Empresa de Pesquisa Energética

Indicative Transmission Gas Pipeline Plan

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1. Introduction

The Indicative Transmission Gas Pipeline Plan (PIG) is part of a set of studies prepared by EPE with the purpose of subsidizing the planning of the Brazilian natural gas sector, aiming at presenting investment opportunities in transmission gas pipelines in the country. The indicative projects, presented at a design level, allow to expand the capacity, and increase the security of natural gas supply in Brazil. These alternatives allow the connection of new supplies to the Natural Gas Transport System (STGN[1]), the connection of the STGN to new areas not yet served by natural gas and the connection of isolated supply and demands among themselves.

The first Indicative Transmission Gas Pipeline Plan was published in 2019 and it considered the contributions received during the Gas to Grow initiative, the review of the role of studies on the expansion of the Brazilian transmission gas pipeline network promoted by Decree No. 9,616/2018, the guidelines established by the New Gas Market initiative, as well as improvements made by EPE regarding project assessment systems and cost databases. Under the terms of Decree 9,616/2018, "EPE shall prepare the expansion studies of the pipeline network in Brazil taking into account the carriers investment plan, the market information and the guidelines of the Ministry of Mines and Energy".

Furthermore, pursuant to Article 4 of Law No. 10,847, of March 15, 2004, "it is the responsibility of EPE (...) prepare studies related to the master plan for the development of the natural gas industry in Brazil".

To achieve such goals, the PIG presents the assessments carried out by EPE regarding the transmission gas pipelines that may be implemented in coming years in Brazil, in an indicative manner, based on supply and demand studies, in addition to technical and economic and socio-environmental analyses. More specifically, based on the spatial detailing of the estimated supply and demand for natural gas in Brazil, the PIG aims to propose and review indicative transmission gas pipelines alternatives that can interconnect the natural gas potential supply and demands to the integrated network, or even connect them together, in the case of isolated systems.

Thus, annually from March 1 to 31, EPE makes available on its website the natural gas market data collection and storage system (INFOGÁS) to gather information on natural gas supply, demand, and infrastructure projects that any sector agent may submit, upon request for registration.

The information received are considered by EPE during the preparation of the Ten-Year Energy Expansion Plan (PDE[2]) and of the Indicative Natural Gas Processing Plant and Gathering Pipeline Plan (PIPE[3]), in addition to the PIG itself. In this cycle, due to difficulties presented by the Covid-19 pandemic, the deadline for receiving contributions was exceptionally extended, and had contributions from only one company, containing information that was used in the PIG 2020 cycle.

This study is a planning tool for the natural gas sector, in addition to introducing a series of advances such as:

[1] In Portuguese, *Sistema de Transporte de Gás Natural*.
[2] In Portuguese, *Plano Decenal de Expansão de Energia*.
[3] In Portuguese, *Plano Indicativo de Processamento e Escoamento de Gás Natural*.

• reduction of information asymmetry on demand and supply potential, assessments of socio-environmental conditions and route proposals, contributing to the identification of opportunities by the industry;

• transparent dissemination of the methodology, premises and assessment criteria used for preparation of the studies;

• coordination of expectations and interest among players of the natural gas industry aiming to promote investments in transmission gas pipelines in Brazil.

Figure 1 outlines the methodology used in this study.

Figure 1. Methodology for analysing alternatives for expanding the transmission gas pipeline network
Source: EPE.

First, based on the Supply and Demand studies carried out by EPE, and on complementary information, demand/supply pairs are defined for the development of gas pipeline alternatives to be studied. In addition to specific connections between supply and demand, alternatives may include connecting new supplies to the STGN, or connecting the STGN to new demands that have not yet been connected. The socio-environmental analysis helps choosing the routes, suggesting the most suitable corridors for the passage of the gas pipelines. After defining the route, it designs the project, determining the diameter of the gas pipeline and other technical characteristics. Finally, it estimates the costs (CAPEX) of each alternative.

This study should be read along with the 2019 Indicative Gas Pipelines Plan, as it complements the projects studied in that plan. Thus, the projects studied in this cycle must be complementary to the panorama of the existing, estimated, and indicative natural gas infrastructure assessed in the previous Plan. Moreover, it adopts the same analysis methodology used in terms of technical criteria, costs and socio-environmental characteristics.

The PIG 2020, however, brings an additional analysis to that carried out in the first edition of the study, and presents, in the following section, a study about the sharing of rights-of-way between projects of transmission gas pipelines and other infrastructure, which shows potential for savings in scope and cost reduction in several sectors, such as telephony and liquid fuel supply.

After that, it presents the five projects reviewed, which refer to alternatives based on the pipelines authorized before Law 11,909/2009 or to the expansion of existing pipelines, and those related to the connection of new supplies to the existing transmission gas pipeline network. It presents the technical, economic, and socio-environmental criteria for each alternative studied. At the end, the results of the study are summarized and commented on jointly, evaluating the conditions that may influence their feasibility, as well as the prospects for implementing each project. Finally, the last section provides an update on the projects reviewed in the 2019 cycle.

2. Sharing of Rights-of-Way

The international literature widely discusses the topic of sharing of rights-of-way (ROW) between linear projects such as highways, optical fibre cabling, electric power transmission lines, multi-product pipelines, among other types of installation, since the creation of the main network industries in several countries. One of the main forums where this discussion takes place is that of the telecommunications sector, since optical fibre corridors require little space and present reduced risk when assessed with other facilities in the same range (US DOT, 1996). However, guides containing recommendations for risk mitigation can be found in the literature in sectors where there are greater technical challenges, such as oil and oil products, natural gas, and biofuels (INGAA, 2008).

Overall, the sharing of rights-of-way has the potential to reduce socio-environmental impacts by not giving rise to the opening of new ROWs, in addition to presenting scope savings, especially when several pipelines are installed together, making the stages of mobilization and demobilization of equipment, excavation and restoration of the soil more efficient (INGAA, 2008).

2.1. Technical and economic issues

The sharing of rights-of-way by linear projects is influenced by social, environmental and safety issues (especially when traversing environmentally sensitive areas or urbanized regions), and mainly by technical and economic issues, which can make sharing feasible or unfeasible, given the ability to whether their effects are mitigated. The technical issues surrounding the sharing depend on what infrastructure will be considered in parallel, and what the extent of parallel construction is.

2.1.1. Parallel Construction with Electric Power Transmission Lines

In some metallic pipeline projects, parallel construction with electric power transmission lines may occur, which can cause undesirable electrical and magnetic effects. These effects may result in increased corrosion, thus requiring more attention, which may result in higher investments in cathodic protection systems. Given that the Brazilian electric power transmission system consists mainly of alternating current transmission lines (AC power line), it carries out an assessment on the consequences of the parallel construction between such transmission lines and metallic pipelines.

In general, a consequence of the parallel construction or intersection between an AC power line and a metallic pipeline is the possibility of induced voltages and currents on the surface of the pipeline, due to the manifestation of electromagnetic fields during the operation of these AC power lines. Additionally, DIPRA (2017) and INGAA (2015) mention that the magnitude of induced currents and voltages are a function of numerous variables, such as:

- the length of parallelism between the AC power line and the pipeline;
- the longitudinal resistance of the pipeline;
- the resistance of the pipeline coating;
- the electrical resistance of the soil along the extension of the parallelism;
- the current capacity and voltage rating of the AC power line.

According to MELLO (2015), metallic gas pipelines that transport natural gas are structures that must not operate with voltage and/or current on their surface. Ultimately, they must be properly grounded. Otherwise, a series of undesirable effects, from the point of view of both safety and environmental pollution, can occur. For example, if the voltage induced on a metallic pipeline is large enough to generate sparks on that pipeline, explosions can occur, considering the contact of the spark with the flammable content. In addition, corrosion in these materials, due to induced currents, can cause leakage of materials that pollute the environment.

In this context, the operation of gas pipelines that parallel, whether they share a ROW or not, or that intersect AC power lines at a certain angle, can be dangerous for both the people working on their construction and maintenance and for the occurrence of accidents in such equipment, due to accelerated wear caused by the electromagnetic fields generated by AC power lines.

Among the main electrical phenomena that affect the operation of the metal pipelines, SHWEHDI and JOHAR (2003) highlight:

- electrostatic or capacitive interference – it occurs for pipelines not buried and well insulated from the ground. A voltage proportional to the AC power line operating voltage is induced in them;
- resistive interference – it occurs when lightning strikes a transmission structure or when phase-ground faults[4] occur, raising the electrical potential of the soil surrounding the AC power line, including the metal pipeline;
- magnetic interference – it occurs when the magnetic field that varies over time induces voltages in the metallic pipeline, thus creating flowing currents. It is preferable that the average distances between the project axes are the largest possible. In addition, intersections perpendicular to AC power lines considerably mitigate the magnetic induction effect (MELLO, 2015; SHWEHDI and JOHAR, 2003; INGAA, 2015). When this is not possible, it is desirable to maintain angles of 60° or more.

Either way, in the inevitable cases of closer approximation between gas pipelines and AC power lines, either by sharing of rights-of-way or intersection, due to socio-environmental or even economic restrictions, DIPRA (2017) proposes two measures that, together, would result in minimal induced voltages and/or currents in the metallic pipelines: (i) coating aiming at the electrical shielding of the pipeline and (ii) greater segmentation of the pipelines through wider installation of rubber-gasketed joints. It is noteworthy that the ideal solution, however, involves the application of both measures.

In terms of the minimum distance to be considered between the average axis of the gas pipelines and the average axis of the AC power line, it is reasonable to think that calculations should be made on a case-by-case basis in order to estimate the distances in which these effects are acceptable, considering: (i) the civilian and working population moving around the pipelines and (ii) maintaining the physical aspect of the pipelines with a high level of maintenance, taking into account possible corrosions accelerated by the effects of such inductions.

[4] Phase-ground faults: are the result of a short circuit in which one or more phases are sent to the soil.

2.1.2. Parallel Construction with Optical Fibre Cabling

The coexistence of gas pipelines and optical fibre cabling is recurrent in the oil and gas industry, mainly because some equipment is operated digitally, requiring the passage of optical fibre cabling next to the pipeline. Newer technologies allow the use of optical fibre cables to monitor intrusions in the pipeline, leaks, and excessive vibration of the pipes (APRC, 2016). It is recommended that not all installed bundles are used by the facility's owners, which presents an opportunity for the use of the remaining bundles for telecommunications.

Thus, this parallel construction does not generate relevant electromagnetic interference that could pose technical challenges to the operation of both infrastructures, although the procedures for the operation and maintenance of each structure must be adapted if there is an equipment that can generate sparks or, in some way, interfere on infrastructure that is not the subject of the maintenance campaign.

According to the United States Department of Transportation (US DOT, 1996), the main issues to be considered in sharing the right-of-way between optical fibre and other infrastructures are much more related to the distribution of responsibilities among the agents involved, in addition to security issues and legal attributions in the case of accidents. The access of maintenance teams must be ensured within the security rules of the company that owns the land, since it may be necessary to install repeater equipment, connections, terminals, and control boxes in the ROW. The procedures for authorization and regulation of activities should also be reviewed, since more than one state government may participate, in addition to the federal scope that may be involved in the process (US DOT, 1996).

It should be noted that Decree 10,480/2020 was recently published, which provides for measures to encourage the development of telecommunications network infrastructure and includes gas pipelines, oil pipelines and other pipelines for handling fluid hydrocarbons and biofuels among infrastructure projects of public interest that should include the installation of infrastructure for telecommunications networks, under the terms of article 16 of Law 13,116/2015, so that the sharing of infrastructures, in this case, becomes a relevant issue in project structuring.

2.1.3. Parallel Construction with Pipelines

The sharing of rights-of-way between metal structures, and especially between pipelines that have high internal shear stress such as gas pipelines, oil pipelines, ethanol pipelines, multi-product pipelines, slurry pipelines and water and sewage pipelines, presents technical issues especially regarding mitigating their corrosion and reducing risk due to the joint probability of incidents in the projects involved.

In this sense, cathodic protection techniques, which are already applied in cases where the ROW has only one pipeline, gain special attention in the scope of sharing, since cathodic protection systems need to be designed considering all the infrastructures present in the ROW (APRC, 2016). Such systems must be adjusted and even redesigned if new pipelines are included, since the applied electrical voltages can be harmful to the pipelines if they are insufficient – not being able to mitigate corrosion – or if they are excessive – causing, for example, the formation of pockets of hydrogen in the metal.

In the specific case of slurry pipelines, which carry a current formed by solids and liquids, the issue of vibration must be considered in the design of the pipeline itself and of pipelines that share the ROW with it, and the characteristics of the soil must be assessed and possibly adapted so that there is no displacement of structures inside the ditch filled with sediments that are not properly compacted. Threats to the integrity of the pipelines that should be assessed in terms of soil may include landslides, rocks fall and other movements related to rain and wear due to flow of water currents through the soil over the useful life of the projects (IPT[5], 2018).

Sharing with pipelines of water, oil, liquids, and other gases is more frequent, and there are cases where environmental agencies recommend such sharing so that there is less impact on the environment when installing all projects. An illustrative case is the ROW that was designed for the pipelines that would connect the GasLub Itaboraí Hub (former COMPERJ), in Itaboraí/RJ, to REDUC, in Duque de Caxias/RJ, including the installation of nine parallel pipelines that would transport several products – natural gas, crude oil, diesel, naphtha, kerosene type jet fuel, fuel oil, LPG (ESTEIO, 2010).

A study carried out by members of the Interstate Natural Gas Association of America - INGAA established guidelines to be considered in the design and construction of pipelines sharing rights-of-way, or in the construction of pipelines in ROWs where underground infrastructure already exists. Among the points of attention raised, the following should be mentioned (INGAA, 2008):

- damage prevention is a responsibility shared by several stakeholders including facility owners, locators, operators, emergency services, contracting companies and contractors, and all those who work or live in the vicinity of the facilities;

- during route selection, the shared corridor project must consider the research of possible existing underground structures in the ROW, in addition to the assessment of aboveground structures adjacent to it, and the evaluation of wetland, vegetative cover, topography, geology;

- agents must establish agreements on the distance between the projects, on the installation of each project separately or together, and on the performance of shared activities at specific points in the ROW;

- the agreements should especially address the cathodic protection system, considering the coordination between the parties, as well as the cathodic protection systems already existing in the ROW, in addition to the location of anodes, test stations, etc.;

- operators of existing facilities must request the marking and signalling of their facilities every 50 feet (equivalent to 15.24 m) over the ground, and can provide a supervisor to monitor the installation of new projects in the area where the excavation is taking place;

- any activity to be carried out in the ROW must have the prior agreement of the owner of the existing facilities, and excavators must have their side teeth removed to prevent them from reaching the existing pipelines when excavating the new ditch within the minimum distance limits;

- after construction, all events occurred, as well as lessons learned, shall be reported and As-Built documents[6] should be made available so that the operator of the existing facilities has access to the data of the new pipeline at the time of future maintenance.

[5] IPT – *Instituto de Pesquisas Technológicas* or Institute for Technological Research

[6] Technical representations of the project executed as plans, sections and schemes of materials and equipment containing all the details implemented during the construction and installation stages.

2.1.4. Cost Reduction Potential Estimate

The sharing of rights-of-way between gas pipelines and other infrastructure has the potential to reduce the total costs of each project. If the construction is jointly, there is the possibility of also sharing Environment, Health and Safety (EHS) equipment and activities. Even if they are not installed concurrently, there may still be cost sharing for facilities that have already been built on site by the owner of the first infrastructure. In all cases, land acquisition and Construction and Assembly costs represent the main scope savings from sharing, since their costs shall be distributed among the projects, or allocated in one of the projects and reimbursed by the others through a fixed, monthly, or annual payment.

For assessing the potential for CAPEX reduction when sharing rights-of-way, the cost amount of each infrastructure related to this item must be reviewed, then the value must be distributed among the projects. In the case of ROW lease, the amounts could be considered as operating cost (OPEX), being included as an expense in the cash flow of the new infrastructure and as revenue in the cash flow of the original infrastructure. To estimate the lease, for example, a percentage on the land value or a percentage defined in the form of a typical UFIR[7]/km.year metric can be used.

Other items may increase the costs arising of sharing of rights-of-way, such as cathodic protection systems, which, as mentioned, should become more robust to adjust to the new profile of the metallic structures included in the ROW. However, even this absolute increase in some cost items can be reflected in a lower cost allocated to each infrastructure, when dividing the item and the reimbursements among the facility owners. In addition, cooperation between the agencies responsible for assessing environmental, historical heritage, defence, among others aspects (FERC, 2002) and the sharing of rights-of-way between infrastructures (FERC, 2012) have been increasingly recommended, due to its potential to mitigate impacts on water bodies, reduce costs and the need to suppress vegetation (which also has associated costs).

2.2. Legal and regulatory framework

The Brazilian legal and regulatory framework for the sharing of rights-of-way in linear projects includes Law No. 9,472/1997 (BRASIL, 1997), in addition to ANEEL[8], ANATEL[9] and ANP[10] joint Resolution No. 01/1999 (ANEEL; ANATEL; ANP, 1999) and ANP Resolution No. 42/2012 (ANP, 2012a), which regulate it. According to article 73 of Law No. 9,472/1997,

> Art. 73. Telecommunications service providers of collective interest shall be entitled to use posts, pipelines, conduits, and **easements** belonging to or controlled by a telecommunications service provider **or other services of public interest**, in a non-discriminatory manner and at **fair and reasonable prices and conditions**.

[7] UFIR – *Unidade Fiscal de Referência* or Tax Reference Unit.
[8] ANEEL – *Agência Nacional de Energia Elétrica* or Brazilian Electricity Regulatory Agency.
[9] ANATEL – *Agência Nacional de Telecomunicações* or Brazilian Telecommunications Agency.
[10] ANP – *Agência Nacional do Petróleo, Gás Natural e Biocombustíveis* or National Agency of Petroleum, Natural Gas and Biofuels

> Single paragraph. The regulatory agency of the assignee of the means to be used is responsible for defining the conditions for proper compliance with the provisions above.
>
> (BRASIL, 1997; emphasis added).

As for ANEEL, ANATEL and ANP joint Resolution No. 01/1999, it reads:

> Art. 2 The guidelines set out in this Regulation apply to the sharing of infrastructure associated with the object of the grant issued by the Granting Authority, among the following agents:
>
> I - electricity utility operators;
>
> II - telecommunications service providers of collective interest; and
>
> III - operators of pipeline transportation services for oil, oil products **and natural gas**. (...)
>
> Art. 7 The infrastructures and the corresponding items that can be shared are divided into three classes, as follows:
>
> I - Class 1 – **administrative easements**;
>
> II - Class 2 – pipelines, conduits, posts, and towers; and
>
> III - Class 3 – non-activated metallic, coaxial, and **optical fibre** cables.
>
> (ANEEL; ANATEL; ANP, 1999; emphasis added).

ANP Resolution No. 42/2012 details the rules for sharing infrastructures included in Class 1, that is, "administrative easements", defining the procedures for requesting and determining, among other items, that:

> Art. 10. **A legal representative of the applicant must formally make the request for sharing** and it must contain the technical information required for the analysis of its feasibility by the holder. (...)
>
> Art. 12. Sharing **may only be denied for reasons of limitation in capacity, safety, stability, reliability, violation of engineering requirements** or due to terms and conditions issued by the ANP or other agencies, within the scope of its powers. (...)
>
> Art. 20. The prices to be charged and other commercial conditions, referred to in item IV of article 19, can be **negotiated freely by the agents**, although complying with principles of **isonomy** and **free competition**.
>
> (ANP, 2012a; emphasis added).

Based on the legal and regulatory framework addressed, it understands that developers who are interested in the construction of gas pipelines may assess in detail the rights-of-way located in the project route, taking advantage of parallel construction when possible, aiming at reducing costs and mitigating socio-environmental impacts. The agents shall negotiate freely the sharing of rights-of-way, and the agreements must consider fair and reasonable, as well as isonomic and non-discriminatory conditions.

It is worth mentioning that the projects reviewed in this document incorporate sharing possibilities where applicable, considering the existing facilities in the vicinity of the route, and such possibilities are commented during the description of the projects where they apply.

