UNCONVENTIONAL SOURCES OF GASEOUS ENERGY IN THE SOUTHERN REGION OF BRAZIL: A COMPARATIVE SWOT ANALYSIS

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ABSTRACT

The southern region of Brazil is diverse when it comes to unconventional gaseous energy sources with high methane concentrations. Located above the Paraná Sedimentary Basin, the region has great potential to produce shale gas and coalbed methane, situated in the Ponta Grossa and Rio Bonito Formation, respectively. In addition, the generation of biomethane from pig farming effluents in the state of Paraná has been gaining national prominence. In this sense, this work aimed to carry out a comparative SWOT analysis of three potential methane sources in the southern region of Brazil: (1) shale gas, (2) coalbed methane, and (3) biogas from swine effluents. This qualitative study debated each option regarding its regional impacts, developed gas distribution infrastructure, and investments in R&D for risk mitigation. A clearer consolidation of the federal government's competence and states would bring more confidence and predictability to the market and promote better policy and legal security for investors.

Keywords: Shale gas; Coalbed Methane; Pig manure; Biomethane; Southern Brazil.

RESUMO

A região Sul do Brasil dispõe de diversas fontes energéticas gasosas não convencionais. Localizada acima da Bacia Sedimentar do Paraná, a região possui grande potencial de exploração de gás de folhelho e metano de carvão nas formações Ponta Grossa e Rio Bonito, respectivamente. Além disso, a geração de biogás na região, proveniente do efluente da suinocultura no estado do Paraná, vem ganhando destaque nacional. Nesse sentido, este trabalho teve como objetivo a realização de uma análise comparativa, via Matriz SWOT, de três potenciais fontes energéticas gasosas na região Sul do Brasil: (i) o gás de folhelho, (2) o metano de carvão e (3) o biogás oriundo de efluentes da suinocultura. Este estudo, de caráter qualitativo, realizou um debate de cada opção energética com relação aos seus impactos regionais, infraestrutura de distribuição e investimentos em pesquisa e desenvolvimento para a mitigação de riscos. Verificou-se que uma clareza maior entre as competências estaduais e federais poderia trazer maior confiança e previsibilidade para o mercado, além de promover políticas públicas mais assertivas e maior segurança jurídica para os investidores.

Palavras-chave: Gás de Folhelho; Metano de Carvão; Esterco Suíno; Biometano; Sul do Brasil.

1. INTRODUCTION

The southern region of Brazil (SRofB) has a wide diversity when it comes to gaseous energy sources. The generation of biogas from pig farming substrate in southern Brazil has gained national prominence through projects and research incentives. This support is provided mainly by CIBiogás (International Center for Renewable Energies - Biogas), a Science and Technology Institute located within the Itaipú Technological Park (PTI), in Foz do Iguaçu, PR (CIBIOGÁS, 2020). The institute's support to farmers in the region has contributed to this technology adoption by local landowners. In addition, the SRofB is above the Paraná Sedimentary Basin (PSB), an area with great potential for the exploration of shale gas and coalbed methane. These gaseous sources are already commercially explored in some countries but not Brazil (EPE, 2019).

This work carries out a comparative SWOT analysis between three potential energy sources with high methane concentration in the SRofB: two from unconventional fossil sources and one from a biogenic origin. We seek to understand the main competitive advantages between them and what barriers have to be overcome. Due to this study's qualitative nature, we do not propose to point out which option will be the most adequate or preferable, but rather to carry out a broad debate on its aspects and impacts in the region.

The studied first source will be the shale gas present in the Ponta Grossa Formation in the PSB, extracted by the hydraulic fracturing technique. It is an unconventional natural gas source (EIA, 2013) since it is difficult to access the resource contained in low permeability reservoirs (ANP, 2010). The second unconventional source will be the coalbed methane present in the Rio Bonito Formation in the PSB, between Rio Grande do Sul (RS) and Santa Catarina (SC) (KALKREUTH et al., 2008). The third source will be the biogas from swine effluents, generated through anaerobic digestion, present with the highest concentration in western Paraná (PR) and SC and the northwestern RS (BIOGÁS BRASIL, 2019).

2. LITERATURE REVIEW

The SRofB comprises three states: PR, SC, and RS. The region, with a total area of around 576,774 km² (corresponding to less than 7% of the total national area), shares its borders with Paraguay and Argentina in the west, Uruguay in the South, the Atlantic Ocean in the east, and the Brazilian states of São Paulo (SP) and Mato Grosso do Sul (MS) in the North (IBGE, 2021a), as shown in Figure 1. In addition, SRofB has a total estimated population of around 30 million people (IBGE, 2020a), more than countries like Australia, Israel, and Venezuela, or more than the population of Norway, Sweden, Finland, and Denmark together (UN, 2019).

