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Brazil's New Gas Law: Analysis, Implications, and Remuneration of Gas Processing Plants with Non-Discriminatory Access to Customers

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ABSTRACT

Brazil will increasingly rely on the availability of natural gas as new discoveries in the Pre-Salt portion are explored. Currently, a substantial amount of the gas produced associated with oil is reinjected (60,84 million m^3/day in 2021, according to the Ministry of Mines and Energy), with the lack of structure being one of the factors for this non-energy purpose. The New Gas Law proposes to fill this gap by stimulating investments in infrastructure. In this sense, market opening has the potential to promote the rupture of natural monopolies by providing access to infrastructure, including Natural Gas Processing Plants (NGPP). This units, in addition to conditioning the gas for sale, allow the recovery of higher molecular weight fractions, or (Natural Gas Liquid). However, the instructions for this access required by the government are insufficient for issues related to the NGL recovery efficiency of these units, as well the method of remuneration arising from the NGL production capacity. It is proposed in this paper to include a processing tariff, based on static simulation of available technological routes. Comparison of energy spent and NGL recovery efficiency will allow to formulate the gas price, unfolding from the price of the molecule.

Keywords: Natural Gas, Natural Gas Processing Plants, Brazil's New Gas Law, Processing Tariff, Natural Gas Regulation
JEL Classifications: P48

1. INTRODUCTION

Natural gas, although being a fossil fuel, is considered as a transition energy for sources with lower carbon emissions (Vera et al., 2023) (Thomas et al., 2022) (Vahl and Filho, 2015). In Brazil, the use of natural gas is currently intended for thermoelectric generation, thermal sources in industry, or, as inputs in petrochemicals (Ministry of Mines and Energy, 2022). Its origin is commonly associated with oil production, as it can be obtained as a fraction of the extracted composition or, it can come from exclusive reservoirs, called "non-associated gas". As exploration of the Pre-Salt portion increased, there is a tendency to increase the availability of this input as unspecified gas for consumption, since making it available to the market requires compliance with quality parameters (Goldemberg et al., 2014) (Kan et al., 2019) (Silva et al., 2023). This scenario requires the need for investments in infrastructure to compose a network structure (essential facility), capable of meeting the productive chain, that is, production, conditioning and distribution of natural gas. Currently, the holder of the gas processing sector in Brazil is Petrobras, not by virtue of an institutional monopoly, but a natural one since it has processing units that account for 97% of the national supply to the market. Concerning the Brazilian natural gas sector, the authors Leal et al. (2019) point out that the market is marked by what happens in most countries in South America, where there are a series of monopolies at national and regional levels (Leal et al., 2019). This condition occurs where there is virtually no competition between gas suppliers, except in the specific case of Liquefied Petroleum Gas (LPG) distributors in Brazil, which compete for retail sales.

In Brazil, the regulations that have effectively existed up to now, under the Gas Law 11.909/2009, did not require permission for third parties to access this existing infrastructure. Regulatory frameworks, like this, are considered insufficient, in which the need for advances in strategic planning and investment is demonstrated, in addition to changes in appropriate policies for the market by government agencies. Such factors can guarantee a long-term energy policy aimed at the sustainable development of the natural gas industry in Brazil (Leal et al., 2019).

To fill this gap, one of the strategies forecast in the proposal for the New Gas Law (Decree no. 10.712/2021) refers to third-party access to essential infrastructure, including the Natural Gas Processing Plants (NGPP). In this sense, the Energy Research Company (EPE -*Empresa de Pesquisa Energética*) is the author of a technical note with an analysis of this new configuration, which reinforces the concepts referring to the essentiality of the NGPPs in the infrastructure for the natural gas industry. What justifies the entry of these new players, a term used in the sector, into the structures in the "New Gas Market" is precisely the expansion of investments in infrastructure in the sector, highlighted here for the NGPPs. This boosting is potentially responsible for leveraging the industry's competitiveness from the production system and flow, up to the use as inputs for the other sectors (Energy Research Company, 2020).

The report warns that regulations or arbitrations must be revised to prevent unrestricted use of the units without considering the implications for the holders of the dominant structure until then (in Brazil, corresponding to Petrobras). The existing risk considers that legal imposition of access to a NGPP, conducive to reduction or stagnation in investments, instead of generating incentives for the construction and expansion of infrastructure (Energy Research Company, 2020). The technical study informs about the risk of the current operator being forced to invest to allow expansion and access, without necessarily an obvious return. This case can be exemplified by the need to adjust tax measurements for custody transfer. However, the EPE technical note does not discuss the pricing methodology for the gas to be processed for the various variables that may influence the value of this input, since this provision of service in Brazil is unprecedented until then.

Faced with this risk, this work proposes an analysis of the new billing modality in the NGPPs by processing fee, in detriment to the model that consisted of the purchase of gas by the producing units and appropriation of the products. The analysis focuses on energy consumption and on the recovery efficiency of Natural Gas Liquid (NGL), which is the fraction of compounds with molecular weight from propane, based on static simulation of chemical processes. In this way, it intends to quantify the tariff according to the energy cost for the main demands in a NGPP, such as, the heat needed to fractionate the gas, as well as the energy needed for compression, according to the technology used. The analysis supports the need for the regulatory agency to ensure mediation between the NGPPs and contracted parties, performing the role of reconciling possible gaps in a market that is not mature yet.

2. LITERATURE REVIEW

This section brings a context of the natural gas scenario in Brazil, its supply chain and infrastructure, as well as investigates possible gaps in the sector. The analysis contains simulated information on the technological routes applied to formulate a gas pricing proposal based on a processing fee.

2.1. Natural Gas Processing Plants (NGPP) and their Role in the Gas Chain

One of the implications that the NGPPs will have to face with the New Gas Law, is the change to a model analogous to the provision of services. This model comprises a new way of acting for contractors (companies that hold the NGPPs), which will be evaluated in terms of deliveries and performance. The requested efficiency, in this case, is related to the NGPP's ability to add value to natural gas, treated here as an input. It is expected, as an efficiency of natural gas processing, the maximum recovery of higher molecular weight fractions, which give rise to products with higher added value such as LPG and stabilized condensate (Wang and Abbas, 2016).

