrigerants	400 (Indonesia) – 600 (Western Australia)	385 - 398	0.5 - 1.0

Source: Elaborated by the authors based on Lee et al. (2001), Mokhatab (2013), IGU (2015) and World Bank et al. (2015).

As described previously, the cost figures are literature based, therefore reflect experts' opinions, mainly reported on technical visits. Therefore, there is a relevant limitation on this figure to allow one to associate each cost figure with each region. This imitates more robust and sound cost estimation and segregation between technologies.

In addition to the material reported in literature, it is possible to compute the liquefaction cost in the only Brazilian plant, at the Gemini Project. The amount invested in the plant, which uses Black

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[2] It is observed in Almeida Trasviña (2016) the optimization of the liquefaction process using mixed refrigerants in which the energetic consumption is reduced significatively, allowing it to reduce the energy consumption up to 4.3%.

& Veatch, which deploys PRICO process, or mixed refrigerant process, was USD 27 million. The plant liquefaction capacity is 380 thousand m^3 of LNG per day.

When converted to the units adopted in the literature one can obtain 0.11 MTPA, which is within the small-scale range adopted. Therefore, the resultant cost of this approximation is 254.57 USD/TPA. This value is from 2004, and when adjusted to 2018 terms with US inflation, it results in 323.44 USD/TPA. This adjusted value is lower than the minimum observed in China with similar technology, suggesting that distortions by exchange rates and/or inflation might have taken place. Nevertheless, this analysis is valid to provide some order of magnitude.

Regarding the operational costs, Lee et al. (2001), Garcia-Cuerva and Sobrino (2009), IGU (2015), and World Bank et al. (2015) describe as key elements of those costs the following: manpower, refrigerant cost, electricity cost, maintenance, general expenses, and insurance. Table 8 compiles this information reported in literature for mixed refrigerant liquefaction plants with values reported in USD and 2018 terms.

Table 8: Typical operational costs of a liquefaction plant with mixed refrigerants

Description	Quantity	Metric	Value (USD 2018)
Manpower (operation maintenance)	57	employee/plant	2,337.46
Refrigerants (ethane)	644	Tonne/TPA	1,640
Refrigerants (Propane)	1544	Tonne/TPA	726
Chemicals (Gas treatment)	-		984,194
Electricity	385 - 557	kWh/tonne of LNG	0.15/kWh
Maintenance	2%	% CAPEX/year	Variable
General expenses	20%	% (of manpower and maintenance)/year	
Insurance	0.75%	% do CAPEX/year	

Source: Elaborated by the authors based on Lee et al. (2001), Garcia-Cuerva and Sobrino (2009), Mokhatab (2013), Igu (2015) and World Bank et al. (2015).

Even with the limitation observed in these cost figures reported in the literature and related to investments and operational costs as per tables 7 and 8, these figures allow one to start the evaluation and assessment of the total cost in a liquefaction plant.

3.2. LNG logistics

This section describes how LNG is transported in the roadways mode, including truck characteristics, cryogenic tank specification, and the key cost of drivers for those elements, reported in the literature and based on the technical visit done to two importation terminals in Portugal and Spain.

The LNG is usually transported in two types of insulated tanks, which are designed to keep the fluid at -163ºC. The first, named conventional, is well known for having no mobility capacity between transportation modes such as ship, truck, and railroads and has a maximum transportation capacity of 42 m^3. The second, named container tank, can store up to 32 m^3 and has high mobility capacity between transportation modes.

One example of this integration is the case of the NG supply of Madeira Island. The island is supplied by NG that comes from an LNG terminal located in Portugal. The logistics take place via container tanks which start their journey being transported by trucks for 159 km towards the Lisbon port. Then the tanks are loaded onto a cargo ship which delivers the tanks to Maderia Island Port. Once there, another truck journey takes place for an additional 39 km to connect the port and a power plant with capacity to generate 450GWh/year, which is the end use of the NG in that case (ALVES et al., 2005; FRAGA; LIAW; GALLO, 2017).

Also, from the same LNG importation terminal, an additional 38 autonomous regasification units (AGU), located between 100 km and 640 km away from the terminal, are supplied by LNG, delivered by trucks and imported from conventional liquefaction plants.

In a visit to the Spanish terminal, of the ENAGAS company, it was possible to observe that 6,740 operations of LNG logistics by trucks took place to 1,033 destinations in 2016. This LNG arrived from four importation terminals around Spain and these operations account for 18% of the total LNG transported. The visited terminal, located in Cartagena, supplied LNG to 201 destinations. One can then conclude, based on those visits, that the LNG logistics by trucks accounted for more than 10 thousand trips per year and, in the Spanish case, corresponded to 18% of the total imported LNG volume (FRAGA; LIAW; GALLO, 2017).

Those small-scale operations started as an additional way of monetizing imported LNG to off-grid regions, where pipeline infrastructures are neither existent nor feasible. Therefore, this configuration can help in easing the idle capacity of storage tanks. In an attempt to transfer th is concept to Brazil, considering most of the importation LNG terminals are located in coastal areas, an investment in transshipment is required to either load trucks or to load storage tanks.

It has also been reported in the literature that the conventional tank capacity can vary from 20 m^3 to 60 m^3. However, the selection of each tank is project specific and should be related to local regulation such as maximum loads allowed in the roads.

It has been verified that both LNG storage tanks have different boil-off rates and robustness levels. The container tank demonstrated a lower boil-off rate (0.13%) and a higher robustness when compared to the conventional tank with boil-off rate (1.13%) (GARCIA-CUERVA; SOBRINO, 2009).

In regard to the trucks, they can be of three axles to fit smaller tanks up to 20 m^3 and with 85% filling capacity. Also, trucks can have more axles to fit higher capacity volume tanks up to 60 m^3. The selection of truck type is dependent on the existing local infrastructure (GARCIA-CUERVA; SOBRINO, 2009; IGU, 2015).

In terms of cost formation, the key elements identified in the technical visit and reported in the literature are highlighted in Tables 9 and 10. Table 9 demonstrates the investment indicatives, by tanks or trucks, as per IGU (2015) and discussion realized on the technical visits (FRAGA; LIAW; GALLO, 2017). All figures are adjusted to 2018 terms and by the US inflation rate, CPI.

Table 9: CAPEX for small-scale LNG logistics

Item	Specification	Value (USD 2018)
Cryogenic Tank	32 m^3 to 40 m^3	175,749/tank
Truck	For tanks from 32 m^3 to 40 m^3	30,000/truck

Source: Elaborated by the authors based on IGU (2015) and Fraga, Liaw and Gallo (2017).

Araújo et al. (2014) analyzed the general context of the transportation of goods by roads in the route of the states of São Paulo and Rio de Janeiro, which represents a significant share of the distribution companies and autonomous works preforming freight operations. The raw data of operational costs was considered in this chapter and is demonstrated in Table 10. These costs are indicative for driver costs, tires, maintenance, and manpower, adjusted to 2018 terms and converted to USD.

The international literature contemplates logistic cost in an aggregate way; however, it is important to consider local aspects of the cost formations, in this case Brazil, which can be relevant for an accurate cost estimate.

In terms of road extension, Brazil has experienced an ACGR of 1.5% between 2001 and 2015 of the paved roads, reaching an overall extension of 210,000 km. The states of Minas Gerais and São Paulo have the highest concentrated share of roads, however, 48.6% of those roads have shown regular, poor, or very poor quality. In regard to geometry and signalization, 57.3% of those roads have reported issues (CNT, 2016).

Table 10: OPEX small-scale logistics by Trucks

Item	Specification	Value (USD 2018)
Fuel Consumption	Diesel yield: 2.2 km/liter	0.91/liter
Driver per Truck	3 drivers	41,174/year/truck
Tire	11% of total logistic cost	Variable
Maintenance	14% of total logistic cost	
Manpower	14% of total logistic cost	

Source: Elaborated by the authors based on Araújo et al. (2014), IGU (2015) and Fraga, Liaw and Gallo (2017).

3.3. Storage and regasification of LNG in small-scale

Small-scale regasification units, composed of vaporizers, are usually associated to a storage tank. For instance, in the Portuguese case, described previously, for both the 38 ARU and also at Madeira Island, a storage tank was associated to the regasification unit, allowing the safety of the supply to the end users (FRAGA; LIAW; GALLO, 2017).

The vaporizers are selected in function of climate conditions, desired production flow, and industrial standards, which are all project specific. The goal is to maximize the net presented value of each situation, which could result in a selection of modular scaling-up, to meet demand growth. There are four categories of vaporizers for small-scale LNG. They are (i) Open Rack Vaporizer, (ii) Submerged Combustion Vaporizer (SCV), (iii) Shell and Tube Vaporizer (STB) and (iv) Ambient Air Vaporizer (AAV) (MOKHATAB, 2013; WORLD BANK et al., 2015). Table 11 contains a qualitative analysis, based on the literature review of each available technology for regasification in small-scale.

Table 11: Qualitative analysis of regasification technologies

Technology		**Pros**	**Cons**
Open Rack Vaporizer (ORV)	Uses river or ocean waters as heating medium. The water is injected at the heat exchangers along with the LNG. This technology is characterized by the easy access for maintenance and water quality assurance measurements	Low operational cost. Well established technology and with no need of physical intervention.	CAPEX required for water injection systems. Maintenance costs of water injection systems. Environmental impacts due to water disposal and subject to regulatory framework.
Submerged Combustion Vaporizer (SCV)	Uses the heat generated at the combustion of the boiled-off gas in low pressure with the objective of increasing the temperature of the water and, consequently the heat exchange with the LNG.	Low capital investment requirements when compared to ORV. Allows configuration adjustment to fit climate conditions and can be optimized via electricity generation with the burning of boil-off gas.	Greater emission in relation to other systems. High operational costs as a function of consumption of NG and eventual spot demands for NG.
Shell and Tube Vaporizer (STB)	Uses ocean water as the heating medium. Can be operated in an open or closed cycle. Similar operations to ORV.	More compact, lower capital requirements when operated in open cycle and lower operational costs than ORV.	Disposal of water, when operating in open cycle. Risk of accidental spill of water in open cycle and Glycol when operating in closed cycle. High operational costs in closed cycle.
Ambient Air Vaporizer (AAV)	The ambient air is the heating medium in heating up the LNG. Can be operated by direct heat exchange between LNG and/or air or with intermediate fluids.	Negligible environmental impact and greenhouse gases emission. Negligible operational and maintenance cost.	Higher intensity of capital. Higher demand for heat exchange area. Potential risk related to frozen air circulation.

Source: Elaborated by the authors based on Mokhatab (2013), Igu (2015), World Bank et al. (2015) and Fraga, Liaw and Gallo (2017).

The regasification capacity follows the same interval for liquefaction capacities, in other words, from 0.1 to 1 MTPA. The cost figures adopted for a reference are reported on Table 12. Although there is no detailed information available in the literature regarding operational costs, including manpower, this chapter indicates a figure as suggested from Garcia-Cuerva and Sobrino (2009) and which reflects manpower, consumables, electricity, and other items existing in a satellite plant.

Table 12: CAPEX & OPEX for regasification unit

Description	Value (USD 2018)
CAPEX	104.81/TPA
OPEX	255,442/year/plant

Source: Elaborated by the authors based on Garcia-Cuerva and Sobrino (2009).

For the small-scale storage of LNG, IGU (2015) proposes two types of storage tanks being either pressurized or at atmospheric pressure. Those two types of tanks can be designed to different integrity standards, which, as suggested by Mokhatab (2013), are single containment, double containment, or full containment. The main difference between those types is the safety level against wall rupture and/or ignition. Therefore, the higher the containment level the higher the cost, which could vary as much as 20%.

Among the pressurized tanks, there are two types of design, called bullet and cylinder, with the former enabling gains of boil-off gas management and the latter having more storage capacity per tank. It is worth highlighting that the latter has a limited storage capacity and has not been widely deployed when compared to the former (IGU, 2015). The re-use of boil-off gas in the regasification plant or recondensing can be obtained via boil-off management systems (MOKHATAB, 2013).

Among atmospheric pressure tanks, there are also two types of tanks called flat bottom and bullet. Both differ in their design geometry and in some safety characteristics and allowed capacity, the former being the option with the best performance and lower deployment costs (IGU, 2015).

In relation to the investments per installed capacity of the storage tanks, Table 13 contains the capacity interval (between

500-3000 m^3) and the unitary investment. It is assumed that the operational costs of storage of LNG is associated with the regasification unit cost.

Table 13: Capacity and unit costs of small-scale storage LNG tanks

Description	Value
Tank capacity	500 – 3000 m^3
CAPEX	850 – 3183/m^3

Source: Elaborated by the authors based IGU (2015) and Fraga, Liaw and Gallo (2017).

4. Conclusion

The information presented in this chapter regarding the cost drivers, the capacity intervals of NG compression, NG liquefaction, as well as logistics and the state-of-the-art technology deployed in small-scale LNG and CNG, allows one to conceive and differentiate those two ways of conditioning CO_2, which both can be adopted as alternatives for supplying off-grid areas.

Although the worldwide NG logistics have occurred predominantly by pipelines, a trend is observed of significant growth to the LNG supply, which consists of cooling NG to cryogenic temperatures, aiming to increase its density to a ratio of 1:600, which means 1 m^3 of LNG has 600 m^3 of NG. This process is not new, however, technological improvement and scaling-up processes allowed its growth. It is expected that LNG will surpass NG trade in the coming 20 years (BP, 2017).

Additionally, the LDCs have shown growing interest in projects of virtual pipelines, such as the city of Campos do Jordão, to supply industrial, commercial, and residential sectors (MAIA, 2016). The utilization of CNG has also been observed in six other municipalities in the state of São Paulo, which can be considered insignificant when compared to the total potential of the way of NG logistics.

In that context, this chapter is relevant to foster the discussion of the technological, economic, and logistic aspects involving NG supply by CNG and LNG in small-scale, giving subsidies for future simulations of feasibility of projects within these systems.

