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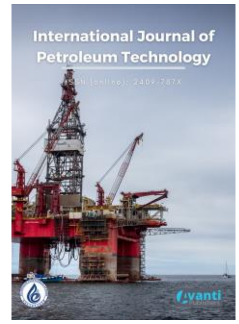

Gas to Wire (GTW) Model in Brazil: Challenges and Possibilities

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ABSTRACT

The expansion of natural gas production in Brazil presents some obstacles, the main one being the reduced volume of investments in expanding the transportation, distribution, and commercialization of natural gas produced offshore and onshore in the country. If, on the one hand, the lack of investments in infrastructure for the flow of natural gas produced in the country prevents the expansion of natural gas production in the onshore basins, the transformation of electric power near the reservoirs of natural gas has enabled the viability of projects for exploration and production of natural gas in the Brazilian onshore basins. A review of literature and analysis of secondary data allows the study of technical, legal, and economic factors that enable the implementation of a reservoir to wire projects, from the production of natural gas in the onshore basins of Brazil, aiming at the supply of electric power to the National Electric System. This way, natural gas changes its condition as a complementary energy source, together with the National Electricity System, to exercise the function of a basic energy source for parts of the national system.

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1. Introduction

The beginning of Brazilian natural gas production is associated with the development of oil exploration and production in the sedimentary basins of Recôncavo and Sergipe-Alagoas and, in the constitution of the Brazilian government-controlled oil company, Petróleos do Brasil S.A. (Petrobras) in 1953 [1].

Over the following decades, the development of natural gas production in the country was placed in a secondary position in the interest of Petrobras due to the country's relentless pursuit of oil self-sufficiency that lasted until the past decade [2].

The opening of the oil and natural gas exploration market in Brazil with the amendment to Constitution No. 9 in November 1995, regulated by Law 9,478 of 1997, did not substantially alter the production of natural gas in the country, which continued to have Petrobras its most significant producer and, consequently, supply in the local market fell short of the potential of domestic demand [3].

Over the decades, the predominance of water sources in the Brazilian electric matrix also contributed to the low expansion of the natural gas supply in the country. To the point of 2020, the Brazilian electric matrix is composed of renewable sources, approximately 86% of the total [4].

According to [5], water and wind sources are positioned as pillars of the National Interconnected System (SIN), responsible for about 76% of the total. In turn, thermal plants powered by natural gas or Liquefied Natural Gas (LNG) (8% of the total) are dispatched according to the current hydrological conditions, allowing the management of water stocks stored in the reservoirs of hydroelectric plants to ensure future service.

Thermal plants powered by natural gas or LNG, when not being dispatched to the system intermittently, result in the loss of part of the attractiveness for investments aimed at increasing the supply of natural gas for the generation of electrical power in the national market.

Another regulatory obstacle concerns the non-possibility of transportation by third parties in the gas pipelines with idle capacity, which would allow the viability of electric power generation projects from imported LNG.

If, on the one hand, the secondary positioning of natural gas both in the production of hydrocarbons and in the composition of the Brazilian electrical matrix and regulatory obstacles prevent the expansion of the production of natural gas or the import of LNG, aiming at the use in the generation of electrical energy, on the other hand, the presence of electric power transmission and distribution lines in large part of the national territory, allows the implementation of thermal plants, located near the onshore natural gas producing units, through the Gas to Wire (GTW) projects or Reservoir-to-Wire (R2W).

The monetization of onshore natural gas, using the GTW model, makes it possible to explore and produce natural gas projects with different reserve volumes, which enables the economic viability of projects with a low volume of natural gas reserves, taking the thermoelectric as an example, of Imetame Energia in the Recôncavo Basin, or of a large volume of gas, exemplified in the Eneva thermoelectric complex in the Parnaíba Basin.

2. Materials and Method

In this paper, from the Review of literature and analysis of secondary data provided by ANP (the Brazilian National Agency of Petroleum, Natural Gas and Biofuels), EPE (the Brazilian Energy Research Office), and ONS (the Brazilian National Power Grid Operator), allowed the study of technical, legal and economic factors that enable the implementation of a reservoir to wire projects, from the production of natural gas in the onshore basins of Brazil, aiming at the supply of electric power to the National Electric System.

3. Results

3.1. The Production of Natural Gas in Brazil

The exploration and production of natural gas in Brazil dates back to the first half of the twentieth century. The initial landmark was the discovery of the Aratu Field in the Recôncavo Basin in 1942 [6]. The location of the producing field, on the outskirts of Salvador, the capital of the State of Bahia, enabled its economic viability by using natural gas in the industrial activities of companies in the region.

In 1953, the constitution of Petrobras intensified the activities of exploration and production of hydrocarbons in the country; however, even in the following two decades, the occurrence of several discoveries of natural gas fields, associated or not with oil, in the Recôncavo and Sergipe-Alagoas, the use of natural gas was restricted to industrial activities.

