CHAPTER 8

SUSTAINABILITY ANALYSIS OF BIOGAS PRODUCTION AND ITS BARRIERS WITHIN THE BRAZILIAN LEGISLATIVE FRAMEWORK

Acceptance date: 01/12/2023

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ABSTRACT: In Brazil, production growth and the transition to renewable energy have been driven by specific government policies, environmental regulations, and tax incentives. Biogas is considered a promising alternative for renewable energy development, making it crucial to analyze standards and regulations for its production. This chapter presents an exploratory, descriptive, and bibliographic review of the government policies development in Brazil related to the dissemination of biogas production technology and how these regulations directly affect sustainability aspects. The results reveal several lacks of clarity and standardization within the biogas legislative framework, potentially leading to uncertainty, misunderstandings, and misinterpretations. Economically, costs impact biodigester development, with lacking government financial mechanisms affecting farmers, especially small agricultural and small-scale biogas producers. On the other hand, fiscal incentives are crucial for renewable energy. Socially, limited awareness hampers biogas technology acceptance and performance, hindering public and political support. Environmentally, biogas offers cleaner energy and emission reduction, so its non-implementation can affect the country's goals. Thus, the gaps within the legislative framework strongly affect the sustainability pillars of the biogas and biomethane production system.
KEYWORDS: barriers, biogas, legislative framework, sustainability.

1. INTRODUCTION

The interest and importance of global warming and the reduction of greenhouse gas (GHG) emissions have grown (Etminan *et al.*, 2016). These issues occupy prominent positions on the

political agendas and regulatory frameworks of several countries worldwide (Rogelj *et al.*, 2016), leading many scientists to call for immediate changes in existing energy systems (Nevzorova and Kutcherov, 2019). Thus, the search for and acquisition of new renewable energy sources and biofuels has intensified.

The three main gases that contribute to GHG emissions are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Worldwide, anthropogenic activities cause 50% of the total methane emitted, which is released by the decomposition of biogenic material from landfills, municipal wastewater, and agricultural and industrial activities (Nevzorova and Kutcherov, 2019).

Methane is the main gas in biogas (Hajjaji *et al.*, 2016; Poeschl *et al.*, 2012). Biogas can be produced through anaerobic digestion, a bioconversion process of organic substances, especially biomass residues (Yu and Schanbacher, 2010; Singh *et al.*, 2020).

Biogas is considered a promising alternative for the development of renewable energies (Rose *et al.*, 2014; Thrän *et al.*, 2020) and can be burned in heating systems (Abanades *et al.*, 2021) or when purified into biomethane, used as fuel in vehicle engines (Robin *et al.*, 2014). Furthermore, cogeneration plants can use biomethane to generate electricity, which can be used directly by the producer to meet their internal demand or sold (Sukun *et al.*, 2020. Kucher *et al.*, 2022).

Although it has several applications and is an important source of renewable energy, the full potential of biogas can only be exploited sustainably if its production and use are properly regulated (Popp *et al.*, 2014; Abanades *et al.*, 2021).

Biogas production has environmental, economic, and social benefits. However, it can affect other aspects, such as quality, global carbon and nitrogen cycles, competitive uses of raw materials, land use conversion in areas less suitable for sustainable agriculture, and land use changes (Thrän *et al.*, 2020).

Worldwide, the barriers study to implement biogas production technology has been growing rapidly. Mukeshimana *et al.* (2021) addressed the gaps in the literature focusing on the main barriers for the adoption of family biodigesters in Rwanda. Nevzorova and Kutcherov (2019) conducted a comprehensive barriers assessment of biogas wider adoption, aiming to understand the main challenges that currently hinder the adoption of biogas as an energy source. On the other hand, a comprehensive review about the recent progress in biogas technologies focuses on the advances in waste conversion to produce electricity, heat, and other forms of energy was performed by Abanades et al. (2021). Alvarez *et al.* (2019) investigated the hypothesis that more flexible and up-to-date regulations on renewable energy would have a positive impact in Peru. Their research considered the disparity between the slow advancement of regulations and the faster progress of science and technology. Thrän *et al.* (2020) investigated how sustainable has been managed during the German development, the biogas market.

Most resources used for biogas production are from the agricultural sector (Nevzorova and Kutcherov, 2019). In Brazil, livestock is one of the main economic activities of the country and the main source of environmental pollution in rural areas (Potenza *et al.,* 2021). Therefore, legislation for producing biogas and biomethane as a renewable energy source is related to different economic sectors.