Regardless of changes in legislation, gas processing has been a constant theme in different approaches aimed at increasing energy efficiency (Franco et al., 2020), (Kherbeck and Chebbi, 2015) and at the recovery of liquids (Amaral Junior et al., 2019), (Yoon et al., 2017). In the above cases, energy efficiency points to opportunities to reduce energy demand for processing, normally translated into units of volume per energy. Efficiency in the recovery of liquids means the ability to remove compounds of molecular weight greater than propane, that is, recovery of C_3+ (simplified notation for C_3H_8 propane and other hydrocarbons). This portion is usually recognized as a gas with a high concentration of C_3+, the "rich gas", that is, a compound with a high recovery potential of NGL, which is an input for other products such as LPG, stabilized condensate (known as C_5+), petrochemical butane, among others (Wang and Abbas, 2016). Figure 1 shows a diagram of the stages of production, conditioning in a typical NGPP, including the storage and transfer of products.

In Figure 1, it is possible to verify that the path of the gas, since its extraction, may or may not pass through a production unit, depending on the composition of the mixture. Once it is extracted, it must go through separation steps (slug catcher), purification, removal of acid gases or other contaminants. From that point on, the gas is subjected to an NGL condensation stage for further fractionation and production of derivatives.

Particularly in Brazil, the NGPPs are concentrated in the Southeast region. As can be seen on the gas grid Infrastructure map, Figure 2, the location is favorable, according to the confirmed pre-salt reserves in the Basin of Santos. This fact corroborates the growing participation of the state of São Paulo as a producer of NGL.

Figure 1: Flowchart of steps from extraction to sale of natural gas and generated products (Mokhatab et al., 2015)

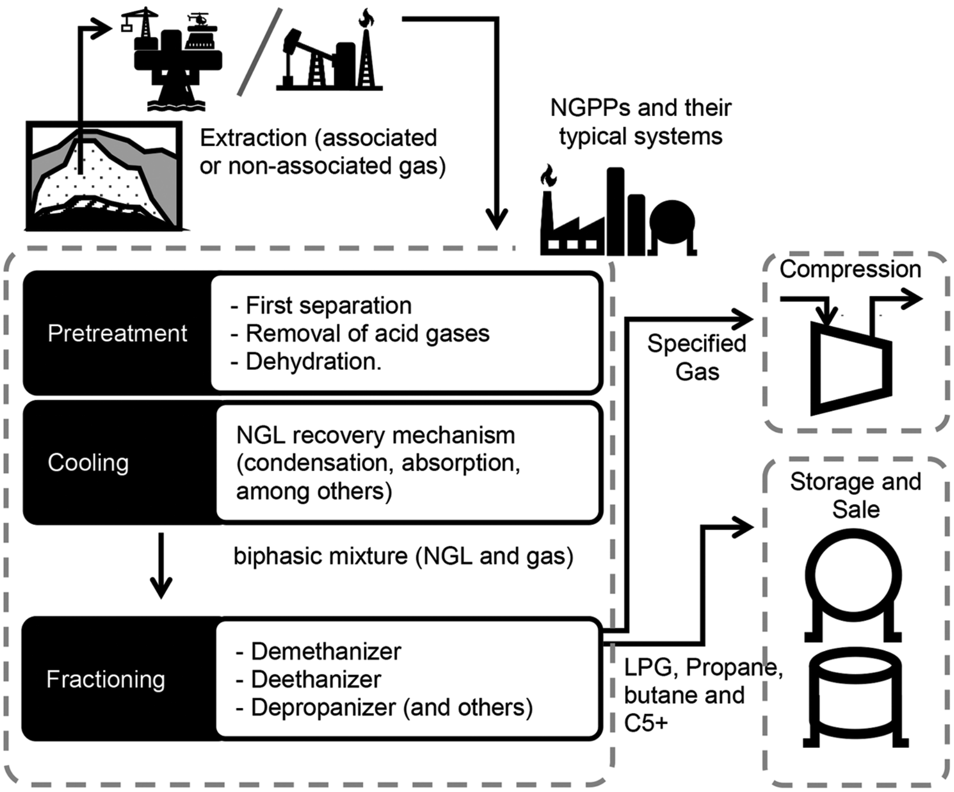
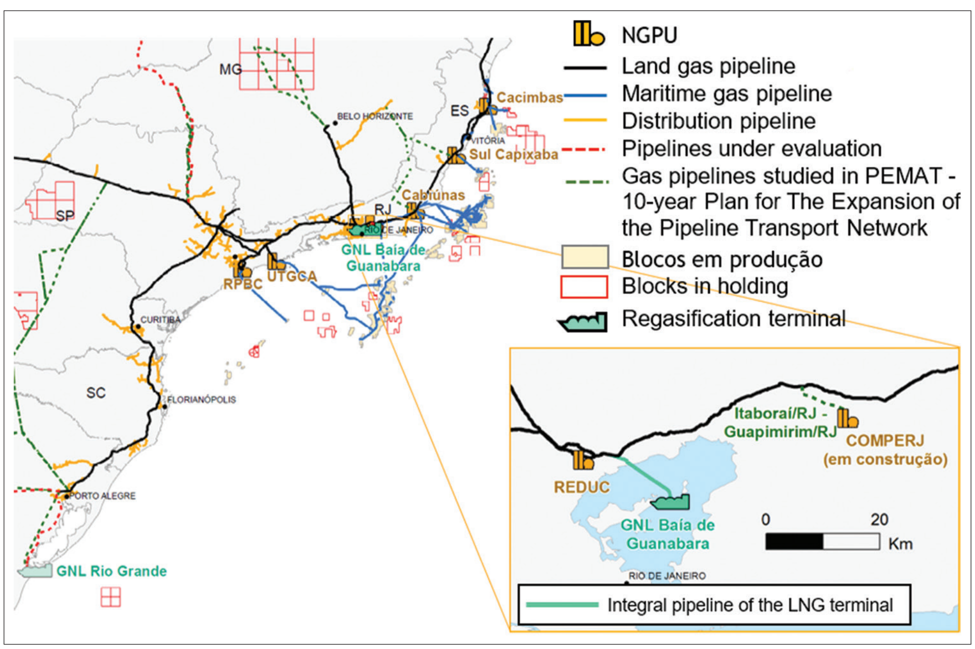