In the wake of the 1979 Price Shock and the increase of investments in the exploration and production of offshore oil and natural gas in the basins of the eastern Brazilian margin, especially in the Campos and Espírito Santo basins, it led to diversification, both in production and use of natural gas.

In the 1980s, natural gas production in the Campos Basin expanded to the residential and transportation sectors and industrial sectors in Rio de Janeiro and São Paulo [7]. In 1986, the increase in the supply of natural gas in the country took place with the entry into operation of the Guamaré-Cabo gas pipelines, the first interstate gas pipeline in the country, connecting the producer state of Rio Grande do Norte, with consumers from Paraíba and Pernambuco [8].

In the following decade, the expansion of the supply of natural gas in the domestic market was provided by the importation of Bolivian natural gas, starting in 1998, through the Brazil-Bolivia Gas Pipeline (GASBOL), a gas pipeline connecting the locality of Río Grande near Santa Cruz de la Sierra (Bolivia) and Porto Alegre, capital of the state of Rio Grande do Sul (Brazil) [9].

In the past decade, the increase in natural gas supply occurred due to the construction of new gas pipelines connecting GASBOL to other states in the southeastern and central-western regions of Brazil, which still needed to be served by imported natural gas [9]. Another factor in the availability of natural gas was the entry into operation of the Southeast-Northeast Gas Pipeline (GASENE), a network of gas pipelines linking producer and consumer states in the Northeast with producers and consumers in the Southeast [10].

In terms of new sedimentary basins producing natural gas, the entry into operation of the Urucu-Manaus Gas Pipeline in 2009 made the production of natural gas economically viable in the Solimões Basin in the northern region of the country. In this sense, the technical and economic feasibility of the exploratory model of the Brazilian Pre-salt in 2005, especially in the Santos Basin, boosted and expanded the Brazilian production of natural gas [1].

The Brazilian pre-salt contributed decisively to the increase of both reserves and the production of natural gas in the country, to the point that the country currently holds the second largest reserve of natural gas in Latin America, with 380 billion cubic meters [11], enabling a strong increase in national production of natural gas between 2010 and 2019 (Fig. **1**).

The Brazilian pre-salt is responsible for 66% of the total natural gas produced in the country [5]. This participation tends to increase in the coming years because it is the world's most significant offshore hydrocarbon reserve [1].

Although the production of natural gas in the Brazilian pre-salt tends to increase in the coming years, the use of offshore production for the generation of electric energy faces two critical obstacles:

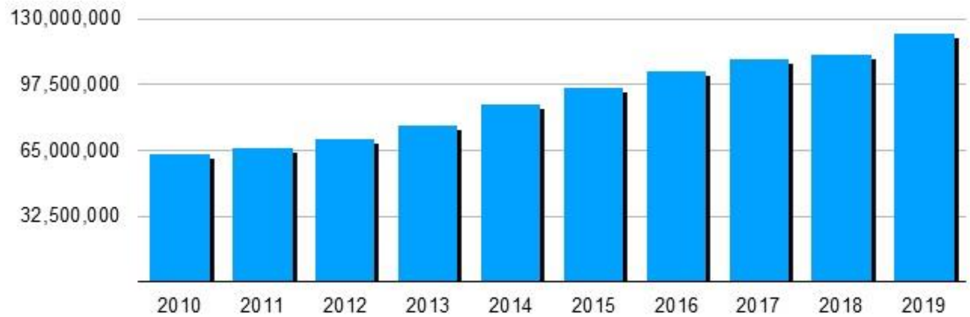

Figure 1: Natural gas production in Brazil (in millions of m3/day) between 2010 and 2019 [11].

I. The first concerns the large volume of investments necessary for the flow of all gas produced in offshore fields, in the construction of units for processing the natural gas produced located on the Brazilian coast, or in the use of new technologies close to the producing fields, aimed at harnessing natural gas;

II. The second, as a result of the first, is the high rate of reinjection of natural gas in the producing fields, as a result of which there is no possibility of draining the entire production. In August 2020, the percentage of reinjected natural gas reached 44% of the total produced [12].

In terms of the potential of natural gas to be produced in the onshore portion of Brazilian sedimentary basins, the lack of investments in the implementation of a network of gas pipelines that could be distributed in most parts of the country makes it impossible to increase investments in natural gas exploration and production.

Although the regulation of the entry of new companies in the activities of exploration and production of oil and natural gas occurred in 1997, through Law 9,478, the Parnaíba Basin was the only sedimentary basin that expanded the activities of exploration and production of hydrocarbons above all, natural gas, about the monopolistic period exercised by Petrobras [3].