However, a study has not been published focused on the failures of the legal framework in Brazil regarding the production of biogas and biomethane. Thus, this chapter explores the development of government policies in Brazil that relate to the dissemination of biogas production technology and how these regulations directly affect social (agribusiness: farmers and producers of raw materials), economic, and environmental aspects, putting their sustainability at risk.

2. METHODOLOGY

In the Brazilian context, a comprehensive analysis of the norms and incentives for the biogas sector over decades is essential to understand its legislative evolution, development, and challenges. The trajectory from the 1970s to the present day allows for a panoramic view, highlighting both the progress and the gaps in legislation related to this biofuel.

The research methodology includes an exploratory, descriptive, and bibliographic review to collect political information and the legislative framework related to biogas production in Brazil.

Initially, a systematic literature review on Brazilian legislation was developed using the databases of Google Scholar, Capes Journals, Web of Science, government and official websites of different institutions, websites of legally established Brazilian companies and associations, and leaders in research related to biogas and biomethane. The following keywords were used separately and in random combinations in Portuguese: *"Histórico", "Historia", "Leis Brasileiras", "legislação", "Brasileira", "Biogás", "biofertilizantes", "Brasil"*; and in English: "Brazilian", *"Brazil", "Laws", "Legislation", "Biogas", "Biofertilizer", "Historical"*.

To understand the evolution of Brazilian laws, a time interval from the 1970s to 2022 was considered. All statutes, normative resolutions, decrees, and bills that could directly or indirectly influence the development of the biogas market and its effect on the sustainability of the process were analyzed. Direct influence includes those standards that textually name biogas or its production process and affect its entire chain. Indirect influence refers to those standards that affect the use, sale, and distribution of products, such as the sale of energy from renewable sources. State and government regulations on the production of renewable energy, electricity, solid waste, and the environment were considered, as they are correlated with the production of biogas.

After exploring the national legislation trajectory, the shortcomings and failures of existing legislation to encourage the biogas production were analyzed. In addition, efforts

were made to understand how the development of government policies in the country related to the dissemination of biogas production technology as well as the federal legal framework and state regulations directly affect the pillars of sustainability (Rogelj *et al.*, 2016).

3. EVOLUTION OF BRAZILIAN BIOGAS LEGISLATION

Since the 1970s and 1980s, highlighted by the Stockholm Declaration in 1972 and the First World Climate Conference in 1979, the severity of climate change has been recognized, and global concern has grown about the implementation of the Clean Development Mechanism and the reduction of GHG emissions. According to Johon (2010), the 1970s also witnessed a renewed emphasis on the energy issue, driving change in the world energy model toward greater diversification through the use of alternative and renewable energy sources.

In Brazil, the oil crisis beginning in 1979 aroused the government's interest in biogas production due to the low cost of deploying biodigesters (CIBiogás, 2023a). This emerging technology, internationally highlighted for the mitigation of environmental impacts and waste treatment, led to the creation of the Energy Mobilization Program (PME – *Programa de Mobilização Energética*), approved by Decree No. 87,079/1982. Biogas and biomass were mentioned as a second priority and a local solution for power generation, aiming to progressively replace petroleum products with alternative fuels produced in Brazil. However, due to the lack of technical knowledge about biodigester technology and the shortage of specialized labor, operational problems arose, leading to the abandonment of the technology a few years later (CIBiogás, 2023).

In the 1990s, the National Program for Family Agriculture (PRONAF – *Programa Nacional para a Agricultura Familiar*) was created by Decree No. 1,946/1996 to promote sustainable development in family farming. Offering the lowest interest rates on rural financing and having low default rates, the PRONAF is implemented by public and private banks, the National Bank for Economic and Social Development (BNDES – *Banco Nacional de Desenvolvimento Econômico e Social*) and rural credit cooperatives. It is present in almost all Brazilian municipalities. Within PRONAF, the Technical Assistance and Rural Extension subprogram (ATER - Assistência Técnica e Extensão Rural) seeks to foster income generation through activities that encourage farmers to produce biofuels, among other activities.