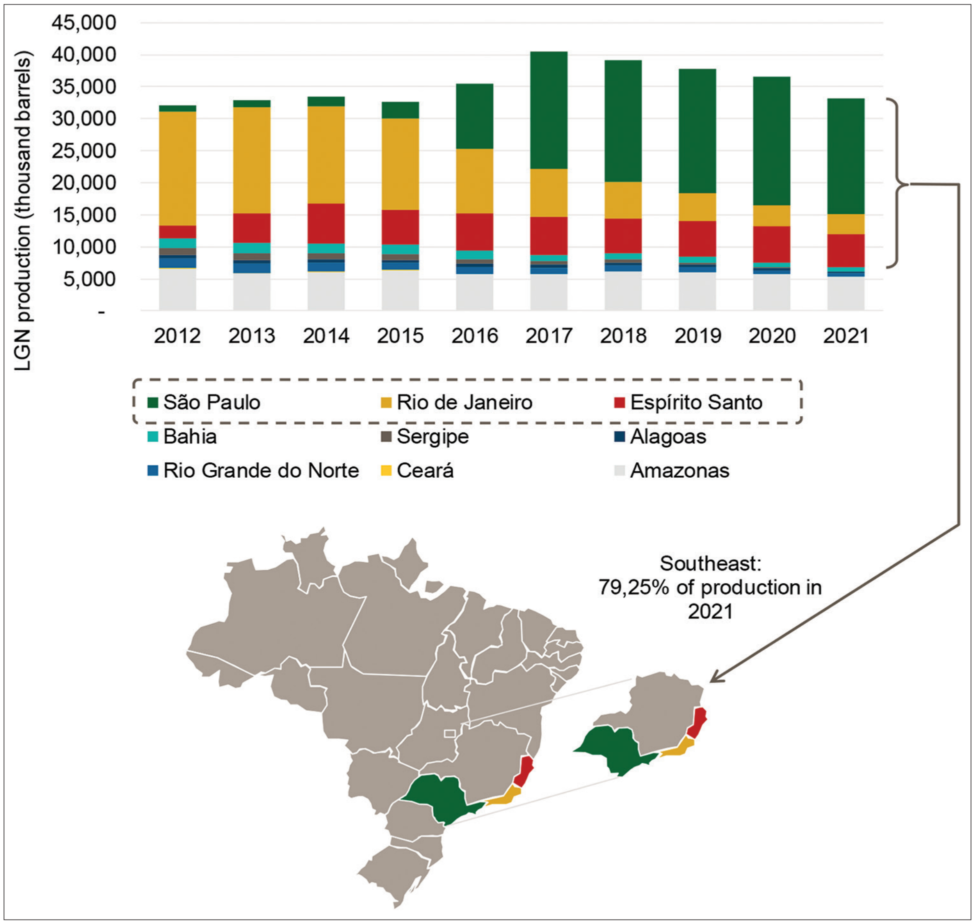
Figure 2: Map of transport pipeline infrastructure (Southeast) (Energy Research Company, 2019)



As seen in Figure 2, the concentration of NGPPs in the Southeast region suggests a potential for attractive players to use the existing infrastructure in the UTGs (Gas Treatment Units) of Cacimbas (Linhares -ES), South Capixaba (Anchieta-ES), Cabiúnas (Macaé – RJ), Caraguatatuba (SP), besides the RPBC Refinery (Cubatão-SP). These Units are currently integrated into the pre-salt unprocessed gas flow networks (routes), which will rely on the UTG in Itaboraí (RJ) to expand the processing capacity, still under construction (highlighted in Figure 2). This concentration of units in that region has shown an increase in the supply of NGL, mainly from 2016, with emphasis on the participation of the state of São Paulo, as can be seen in Figure 3 (NGL production in barrels per day since 2011).

Total production in 2021, according to the Statistical Yearbook (Ministry of Mines and Energy, 2022), pointed to 33,15 thousand

Figure 3: NGL production by region, according to Statistical Yearbook 2022 (Ministry of Mines and Energy, 2022)



barrels of NGL, with the Southeast region responsible for 79.25% of this value, as shown in Figure 3. This fact by itself testifies not only the importance of the Southeast region, but also the better use and recovery of NGL, which is an input for other products that are still in deficit in the country, such as LPG. In 2020, the total demand for LPG was 84,760 barrels, being necessary to import 26.8% of that value.

Faced with these opportunities for optimizing the recovery processes involved in NGPPs (NGL recovery and consumed energy), a recent study evaluated the energy consumption in a NGPP, including the restriction of a minimum recovery limit of 90% of propane and higher molecular weight compounds (C_3+) (Franco, et al., 2020). The authors manipulated operational parameters, such as temperature and pressure, analyzing molar compositions of C_3+ natural gas: 11.2%, 8.9% and 5.5% (i.e., respectively "rich", "average" and "poor" gas). The results were subjected to six evaluation criteria, such as energy, economy, recovery, production, safety, and quality performance. The authors observed a reduction in the specific energy consumption of 21.1% for the composition of 5.5%, and an increase in the economic margin (US$/h) of 0.35%. This balance between reduced consumption and reduced recovery of NGL, observed at 3.8%, brought flexibility to the processing, guaranteeing the quality criteria required by the ANP.

Such a study is important for the proposal of investigating the technical aspects for the access of units to third parties (players). This need arises because parameters of efficiency and guarantee of the recovery of NGL are targets for investors due to the greater added value of products such as LPG and C5+ (gasoline from natural gas) (Amaral Junior et al., 2019). The gaps to be filled include answering questions about what the minimum recovery of interest is required from third parties. It is also intended to investigate the value of the processing fee correlated to the expenditure of the NGPP that can guarantee the financial return to the unit, as well as helping in the solution of the trade-off, referring to investments in face of the uncertainties of the entry of players to the existing infrastructure.

Another proposal for configuration of the NGL recovery process was studied by (Yoon et al., 2017). The authors consider improvements based on a unit with a turbo-expansion liquid condensing mechanism. This is one of the technologies employed for the recovery of NGL, that performs adjustments in the arrangements and supply currents. With composition variations and optimization of unit operations, it was possible to simulate additional heat recovery in one of the fractionation towers (which removes methane at the top), which increased the energy efficiency of the process. The main point was the use of a methodology that integrated the streams, which allowed comparison with conventional turbo-expansion process designs. The results obtained, in turn, pointed to the so-called "hy-NGL" proposal, which optimizes the cycles of fractionating tower currents as capable of guaranteeing up to 18% energy savings (for currents rich in C_3+ in the feed), although reducing this efficiency according to the reduction of the "richness" of the incoming gas. The study by (Yoon et al., 2017) is similar to the analysis made by (Amaral Junior et al., 2019), in which the authors simulated a series of NGL recovery mechanisms, according to input compositions with three types of richness: "poor", "average", and "rich" in C_3+. This study showed the potential to support the decision of which process (or arrangement) should be selected according to energy consumption and NGL recovery factor.