In October 2020, the production of natural gas in Brazil was distributed in 12 sedimentary basins (Fig. **2**), of which 8 accounted for 129 million m3/day or 99.4% of the total produced (Fig. **3**). The production of offshore natural gas reached 107 million m3/ day, or approximately 82% of the total, the production in the Santos and Campos basins reached 101,5 million m3/day, or 78% of the total. On the other hand, the onshore basins produced 18% of the total, with the Solimões, Parnaíba, and Recôncavo basins responsible for 17% of the total produced (Fig. **3**).

The Paranaíba Basin produced approximately 7 million m3 of natural gas/day, or 5% of the total, with the ENEVA company being responsible for its totality in the basin's production [12]. The production of natural gas in the Parnaíba Basin was only economically viable through the implementation of GTW projects.

The Recôncavo Basin produced approximately 2 million m3 of natural gas/day, or about 2% of the total (Fig. **3**), distributed between Petrobras and small companies. In this basin, in 2019, the first GTW project was inaugurated and implemented by the Imetame company. New projects should be implemented in the Recôncavo Basin, in the coming years, either by Imetame or other companies.

3.2. The Brazilian Electric Matrix

The Brazilian electric matrix is composed of renewable sources (hydro, biomass, wind); thus, the electric generation from natural gas has a complementary function.

In 2019, the renewable sources of the Brazilian electric matrix were responsible for 85% of all electricity produced in the country. On the other hand, fossil sources account for 15%, with natural gas accounting for 9% (Fig. **4**).

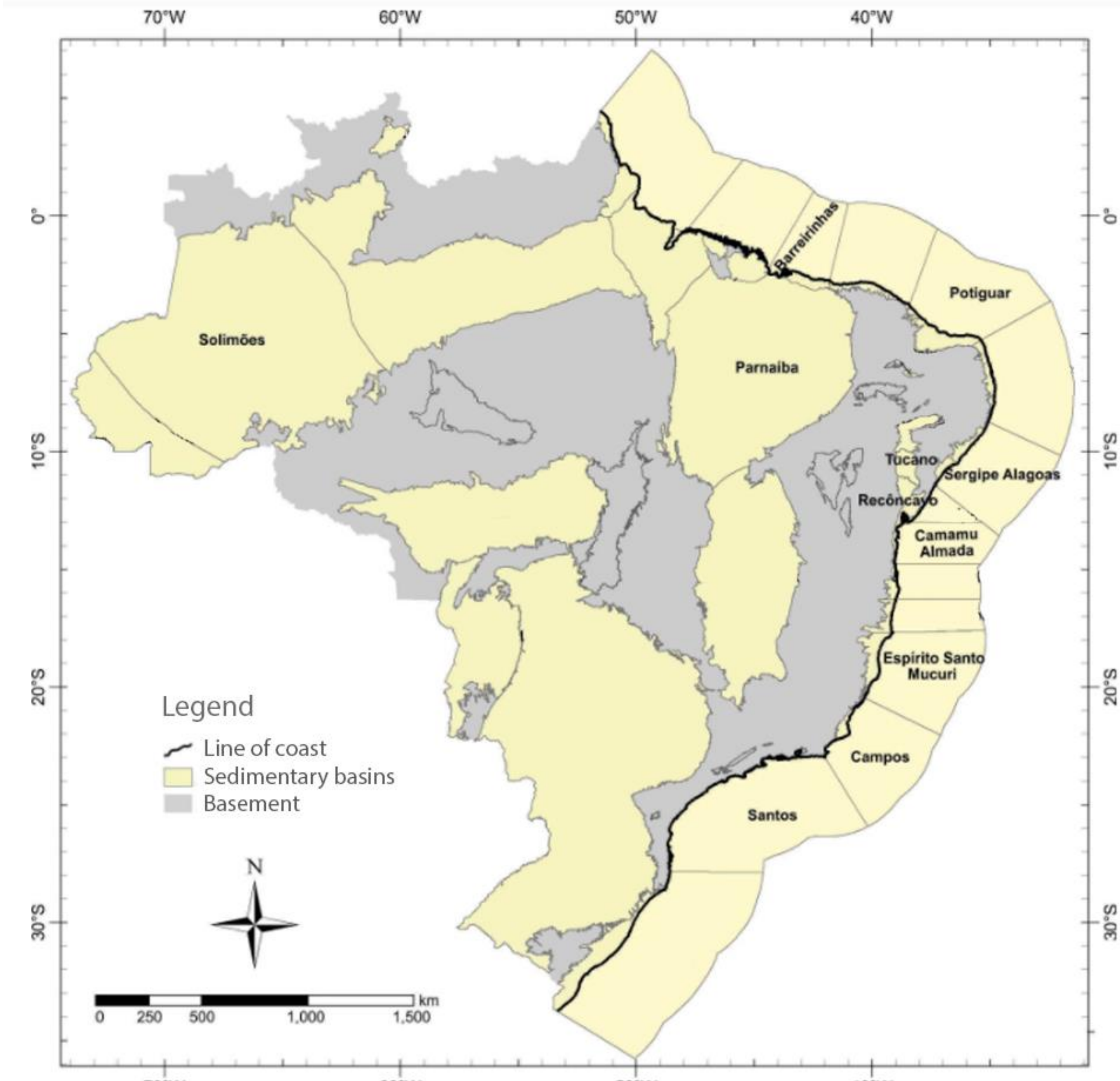

Figure 2: Brazilian sedimentary basins producers of natural gas [3].