2.3. Sectors with possible integration

As previously discussed, sharing rights-of-way not only leads to excellent feasibility regarding the telecommunications sector, especially with optical fibre, but also begins to be included in the scope of the normative obligations to be considered by the economic agents, with the publication of the Decree No. 10,480/2020.

Gas pipeline sharing gains special attention as these facilities generally already include in their scope the passage of optical fibre bundles, required for valve operation and constitution of control and automation system, including spare bundles that are not used often (APRC, 2016).

When reviewing information on whether Brazilian municipalities are served by optical fibre infrastructure, it is possible to notice a concentration of municipalities that are not served in the Midwest and North Regions, in addition to areas in the countryside of Bahia, North of Minas Gerais and countryside of Rio Grande do Sul, as shown in Figure 2.

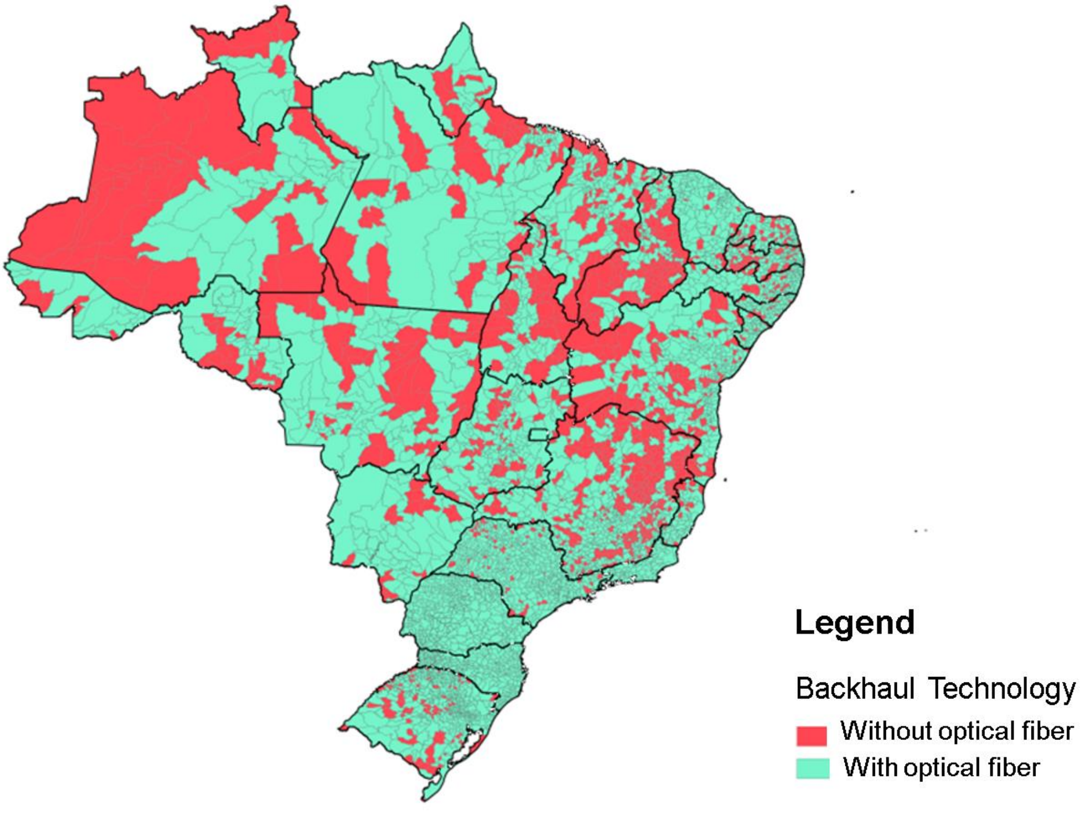

Figure 2. Municipalities with or without optical fibre cabling
Source: ANATEL (2020a).
Note: Backhaul represents the network infrastructure that supports broadband connection (ANATEL, 2020b)

Therefore, new pipelines going to these areas could establish agreements with telecommunications companies for the joint installation of pipelines for optical fibre, or negotiate the use of their unused optical fibre bundles, depending on cost parameters and legal forecasts for such, as previously mentioned. This sharing could contribute to increase the universal access to high-data flow internet, in addition to establish high speed and security digital networks, enabling greater efficiency in the operation of projects in the energy and industrial sectors, among others.

As to Brazilian water resources, the National Water Security Plan showed that areas with higher human and economic activity concentration are more critical in relation to water security issues. Additionally, it is worth noting that the areas with minimum or low water security are found mostly in the Northeast, in the countryside of Bahia, and in the extreme South, as observed in Figure 3 (ANA, 2019).

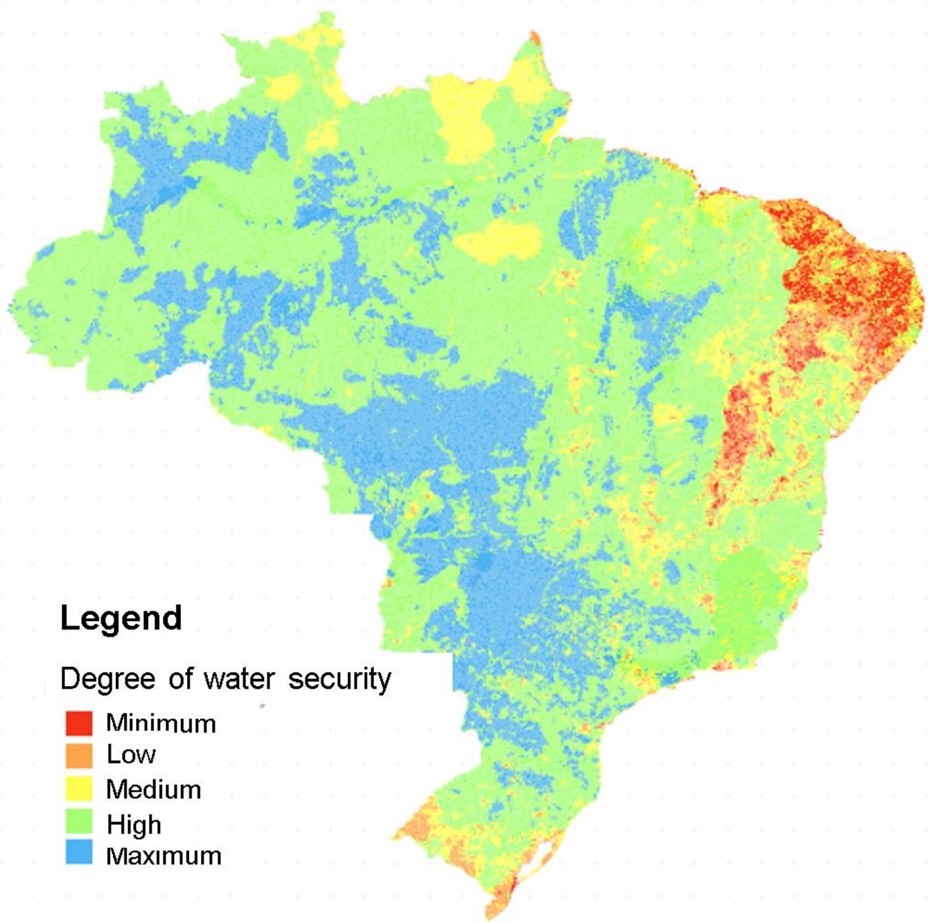

Figure 3. Level of Water Security planned for 2035 in the National Water Security Plan
Source: ANA[11] (2019).

Joint strategies could mitigate this concern by allowing better water management between surplus and deficit regions, including, for example, the installation of pipes to exchange flows, adjustment of authorizations for offtake flows by industrial centres, among other initiatives. Water management can also be related to the onshore Exploration and Production (E&P) activity, especially in operations with high water consumption, which would allow greater sustainability and feasibility in the development of new E&P projects involving rights-of-way for oil pipelines, gas pipelines and water pipelines that are assessed and designed together.

[11] ANA – *Agência Nacional de Águas e Saneamento Básico* or Brazilian National Water and Sanitation Agency

As to the integration between pipeline modes, in addition to sharing the right-of-way itself, integrated projects can be developed considering gas pipelines, multi-product pipelines and other modes, also assessing modes replacement in cases where the existing infrastructure is saturated. In Brazil, most of the production of liquid fuels and ores is transported by road, rail, or waterway (STUKART et al, 2018; MINFRA, 2018), concomitantly with the transport of people and other cargo such as grains, foodstuffs, and products in general. With the growth in demand for these goods, the analysis of alternative means of transport becomes more important in cases where this proves possible, and in this specific case, multi-product pipelines (for transporting liquid fuels) and slurry pipelines (for transporting ores) gain special attention.

In the case of existing and planned railroads, as shown in Figure 4, for example, the establishment of logistical routes could be assessed considering intermediate stations for changing modes, thus allowing the use of railroad-pipeline integration in favour of greater efficiency and lower transport costs. The transport of compressed or liquefied natural gas is also possible by railways, although there are regulatory issues and technical aspects yet to be considered (REUTERS LEGAL, 2020).

Figure 4. Railway map of Brazil
Source: ANTF[12] (2020).

If the above issues are addressed, the existing railroads could assist in taking natural gas to the countryside of Brazil, creating new markets, and serving new areas. However, as indicated in the case of electric power transmission lines, it may not be feasible to share ROWs between gas pipelines

[12] ANTF – *Associação Nacional dos Transportes Ferroviários* or National Association of Railway Transport

and railway lines over large extensions, given the issues of magnetism and sparking involved in these structures.

Thus, sharing rights-of-way between projects of gas pipelines, multi-product pipelines, water pipelines, optical fibre, among others, can present great scope savings and allow a lower global cost, in addition to mitigating socio-environmental impacts and reducing the extent of deforested areas, making it cheaper to maintain the ROW that will be used jointly. However, for such sharing to occur, technical and safety issues arising from parallel construction of pipelines must be properly addressed in engineering projects.

2.4. Corridors of Interest

From 2018 to 2020, the Ministry of Infrastructure published several reports that make up the Strategic Logistic Corridors Project, presenting analyses on the flow of cargo in Brazil divided by the type of goods transported. In this sense, given the factors mentioned above about projects with greater sharing potential, the reports "Strategic Logistic Corridors: Oil and Fuels" (MINFRA, 2020) and "Strategic Logistic Corridors: Iron Ore Complex" (MINFRA, 2018) are especially important for the issue of sharing of corridors with transmission gas pipelines.

As to sharing between gas pipelines and slurry pipelines, it appears that there are opportunities for carrying out feasibility studies especially in the Maranhão - Pará and Espírito Santo - Minas Gerais - Rio de Janeiro axes, as shown in Figure 5.

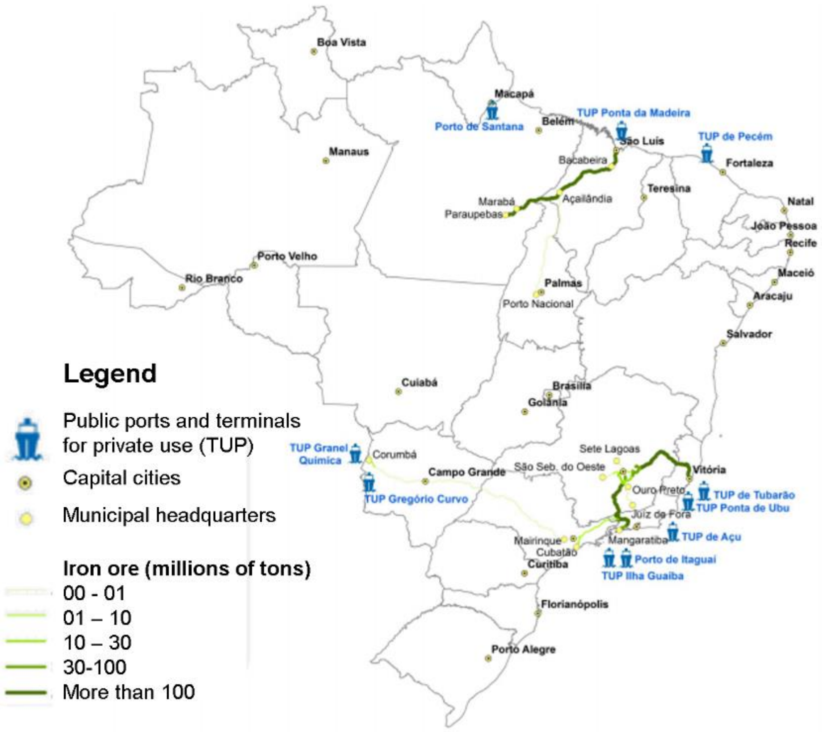

Figure 5. Railroad Handling Map - Iron Ore
Source: MINFRA (2018).

Both axes mentioned handle over 100 million tons of iron ore per year, destined for the domestic and foreign markets. In addition to the possibility of studies on slurry pipelines that can reduce the value of ore transport, now carried out by railways, the possibility of studies that assess the demand for natural gas to serve steel hubs in activities such as pelletising and possibly direct reduction is indicated.

As for other fuels, the opportunities for sharing the ROW between gas pipelines and multi-product pipelines are more comprehensive, including possible new projects for the transportation of gasoline, diesel oil, aviation kerosene, biodiesel, and ethanol throughout Brazil. The study on oil and fuels of the Ministry of Infrastructure (MINFRA, 2020) presents the coverage area of the logistical corridors and Figure 6 highlights specifically the gasoline and diesel corridors.

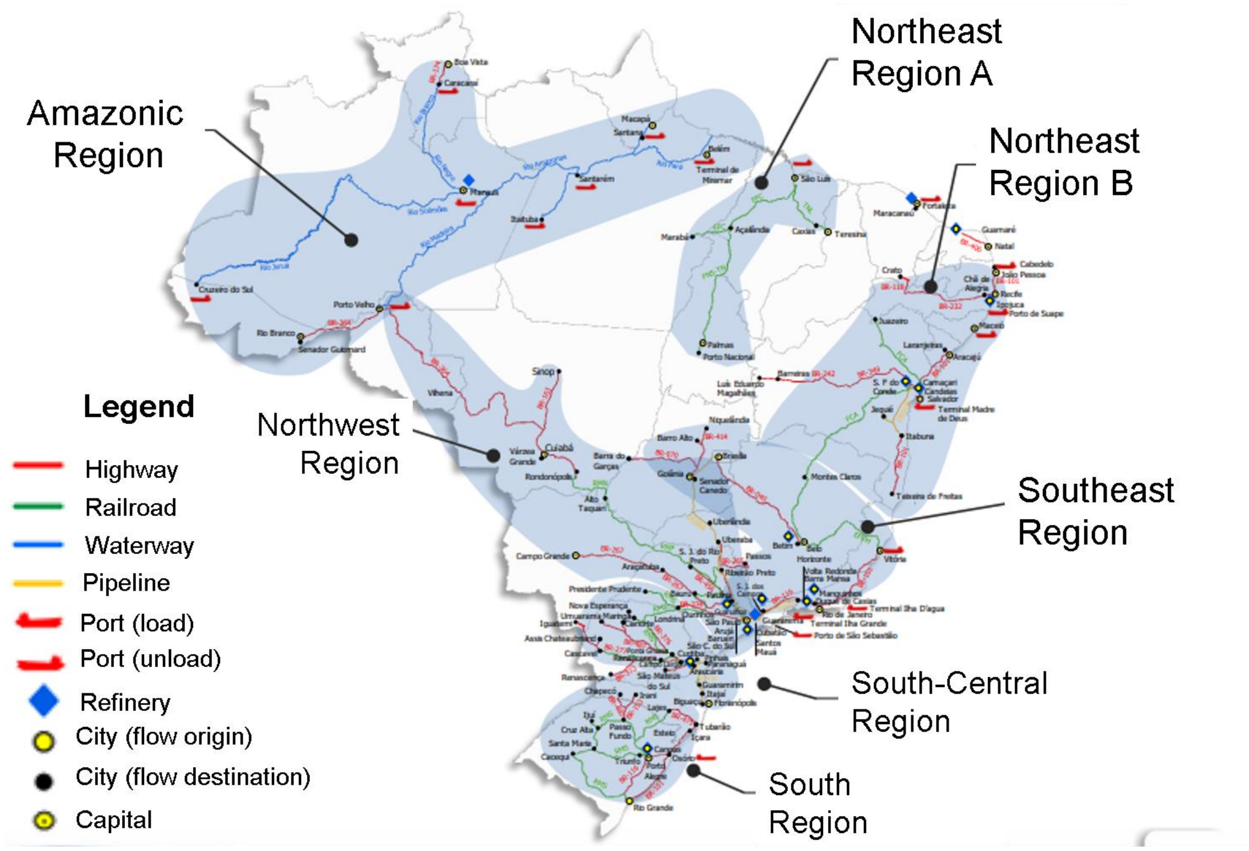

Figure 6. Gasoline and Diesel Logistics Corridors
Source: MINFRA (2020).

The study verified the existence of 26 logistical corridors for all fuels studied, as shown in Table 1, some of which would already be served partially by pipelines. However, in general, they are served mainly by road, rail, and waterway transport. In addition to the still incipient extension of pipelines for transporting liquid fuels in Brazil, it appears that the main infrastructures of this type are close to saturation (EPE, 2019a).

Table 1. Fuel Logistic Corridors

Gasoline and Diesel	Airplane Kerosene	Biodiesel	Ethanol
Northwest	Amazon	Northwest	Northwest
Amazon	North	North	North
Northern Northeast	Northeast 1 - (CE/PI)	Northeast	Northeast
Southern Northeast	Northeast 2 - (PE/PB/RN)	Southeast	Southeast
Southeast	Northeast 3 - (BA/SE/AL)	South	South
Mid-South	Southeast	-	-
South	Mid-West	-	-
-	South 1 - (PR/SC)	-	-
-	South 2 - (RS/SC/PR)	-	-

Source: MINFRA (2020).

In this sense, oil pipeline projects have been studied proposing pipeline transportation as a possible solution to reduce fuel transportation costs, alleviate road infrastructure and increase supply security considering road impediment issues as recently seen for diesel. Among the examples of studies that can be mentioned are the Indicative Oil Pipelines Plan (PIO), being prepared by EPE (EPE, 2019a), the study carried out by Loggi in partnership with the IBP, indicating about BRL 12.3 billion of possible investments for fuel logistic (IBP, 2019) and the study of an ethanol pipeline with about 43 km in São Paulo presented by Logum Logística (LOGUM, 2020).

2.5. Case Study: Brasil Central

To review the potential cost savings made possible by the sharing of right-of-way, a case study was made considering the Brasil-Central gas pipeline project, assessed in the PIG 2019 cycle (EPE, 2019b). First, the costs of this project have been updated from the June 2019 base date to the June 2020 base date; then, costs were assessed for two cases: (i) without sharing the ROW, with the project's CAPEX covering payment for the entire land that corresponds to the route and (ii) considering the sharing of the ROW with a variable number of pipelines (from 2 to 6 pipelines).

As a premise, the shareable costs of the pipeline refer to the items that are related to the purchase and preparation of land (involving acquisition, indemnity, etc.). The other costs that refer only to the gas pipeline project (piping, complementary installations, etc.) were deemed not shareable, which means they were not divided among the other projects. Therefore, 62% of the costs related to the Brasil Central Gas Pipeline are shareable, while the remaining 38% refer only to this project, and cannot be shared with other agents.

Land, Construction and Assembly costs and taxes and BDI related to these elements were considered the shareable portion. Such costs were shared since the launch of all pipelines sharing the project right-of-way was considered to be simultaneous. Figure 7 below shows the results related to 6 sharing cases.