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Chapter VI

Natural gas' new expansion frontiers: the small-scale supply throughout Brazilian railway

Cylon Liaw
Anna Luisa Abreu Netto
Edmilson Moutinho dos Santos

1. Introduction

For over two decades, since the Bolivia-Brazil (GASBOL) gas pipeline deployment in 1999, the natural gas (NG) has been continuously posed as an energy public policy priority. Several incentive plans ensured the NG supply for power generation, industrial, and vehicular uses, i.e., Thermoelectricity Priority Program (2000), Network Project (2003), NG Use Massification Plan (2004) and PLANGAS (2007) (COLOMER, 2014).

This chapter stresses new supply possibilities on logistic routes based on their growing relevance in the energy matrix and demand projection – specifically, cryogenic wagons or containers filled with liquefied natural gas (LNG) and hauled via railway, an alternative for pipeline construction restrictions.

Japan stands as a forerunner, utilizing refrigerated containers on railways and trucks since 2000. Mainly imported from Southeast Asia, Qatar, and Russia, the Japanese LNG demand represents 32.3% of the globally traded volume (IGU, 2017).

The Japan Petroleum Exploration (Japex), an international oil company, uses the so-called satellite system to connect LNG plants and LDCs (local gas distribution companies), employing multimodal means to overcome infrastructure hurdles.

Far from the pipeline network, thermal power plants, or any other relevant economic activity dependent on NG in Brazil, lack the compelling infrastructure to thrive. Brazil's North and Midwest regions show an increasing gas consumption, the latter due to agribusiness growth, according to PNE 2050 (National Energy Plan), emphasizing the need for NG transportation solutions.

Though poorly developed, the Brazilian railway stands as a feasible alternative to supply NG to consumers distant from the pipeline network, alongside road and water transportation in an optimized logistics integration.

Lacking long-run capital and infrastructure investment capacity, Brazil should prioritize road and rail urgent expenditures, looking for NG consumption expansion and postponing pipeline network expenses for more favorable economic conditions and mature gas markets.

2. NG railway transport

Within the presence of railway infrastructure, NG can surpass the absence of pipelines. Until 2018, few planned LNG hauling railways were in place, and even fewer were currently operational, as in Japan, Sweden, and in the United States (US).

In a liquefied state, the NG kept in cryogenic tanks or ISO containers holds its low temperature of -163ºC at 1 atm. Under such conditions, the volume is 600 times smaller than the molecule of natural gas in the gaseous state (RAGNAR, 2014). The compressed natural gas (CNG) has the volume 200 times smaller than the molecule of the gas. For further details, see Kumar et al. (2011) and Mokhatab et al. (2014), including a thorough supply chain analysis.

Compared to gaseous NG and compressed NG, with a higher energy density, therefore holding more molecules per volume, liquefied NG has a competitive transportation cost-benefit. For this reason, the railway transportation literature seldom addresses CNG's competitiveness over LNG and the mainstream diesel fuel, found only in test transcriptions and rarely in operation (GNA, 2014).

Table 1 presents a comparison between the LNG rail tank cars and ISO container for LNG railway transport as follows:

Table 1: Comparison of rail transportation of ISO LNG containers and LNG rail tank cars

ISO LNG container by rail	LNG rail tank car
Small volume units.	Large volume rail cars.
Transportation by rail approved by special permit from Federal Railway Administration. Some states may have a regulatory impact on the transportation of LNG.	No rail car has yet been designed, tested, and approved for use in the U.S.
Containers can be drayed by truck between rail terminals and liquefaction plants.	Rail sidings to LNG liquefaction plants are required for loading of LNG rail cars.
Alternative truck delivery may be an option if there is rail network failure.	Rail network closure stops transportation of rail car.
A loading/unloading system is required at terminals. Top picks, cranes, or straddle carriers. Additional handling increases risk of accidents.	No special off-track equipment required to load
Containers can be used for storage at the end user's location(s).	Rail car could be used for storage by customer if approved rail sidings are available.
Containers are approved and can be transferred to marine and truck modes as well as rail.	Unable to transfer rail cars to truck. Approval would be required for transfer to marine car ferries.
Containers carry less than a dedicated LNG truck. The rail ISO LNG containers require less highway mileage than all truck transportation for the same movement of cargo. This means less traffic congestion, lower environmental pollution, and lower costs.	Tank rail cars remove the equivalent of two and a half or three trucks off the highway. This means less traffic congestion, lower environmental pollution, and lower costs.

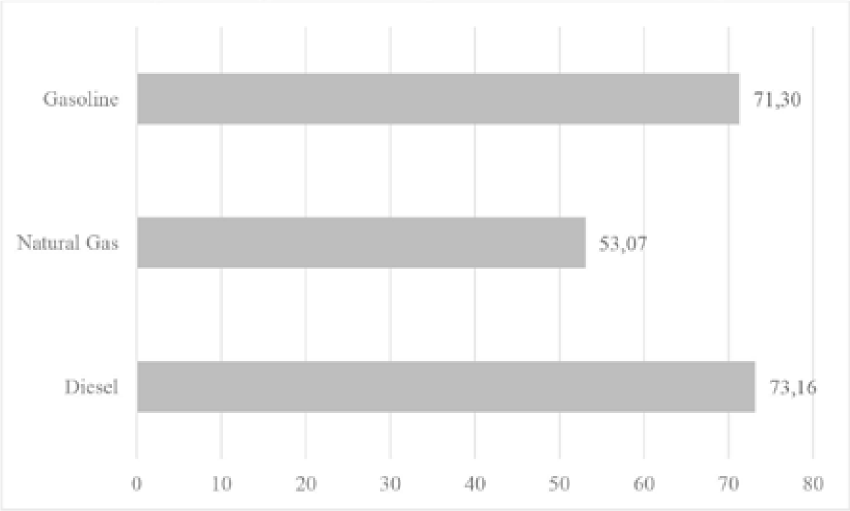
Source: Elaborated by the authors based on Ragnar (2014).

When it comes to environmental advantages, NG has a lower impact over conventional fuels, with 25% less CO_2 emission than gasoline and diesel, as shown in Figure 1.

These benefits may promote natural gas' new expansion frontiers toward high carbon footprint economic regions without long-run emission cut plans, especially regarding the transportation sector.

LNG railway transportation finds its optimized use where pipelines face economic or technical construction difficulties. For example, ocean and deep sea crossings (which nearly led to the globally adopted LNG naval transport), mountainous regions or any other geographic restraints, severe environmental restrictions, far distances to consumer spots, and mainly small-scale markets (EPE, 2007).

Figure 1: Kg CO_2 emission per MMBTU in fuel burning



Source: Elaborated by the authors based on EIA (2016).

Generally speaking, gas pipelines are high-cost expenditures and long-course deliverables, frequently subject to delays due to mandatory construction and operation licensing and authorization. Road and rail infrastructures deal with the same struggles; however, regarding their essential condition, core to broader interests and economic activities, this might ease some of these common barriers.

Furthermore, boosting cargo density via multimodal means envisions the optimized use of idle and preexistent infrastructures, hence avoiding or deferring long-term expenses in countries with lingering recovering investment capacity, similar to Brazil.

3. NG small-scale transport

Small-scale LNG production and supply niche relates to incipient NG markets, urging to monetize this natural resource. Either for geographic or economic restrictions, remote gas demand or supply, or power peak demand backup, the small-scale alternative stands feasible for regions without a pipeline network (IGU, 2015).

Parallel to rail transport, road and water modalities strengthen an interchangeable cost-benefit LNG logistics set to efficiently supply a 0.05 to 1.0 MTPA (million tons per annum) range. This coordinated array receives the "virtual pipeline" nomination as NG carriers, both compressed or liquefied (ERIA, 2018). Thus, this chapter highlights the ISO container option matching the needed flexibility of smaller volumes and faster transshipment among transportation means.

In Brazil, the LDC majority belongs to the small-scale demand range (14 out of 24), whereas five companies surpass 1 MTPA demand, representing 66% of the NG total trade in 2014 (DA SILVA et al., 2017). Table 2 sums up the 2014 LDC's average annual NG demand (MMm³/day) and its LNG equivalent (MTPA).

Table 2: Brazilian NG demand per LDC

Local Gas Distribution Companies (w/ corresponding location)	2014 Average NG demand (MMm³/day)	LNG equivalent (MTPA)	Annual demand range
Comgas (SP)	14.95	4.04	**> 1 MTPA**
Ceg (RJ)	14.79	3.99	
Ceg Rio (RJ)	10.55	2.85	
Gasmig (MG)	4.21	1.14	
Bahiagás (BA)	3.89	1.05	
BR Distribuidora (ES)	3.49	0.94	**0.05 - 1 MTPA**
Cigás (AM)	3.43	0.93	
Copergás (PE)	3.29	0.89	
Compagás (PR)	2.9	0.78	
Msgás (MS)	2.59	0.70	
Sulgás (RS)	1.97	0.53	
Cegás (CE)	1.91	0.52	
Segás (SC)	1.82	0.49	
Gás Natural Fenosa (SP)	1.18	0.32	
GasBrasiliano (SP)	0.8	0.22	
Algás (AL)	0.61	0.16	
Pbgás (PB)	0.34	0.09	
Potigás (RN)	0.34	0.09	
Sergás (SE)	0.29	0.08	
Cebgás (Brasília)	0.01	0	**0.05 MTPA**
Mtgás (MT)	0.01	0	
Gasmar (MA)	0.01	0	
Gaspisa (PI)	0	0	
Goiasgás (GO)	0	0	
TOTAL	73.4	19.83	

Source: Elaborated by the authors based on Da Silva et al. (2017).

LNG bulk hauling may induce a rise in NG consumption in LDC's regions, gradually stimulating the demand with a steady and continuous liquefied gas supply. Changes in the local energy matrix will come from the substitution of pollutant and expensive resources, followed by economic stability, which justifies the pipeline construction under a firm demand and adequate supply capacity scenario.

4. Brazilian railway network and transportation matrix

Distant from exhibiting an efficient transportation matrix benchmark, the World Economic Forum's Global Competitiveness Index ranks Brazil at the bottom layer among 144 countries (Schwab, 2019). Regarding the transportation sector, Brazil's rail and road system fragilities drag both modalities to, respectively, 95th and 112th position, raising awareness upon a staggering summary of a 61.1% road dependent matrix for cargo transportation (CNT, 2018a).

The National Transport Confederation (CNT, acronym in Portuguese) took a 105,814 km sample to conduct a road condition survey in 2017. With 61.8% classified as regular, low, or very bad, representing a 3.6% increase from 2016, the overall road quality perception emphasizes an inefficient and expensive road system on which Brazil heavily relies (97% of total transportation fuel consumption belongs to road use). According to CNT (2018b), the estimated diesel fuel waste of 807.2 million liters due to its poor road conditions is equivalent to a USD 673.7 million[1] financial loss.

Due to a decade of insufficient investment capacity, a substantial sum of USD 80.4 billion (almost 14 times the Ministry of Transport, Port, and Civil Aviation's annual budget) would be necessary to put the transportation sector back on track (CNT, 2017b). Among BRICS countries (except China), public transportation investment claimed an average of 3.7% of the 2016 GDP (O Estado de S. Paulo, 2016), while Brazil sat at a rate of 0.17% in 2017 (CNT, 2019).

The bulk cargo road transportation began in Brazil right after the 2nd World War (1939-1945), designed for short distances and

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[1] 2018 Federal Reserve's Foreign Exchange Average Rates (1 USD = R$ 3.6513). Available at https://www.federalreserve.gov/releases/g5a/current/.

high-added product delivery. The related industry expanded within the arrival of multinational automobile manufacturers, stimulated by the recently unveiled CSN (an acronym for National Steel Company) and Petrobras, respectively, steel and oil production companies (REGO; FAILLACE JUNIOR, 2017).

The railroads composed the core of the transportation sector at the time of the monarchy, always in the hands of private investors, and in exchange for the guarantee of interest (5% on invested capital) and tax exemption on imports. In the mid-19th Century, the expansion of the railroad network was stimulated to accompany the development of the coffee cycle. However, once this prosperous economic cycle ended (1930s), the railroads fell into disuse and were reincorporated to public management in deficit. Afterward, the Plano de Metas (Target Plan) set industry and road transportation as the Juscelino Kubistchek administration's priorities (1956-1961), which brought more emphasis to highways at the expense of railroads. In the 1990s, the era of railroad privatizations began and was concluded in 1999 (DUMIT, 2005).

In 2018, 12 concessionaires performed over 29,165 km of Brazil's railway, as seen in Figure 2, compared to 1,735,607 km of highways and 19,464 km of waterways (CNT, 2018a).

Figure 2: Brazil's railway map

Table 2 describes the concessionaires per track gauge and coverage in Brazil. As track gauge varies throughout the country, further integration seems distant, aggravated by high transshipment costs, eroding railway competitiveness.

Table 2: Main railway line and branch coverage per concessionaire, according to track gauge (in 2015)

Concessionaires regulated by ANTT[1]	Origin	Track gauge			Total (km)
		1,6 m	1 m	Mixed	
ALLMN – América Latina Logística Malha Norte	–	735	–	–	735
ALLMO – América Latina Logística Malha Oeste	RFFSA[2]	–	1,953	–	1,953
ALLMP – América Latina Logística Malha Paulista	RFFSA	1,533	305	269	2,107
ALLMS – América Latina Logística Malha Sul	RFFSA	–	7,223	–	7,223
EFC – Estrada de Ferro Carajás	–	997	–	–	997
EFVM – Estrada de Ferro Vitória a Minas	–	–	888	-	888
FCA – Ferrovia Centro-Atlântica	RFFSA	–	7,065	130	7,215
FNS S/A – Ferrovia Norte-Sul TRAMO NORTE (VALEC-Subconcessão)	–	745	–	–	745
FERROESTE – Estrada de Ferro Paraná Oeste	–	–	248	–	248
FTC – Ferrovia Tereza Cristina	RFFSA	–	163	–	163
MRS – MRS Logística	RFFSA	1,708	–	91	1,799
FTL S/A – Ferrovia Transnordestina Logística	RFFSA	–	4,257	20	4,227
VALEC/Subconcessão: Ferrovia Norte-Sul TRAMO CENTRAL	–	815	–	–	815
Subtotal	**–**	**6,533**	**22,122**	**510**	**29,165**

Source: Extracted from ANTT (2015).