In the 21st century, the Brazilian agricultural sector has shown significant interest in biogas production, driven by the enormous generation of manure, especially in pig farming (Lima, 2007), and by the opportunity to participate in the carbon credit market. The second edition of the National Environmental Program (PNMA II, 2000 - edition II – *Programa Nacional do Meio Ambiente*) was established in 2000. This program facilitated the implementation of environmental projects in pig production, exemplified by the Santa Catarina Pig Farming

project, which constructed two biodigesters on pig-producing properties to demonstrate and encourage the adoption of this technology (Lima, 2007).

In this century, biogas production technologies have gained momentum in Brazil, with rapid growth evidenced by several studies (Kunz *et al.*, 2016; CIBiogás, 2021; ABEEólica, 2020). These technological advances stimulated research, structured government policies, development of laws, programs, and finally, economic and tax incentives. A notable example of this interest in the energy sector is Statute No. 9,991/2000, which promotes investments in research and development, as well as energy efficiency by companies in the electricity sector. In addition, the legislation encourages research into systems that generate renewable energy.

In 2002, the Incentive Program for Alternative Energy Sources (PROINFA – *Programa de Incentivo* às *Fontes Alternativas de Energia*) was established to increase the participation of renewable sources, such as small hydroelectric plants, wind power plants, and biomass thermoelectric projects, in the production of electricity. The program, governed by Statute No. 10,438/2002, favors entrepreneurs without corporate ties with generation, transmission, or distribution companies. According to Eletrobrás (2023), PROINFA is considered the largest global program to encourage alternative sources of electricity.

Through the program, a significant improvement in biogas production occurred in 2004. However, this renewable source still played a secondary role behind conventional sources, such as hydroelectricity and fossil fuel thermal power plants (Correa, 2015). Even with an improvement in the biogas production sector, until 2005, no state had created regulations that facilitated the development of this technology.

In 2006, the National Agroenergy Plan (*Plano Nacional de Agroenergia*) was established to promote less use of fossil fuels, expand the production and consumption of biofuels, protect the environment, explore the international market, and contribute to social inclusion (MAPA, 2006).

The pioneering Solid Waste Policy of the state of São Paulo (Statute 12,300/2006) encouraged and increased interest in using solid waste to generate energy and fuel from renewable sources. With this policy, the treatment and final disposal of the various wastes generated by society began to boost the development of new technologies, research, and regulations involving biogas and other renewable sources.

In the field of renewable energy, the state of São Paulo (SP), through Decree No. 51,736/2007, which established the Special Bioenergy Commission of the State of São Paulo sought to organize the necessary attributions and governmental actions for the development of renewable energy generation activities in the state, including subsidies, evaluations, research, and the preparation of the State Bioenergy Plan. This decree prioritized the production of renewable energy from biodiesel and ethanol; however, it did not directly cover biogas due to the greater volume of studies, development, production, and marketing of these biofuels (Sánchez *et al.,* 2017; REN21, 2020).

The company Paranaense de Energia (COPEL) in the state of Paraná began to be interested in distributed micro- and mini-generation. It constructed a plant connected to the low-voltage network that generates and distributes electricity from biogas generated by properly managing organic waste from animals raised on small farms (Sapatel, 2020). Furthermore, through Resolution No. 1,482/2008, a pioneer in Brazil in recognizing biogas as an energy source, the Distributed Generation Program with Environmental Sanitation (*Programa de Geração Distribuída com Saneamento Ambiental*) was authorized, presented by COPEL as a pilot project for the implementation of low voltage distributed generation (DG) lasting six months, marking incursions by the sector.

In 2009, the state of Maranhão instituted Statute No. 8923/2009. This regulation encourages the use of energy from any potential source linked to the services, including energy from biogas resulting from sanitary sewage treatment and treatment or final disposal of solid waste.

In the same year, a partnership was formalized between the Itaipu Technological Park (PTI - Parque tecnologico de Itaipu) and the Brazilian Agricultural Research Corporation (Embrapa – *Empresa Brasileira de Pesquisa Agropecuária*) to develop the Biogas Laboratory (CIBiogás, 2023a). PTI implemented the program of energy applications from renewable sources in DG for biogas, validated by Authorizing Resolution No. 1,482/2008 of the National Electric Energy Agency (ANEEL– *Agência Nacional de Energia Elétrica*) (CIBiogás, 2023a). Another pilot project, approved through this resolution, is the *Granja São Pedro* project of the Colombari family. This innovative project in Brazil uses biogas as a raw material to generate electricity for DG (CIBiogás, 2023a; Sapatel, 2020).