Although most of the electricity generation in the country originates from water sources, the tendency to increase in the coming years there are two limitations [5]:

I. Most of the untapped potential is found in the northern region and brings with it a series of challenges, mainly of an environmental nature, for its use in expanding the supply of electricity;

II. The development of small plants (PCH) and Hydraulic Generating Plants (CGH).

The wind supply, in turn, has become highly competitive, in terms of energy prices, compared to the others (Table **1**). Wind generation may also expand from the implementation of offshore wind projects; however, the high costs for implementing the projects, the need for technical and socio-environmental studies, and the absence of a regulatory model, at this point become obstacles [5].

In terms of increased electricity generation from the photovoltaic solar source, the drop in generation costs in recent years has increased the share of this source in the Brazilian electric matrix.

Table 1: The average energy price contracted in the auctions of ANEEL in 2019 [5].

Energy Source	Average Price (R$)
WIND	89,93
NATURAL GAS	188,87
PHOTOVOLTAIC SOLAR	75,93
BIOMASS	183,88
HYDRO	201,95

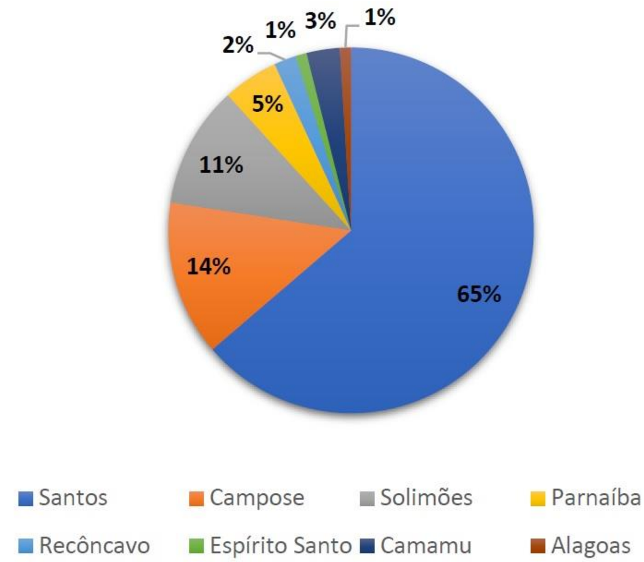

Figure 3: The percentage of participation in natural gas production from the main sedimentary basins [12].

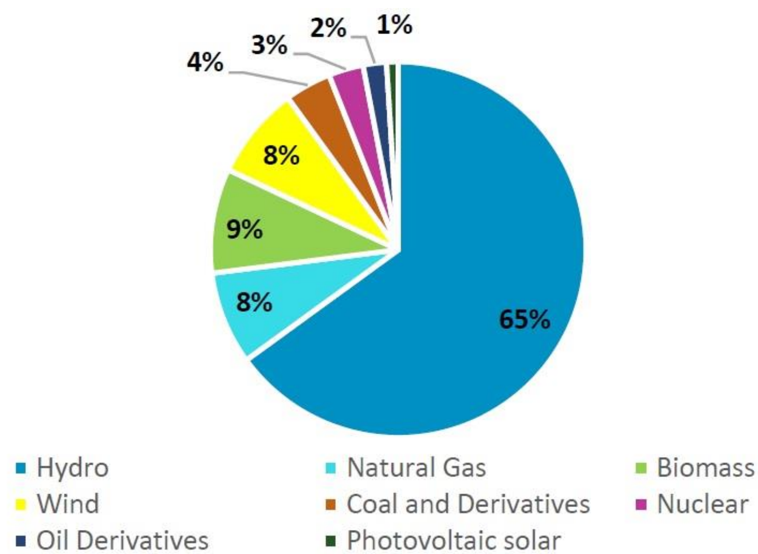

Figure 4: The percentage of participation of the electric energy source in Brazil in 2019 [5].

In the coming years, if the costs of electricity generation from the photovoltaic solar source continue to fall, it will undoubtedly increase the economic attractiveness and, consequently, the participation of this source in the national energy matrix.

The biomass produced from the industrial processes of the sugar-energy and cellulose sectors has shown significant increases in the participation of the national electric matrix; however, the tendency to increase its participation be linked to the increase in the production of those industrial products for the following years, sugar, ethanol and cellulose.

Natural gas will be the primary fossil fuel for the country's expansion of thermoelectric generation in the following years. Thus, the supply will come from imported LNG, having its combined use, in the supply of thermoelectric plants, with the national natural gas being produced in the Brazilian pre-salt or the post-salt of the basins of the Brazilian east coast.