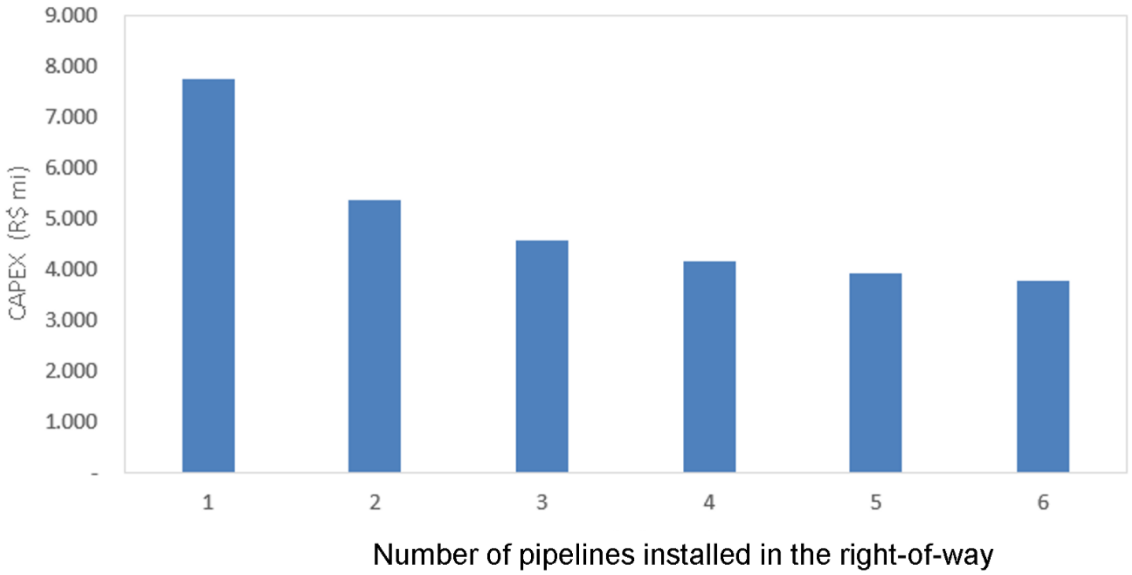

Figure 7. Total investment of the Brasil Central Gas Pipeline in relation to different levels of right-of-way sharing
Source: EPE
Note: the base date used was June 2020 and the estimates were based on the analysis of design projects, with -20% to -50% and +30% of +100% accuracy.

It is possible to see that sharing the right-of-way allows a reduction in CAPEX costs by dividing some costs with the other projects installed in the same ROW. Another point worth mentioning is that the cost reduction is proportionally more significant when there are fewer pipelines. In the case study presented, the reduction was significant when sharing with up to three pipelines, that is, up to four pipelines in the same ROW, as shown in Table 2. A 31% reduction in costs was noticed when sharing the right-of-way of the Brasil Central Gas Pipeline with one other project. On the other hand, the additional reduction was only 20% when sharing the ROW with 5 other projects.

Table 2. Number of pipelines in the right-of-way, CAPEX, and cost reduction due to sharing

Number of pipelines in the ROW	CAPEX (thousand BRL)	Cost Reduction
1 pipeline	7,746	0%
2 pipelines	5,354	31%
3 pipelines	4,556	41%
4 pipelines	4,158	46%
5 pipelines	3,919	49%
6 pipelines	3,759	51%

Source: EPE
Note: Note: the base date used was June 2020 and the estimates were based on the analysis of conceptual designs, with -20% to -50% and +30% of +100% accuracy.

Table 2 and Figure 7 show the characterization of a plateau in CAPEX values, as the number of pipelines in the same right-of-way increases. This makes non-shareable costs more significant, increasing their influence on the total cost.

Thus, it is possible to notice an asymptotic behaviour tending to the value of BRL 3.5 billion, corresponding to the limit of scope savings by increasing the number of pipelines in the ROW. Therefore, for the case study of the Brasil Central gas pipeline after five pipelines in the same right-of-way, CAPEX is virtually the same.

As to the projects that could share the ROW with the Brasil Central gas pipeline, by analysing the infrastructure previously presented, there is the possibility of building a multi-product pipeline for transporting liquid fuels, replacing the road modal, and serving a stretch of the “Mid-South” logistic corridor indicated by the Ministry of Infrastructure. Based on the map presented by ANATEL, there is also the possibility of optical fibre connection with the municipalities West of Uberaba/MG that do not yet have the infrastructure to do so, if the cabling project shares the ROW with the Brasil Central gas pipeline or if the owner of the future pipeline offers other companies the capacity available in their optical fibre bundles. As mentioned earlier, however, such sharing shall depend on detailed technical-economic assessments and it must comply with the current regulatory framework.

3. Detailing of Indicative Transmission Gas Pipelines

In the current study cycle, we first sought to assess the feasibility of transmission gas pipelines whose initial designs come from ANP authorizations prior to the publication of the Gas Law (Law 11,909 of 2009). These authorized gas pipelines have not yet been built, but their premises served as framework for proposing ideas for expanding the pipeline network. It is noteworthy that although these authorizations guided the path to be followed by natural gas, changes were necessary in the final route, prepared by EPE in this cycle, due to the new considerations of potential supply and demand for natural gas.

The PIG 2020 also detailed gas pipelines previously studied by EPE, such as the Penápolis/SP - Uruguaiana/RS (Chimarrão) gas pipeline and its variations and the Santo Antônio dos Lopes/MA - Barcarena/PA gas pipeline, assessed in the Ten-Year Pipeline Network Expansion Plan - PEMAT 2022 (EPE, 2014). Both were reassessed considering new routes based on recent studies of natural gas demand, such as those prepared by natural gas Local Distribution Companies (LDCs) and by BNDES (2020), in addition to EPE georeferenced analyses of potential consumer hubs.

It should be noted that some of the assessed gas pipelines seek to increase the integration of natural gas industry and make this energy available to new consumer markets, with an emphasis on the interconnection of new capitals to the transmission gas pipeline network. For this purpose, we can mention the Santo Antônio dos Lopes/MA - Caucaia/CE Gas Pipeline that traverses Teresina, the Santo Antônio dos Lopes/MA - São Luís/MA Gas Pipeline that transports gas to the capital city of Maranhão, São Luís and the Santo Antônio dos Lopes/MA - Barcarena/PA Gas Pipeline, which is near the metropolitan region of Belém, the capital city of Pará. In addition to these, the Presidente Kennedy/ES - São Brás do Suaçuí/MG gas pipeline was also assessed, since it could be an alternative to internalize the use of natural gas in the eastern region of Minas Gerais. Figure 8 presents the transmission pipeline projects studied in the PIG 2020 cycle.

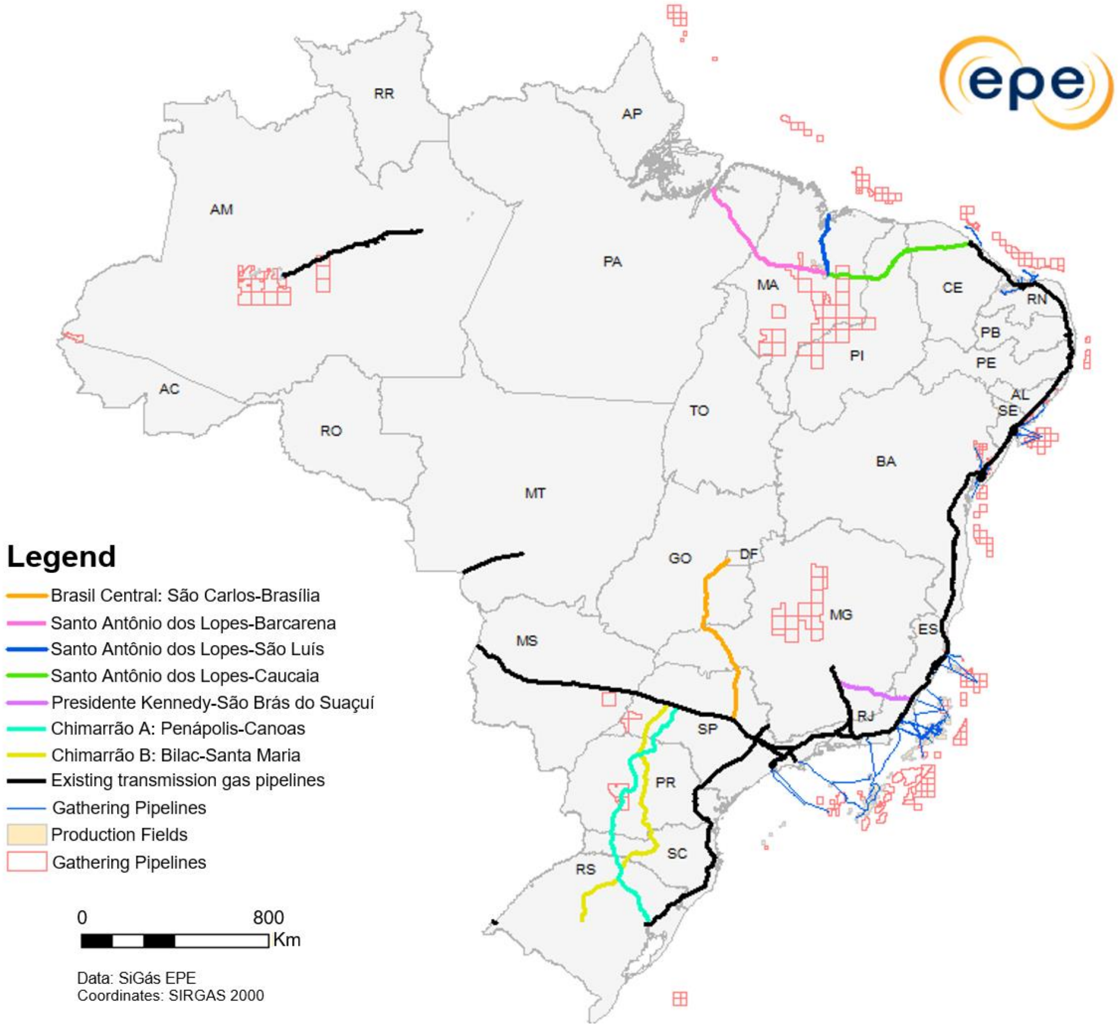

Figure 8. Location map of the studied transmission gas pipeline alternatives.
Source: EPE.

The municipality of Santo Antônio dos Lopes/MA was chosen as the focal point for three gas pipeline alternatives due to the existence of natural gas infrastructure associated with the Parnaíba Thermoelectric Complex, whose current or future operation may benefit from the studied scenarios. Furthermore, the production potential of the natural gas fields in the vicinity of this municipality, and the exploration potential of the Parnaíba Basin could meet the estimated potential demands in the studied states. In addition, the routes proposed in the PIG 2020 traverse LNG terminal projects both under development (Barcarena/PA) and under study (São Luís/MA). Due to these considerations, the three pipelines connected to the municipality of Santo Antônio dos Lopes were considered bidirectional.

The coexistence possibility of the LNG terminals in Barcarena and São Luís can make the gas pipeline alternatives studied mutually exclusive, depending on the characteristics of each project, since the LNG from the Barcarena Terminal could supply São Luís or the LNG from the Terminal in São Luís could supply Barcarena. These scenarios, however, require better definition of the number and size of the LNG terminals that should be installed in the region, which shall result in the redesign of the gas pipelines that would end up transporting larger volumes of natural gas since the gas pipelines were designed considering an LNG supply at only one of its ends.

Finally, it is important to highlight that the demands used for designing the pipelines in this study were estimated considering alternatives for consumption growth, either due to new demands or the replacement of other energy sources with natural gas. This difference between the volumes estimated by EPE for this study and by BNDES (2020) and the volume used for designing allows the accommodation of any possible growth, as well as enables the scaling of the infrastructures, such as the installation of compression stations.

The main physical and socio-environmental characteristics were assessed for each route alternative, highlighting especially those with the greatest possibility of affecting Construction and Assembly cost estimates. The route analyses were based on public satellite images available on Google Earth®. In addition, public georeferenced data was used from IBGE (IBGE, 2016), CPRM[13], FUNAI[14], INCRA[15] and ANA, among others databases.

Subsequently, the routes were assessed in more detail in terms of social and environmental aspects, such as indigenous areas, settlements, quilombola[16] areas, areas of environmental preservation and areas of archaeological interest, among others. After this detailed analysis, specific changes were made to the route to minimize socio-environmental impacts, in addition to technical recommendations on such aspects.

It is worth mentioning that, in the scope of this study, no field work, geotechnical investigations to characterize the material to be excavated, aerial surveys, bathymetric surveys, risk analysis studies and technical visits to the places crossed by the proposed routes were carried out, since this work constitutes a study of long-term conceptual design. Therefore, the construction and socio-environmental details of each alternative should be provided in later stages involving environmental licensing, basic project, and executive project.

Such details in the studies are of great importance in the scope of the Feasibility Studies (considering Engineering, Economic and Socio-Environmental aspects) - for each project and shall be part of the scope of the following stages, with companies interested in the implementation of the projects being responsible for carrying them out. In addition, companies that are going to build and/or operate each gas pipeline project in the future should also be responsible for expressing interest to the competent government agencies to obtain their respective authorizations and technical consultations, such as city and state governments, environmental agencies, FUNAI, IPHAN[17], ICMBio[18], INCRA, DNIT[19], ANA, ANP, ANTAQ[20] and the Navy, among others.

The route proposals were prepared initially based on technical data compiled by EPE, in addition to general observations on the areas to be crossed and on the relief. Difficulty factors were assessed, such as the type of relief, the amount of river crossings and intersections with roads, highways, etc., the greater or lesser possibility of rocks presence from geological maps and the

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[13] CPRM – *Serviço Geológico do Brasil* or Brazilian Geological Survey

[14] FUNAI – *Fundação Nacional do Índio* or Brazilian National Indian Foundation

[15] INCRA – *Instituto Nacional de Colonização e Reforma Agrária* or National Institute for Colonization and Agrarian Reform

[16] Communities comprised of descendants and remnants of communities formed by enslaved people who escaped in the past.

[17] IPHAN – *Instituto de Patrimônio Histórico e Artístico Nacional* or Cultural Heritage Institute

[18] ICMBio – *Instituto Chico Mendes de Conservação da Biodiversidade* or Chico Mendes Institute for Biodiversity Conservancy

[19] DNIT – *Departamento Nacional de Infraestrutura de Transportes* or Brazilian National Department of Transport Infrastructure

[20] ANTAQ – *Agência Nacional de Transportes Aquaviários* or Brazilian National Water Transportation Agency

possible existence of wetlands. The geological maps on a regional scale served as the basis for an expeditious assessment of the possible difficulties for excavating the materials. Subsequently, a geological-geotechnical mapping in greater detail and with the characterization of soils and rocks should be prepared to estimate their mechanical behaviour with greater reliability.

In the construction aspects' case for special projects, the typical methods most used in the industry were adopted, but the final decision on the need for horizontal directional drilling (HDD), for example, shall be studied and decided later, after discussions between the developer and other stakeholders, and it shall depend on the detailed studies' results. The executive projects for river and road crossings and other intersections must meet the requirements of technical standards, good engineering practices and the guidelines determined by the agencies responsible for the operation and/or regulation of that area. In addition, all geological, hydrological and erosion profile studies, bathymetric surveys and others considered necessary for the preparation of the executive project on crossings and intersections should be carried out.

Among the main technical standards and regulations consulted in this phase of the study, it is worth mentioning ABNT[21] NBR[22] 12712:2002; ABNT NBR 15280-2:2016, ABNT NBR 8036:1983, ASME B 16.5, ASME B 31.8 and the Technical Regulation of Terrestrial Pipelines - RTDT[23] (ANP, 2011). The other engineering standards and recommended practices should be reviewed and followed by the companies responsible for the execution, maintenance, and operation of each project.

In this study, the costs of transmission gas pipelines were estimated using the Transmission Gas Pipeline Cost Assessment System – SAGAS in Portuguese, a tool developed by EPE containing cost databases for pipeline projects. Thus, the total cost of each alternative was estimated considering the following groups of direct and indirect costs:

1. Piping (direct cost): includes material's acquisition, coating and shipping to the construction site;

2. Components (direct cost): includes the acquisition and Construction and Assembly of valves, launchers, and receivers for pipeline inspection gauges (PIGs) and cathodic protection system;

3. Construction & Assembly (direct cost): includes the preparation of the ROW, construction and assembly of the gas pipeline, crossings by bridge, commissioning of the gas pipeline and trepanning service in existing pipelines, if necessary. It also includes the costs of managing the mobilization/demobilization and implementation of the construction site;

4. Complementary Installations (direct cost): includes the acquisition and Construction and Assembly of measurement stations and interconnection stations, as well as the materials and services for supervision and control of these facilities, which shall be connected later to the SCADA system of the gas pipeline;

5. Supervision and Control Systems, Communication and Leak Detection (direct cost): includes materials and services from the SCADA system and other systems necessary for the operation of the gas pipeline and valves;

[21] ABNT – *Associação Brasileira de Normas Técnicas* or Brazilian Association of Technical Standards
[22] NBR – *Norma Brasileira* or Brazilian Standard
[23] RTDT - Regulamento Técnico de Dutos Terrestres or Technical Regulation of Terrestrial Pipelines

6. Land (direct cost): includes the easement for gas pipelines built in a new right-of-way, as well as land for complementary installations and valves; in cases where the right-of-way is shared, the cost for leasing the land was considered in OPEX;

7. Engineering Design, Compensation and Environmental Licensing (indirect cost): includes costs with feasibility studies, basic design, executive design and as-built;

8. BDI - Budget Difference Income (indirect cost): includes costs with the central administration of the project, a specialized team for the purchase of equipment and materials, in addition to services' hiring, legal advice and other activities related to project management; and

9. Contingencies (indirect cost): portion of the cost provisioned for expenses with adjustments in quantities, price variations between the time of the estimate and the actual payment for materials and services, among other uncertainties that may occur in the project.

The cost estimates considered the reference date as June 2019 and they may be compared to conceptual designs, with an accuracy margin of -20% to -50% and + 30% to + 100%, according to AACEI (2011).

3.1. Penápolis-Canoas and Bilac-Santa Maria (Chimarrão A and B) Gas Pipeline

The gas pipeline project called "Chimarrão Gas Pipeline" consists of a new infrastructure for transporting natural gas with the purpose of serving areas without natural gas supply in Paraná, Santa Catarina and Rio Grande do Sul states. Figure 9 shows these alternatives' routes.

This project has already been reviewed in a simplified version in the 2022 PEMAT (EPE, 2014) and compared with the option of expanding GASBOL through loops and changes in the compression stations along its Southern stretch, leading to 5 expansion alternatives that are listed in that study's annex. In the PIG 2020 cycle, the Chimarrão Gas Pipeline shall be reviewed in detail, using two alternatives: the Penápolis/SP - Canoas/RS Gas Pipeline (from now on referred to as Alternative A) and the Bilac/SP - Santa Maria/RS Gas Pipeline (from now on referred to as Alternative B).

These two alternatives were built based on information received from the LDCs in the Southern Region and on the estimates of potential demand assessed by EPE for this study and by BNDES (2020), considering the potential of replacing other fuels with natural gas and the growth of the industrial market in the main sectors analysed. Both alternatives serve the three states of the Brazilian Southern Region, but passing through different municipalities. If one of the transmission gas pipeline projects is to be built, the demands envisaged in the other alternative could be met through distribution pipelines.

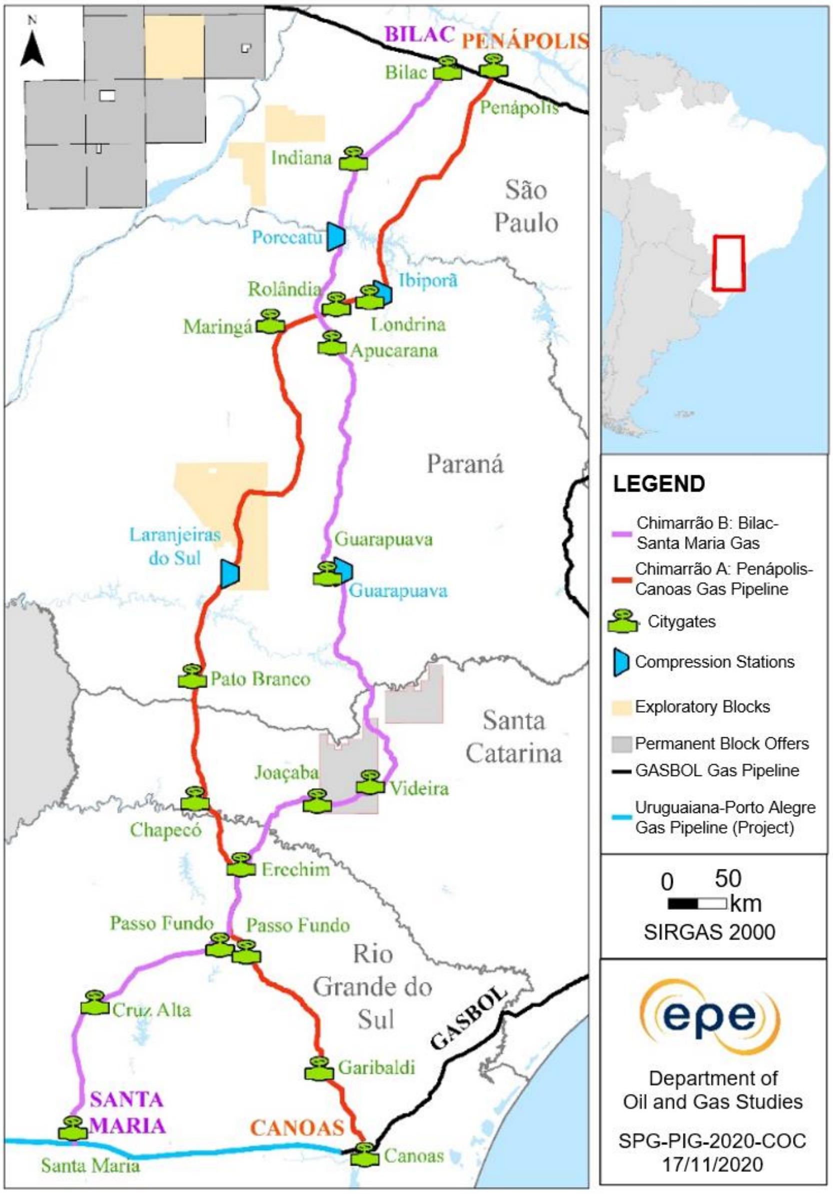

Figure 9. Location map showing Chimarrão A and B gas pipelines.
Source: EPE.