Figure 1 - The Political Map of Brasil, with the indication of the SRofB

This work consists of a qualitative SWOT analysis through bibliographic and exploratory research, which aims to understand the current situation and prospects for three gaseous energy sources in the SRofB. A SWOT analysis is a strategic planning tool used to assess an organization, a plan, a project, or a business activity, focusing on the strengths and weaknesses (internal factors) and the opportunities and threats (external factors) of the study object (GÜREL and TAT, 2017).

The lack of a quantitative approach in this study is due to the limitations of the SWOT analysis when not employed with an auxiliary quantitative methodology. After mapping internal and external factors, we develop strategies to use the strengths to tackle internal weaknesses, suppress threats and take advantage of opportunities (DYSON, 2004).

This work sought to position the energy sources based on four strategic evaluation criteria:

(a) Resources (internal): this criterion evaluated the available resources in the SRofB with the potential for developing exploratory activities of the energy sources studied in this work. We present geological maps and agribusiness land use data to examine the region's exploration potential.

(b) Technology (internal): this criterion analyses the technological level and the maturity of engineering techniques that exploit the resources. Within this perspective, environmental impacts are directly related to current practices.

(c) Policy (external): political, legal, and social issues related to the exploration activities of each energy resource are verified by this criterion, as well as socio-economic, regulatory, and environmental aspects, such as court decisions.

(d) Market (external): by this criterion, contents related to the commercialization of the gases produced, supply chain, demand, logistics, and infrastructure, from the production site to the final consumer, were analyzed. We also considered aspects related to the global trend for cleaner fuels and the need for a safer and more transparent energy matrix.

After the bibliographical analysis, we discuss the energy sources comparatively to each other, seeking to determine their chances of success. International literature provides numerous studies that performed a comparative SWOT analysis applied to the energy industry, both for renewable and fossil energy sources.

Fertel et al. (2013) sought to identify the competition between energy and climate policies in Canada's federal and provincial spheres and concluded that the lack of coordination and consistency between them is a weakness. Kutcherov et al. (2020) used the SWOT methodology to assess Russia's prospects for natural gas exports. They identified the growth of gas production and exports by the United States as a threat, increasing the competitiveness of markets traditionally dominated by Russia.

In the United States, Cronshaw and Grafton (2016) used the SWOT methodology to assess the rapid growth of the shale gas industry in Pennsylvania. They proposed regulatory principles to reduce associated risks. Wan et al. (2014) studied the barriers to developing China's shale gas industry. They observed the necessity of breaking the monopoly of the major state-owned companies over high-quality reserves, creating fair competition between service providers, and improving the water management system.

In South America, Waterworth and Bradshaw (2018) compared Argentinian shale gas with Brazilian pre-salt via a SWOT matrix, while Carbone-Neto et al. (2021) also used the SWOT matrix and developed an exploratory study on hydraulic fracturing in Brazil. The authors considered that the fracking technique is at an advanced stage and that a regulatory definition is necessary to ensure the proper environmental, social, and safety obligations. These studies have presented the overall views of both countries and contributed to the perception of the SRofB potential.

3. FOSSIL AND UNCONVENTIONAL GAS SOURCES

Present in Brazil, Paraguay, Uruguay, and Argentina, the PSB extends most in the Brazilian territory, with approximately 1,121,239 km² in the southeast and central regions of the country (EPE, 2019). The PSB is present in PR, SC, and RS (ZALÁN et al., 1990).

Exploratory activities of hydrocarbons in the PSB started around 1892 by private companies and public institutions. These initial activities entailed shallow drilling wells close to tar sands areas (ZALÁN et al., 1990). Despite the conventional exploratory activity in the PSB and a large amount of geological data available for the region, no unconventional gas has been commercially explored yet (EIA, 2015b).

Since the 1980s, Brazil has focused much of its oil and gas exploration efforts on offshore reserves, while onshore resources have had little exploratory activity (LENHARD et al., 2018). The successful exploration of unconventional onshore reserves in other countries has attracted stakeholders' attention to the Brazilian sedimentary basins (GOMES, 2011). Ahead, we present what is currently known about two kinds of unconventional gases and present a SWOT matrix for each of them.

3.1 Shale Gas

Resources: The occurrence of shale gas in the PSB is mainly concentrated in the shales formed in the Devonian period of the Ponta Grossa Formation (EPE, 2019), as shown in Figure 2 (adapted from EPE, 2019). Estimations show that shale gas resources in the region correspond to approximately 12.73 trillion m³, of which 2.27 trillion m³ are recoverable, with an expected gas production between 284.26 to 994.92 million m³/km² (EIA, 2015b).