[1] ANTT: Agência Nacional de Transportes Terrestres (National Land Transport Agency).

[2] RFFSA: Rede Ferroviária Federal S/A (Federal Railway Network).

As the railways' core business, cargo-hauling was responsible for 20.7% of the 2017 total bulk cargo transported in Brazil. Conversely, passenger transportation stays restrained to two railways: Estrada de Ferro Carajás (EFC) and Estrada de Ferro Vitória-Minas (EFVM) (CNT, 2017a).

Federal administration also runs some of the above-mentioned railways, such as VALEC, Ferrovia Norte-Sul (FNS), Ferrovia de Integração Oeste-Leste (FIOL), and Ferrovia Transcontinental. Public and private investments represented USD 1.95 billion[2] in 2015, a two-fold increase compared to 2010, though only applied to the completion of delayed constructions or small track maintenance.

Following the Logistics Investments Program (2012) and the Logistics National Plan (2018), the federal government looks forward to attracting private investments within railway expansion perspectives, anticipating concession contract renewal for another 25 years. Five concessionaires (Rumo, MRS, Carajás, Vitória-Minas, and Centro-Atlântica) took this opportunity, expected to raise almost USD 7 billion[3] in the coming years.

According to ANTT (2017), iron ore and soy stood at the forefront as top exported commodities transported by rail, between 2006 and 2016, representing 77% to 85% of total bulk cargo. Considering the 72% to 79% of iron ore participation, Brazilian railways prioritize feedstock export through coastal ports. Sugar and corn contribution is steadily rising among rail bulk commodities, as agricultural productivity grows in parallel. Oil products are part of the rail bulk cargo portfolio, connecting refineries or importation coastal terminals to the countryside (DUMIT, 2005).

In this regard, rail should also be perceived as a growth driver into the Brazilian countryside, highlighting its cost and volume advantages for greater distances and integrating the five geographic regions through multimodal means. The same multimodality is key to an energy mix diversification, with LNG delivery to distant

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[2] 2015 Federal Reserve's Foreign Exchange Average Rates (1 USD = R$ 3.3360). Available at https://www.federalreserve.gov/releases/g5a/20160104/.

[3] 2018 Federal Reserve's Foreign Exchange Average Rates (1 USD = R$ 3.6513). Available at https://www.federalreserve.gov/releases/g5a/current/.

production areas with physical or economic restraint to pipeline network access.

The natural gas pipeline network concentrates the majority of its 9,409 km on the Brazilian coast, mainly serving state capitals and isolated stretches (MTPA, 2018). In the purpose-built Figure 3, the overlapped railway and transportation pipeline networks underline the unprecedented opportunity to deliver LNG by rail wherever pipelines are inexistent. Presumably, railway and pipeline networks will keep expanding into midland and set LNG hubs at the intersection points, concentrating agribusiness and other economic activities on this energy supply. Also, they could benefit from railway proximity to deliver feedstock and end products. Once installed, these hubs will liquefy and compress natural gas from pipelines and use trucks or barges with lower initial costs to reach end users.

Figure 3: Railway and transportation pipeline networks crossover (current and planned)

Source: Map elaborated by Denis Martins Fraga.

Currently going through a divestment process, Petrobras lacks the necessary bold and long-term investment capital to deal with pipeline expansion, neither having detected reasonable demand nor stimulated a proper one to justify this venture. Thus, it does not present any plans in the PEMAT[4] 2022 report, a national guiding reference for pipeline network expansion (EPE, 2014). To better understand NG transportation, Brazilian ethanol logistics revised by Taioli, Moutinho dos Santos, and Colin (2008) may share common ground issues and solutions to unlock NG's potential.

5. Case analysis based on the potential small-scale LNG demand in Brazil

In this topic, two cases will be discussed, within the Brazilian context, that may benefit from the development of small-scale LNG transportation by trains in the country. These cases are interesting candidates for further analysis, considering other factors not discussed here. The potential demands described below were measured on a small scale, i.e. up to 1 MTPA.

5.1 Greater natural gas participation in the agricultural sector

Agricultural and household consumption supported the 1% growth of the 2017 Brazilian GDP, while other sectors had an inferior or equal performance compared to 2016. The 2017 agricultural GDP achieved a new historical annual record since 1996, showing an increase of 14.5% as opposed to the 2016 3rd quarter and a 13% increment as contrasted with the previous year (CORREIO BRAZILIENSE, 2018; MAPA, 2018).

Until 2017 3rd quarter, the agricultural sector accumulated 5.7% of aggregated participation, revealing a bigger picture: 23% to 24% of Brazil's GDP comes from agribusiness[5]. Those exports were also relevant to this upward rise, accounting for

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[4] PEMAT: Ten-Year Expansion Plan for the Gas Pipeline Transport Network

[5] Agribusiness GDP considers the facilities' primary activities, transformation, and distribution roles.

48% of total Brazilian exports and representing a USD 81.8 billion sectorial surplus.

Soy products (grain, bran, and oil) were essential to the 24.8% 2017 expansion rate and USD 31.7 billion in revenue, mostly from grains (33% growth and USD 25.7 billion in revenue). Corn export resulted in USD 4.5 billion (25% growth), while the sugarcane sector (sugar and ethanol) brought USD 12.2 billion in revenue (7.8% growth) (CNA, 2018a). The railway was responsible for 47% of total exported agribusiness commodities transportation, whereas 42% came by highways and 11% from waterways (CNA, 2018a).

Regarding job creation in 2017, the agricultural sector placed 2nd (just behind commerce), with 37,000 jobs spread over orange plantations (39.4%), agricultural support (20.9%), soy plantations (12.5%), and poultry (27.2%) (CNA, 2018b).

The agricultural business depends on competitive production costs to maintain its international market, and fertilizers are critical for the cost matter. Domestic fertilizer production cannot supply the local demand (in 2017, 76.4% imported from Russia and China, highlighting the national vulnerability to global price oscillation) (ANDA, 2018).

Table 3 shows a corn and soy production cost breakdown focused on the fertilizer participation for the top duo crops in Brazil, concentrating 85% of total grain production. While corn depends on nitrogenous fertilizers, soy plantations rely on potassium types. It is worth mentioning that corn is subject to technology cost variations, according to the applied type (high or medium technology).

Regarding this scenario, and once guaranteed the technical and economic viability for pre-salt oil and natural gas exploitation, local fertilizer production may come in handy as cheap NG feedstock becomes available. According to Globalfert (2018), abundant Russian NG provides competitive nitrogenous fertilizers (i.e., urea produced from natural gas' ammonia) at a cost-effective level.

Table 3: Fertilizer participation in the total production cost (corn and soy)

Soy crop 2018/2019 (R$/hectare)

Transgenic	**West**	**North**	**Southeast**	**Northeast**	**Mid-North**	**South Central**	**MT*****
Fertilizer	678.49	586.34	578.24	556.04	564.06	645.34	586.94
Total Cost	3,195.24	3,583.74	3,509.83	3,472.95	3,555.45	3,290.48	3,466.39
%	21.20%	16.40%	16.50%	16.00%	15.90%	19.60%	16.90%

Conventional	**West**	**North**	**Southeast**	**Northeast**	**Mid-North**	**South Central**	**MT*****
Fertilizer	678.49	-	578.24	556.04	564.79	-	589.6
Total Cost	3,400.86	-	3,487.02	3,462.24	3,792.99	-	3,556.36
%	20.00%	-	16.60%	14.90%	14.90%	-	16.60%

Corn crop 2017/2018 (R$/hectare)

High Technology*	**West**	**North**	**Southeast**	**Northeast**	**Mid-North**	**South Central**	**MT*****
Fertilizer	479.37	467.08	704.04	583.15	486.13	650.96	549.88
Total Cost	2,719.38	2,665.96	2,848.7	2,843.32	2,810.86	3,036.83	2,822.87
%	17.60%	17.50%	24.70%	20.50%	17.30%	21.40%	19.50%

Medium Technology**	**West**	**North**	**Southeast**	**Northeast**	**Mid-North**	**South Central**	**MT*****
Fertilizer	342.41	266.9	500.03	429.91	349.97	484.58	393.4
Total Cost	2,360.43	2,347.43	2,477.88	2,506.3	2,523.17	2,477.15	2,483.02
%	14.50%	11.40%	20.20%	17.07%	13.90%	19.60%	15.80%

***High Tech = 120 sac/hectare **Medium Tech = 100 sac/hectare ***MT: Mato Grosso State**

Source: Elaborated by the authors based on ANDA (2018).

In 2017, among N (nitrogen), P (phosphorus), and K (potassium) imported fertilizers, 36% were N-based types (8.7 million tons), of which 63% came from urea, representing a 37% increase from 2016. Corn, rice, beans, and wheat crops consume most N-based fertilizers (GLOBALFERT, 2018).

Considering the domestic production, Petrobras almost dominates nitrogenous-type production with four units (Table 4) currently on sale, according to the Management and Business Plan 2017-2021 report. In Table 4, UFN IV (Linhares/ES) and UFN V (Uberaba/MG) are in the study phase, thus not considered for the analysis (VALOR ECONÔMICO, 2018).

Table 4: Petrobras' nitrogenous fertilizer production plants

Plant	**City**	**Status**	**Asset value (US$ MM)**	**Urea production (kt/year)**	**Ammonia production (kt/year)**	**NG source**
Fafen-BA	Camaçari	On sale	500	1,100 (BA + SE)	900 (BA + SE)	Near oil field
Fafen-SE	Laranjeiras	On sale	600			
Fafen-PR	Araucária	On sale	350	700	475	REPAR
UFN III (MS)	Três Lagoas	On sale (80% finished)	700	1,109	173	Inexistent

Source: Elaborated by the authors based on Valor Econômico (2018).

An expected negative trade balance would result from the sale, a contradictory move from Petrobras' natural gas prioritization as a transition element toward renewables. These units are currently in progressive production shutdown; this asset divestment will force an increase in Brazil's imports until the newcomers' arrival, who will hardly agree with the proposed selling price (VALOR ECONÔMICO, 2018).

As indicated by BNDES (2012), the following propositions may ease some local fertilizer production hurdles, such as:

- High NG costs with domestic production: pre-salt exploration and production might bring down its costs;
- Negative trade balance due to fertilizer importation increase: it depends on domestic production stimulus;
- Port infrastructure and logistics: improvement opportunities in storage and multimodal investment;
- Tax issues that favor imported products (i.e., ICMS waiver): 2% rate reduction on Financial Compensation for the Exploration of Mineral Resources (CFEM, acronym in Portuguese);
- Lack of a sectorial regulatory benchmark: in 2012, there were three ongoing law reform projects in the mining sector, which comprises fertilizers;
- Lack of more significant investment incentives to innovation: ongoing initiatives concerning organomineral fertilizer and polymer usage.

Although numerous difficulties are present for fertilizer's national development, Brazil sustains multiple ways to thrive, either with NG coming from the pre-salt or an imported source (considering an expected LNG price reduction in the coming years). A significant imported volume increase for fertilizers would put Brazil in a vulnerable position, justifying the multimodal container transportation to support the continuous long-term agribusiness growth.

Another potential[6] use for NG in agribusiness is diesel substitution in working machines. The possibility of biomethane or NG engine adoption (SCHNEPF, 2004) has been available since 2017, i.e., New Holland T6 140 tractor or Palesse GS4118K harvester (NEW HOLLAND, 2017; GOMSALMASH, 2017).

A 2018 IFAG study analyzed the fuel price fluctuation influence over agricultural production costs (2017/2018 crop sample), as diesel varied from R$ 2.88/liter to R$ 3.09/liter (R$ 145.35/hectare to 155.96/hectare). The aftermath pointed out a R$ 35 million additional cost for soy crop in the state of Goiás. Regarding the soy production process, most of the diesel consumption is concentrated on the harvest (48.15%), plantation (20.7%), tillage conditioning (15.85%), and pre-plantation (15.3%) stages. The calculated fuel consumption was 50.46 liters/hectare, and, as a tax increase result, the diesel cost participation rose from 4.7% to 5.1%. Overall, a R$ 103,095,873.75 cost increase for all crops highlights the diesel substitution opportunity for competitive NG prices and logistics (IFAG, 2018).

5.2 LNG fueled locomotives

An EIA's 2050 projection (2018) considers natural gas expansion over heavyweight vehicles and cargo trains in the USA. The latter showed particular interest among all Class I[7]

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[6] For other possibilities of fuel substitution within agricultural processes, please read the "Energy Use in Agriculture: Background and Issues" (Schnepf, 2004) paper. It clarifies every fuel used in each production stage, underscoring the NG indirect use percentage in fertilizer and pesticide production. Available at: <http://nationalaglawcenter.org/wp-content/uploads/assets/crs/RL32677.pdf>.

[7] USA railway companies with an equal or superior annual operating revenue of USD 457.91 million. Currently, there are seven companies in bulk cargo transport: Burlington Northern Santa Fe (BNSF), CSX Transportation, CN/Grand Trunk,

companies, whose efforts to replace diesel with LNG locomotives began in the '80s. Some of the Class II[8] companies started an LNG fleet update, such as Florida East Coast Railway. In this case, the whole all-new 24-locomotive fleet can cover 1,450 km at a maximum speed of 97 km/h, taking 90 minutes for a 40 m^3 LNG ISO container refueling, equivalent to 22,680 diesel liters (IRJ, 2017).

As expected, savings on fuel cost and an operational cost reduction would ease the consumption of 3.6 billion diesel liters or 7% of the total consumed in the USA, accounting for USD 11 billion spent only in Class I over 2012, which represented 23% of total operational costs (CHASE, 2014). The author stated that the fuel savings would entirely absorb an estimated USD 1 million in incremental costs for locomotive retrofit and a cryogenic tank acquisition, compared to a USD 2 million investment for a new diesel engine locomotive.

In the reference scenario, potential savings between 2020 and 2040 would reach USD 1.5 million and surpass USD 2.5 million, the latter considering a significant high oil barrel price. With plummeting oil prices, savings are no match for the substitution offset (Chase, 2014).