3.1.1. Route Summary

The route established for Alternative A is 1,168 km long and traverses 86 municipalities, 12 in São Paulo, 30 in Paraná, 12 in Santa Catarina and 32 in Rio Grande do Sul. The route defined for Alternative B is 1,237 km long and traverses 69 municipalities, 9 in São Paulo, 23 in Paraná, 14 in Santa Catarina and 23 in Rio Grande do Sul.

The proposed routes considered the optimization of topographical aspects, proximity to potential gas delivery points, highways and accesses, minimization of interference in forest formations and Permanent Preservation Areas (PPAs) of water courses, in addition to deviations from conservation units, indigenous lands, quilombola territories, rural settlements, rural improvements and buildings in general, reservoirs, mining processes in the mining concession phase, rugged reliefs, urban and expansion areas.

Both routes cross regions with good road access, with several federal and state roads (BR-158, BR-377, BR-285, BR-470, BR-153, RS-122, RS-342, SC-482, SC-355, SP-483, SP-421, among others), which shall facilitate logistics during the project's construction phase.

3.1.2. Socio-environmental analysis and construction difficulties

According to the database consulted, the routes do not interfere with conservation units, indigenous lands, quilombola territories or rural settlement projects, as shown in Figure 10. It is worth mentioning that the Alternative A route intercepts a stretch of the National Passo Fundo Forest buffer zone, a federal conservation unit for sustainable use located in Mato Castalhano/RS.

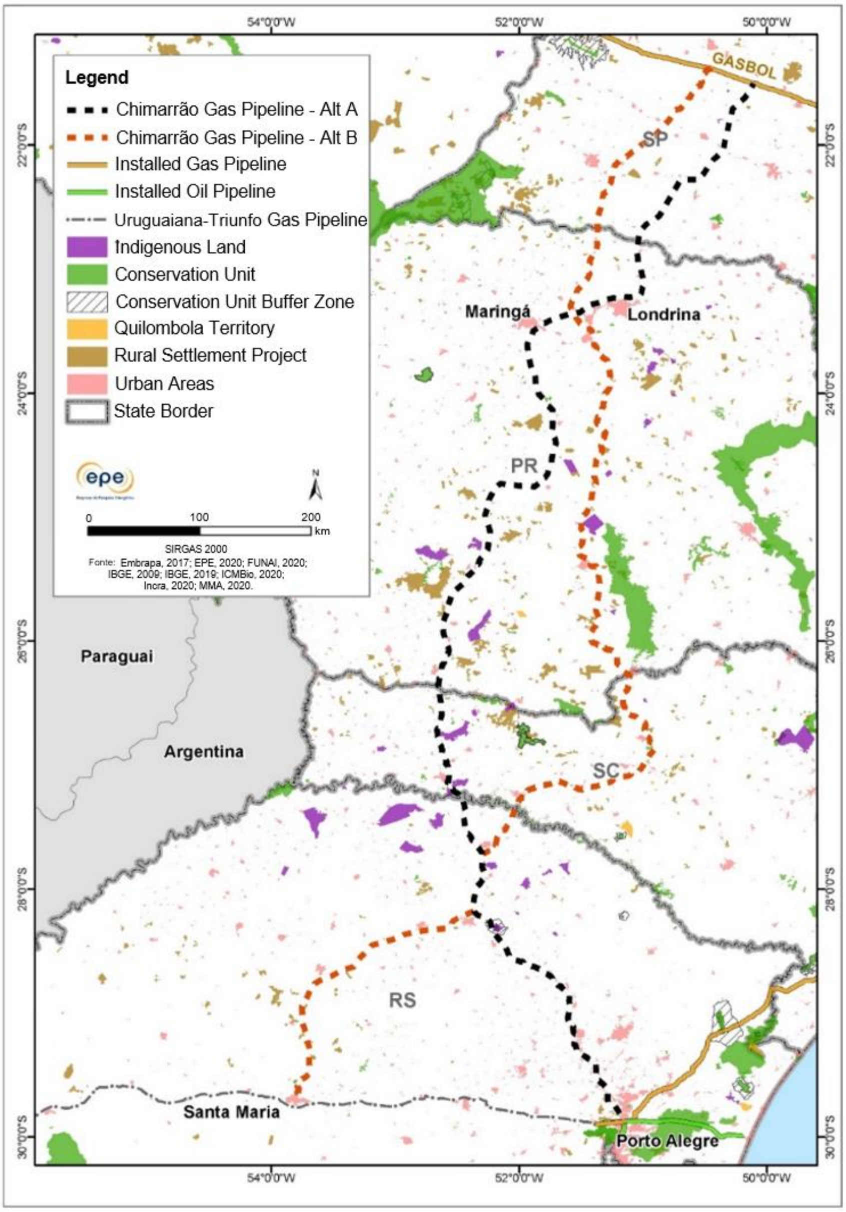

Figure 10. Areas of socio-environmental relevance in the Chimarrão gas pipeline region
Source: EPE

It should also be noted that some indigenous lands are located less than 3 km from the proposed routes, which may require the preparation of Studies on the Indigenous Populations during the project's licensing, as determined by the Interministerial Ordinance Number 60, published in March 24th, 2015 (IPHAN, 2015). Table 3 below shows the list of indigenous lands located in the vicinity of the routes.

Table 3. Indigenous lands (IL) located less than 3 km from the routes

<table>
<tr><th>Natural Gas Pipeline Alternative</th><th>IL Name</th><th>Municipality / State</th><th>Distance of IL in relation to the route (km)</th></tr>
<tr><td rowspan="2">A</td><td>Mato Castelhano</td><td>Mato Castelhano/RS</td><td>0.8</td></tr>
<tr><td>Marrecas</td><td>Turvo e Guarapuava/PR</td><td>0.7</td></tr>
<tr><td>A / B</td><td>Ventarra</td><td>Erebango/RS</td><td>0.7</td></tr>
<tr><td rowspan="5">B</td><td>Aldeia Kondá</td><td rowspan="4">Chapecó/SC</td><td>1</td></tr>
<tr><td>Toldo Chimbangue</td><td>0.5</td></tr>
<tr><td>Toldo Chimbangue II</td><td>2.2</td></tr>
<tr><td>Toldo Pinhal</td><td>2</td></tr>
<tr><td>Xapecó</td><td>Abelardo Luz e Entre Rios/SC</td><td>1</td></tr>
</table>

Source: EPE.

The routes traverse regions with very similar land use context. Both start west of the state of São Paulo, in a region with large pasture areas with few fragments of native vegetation. Around the Paranapanema River there are large agriculture areas. The proposed routes cross the Paranapanema River at the border of Paraná and São Paulo states. Alternative A passes upstream from the Capivara Hydropower Plant, which implies an important crossing of the reservoir. Alternative B, on the other hand, is located downstream from the Plant and, therefore, the crossing is shorter. Regarding the water bodies, both routes have four reservoir crossings.

In Paraná, land use is characterized by the existence of large growing areas of soybeans and corn, small extensions of pastures and some fragments of Atlantic Forest. It is important to note that in the northern region of the state of Paraná, both routes traverse the urban expansion corridor formed by Maringá, Londrina and adjacent municipalities.

In Santa Catarina, both alternatives follow areas characterized by the presence of small properties located in a region of wavy to rugged relief. However, in the Alternative A route, there are large extensions with annual crops and a few forest fragments. Alternative B, in turn, crosses regions with large fragments of vegetation and extensive areas of forestry.

In Rio Grande do Sul's Mountain Range, the routes cross areas characterized by large fragments of Atlantic Forest, forestry, and small agricultural properties with perennial crops. In the Plateau of the northern region of Rio Grande do Sul, the pipeline project traverses a region with a predominance of soy growing properties. Alternative A ends in the Porto Alegre's Metropolitan Region, in the municipality of Canoas, where urban expansion vectors can be seen among fragments of vegetation, pastures, non-perennial crop areas and stretches with floodplains. As for the final stretch of Alternative B, as it crosses the central region of the state, it traverses large areas of pasture and soybean and corn crops, with less forest fragments.

The routes cross mostly hills, plateaus, and low mountains (CPRM, 2002). There are stretches with more rugged topography referring to embedded valleys and mountain cliffs, in which the routes sought to optimize the topographical aspects, avoiding more relevant slope ruptures, such as fault or plateau cliffs, natural ravines, canyons and sharper mountain tops. These streches are more expressive in route A than in alternative B, since alternative A crosses Rio Grande do Sul's Mountain Range and may represent greater constructive complexity. In route A there is also a relevant crossing in an unconsolidated sediment deposit area between the municipalities of Sapucaia do Sul and Portão (Rio Grande do Sul) that indicate geotechnical complexity.

The Alternative A route interferes with 38 mining processes in the mining concession phase (1), mining requirement (4), research authorization (17), research requirement (4), licensing (7), application and registration of extraction (5), involving substances such as sand (5), anthracite (1), mineral water (3), clay (13), basalt (4), mineral coal (1), grit (1), Diabase (1), Lignite (1), sapropelite (1), Peat (1) copper ore (1) and gravel (5).

The Alternative B route, on the other hand, interferes with 24 mining processes in the research authorization phase (19), mining requirement (3), research requirement (2), involving substances such as sand (10), sandstone (2), clay (4), basalt (6), grit (1) and gold ore (1). It is important to mention that in cases where it was not possible to deviate, the routes were developed aiming at minimizing the respective interference.

The routes traverse a significant number of high voltage electric power transmission lines (TLs) (≥ 238 kV). Alternative A intercepts 46 TLs in operation and 14 routes of planned TLs. Alternative B traverses 35 TLs in operation, in addition to nine planned TL routes. Due to the high number of interferences in TLs, the developer who build the gas pipeline must observe the crossing criteria with the transmission companies, in addition to assess issues related to parallel construction with the lines and possible engineering solutions to mitigate corrosive processes related to electromagnetic induction.

It is also noteworthy that both alternatives intercept railroads along their lengths, and the gas pipeline developer must assess the specific conditions for carrying out the intersections.

3.1.3. Thermo-fluid-hydraulic Design

The Chimarrão A and Chimarrão B gas pipelines were studied to reach areas without natural gas supply. Both pipelines start with gas injection points in the Bolivia-Brazil Gas Pipeline (Gasbol). In addition to supplying gas through Gasbol, an injection of Argentine gas through interconnection with the authorized Uruguaiana - Porto Alegre Segment 2 pipeline would be possible in the future. Both alternatives for the Chimarrão gas pipeline were designed for a demand of 8 million m³/day along the route. The location of the delivery points was determined across the municipalities with the highest demands, according to the EPE assessments of potential replacement of sources and to the study of gas demand in Brazil by BNDES (2020). An influence radius of 50 km was used also to determine the demands, considering that even this distance from the pipeline would still be a region supplied with natural gas by Chimarrão, due to the distribution pipelines that would meet these demands.

The Chimarrão A gas pipeline starts in the municipality of Penápolis/SP and ends in Canoas/RS. Along the route, 9 delivery points were considered, namely Penápolis/SP (0.5 million m³/day), Londrina/PR (1.5 million m³/day), Maringá/PR (0.5 million m³/day), Pato Branco/PR (0.5 million m³/day), Chapecó/SC (1.5 million m³/day), Erechim/SC (0.5 million m³/day), Passo Fundo/RS (1.0 million m³/day), Garibaldi/RS (0.5 million m³/day) and Canoas/RS (1.5 million m³/day).

The gas pipeline design was made using thermo-fluid-hydraulic simulations, resulting in a 20-inch pipeline using 2 compression stations: one in the municipality of Ibiporã/PR and the other in the municipality of Laranjeiras do Sul/PR.

The Chimarrão B gas pipeline starts in the municipality of Bilac/SP and ends in the municipality of Santa Maria/RS. Along the route, 10 delivery points were considered, namely Bilac/SP (1.0 million m³/day), Indiana/SP (0.5 million m³/day), Rolândia/PR (1.0 million m³/day), Apucarana/PR (0.5 million m³/day), Guarapuava/PR (0.5 million m³/day), Videira/SC (0.5 million m³/day), Joaçaba/SC (1.5 million m³/day), Passo Fundo/RS (1.0 million m³/day), Cruz Alto/RS (1.0 million m³/day) and Santa Maria/RS (1.0 million m³/day). The gas pipeline design was made using thermo-fluid-hydraulic simulations, resulting in a 20-inch pipeline using 2 compression stations: one in the municipality of Porecatu/PR and another in the municipality of Guarapuava/PR.

3.1.4. Cost Estimate

Table 4 and Table 5 detail the costs associated to the projects, grouped in items.

Table 4. Costs associated to Chimarrão A gas pipeline project

Description		
Direct Costs	**BRL thousand**	**%**
Piping	2,356	19.9
Components	122	1.0
Construction and Assembly	4,739	40.0
Complementary Installations	361	3.1
Supervision and Control, Communication and Leak Detection Systems	158	1.3
Land	1,037	8.7
Indirect Costs		
Engineering, Compensation and Environmental Licensing Project	61	0.5
BDI – Budget Difference Income	1,753	14.8
Contingencies	1,271	10.7
TOTAL INVESTMENT (base date June/20)	**11,858**	**100**

Source: EPE.

Note: estimates based on the analysis of conceptual designs, with -20% to -50% and +30% of +100% accuracy.

Table 5. Costs associated to Chimarrão B gas pipeline project

Description		
Direct Costs	**thousand BRL**	**%**
Piping	2,481	20.0
Components	125	1.0
Construction and Assembly	4,932	39.8
Complementary installations	370	3.0
Supervision and Control, Communication and Leak Detection Systems	167	1.4
Land	1,099	8.9
Indirect Costs		
Engineering, Compensation and Environmental Licensing Project	61	0.5
BDI – Budget Difference Income	1,829	14.8
Contingencies	1,326	10.7
TOTAL INVESTMENTS (data base June/20)	**12,390**	**100**

Source: EPE.
Note: estimates based on the analysis of conceptual designs, with -20% to -50% and +30% of +100% accuracy.

Both pipelines are over 1,100 km long, and their construction ends up requiring 5 to 6 work fronts, making the Construction and Assembly cost very expressive, as shown in Table 4 and Table 5, representing approximately 40% of the total cost of these projects. In addition, this high Construction and Assembly cost may be justified by the fact that approximately 75% of the project extension would be installed on rocky terrains, which makes the construction process more complex and, consequently, more expensive. In addition, both pipelines have many associated infrastructure elements, such as delivery points (9-10) and compression stations (2).

Another item that stands out in the total cost of these projects is land cost. The cost of land acquisition in the South Region is more expensive (especially in comparison to the cost of the other projects studied in the PIG 2020), added to the fact that both alternatives cross extensive areas in urbanization, which present higher values than the ones in rural areas, predominant in the other PIG 2020 pipelines. All these elements make this item significant in the costs of both alternatives, representing approximately 9% of the total cost of the projects.

Although the cost related to piping represent 20% of the total cost of the alternatives, they suffer little influence from the characteristics of the project, and their variation results mainly from exchange rate variations.

When comparing both alternatives, it is possible to notice that the cost of the Chimarrão B Gas Pipeline is about 4.5% more expensive than alternative A, being also 69 km longer in relation to it and having an additional delivery point. Such differences end up justifying the higher value of the Chimarrão B Gas Pipeline compared to Chimarrão A in all the items considered.

3.2. Presidente Kennedy/ES – São Brás do Suaçuí/MG Gas Pipeline

The proposal for this gas pipeline was based on the intention to connect new existing gas supplies (LNG from Açu Port, Sul Capixaba DPCU[24], Cabiúnas NGPP[25] and Cacimbas NGPP) and possible ones (LNG from Central Port, and Routes 5a, 6a and 6b, identified in the PIPE 2019 (EPE, 2019c) from the north of Rio de Janeiro and south of Espírito Santo to the state of Minas Gerais. Several projects in this proposal could be possible, but in this case, we decided to study the possibility of a gas pipeline following the route of a slurry pipeline designed by the company Ferrous. The company later gave up on the slurry pipeline construction project, which could enable a conversion of the right-of-way that already had a Previous Environmental License (CORREIO DE MINAS, 2016).

The pipeline layout, herein named Presidente Kennedy/ES - São Brás do Suaçuí/MG (Figure 11), followed almost the entire slurry pipeline route, based on the premise that the conversion of the pipeline ROW license could streamline steps in the construction of the gas pipeline.

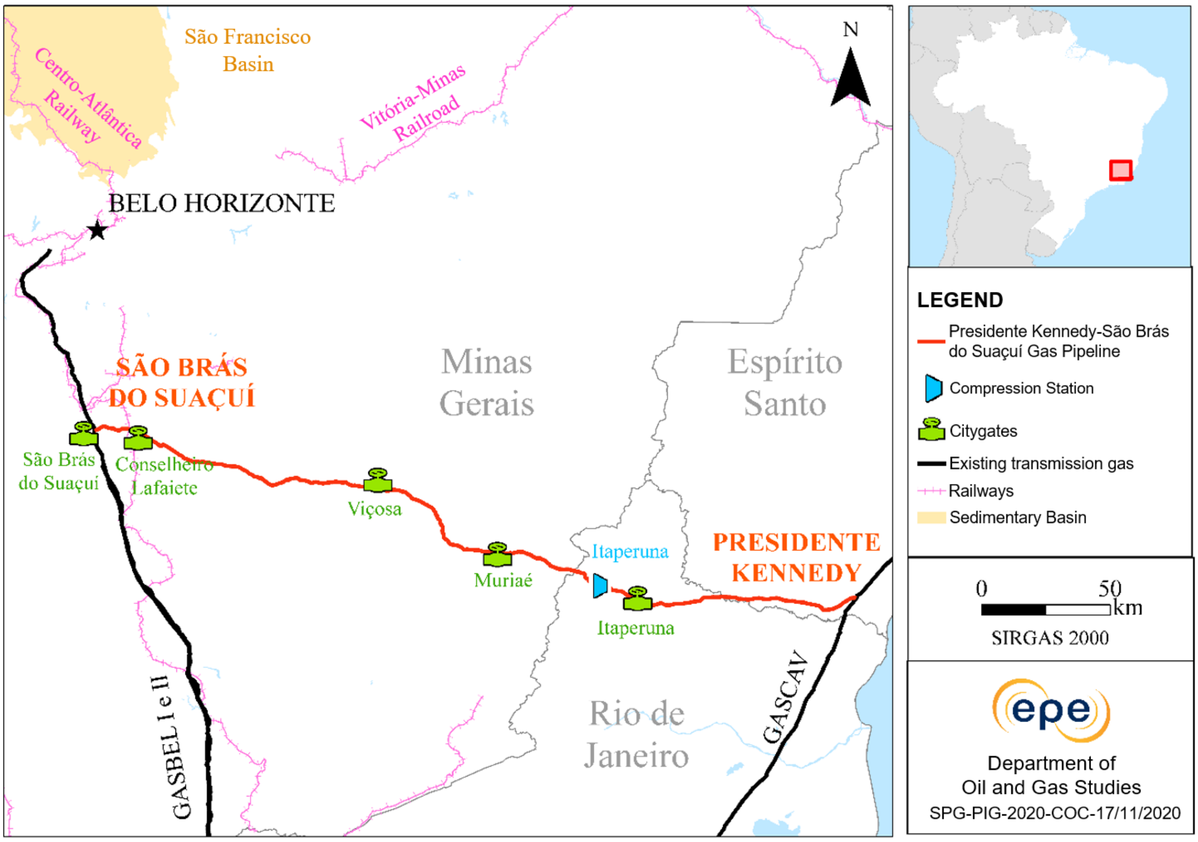

Figure 11. Location map of Presidente Kennedy/ES - São Brás do Suaçuí/MG gas pipeline.
Source: EPE.