This figure represents about one-third of the Vaca Muerta reservoir in Argentina's Neuquen Basin (EIA, 2015a). The shale gas reservoirs in PSB represent a prominent position in South America.

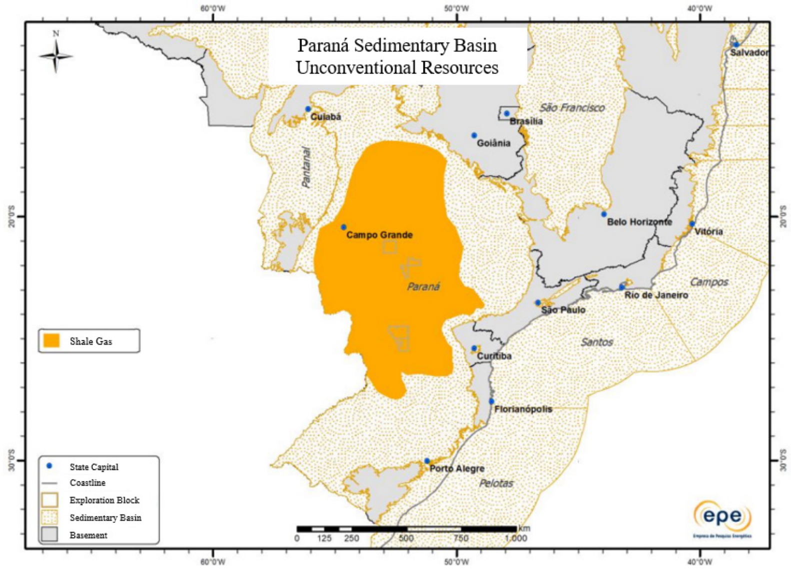

Figure 2 - Shale gas resources in the PSB adapted from EPE (2019)

Technology: The current technology to explore shale gas is hydraulic fracturing, in which a high-pressure fluid composed of water, sand, and chemicals is injected into the drilled well, opening fractures in the rocks. After the well depressurization, the hydrocarbons flow from the fractured rock to the surface (CTMA, 2016). This technology is widely used in countries with significant shale gas production: the United States, Canada, and Argentina (EIA, 2013).

The development of the shale gas industry has been constantly associated with a series of environmental problems due to hydraulic fracturing. Impacts such as groundwater pollution, explosions, small seismic events, contamination of rivers and soil, leaks of toxic and flammable gases, substantial consumption of water resources, among others, constitute a set of factors that affect the general public perception of that technology (ZOBACK et al., 2010). Those environmental risks are also associated with the exploitation of conventional onshore gases. Zoback et al. (2010), Jenner and Lamadrid (2013), and Holditch (2013) indicate that a more detailed monitoring and transparency of operations, consistent environmental regulation, and the use of good practices in shale gas exploration can minimize the risks associated with the hydraulic fracturing technique.

In Brazil, the Poço Transparente project, a strategy defined by the Ministry of Mines and Energy in the REATE 2020 program (MME, 2020c), aims to apply the hydraulic fracturing technique in a model well. Its objective is to assess production feasibility and the risks of developing a country's regulatory framework for shale gas exploration (EPBR, 2019).

Policy: In Brazil, the upstream (exploration, production, and processing of natural gas), and the midstream (transport and storage of natural gas) activities, are the responsibility of the Federal government. Downstream (distribution and sale to the final consumer of gas) activities are the responsibility of the states (FGV, 2014; GOMES, 2014).

The primary federal laws governing the natural gas sector are the Petroleum Law (n° 9,478/1997) and the Gas Law (n° 11,909/2009) (ARAÚJO, 2016). While the former established the end of Petrobras' monopoly and opened the market to new investors (FGV, 2014), the latter brought more bureaucracy to the sector. According to the Ministry of Mines and Energy, no new gas pipeline has been built in Brazil since the Gas Law in 2009. All existing natural gas infrastructure was previously built under a permission regime. Law No. 14.134, sanctioned in 2021, aims to repeal the Gas Law of 2009 and bring greater competitiveness and autonomy to the sector (BRAZIL, 2021; MME, 2020a).

At the state level, the Federal Constitution of 1988 granted the states of the Union the exclusivity of local piped gas services. Thus, since the 1990s, many states have created their piped gas supply companies through state laws (ARAÚJO, 2016). In southern Brazil, the companies Compagás, SCGás, and SulGás own all the concession areas for the distribution and sale of natural gas in PR, SC, and RS, respectively (ABEGAS, 2021).