In the coming years, natural gas production in onshore sedimentary basins should be made possible by implementing GTW projects aimed at generating electricity by thermoelectric plants.

3.3. National Interconnected System

The NIS is a nationally interconnected electrical system characterized by a system for producing and transmitting electricity in Brazil from significant hydro-thermo-wind sources, with the predominance of hydroelectric and wind power plants at the base of the system.

In December 2020, the NIS consisted of an electric matrix with approximately 165 MW of installed capacity, of which 86% are from renewable sources and 14% from non-renewable sources (Fig. **5**).

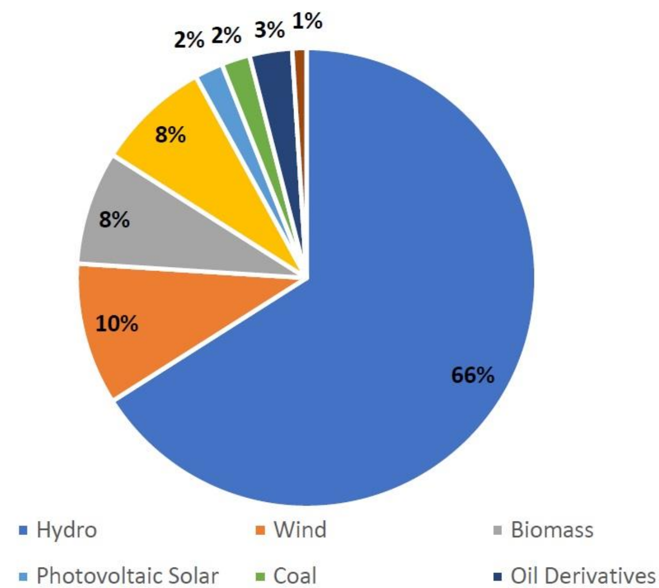

Figure 5: Percentage of participation of the energy sources in the installed capacity of electric generation in Brazil (in December 2020) [4].

The NIS comprises four subsystems: South, Southeast/Midwest, Northeast, and most of the North region. The subsystems, in turn, are connected using the transmission grid (Fig. **6**), which allows the transfer of electricity between subsystems, allows the achievement of synergistic gains, and explores the diversity between the hydrological regimes of the basins [13].

While hydroelectric and wind power plants make up the basis of the system, thermal power plants, generally installed mainly in the Northeast and South regions and located close to the main cargo centers, play an important strategic role, as they contribute to the safety of the NIS.

The electricity produced from the various energy sources is distributed in the country via the transmission network, 141,756 km in length, positioning itself as one of the largest transmission systems in the world. It runs practically the entire national territory except for the state of Roraima, as seen in Fig. (**6**).