The significant changes in relation to the slurry pipeline took place at the beginning of the gas pipeline, where it starts from the connection point of another gas pipeline described in the PIG 2019 (EPE 2019b), Porto Central - GASCAV, and at the end of the route, where it interconnects with GASBEL

[24] Dew Point Control Unit
[25] Natural Gas Processing Plant

pipeline, at the existing delivery point of São Brás do Suaçuí. In its original project, the slurry pipeline ended in the municipality of Congonhas/MG.

3.2.1. Route Summary

The route is 332 km long, crossing 25 municipalities, 3 in Espírito Santo, 3 in Rio de Janeiro and 19 in Minas Gerais. As mentioned, the gas pipeline starts at the GASCAV, in the municipality of Presidente Kennedy/ES, and goes to the GASBEL, in São Brás do Suaçuí/MG, as shown in Figure 12.

To define its route, whenever possible, we sought to deviate from urban areas and forest areas. In addition, proximity to highways and accesses was considered to reduce the need for opening new ones and, consequently, to minimize the impact on vegetation.

The route crosses regions with good road support, with federal and state highways like BR-101, BR-393, BR-356, BR-482, ES-177, RJ-214, MG-132, among others. However, in some stretches there is a shortage of paved roads, especially in the state of Minas Gerais, a fact that should bring some logistical challenges in the construction phase.

This route crosses 3 high voltage transmission lines (TLs) (≥ 238 kV), in addition to the route for a projected line. In Mimoso do Sul/ES and Conselheiro Lafaiete/MG, it intersects railways. Therefore, it is important to assess the specific conditions for these crossings with the companies responsible for their operation (roads, highways and electric power transmission lines).

Starting in the municipality of Presidente Kennedy, in the extreme south of Espírito Santo, the gas pipeline runs through the north of the state of Rio de Janeiro, entering the Zona da Mata region in the state of Minas Gerais until it reaches the municipality of São Brás do Suaçuí, in the vicinity of Conselheiro Lafaiete, approximately 75 kilometres south of the capital city of Minas Gerais.

3.2.2. Socio-environmental Analysis and construction difficulties

According to the database consulted, there are no intersections with indigenous lands or quilombola territories (Figure 12).

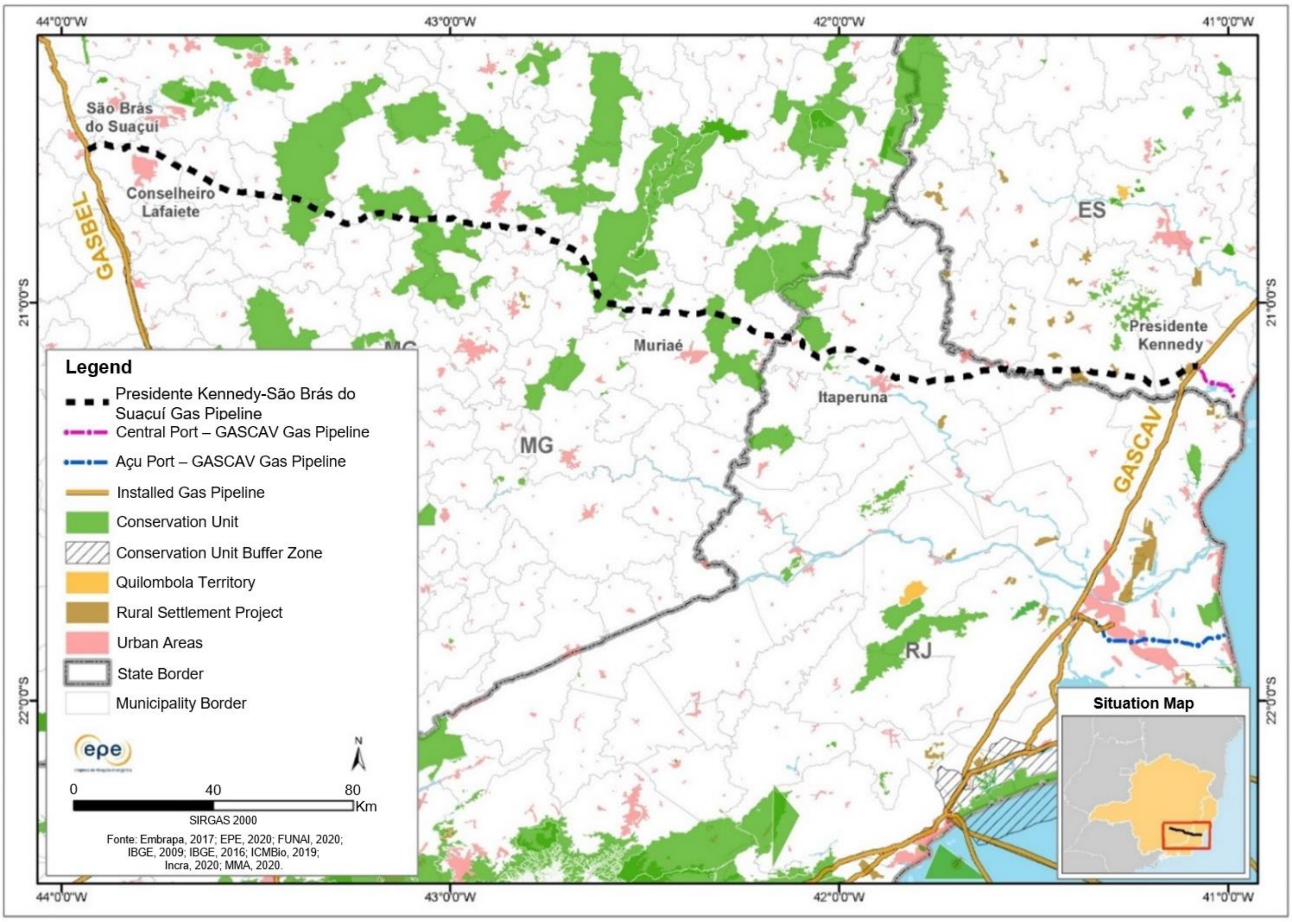

Figure 12. Areas of socio-environmental relevance of Presidente Kennedy/ES – São Brás do Suaçuí/MG gas pipeline
Source: EPE.

Whenever possible, priority was given to passages through regions that have already been altered and have no vegetation. In the phase of detailing the route, the interested company should contact the municipal agencies that manage these units to verify the existence of environmental protection plans and possible conditions for the passage of the gas pipeline. Table 6 shows the seven conservation units intercepted by the gas pipeline project.

Table 6. Conservation units intercepted by the gas pipeline route.

Conservation unit	Municipality / State
Rio Preto Municipal NPA	São Sebastião da Vargem Alegre/MG
Montanha Santa Municipal NPA	Guiricema/MG
Senhora de Oliveira Municipal NPA	Senhora de Oliveira/MG
Presidente Bernardes Municipal NPA	Presidente Bernardes/MG
Pontão Municipal NPA	Muriaé/MG
Piranga Municipal NPA	Piranga/MG
Ervália Municipal NPA	Ervália/MG

Source: EPE.

In the state of Minas Gerais, the gas pipeline route traverses seven municipal Natural Protected Areas (NPAs), the majority of which are of large territorial extension. It is important to highlight that the NPAs consist of conservation units in the least restrictive group, generally allowing the implementation of projects within their boundaries.

In the municipalities of Presidente Kennedy and Mimoso do Sul, in the state of Espírito Santo, the route intersects the José Marcos de Araújo Santos and Rancho Alegre rural settlement projects, respectively.

In the state of Espírito Santo, the gas pipeline route crosses a region with a predominance of pastures, with little relevance for agricultural activities, and sparse fragments of native vegetation associated with water courses and wetlands. Except for the municipality of Apiacá, there are no urban areas in the vicinity of the proposed route in this stretch. .

When entering the territory of the state of Rio de Janeiro, the pattern is very similar to that of the state of Espírito Santo. However, the relief is characterized by steeper slopes, and it is possible to notice the presence of crop areas with larger dimensions and lesser fragments of native vegetation. In the municipality of Itaperuna the route is close to an urban expansion vector.

In the territory of Minas Gerais, the route crosses areas of mountainous relief, in which fragments of native vegetation are associated with hill tops and slopes. In this section, the route passes close to many centres and areas of urban expansion. Most of the areas not occupied by vegetation are characterized by pastures, with little emphasis on agriculture.

Low hills and mountains, and mountainous domains predominate along the route, in addition to fluvial-marine plains, on a smaller scale (CPRM, 2002). This relief configuration should mean construction complexity for the implantation of the gas pipeline, especially in mountainous areas, regarding the transportation of equipment, materials, and personnel, as well as for excavation, land cleaning and drainage solutions. On the other hand, the crossings on the plains mentioned are not significant. In relation to water bodies, the route does not traverse reservoirs and there are no significant crossings over water courses in the project's region.

The route interferes with 130 mining processes in the mining concession phase (4), research requirement (27), research authorization (77), licensing (3), mining requirement (16), licensing requirement (3), involving substances such as sand (12), clay (1), mineral water (1), kaolin (2), bauxite (2), aluminium (7), steatite (1), feldspar (2), phyllite (1), lithium (1), manganese (7), pyrobetuminous shale (1), iron ore (10), gold (57), quartz (1), gravel (1), peat (1) and granite (22). It is important to mention that the region has a wide presence of mining processes, and it is not possible to deviate from them. The Muriaé/MG region concentrates many open pit aluminum minesl. At the end of the route, near Conselheiro Lafaiete/MG, it traverses iron ore mines.

3.2.3. Thermo-fluid-hydraulic Design

From the natural gas supply point of view, the project capacity of the LNG terminal in Central Port of 20 million m³/day was considered, discounting the 8 million m³/day flow of thermal power plants with projects near the port. Thus, a pipeline was designed to reach a maximum capacity of up to 12 million m³/day. Although almost three times the size of the current gas market in Minas Gerais, this consideration in line with the Government and state industries expectations for gas market expansion (CPG, 2019).

Strategic delivery points were distributed along the pipeline route in regions where potential demands were located based on an EPE demand study and on a study of BNDES (2020). Thus, the citygates with their respective flows were defined: Itaperuna/RJ (1 million m³/day), Muriaé/MG (4 million m³/day), Viçosa/MG (2 million m³/day), Conselheiro Lafaiete (1 million m³/day) and a new delivery point in São Brás do Suaçuí/MG (4 million m³/day).

For the configuration described above, through thermo-fluid-hydraulic simulations, a 20-inch gas pipeline was designed, requiring one compression station in the municipality of Itaperuna/RJ, at km 102 of the pipeline (direction ES-MG).

3.2.4. Cost Estimate

Table 7 details the costs calculated for each item highlighted. From a construction point of view, the difficulty predicted in the Construction and Assembly of the pipeline stands out due to a high probability of encountering hard rocks (igneous and metamorphic) during the excavation phase. Regarding land occupation close to the project, Location Class 1, that is, rural areas stand out (98.8%) with low acquisition cost compared to other classes.

Table 7. Costs associated to Presidente Kennedy/ES – São Brás do Suaçuí/MG gas pipeline project

Description		
Direct Costs	**thousand BRL**	**%**
Piping	618	15.9
Components	31	0.8
Construction and Assembly	1,900	49.0
Complementary installations	223	5.7
Supervision and Control, Communication and Leak Detection Systems	12	0.3
Land	37	0.9
Indirect Costs		
Engineering, Compensation and Environmental Licensing Project	18	0.5
BDI - Budget Difference Income	603	15.5
Contingencies	438	11.3
TOTAL INVESTMENT (base date Jun/20)	**3,880**	**100**

Source: EPE.
Note: estimates based on the analysis of conceptual projects with -20% to -50% and +30% of +100% accuracy.

It is worth mentioning that there are other possibilities to connect new supplies from the north of Rio de Janeiro and south of Espírito Santo to Minas Gerais to partially use the structure proposed here or new routes, even from other slurry pipelines that commonly cross the states. However, with new outflow routes possible for the region, as presented in the PIPE 2019 (EPE, 2019c), in addition to new LNG terminals being proposed, it will be necessary to find a consumer market for this new natural gas that reaches the coast. Thus, the state of Minas Gerais, with plans to expand its gas market, may be one of the destinations for possible monetization of part of this gas.

3.3. Santo Antônio dos Lopes/MA – Caucaia/CE Gas Pipeline

The gas pipeline project called Santo Antônio dos Lopes/MA-Caucaia/CE, shown in Figure 13, consists of a new natural gas transmission infrastructure based on a stretch of the Meio Norte Gas Pipeline, authorized by ANP before the signing of Law 11,909/2009. This gas pipeline extends the integrated network, connecting, along its route, the states of Maranhão and Piauí, including its capital.

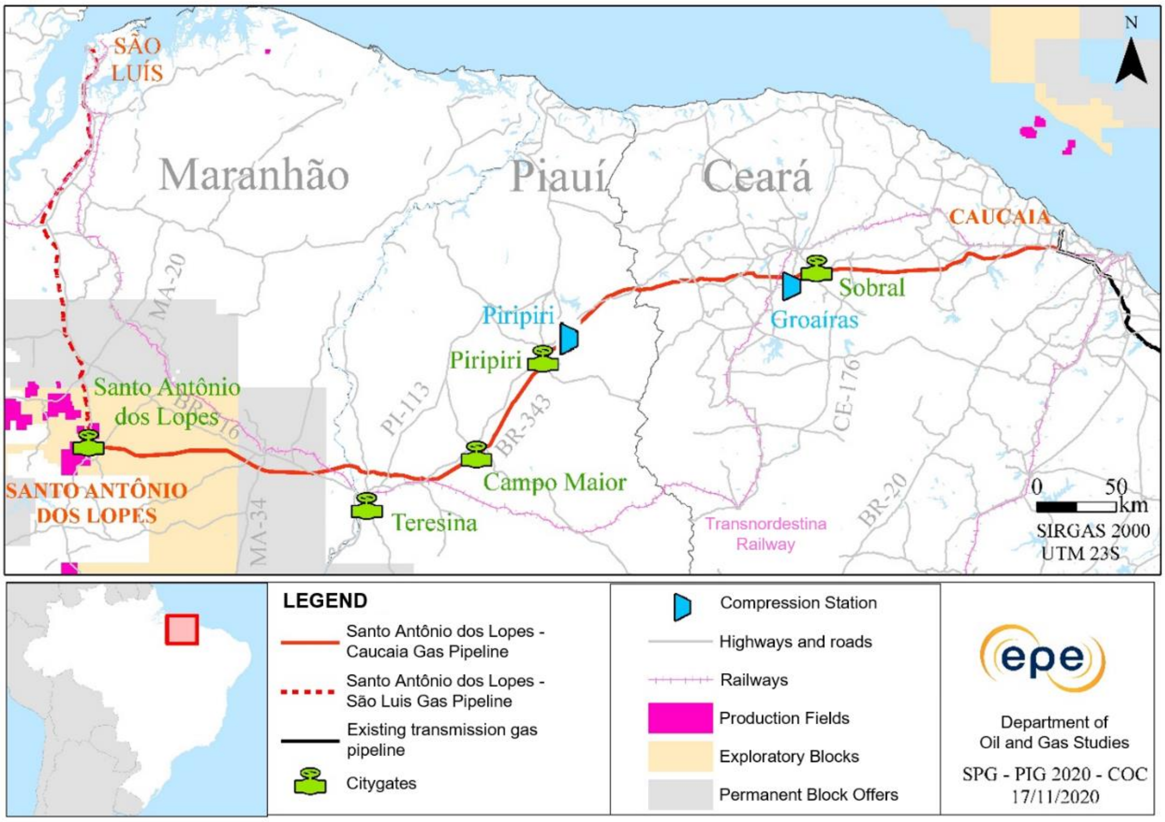

Figure 13. Location map of Santo Antônio dos Lopes/MA-Caucaia/CE gas pipeline.
Source: EPE.

As mentioned, this gas pipeline was based on the route of the Meio Norte Gas Pipeline, however, its route changed to allow a connection to the municipality of Santo Antônio dos Lopes/MA. The pipeline assessed in this study considered the information received from GASMAR, local distribution company of the state of Maranhão, in addition to the estimates of potential demand assessed by EPE and in the study of BNDES (2020), considering the potential of replacing other fuels with natural gas and the industrial market growth in the main sectors analysed.

It is noteworthy that the demands used in the design of this gas pipeline included slack to accommodate any growth that may be observed and that has not been noticed by EPE, such as unseen restrained demands that may be met by the arrival of the gas pipeline or even growth beyond those estimated in this study. This growth margin also allows for a ramp-up of the compression stations that were designed in this study.

3.3.1. Route Summary

The route of this gas pipeline is 684 km long and runs through 29 municipalities, 6 in Maranhão, 9 in Piauí and 14 in Ceará, with the Parnaíba Complex in Santo Antônio dos Lopes, Maranhão and the connection between the Pecém LNG terminal and the existing GASFOR I gas pipeline in Caucaia, Ceará. It is noteworthy that the definition of the route considered the optimization of topographical aspects, the proximity to highways and accesses, diversion of rural settlement projects and, when possible, minimization of interferences in forest formations.

The route established for the Santo Antônio dos Lopes - Caucaia gas pipeline crosses areas well served by paved roads, which shall facilitate logistics for moving equipment during the gas pipeline construction phase. Nineteen high voltage transmission lines (TL) (≥ 238 kV) are intercepted, along with the preliminary route of four planned lines, in addition to railroads at four points, in the municipalities of Timon/MA, Altos/PI, Cariré/CE and Caucaia/CE, which shall require negotiations with the companies responsible for their operation and owners of these linear infrastructures to verify the conditions for intersections (EPE, 2020a).

The proposed route for the gas pipeline starts in the central region of Maranhão and crosses the entire eastern half of the state until it reaches Piauí, running close to the capital city, Teresina. In this state, the route moves northeast towards the border with Ceará. Finally, the route crosses the entire northwest region of Ceará territory until it ends in Caucaia, in the Metropolitan Region of Fortaleza, close to the Pecém Industrial and Port Complex.

3.3.2. Socio-Environmental Analysis and construction difficulties

In Maranhão, the route begins in a region of biome transition where there are elements of the Amazon Forest, Brazilian Savanah and Semiarid. This mosaic creates the Mata dos Cocais, characterized by the presence of plant species such as carnauba palm and babassu. As it moves eastwards, the attributes of the Semiarid biome become more evident. In the east of the state there are large stretches of native vegetation and the anthropized areas are occupied mainly by pastures and small urban centres scattered along the route, except for the urban area of Caxias, which is the largest urban centre in this region of Maranhão (EMBRAPA, 2017; ICMBIO, 2020).

According to the databases consulted, the Santo Antônio dos Lopes - Caucaia Gas Pipeline does not cross indigenous lands, quilombola territories or rural settlement projects (FUNAI, 2020; INCRA, 2020).

In the state of Piauí, the route crosses the Serra da Ibiapaba NPA, an extensive federal conservation unit for sustainable use (Figure 14). When defining the final route, it is important to consult the managing agency of this unit (Chico Mendes Institute for Biodiversity Conservancy - ICMBio) to assess the management plan and possible conditions for the gas pipeline passage (MMA, 2020).