As expressed in the Petroleum Law, the National Agency of Petroleum, Natural Gas, and Biofuels (ANP) prepares the bidding process for concessions of areas to explore and produce unconventional natural gas in Brazil. In 2013, ANP presented the 12th Bidding Round to explore seven Brazilian sedimentary basins, including the PSB (ANP, 2013). However, after granting the blocks, Paraná state, through a court injunction issued by the Federal Public Ministry (MPF) in 2017, suspended the effect of all concession contracts within the state's limits. This decision was motivated by the understanding that, because the bidding process allowed the use of hydraulic fracturing technology, the MPF assessed potential risks to the environment, human health, and economic activity based on the precautionary principle (JUSBRASIL, 2014). In addition, the exploration of shale gas by using the hydraulic fracturing method was definitively prohibited in PR after Law No. 18.878 in 2019 (AGÊNCIA DE NOTÍCIAS DO PARANÁ, 2019). This regulatory barrier poses an enormous political challenge in the state with the most significant potential for shale gas production in the SRofB.

Market: In recent years, the natural gas market has undergone significant transformations in Brazil through Federal Government initiatives to improve the business environment and promote a smooth transition from a market dominated by a single agent to one with greater liquidity (COMPAGAS, 2020). In the SRofB, the average daily consumption of natural gas for 2020 was 5.37 million m³/day, representing around 9.1% of the total national demand, an increase of almost 15% in five years (MME, 2020b).

Most of the natural gas that supplies the SRofB comes from Bolivia (MME, 2020b), which reaches distributors through GASBOL, the Bolivia-Brazil gas pipeline (MOUTINHO DOS SANTOS et al., 2020). Its price to final consumers depends on exchange rate variation as it is an imported gas (BNDES, 2013). Despite this, the average price in SRofB was around US$ 10.43/MMBtu in 2020, while the national average was around US$ 11.47/MMBtu for industrial consumers (MME, 2020b). In the United States, the price of natural gas for industrial consumers is around US$ 2.90/MMBtu (ANDRADE et al., 2021a). In Argentina, a producer of shale gas and Brazil's neighbor, the price of natural gas for the final consumer was set by the Argentine government at US$ 4.00/ MMBtu for 2019 (EPE, 2020).

Table 1 summarizes the primary information presented in this section as a SWOT matrix, with the attribution of strengths, weaknesses, opportunities, and threats for shale gas in Southern Brazil.

Tabela 1 – SWOT matrix for shale gas in the SRofB

	Resources		**Technology**	
Internal Factors	Strengths	Weaknesses	Strengths	Weaknesses
	- Large reserves in PR. - Existence of conventional oil and gas exploration. - Robust geological data.	- Non-renewable resources.	- Relatively consolidated technology in the sector. - Competent Brazilian technicians and engineers.	- Risks of negative environmental and social impacts associated with the technique. - Large water consumption
External Factors	**Policy**		**Market**	
	Opportunities	Threats	Opportunities	Threats
	- Stimulus from the federal government in the creation of a regulatory framework. - Federal government encouragement to develop hydraulic fracturing technology.	- Prohibition by the government of PR on the use of the hydraulic fracturing technique.	- Increase the supply of natural gas, boosting the industry's competitiveness. - Reduce the region's dependence on foreign natural gas. - Low intermittency of natural gas production	- Limited distribution infrastructure.

3.2 Coalbed Methane

Resources: The principal Brazilian sedimentary succession bearing coal occurs in the Rio Bonito Formation in the PSB, mainly in RS and SC (KALKREUTH et al., 2008). The coal layers present in the Rio Bonito Formation act as methane generating rocks and natural gas reservoirs due to their microporosity (LEVANDOWSKI, 2013).

Coalbed methane can be found in two main deposits of the Rio Bonito Formation: the carboniferous areas of Santa Terezinha and Chico Lomã, both located in the northeast region of RS (EPE, 2019). Figure 3 (adapted from EPE, 2019) shows the region comprising the coalbed methane reserves in the PSB. Both areas present high-methane gas content (above 94%) and has an estimated potential of 5.48 billion m³ (KALKREUTH et al., 2008) and 1.32 billion m³ (LEVANDOWSKI, 2013), respectively. However, the research carried out in the region still has little representation, and data are still scarce to reach any more assertive conclusion regarding the potential volume of the reserve (EPE, 2018).