Brazil's first LNG locomotive experience occurred in December 2009 with Vale's R$ 2.4 million investment in Trem Verde, a General Electric's BB 36 diesel engine conversion project (O ESTADO DE S. PAULO, 2009). A cooperative effort between White Martins' gas liquefaction expertise, PUC-SP (Pontifical Catholic University of São Paulo), and USP (University of São Paulo) research teams estimated a R$ 460 million economy total, also avoiding 73 tons of CO_2 emission per year. The experiment took place on the Estrada de Ferro Vitória-Minas railway, with a 1,200 km range autonomy and considering 50% to 70% of diesel substitution by LNG.

Based on the USA savings simulation brought by Chase (2014), a twelve Brazilian railway concessionaires sample had similar

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Kansas City Southern, Norfolk Southern, Soo Line and Union Pacific (UP) (USDOT, 2017).

[8] USA railway companies with annual operating revenue between USD 36.6 million and USD 457.9 million (USDOT, 2017).

parameters to run a two-scenario test, with 2016/2017 data from ANTT (2018) and CNT (2017a):

- Scenario 1: 100% diesel locomotive substitution by LNG;
- Scenario 2: 80% diesel locomotive substitution by LNG, with the remaining 20% for ignition.

More conservative, but realistic, Scenario 2 uses the manufacturer's proven 80% substitution rate technology (i.e., used in Florida by General Electric). A complete substitution of diesel locomotives (Scenario 1) faces technical constraints, as the electrical system lacks market validation against the dominant compressed ignition technology. The simulation is still valid to observe savings potentialities in the short and long-run. Table 5 presents the simulation input and output parameters:

Table 5: Simulation input and output parameters

Input parameters	Output parameters
Number of locomotives (average)	Diesel consumption (liters)
Annual diesel consumption (liters/1,000 TKU)	Total diesel consumption cost (R$)
Diesel price (R$/liter): October/2016 and June/2017	LNG equivalent (m^3)
LNG price (US$/mmBTU): August/2016 and October/2017	LNG equivalent (MTPA)
Exchange rate (R$/US$): related year average	LNG (US$/$m^3$)
TKU (million)	Total LNG consumption cost (US$)
	Total LNG consumption cost (R$)
	Cost savings (R$)
	ISO container quantity (20, 30, and 40 m^3)

Source: Elaborated by the authors.

Opting out of other relevant parameters was reasonable for this preliminary savings simulation, though it could deviate from the real gains. A whole cost variety remains unclear for the Brazilian context, but potentially useful for future studies associated with sensitivity analysis on available data: LNG container logistics, locomotive retrofit, cryogenic tanks, infrastructure investment (filling stations, liquefication, and regasification units), and equipment investment (i.e., adapted wagons).

Differences between 2016 and 2017 exchange rates, diesel and LNG prices, and annual production per concessionaire directly affect cost savings results. For example, LNG prices fluctuated from USD 5.08 (2016) to USD 3.99 (2017) (EIA, 2018), whereas diesel prices rose R$ 0.67, forming an optimal scenario for fuel substitution, alongside currency appreciation. An annual production growth trend means upward diesel consumption, thus reinforcing the need for a cheaper and less pollutant fuel.

Concerning ISO container quantity, transportation enterprises would be interested in product diversification while supplying a steady demand. Each size meets a different consumer profile with a 20, 30, and 40 m^3 capacity simulation according to its volume and frequency demand, allowing greater flexibility to various delivery locations. Filling station availability is essential for medium and long distances, therefore affecting the container size choice.

For LNG logistics to filling stations, companies like Brado Logística could use its multimodal expertise to haul the liquefied natural gas through railways integrated with highways and waterways. Besides, these enterprises might help to develop LNG for trucks and barges.

Controlling the largest railway network and the vast majority of locomotives (on average), Rumo (RMN, RMO, RMP, and RMS) would seize more meaningful and faster economies, being responsible for most of the agricultural export commodities from the Midwest and South regions. 75% of Brazil's total bulk cargo transportation goes to iron ore, mainly hauled by MRS, VLI (EFC), and Vale (EFVM and EFC) (EPL, 2017).

Scenario 1 (Tables 6 and 7 in Annexes) illustrates a small-scale demand of 0.918 MTPA (2016) and 0.956 MTPA (2017), respectively, accounting for R$ 2.6 billion (74%) and R$ 3.7 billion (85%) savings over diesel consumption costs, with 100% LNG adoption. Tables 8 and 9 (in Annexes) show Scenario 2, with a small-scale supply (80% LNG adoption) of 0.734 MTPA (2016) and 0.765 MTPA (2017), saving respectively R$ 1.3 billion (40%) and R$ 2.1 billion (48%). A smaller economy volume is due to the 20% diesel reserved for compressed ignition, directly impacting the total fuel cost variable. The absence of information limits a thorough simulation with investment costs and a payback period, thus undermining the final investment decision.

According to ANTT (2012) CO_2 conversion factor, Scenario 1 would avoid 3 million tons of CO_2-eq emission in 2016 and 2017. On the other hand, Scenario 2 would prevent 2.4 million tons of CO_2-eq emission for both years. The CO_2-eq reduction amount has a small volume compared to transportation totals due to the low contribution of rail diesel consumption.

6. Conclusion

This chapter presented the rail means as an LNG small-scale supply alternative for Brazil. As pointed out before, railway transportation shows particular features to overcome pipeline construction technical or economic restraints.

Brazil exhibits a scarce railway network, plus cargo transportation that is highly dependent on inefficient and costly highway means. In this scenario, some pipeline and railway network intersections could host valuable NG hubs, mainly for agroindustry. Also, as liquefaction and compression NG hubs, the gas smoothly flows towards the midland with fair costs. It might become a steady fuel source in substituting less sustainable and CO_2 emitting options, i.e., gasoline and diesel.

As an operational precondition, NG would increase its participation among agricultural activities, especially regarding fertilizer production. Also, LNG appeared as a viable solution for the replacement of diesel locomotives.

Though pre-salt increased Brazil's NG reserves, delivery options are quite limited. Reflecting on LNG multimodal transportation is essential to NG outlet and the expansion of its frontiers, considering pipeline restraints in the Brazilian continental dimension. Railway integration among highway and waterway means is determinant to NG supply diversification.

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Annexes

Table 6: Potential savings on 100% diesel locomotives substitution for LNG (All concessionaires– 2016) – Scenario 1

	EFC	EFPO	EFVM	FCA	FNSTN	FTC	FTL	MRS	RMN	RMO	RMP	RMS	TOTAL RUMO	2016 TOTAL
Locomotive units (average)	300	15	315	589	25	17	99	768	184	38	276	420	918	3,046
Annual consumption (liters/1,000 TKU)	2.05	15.53	2.48	10.48	3.23	7.38	14.94	3.48	2.43	19.88	11.12	7.77	-	-
TKU (million)	136,268	131	74,559	19,045	4,456	224	652	65,646	22,998	797	4,556	11,831	40,182	341,163
Diesel (liters)	278,744,943	2,033,636	184,646,084	199,599,667	14,400,740	1,651,994	9,744,724	228,478,971	55,788,430	15,844,623	50,639,702	91,897,670	214,170,425	1,133,471,184
Diesel (R$/liter)	3.050	3,050	3,050	3,050	3,050	3,050	3,050	3,050	3,050	3,050	3,050	3,050	-	-
Diesel total cost (R$)	850,172,077.22	6,202,591.18	563,170,556.67	608,778,983.04	43,922,256.08	5,038,581.51	29,721,407.72	696,860,861.81	170,154,710.86	48,326,101.56	154,451,089.92	280,287,893.37	653,219,795.71	3,457,087,110.94
LNG equivalent (m^3)	501,741	3,661	332,363	359,279	25,921	2,974	17,541	411,262	100,419	28,520	91,151	165,416	385,507	2,425.755
LNG equivalent (MTPA)	0.226	0.002	0.150	0.162	0.012	0.001	0.008	0.185	0.045	0.013	0.041	0.074	0.173	0.918
LNG (US$/mmBTU)	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	-	-
LNG (US$/$m^3$)	121.92	121.92	121.92	121.92	121.92	121.92	121.92	121.92	121.92	121.92	121.92	121.92	-	-
LNG total cost (US$)	61,172,250.29	446,293.72	40,521,691.04	43,803,344.43	3,160,328.73	362,539.98	2,138,538.12	50,141,081.08	12,243,105.65	3,477,197.69	11,113,186.36	20,167,495.06	47,000,984.75	248,747,052.14
LNG total cost (R$)	213,491,153.51	1,557,565.09	141,420,701.74	152,873,672.05	11,029,547.27	1,265,264.54	7,463,498.02	174,992,372.96	42,728,438.71	12,135,419.93	38,785,020.39	70,384,557.75	164,033,436.78	868,127,211.96
Exchange rate R$/US$	3.49	3,49	3,49	3,49	3,49	3,49	3,49	3,49	3,49	3,49	3,49	3,49	-	-
Cost savings (R$)	636,680,923.72	4,645,026.09	421,749,854.93	455,905,310.99	32,892,708.81	3,773,316.98	22,257,909.70	521,868,488.85	127,426,272.15	36,190,681.64	115,666,069.53	209,903,335.62	489,186,358.93	2,588,959,898.98
ISO container (20 m^3) units	25,087	183	16,618	17,964	1,296	149	877	20,563	5,021	1,426	4,558	8,271	19,275	102,012
ISO container (30 m^3) units	16,725	122	11,079	11,976	864	99	585	13,709	3,347	951	3,038	5,514	12,850	68,008
ISO container (40 m^3) units	12,544	92	8,309	8,982	648	74	439	10,282	2,510	713	2,279	4,135	9,638	51,006

Source: Elaborated by the authors based on ANTT (2018) and CNT (2017a).

Table 7: Potential savings on 100% diesel locomotives substitution for LNG (All concessionaires– 2017) – Scenario 1

	EFC	**EFPO**	**EFVM**	**FCA**	**FNSTN**	**FTC**	**FTL**	**MRS**	**RMN**	**RMO**	**RMP**	**RMS**	**TOTAL RUMO**	**2017 TOTAL**
Locomotive units (average)	315	15	313	628	23	17	100	751	194	41	257	373	865	3,026
Annual consumption (liters/1,000 TKU)	1.97	20.59	2.31	10.22	3.44	6.96	14.69	3.44	2.17	18.62	12.19	5.08	-	-
TKU (million)	155,538	159	73,518	24,429	7,315	206	645	63,909	31,663	858	3,444	13,556	49,520	375,239
Diesel (liters)	306,114,046	3,275,650	169,797,638	249,675,620	25,185,771	1,432,263	9,481,376	219,596,049	68,858,846	15,973,003	41,989,014	68,891,219	195,712,082	1,180,270,495
Diesel (R$/liter)	3.723	3.723	3.723	3.723	3.723	3.723	3.723	3.723	3.723	3.723	3.723	3.723	-	-
Diesel total cost (R$)	1,139,662,594.39	12,195,243.32	632,156,606.40	929,542,331.51	93,766,623.98	5,332,316.99	35,299,164.62	817,556,088.84	256,361,484.94	59,467,488.73	156,325,100.50	256,482,008.37	728,636,082.54	4,394,147,052.59
LNG equivalent (m³)	551,005	5,896	305,636	449,416	45,334	2,578	17,066	395,273	123,946	28,751	75,580	124,004	352,282	2,124,487
LNG equivalent (MTPA)	0.248	0.003	0.138	0.202	0.020	0.001	0.008	0.178	0.056	0.013	0.034	0.056	0.159	0.956
LNG (US$/mmBTU)	3.99	3.99	3.99	3.99	3.99	3.99	3.99	3.99	3.99	3.99	3.99	3.99	-	-
LNG (US$/m³)	95.76	95.76	95.76	95.76	95.76	95.76	95.76	95.76	95.76	95.76	95.76	95.76	-	-
LNG total cost (US$)	52,764,265.93	564,617.16	29,267,679.27	43,036,087.19	4,341,220.91	246,876.39	1,634,285.90	37,851,331.70	11,869,061.63	2,753,234.51	7,237,562.43	11,874,641.64	33,734,500.21	203,440,864.67
LNG total cost (R$)	168,318,008.33	1,801,128.75	93,363,896.88	137,285,118.13	13,848,494.70	787,535.70	5,213,372.02	120,745,748.13	37,862,306.59	8,782,818.10	23,087,824.15	37,880,106.83	107,613,055.66	648,976,358.29
Exchange rate R$/US$	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	-	-
Cost savings (R$)	971,344,586.07	10,394,114.57	538,792,709.52	792,257,213.38	79,918,129.28	4,544,781.29	30,085,792.59	696,810,340.72	218,499,178.35	50,684,670.63	133,237,276.35	218,601,901.55	621,023,026.88	3,745,170,694.30
ISO container (20 m³) units	27,550	295	15,282	22,471	2,267	129	853	19,764	6,197	1,438	3,779	6,200	17,614	106,224
ISO container (30 m³) units	18,367	197	10,188	14,981	1,511	86	569	13,176	4,132	958	2,519	4,133	11,743	70,816
ISO container (40 m³) units	13,775	147	7,641	11,235	1,133	64	427	9,882	3,099	719	1,890	3,100	8,807	53,112

Source: Elaborated by the authors based on ANTT (2018) and CNT (2017a).