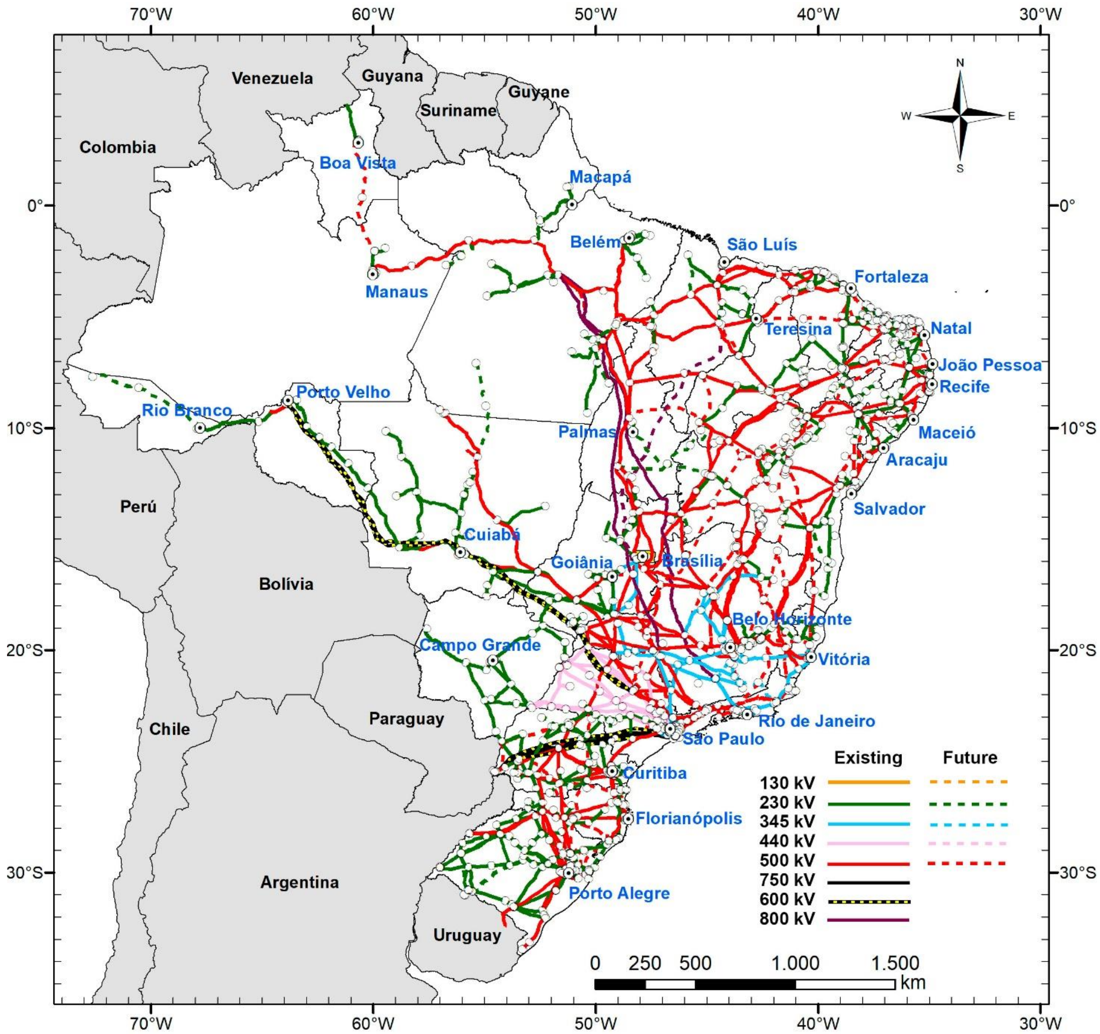

Figure 6: Actual Transmission System of electric power in Brazil [13].

4. Discussion

4.1. Gas to Wire (GTW) Model

The economical use of natural gas, from its use in the generation of electricity, close to the zones producing natural gas and, consequently, transporting it in the form of GTW electricity, has proved to be highly viable in the main onshore sedimentary basins in Brazil.

The increase in investments in the exploration and production of natural gas in the Parnaíba and Recôncavo basins are directly related to the implementation of GTW projects. The implementation of these projects is linked to the climatic, technical, and economic factors of the national electricity system:

I. The periods of drought that occur in drainage basins, which result in the reduction of electricity generation by hydroelectric plants;

II. The distance from the natural gas-producing fields to the large consuming centers;

III. The limited network of gas pipelines in the country and the concentration, mainly on the Brazilian coast (Fig. **7**). The network has more than 9 thousand km of pipelines. If we compare with other countries, the difference is noticeable; for example, Argentina has more than 15 thousand km, and the United States has close to 550 thousand km of pipelines [14];

IV. The economic factor is the competitiveness of the electricity production cost from that of natural gas compared to other energy sources.