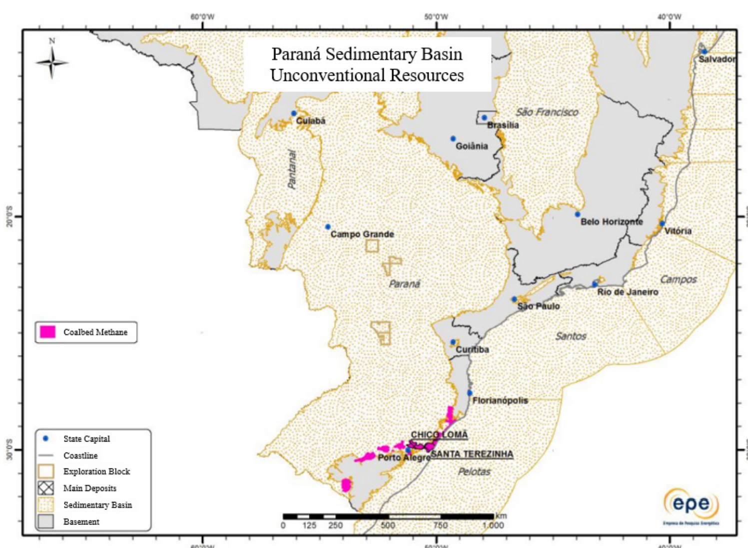

Figure 3 - Coalbed Methane resources in the PSB adapted from EPE (2019)

Technology: Technologies for the exploration of methane gas in coal deposits are used according to the particular characteristics of each area, which can be: (i) virgin deposits, still unexplored, (ii) active mines, where mining activities are still present and (iii) abandoned mines, where coals have not yet been mined but have already suffered some disturbance (EPE, 2018). In addition, the drainage of natural gas present in virgin deposits is a recommended practice by the mining industry before coal exploration activities. The prior extraction of natural gas, mainly methane and carbon dioxide gases, has as main objectives the reduction of the mine's explosive potential after the start of mining activities and the elimination of future accumulations of these gases in concentrations above a prescribed maximum limit by the industry (BLACK, 2011).

The industry can use several methods to carry out the drainage of natural gas in virgin coal deposits, considering both exclusive explorations for the energy use of the gas and drainages for future mineral exploration. Such methods are excavating vertical wells, Under-Reamed Vertical Borehole, Cavitated Vertical Borehole, and hydraulic fracturing with horizontal excavation for situations where the mineral has low permeability (LOFTIN, 2009). The conditions and particularities of each reserve will determine the most suitable method for extracting the gas contained in coal (JOHNSON et al., 2006).

Regarding the environmental impacts of the methods above, the risks are similar to the exploration of underground resources onshore through the excavation of wells: contamination of the water table, rivers, and surrounding soil by the leakage of fluids in exploration operations, land deformation, pollution noise and negative impact on the local landscape (ULIASZ-MISIAK et al., 2020). On the other hand, the coal layers of the Rio Bonito Formation in the PSB are an area of great potential for carbon capture and storage (ROCKETT et al., 2011), given the greater affinity that coal has with carbon dioxide than with methane (LOFTIN, 2009).

In active mines, methane from coal is extracted through a ventilation system during mining activities (EPE, 2018). Given the increasingly frequent inclusion of these ventilation systems in the costs of the mining process by the industry, aiming to achieve better safety for the site (LIU et al., 1998), the gases captured in the outputs of these systems could be used for energy purposes, after filtering. Thus, in addition to attributing an extra economic value to coal mining activities, filtering the gases emitted would reduce the environmental impact of fugitive emissions of greenhouse gases (EPE, 2018). A similar extraction process in abandoned mines, where underground or surface-installed pumps suck the coal methane, is also possible (EPE, 2018).

Policy: No federal resolution explicitly addresses the exploration of methane gas associated with coal in Brazil. Since coal is a mineral, all its mining activity is covered by Decree-Law No. 227/1967, establishing the Mining Code. Thus, all exploration research on coal reserves must be accompanied by the National Department of Mineral Production (DNPM) (BRAZIL, 1967). Regarding the exploration of methane gas in virgin coal deposits, the activities will be subject to the definitions of the Petroleum Law from 1997, which provides the national energy policy and establishes the guidelines for specific programs for the use of resources available in the country's energy matrix, including coal and its derivatives (BRAZIL, 1997). Currently, the second paragraph of Article 23 of the Petroleum Law gives ANP the power to grant the concession for coalbed methane exploitation to holders of mining rights or authorization to research coal deposits in Brazil (BRAZIL, 1997).

RS holds around 88% of the national coal reserves (GOMES et al., 1998) and created, in 2017, the State Policy on Mineral Coal, establishing the Carbochemical Pole of RS. With this initiative, RS aims to reduce external dependence on inputs for industries and promote sustainable economic development based on the state's coal. In addition, the institution of the Carbochemical Pole intends to use mineral coal in the production of energy and synthesis gas, providing final sustainable disposal of waste generated in the processes (RIO GRANDE DO SUL, 2017). However, there is no direct mention of coalbed methane exploitation in this state policy.