In the Maranhão municipalities of Codó and Caxias, the route runs 3.8 km and 2.1 km from the Quilombolas Territories Mocorongo and Usina Velha, respectively, which may require the developer to prepare the Quilombola Component Study in the gas pipeline licensing phase, as determined by Interministerial Ordinance No. 060, of March 24, 2015 (INCRA, 2020). According to information from the *Fundação Cultural Palmares*[26] (FCP), there are 30 certified quilombola communities in the municipalities crossed by the route not yet included in the georeferenced base provided by the National Institute of Colonization and Agrarian Reform (INCRA). Therefore, when preparing the engineering project for the gas pipeline, it is important to verify if these communities have already been demarcated so that any deviations can be made. Figure 14 shows the analysed route.

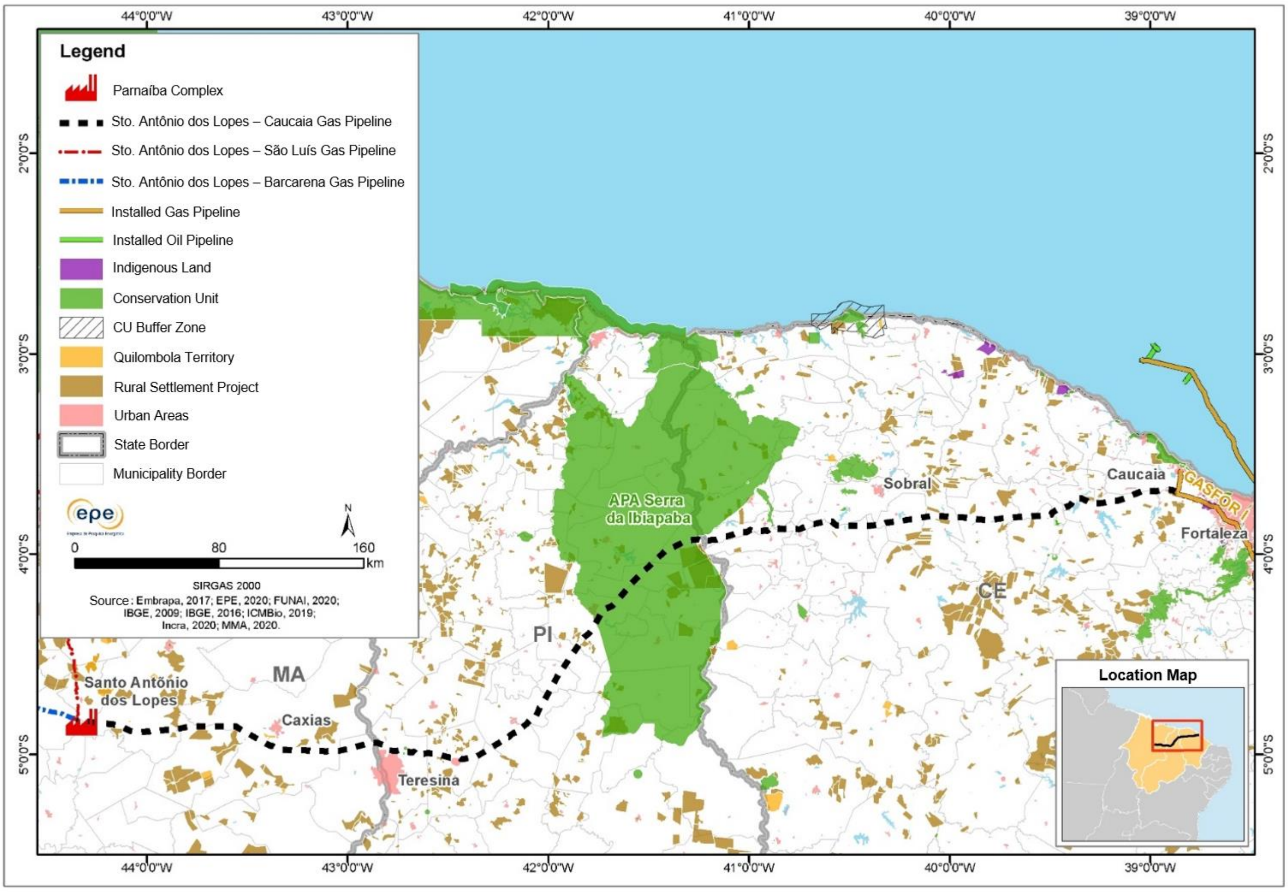

Figure 14. Areas of socio-environmental relevance of Santo Antônio dos Lopes/MA – Caucaia/CE gas pipeline
Source: EPE.

After crossing the Parnaíba River, on the border between Maranhão and Piauí, the route runs near the urban area of Teresina and enters areas with Semiarid characteristics, with low density vegetation with shrubs of twisted branches, small and adapted to the semiarid climate. In this region there are few pasture areas, small areas for growing subsistence crops, sparse and small urban centres, and shrub vegetation, especially around wetlands and water courses (EMBRAPA, 2017; ICMBIO, 2020).

At the eastern end of Piauí and in Ceará territory, the route crosses the Serra do Ibiapaba, with vegetation of different characteristics, including traces of the Atlantic Forest, Brazilian Savanah, and Amazon biomes. In the rest of the route, within the state of Ceará, there are large areas of Semiarid, where there is little presence of pastures, small areas of subsistence agriculture and small

[26] Palmares Cultural Foundation

urban centres, except for Sobral, the largest city on the stretch. The final boundary of the route near the Pecém Industrial and Port Complex has important areas of agricultural production (EMBRAPA, 2017; ICMBIO, 2020).

Along the gas pipeline, hills, tableland, and planed surfaces are predominant, in addition to mountainous escarpments and fluvial-marine plains, to a lesser extent. From a general point of view, this configuration of relief is favourable for the implementation of the gas pipeline, since there are few sections with difficult topography (CPRM, 2010). On the other hand, it is important to highlight that a significant part of the route traverses surfaces with exposed soil and with evidence of erosive processes on sandstones, pelites, shales and other sedimentary rocks, especially in municipalities in the states of Piauí and Maranhão. There is also a section in the municipality of Caxias, in Maranhão, with evaporites and limestones, rocks that may be subject to dissolution and topography changes (CPRM, 2002). Regarding water bodies, the region of the project has many reservoirs, but it is possible to deviate from them. There is a crossing on the Parnaíba River, although it is short.

The layout interferes with 40 mining processes in the mining concession phase (3), mining requirement (5), research requirement (4), research authorization (23), licensing requirement (4), licensing (1), involving substances such as sand (7), mineral water (1), sandstone (3), clay (1), limestone (9), gypsum (3), marble (1), magnesite (1), copper ore (6), iron ore (2), quartz (1), quartzite (1) and granite (4). It is important to mention that in cases where it is not possible to deviate, the routes were designed aiming at minimizing the respective interference (ANM[27], 2020).

Along the route of this gas pipeline, it is interesting to mention the small number of larger crossings. It crosses mainly access roads, unpaved dirt roads and one-way paved roads, namely BR-135, BR-222, BR- 316, BR-343, BR-403, BR-407 and the state roads CE-156, CE-168, CE-179, CE-187, CE-341, CE-362, PI-112, PI-113, PI- 115, PI-258, PI-320, MA-034 and MA-127. Regarding the crossing of rivers and other bodies of water, there are approximately 25 crossings up to 150 meters wide, while in greater extensions the rivers Parnaíba (500 m) and Jaibaras (200 m) stand out.

The relief of this route is located mostly in flat regions and with considerable presence of sedimentary rocks, which should facilitate the construction process of this pipeline, although attention should be paid due to the possibility of sinkage and subsidences due to the type of rocks crossed.

3.3.3. Thermo-fluid-hydraulic Design

Since the purpose of the Santo Antônio dos Lopes - Caucaia gas pipeline is to connect the states of Maranhão and Piauí to the integrated network, it was considered that the gas for supplying this pipeline could come from the LNG surplus at the São Luis/MA terminal, as well as production infrom the Parnaíba Basin, in the state of Maranhão, or LNG from the currently existing terminal in Pecém, in the state of Ceará. Therefore, a bidirectional pipeline was designed with 8 million m³/day capacity, equivalent to the surplus of the terminals to be implemented, and slightly higher than that currently authorized by the ANP for the Pecém terminal (ANP, 2012b) and whose authorization can be updated to allow greater capacity of this terminal. Thus, this pipeline could be supplied with a volume of 8 million m³/day by either end.

[27] ANM – *Agência Nacional de Mineração* or Brazilian National Mining Agency

Along the route, four delivery points for natural gas with a capacity of 0.5 million m³/day and one delivery point with a capacity of 6 million m³/day were considered. The location of the 0.5 million m³/day points was determined across the municipalities with the highest demands, according to the EPE's assessment of potential replacement of sources and to the study on gas demand in Brazil from BNDES (2020). The delivery point of 6 million m³/day was chosen due to the possibility that this pipeline would also meet demands at the Parnaíba Thermoelectric Complex, in addition to the possibility of transferring the gas to any of the adjacent pipelines. It is noteworthy that the demands used to design the gas pipeline showed slack so as not to restrict the future growth of demands. Thus, delivery points of 0.5 million m³/day were considered for Sobral/CE, Piripiri/PI, Campo Maior/PI and Teresina/PI, and the 6 million m³/day point in Santo Antônio dos Lopes/MA.

The design of the Santo Antônio dos Lopes - Caucaia Gas Pipeline was made through thermo-fluid-hydraulic simulations, resulting in a 20-inch pipeline using 2 compression stations: one in the municipality of Piripiri/PI and another one in the municipality of Groiaras/CE. It should be noted that the slack margin in demands ends up allowing the entry staggering of the compression stations due to growth in demand over time.

3.3.4. Cost Estimate

Table 8 details the costs associated with the project, grouped under items. It is worth highlighting the influence of Construction and Assembly costs, as a result of the need to adopt 3 construction fronts due to the extension of the pipeline, and the low land costs, since most of the route crosses only Location Class 1 rural areas, resulting in low land acquisition costs and indemnities.

Table 8. Costs associated to Santo Antônio dos Lopes/MA – Caucaia/CE gas pipeline project

Description		
Direct Costs	**thousand BRL**	**%**
Piping	1,335	21.7
Components	83	1.3
Construction and Assembly	2,676	43.4
Complementary installations	308	5.0
Supervision and Control, Communication and Leak Detection Systems	25	0.4
Land	145	2.4
Indirect Costs		
Engineering, Compensation and Environmental Licensing Project	35	0.6
BDI - Budget Difference Income	914	14.8
Contingencies	638	10.4
TOTAL INVESTMENT (data base Jun/20)	**6,159**	**100**

Source: EPE.

Note: estimates based on the analysis of conceptual projects, with -20% to -50% and +30% of +100% accuracy.

3.4. Santo Antônio dos Lopes/MA – São Luís/MA Gas Pipeline

The proposal for this gas pipeline was based on the intention to connect the gas supply from the Parnaíba Basin to the capital of the state of Maranhão, São Luís. This gas pipeline is also part of the gas pipeline network already authorized by Gas Law No. 11,909/2009, and is part of the project for a pipeline network in the region called Meio Norte.

The origin changed to the municipality of Santo Antônio dos Lopes/MA to interconnect the Parnaíba Thermoelectric Complex, which already uses the natural gas explored and processed in the region. Thus, if there is a surplus in production, this gas could be made available to São Luís and surrounding areas. The way it is structured, this pipeline project makes it possible to outflow gas in the opposite direction if there is a source of natural gas, such as an LNG terminal in São Luís, and it is interesting to provide security of supply for the Parnaíba Thermoelectric Complex. Thus, the gas pipeline was designed to operate bidirectionally. Figure 15 shows the pipeline route.

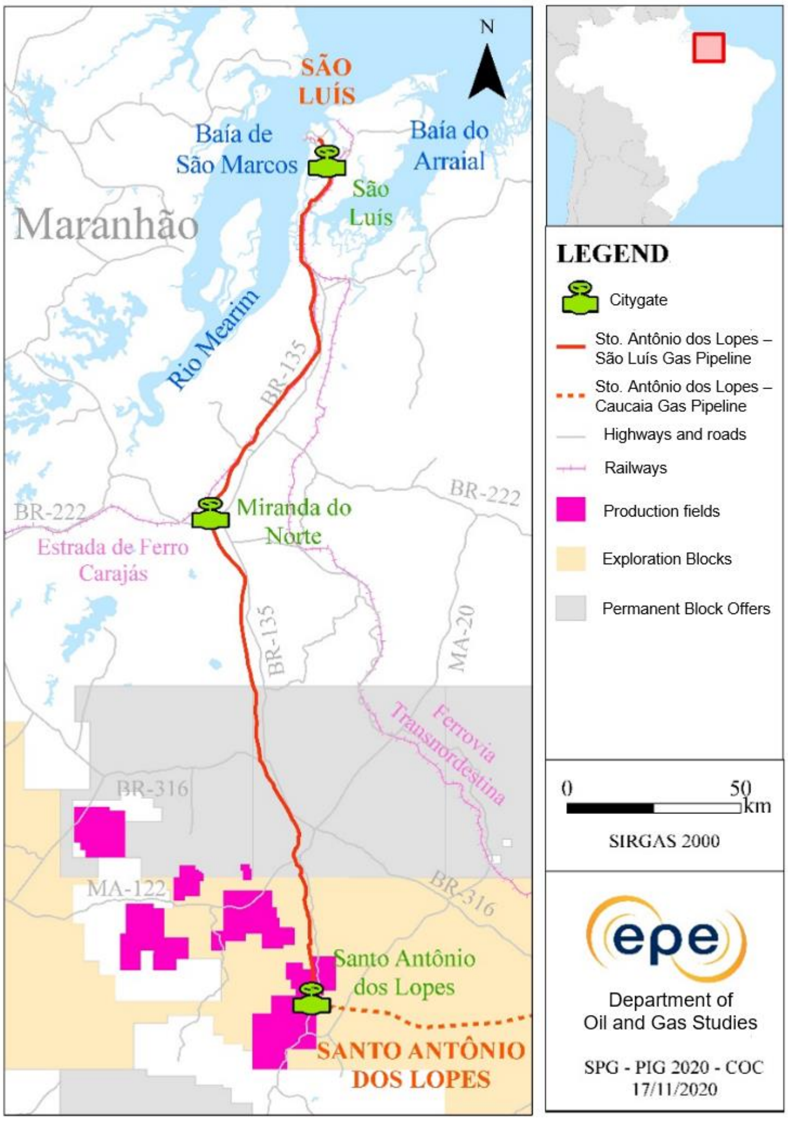

Figure 15. Location map of Santo Antônio dos Lopes/MA-São Luís/MA gas pipeline
Source: EPE.

3.4.1. Route Summary

Departing from the Parnaíba Thermoelectric Complex, in Santo Antônio dos Lopes and ending in the vicinity of the Itaqui Port, in São Luís, the route established for the gas pipeline is 282 km long and crosses 15 municipalities in the state of Maranhão. The established route follows along the BR-153 highway, which should be the main road support during the construction of the project.

3.4.2. Socio-environmental Analysis and construction difficulties

The definition of the route considered the optimization of topographical aspects, the proximity to highways and accesses, minimization of interferences in forest formations and NPAs of water courses, in addition to deviations from wetlands, conservation units, indigenous lands, quilombola territories, rural settlements areas, rural improvements and buildings in general, reservoirs, mining processes, urban and expansion areas.

As shown in Figure 16, the proposed route is located entirely within the territory of the state of Maranhão. The central region of this state, where the route begins, is characterized by being a biome transition zone, where there are elements of the Amazon Forest, Brazilian Savanah and Semiarid, a mosaic that created the Mata dos Cocais.

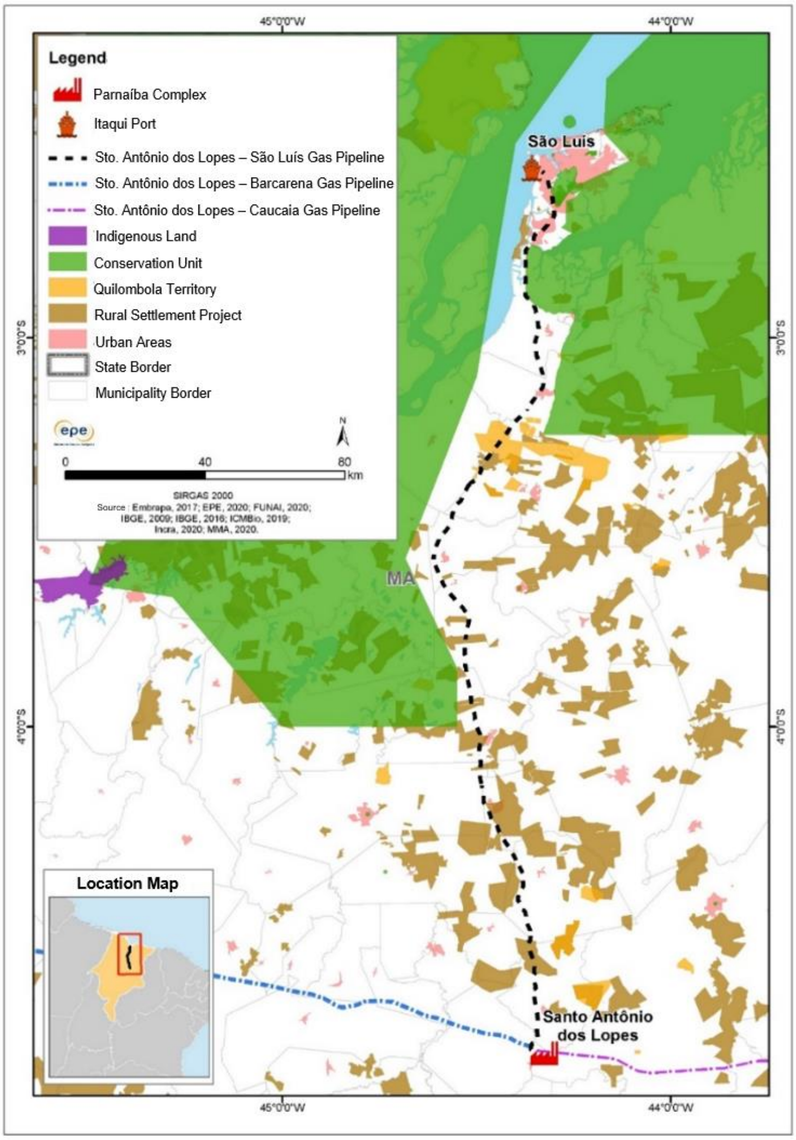

Figure 16. Areas of socio-environmental relevance in Santo Antônio dos Lopes – São Luís gas pipeline region
Source: EPE.

According to the database consulted, the route does not intersect with conservation units or indigenous lands. However, in the vicinity of São Luís, the route runs close to two state Natural Protected Areas (Upaon-Açu/Miritiba/Alto Preguiça NPA and Maracanã Region NPA), which are conservation units of Sustainable Use group.

Due to the large number of rural settlement projects in the region, it was not possible to establish a route that would avoid crossing these areas. Table 9 shows the 12 settlements intercepted by the gas pipeline route.

Table 9. Rural settlement projects intercepted by the gas pipeline route

Name of the rural settlement project	Municipality / State
Faveira Diamantina	Alto alegre do Maranhão/MA
Alto Alegre	
Santa Cruz	Capinzal do Norte/MA
Entroncamento	Itapecuru Mirim/MA
Riachuelo	Lima Campos/MA
Lago do Coco	Matões do Norte/MA
Agroalegre	
São Benedito	São Mateus do Maranhão/MA
Ouro Azul	
Bocaina	
Timbaúba	
São Raimundo II	

Source: EPE.

There are quilombola territories on the margins and in the vicinity of BR-135, which prevented a route that deviated from all units. Close to the borders of the municipalities of Itapecuru-mirim and Anajatuba, the gas pipeline route crosses two quilombola territories - Santo Rosa dos Pretos and Monge Belo. In addition, the route is less than 5 km from five other quilombola territories, which may involve the preparation of Quilombola Component Studies during the licensing of the project, as determined in Interministerial Ordinance No. 060, of March 24, 2015 (IPHAN, 2015). Table 10 lists the quilombola territories located up to 5 km from the route.