Until that time in the history of biogas, most of the advances made in the country had been developed in the south region. The regulations related to renewable energies emphasized the individual support of each state, and biogas was not considered a primary energy source. Thus, in the period between 2000 and 2010, Brazil gained a better understanding and learned about biogas production technology.

After 2010, more specific policies for generation of biogas and renewable energy emerged, such as the creation of the Renewable Energy Observatory for Latin America and the Caribbean (*Observatório de Energias Renováveis para América Latina e Caribe*), resulting in the formation of the Center for Biogas Studies (CEB *Centro de Estudos do Biogás*), through a technical partnership between the United Nations Industrial Development Organization (UNIDO), Itaipu Binacional, and Eletrobrás (FIERP, 2023).

The Low Carbon Agriculture Program (ABC - *Plan Centro de Estudos do Biogás*) was established and approved, as defined in Decree No. 7,390/2010. This program aimed to organize and plan the adoption of sustainable production technologies. It was designed to meet the country's commitments to reduce GHG emissions in the agricultural sector (MAPA, 2012). With national coverage and valid from 2010 to 2020, the ABC Plan is recognized as the largest plan to promote sustainable technologies in the agricultural and forestry sectors

worldwide. Due to its successes, the program was extended for another 9 years from 2021 to 2030 (GovBr, 2021).

The ABC Plan consists of several programs. However, according to Embrapa (2021), the program for the recovery of degraded pastures and the treatment of animal waste (pig and dairy farming), despite technological advances, has faced challenges in its development, installation, and improvement because its improvement goals have not been met.

The year 2012 was important for electricity from renewable sources, including biogas. The ANEEL prepared Normative Resolution No. 482/2012, to establish the general conditions for the access to electricity distribution systems by micro- and mini-generation. With the implementation of this resolution, considerable advances occurred in the field of micro- and mini-generation of energy. The Electricity Compensation System enabled Brazilian consumers to generate their own electricity from renewable sources (Sapatel, 2020). Furthermore, the surplus could be supplied to the local distribution network in exchange for energy credits (Correa, 2015). Thus, the system further motivated the production of energy from biogas, because when generated in decentralized areas and its surplus marketed, it is considered a sustainable solution and compliant with the circular economy, transforming an environmental liability into an energy asset.

In Paraná, under Statute No. 17,188/2012, rural landowners could sell to COPEL the electric energy generated by small generators using renewable energy sources. In the state of São Paulo, the São Paulo Biogas Program and its Managing Committee Program were established by Decree No. 58,659/2012. The objective of this program was to encourage and expand the participation of renewable energies in the state's energy matrix, highlighting the positive externalities of generating fuel gases from biomass. The state of Rio de Janeiro created a state renewable natural gas policy in Statute No. 6361/2012, which provides incentives for generating fuel from organic waste by transforming it into biogas to help reduce the production of greenhouse gases in the state.

The state of Minas Gerais passed legislation directly related to biogas production, Decree No. 46,296/2013, dealing with the Mineiro Renewable Energy Program and establishing measures to encourage the production and use of biogas and biomethane as renewable energy. In Paraná, the International Renewable Energy Center (CIBiogás – *Centro Internacional de Energias Renováveis*) was incorporated, becoming a center of competence at the PTI. In Pernambuco, Decree No. 39,059/2013 granted incentives to the company Gases Renováveis do Brasil LTDA. In São Paulo, Decree No. 59,038/2013 established the São Paulo Biofuels Program. In Espírito Santo, Decree No. 3,453/2013 provided a state policy to encourage renewable energies, including wind, solar, biomass, and other renewable sources, and aimed to appropriately adapt the treatment of organic waste and economically exploit biomethane generated in landfills. It also sought to integrate biomethane into the natural gas network to distribute this resource in the state.

The Brazilian Association of Biogas and Biomethane (ABiogás – *Associação Brasileira de Biogás e Biometano*) was created in 2013 to foster the country's potential production of energy and fuel from agricultural waste, landfills, sanitary effluents, and animal waste from slaughterhouses and dairy products. Currently, ABiogás is a consolidated science and technology institution that drives the sustainability of the sector and makes it more competitive, covering regulatory environment analysis and public policies (Abiogás, 2023).