Market: Brazil, unlike countries such as the United States, Canada, Russia, China, India, and Australia, for example, still does not have an established industry for the use of coalbed methane (ANDRADE et al., 2021b). The various uses for coalbed methane are related to the type of deposit from which the gas was extracted. For example, in virgin deposits, it is possible to use methane as a substitute for natural gas (either in the form of LNG or by direct injection into the grid) or use it to generate electricity on-site (EPE, 2018). In active mines, since gases must be vented out of the workplace for safety reasons, the use of methane could generate both a reduction in the mine's operating costs if used for the maintenance of the mine or extra income if filtered and sold to other consumers (EPE, 2018).

Table 2 summarizes the primary information presented in this section as a SWOT matrix, with the attribution of strengths, weaknesses, opportunities, and threats for coal bed methane in Southern Brazil.

Table 2 - SWOT Matrix for coalbed methane in the SRofB

	Resources		Technology	
	Strengths	Weaknesses	Strengths	Weaknesses
Internal Factors	- Large resources in the northeast of RS.	- Scarce and unrepresentative geological data compared to other resources.	- Relatively consolidated technology in the sector. - Competent Brazilian technicians and engineers. - Increased safety and benefit from methane gas in active mines. - Potential for CO_2 capture and storage.	- Risks of adverse environmental impacts associated with extraction techniques in virgin deposits.
	Policy		Market	
	Opportunities	Threats	Opportunities	Threats
External Factors	- Petroleum Law authorizes exploration of coalbed methane for holders of mining or exploration rights. - Interest of RS in resource development.	- Absence of a specific regulation on coalbed methane resources in Brazil.	- Increase the supply of natural gas, boosting the industry's competitiveness. - Reduce the region's dependence on foreign natural gas. - Possibility of carbon capture and storage.	- Limited distribution infrastructure.

4. RENEWABLE GAS SOURCES FROM AGRICULTURAL ACTIVITIES

Agribusiness in Brazil is one of the most relevant sectors in the share of the national GDP, representing around 26.6% of the Brazilian GDP in 2020 (CEPEA/CNA, 2021). The country is the leading producer worldwide of soy, sugar cane, coffee, orange, and other agricultural products (FAO, 2019). Brazilian livestock also occupies a prominent position worldwide, being the largest beef exporter, exporting about a quarter of its production (ABIEC, 2020). In addition, Brazil is the third and fourth-largest producer of broiler chicken and pork, respectively (EMBRAPA, 2019).

4.1 Biomethane from swine effluents

Resources: SRofB has the highest concentration of swine production in the country, representing 66.0% of the national output in 2019, with an increase of approximately 159.5% in the last 20 years (EMBRAPA, 2020). In international trade, SC contributed 55.5% of all

Brazilian pork exports in 2019, followed by PR and RS, respectively, with 22.9% and 15.8% of national pork exports in the period (EMBRAPA, 2019).

The herd of swine in the SRofB was approximately 20 million heads in 2019, representing about 49.5% of the national total (IBGE, 2020b). Figure 4 (adapted from BIOGÁS BRASIL, 2019) shows the regions with potential for generating biogas in southern Brazil through swine farming.

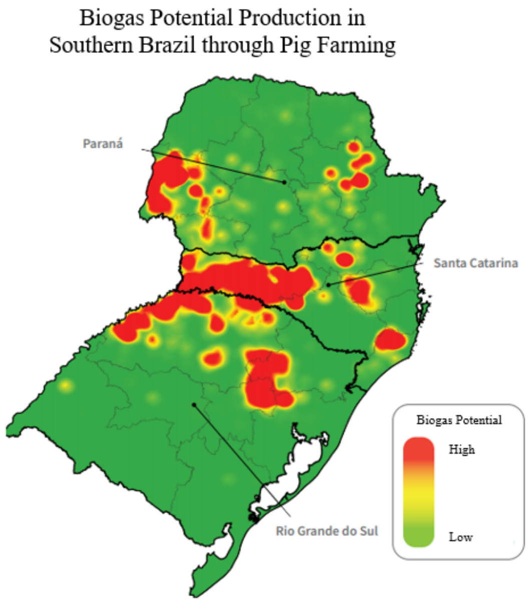

Figure 4 - Biogas Potential Production in SRofB through pig farming adapted from Biogás Brasil (2019)

Considering that the average daily production of manure is around 2.35 kg/animal (OLIVEIRA, 1993), the estimated annual production in the region was approximately 17.1 million tonnes in 2019. One ton of swine manure can generate between 33 to 39 m³ of methane gas (PROBIOGÁS, 2015). Thus, assuming the transformation of all swine manure from the SRofB in 2019 into methane gas, the generation potential would be between 566.1 million m³ CH_4/year to 669.0 million m³ CH_4/year.