Table 8: Potential savings on 80% diesel locomotives substitution for LNG (All concessionaires– 2016) – Scenario 2

	EFC	EFPO	EFVM	FCA	FNSTN	FTC	FTL	MRS	RMN	RMO	RMP	RMS	TOTAL RUMO	2016 TOTAL
Locomotive units (average)	300	15	315	589	25	17	99	768	184	38	276	420	918	3,046
Annual consumption (liters/1,000 TKU)	2.05	15.53	2.48	10.48	3.23	7.38	14.94	3.48	2.43	19.88	11.12	7.77	-	-
TKU (million)	136,268	131	74,559	19,045	4,456	224	652	65,646	22,998	797	4,556	11,831	40,182	341,163
Diesel (liters)	278,744,943	2,033,636	184,646,084	199,599,667	14,400,740	1,651,994	9,744,724	228,478,971	55,788,430	15,844,623	50,639,702	91,897,670	214,170,425	1,133,471,184
Diesel (R$/liter)	3.050	3.050	3.050	3.050	3.050	3.050	3.050	3.050	3.050	3.050	3.050	3.050	-	-
Diesel total cost (R$)	850,172,077.22	6,202,591.18	563,170,556.67	608,778,983.04	43,922,256.08	5,038,581.51	29,721,407.72	696,860,861.81	170,154,710.86	48,326,101.56	154,451,089.92	280,287,893.37	653,219,795.71	3,457,087,110.94
LNG equivalent (m^3)	401,393	2,928	265,890	287,424	20,737	2,379	14,032	329,010	80,335	22,816	72,921	132,333	308,405	1,940,604
LNG equivalent (MTPA)	0.181	0.001	0.120	0.129	0.009	0.001	0.006	0.148	0.036	0.010	0.033	0.060	0.139	0.734
LNG (US$/mmBTU)	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	-	-
LNG (US$/$m^3$)	121.92	121.92	121.92	121.92	121.92	121.92	121.92	121.92	121.92	121.92	121.92	121.92	-	-
LNG total cost (US$)	48,937,800.23	357,034.98	32,417,352.84	35,042,675.54	2,528,262.99	290,031.99	1,710,830.49	40,112,864.86	9,794,484.52	2,781,758.15	8,890,549.09	16,133,996.05	37,600,787.80	198,997,641.71
LNG total cost (R$)	170,792,922.80	1,246,052.07	113,136,561.40	122,298,937.64	8,823,637.82	1,012,211.63	5,970,798.42	139,993,898.37	34,182,750.97	9,708,335.94	31,028,016.31	56,307,646.20	131,226,749.42	694,501,769.57
Exchange rate R$/US$	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49	-	-
Cost savings (R$)	339,310,323.53	2,475,502.64	224,765,772.61	242,968,452.18	17,529,715.83	2,010,937.28	11,862,046.21	278,122,618.72	67,910,075.55	19,287,325.00	61,642,637.64	111,865,089.82	260,705,128.00	1,379,750,497.00
ISO container (20 m^3) units	20,070	146	13,295	14,371	1,037	119	702	16,450	4,017	1,141	3,646	6,617	15,420	81,610
ISO container (30 m^3) units	13,380	98	8,863	9,581	691	79	468	10,967	2,678	761	2,431	4,411	10,280	54,407
ISO container (40 m^3) units	10,035	73	6,647	7,186	518	59	351	8,225	2,008	570	1,823	3,308	7,710	40,805

Source: Elaborated by the authors based on ANTT (2018) and CNT (2017a).

Table 9: Potential savings on 80% diesel locomotives substitution for LNG (All concessionaires– 2017) – Scenario 2

	EFC	EFPO	EFVM	FCA	FNSTN	FTC	FTL	MRS	RMN	RMO	RMP	RMS	TOTAL RUMO	2017 TOTAL
Locomotive units (average)	315	15	313	628	23	17	100	751	194	41	257	373	865	3,026
Annual consumption (liters/1,000 TKU)	1.97	20.59	2.31	10.22	3.44	6.96	14.69	3.44	2.17	18.62	12.19	5.08	-	-
TKU (million)	155,538	159	73,518	24,429	7,315	206	645	63,909	31,663	858	3,444	13,556	49,520	375,239
Diesel (liters)	306,114,046	3,275,650	169,797,638	249,675,620	25,185,771	1,432,263	9,481,376	219,596,049	68,858,846	15,973,003	41,989,014	68,891,219	195,712,082	1,180,270,495
Diesel (R$/liter)	3.723	3.723	3.723	3.723	3.723	3.723	3.723	3.723	3.723	3.723	3.723	3.723	-	-
Diesel total cost (R$)	1,139,662,594.39	12,195,243.32	632,156,606.40	929,542,331.51	93,766,623.98	5,332,316.99	35,299,164.62	817,556,088.84	256,361,484.94	59,467,488.73	156,325,100.50	256,482,008.37	728,636,082.54	4,394,147,052.59
LNG equivalent (m³)	440,804	4,717	244,509	359,533	36,268	2,062	13,653	316,218	99,157	23,001	60,464	99,203	281,825	1,699,590
LNG equivalent (MTPA)	0.198	0.002	0.110	0.162	0.016	0.001	0.006	0.142	0.045	0.010	0.027	0.045	0.127	0.765
LNG (US$/mmBTU)	3.99	3.99	3.99	3.99	3.99	3.99	3.99	3.99	3.99	3.99	3.99	3.99	-	-
LNG (US$/m³)	95.76	95.76	95.76	95.76	95.76	95.76	95.76	95.76	95.76	95.76	95.76	95.76	-	-
LNG total cost (US$)	42,211,412.75	451,693.73	23,414,143.42	34,428,869.75	3,472,976.73	197,501.12	1,307,428.72	30,281,065.36	9,495,249.30	2,202,587.61	5,790,049.94	9,499,713.31	26,987,600.17	162,752,691.73
LNG total cost (R$)	134,654,406.66	1,440,903.00	74,691,117.50	109,828,094.50	11,078,795.76	630,028.56	4,170,697.62	96,596,598.50	30,289,845.27	7,026,254.48	18,470,259.32	30,304,085.46	86,090,444.53	519,181,086.63
Exchange rate R$/US$	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	-	-
Cost savings (R$)	549,143,149.97	5,876,242.99	304,602,846.34	447,897,304.40	45,181,178.63	2,569,361.64	17,008,801.15	393,937,054.81	123,527,045.69	28,654,238.76	75,324,800.98	123,585,119.56	351,091,204.99	2,117,307,144.92
ISO container (20 m³) units	22,040	236	12,225	17,977	1,813	103	683	15,811	4,958	1,150	3,023	4,960	14,091	84,979
ISO container (30 m³) units	14,693	157	8,150	11,984	1,209	69	455	10,541	3,305	767	2,015	3,307	9,394	56,653
ISO container (40 m³) units	11,020	118	6,113	8,988	907	52	341	7,905	2,479	575	1,512	2,480	7,046	42,490

Source: Elaborated by the authors based on ANTT (2018) and CNT (2017a).

Chapter VII

LNG Regulation: Analysis of the Gemini Project under the Brazilian Federal Supreme Court

Hirdan Katarina de Medeiros Costa
Karina Ninni Ramos
Paola Mercadante Petry

1. Introduction

Constitutional Amendments No. 5/95 and No. 9/95 modified articles 25, § 2 and 177, both of the Federal Constitution of 1988, relating to the distribution and transportation of natural gas.

The Federal Constitution established a regime of subtle limits with regard to the scope of action of federal states, responsible for gas distribution, and the Union, responsible for gas transportation. In this regard, in 2019, the Brazilian Federal Supreme Court (STF) decided on the federative conflict between the National Agency for Oil, Natural Gas, and Biofuels (ANP) and the regulatory agency of São Paulo, ARSESP, ruling that is was under their jurisdiction to decide which standard should be applied to the case of the plant of liquefied natural gas in the municipality of Paulínia, in the state of São Paulo.

Therefore, the objective of this study is to verify the regulatory models outlined on the constitutional and legal levels regarding state agencies and the ANP, in order to make evident the powers of each of these parts and to analyze the decision of the STF. This chapter deals with the conjuncture of the LNG chain in Brazil, the legal conflicts that exist in this sphere and contextualizes possible regulatory obstacles in view of the forwarding of a policy to open the gas market in the country.

In addition to the relevance of the discussion in times of recent movement in the sector, instituted by Resolution No. 16/2019 of CNPE, New Gas Market, LNG is configured as an alternative fuel to enable the use of gas in scenarios in which pipeline construction is not feasible or not indicated and may contribute to improved energy security in the country.

The efficiency of LNG, its flexibility and operational security are advantages of this energy source to balance the seasonality of renewable energies, which tend to be present in the country's energy matrix and to promote the resilience of the natural gas transportation system in the national territory. For that, there is a need for regulation throughout the LNG chain that allows compatible prices, favors investments with greater predictability of revenues, optimization of installed capacity, and reduction of the risks of legal conflicts, which can increase transaction costs and inhibit the entry of more companies in this market (EPE, 2019a).

2. Case study - legal conflict in distribution and transportation - LNG: The case of the Gemini Project

The Gemini Project is a joint venture between Petrobras and White Martins, implemented in 2006 to distribute and sell liquefied natural gas (LNG) (ROMEIRO, 2018, p. 285). The case study approaches the decision of the Supreme Court on this project, which urges the need to differentiate between gas distribution and transportation at the national and state levels, in the regulatory sphere.

The discussion involves the Gemini Project, a partnership between Petrobras and the White Martins company for liquefaction and distribution of natural gas from Bolivia. White Martins, Petrobras, GNL Gemini, TBG (Transportadora Brasileira Gasoduto Bolívia-Brasil SA) and the Union, all involved in the Gemini Project, filed a lawsuit in the Federal Court in São Paulo to question the ordinance issued by the Public Services Commission of Energy of the State of São Paulo (CSPE, the sector's regulatory agency at the moment, currently called ARSESP).

Within the scope of this project, the gas arrives from a branch of Gasbol, it is liquefied and sold to consumers located within a radius of up to 1000 km from the liquefaction plant installed in Paulínia (SP), with a liquefaction capacity of 440 thousand m³/day (ROMEIRO, 2018, p. 285 and 286).

From a legal point of view, the Federal Constitution defined the distribution of piped gas (gas distributed by pipelines) as a state jurisdiction; and, as a federal jurisdiction, the other activities of the natural gas industry. The Brazilian Federal Constitution presented that:

> Art. 25. States are organized and governed by the Constitutions and laws they adopt, subject to the principles of this Constitution. Paragraph 2. It is the responsibility of the States to directly exploit, or by means of a concession, the local piped gas services, as provided for by the law, prohibiting the publication of a provisional measure for its regulation (Wording given by Constitutional Amendment No. 5, 1995).
>
> Art.177. The Union's monopoly consists of:
> I - the research and mining of oil and natural gas deposits and other fluid hydrocarbons; (See Constitutional Amendment No. 9, 1995)
> II - the refining of domestic or foreign oil;
> III- the importation and exportation of basic products and derivatives resulting from the activities provided for in the previous items;
> IV - the maritime transportation of crude oil of national origin or basic oil derivatives produced in the country, as well as the transportation, by means of a conduit, of crude oil, its derivatives and natural gas of any origin.

However, through the interpretation of art 56 of Law 9,478/1997 (Oil Law), ANP understood that the sale of bulk gas, specifically LNG, by potential interested parties is permitted.

In 2005, the judge of the 11th Federal Court of Justice - Judiciary Section of São Paulo - granted a request for advance protection (Ordinary Action 2005.61.00.029794-9) to order the CSPE to abstain from the practice of any act or application of any penalty with respect to the transportation facilities of Transportadora Brasileira Gasoduto (TGB) and the Projeto Gemini Comercialização e Logística de Gás Ltda. According to the authors, Petrobras and White Martins, the supply of piped gas to the Gemini Project is a mere transportation activity, under the jurisdiction of the Union, as defined in article 177, item IV, of the constitutional text.

The request was granted in the first degree with advance notice of injunction to order the State of São Paulo Agency, CSPE, to abstain from taking any action against the Gemini Project. The CSPE and Gas Company of São Paulo (Comgás) appealed against the decision arguing about the injurisdiction of the federal court and asking for the decision to be reformed.

The judge denied the request and the rapporteur decided that it would be up to the Federal Government and the ANP to provide and regulate the gas supply service to the Gemini Project and not the State of São Paulo and the CSPE.

The controversy that has involved the Gemini Project since its inception is the presence of Petrobras in the consortium and the capture of strategic anchor customers, pointed out as possible competitive damage, according to Diogo Lisbona Romeiro, who signs an article about the case in the book Regulatory Market News of Brazilian Gas (ROMEIRO, 2018). Anchor customers are those whose demand justifies investment in networks and infrastructure to take gas to where they are. Once the network is in place, with a fixed customer responding for good demand, the supplier can just expand the consumer base.

The Gemini Project started to operate in order to take LNG to places not yet served by the gas pipeline network. Under the agreement, White Martins operates the plant and Petrobras enters the supply of natural gas (ROMEIRO, 2018, p. 286). However, from the beginning, this arrangement bothered some sectors.

First, CSPE contested that the supply of gas in a state concession area is characterized as a public distribution service activity, subject to tariff regulation by the state regulatory agency and a remuneration margin for Comgás, since the Constitution considers distribution as a service under state jurisdiction (RCGILex, 2019a).

According to Romeiro (2018), as Brazilian legislation does not differentiate “transportation” from “distribution” due to physical characteristics of the infrastructure used by both (pipe diameter, pressure, etc.), a gap was opened to challenge the use of a few meters of pipelines to transport gas from the Gasbol branch, where it arrives, to the liquefaction plant. According to the partners in the joint venture, the supply of piped gas to the Gemini Project would be a mere transportation activity, under the jurisdiction of the Union, and not distribution (state jurisdiction).

In addition to the question regarding the jurisdiction of distribution of NG, the supply of gas to the liquefaction plant also generated controversy, since NG had a cost close to zero, as it was part of Petrobras' counterpart in the contract with White Martins – and it was settled from the beginning of the project. The case sparked several administrative, regulatory, and judicial disputes, involving institutions such as the Administrative Council for Economic Defence (CADE), which in 2016 revised the terms of the initial approval of the project (already in operation for ten years), applying fines and sanctions (ROMEIRO, 2018, p. 295).

In an article on May 10, published on the RCGILex website, Professor Hirdan Costa commented that, despite the decision on the Gemini case not being judged in the Federal Court Plenary Session, there are preliminary injunctions issued by ministers involved. Carmen Lúcia entered into the merits of the issue, recognizing that the jurisdiction for distribution lies with the states (RCGILex, 2019a). Besides that, the minister recognized that the project should continue while the matter was not judged as the companies involved in the Gemini Project had filed for early protection in the Federal Court (RCGILex, 2019a).