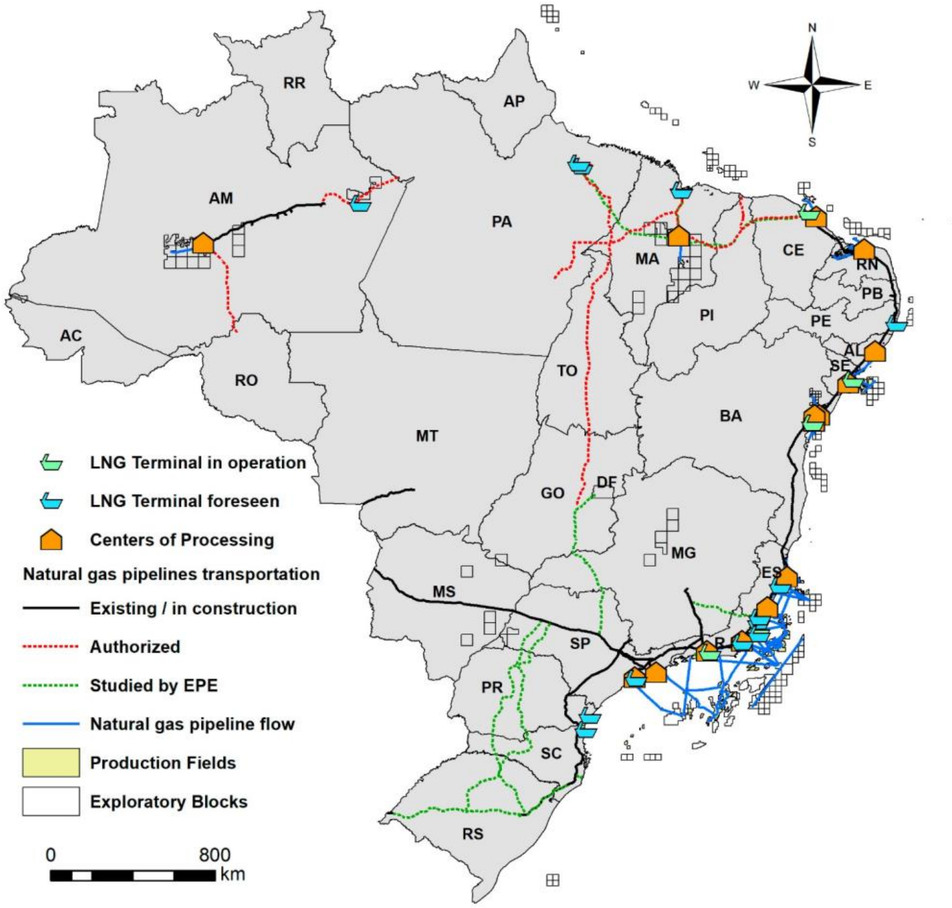

Figure 7: Existing supply and natural gas transportation infrastructure and pipeline transportation authorized and studied by EPE [14].

Currently, GTW projects from producing natural gas in Brazil's onshore sedimentary basins are located in the Parnaíba and Recôncavo basins. There are two projects in operation, the first by the company ENEVA, which pioneered in the country, implemented in the Parnaíba Basin, from the beginning of production in the Gavião Real (2013), Gavião Vermelho (2015), Gavião Branco (2016) and Gavião Branco Sudeste (2016).

The four fields supply natural gas to the Parnaíba Complex, formed by four thermal plants, whose total electricity generation capacity is of the order of 1429 MW, which supplies electricity to the National Interconnected System.

The second GTW project was implemented in Brazil in 2018, implemented by the company Imetame Energia in the Recôncavo Basin. The project consists of the supply of natural gas by Campo Cardeal do Nordeste to Thermoelectric Power Plant Prosperidade I, located in the municipality of Camaçari, in the state of Bahia, with a capacity of 28 MW of power generation. After the natural gas transformation into electrical power, the energy produced at the plant is supplied to the National Interconnected System (SIN).

4.2. Regulatory Framework

As stated above, Gas to Wire (GTW) or Reservoir-to-Wire (R2W) is a natural gas exploration model that integrates exploration and production processes with natural gas as a source of electrical energy. The gas is extracted, treated, and serves as fuel for producing electrical energy, which is then drained to the National Interconnected System - “NIS” from the transmission network located in the vicinity of the plant.

The model is relevant for the exploration and production of onshore natural gas in Brazil since it allows the integration of the entire production chain. However, despite its advantages, the current regulations certainly present complex obstacles not only for the model itself but for the sector as a whole.

In this sense, one of the most relevant problems is the fact that the Federal Constitution [15] established a strict division of powers between the Union (articles 20 and 177) and States (25, §2), as explained below:

“Art. 20. The following are the property of the Government [...] IX - mineral resources, including those of the subsoil;

Art. 177. The Federal Government monopoly consists of: I - research and mining of oil and natural gas deposits and other fluid hydrocarbons;

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 exploit, or use a concession directly, the local piped gas services, by the law, prohibiting the publication of a provisional presidential decree for its regulation.”

Based on the above wording, it is possible to note that, on the one hand, research and exploration of natural gas deposits constitute a monopoly of the Union - by the provisions of article 20, item IX of the Federal Constitution [15], which establishes that mineral resources are federal assets. While "local piped gas services" are the responsibility of the States. The term "local" that defines the state's jurisdiction means that services such as gas transportation (through a gas pipeline) are under federal jurisdiction. In contrast, the distribution of piped gas and other local services is the jurisdiction of the state.

Regarding the division of powers, Gustavo Binenbojm [16] has the following comments:

"Art. 25, §2, of the Constitution of the Republic refers to "local piped gas services," leading to the understanding, through the use of the plural, of the coverage of all possible local piped gas services, and not just some. It follows simply from the constitutional system in force that the national transport of natural gas using pipes is within the jurisdiction of the Union to make the good available to the country as a whole. It is, of course, a corollary of the Brazilian federal system, which puts the Federal Union in charge of promoting activities of national interest. Thus, the transport carried out by the Union (or by its contracted state or private companies) will be carried out in bulk to serve the different units of the Federation. States are responsible for exploring local piped gas services. Therefore, these are activities of regional and local interest, consistent in retail distribution through the different channeling branches derived from the main line (the national pipeline) to serve specific users. It does not matter, for delimiting powers, whether the specific users are homes, commercial entities, or industrial entities, whether the piped gas is used to light residential or industrial stoves, or whether it is cooled, liquefied, and stored for later sale to third parties. What matters is that the satisfaction of such users, through a divisible and specific channeled delivery of the good, constitutes a public service of regional and local interest, in charge, of course, of the minor entity (the Member State), and not of the greater entity (the Union). Thus, it is correct to delimit a distribution of jurisdiction between the Union and the Member States, about the movement of natural gas, in the following terms: (a) the Union, through Petrobrás or its privately contracted company, is responsible for the activity of economical transportation of bulk gas from the producing areas to the "reception points" (city gates) located in each state; (b) the Member States, directly or through their concessionaires, is responsible for providing public piped gas services, by dividing the product to individual users of any kind (residential, industrial, commercial, automotive, among others)."