This range of process alternatives can direct the actors in the new model, which consists of access to the NGPPs, with emphasis on the Southeast region (Figure 1), where the players can determine the performance according to the opportunity cost of the products (with different demands). Although the demand for natural gas is commonly higher in periods of drought, with consequent greater dispatch by thermoelectric plants (Ministry of Mines and Energy, 2022), as it does not require a process with technology for high recovery of NGL, such as simple cooling by expansion (Joule-Thomson effect), manages to remain at a value with few variations. For a better understanding, some of these processes were studied in order to compare their performance with this focus on determining recovery, as done by (Chebbi et al., 2010), (Getu et al., 2013) and (Amaral Junior et al., 2019). Of these, the highlights are the routes of turbo-expansion, Joule-Thomson, cooling and mechanical refrigeration (processes selected for simulation in the item Methodology of this work). In this case, the opportunity cost is directly related to how much you want to pay as a processing fee, considering the production of liquid (NGL) and its derivative products. Likewise, an already installed capacity can determine the price of its processing fee, according to the existing recovery technology, and can even adjust arrangements and chains to differentiate the prices practiced. It is worth mentioning that the processing is not yet practiced, since it is not considered in the composition of the gas price. To do so, currently, the billing consists in the volume sale of residual gas from the production by the productive units (platforms and onshore fields) to the NGPPs, which profit from the products.

2.2. Obstacles to Expanding the Processing Capacity of NGPPs

An approach on the economic paths for natural gas infrastructure in Brazil was carried out by Kerdan et al. (2019), who proposed a model of these structures for the case of the South Region of the country. The authors reinforce the role of natural gas in Brazil energy diversification, which contributes to the reduction of energy imports. The justification for the importance of this source is due to its low carbon emissions and competitive prices, when compared to other petroleum derivatives (Kerdan et al., 2019) (Campos et al., 2017). However, the study points out that the low dependence on gas demand, in certain sectors and regions (predominant role of hydroelectricity and sugarcane products), does not favor a stimulus to expand the infrastructure of the natural gas industry. As a result, the pipeline arrangement and current network are limiting factors in forecasting an increase in the demand, something that should be a point of concern for the sector.

Associated with this concern, Oliveira and de Moraes Marreco (2006) point out problems that contribute to the lack of investments, such as the dominance of the market (natural monopoly) by Petrobras. Although state-owned companies have diversified itself regarding production, transport and commercialization processes, even so, development within these subsectors ends up being associated with their strategies. An example of this is the 2023-2027 strategic plan, in which 83% of investments (Capex) are earmarked for Exploration and Production and only 2% for the Gas and Energy sector (Petrobras, 2023).

In a study on the possibilities of power generation by natural gas, Oliveira and de Moraes Marreco (2006) additionally highlight the barriers that prevent the expansion of the sector, such as contract clauses (for example, "take or pay"), which can be unattractive to companies depending on changes in demand. This study also agrees with the difficulties of regulating the sector, currently under the responsibility of the ANP, since distribution issues are the responsibility of regional institutions.

From an investor's point of view, for thermal generation powered by natural gas, for example, the authors highlight some concerns. Among them, (1) the real need to build a new thermal energy capacity and (2) the return on investment, being (1) associated with the inputs of other non-fossil sources in expansion. When exploring the different scenarios, at the time, about the feasibility of using gas for electricity generation by the private sector, Oliveira and de Moraes Marreco (2006) conclude that it is unfeasible, unless there are financial subsidies.

Regarding the alternative of reinjecting gas into the reservoirs, as a way of disposing of the input, widely adopted in Brazil, this is presented as the lowest cost option to make oil production feasible. This fact is perceived in the natural gas balance sheets issued by the Ministry of Mines and Energy, which indicate that the average reinjection in 2020 doubled, compared to 2017, reaching about 67,9 million m^3/day (Ministry of Mines and Energy, 2022). That is, the supply of gas produced, but not conditioned to consumption, comes up as a result of oil production, since its destination is seen as a by-product, if it is not sent to a NGPP. This condition denotes the subtlety of natural gas, in which efforts for its conditioning and commercialization are still timid.

The ideas and discussions presented reinforce the need for efficient action by the ANP in ensuring the compliance with the sector's policies and regulations in order to attract investors and, consequently, the development associated with it. There is no doubt that the development of the natural gas industry is a unique opportunity to stimulate local investment (Campos et al., 2017). In a study on the natural gas industry in Espírito Santo, for example, Campos et al. (2017) highlights the obstacles related to this development, such as the high level of investment required for the expansion of piped gas distribution infrastructure. Here again, hostage to the natural monopoly, once that Petrobras and the subsidiary BR Distributor did not foresee, in their management reports, the expansion of the infrastructure for the gas transport pipelines. Another difficulty reported in the study comprises the difficulty of forming a captive gas market due to the use of replacement fuels, such as electricity and LPG, yet another example in which public policies could potentially interfere with this objective. In this sense, the Government, through the Law nº 14.134/2021, intends to promote a new legal framework with the objective of forming an "open, dynamic and competitive" market. This proposal was prepared based on the international experience in the European Union, United Kingdom and Norway, compiled in a technical note by the Energy Research Company (2020) which evaluates essential infrastructure such as gas pipelines, NGPUs and NGL terminals from the perspective of third-party access. However, the issue addressed by the study is related to the impacts of these new proposals provided for in the New Gas Law on the existing infrastructure and how a charging alternative can contribute to the attractiveness and promotion of the sector, specifically, for gas processing.

3. METHODOLOGY

The work has two main sections: the first one brings an approach as exploratory research considering the analysis of the current legislation, the recent publication of the New Gas Law (nº 14.134/2021) and the second consists of the literature review on the units of natural gas processing. It is important to know the natural gas processing units, allowing an analysis of the implications when they are made available to third parties, as processes by partnerships (players) in the model proposed in the New Gas Law. Such implications are related to non-compliance with the current structure that makes up the units, which were not prepared for this model. An example is the absence of a tax measurement approved by the ANP, with the need for adaptation works. For this, it is necessary to know the technical part of the NGPP, that is, the technology used to obtain energy data necessary for its operation. This information makes it possible to guide towards a processing tariff model, based on the calculation of the demands and particularities of the technologies used. Table 1 summarizes the process parameters, types of NGPPs, composition of feed used and other essential elements, performed by static simulation with the aid of commercial software Aspen Hysys®, widely used in industry and for academic purposes (Amaral Junior et al., 2019).