The complaint of CSPE went directly to the Supreme Court, as it is a constitutional matter, but until today, it has not been judged at the organ's Plenary Session, which generates, or has the potential to generate, insecurity for all intending to enter the liquefied natural gas (LNG) market.

In 2006, the current President of the Federal Court, Minister Ellen Gracie, granted an injunction in the Complaint (RCL 4210) to suspend the course of proceedings that are being processed in the São Paulo Federal Court on actions that deal with the jurisdiction for the supply of piped gas in the state.

Minister Ellen Gracie understood that there was "undeniable relevance" in the grounds of the complaint in the sense of the occurrence of a federal conflict and highlighted the importance of the continuity of the provision of the public service for the supply of piped gas. The minister also determined the suspension of the decision of the rapporteur who granted the request for anticipation of protection and maintained the decision in the main action that recognized the existence of a federal conflict. Finally, the minister provisionally suspended the processing of the Ordinary Action before the 11th Federal Court and the appeals in progress at the Federal Regional Court of the 3rd Region:

> PRELIMINARY DECISION - GRANTED
> [...] I DEFER, ON A PRECARIOUS BASIS, THE PRELIMINARY INJUNCTION, ONLY TO: A) PROVISIONALLY SUSPEND THE EFFECTIVENESS OF THE DECISION OF THE RAPPORTEUR OF AI 2006.03.00.015778-8, PRONOUNCED ON 03.09.2006 AND WHICH HAD GRANTED A REQUEST FOR ADVANCE RELIEF, MAINTAINING, HOWEVER, THE LEGAL EFFECTS AND THE FACTUAL STATUS QUO RESULTING FROM THE DECISION PRONOUNCED BY THE JUDGE ON DUTY, ON 12.27.2005, IN THE RECORDS OF THE ORDINARY LAWSUIT 2005.61.00. 029794-9; B) PROVISIONALLY SUSPEND THE PROCEEDINGS OF SAID ORDINARY LAWSUIT 2005.61.00.029794-9 BEFORE THE 11TH FEDERAL COURT OF SÃO PAULO, AS WELL AS THE INTERLOCUTORY APPEALS 2006.03.00.003568-3, 2006.03.00.003563-4 AND 2006.03.00.015778-8 IN PROGRESS IN THE FEDERAL REGIONAL COURT OF THE 3RD REGION, MAINTAINING, SI ET IN QUANTUM, IN THE MENTIONED JURISDICTIONS, THE RECORDS OF THE RESPECTIVE ACTS. INFORMATION IS REQUESTED. COMMUNICATE, WITH URGENCY. PUBLISH IT.
> Min. Ellen Gracie.

The decision of Minister Carmen Lúcia published on October 11, 2006 acknowledged that the conflict is of a federative nature and that it should continue on trial by the Federal Court, maintaining the activities of the joint venture and the suspension of penalties as well as the decision on the urgency that was given to the case.

The jurisdiction to judge the question now posed belongs to the Federal Court, since it is eminently constitutional in nature, as 'it deals with the division of powers in matters of natural gas, dictated by articles 177, IV and 25, § 2, of the CF' which would be threatening "the federative balance."

Considering that the constitutionally monopolized economic activities for their performance by the Federal Government are of an exceptional nature, it seems less burdensome, in this step of the judicial disputes, to suspend the activity of distribution of natural gas by Petrobras to White Martins, as contained in the dispatch from the eminent Minister Ellen Gracie.

The provisional suspension of the processing of the Ordinary Action 2006.03.00.029794-9 before the 11th Federal Court of the Judicial Section of São Paulo is maintained, as well as the Appeals 2006.03.00.003568-3, 2006.03.00.003563-4, and 2006.03.00.015778-8 in progress at the Federal Regional Court of the 3rd Region, with the records held in the aforementioned jurisdictional bodies.

The legal and factual effects produced by the activities carried out up to the date of publication of the preliminary decision are maintained, starting to guarantee that the gas distribution activities are performed by the competent state entities for that purpose, in the form of art. 25, § 2, of the Constitution of the Republic and until the final judgment of this Complaint, which will be dealt with urgently.

The most recent decision given by the 2nd Panel of the Federal Court under the chairmanship of Minister Ricardo Lewandowski is as follows:

Decision: The Panel, by unanimous vote, upheld the claim to recognize the existence of a federative conflict, revoking the contested decisions, and determined that the records be brought to this Court for further processing, maintaining the preliminary injunctions previously granted, under the terms of the vote of the Rapporteur. Those who spoke: for the State of São Paulo, Dr. Rodrigo Menicucci; for COMGÁS, Dr. Marcus Vinícius Furtado Coelho; for White Martins, Dr. Osmar Mendes Paixão Côrtes; for Petrobras, Dr. Tales David Macedo; and, for the Union, Dr. Adriano Paiva. Presidency of Minister Ricardo Lewandowski. 2nd Class, 3.26.2019.[1]

After the appeal period, this judgment became final, therefore, it was decided that there is a federative conflict and that it is up to the Federal Court to judge all actions pertinent to the matter.

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[1] Federal Court Decision. Portal STF, 2019 <http://portal.stf.jus.br/processos/detalhe.asp?incidente=2370757> Accessed: Oct 10, 2019.

Therefore, all the records went up for the purposes of the Court's final pronouncement, in other words, on the jurisdiction of ANP or ARSESP to regulate and inspect the LNG plant in question.

Professor Edmilson Moutinho dos Santos warned about the consequences, for the market, of the deadlock in the legal sphere, stating that the conflict has lost its purpose in itself, as LNG is not a priority now (RCGILex, 2019a). He noticed that the consequent insecurity is not impeding the planning and approval of new projects for the use and distribution of LNG in bulk, as is the case of an Eneva project that recently won the Auction for Supply to Boa Vista and Connected Locations (Generation Auction 01/2019), from the National Electric Energy Agency (ANEEL, 2019). In this case, Eneva will use the NG from the Azulão field, in the Amazonas Basin, for liquefaction and use in a UTE in Roraima.

Edmilson Santos and Hirdan Costa (RCGILex, 2019a) said they feared that the consortium signed between Petrobras and White Martins will end before the Federal Court decision is made. However, regardless of whether the consortium disintegrates or not, the definitions that are at stake are important in the scenario of liberalization and maturation of the Brazilian gas market. It is expected that the increase in the records determined by the last decision of the Federal Court will speed up the judgment of the case and that this dialogue can favor negotiations between public and private members in the sector.

In 2019, an analysis conducted by ANP indicated the cancelation of authorizations necessary for the operation of the consortium. According to an article published by the specialized website Epbr[2] (2019), the Superintendence of Infrastructure and Movement (SIM) of ANP concluded, in a technical note sent to CADE, that the revocation of authorizations for the transportation and sale of gas is allowed as a form of punishment to the Gemini consortium. The document suggested a period of 540 days to Petrobras and the Gemini consortium for the effective revocation of authorizations, avoiding the shortage of customers. After this period, the consortium would no longer be able to distribute LNG

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[2] Gemini case: new punishment may forbid joint operation of Petrobras and White Martins. Epbr, July 8, 2019. Avaliable at: https://epbr.com.br/caso-gemini-nova-punicao-pode-proibir-operacao-conjunta-de-petrobras-e-white-martins/

and Petrobras would not be allowed to load and market at the Gemini delivery point.

In May 2020, the Gemini Project case entered the stage of producing evidence, after a meeting convened by the Mines and Energy Ministry (MME) with the companies of the Gemini consortium. It has been pending in the Supreme Court for 14 years (BRASIL ENERGIA, 2020).

After considering the case presented, the chapter goes into the legislative and literature review on the role of regulation of the respective competent agencies in transportation and distribution and concludes with other cases that may imply similar legal issues.

3. From the interventionist to the regulatory state

The idea of State evolved from the city-states of antiquity into the Modern State after the French Revolution. From this modern meaning, sculpted by the commandments of freedom, equality, and fraternity, it was pointed out, first, for a model of liberal state, which brought in its core the pursuit of the minimum state, effected by the freedom of initiative, private property, and autonomy of the will. The search for well-being went beyond the limitation of individual freedom in relation to that of others (SOUTO, 2000).

On the other hand, after the world crisis of 1929 and the Second World War, the bases for the emergence of the Social and Interventionist State were reinforced, in which contractual leadership prevailed, in order to equal out the unequal ones (SOUTO, 2000).

The Constitution of 1988 shows that the State's action would take place within the "relevant collective interest" or "national security imperative," adding the fact that the State only entered the economic domain in these two hypotheses, in addition to Article 174.

Therefore the original constituent provided that the activities resulting from the Oil Industry would be linked to this "national security imperative" and, thus, treated the matter as a Union monopoly to be exercised by the state-owned company, Petrobras.

It so happens that the world, after the historical context of the end of the Cold War, went through a process of intensification of transnational relations, detaching, especially, from the power of the nation-state. Countries, especially the developing ones, are in need of State Reform. A State adapted to the market understands the necessity of leaving it free to its own game, without interfering in it.

In this view, the legislator started, especially in Collor´s government, the adaptation of the Brazilian State to the context of economic globalization, reducing its size, wiping it out by means of fiscal adjustments and other measures with a view to ending the public deficit that existed at the time.

In the path of reforms to the Federal Constitution of 1988, the legislator went through the privatization projects, incorporating its new guidelines, the end of natural monopolies in the so-called public services (or economic activities in the broad sense) and in certain economic activities in the strict sense.

Thus, with the edition of the amendments, after those of revision to the constitutional text, the possibility of entry of private national and foreign companies to sectors that used to be exploratory in nature and exclusively state owned, was undertaken in 1995. Constitutional Amendment no. 5/95 was enacted, related to the jurisdiction of the federal states, which, amending article 25, paragraph 2, "ended the state monopoly on the exploitation and distribution of local piped gas services, allowing the establishment of the concession regime, whose regulation will be made according to the law" (BONAVIDES, 2000). This therefore modified the previous text, in which exploration and distribution took place exclusively with the state-owned company or directly exercised by the federated state.

In November of the same year, Amendment Nº. 9 was issued, making the Union's monopoly in the oil and natural gas sector more flexible, through the possibility of the government to hold contracts with state or private companies.

With the reform attempted by the legislator, the model of direct interventionism was changed, in which the State carried out such activity through its state-owned company, to then allow the activities of other entities to be carried out, the so-called regulatory agencies, covering not only supervisory but also normative, sanctioning, and promoting functions. Thus, with the reform undertaken by the legislator, that model of direct interventionism was partially altered, allowing the entry of other business actors in this market.

The richness of the matter lies in the configuration in terms of the jurisdiction granted to the federal states to provide the piped gas service, concurrently with the fact that the Union is the holder of the rights to explore and regulate natural gas, hydroelectric energy, oil and gas, and nuclear power.

4. Scope of action of state regulatory agencies

Due to the constitutional delimitation of the jurisdiction of the states over the exploitation of the piped gas service, there are potential conflicts regarding the scope of regulation of the state and federal government agencies, given the subtle limits of the matter. In a simplified way, the state government agencies are responsible for dealing with the distribution and the federal government agencies for the transportation of natural gas.

Due to the conflicts, the need is emphasized to indicate the limits of the actions of the government agency or secretariat responsible for regulating the respective sector. In the case discussed in this chapter, the relevance of the existence of state agencies in the current concession model for the distribution of piped gas is perceived.

Generally, the jurisdiction of the state agency can be tied to that of the federated state and as established in the domestic legislation. However, this situation must be in accordance with the Federal Constitution, and, therefore, since the Union has the jurisdiction to legislate on energy, which covers natural gas, as a way of establishing a mechanism for the division of jurisdictions, it is understood that it is the responsibility of the Union to legislate with rules of a general nature. Thus, as far as competence to legislate is concerned, in general matters of national interest, the jurisdiction will be the Union's, while states have jurisdiction within their respective local interest.

José Roberto Cavalcanti (2002) explains that the state legislation could deal with the distribution of natural gas differently from the technical specification provided in the federal legislation.

Thus, in Cavalcanti's (2002) opinion, considering the relevance of specifying uniform gas in national territory, it is not up to the states to deal with this matter.

In this line of reasoning, the regulatory jurisdiction of the state agencies connects to the local interest, emphasizing the aspects related to the service of fuel and piped natural gas destined to the end user, domestic or industrial in general. Therefore, there can be no distortion of this jurisdiction, not being possible for the state to address the use of NG as raw material or transportation for a non-end user. The state, for example, has the right to demand that third parties do not transport or sell gas to final consumers (users) located in its territories.

5. Scope of action of the National Petroleum Agency (ANP)

The performance of ANP in the gas market is not only supervisory, but also legislative, executive, and judicial. Despite the fact that the regulatory structure of natural gas is still being defined, an example of this ideological limbo was the revocation of Ordinance No. 169/98 of the ANP, by Ordinance No. 62/01, which dealt with the system of free access in the country. Based on the experience, it can be said that the agency's role in this market is to guarantee a minimum administrative, normative, and supervisory order for an environment where technological and market evolution is in constant dynamism.

The purpose of regulating this market, therefore, is to guarantee its efficiency in fulfilling public interest functions. The ANP's jurisdiction is restricted until the passage of the transportation pipelines through the city gate, which is a benchmark for transferring jurisdiction to state distributors.

The importance of ANP in the context of the oil and oil products transportation market lies in the fact that Petrobras still has a patent monopoly on this market, since this company is a vertical structure (which operates both in oil exploration and in the resale of oil products). This fact is able to create the risk of unfair competition and predatory prices.

The dynamics of the market, in constant technological evolution, and the reorganization of the companies that operate in the sector to guarantee their own survival lead to an urgent need to have a strong public entity capable of not submitting to the lobby and pressures from large companies. In addition, the public entity is able to act with a specialized technical profile for the specificities inherent to it, but without leaving it entirely to the players'[3] desire.