In 2014, Paraná implemented Decree No. 11,671/2014, which established the Paraná Renewable Energy Program – Illuminating the Future (*Programa Paranaense de Energias Renováveis – Iluminando o Futuro*) and includes measures to stimulate the production and use of renewable energy. Simultaneously, the CIBiogás association launched the Biomethane Mobility Project to reduce GHG emissions using biomethane as a vehicle fuel (CIBiogás, 2023b).

Enacted in 2015, National Agency of Petroleum, Natural Gas, Biofuels (ANP *Agência Nacional do Petróleo, Gás Natural e Biocombustíveis*) Resolution No. 8 specified the characteristics of Brazilian-produced biomethane intended for commercialization throughout the country. Subsequently, Normative Resolution No. 687/2015 was implemented to improve the guidelines established by Resolution No. 482/2012, enabling the installation of small generating plants and allowing the credits to be attributed to producers when the amount of energy they produce exceeds the energy consumed (SUNENERGIA, 2017).

Santa Catarina, in Decree No. 233/2015, created the Santa Catarina Clean Energy Program (SC+ENERGIA Program – *Programa Catarinense de Energias Limpas*), whose main objective was to provide guidelines for using waste, such as feces and urine from livestock, especially in pig farming, to generate energy through biodigesters. In addition to solve environmental issues, this new policy aimed to provide farmers with an additional source of income and diversify the energy matrix in Santa Catarina.

In 2016, the Biogasfert project was implemented by a consortium composed of Embrapa, PTI, CIBiogás, and the International Hydroinformatics Center (CIH - *Centro Internacional de Hidroinformática)*, currently known as the Territorial Intelligence Center (*Núcleo de Inteligência Territorial*). The objective of the project was to promote studies and technological solutions for the integrated use of biogas, biofertilizers, and other organic minerals derived from animal waste from different agricultural production systems, concentrating these advances mainly in Brazilian South region (CIBiogás, 2023a).

In the state of Rio Grande do Sul, Statute No. 14,864/2016 established the Institute of State Policy on Biogas and Biomethane as well as the Gaucho Program to Encourage the Generation and Use of Biogas and Biomethane (RS-GÁS – *Programa Gaúcho de Incentivo à Geração e Utilização de Biogás e de Biometano*). This was the first specific law to promote the generation, production, marketing, transport, and use of biogas and biomethane; energy production; and vehicular fuel to care for the environment and reduce GHG emissions. In the state of Piauí, Statute No. 6901/2016 created the Piauí Clean Energy Development

Incentive Program (PROPIDEL – Programa Piauiense de Incentivo ao Desenvolvimento de Energias Limpas), aiming to encourage biogas production in the state of Piauí through the installation of biodigesters on rural properties. In Roraima, Statute No. 1109/2016 created the State Policy to Encourage the Generation and Use of Solar, Wind, and Biomass Energy. The main objective of both these laws is to encourage the production and use of clean energy sources in the respective states, promoting economic development and environmental sustainability.

Thus, between 2010 and 2016, Brazil made significant progress in the biogas sector, with notable advances in technologies, regulatory frameworks, research, and project development (EPE, 2017a). The share of biogas in the Brazilian energy matrix grew from 0.01% to 0.05%, representing an increase of 400%. In 2016, biogas accounted for 1% of the total energy supply in the country, standing out compared to other energy sources derived from biomass (EPE, 2017a)

In 2017, the federal RenovaBio program was implemented, characterized as the National Biofuels Policy, an initiative of the Ministry of Mines and Energy (MME – *Ministério de Minas e Energia*). This program aimed to "encourage and expand the production and participation of biofuels in the transport energy matrix of the country, based on environmental, economic, and social predictability and sustainability, establishing annual national decarbonization targets" (EPE, 2017b). Statute No. 13,576/2017 established the program and provided specific incentives for the large-scale biogas production (Stilpen *et al.*, 2018).

The ANP established Resolution No. 685/2017, which defines rules for the quality control and specifications of biomethane produced from landfills and wastewater treatment plants, intended for use in vehicles and residential, commercial, and industrial facilities throughout the national territory. This measure allows appropriate parameters for the commercialization of biogas nationwide.

The implementation of regulations, programs, plans, and incentives for biogas production in Brazil marks a new phase for the sector, enabling its commercialization as a substitute for natural gas. These measures boost the development of a new economic activity and the entry of new agents into the market while promoting sustainable practices.