The process variables in Table 1 are assumptions according to what is typically practiced by the the receipt of gas from the production units in Brazil, as considered by Amaral Junior et al. (2019). Regarding the technological routes employed, the variations consist of condensation mechanisms by temperature reduction, either by expansion (turbo-expansion, Joule-Thomson), by mechanical heat removal, or a combination of methods. Figure 4 shows a schematic of the combination of the TEMR, JTMR, JT and TE processes.

As shown in Figure 4, the focus of the gas processing simulation comprises the cooling sections (HE-01, HE-02, HE-03, HE-04, HE-05 and HE-06), condensing mechanism (TE -01, VLV-02 and VLV-03) and fractionation (T-01, T-02 and T-03), disregarding previous steps, such as acid gas removal and dehydration. The different feed streams (poor, average and rich gas) undergo thermal integration with the output stream and may, depending on the selected route, pass through specific heat exchangers of the mechanical refrigeration circuit (RM, with HE- 02 and HE-04). As the gas cools, the fractions from propane condense, and the vessel V-01 is required for scrubbing. The liquid fraction (bottom of V-01) is directed to the first tower, T-01 and the top gaseous fraction goes on for expansion, either by turbo-expansion (TE, isentropic process) or by a valve (JT, free expansion, with Joule-Thomson effect, isenthalpic), as highlighted in blue. For the route using the turbo-expander (TE-01), energy is used in the form of work (energy current QTE-01), used to pre-compress the dry gas in the C-01, which will be exported by compressor C-02 ("sales gas" current). Differently, in free expansion (VLV-02 "Joule-Thomson"), there is no use of energy (entropy increases) and compression depends exclusively on the C-02 compressor. Both in the process using turbo-expansion and the Joule-Thomson valve, a portion of the gas leaving the V-01 is subcooled by exchanging heat with the top of the T-01, through the HE-06. This current makes up for the lack of reflux, ensuring the retention of higher molecular weight compounds that would tend to exit through the top of the tower. From T-01, the fractionation of the products of interest takes place: at the top of T-01, the majority flow of sales gas (C_1 and eventually C_2) and at the bottom, the LNG to proceed to T-02 and T-03 respectively, producing the C_2 streams, a mixture of C_3 and C_4 (LPG) and, finally, gasoline from natural gas (C_5+).

Table 1: Summary of variables and information used in the analysis

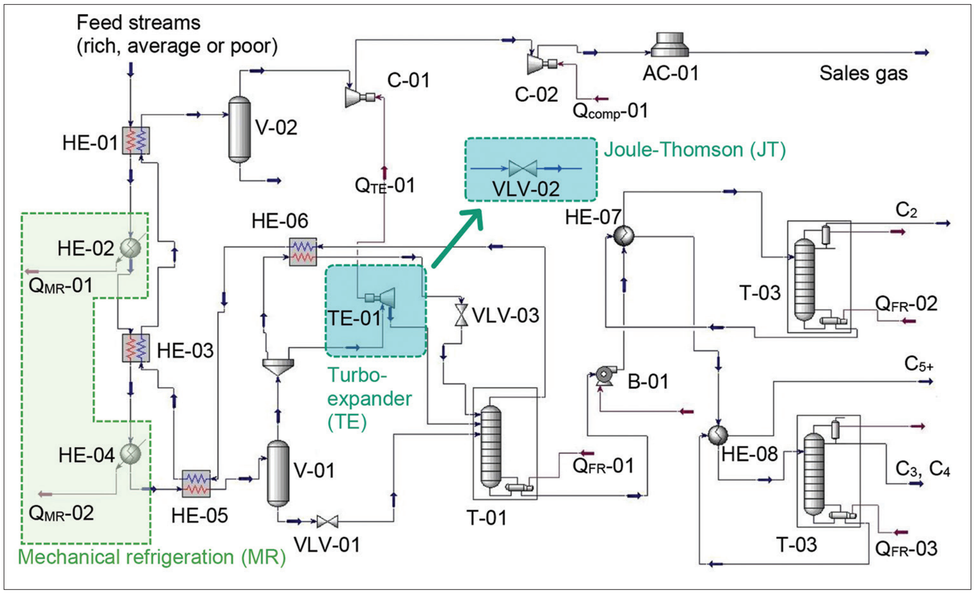
Employed Technologies	Turbo-expansion with Mechanical Cooling (TEMR) Turbo-expansion (TE) Joule-Thomson with Mechanical Cooling (JTMR) Joule-Thomson (JT)
Feed Composition	
Feed flow 1 ("rich" gas)	C_1=78.01% C_2=9.66% Richness (Content of C_3+) = 11.20% Inert (CO_2, O_2, N_2) = 1.13%
Feed flow 2 ("average" gas)	C_1=77.94% C_2=11.93% Richness (Content of C_3+) = 8.90% Inert (CO2, O2, N2) = 1.27%
Feed flow 3 ("poor" gas)	C_1=84.70% C_2=5.45% Richness (Content of C_3+) = 5.50% Inert (CO_2, O_2, N_2) = 4.34%
Thermodynamic Package	Peng-Robinson
Inlet Flow	3500000 m^3/d
Inlet Pressure	7000 kPa
Temperature at the Entrance	25 ºC
Pressure After Expansion	2000 kPa
Exit Temperature	25 ºC
Export Pressure	7000 kPa
Variables of Interest	Energy required in the process Energy per LNG production

4. RESULTS AND DISCUSSION

4.1. Pricing and Proposed Processing Fee

Regarding the composition of the price of natural gas (average price), the value now practiced is defined by the "molecule price" itself, plus the transport tariff, distribution margin and PIS/COFINS

Figure 4: Flowchart with the variation of the technological routes of the TEMR, JTMR, JT and TE processes



and ICMS taxes (taxes related to security, circulation of products and services). The term "molecule price" refers to the practical, non-literal term adopted by the sector to specify the portion that is equivalent to the gas with its respective characteristics of the mixture (composition and purity). These plots are exemplified in Equation 1 and illustrated in Figure 5.