In the case of LNG, the MME authorizes the transaction in terms of importing and exporting and the ANP releases and monitors the product until the procedure of the tax authorities is finished. ANP is also responsible for authorizing the construction and monitoring of the operation of the LNG terminals. Brazil imports LNG from countries such as Nigeria and Qatar and currently has three LNG terminals, which belong to Petrobras, but these structures have periods of idleness. In this sense, the company is studying the possibility of increasing its revenue by opening and providing access to third parties (BOTÃO, 2019).

The Gas Law (11.909/2009) allows the use of regasification terminals by third parties. However, some barriers to marketing and handling make it difficult to use these terminals on a shared basis. Button (2019) pointed out that the swap and dispatch flexibility of thermal power plants are examples of operations that face regulatory barriers.

The swap allows the optimization of gas transportation flows through financial compensation due to the mismatch between the physical movement of the gas and that agreed in the contract. In physical terms, this operation is possible due to the homogeneous character of the gas moved in the ducts, allowing the gas from one charger to be used by another. However, there is still no regulation or tax structure that comprehends this commercial operation in the country, and such scope is important to prevent the consumer from having high costs resulting from double taxation on the purchase and sale of hydrocarbons (BOTÃO, 2019).

ANP Resolutions No. 50/2011 and No. 52/2015 regulate the operations at the terminals, as well as the choice of integral gas pipelines, the registration of self-producer, auto-importer, and the

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[3] Companies of the transport sector.

commercialization of LNG after the process of payment of the cargo. Regarding the registration of free consumers, it is up to the competent regulatory body of each State (BOTÃO, 2019).

Decree No. 7382/2010, in turn, regulates the transportation of LNG, after regasification, to the final consumer through the network. Thus, through the decree, the ANP aims to discipline the criteria of autonomy and independence of the activity of natural gas transportation, promoting free competition, transparency of information, and efficient use of infrastructure (BRASIL, 2010).

6. Framework of the legal regime for natural gas distribution

Thus, when first investigating the scope of the term piped gas, it is understood by the best hermeneutics technique, that the Federal Constitution uses the term “gas” with the meaning of hydrocarbon mixture, and this jurisdiction does not extend to all and any type of gas (CAVALCANTI, 2002).

José Roberto Cavalcanti (2002) exposes understanding in the sense that a historical interpretation of the Constitution points to the commercialization of gaseous hydrocarbons to be used as fuel. The author continues to explain that his position is supported by the fact that “the spirit of the constitutional norm is to attribute to the States the jurisdiction for the service of energy distribution and not of raw material” (CAVALCANTI, 2002).

Within this view, when natural gas is destined for raw material it will therefore not be within the jurisdiction of the States. The jurisdiction of States is restricted to the distribution of natural gas through pipelines to end users, whether domestic or industrial in general.

With regard to the framework of the piped gas distribution activity, it is highlighted that “they have remained as providers of public services, similar to water and electricity services. (...) Often, the responsibility for regulation lies on a state public agency or company linked to the infrastructure sector” (TURDERA, 2002).

In this way, the concessionaire, whether public or private, is under the specific rules of the activities considered as public service, which, as a rule, as they are also commercial services, have legal rules of common law, derogated, sometimes more, sometimes less, by public law (PIETRO, 2001).

However, "public law applies with regard to the relationship between the entity providing the service and the political legal entity that instituted it" (PIETRO, 2001).

According to Maria Sylvia Zanella Di Pietro (2001), public service is "any material activity that the law attributes to the State to exercise directly or through its delegates, with the objective of concretely satisfying collective needs, under a totally or partially public legal regime."

Thus, the piped gas distribution service is subject to the principles of public law regarding the matter, namely, the continuity of the public service, since the service must be uninterrupted; the mutability of the legal regime, with the flexibility of its regime when the public interest says so; and the equality of users.

With this legal framework, concessionaires are compelled to follow what was established by the regulator in the natural gas distribution market. For this reason, currently, we see the concrete performance of government agencies or bodies that regulate the activities of this sector.

7. Main characteristics regarding the transportation of natural gas

Within the scope of natural gas transportation, it's currently regulated by Ordinance No. 170/1998, of the ANP, which regulates the provisions of arts. 56 and 59 of the oil law.

Despite the growing importance of the NG market in Brazil (in view of the instability of the value of a barrel of oil on the international market), in comparison with oil itself, it is still at a lower level of regulatory rigidity. There is only the need for an authorization by the Agency (Art. 1, caput) and that the interested company dedicates itself, exclusively, to the transportation of natural gas (Art. 6) in order to operate in the transportation market.

In spite of this apparent prioritization of oil, to the detriment of NG, in terms of regulatory rigidity, this may even constitute an advantage for companies interested in operating in this sector, since the authorization in these cases has specific features that do not exist in the classic authorization of administrative law. In that case, it cannot be revoked *ad nutum*, but only as a result of specific situations, thus ensuring greater security for contractors.

The activity of transporting natural gas includes, in addition to the use of pipelines, maritime, fluvial, lake, and terrestrial installations, not counting the liquefied and liquefied natural gas regasification units - GNL - (Ordinance No. 170, art. 1, § 1), regardless of whether they are aimed at the internal supply of this merchandise, importation, or exportation.

The transportation of natural gas is an activity under the federal monopoly (Federal Constitution, art. 177, IV), where high initial investment costs are demanded, as it is a network industry[4], and is currently under a natural[5] Petrobras monopoly, since it is the largest holder of the pipeline network in the country.

In the past decade, the Executive Branch proposed a new legal statute, through Bill No. 6.673 of 2006, in view of the need to adapt the legal framework to the reality that appeared before the natural gas industry. The argument was that the regulations provided for in the Petroleum Law were insufficient for the expansion of the gas pipeline network in the national territory; for the development of the market, long-distance domestic transportation was necessary, under a typical natural monopoly structure. The legislative process took three years of discussion, resulting in Law No. 11,909 of March 9, 2009, known as the Gas Law. The new legal status, despite the various instruments provided, was not sufficient to promote the competition necessary to the final consumer: Petrobras remains as the main producer of natural gas, owner of the gas pipeline network, and, consequently,

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[4] A network industry means the one for which the flow of its goods depends on a previously installed infrastructure, which, in the case of natural gas, are the pipelines through which it is drained, from the refinery to the distributors and from them to the final consumers.

[5] A natural monopoly is characterized by being a sector whose activity does not involve the performance of several agents under the perspective of free competition, due to the high costs of initial investment and the developed business itself, which would lose economic viability if there were more than one participant.

monopoly transporter and loader in Brazilian territory (COSTA; ARAUJO; MASCARENHAS, 2019).

ANP Ordinance No. 118/2000 provides for the distribution of bulk liquefied natural gas (LNG), as well as the construction, expansion, and operation of liquefaction and regasification units for natural gas. The construction, expansion, and operation of installations for handling oil, its derivatives, natural gas, including liquefied gas (LNG), biofuels, and other products regulated by the ANP are regulated by ANP Resolution No. 52/2015.

Resolution no. 52, of December 2, 2015, incorporated into the normative framework new interpretations and concepts of the Gas Law applied to the construction, expansion, and operation of various facilities used for the transportation of natural gas (COSTA; ARAUJO; MASCARENHAS, 2019).

a. Free access and competitive law in the transportation of natural gas

The role of competition law is, therefore, within the context of the entry of new participants in the use of existing pipelines, that of ensuring that they do not start to act together, either to expel another participant or to act in the form of an oligopoly.

The development of free access serves, in the case of the natural monopoly exercised by Petrobras, to make it more flexible without making the activity economically unfeasible, as competitors will be able to participate in this market, but always with necessary compensation and with the use of the idle spaces in the existing pipelines.

This is forced competition, which is not inherent in the market in question, but whose existence is necessary to avoid the harmful effects of the existence of a sector in the market dominated exclusively by a single company. Even in this case, there is still a certain level of participation by the government.

In the case of transportation through pipelines, which is the most used for natural gas in Brazil, given the essential character of this asset (it must be remembered that distribution is characterized as a public service), the ownership of these pipelines must fulfil its social function, which is certainly not to keep a whole economic sector in the possession of a single person. Thus, if there is idleness in them, it is essential to make full use of them. Such provision is found in the oil law itself, when it allows them to be reclassified (art. 59) as transportation pipelines previously considered only as transfer pipelines (whose interest in them belongs only to their owner).

Accordingly, as part of its divestment program in the gas sector, in mid-June 2019, Petrobras was able to complete the sale of 90% of the Transportadora da Gás Associado S/A (TAG) to the consortium formed by the Franco-Belgian Engie and Canadian fund Caisse de Dépôt et Placement du Québec (CDPQ). The consortium paid R$ 33.5 billion for the assets, which consist of 4,500 kilometers of gas pipelines between the North and Northeast of the country (INFOMONEY, 2019).

The sale caused a lot of controversy because it was carried out without the approval of Congress and without bidding - a matter taken to the plenary of the STF and voted on June 6, 2019. By a majority, the agency decided to release the sale of the controlling interest in subsidiaries of public companies and mixed-capital companies without the need for legislative approval or a bidding process. The decision paved the way for companies like Petrobras and Eletrobras to sell their subsidiaries (RCGILex, 2019b). A week after the decision, Petrobras concluded the sale of TAG - considered, until now, as the largest operation carried out within the scope of the divestment of NOC in the gas sector.

Finally, on June 25, 2019, the National Energy Policy Council (CNPE) published Resolution 16 with guidelines for the implementation of the New Gas Market, a federal-level program with the objective of expanding the gas industry in Brazil, with the accession of states.

The standard presents the guiding principles for the establishment of a natural gas market in a coordinated manner, including the sale of assets in an attempt to diversify agents active in all links of the industry chain, and recommending the privatization of the shares held by Gaspetro in the distributors state (RCGILex, 2019).

According to the MME, the Resolution's guidelines include Art. 3, item I, which suggests the sale of the shares Petrobras holds today in the natural gas transportation and distribution companies. Another guideline states that Petrobras, which currently holds 100% of the gas transportation capacity in the system, defines how much of that capacity it wants to use at each entry and exit point of the gas pipeline network, allowing new agents to offer gas on the national market (RCGILex, 2019).

In line with the new guidelines, Petrobras is moving to sell its 51% stake in Gasbol, the gas pipeline that connects Brazil and Bolivia. Recently, the company signed an agreement with CADE that foresees the sale of control of TBG, the gas carrier that owns Gasbol, by 2021. One of the interested parties is precisely Yacimientos Petrolíferos Fiscales Bolivianos (YPFB), which already holds 12% of TBG (NUNES, 2019).

With regard to projects such as Gemini, in which the low cost of NG is vital for maintaining the business, it is worth questioning the possibility of maintaining this cost in the event of the sale of Petrobras' stake in Gasbol.

Recently, the Administrative Council for Economic Defense (CADE) and Petrobras entered into a Term of Commitment to Cease Predatory Practice (TCC), the purpose of which is to sell the state's transportation pipeline network. Based on the aforementioned term, Petrobras committed itself to dispose of 100% of its transportation assets as a way to de-verticalize its operations in the natural gas industry. Despite possible competition, the state-owned company, as it continues to be Bolivia's main importer of natural gas and the main producer of the input on the Brazilian coast, has mechanisms to maintain itself as a monopolist loader in Gasbol. Thus, if it were the main carrier of the pipelines to be sold, it would remain a monopolist at the entrance and exit of natural gas transportation (COSTA; ARAÚJO; MASCARENHAS, 2019).

It is necessary to guarantee transparency in such a way that the entrance prices at the city gate reflect no more than the cost of distribution as a local service. The remuneration of the responsible agent is also important with the due low-risk portion that characterized the activity. Besides, the possibility of expanding the local service is necessary for the better use of the means of production in the regional economy (COSTA; ARAÚJO; MASCARENHAS, 2019).

Therefore, Gemini's operations have generated legal and administrative conflicts, and the dispute has been referred to the STF, which has yet to make a decision on the differentiation between "transport" and "distribution," however, it was acknowledged that the issue is in fact the jurisdiction of the STF. The case illustrates certain conditions of legal uncertainty that the country offers for investments in the LNG sector. In this sense, it is relevant to analyze the situation to delineate regulatory jurisdictions at the federal and state levels regarding these two stages of the energy chain. The intention is to foresee and resolve regulatory obstacles to favor projects, in progress and in the future, to expand the infrastructure for use and commercialization of LNG in the country.

8. New cases involving LNG in Brazil

In Brazil, there is only one liquefaction plant operating, in Paulínia (SP), to serve the aforementioned Gemini Project. Liquefaction decreases the volume of NG by 600 times, making it easier to transport and store. In the meantime, LNG must be stored and transported at around -160 °C. Although the costs of these operations are high, the liquefaction of NG has boosted the gas market globally. Until the 1960s, when there was development and implementation of liquefaction technologies, large-scale maritime transport, reception, and regasification of the energy source, the NG market was a regional activity, with transportation done, basically, through gas pipelines (BCCS, 2014, apud RAMOS et al., 2019).

The construction of the first LNG regasification terminals has the intention of providing the flexibility of gas supply. In this sense, Petrobras built three LNG terminals in the country, covering the states of Rio de Janeiro, Bahia, and Ceará. The use of the terminals has followed the regional demand and the company's logistical strategy and the terminals operate mainly in supplying the thermoelectric market. Thus, Petrobras maintains the strategy of purchasing LNG only on the spot market, when it is necessary to dispatch these thermoelectric plants (EPE, 2019a).

Thermoelectric projects that follow the business model of natural gas thermoelectric plants (UTE) linked to LNG terminals have been one of the most competitive alternatives for contracting new energy. In this context are the following winning projects from the last auctions: TPP Porto do Sergipe I, in Barra dos Coqueiros/SE; UTE Gás Natural Açu (GNA) I (formerly UTE Novo Tempo) and UTE GNA II, both in Porto do Açu, in São João da Barra/RJ (EPE, 2019a). In addition to these projects, Eneva also won an auction with the project to build a natural gas thermoelectric plant in Boa Vista in the state of Roraima, which is not interconnected with the Brazilian power system.