Table 10. Quilombola territories (QT) located less than 5 km from the gas pipeline route

Name of quilombola territory	Municipality / State	Distance of the QT in relation to the route (km)
Queluz	Anajatuba e Itapecuri-Mirim/MA	0.03
Pedrinhas		0.1
Cariongo	Santa Rita/MA	1
Santana e São Patrício	Santa Rita e Itapecuru-Mirim/MA	1.2
Santa Maria dos Pinheiros	Itapecuru-Mirim/MA	2.2

Source: EPE.

It should also be noted that, according to information from *Fundação Cultural Palmares* (FCP), there are 122 certified quilombola communities in the municipalities crossed by the route that are not yet included in the georeferenced database provided by INCRA. Therefore, when preparing the final route of the gas pipeline, it is important to check whether these communities have already been demarcated so that any deviations can be made.

The entire region through which the route runs is heavily anthropized, with a predominance of pastures and small areas for growing subsistence crops, amid fragments of native vegetation. Several urban centres, as well as their associated growth vectors, can be found in the vicinity of the route, with emphasis on the São Luís Metropolitan Region. Near the coast, the vegetation is characterized by the low grassland formation with mangrove areas associated with water bodies.

Along the route, hills and flattened surfaces are predominant, in addition to dissected tableland, low plateaus and fluvial-marine plains, on a smaller scale (CPRM, 2002). Despite the favourable relief, the plains mentioned consist of sedimentary deposits with materials of different granulometry and water level close to the surface or outcrop, suggesting greater geotechnical complexity for the installation of the gas pipeline. Such surfaces are more evident in the cities of São Mateus do Maranhão and Bacabeira. In relation to water bodies, the route does not cross reservoirs and there are no significant crossings over water courses in the region of the project.

The route interferes with 11 mining processes in the process of requesting research (2), research authorization (8), licensing (1), involving substances such as sand (6), mineral water (1), gold ore (2), bauxite (1) and granite (1). It is important to mention that in cases it was not possible to deviate, the routes were developed aiming at minimizing the respective interference. The route intersects with seven high voltage transmission lines (TLs) (≥ 238 kV) and with the route of two planned lines. It is important to note that in some sections the proposed route for the gas pipeline is close to and parallel to some of these lines and the Carajás Railway, especially on the stretch from Anajatuba to the Itaqui Port. The proximity to the TLs should require the adoption of engineering solutions that mitigate the risk of pipeline corrosion caused by electromagnetic induction.

3.4.3. Thermo-fluid-hydraulic Design

From the supply point of view, a maximum outflow possibility of up to 7 million m³/day was considered based on the maximum consumption of the Parnaíba Thermoelectric Complex, according to the potential of the Parnaíba Basin for a horizon until 2030 (EPE, 2019d). The full flow could be made available to the pipeline if there is an interest in monetizing the gas when the complex's thermoelectric plants are not dispatched. The value is also in line with a LNG terminal module that could be installed in the São Luís Port and supply gas in the reverse direction, in case the complex needs to be supplied.

Strategic delivery points were distributed along the pipeline route in regions where potential demands were identified in an EPE demand study and a study of BNDES (2020). Thus, the delivery points with their respective flows were defined: Santo Antônio dos Lopes/MA (5.5 million m³/day), Miranda do Norte/MA (1.5 million m³/day) and São Luís/MA (5.5 million m³/day). When operating in one direction, the gas origin delivery point would have its offtake at zero.

Through thermo-fluid-hydraulic simulations, a 20-inch pipeline was designed without the need for a compression station. It is worth noting that the natural ramp-up that takes place in the gas pipeline after its construction can postpone the construction of some of the delivery points mentioned previously to a future moment after the completion of the gas pipeline or even allow its construction in modules. However, for budgeting purposes, it was considered the final complete project dimensioned to 7 million m³/day.

3.4.4. Cost Estimate

Table 11 details the costs calculated for each highlighted item. From a construction point of view, the difficulty foreseen in the Construction and Assembly of the pipeline stands out due to a large number of wetlands (37% of the route). Regarding land, the majority of Location Class 1 rural areas (90%) stands out, however, the pipeline runs for about 24 km in a densely populated area, in addition to industrial and port regions, which raises the Region's Location Class to 2 and 3, thereby also increasing the land acquisition costs of this project.

Table 11. Costs associated to Santo Antônio dos Lopes/MA – São Luís/MA gas pipeline project

Description		
Direct Costs	**thousand BRL**	**%**
Piping	517	13.5
Components	22	0.6
Construction and Assembly	1,520	39.6
Complementary installations	72	1.9
Supervision and Control, Communication and Leak Detection Systems	12	0.3
Land	621	16.2
Indirect Costs		
Engineering, Compensation and Environmental Licensing Project	16	0.4
BDI - Budget Difference Income	612	16.0
Contingencies	448	11.3
TOTAL INVESTMENT data base Jun/20)	**3,840**	**100**

Source: EPE.

Note: estimates based on the analysis of conceptual projects, with -20% to -50% and +30% of +100% accuracy.

It is worth mentioning that this gas pipeline can be dispensed with small scale LNG routes at first, until it reaches sufficient scale to make the gas pipeline construction feasible. Small-scale LNG terminal projects are already being studied in São Luís, as discussed in EPE (2020b), by Golar Power. Given the more sensitive pipeline construction conditions in the North/Northeast of the Brazil for socio-environmental reasons, in addition to a more fragmented demand characteristic of the region, the solution could be the vector for the construction of the gas pipeline later on.

3.5. Santo Antônio dos Lopes/MA – Barcarena/PA Gas Pipeline

The Santo Antônio dos Lopes/MA-Barcarena/PA gas pipeline connects the Parnaíba Basin, in Maranhão, to the Vila do Conde Organized Port, in the municipality of Barcarena, in the metropolitan region of Belém/PA. It is a route similar to the concept of the Pará Gas Pipeline (Açailândia/MA-Barcarena/PA stretch traversing Paragominas/PA) authorized by ANP before the signing of the Gas Law 11,909/2009. As Barcarena is part of the metropolitan region of Belém, there is the possibility of supplying natural gas to the capital of Pará.

In Maranhão, the dry natural gas produced in the onshore fields of the Parnaíba Basin supplies the Parnaíba Thermoelectric Complex, which has a hired capacity of 1.9 GW, of which 1.4 GW are in operation with a current consumption of approximately 8.4 million m^3/day (ENEVA, 2020). In Pará, the project for the construction of an LNG regasification terminal with a capacity of 15 million m^3/d is currently under development to supply the 605 MW Novo Tempo Barcarena TTP[28], of the Barcarena Power Plants (Celba), which has as partners Golar Power and Evolution Power Partners (EPP), winner of the A-6 new energy auction (EPBR, 2019). In August 2020, the Department of

[28] Thermoelectric Power Plant

Environment and Sustainability of Pará (SEMAS-PA) issued the environmental installation license LI 3044/2020 (case 2019/0000048189) for the thermoelectric power plant, terminal and 20-inch and 3.4 km long gas pipeline (SEMAS-PA, 2020). In addition, Barcarena is an important industrial hub for the processing and export of kaolin and alumina and the production of aluminium and electric power transmission cables.

Based on the new possible supplies and potential demands for natural gas in the states of Maranhão and Pará, the Santo Antônio dos Lopes/MA-Barcarena/PA route alternative was proposed, as shown in Figure 17.

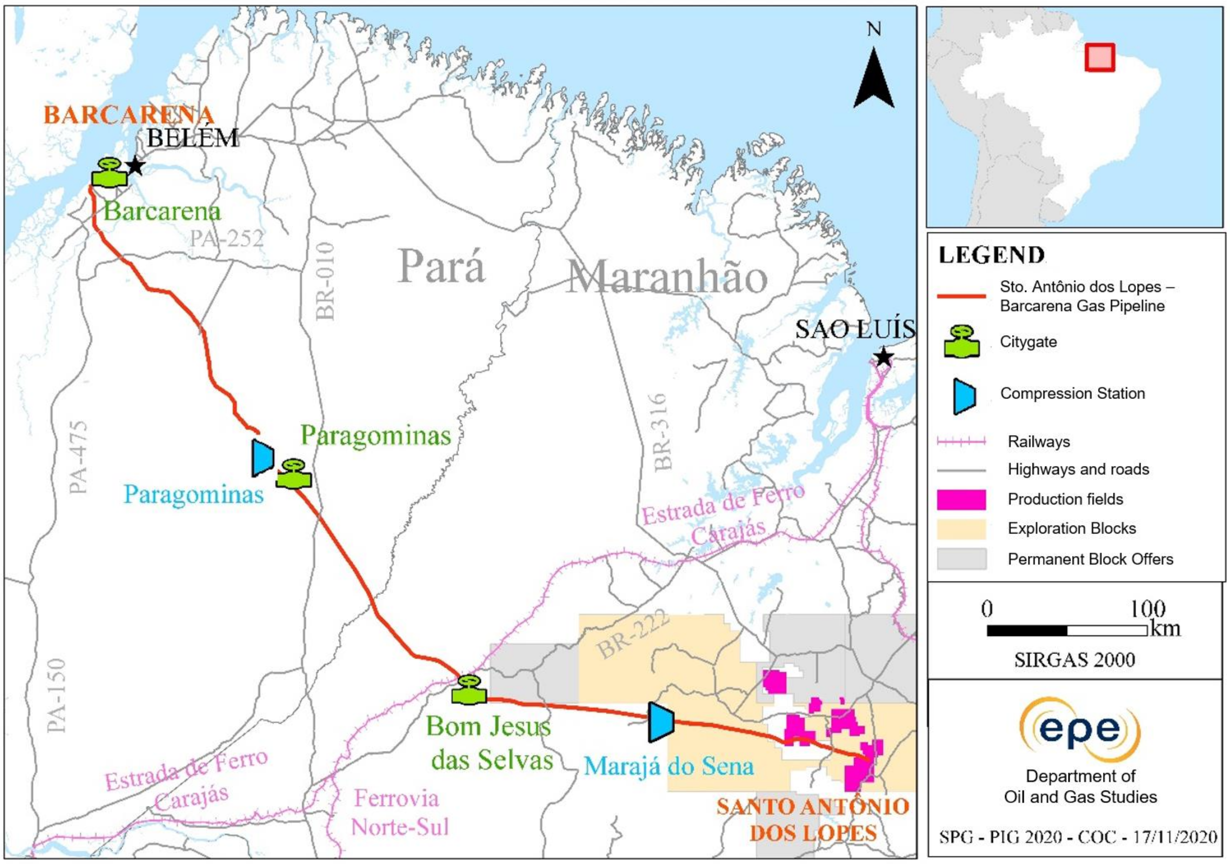

Figure 17. Location map of Santo Antônio dos Lopes/MA-Barcarena/PA gas pipeline
Source: EPE.

3.5.1. Route Summary

The Santo Antônio dos Lopes-Barcarena gas pipeline is 677 km long, 20 m wide and runs through 23 municipalities, 15 in Maranhão (Santo Antônio dos Lopes, Pedreiras, Poção das Pedras, Bernardo do Mearim, Igarapé Grande, Lago dos Rodrigues, Lago do Junco, Lago da Pedra, Paulo Ramos, Marajá do Sena, Santa Luzia, Buriticupu, Bom Jesus das Selvas, Bom Jardim and Itinga do Maranhão) and 8 in Pará (Ulianópolis, Paragominas, Ipixuna do Pará, Tomé-Açu, Acará, Moju, Abaetetuba and Barcarena).

It is important to note that the current route, although also connecting the municipalities of Santo Antônio dos Lopes and Barcarena, differs from corridors 1 and 2 (each 20 km wide) that were assessed in the 2022 PEMAT (EPE, 2014). In that document, Corridor 1 (south of the Alto Rio Guamá, Alto Turiaçu, Awá and Caru Indigenous Lands) was 724 km long and run near the municipalities of Dom Eliseu, Ulianópolis and Paragominas. Corridor 2 (north of those indigenous lands) was 693 km long, closer to the coast and to municipalities such as Nova Olinda do Maranhão, Santa Luzia do Pará and Capitão Poço. Since the publication of the 2022 PEMAT report, the socioeconomic premises, methodologies for reviewing costs and construction difficulty factors were updated and it was decided to study a new route for this alternative in the PIG 2020. Corridor 1 of the 2022 PEMAT would be the closest to the current route proposed in the PIG 2020.

About 664 km of the gas pipeline would be built in a new ROW and 13 km would share the existing ROW of the Paragominas/PA-Barcarena/PA slurry pipeline of the Hydro company to reduce the impacts on fauna, flora, and the surrounding populations. This slurry pipeline is 244 km long and transports bauxite from the mines in Paragominas to the Alunorte Refinery, where it is turned into alumina (HYDRO, 2019).

3.5.2. Socio-environmental Analysis and construction difficulties

The studied region has great socio-environmental sensitivity due to the presence of indigenous lands (IL), conservation units (CU), wetlands and areas of native vegetation. The Alto Rio Guamá, Alto Turiaçu, Awá and Caru ILs, and the Gurupi Biological Reserve (Rebio) stand out. Figure 18 shows these aspects along the route.

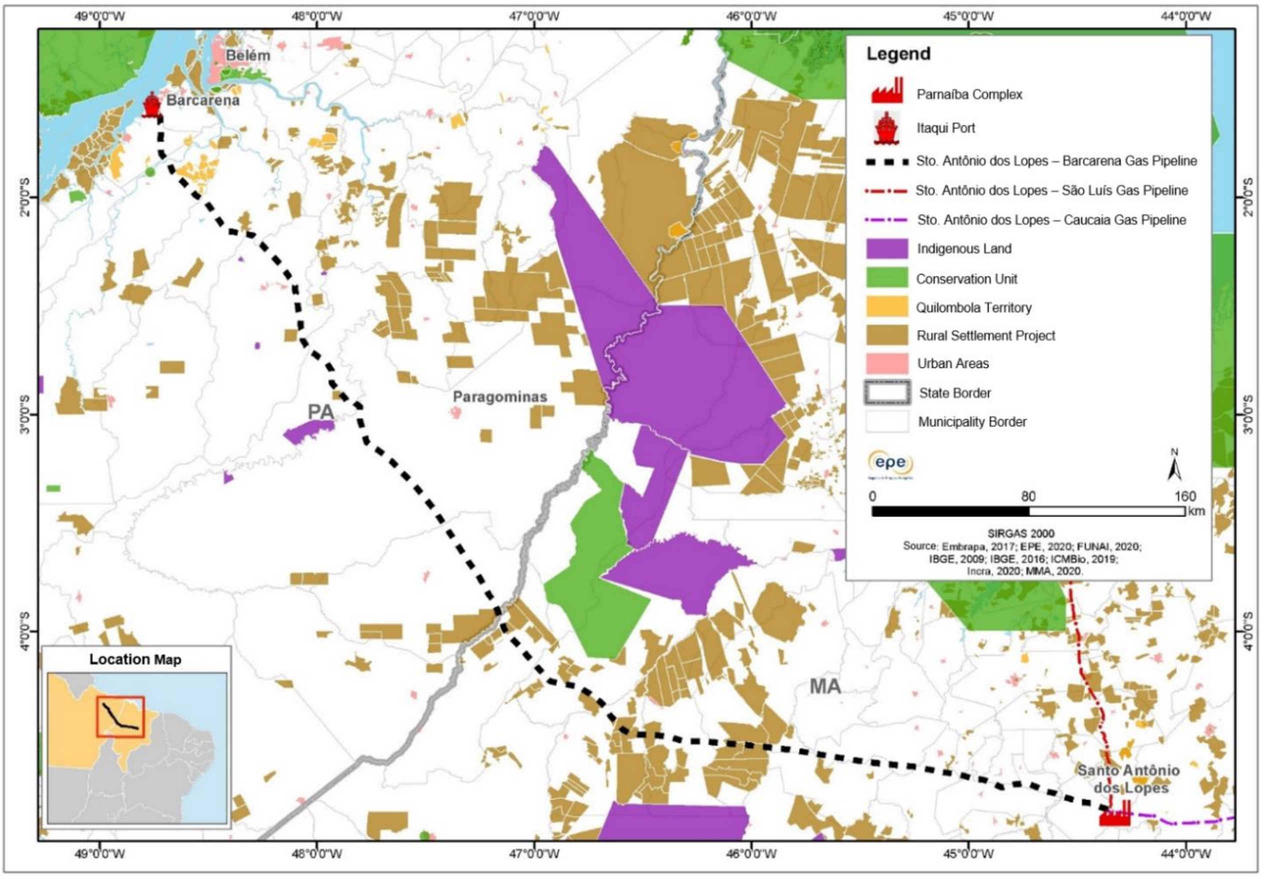

Figure 18. Areas of socio-environmental relevance of Santo Antônio dos Lopes/MA – Barcarena/PA gas pipeline
Source: EPE.

According to the data consulted, the proposed route does not cross conservation units, indigenous lands or quilombola territories. However, in the municipality of Moju/PA, the route is less than 5 km away from four quilombola territories (QTs), as shown in Table 12, which may require the developer to prepare Quilombola Component Studies during licensing, as determined in Interministerial Ordinance No. 060, of March 24, 2015 (IPHAN, 2015).

Table 12. Quilombola territories located less than 5 km from the gas pipeline route

Name of que quilombola territory	Municipality / State	Approximate distance from QT to the route (km)
São Sebastião	Moju/PA	0.06
Centro Ouro, Nossa Senhora das Graças		0.25
Santa Maria do Traquateua		2.8
Santa Luzia do Tracuateua		3

Source: EPE.

It is important to mention that, according to information from *Fundação Cultural Palmares* (FCP) there are 24 certified quilombola communities in the municipalities crossed by the route that are not yet included in the georeferenced base provided by INCRA. Therefore, when preparing the final route of the gas pipeline, it is important to check whether these communities have already been demarcated so that any deviations can be made.

In the region where the project is implemented, there are many rural settlement projects (see Table 13), which made it impossible for the gas pipeline route to avoid crossing these units. However, it should be noted that the route was developed seeking, whenever possible, to reduce interference in settlements. Among the intercepted rural settlement projects, there are Alto Boa Vista (Itinga do Maranhão/MA); Passo Livre (Bom Jardim/MA); Rosa Saraiva, Santa Inácia and Faisa (Santa Luzia/MA); Silver Triangle (Buriticupu/MA); Mapisa, Raimundo Panelada/Simasa, São Francisco/Boa Viagem (Bom Jesus das Selvas/MA); Floresta Gurupi I (Ulianópolis/PA) and Diamantina II (Ipixuna do Pará/PA).

Table 13. Rural settlement projects intercepted by the gas pipeline route

Name of the rural settlement project	Municipality / State
Alto Boa Vista	Itinga do Maranhão/MA
Passo Livre	Bom Jardim/MA
Rosa Saraiva	Santa Luzia/MA
Santa Inácia	
Faisa	
Triângulo de Prata	Buriticupu/MA
Mapisa	Bom Jesus das Selvas/MA
Raimundo Panelada/Simasa	
São Francisco/Boa Viagem	
Floresta Gurupi I	Ulianópolis/PA
Diamantina II	Ipixuna do Pará/PA

Source: EPE.

In Maranhão, the route begins in a biome transition region where there are elements of the Amazon Forest, Brazilian Savanah and Semiarid. This mosaic creates Mata dos Cocais, which is characterized by the presence of plant species such as Carnauba Palm and Babassu. As it advances westward, the vegetation takes on characteristics of the Amazon Forest, with dense woodland, with large trees. The anthropized areas are occupied mainly by pastures and small dispersed urban centres. Near the border with the state of Pará, there is a mosaic formed by large fragments of native vegetation amid extensive areas of cultivation.

In the region of Pará, there are large corridors of native vegetation. In the municipality of Paragominas, next to native forest areas, there is intense mining activity (kaolin and bauxite), in addition to large soy and corn growing properties. In the rest of the route, up to the Metropolitan Region of Belém, there are many pasture areas associated with small growing areas amid native vegetation.

In the relief, the hills, erosive features, and low mountains stand out, in addition to the tableland, plateaus and plains (CPRM, 2002). The stretches with the highest slopes can be avoided after the aerial survey and the relief modelling stages that must be carried out by the interested agents.

The route interferes with 28 mining processes in the mining concession phase (3), mining requirement (15), research authorization (8), licensing (1) and licensing requirement (1), involving substances such as bauxite (19), kaolin (6), aluminium ore (1), sand (1) and gravel (1). The concentration of mining processes in the municipalities of Paragominas and Ulianópolis, in the state of Pará, stands out, which shall demand greater attention in the route refinement during negotiations with the holders of the respective mining rights.