Technology: There is currently a wide variety of technologies available for energy generation using biomass as an input, either a thermochemical or a biochemical process (IRENA, 2012). To manage livestock effluents, anaerobic biodigesters are widely used due to their efficiency in generating biogas, biomethane, and electricity; or generating biofertilizers demanded by the agricultural industry (PEREIRA et al., 2009). There are currently 152 biodigesters operating in SRofB, considering that around 94.7% are small plants, with a maximum production of 1.00 million Nm^3/year. PR, SC, and RS produced 17.8% of the total national volume (CIBIOGÁS, 2020).

The anaerobic digester most used in Brazil is the covered lagoon model, also known as the Canadian model (ANDRADE, 2018). This type of biodigester consists of a waste (substrate) entrance, an underground fermentation chamber, an upper blanket (to retain the biogas), an exit for the digestate (and biofertilizer after treatments), and a stopcock for the exit of biogas. This type of biodigester can directly receive sunlight, increase the effluent fermentation temperature, and improve efficiency (PEREIRA et al., 2009). However, covered lagoon biodigesters lack technological devices, not allowing accurate control of the fermentation temperature and other essential aspects of the process. Due to high annual thermal variations in the SRofB, there are inconstancies in biogas production (PEREIRA et al., 2009).

The use of biodigesters to treat swine effluents is a valuable solution for reducing the environmental impacts generated by the industry, promoting proper ecological sanitation, and avoiding methane emissions directly into the atmosphere (FERNANDES, 2012).

Policy: In Brazil, biomethane specifications are regulated by the ANP, by Resolutions No. 8/2015, No. 685/2017, and, later, by No. 858/2020. ANP Resolution No. 8/2015 establishes the specifications of biomethane from agroforestry and commercial organic waste intended for vehicular use, residential, and commercial installations in Brazil. Biomethane is thus defined as a gaseous biofuel derived from biogas purification. This Resolution also stipulates the rules for usage and quality control of biomethane production throughout the national territory (ANP, 2015). ANP Resolution No. 685 establishes the rules for approving the quality control of biomethane from landfills and sewage treatment plants intended for vehicular use, residential, industrial, and commercial facilities throughout the national territory, updating the ANP Resolution No. 8/2015. This Resolution waives the obligations of quality control of biomethane for electricity generation purposes (ANP, 2017). ANP Resolution No. 828/2020, which provides the necessary information in the quality control documents and data submission to the ANP, updates the previous Resolutions (ANP, 2020).

In 2017, Law No. 13.576/2017 instituted the National Biofuels Policy (RenovaBio). This policy aims to contribute to the Paris Agreement under the United Nations Framework Convention on Climate

Change, promoting an adequate production of biofuels and increasing their participation in the Brazilian energy matrix, aiming to reduce greenhouse gas emissions (BRAZIL, 2017). In general, RenovaBio's principle is to encourage technological development and innovation through the following devices: Decarbonisation Credits, certification of biofuels, compulsory additions of biofuels to fossil fuels, and tax, financial and credit incentives (DELGADO et al., 2017).

At the state level, the three southern states have their own regulations. PR has Law No. 19.500/2018 that created the State Biogas and Biomethane Policy, in which the public authorities promote the production and consumption of biogas and biomethane by establishing rules and encouraging production chains to decompose organic matter. According to the state Secretary for the Environment at that time, the objective of the law was to provide legal certainty for entrepreneurs who wished to invest in the sector and develop it through renewable energy (PARANÁ, 2018).

SC instituted the State Biogas Policy (Law No. 17.542/2018) to protect the environment by minimizing the impacts of animal protein production in the state. SC also encourages biodigestion of animal, urban and industrial waste (SANTA CATARINA, 2018). RS instituted the State Biomethane Policy in 2016 (Law No. 14.864/2016) to promote research and development of biomethane, attracting investments for infrastructure and proper disposal of organic waste (RIO GRANDE DO SUL, 2016).

Market: Biogas can generate electricity, thermal energy, or biomethane (PROBIOGÁS, 2016). When meeting the specifications established by ANP Technical Regulation No. 1/2015, biomethane may be mixed with natural gas (ANP, 2015), both sources competing for the same consumer market. Hence, biomethane can be sold in compressed gas or directly injected into the natural gas grid (DELGADO et al., 2017). Thus, as the region is dependent on Bolivian natural gas (MME, 2020a), the increase in the supply of biomethane in the market could reduce this dependence and increase the competitiveness of the industry as a whole through a more attractive final price.

The electricity produced from biogas can be monetized both in its commercialization in captive markets (by public auctions) and free markets or in distributed generation, where the energy will be consumed in the same place where it is generated (DELGADO et al., 2017). From the swine farmer's point of view, even if the initial generation of electricity from biogas is not on a large enough scale for commercialization, it is possible to use it for the internal supply of the property/company, reducing costs with energy. The same logic is valid for the generation of thermal energy (FERNANDES and MARIANI, 2019).