In a recent report on LNG regasification terminals in Brazil (EPE, 2019), in addition to the LNG reception and regasification terminals that will feed the aforementioned UTEs, another 15 projects appear at different stages of planning and execution, 13 on the coast and two projects for river terminals, in the states of Pará (PA) and Amazonas (AM).

a. UTE Porto do Sergipe I, Barra dos Coqueiros/SE

The company Centrais Elétricas de Sergipe S.A. (CELSE) is about to complete the project of the thermoelectric complex that also involves an LNG terminal in the state of Sergipe and transmission lines. The project is the first private initiative type LNG-to-Power in Brazil and when completed it will have the largest thermoelectric plant in Latin America, with 1.5 GW of expected power (EPE, 2019a). The 33km-long 500 kV transmission line will take the energy generated at the Porto de Sergipe I Thermoelectric Plant to the Jardim Substation, in Nossa Senhora do Socorro (SE), from where it will connect to the SIN (National Interconnected System) (CELSE, 2019).

The project has a Floating Natural Gas Storage and Regasification Unit (FSRU), which is expected to be permanently anchored in the terminal 6.5 km from the coast. Samsung in South Korea built this FSRU, named Golar Nanook. The idea is to expand the use of LNG beyond the thermoelectric demand. The company is studying the possibility of a pilot project for LNG-powered trucks and the connection of the terminal to the transportation pipeline network (CELSE, 2019).

b. Regasification terminal Porto de Açu and UTEs, São João da Barra/RJ

In São João da Barra/RJ, Gás Natural Açu (GNA), a joint venture between Prumo Logística, BP, and Siemens, is responsible for the construction of an LNG regasification terminal in Porto do Açu. It is a complex of port terminals and the LNG terminal project, which will be located in Terminal 2 of the complex, consists of an FSRU, which received the name BW MAGNA built in Singapore, and should reach the port in 2020. At the port, it will remain docked and operating in the Ship-to-Ship (STS) configuration. The regasification capacity is 21 MMm^3/day and can store up to 174 thousand m^3 of LNG (GNA, 2019).

The terminal will mainly supply the thermal plants, GNA II and I. GNA I will start commercial operation in January 2021, with 1.3 GW of power, consuming 5.5 MMm^3/day of natural gas. GNA II starts operating only in January 2023, with a larger installed capacity expected to reach 1.6 GW and gas consumption of 6.5 MMm^3/day. GNA has a license to double its power generation, reaching up to 6.4 GW. The company also expressed interest in connecting the terminal to the gas pipeline network to supply natural gas for the domestic market (EPE, 2019a).

c. Jaguatirica II TPP, Boa vista/RR

The Auction for Supply to Boa Vista and Connected Locations (Generation Auction 01/2019), of the National Electric Energy Agency (ANEEL), whose notice had been published in April (ANEEL, 2019) was held on May 31, 2019. According to EPE (2019b), the most powerful supply solution (126, 29 MW) is an Eneva project, for the construction of a natural gas thermoelectric plant in Boa Vista (RR).

The project foresees the generation of energy for Roraima from the natural gas produced in the Azulão field, in the Amazonas Basin. The natural gas in the Azulão field will be liquefied and transported by trucks to Boa Vista, the capital of Roraima, where the Jaguatirica II TPP will be installed. Currently, there is no gas production in the Amazonas Basin, only in neighboring Solimões, where Petrobras operates the Urucu fields, connected to Manaus by pipeline.

Eneva secured a contract for the sale of electricity and power in isolated systems for a period of 15 years, starting on June 28, 2021. According to a note published on Canal Energia (2019) on Thursday, June 6, 2019, the company delivered to Techint, with whom it signed a global contract (full EPC, including engineering, construction, and assembly), notification for the beginning of the implementation of UTE Jaguatirica II. The EPC foresees the beginning of commercial operation in up to 24 months.

9. Final remarks

In the course of this study, it was possible to verify the existing importance in the perfect delimitation of the jurisdictions in terms of regulation in the sector of transportation and distribution of natural gas in Brazil.

The new provision on the regulatory framework for energy is still being changed by the Ministry of Mines and Energy, but some concrete results in the upstream area (with the call to the ministry of functions previously foreseen by the ANP, such as the formalization of the concession contract) have already been noticed. The natural gas law is also passing through ongoing analyses, however not all resulted from the new market position (increasingly segmented) or new technologies.

The analyses showed that the consumer market could not be submitted to a single supplier or, even if to a few, ones operating in a cartel structure. It is a highly specialized market, where high initial costs are demanded and, due to its own characteristics, one of them is the infeasibility of storage. With the risks and values involved, it would only be economically viable through a continuous supply contract (take-or-pay contracts, as in the case of GASBOL).

Such risks, however, deserve management, either by the ANP, at the national level, or by the state agencies, technically and legally, able to deal with companies in this market. Otherwise, the situation falls into the Capture theory: the submission of the regulatory agencies to the companies that they should inspect by economic and/or technological factors, according to specialized doctrine mentioned in this work.

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Organizers and Authors

Organizers' information:

Edmilson Moutinho dos Santos. He graduated in economics and in electrical engineering from the University of São Paulo. He has his master's in energy management and policy (University of Pennsylvania) and in energy systems planning (Unicamp). He has a PhD in energy economics from the French Petroleum Institute and the Université de Bourgogne. He is currently an associate professor at the Institute of Energy and Environment of the University of São Paulo. Since March/2019 he is a Scientific Productivity Scholarship Category 2 Researcher of CNPq. Since January/2016, he has coordinated the Energy Economics and Policies Program of the Research Centre for Gas Innovation, and since January 2017, he has coordinated the FINEP/FUSP Project (Support to the Non-Conventional Gas R&D Network in Brazil).

Drielli Peyerl. She graduated in history and geography, both at the State University of Ponta Grossa. She completed her master's degree in territory management - geography, also at the State University of Ponta Grossa. She has her PhD in sciences from Unicamp. She is currently a Young Researcher/Collaborating Researcher at the Institute of Energy and Environment, RCGI, University of São Paulo, coordinating the project entitled Transitions in the History of Energy: Development and New Perspectives on Natural Gas in Brazil, financed by FAPESP - (Process 2017/18208-8 and 2018/26388-9), and the project "Evaluation of Small LNG and CNG Supply Options for Transportation to Off-Grid Locations; and Planning Expansion and Operation of Multimodal Integrated Networks" together with Prof. Dr. Edmilson Moutinho dos Santos. She is working on the themes of energy transition, history of energy and technology, and decarbonization.

Anna Luisa Abreu Netto. She is a lawyer graduated from Universidade Salvador (2011), has an MBA in business management (2016) from Fundação Getúlio Vargas and her master's in administration from the Universidade Federal da Bahia (2018). During her master's degree, she completed an exchange program at Universität Passau (Germany). She is currently a PhD candidate in environmental science at the Institute of Energy and Environment of the University of São Paulo and a collaborator of the Research Centre for Gas Innovation, University of São Paulo. Her line of research includes social perception and social license to operate technologies related to energy transition and climate change, including CCS, energy storage, natural gas, and renewable energy.

Authors' information:

André Luiz Veiga Gimenes. Professor at the Department of Energy, Engineering, and Electrical Automation of the Polytechnic School of the University of São Paulo (EPUSP). Coordinator of GEPEA USP - Energy Group of PEA EPUSP. He has a degree in energy engineering and electrical automation from the University of São Paulo (1997), a master's degree in electrical engineering from the University of São Paulo (2000) and a PhD in electrical engineering from the University of São Paulo (2004). He conducts research in the area of electrical engineering, with emphasis on energy planning and energy management, working mainly on the following topics: solar energy, energy planning, electrical energy, integrated resource planning, sustainable development, and energy efficiency.

Cylon Liaw. He holds a degree in business administration from the Faculty of Economics, Business and Accounting - USP (2011) and a master's in sciences (focus on energy) from IEE/USP (2018). He has experience in the administration area, with interest in energy policies and public policies. He has the theme of natural gas as a concentration field, acting in the Research Centre for Gas Innovation (RCGI) and in the public sector (Secretariat of Economic Development, Energy, and International Relations of the State of Rio de Janeiro). He acts as a consultant for projects of piped gas concessionaires and other variants in the gas sector.

Denis Martins Fraga. He majored in business management from the university center of FEI (2008), post graduate lato sensu in oil and gas at COPPE/UFRJ (2014). He has his master's of science in energy from the University of São Paulo, with an exchange at IFP School, France for extension on petroleum economics and management (2018). Has also worked on research projects with the Research Centre for Gas Innovation RCGI related to small-scale LNG and greenhouse gas emissions. Currently doing his PhD at Imperial College London. Has been working in the oil and gas sector for more than 10 years with experience in the whole chain of economic appraisal, pipeline project development, business development on onshore and pre-salt drilling rigs (Brazil) and on exploration blocks in the North Sea (UK). Lastly, worked in negotiation and strategy development of new natural gas supply contracts in São Paulo.

Dorival Suriano dos Santos Junior. He graduated in chemical engineering from the Federal University of São Carlos (UFSCar). He has more than 10 years of experience in the mining and energy industry in the areas of feasibility study, new business development, FEL Methodology, project management, and environmental management systems. He graduated from the master's program in science (focus on energy) from the Institute of Energy and Environment of the University of São Paulo and works as a researcher at the Research Centre for Gas Innovation (RCGI) - Energy Economics and Policy Program.

Hirdan Katarina de Medeiros Costa. She is a lawyer. Master's in energy and PhD in science from the graduate program in energy at the University of São Paulo (PPGE/USP). Master's in energy and natural resources law from the University of Oklahoma (OU), in the United States. Master's in law (PUC/SP). Post-doctorate in sustainability from the School of Arts, Sciences, and Humanities at USP (EACH/USP). Post-doctorate in energy at the Institute of Energy and Environment at USP. In 2008, she was a visiting researcher at the University of Oklahoma (OU), in the United States. From August 2013 to July 2016, she was a visiting researcher at PRH04 ANP/MCTI. Currently, she is a collaborating professor at PPGE/USP, vice-coordinator of the Policy Program, coordinator of Energy and Economics, and coordinator of Projects 21 and 42, both from the Research Centre for Gas Innovation - FAPESP/Shell.

Karina Ninni Ramos. She is currently pursuing her doctorate in the graduate program in energy (PPGE) of the Institute of Energy and Environment of the University of São Paulo (IEE/USP). She has a degree in social communication (journalism) from the School of Communications and Arts of the University of São Paulo (ECA/USP, 1995), and a master's degree in sustainable development of the humid tropics from the Center for Higher Studies of the Amazon at the Federal University of Pará (NAEA/UFPA, 2001). She specialized in environmental and scientific journalism. She has worked in major newspapers and publishing houses, such as O Estado de S. Paulo, Folha de S. Paulo, Gazeta Mercantil, Editora Abril, among others. She taught in higher education (Unama, Senac São Paulo) and also worked in the third sector (Imazon, Fase Amazônia). She creates and manages content in the area of science, technology, and innovation for research institutes, universities, Research, Innovation and Diffusion Centers (CEPIDs), and entrepreneurs with focus on innovation.

Marcella Mondragon. Master's candidate in energy planning at the Institute of Energy and Environment at the University of São Paulo. Graduated in energy engineering at the Pontifical Catholic University of Minas Gerais. Works as Regulatory Affairs Analyst at Votorantim Energia.

Mariana Oliveira Barbosa. She graduated in geology - bachelor's degree (2018) from the Institute of Geosciences at the University of São Paulo. She is currently a master's student in the postgraduate program in energy at the Institute of Energy and Environment at the University of São Paulo. She is a fellow of the Research Support Foundation of the State of São Paulo, process number 2019/04555-3. She has worked in the field of research on the use of natural gas in the state of São Paulo.

Miguel Edgar Morales Udaeta. Professor and researcher at GEPEA/EPUSP. Professor at EPUSP (2012), Post-doctorate in energy planning and integrated resource planning at USP (1999 and 2003). PhD in electrical engineering from EPUSP (1997), master's in electrical engineering from EPUSP (1990). Degree in electrical engineering from Universidad Mayor de San Simon at "Facultad de Ciencias y Technologia" UMSS/FCyT (1984).

Paola Mercadante Petry. She graduated in chemical engineering at the Polytechnic School of the University of São Paulo (USP) and has her master's in energy science from the Institute of Energy and Environment (IEE/USP). Contributes to RCGI-Project 21 and has experience in biofuel policies, development of technologies for bioenergy, and waste to energy projects.

Stefania Gomes Relva. PhD candidate in sciences – area: power systems, in the program of electrical engineering at Escola Politécnica from USP. Master's in sciences – area: power systems in the program of electrical engineering at Escola Politécnica from USP (2016). Bachelor's in civil engineering from UNICAMP (2012).

Vinicius Oliveira da Silva. PhD candidate in sciences – area: power systems, in the program of electrical engineering at Escola Politécnica from USP . Master's in sciences - area: power systems in the program of electrical engineering at Escola Politécnica from USP (2015). Bachelor's in Mechanical Engineering from UNESP (2011).

The use of natural gas (NG) in Brazil is a theme under the spotlight in recent years, mainly due to the discoveries of NG reserves in the pre-salt, the growing discussion about the use of this source as an element for the energy transition in Brazil, including the use of LNG as transportation fuel, and the increase of liquefied natural gas (LNG) transactions in the world, reaching new markets. In view of the opportunities for LNG in the coming years, this book comes at an opportune moment, discussing the necessary issues for the country's energy sector.

The authors address several topics on NG and LNG that are crucial, including: the importance of NG for Brazil's current energy transition; the regulation of the Brazilian gas market; discussions on the possible renewal of the Bolivian natural gas supply contract for Brazil; the characterization of compressed natural gas and small scale liquefied natural gas; the small scale supply of NG throughout Brazilian railways; and, finally, an overview of the regulatory process of LNG in Brazil, focusing on the Federal Supreme Court decision on the Gemini project.

The book's architecture was designed in such a way that the reader acquires a broader initial vision about NG in the Brazilian context, and then goes into more specific themes, such as those related to LNG and small scale transportation. Although there is a logic behind its organization, the chapters can be read independently. This book can be of great value to the academic public, as well as to investors, companies in the sector, public authorities and other people who need to be equipped with information to evaluate and make decisions about the future of LNG in Brazil.

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