$$Pgas = Molecule + Transport + Distribution + Tax \quad (1)$$

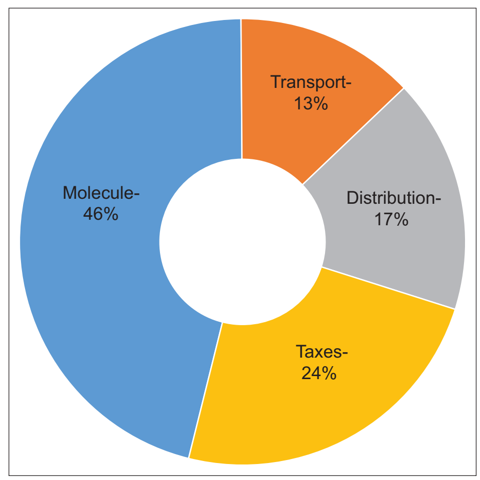
In the case of the value of the molecule, this value will depend on the origin of the gas and its specific charges, as is the case of Liquefied Natural Gas (LNG) whose price is indexed to the barrel of oil, plus fees for reimbursement of transport costs and the operational costs of the liquefaction plants. In the case of the gas molecule produced in Brazil (Petrobras' natural monopoly), the price (PRGN - Natural Gas Reference Price) is calculated according to the criteria of ANP Resolution No. 40 (D.O.U. 12/18/2009), according to Equation 2.

$$PRGN = V_{CGN}.P_{CGN} + V_{GLP}.P_{GLP} + V_{GV}.P_{GV} \quad (2)$$

Where V_{CGN} corresponds to the volumetric fraction of natural gas that can be recovered as condensate, P_{CGN} equals the price of natural gas condensate, with international references CIF (Cost, Insurance and Freight or cost, insurance, and freight of natural gas gasoline, in free translation). In turn, V_{GLP} and V_{GV} are respectively equivalent to the volumetric fractions of LPG and sales gas and their corresponding P_{GLP} and P_{GV} prices.

Regarding the transport tariff, it is a contractual value with readjustments using the General Market Price Index (IGP-M) and depends on the location. For example, the gas imported from Bolivia through the Brazil-Bolivia gas pipeline, or Gasbol, has a transport tariff 20% higher than the gas flowing through the Southeast-Northeast gas pipeline in the period 2017-2019 (EPE, 2019). However, the distribution tariff varies according to the local distribution companies (CDL) and to the type of

Figure 5: Composition of natural gas price according to EPE (2019)



consumption, being a value that, in the same way as the transport tariff, is dependent on the gas pipeline network and the costs of operation and maintenance of the CDLs. Additionally, taxes, contributions and other obligations are portions that make up the price of gas (PIS/COFINS at 9.25% plus ICMS, which varies by state). Figure 5 stratifies the aforementioned portions and allows understanding the relevance of the value of the molecule as well as the associated taxes and tariffs.

*-The cost distribution visualized in Figure 5 shows, for the molecule, the no distinction between intrinsic factors of gas production (extraction) and its treatment (processing), since traditionally it is carried out by a single agent. Even considering the particularities in Brazil, namely, referring to the natural monopoly by a single company and the costs of production, mainly in deep waters, it is worth mentioning that the prices of natural gas (molecule) are comparable to those practiced in Europe, since the value of the molecule in the US is considerably lower (value in U$/MMBTU), as can be seen in Figure 6, justified by the low cost of producing shale gas (non-conventional natural gas).

Figure 6: Comparison of prices with the main markets (Energy Research Company, 2020)

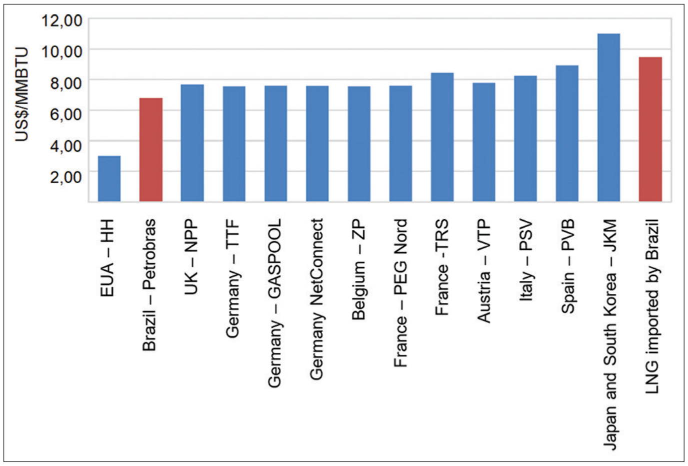


Figure 6 shows the range of prices and their respective indicators for taking a deal in which each trader monitors and articulates values in the gas market. One of the main ones is the Henry Hub (HH) for natural gas, which is the North American reference for local delivery contracts and futures contracts on the New York Mercantile Exchange (NYMEX). In Europe, the following indices stand out: NBP - "Natural Gas Daily Futures" for pricing Natural Gas in the United Kingdom, TTF "Title Transfer Facility" in Holland (and adopted in other European countries) for virtual trading of futures contracts, and natural gas exchanges, as well as others such as GASPOOL and NetConnect in Germany, ZP in Belgium, PEG Nord and TRS in France, VTP in Austria, PSV in Italy and PVB in Spain. In Asia, the reference is the JKM, which is the Northeast Asia spot price index for LNG delivered by ships to Japan and Korea. The price reflects not only the cargo delivered to Japan and Korea, but also destined for Taiwan and China. The high value, compared to other ones in Europe and the United States, is a consequence of the mode of transport by ship, with a high associated cost. The same goes for the price practiced for the purchase of LNG in Brazil (last column highlighted in the graph).

Concerning Brazil, the holder of the natural monopoly determines the pricing of the molecule according to the characteristics of the gas produced, linked to the producing fields, recoverable NGL content (Equation 1) or the volume and price of imported LNG. However, this reality is related to the dominance of the downstream and upstream within the same company, with internal segregation by business units. Once the infrastructure for the treatment of the produced gas is opened for access by third parties, that will inject the gas, requesting the provision of a service, a processing fee is necessary.

The IBP instruction, that guides third-party access to NGPPs, recommends the adoption of the price as a unit value to be processed on an energy basis (million BTU) or volumetric basis (in m³) freely between the parties (Brazilian Institute of Oil and Gas, 2019). However, this instruction does not provide details on pricing, but only refers to the contract with CADE, by requiring the payment of a minimum percentage of the contracted processing capacity, in a firm processing modality, even if it is not used at the moment (send or pay).