SRofB is currently inserted in a favorable regulatory environment for biogas in the region, from national initiatives, such as the RenovaBio program, to specific state policies related to the biogas chain, promoting greater legal certainty for entrepreneurs in the sector. On the other hand, the stakeholders perceive the need for a sector union to attract more investment in the biogas industry (SEBRAERS, 2018). Difficulty in accessing technical, commercial, and legal information and the uncertain relationship between cost and commercial benefit of projects are some of the barriers to developing a more competitive biogas market in Brazil (PROBIOGÁS, 2016).

Table 3 summarizes the primary information presented in this section as a SWOT matrix, with the attribution of strengths, weaknesses, opportunities, and threats for biogas from swine effluents e in Southern Brazil.

Table 3 - SWOT Matrix for Biogas from Swine Effluents in the SRofB

	Resources		**Technology**	
	Strengths	Weaknesses	Strengths	Weaknesses
Internal Factors	- Renewable resources - Expressive herd of swine. - The most significant potential for biomethane generation in the country (from swine production).	- Generation potential is not as significant as non-renewable sources.	- Relatively consolidated technologies in the sector. - Flexibility in the use of anaerobic digestion final products. - Promotes environmental protection.	- Lack of technological devices to contain the intermittence of biogas.
	Policy		**Market**	
	Opportunities	Threats	Opportunities	Threats
External Factors	- Alignment of the federal and state governments in stimulating the generation of biogas. - Positive regulatory environment. - Pioneering of the region in creating policies to stimulate biogas and biomethane production.	- No threats regarding policy were identified.	- Flexibility use of products generated after the anaerobic digestion. - Strong commitment in the region to develop the market.	- Intermittence of biogas production depending on the seasons of the year. - Lack of an industry union to attract more investments. - Competition with other uses for biogas

5. DISCUSSION

This work has compared three potential gaseous energy resources with high methane concentrations in the SRofB. Even though some sources may seem more promising than others, it is essential to note the diversity of unconventional energy alternatives available in

SRofB, fossil and renewable. We evaluate the effects that the new gas law No. 14.134/2021 could contribute to the downstream gas sector, allowing new entrants to the existing infrastructure.

Table 4 shows a summary of the potential production volume of each resource. Among the three gaseous energy sources analyzed in this work, the shale gas present in the Ponta Grossa formation of the PSB was the most considerable amount of available resources in the short and medium-term, followed by coalbed methane from the Rio Bonito formation. Biomethane from swine substrate has a smaller annual production potential, but it is a renewable source.

Table 4 - Methane gas production potential in southern Brazil by resources

Resource	States with greater potential	Methane gas volume (in millions of m³)	Reference
Shale gas – Ponta Grossa Formation	PR	2,270,000.00	EIA (2015b)
Coalbed Methane – Rio Bonito Formation	SC, RS	6,800.00	Kalkreuth et al. (2008), Levandowski (2013)
Biogas from swine effluents (Renewable source, annual value)	PR, SC, RS	566.10	Oliveira (1993), Probiogás (2015)

The hydraulic fracturing technique for extracting shale gas and, in some cases, coalbed methane has been on the market for a long time. However, its usage is associated with some environmental impacts, which were highly relevant and directly affected the public perception of PR. The public and private sectors' encouragement of research and development could minimize these impacts and improve the technique currently used, enabling a reassessment of the restrictions imposed on fracking.

Biogas generation by swine effluents showed great potential in southern Brazil due to the vast technological knowledge regarding biodigesters that use animal production waste as substrate and the large pork production in the region. Furthermore, compared to the hydraulic fracturing technique, anaerobic digestion is viewed by the public as a solution to the environmental liabilities which directly affect their opinion.

The insertion of all three gaseous energy sources studied in this work in the natural gas market of the SRofB could significantly contribute to the development of the regional market. Incentive policies might increase price competitiveness, decrease dependence on foreign natural gas and improve the productivity of the local industry. However, investments in infrastructure for natural gas distribution are essential for more significant ramifications and the efficiency of southern gas pipelines.

6. CONCLUSION

We concluded that the technology used to explore the energy resources would directly influence policy and market issues, being a determining factor for the viability of each energy source. Public and private investments in research and development are essential for deploying new methods for risks mitigation to technologies with high risks of environmental impacts. The inclusion of the local community in the public debate will be crucial to avoid future legal problems, clarify any doubts and insecurities from residents, and create greater legal comfort for the investors. Specific regulation should provide each energy source with a more transparent and objective consolidation of the federal government and state competence. This definition would bring better stability, confidence, and predictability to the market.

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