In 2018, the state of Paraná sanctioned the new State Policy on Biogas, biomethane, and other by-products generated from the decomposition of organic matter through biodigestion in Statute No. 19,500/2018. The main objective of this law is to establish principles, rules, obligations, and instruments for the organization, encouragement, supervision, and support of integrated or non-integrated productive chains, addressing climate change and promoting regional development sustainably. The regulation establishes the production chain for biogas, biomethane, and products related to the decomposition of organic matter (biodigestion) as a set of activities and endeavors interconnected by contractual relations.

In the same year, Santa Catarina instituted its State Biogas Policy based on Statute No. 17,542/2018. Santa Catarina's state policy is comprehensive, including incentives to reduce GHG emissions, purify biogas, use biomethane as a vehicle fuel, and manage the by-products of anaerobic digestion. In addition, Statute No. 302/2018 aimed to encourage companies that produce biogas, methane, and electricity from solid waste in landfills in Santa Catarina. The state of Minas Gerais, in Statute No. 5,240/2018, established the State Biogas and Biomethane Policy and the state of São Paulo with Decree No. 46,476 regulates Law No. 16,001, which establishes the state policy to encourage the development of the productive chain in the biogas and biomethane.

In Rio Grande do Norte, Statute No. 10,338/2018 guides the State Policy on Distributed Generation with Renewable Energies (GDER- Política Estadual de Geração Distribuída com Energias Renováveis). The project Applications of Biogas in the Brazilian Agroindustry, aims to reduce GHG emissions and dependence on fossil fuels. This project promotes the use of biogas in energy generation and mobility solutions in agroindustrial chains in southern Brazil, strengthening the value chain of biogas technology nationwide.

The Panorama of Applied Technologies in the Agribusiness of Biogas and Biomethane (*Panorama de Tecnologias Aplicadas no Agronegócio de Biogás e Biometano*) (MARTINEZ; BÜHRING; MÜLLER, 2019) was released in 2019, providing data on five specific plants, their biodigestion systems, and the technologies used to treat biogas. In addition, the first report on the Biogas Production Potential in Southern Brazil was presented in collaboration between CIBiogás, Embrapa, the UNIDO, the Global Environment Facility (GEF), Itaipu Binacional, the Ministry of the Environment (MMA *Ministério do Meio Ambiente*), the MME, the Ministry of Agriculture, Livestock, and Food Supply (MAPA – *Ministério da Agricultura, Pecuária e Abastecimento*), and the Ministry of Science, Technology, Innovations, and Communications (MCTIC – *Ministério da Ciência, Tecnologia, Inovações e Comunic*ações). The state of Mato Grosso proposed Bill No. 640/2019, addressing the State Policy for Biogas and Biomethane, with additional measures.

In 2020, many of the legislative procedures to incentivize biogas incentives were impacted by the COVID-19 pandemic, resulting in delays. However, both the federal government and the state of Goiás enacted significant initiatives: Bill No. 2193/2020 and Statute No. 20,710/2020, respectively, establishing the Biogas and Biomethane Policy. In addition, the ANP Resolution No. 828/2020 provided information contained in the quality documents and the sending of quality data of fuels produced nationally or imported.

In 2021, Paraná stands out in creating regulations to boost the biogas and biomethane production. Ordinance 118/2021 established technical guidelines for the Paraná Renewable Rural Energy (RENOVAPR – *Paraná Energia Rural Renovável*) program, an integral part of the state agricultural policy for economic and social development. This program plans to promote the DG of electricity, encouraging the production of biogas and biomethane in the state's rural production units.

The state of Maranhão proposed Bill No. 542/2021 to institute its State Biogas Policy. In Rondônia, Bill No. 3791/2021 sought to establish incentives for the energy utilization of biogas originating from sewage and solid urban waste management activities. In Minas Gerais, Bill No. 3865/2021 includes the Incentive Program for the Production and Use of Biogas, Biomethane, and Associated Co-products (PIBB – Programa de Incentivo à Produção e ao Aproveitamento de Biogás, Biometano e Coprodutos Associados), including indication of co-products, such as digestate. São Paulo also proposed Bill No. 3865/2021 to establish its PIBB.