Thus, the proposal to add the processing fee to the composition of gas prices aims to cover portions of energy, Operation and Maintenance (O&M) costs, in addition to other financial costs. For the energy cost portion, the simulation, that was carried out, brings a proposal discussed in the sections below. For the cost of energy, the tariff must consider the expenditure of energy in different forms (heat, work, electricity, etc.) necessary for fractioning (furnaces, heaters, etc.), energy consumed by dynamic equipment (pumps, fans, etc.), losses inherent to the process (burning of the security system - flaring), among others. As for the non-energy cost, such as personnel, support and maintenance, the quantification must consider what is usually used in the sector (market practices), in addition to the history of the installation itself. This portion must be dismembered from the cost of the molecule. In this case, as the main proposal of this work, the unique value of the molecule gives rise to a stratification in portions that are typically object of cost in a NGPP, characterizing a segregation of activities. The relative value of each plot depends on the technologies used in the processing, as compared by Amaral Junior et al (2019), through the energy indicator per NGL flow (MJ/m³), which can define different prices, due to the efficiency in the net production of natural gas. Therefore, Equation 1 can be extended according to the cost quotas of the NGPPs, as proposed in Equation 3:

$$Pgas = \left[Mol. + Proc \begin{pmatrix} Ef + Ed + Emr \\ +Losses + Cm + Cop \\ +Cadm \end{pmatrix} \right] + Tp. + Dist. + Tx \quad (3)$$

Where *Pgas* is the price of gas in US$/MMBTU, that is, dollars per million BTU (the commonly adopted reference is "MM" for million, specifically for this unit), which is added to the transport, distribution and taxes (respectively *Tp*, *Dist,* and *Tx*) and additionally compute the values of Energy for the fractionation (*Ef*), Energy for the dynamic equipment (*Ed*), Energy for the mechanical refrigeration (*Emr*), Energy in terms of losses with the burning inherent to the process (*Losses*), in addition to essential non-energy costs, such as O&M (or OPEX, Operational Expendure) and administrative costs (*Cm*, *Cop* and *Cadm*). Eventually, an additional amount of CAPEX (capital expenditure, i.e. expected investment costs) may still be added to the negotiation, if there is an agreed concerning the forecast of investments with return to the Contracting Party. This stratification for formulating the processing fee implies divergence between the existing NGPUs (mainly in the Southeast region), since these have technologies that differ in terms of energy consumption and O&M costs. That is, there is the possibility of price variation depending on the NGPU chosen by the partner (player). For example, the Cacimba Gas Treatment Unit has technology with high NGL recovery, consequently producing more LPG (with a higher market value) when compared to the Caraguatatuba Gas Treatment Unit. However, the greater the recovery capacity, the greater the energy cost of the technology employed. This discussion is valid, since the player, as a customer, may not be interested in signing contracts with high values (processing fee), in view of the oscillation of the opportunity cost of treated natural gas, LPG and stabilized condensate.

4.2. Energy Factor for the Different Technological Routes to Differentiate the Processing Fee

From the simulation of the different technological routes (Figure 4), one of the focuses of this work, it is possible to differentiate the processing fee according to the NGL production criterion, which is one of the efficiency parameters. A schematic of the selected routes is presented in Figure 7, through a simplified tree of states, in which it is possible to perceive the main difference between the technologies.

From the differences between the condensation mechanisms (JT, JTMR, TE and TEMR) shown in Figures 4 and 7, the static simulation presents different results for the recovery of natural gas in liquid form, with different energy consumptions. In this way, an energy factor concept can be used to differentiate the processing fee, taking as reference the process with the highest energy consumption for the recovery of NGL and according to the characteristic of the input composition (rich, average or poor gas), according to Equation 4.

$$\text{Energy factor} = \frac{\sum E}{\sum E_{nref}} \qquad (4)$$

In which:

$$\sum E = E_f + E_d + E_{RM} + E_{TE} + (\ldots) + E_n \qquad (5)$$

Equation 4 is a ratio between the sum of the energy portions according to the equipment (in energy flow unit, in the case of the simulation, in kcal/h) by the total energy demand for a reference process of higher efficiency for NGL recovery. In this case, the reference process comprises the TEMR process for a rich gas (highest possible recovery). Equation 5 details the consumers' energy quotas in which E_f corresponds to the heat demanded in the fractionation, E_d equals to the energy in dynamic equipment (here exemplified by the compressor) and E_{RM} is the energy required in mechanical refrigeration (for example, propane refrigerant circuit) will bring from the work extracted in the turbo-expansion. The analysis can be expanded to the other consumers, represented by E_n.

The energy factor is dimensionless and ranges from 0 to 1, where 1 corresponds to the technology for which there is greater energy demand, adding up the portions corresponding to the main consumers. That is, the operations with the highest energy demand, considered, correspond to the energy extracted from the gas by mechanical refrigeration (propane refrigerant circuit) in the HE-02 and HE-4 equipment, the heat required for fractionation and the energy for gas compression for sale. On the other hand, for processes using turbo-expansion, energy is used in the form of work that is used in compression, so this energy is accounted for as gain (opposite sign). Table 2 below allows you to visualize the energy factor by comparing the efficiency between processes and input compositions. As mentioned before, the reference for factor = 1 is the TEMR process, which has the highest propane recovery (which is an efficiency parameter for NGL production), although it has the highest energy consumption.

According to Table 2, the process with the highest NGL recovery efficiency for the three compositions (rich, average, and poor) comprises turbo-expansion with mechanical cooling (TEMR). For the case with greater energy demand, which is the TEMR processing rich gas, the factor comprises 1, that is, with a higher