It is estimated that at least 13 directional drilling are required, 7 of them in crossings (Rivers Moju, Capim, Acará, Acará-Mirim, Grajaú, Mearim and Gurupi) and 6 in intersections (Carajás Railway, BR-222, PA -451, PA-151, PA-483 and passage at the Vila do Conde Port). Detailed projects on the conditions and technical characteristics of each directional drilling must be carried out by the agent interested in the construction of the gas pipeline, and discussed with the competent agencies to obtain the respective authorizations and licenses. The following smaller rivers that the gas pipeline would cross are also noteworthy: Pindaré, Mariquita, Jeju, Buriticupu, Verde, Gurupizinho and Potiri.

In addition to the intersections mentioned, others that deserve attention are those with the following roads: BR-10 (Belém-Brasília Highway), MA-06, MA-012, MA-245, MA-323, MA-381, PA-125, PA -140, PA-252 and PA-256. In some regions there are few paved roads, especially on the border between the states of Maranhão and Pará, which may represent logistical challenges during Construction and Assembly. Between the municipalities of Bom Jesus da Selva and Bom Jardim in Maranhão, the route intercepts the Carajás Railway (EF-315), and the developer must assess the specific conditions for carrying out this intersection.

Approximately 649.8 km of the gas pipeline would be in class 1, 24 km in class 2 and 3.2 km in class 3; this last stretch, at first, would be in the port and industrial region of Barcarena. These estimates should be reviewed and improved as the fieldwork, aerial survey and other complementary studies are carried out by agents interested in the construction of the gas pipeline.

As for the relief, the outline crosses predominantly flat relief (62%), followed by smooth relief (19%) and wavy (19%); the latter is present notably in the embedded river valleys. The largest extension of the gas pipeline crosses areas of pasture and undergrowth (59%), while 39% of the total extension crosses areas with larger trees and the rest through crop regions.

The route crosses six high voltage transmission lines (TL) and the preliminary route of two planned lines. Its proximity to the existing Vila do Conde-Mitônia III (Paragominas) 230kV TL and to the Tucuruí-Vila do Conde (C1, C2 and C3) 500kV TL stands out, in addition to the planned Vila do Conde-Tomé-Açu 230kV TL.

It is important to highlight need for economic agents interested in the construction of the gas pipeline to carry out detailed studies such as those necessary for the analysis of risks and damages, in addition to the adoption of good engineering practices to protect fauna, flora, human life and the integrity of potentially affected projects.

The companies that own and/or operate the slurry pipeline and transmission lines should be consulted together with the environmental agencies on the Santo Antônio dos Lopes-Barcarena gas pipeline project, and the preliminary route presented in this publication may change and/or be adjusted depending on the discussions on the technical characteristics and operational needs of the projects.

The total length of the gas pipeline crosses 56% of soft rocks, 42% of unconsolidated sediments and 2% of hard rocks. Among the soft rocks are clay, sandstone and shales of the Itapecuru Group and the Barreiras Group and, among the unconsolidated sediments, there are lateritic deposits (concentrations of iron and aluminium hydroxides) and river deposits.

As no field work or geotechnical surveys were carried out, it is recommended that these subsoil investigation steps, as well as others, are carried out during the later stages of the project.

3.5.3. Thermo-fluid-hydraulic Design

The Santo Antônio dos Lopes/MA- Barcarena/PA Gas Pipeline was studied with the purpose of enabling the connection of the Barcarena/PA terminal, under construction, with the existing gas production hub of Santo Antônio dos Lopes/MA. In addition, the gas pipeline project provides for the possibility of interconnection with the Santo Antônio dos Lopes/MA-Caucaia/CE Gas Pipeline. With that, it would be possible to interconnect the states of Pará, Maranhão, Piauí and Ceará. Like the Santo Antônio dos Lopes/MA-Caucaia/CE gas pipeline, the Santo Antônio dos Lopes/MA-Barcarena/PA gas pipeline was designed to be bidirectional and with a capacity of 8 million m^3/day. This capacity would be compatible with the surplus of the LNG terminal in Barcarena/PA. According to the study, the project would also be able to gather a possible surplus of natural gas production from the Parnaíba Basin to Barcarena.

Along the route, three gas delivery points and two measurement stations were considered. The location of the delivery points was determined across the municipalities with the highest demands, according to the EPE assessments of potential replacement of sources and to the study on gas demand in Brazil by BNDES (2020). The delivery points were in Barcarena/PA (4.0 million m^3/day), Paragominas/PA (1.0 million m^3/day) and Bom Jesus da Selva (1.0 million m^3/day). All the projected demands have values that are higher than the existing demands today, however, this strategy was adopted due to the expectation of increased demands over time, generated through the development of other natural gas consumers along the gas pipeline route. In addition, according to the demand evolution, other delivery points could be installed to provide better service to potential consumers.

The design of the gas pipeline was carried out through thermo-fluid-hydraulic simulations, resulting in a 20-inch pipeline, using 2 compression stations: one in the municipality of

Paragominas/PA and another in the municipality of Marajá do Sena/MA. As observed in other pipeline projects, as the demands along the pipeline layout evolve, it would be possible to scale the start of operation to the compression stations.

3.5.4. Cost Estimate

Table 14 details the costs associated with the project, grouped under items. The most significant cost is related to Construction and Assembly, mainly due to the extension of the pipeline. The piping item also has a high value since it is connected directly to the US dollar exchange rate. Land costs, on the other hand, were low, mainly because most of the route crosses only Location Class 1 rural areas, resulting in low land acquisition costs and indemnities.

Table 14. Costs associated to Santo Antônio dos Lopes/MA – Barcarena/PA gas pipeline project

Description		
Direct Costs	**thousand BRL**	**%**
Piping	1,352	23.1
Components	74	1.3
Construction and Assembly	2,533	43.3
Complementary installations	201	3.4
Supervision and Control, Communication and Leak Detection Systems	9	0.2
Land	202	3.4
Indirect Costs		
Engineering, Compensation and Environmental Licensing Project	24	0.4
BDI - Budget Difference Income	862	14.7
Contingencies	594	10.2
TOTAL INVESTMENT (data base Jun/20)	**5,851**	**100**

Source: EPE.
Note: estimates based on the analysis of conceptual projects, with -20% to -50% and +30% of +100% accuracy.

It is worth mentioning that this project may exclude other alternatives for supplying the region, given the potential for redundancy that other pipelines (Santo Antônio dos Lopes/MA-Caucaia/CE and Santo Antônio dos Lopes/MA-São Luis/MA) may present for connection of supplies and demands, although the pipeline system described in this study allows the interconnection of new states (Piauí, Maranhão and Pará) and their capitals to the STGN[29].

[29] STGN – *Sistema de Transporte de Gás Natural* or Natural Gas Transmission System

4. Results and Discussion

As presented throughout the study, 6 indicative transmission gas pipeline projects were mapped, with the main purpose of connecting new supplies and demands to the STGN. Table 15 shows these projects, along with their estimated extensions, diameters, flows and CAPEX values.

Table 15. Transmission Gas Pipeline Projects reviewed in the PIG 2020 cycle

Gas Pipeline	Extension (km)	Diameter (inch)	Outflow (MMm^3 /day)	Direct Costs (million BRL)	Indirect Costs (million BRL)	Total Cost (million BRL)
Penápolis/SP-Canoas/RS (Chimarrão A)	1,168	20	8	8,773	3,085	11,858
Bilac/SP-Santa Maria/RS (Chimarrão B)	1,237	20	8	9,174	3,216	12,390
Presidente Kennedy/ES-São Brás do Suaçui/MG	332	20	12	2,821	1,059	3,880
Santa Antônio dos Lopes/MA-Caucaia/CE	684	20	8	4,572	1,587	6,159
Santa Antônio dos Lopes/MA-São Luis/MA	282	20	7	2,764	1,076	3,840
Santa Antônio dos Lopes/MA-Barcarena/PA	677	20	8	4,371	1,480	5,851
Total	**4,380**	**-**	**-**	**32,475**	**11,503**	**43,978**

Source: EPE.

Note: estimates based on the analysis of conceptual projects, with -20% to -50% and +30% of +100% accuracy.

The PIG 2020 cycle reviews projects of strategic importance to connect new capitals to the STGN, namely the alternatives Santo Antônio dos Lopes/MA - Barcarena/PA, Santo Antônio dos Lopes/MA - São Luis/MA and Santo Antônio dos Lopes/MA - Caucaia/CE. If they are proven feasible in further detail by the developers, these projects may come to be implemented together or in stages, allowing the connection of the capitals Belém/PA, Teresina/PI and São Luís/MA to the STGN and allowing it to be serviced by natural gas from any supply sources connected to the network, whether national – for example, pre-salt natural gas – or imported – for example, LNG regasified on the coast.

In addition, two alternatives were assessed to allow the service of the countryside of the states of São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul. The alternatives called “Chimarrão A” and “Chimarrão B” allow to expand the supply of natural gas to three states in the South Region, not only complementing the volumes currently delivered via GASBOL, but also serving new areas with potential demand, based on new industrial projects, or replacing the existing consumption of other fuels in existing industrial hubs. In the case of replacement demand, however, the feasibility of the strategy shall depend on the relative prices of natural gas compared to other fuels in the present and following years, so that the project is assessed as feasible throughout its useful life. In this sense, the signs of declines in natural gas prices compared to oil products, due to the change from the gas-oil competition logic to a gas-gas logic, may present a competitive advantage to be considered in the TEFSs[30] of industrial projects.

[30] Technical and economic feasibility studies

While the alternatives assessed in the PIG 2020 are more extensive, some of the projects studied in the PIG 2019, which are based on the interconnection of future LNG terminals to the integrated transmission gas pipeline network, have extensions of 15 to 45 km, since most of them are located close to the existing network. In addition, the estimated costs for each project do not vary linearly with the extension, since the diameter of each alternative, the need for compression stations along its extension, in addition to the parameters related to their construction, can vary a lot.

All the projects listed in this work were studied on an indicative basis, as potential alternatives for the expansion of the transmission gas pipeline network, and their future implementation shall depend on the equation of several factors by the agents interested in each project, such as the signing of natural gas supply agreement; the signing of natural gas demand agreements; the signing of agreements for interconnection with existing gas pipelines; the performance a call for proposals for capacity allocation; the details of socio-environmental and engineering studies; among others.

In general, all alternatives studied can bring new natural gas supply or demand points to the Brazilian Natural Gas Transport System, benefiting the players connected to the integrated network, who could have different options for buying and selling natural gas. Within a more open, dynamic, and competitive market, as foreseen with the New Gas Market initiative, and with entry-exit tariff model, it is expected that these new points of supply or demand may reduce transport tariffs for all shippers in their area of influence, thereby reducing the price of natural gas for end customers in these states, as they shall increase flow rates in the network, resulting in scale gains.

5. Updates on Projects Assessed in Previous Cycles

The PIG 2019 cycle mapped 11 indicative transmission gas pipeline projects, totalling about 2,000 km in length and investments of around BRL 17 billion. Along with the gas pipelines studied in this cycle, the indicative projects already assessed by the PIG methodology total 4,380 km in length, with investments in the order of BRL 44 billion. Figure 19 shows the projects studied in the first two cycles of the PIG.

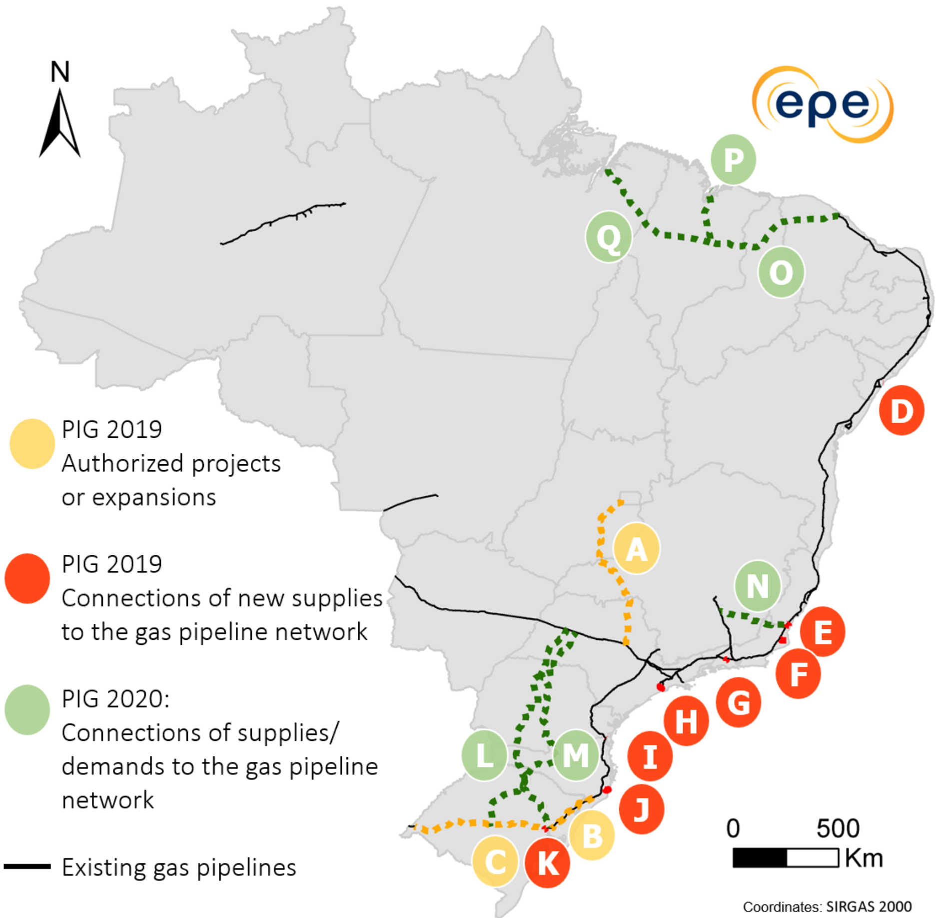

Figure 19. Alternatives studied in 2019 and PIG 2020 cycles.
Source: EPE.

From its design to the beginning of the operation, a transmission gas pipeline goes through several stages. The initial study stage includes the investigation of preliminary supply and demand, the performance of socio-environmental analysis to define the route and the technical analysis to define the extension, delivery points and diameter. Subsequently, the environmental licensing process and the call for proposals for confirmation of capacity and interested agents can begin, which may have several stages of interest manifestation and challenges, and it may be iterative.

Law 11,909/2009 addresses the current granting model of concession (except for gas pipelines related to international agreements), however this model presented some obstacles to the feasibility of new transmission gas pipeline projects in Brazil – this is one of the reasons why we have not seen new transmission gas pipelines since 2010. The New Gas Law, passed in the Chamber of Deputies as

PL 6,407/2013 and currently being processed in the Federal Senate as PL 4,476/2020, provides important definitions regarding information transparency for the entire infrastructure, in addition to the independence and autonomy of transportation, preventing corporate relationship between shippers and new carriers, and valuing competitor's contestability, which may bring tariff moderation. Therefore, a change in the granting models is currently underway in Brazil, which shall bring more agility and legal certainty in the process of implementing new gas pipelines.

Then, with confirmation of the project characteristics, in addition to reserved volumes at the entries and exits, as well as list of shippers to be served, the Final Investment Decision (FID) occurs, along with the construction of the gas pipeline and its operation.

Table 16 shows the progress of the projects studied in this cycle and in previous PIG cycles, based on the main milestones mentioned.

Table 16. Progress of transmission gas pipeline projects reviewed in PIG 2019 and 2020

	Gas pipeline alternatives*	Progress				
		Initial Studies	Under Licensing Process**	FID***	Under Construction	In Operation
A	São Carlos/SP – Brasília/DF (Brasil Central)					
B	Sideróppolis/SC – Porto Alegre/RS (Duplication of GASBOL stretch)					
C	Uruguaiana/RS – Triunfo/RS (Segment 2 of Uruguaiana/RS - Porto Alegre/RS Gas Pipeline)					
D	Sergipe Port - Catu Pilar/SE					
E	Central Port - GASCAV/ES					
F	Açu Port - GASCAV/ES					
G	Itaguaí Port - GASCAR/RJ					
H	Cubatão/SP - GASAN/SP					
I	South Gas Terminal/SC – GASBOL					
J	Imbituba Terminal/SC -GASBOL					
K	Mina Guaíba/RS -Triunfo/RS					
L	Chimarrão A					
M	Chimarrão B					
N	Presidente Kennedy/ES - São Brás do Suaçui/MG					
O	Santo Antônio dos Lopes/MA – Caucaia/CE					
P	Santo Antônio dos Lopes/MA – São Luis/MA					
Q	Santo Antônio dos Lopes/MA – Barcarena/PA					

Source: EPE.

Notes: * Alternatives A to K were studied in the PIG 2019 and alternatives L to Q in the PIG 2020.

**: It includes environmental licensing processes of similar projects, of projects that share stretches or the entire easement, and environmental licensing processes already expired.

***: Final Investment Decision (FID) occurs when the developers confirm that the project has technical, operational, commercial, and financial conditions to move forward to the development and construction stage

6. Conclusions

In the PIG 2020 cycle, 4,380 km of transmission gas pipeline projects were studied, which together represent investments in the order of BRL 44 billion[31]. In addition to this study, the PIG 2019 cycle had already mapped 11 indicative transmission gas pipeline projects, totalling about 2,000 km in length and investments of around BRL 17 billion. Thus, the indicative projects analysed by EPE in the 2019-2020 biennium in the PIG methodology total around 6,000 km in length, with investments reaching BRL 61 billion.

However, for these projects to be built, it is necessary to carry out the new planned supply, as well as the confirmation of new demands for natural gas that would consume such volumes, considering the prices that may be available to the market. The new supply is mainly associated with natural gas from the pre-salt environment in the Campos and Santos Basins, natural gas from the post-salt environment in the Espírito Santo and Sergipe-Alagoas Basins, and natural gas from new LNG regasification terminal projects along the entire coastline that can connect themselves to the network in the coming years.

The quantification of the potential demand for natural gas in the PIG 2020 indicates that large projects are naturally responsible for the largest share of the identified demand. For these projects to be feasible, the use of regional vocations must be combined with greater competitiveness of natural gas and long-term security of supply, especially in relation to other fuels consumed along the projects route that could be replaced with natural gas.

This study also observed that the sharing of rights-of-way between gas pipelines and other infrastructures has the potential to reduce implementation costs for each agent, compared to a situation where the projects were built separately. The sharing of ROWs may help in the universalization of internet access scope in Brazil, in the promotion of water security for locations with greater scarcity, optimization and cost reduction in the multimodal transport of various liquid fuels, among other scope and scale savings.

In this sense, the New Gas Market program may encourage the feasibility of the studied projects, since it shall promote competition in the Brazilian natural gas sector, bringing greater competitiveness and diversity of agents, especially regarding new volumes of supply available to the market. The creation of an integrated Natural Gas Transport System throughout the country shall also help to promote the feasibility of these investments, since the benefits brought by them to the integrated network may be shared by users from the different market areas to which they will be connected. The connection to the existing network shall allow each project to transport volumes of natural gas related to contracts distributed throughout Brazil, and not only those that are in the area of influence of each alternative.

It should be noted that the implementation of each project shall depend on the details of various socio-environmental and engineering aspects, as well as confirmations on demand and supply, and agreements for interconnection with existing gas pipelines. Only after such details have been carried out by the interested companies, it will be possible to confirm how many and which of the projects studied have economic feasibility, and what will be the real increase in the volumes of natural gas handled in Brazil.

[31] Although possibly only one of the alternatives of the Chimarrão gas pipeline will be built, the extension and investment addressed contemplate both options.

Finally, it should be noted that in addition to gas pipelines, several natural gas transport technologies can be assessed to supply the markets, such as the use of "virtual gas pipelines", which are modular systems for transporting compressed or liquefied natural gas (either by road, rail, or river) to meet demands in regions not yet served by conventional gas pipelines. Each of the transport alternatives has a greater or lesser relative competitiveness between them, depending not only on the distance to the final customers, but also on the volumes to be transported. Nevertheless, it is possible to highlight the contribution of virtual gas pipelines in the creation of demand points, especially for great distances, and future studies may consider the complementary performance of the modes over time.

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