This dichotomy - with the need for a solid sectoral policy - is one of the main obstacles to the effective development of the GTW model in Brazil. The discussion revolves around the transfer of ownership between the producer and the thermoelectric generator. Considering that they are different legal entities (which occurs in almost all cases, given that the objectives are different), there will be a transfer of ownership (legal circulation) added to the transfer of molecules (physical circulation).

The physical circulation of natural gas occurs in two ways: by pipeline or in special vehicles for such transportation. In the GTW model, this occurs through pipelines that, however small they are - and added to the legal circulation of natural gas - end up falling under the concept of "local piped gas service."

The Brazilian Supreme Court [17] has already faced this type of conflict:

“In this case, and a still preliminary examination of the matter, the operation carried out by Petróleo Brasileiro S/A - Petrobrás appears to be a local gas service since it imports a true distribution of piped gas to the user. Suppose the user is located in a municipality belonging to the State of São Paulo. In that case, it appears that the jurisdiction to regulate the operation is the state's, through the CSPE, and, always under advisement, subject to further investigation of the matter for the final decision to be made in due time. It should be noted that for the configuration of the local service, the type of destination (own use or cooling and commercialization) and the quantity acquired (industrial or residential) are irrelevant. As Celso Antônio Bandeira de Mello explains, in a previously mentioned opinion, "all specialized piping, whose objective comes from the mere general transportation of gas, escapes the monopoly of the Union and enters the sphere of the State in which this piping is installed. Hence why art? Twenty-five of the Constitution even used a different terminology when referring to the gas transport medium. He spoke of 'piping' to refer to what was the state's responsibility instead of 'tubes,' as he did in art. 177, when qualifying what belonged to the Union."

For this reason, the installation of the gas pipeline and its consequent operation must be aligned with the Member State where the project is located, as this is the competent granting authority for the operation of the "local piped gas service" and, in most of the Sometimes, the state has a company to operate these services, under a natural monopoly regime. Thus, the natural gas distribution structures, however small they may be, should (as a rule) be transferred to the service holders (natural gas distribution concessionaires), who will be responsible for the management, operation, and maintenance of the assets, for a fee.

Therefore, this business model is substantially burdened due to the legal-regulatory peculiarity that falls on natural gas in Brazil, and that could only be circumvented through a structural reform of the market and a joint pact between the entities of the Federation in order to promote the market as a whole and expand the exploitation of natural gas and thermoelectric generation from this input.

For years under discussion in the National Congress, in 2020, Bill No. 6.407/2013 [18] - which aims to change the regulation of the natural gas sector in Brazil - took relevant steps towards its promulgation. However, despite the possible innovations that the new legal framework may bring to the sector, it is certain that the constitutional nature of the monopoly conflict between the Union and the State makes the solution to this problem more complex and that we have to live with this peculiarity to implement projects in this business model.

5. Conclusion

The expansion of investments in implementing GTW projects in Brazil in the coming years will be linked to the association of the most diverse factors, climatic, environmental, technical, economic, and regulatory. Of these factors, we can highlight the following:

From a climatic point of view, the variation of hydrological cycles in drainage basins that locate the reservoirs of hydroelectric plants leads to a decrease in the supply of electricity, which in turn may increase the dispatch of thermal energy from GTW. In this sense, the increase in the supply of electricity through GTW may occur due to the potential for generating electricity from wind power to be concentrated in the Northeast and southern regions of the country.

The environmental aspects that impact the potential implementation of GTW projects refer to the complexity of obtaining environmental licenses for the installation of hydroelectric plants in the Brazilian Amazon region and the limitations for the expansion of sugar cane and eucalyptus crop areas, preventing a significant increase in the production of electric energy from biomass, the result of industrial processes.

The first technical factor that we can highlight refers to the geological knowledge about most of the Brazilian onshore sedimentary basins, accumulated over the decades, and that allows the choice of basins with the greatest exploratory potential for the production of natural gas, which added the second factor, the presence of the NIS's electric power transmission and distribution network, will enhance the implementation of the GTW project.

Economic factors can be analyzed from the great distance from the fields producing natural gas to the main consuming centers, discouraging investments in the construction of gas pipelines to transport the production of hydrocarbons. Thus, the competitiveness of the cost of producing electricity from natural gas attracts investments in GTW projects.

In turn, the regulatory factors that limit the expansion of electric power production, using the GTW model should undergo regulatory changes to enable the attraction of investments in this energy model, which concern the lack of remuneration for electricity generated from natural gas, which is not dispatched to the NIS, and the incidence of state powers, instead of the jurisdiction of the Union, over the transport of natural gas, from the producing field to the thermal plant.

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