Figure 7: Simplified state tree with selected technological routes

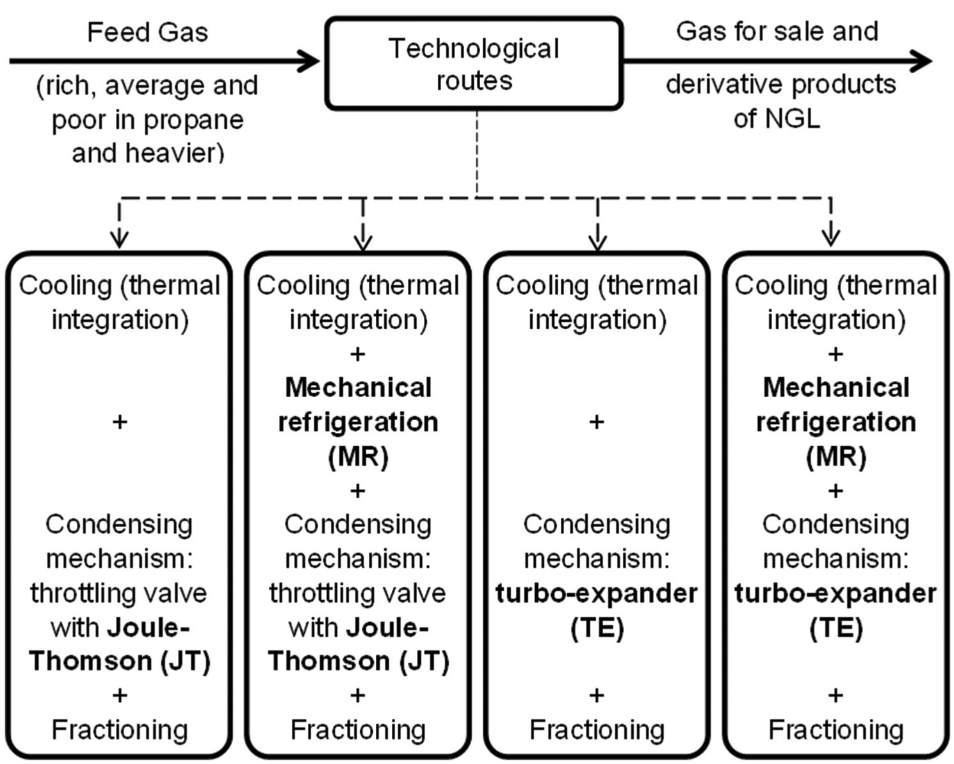


Table 2: Energy factor obtained from the comparison of technological routes

Composition	Process	NGL recovery efficiency/%	Energy factor
Rich Gas	TEMR	96.96	1.00
	JTMR	77.28	0.87
	TE	81.03	0.50
	JT	58.22	0.65
Average Gas	TEMR	93.63	0.87
	JTMR	72.08	0.82
	TE	81.23	0.52
	JT	56.26	0.67
Poor Gas	TEMR	98.01	0.73
	JTMR	95.00	0.82
	TE	94.05	0.53
	JT	71.53	0.65

TEMR: Turbo-expansion with Mechanical Cooling, TE: Turbo-expansion, JTMR: Joule-Thomson with Mechanical Cooling, JT: Joule-Thomson

Table 3: Energy factor in the main energy demands

Composition	Process	Energy factor in the main demands of processes				
		Mechanical Refrigeration		Energy for Fracionation	Energy for compression	Work in TE (gain)
		HE-02	HE-04			
Rich gas	TEMR	0.07	0.18	0.40	0.43	0.08
	JTMR	0.06	0.07	0.23	0.52	N.A.
	TE	N.A.	N.A.	0.22	0.40	0.12
	JT	N.A.	N.A.	0.13	0.52	N.A.
Average gas	TEMR	0.01	0.16	0.36	0.44	−0.09
	JTMR	0.03	0.06	0.20	0.53	N.A.
	TE	N.A.	N.A.	0.23	0.41	0.13
	JT	N.A.	N.A.	0.13	0.54	N.A.
Poor gas	TEMR	0.00	0.09	0.27	0.46	−0.10
	JTMR	0.02	0.07	0.17	0.55	N.A.
	TE	N.A.	N.A.	0.19	0.45	0.11
	JT	N.A.	N.A.	0.09	0.56	N.A.

TEMR: Turbo-expansion with Mechanical Cooling, TE: Turbo-expansion, JTMR: Joule-Thomson with Mechanical Cooling, JT: Joule-Thomson

value in the processing tariff, justified by the greater production. Likewise, as the NGL recovery efficiency decreases, the energy factor reduces, with an impact on the tariff, since the customer will tend to pay for a service according to energy efficiency and cost. In addition, Table 3 stratifies the main energy consumers who are responsible for the total energy factor for the combination of different processes with the compositions.

Through Table 3, it is possible to differentiate the amounts of energy spent on mechanical refrigeration, fractioning, and compression, which is the main dynamic equipment in a NGPP. Items "N.A.", that is, non-applicable, correspond to processes that do not involve mechanical refrigeration. It is worth mentioning that the work extracted in the turbo-expansion is existing and used only in the TEMR and TE processes ("N.A." to the others). As it is a portion of energy saved, it counts with the opposite sign, contributing to the overall efficiency of the process, with regard to the energy spent in NGL production.

Thus, by knowing the cost of the main equipment, it is possible to compare the energy cost and differentiate the price for processing. The customer (player), in this case, can decide on the most appropriate technological route according to the opportunity cost of the products, paying an amount proportional to the NGL recovery efficiency.

5. CONCLUSIONS AND POLICY IMPLICATIONS

The formulation of service provision contracts by NGPPs is complex compared to what is referenced in the preliminary studies of the EPE and the IBP third-party access guidelines, since these do not detail the prices based on the specificities of the processing plants. Considering that there are different energy costs, depending on the NGPP, there is a tendency for the share of processing cost to be different according to the location (with emphasis on the NGPPs in the Southeast).

In this sense, the flexibility, provided for in the contract, is capable of filling this gap by proposing different tariffs depending on the characteristics of the treated gas and the technology used (including the possibility of simplified technological routes, bypass and equipment shutdown). Such flexibility may allow for greater competitiveness among the NGPPs, avoiding low plant utilization rates, thus enabling an increase in revenue. The low processing costs also have the potential to boost the efficient allocation of the portion of gas that is currently reinjected and, therefore, unavailable to the market.

As advocated by the New Gas Law, third-party access is expected to occur in a transparent manner, therefore, the relative value of these installments can be detailed in contracts when negotiating access. The processing tariff, proportional to the efficiency of the technology used and the energy costs involved, proposed by this work, depends on the location and technological routes of each NGPP and must be clearly negotiated, assuming a portion of what was previously destined exclusively for the molecule. That is, the article proposes the segregation of plots as a form of exclusive remuneration for the NGPPs, which is the limitation of the scope of the analysis, due to the unrestricted access of new players.

However, transparency and negotiation of these values must be attributions of the Regulator. In this sense, it is up to the ANP to act as a verifier in any controversies or unexpected conduct between the parties. Besides, the Regulator must still propose policies and incentives to be considered while there are gaps in the legislation to avoid the lack of attractiveness of the existing infrastructure (here, focusing on the processing) considering the market opening. Actions to reduce taxes or charges are appreciable ways to reduce the disparity and damping the peculiarities between the NGPPs, acting as a compensation for processing fees in different employed NGL recovery efficiencies.

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