The recently approved Statute No. 14,134/2021 expanded the regulatory standards originally intended to advance natural gas projects to cover other gases, including biogas. This inclusion aligns with the strategic plan to boost the natural gas sector. In addition, Decree No. 10,712/2021, which regulates the new Gas Law, stipulates that all gases interchangeable with natural gas must receive equivalent regulatory treatment.

Following the lockdowns during the pandemic, the resumption of activities highlighted the importance of renewable energies. Cozzi et al. (2020) noted that this period emphasized the search for fuels, technologies, and structural and governmental changes, including the implementation of new legislation to regulate energy production.

Following the post-pandemic transition phase, several measures were implemented to boost the renewable energy sector, especially regarding biogas and biomethane production. They include Statute No. 14,300/2022, which established the legal framework for distributed micro-generation and mini-generation, the Electric Energy Compensation System (SCEE – *Sistema de Compensação de Energia Elétrica*) and the Social Renewable Energy Program (PERS – *Programa de Energia Renovável Social*), mechanisms that are based mainly on renewable energy production, including biogas.

The National Methane Emission Reduction Program (Metano Zero – *Programa Nacional de Redução de Emissões de Metano*) (MMA ordinance No. 71/2022), the Federal Strategy to Encourage the Sustainable Use of Biogas and Biomethane (*Estratégia Federal de Incentivo ao Uso Sustentável de Biogás e Biometano*) (Decree No. 11,003/2022), and the temporary authorization for the company Cocal Energia S.A. to market biomethane with different specifications (ANP Authorization No. 547/2022) were established. ANP Resolutions No. 886/2022 and No. 906/2022 define specifications and rules for quality control of biomethane from landfills, sewage treatment plants, and organic products and waste, intended for vehicular and residential use, respectively, aimed at their commercialization throughout nationwide.

Pernambuco established a state policy to encourage the generation of renewable energy by rural producers in Statute No. 18,111/2022. Ceará addressed its biogas production and use with Resolution No. 16/2022. Rio Grande do Sul, through Decree No. 56,348/2022, established the Incentive Program for the Generation and Use of Biogas for Electricity Generation (BIOGÁS-RS – *Programa de Incentivo à Geração e Utilização de*

Biogás para Geração de Energia Elétrica). The state of Goiás established the state policy to encourage the use of biomass for the generation and cogeneration of renewable energy through Statute No. 21,737/2022. The state of Mato Grosso do Sul implemented the State Program to Encourage the Development of Renewable Sources of Electricity Production (MS Renovável- *Programa Estadual de Incentivo ao Desenvolvimento das Fontes Renováveis de Produção de Energia Elétrica*) through Decree No. 16038/2022.

3.1. BRAZILIAN TAX INCENTIVES

In addition to the legislation, tax incentives are also needed to encourage the installation and use of new technologies such as biogas and biomethane production. In Brazil, the decrees that present these incentives began in the 2010s.

In Piauí, Decree No. 14,861/2012 defined the guidelines for granting the Environmental Seal to municipalities in line with Ordinary Statute No. 5,813/2008, recognizing biogas production as an alternative for waste treatment and energy generation.

With Tax on Circulation of Goods and Services (ICMS - *Imposto sobre Circulação de Mercadorias e Serviço*s) Agreement No. 112/2013, economic incentives began to be provided to the states of Bahia, Mato Grosso, Rio de Janeiro, and São Paulo that reduced the calculation basis of the ICMS for internal biogas and biomethane outputs.

Several states have adhered ICMS Agreement No. 16/2015 of the National Council of Finance Policy (*Conselho Nacional de Política Fazendária*), which exempts internal electricity-related operations to encourage bioenergy production, especially from biomass and biogas.This agreement aims to ensure equitable conditions between companies importing products and those producing them domestically (Rosa, 2018).

ICMS Agreement 6/2016 authorized the states and the Federal District to grant exemption from ICMS in biogas operations when used as fuel in internal combustion engines or gas turbines.

The creation of ICMS Agreements led different Brazilian states to join the implementation of these agreements and to create their own regulatory frameworks that exempt biogas, as shown in Table 1.

These agreements and regulations reduce the ICMS tax base for internal biogas and biomethane outputs, establishing a tax burden of 12% on the value of the operation; defer the ICMS in operations with machinery and equipment for capturing solar energy; exempt biogas from landfills from the ICMS; and reduce the ICMS tax base for internal biogas and biomethane outputs.

Year	State	Regulation
2016	Bahia, Mato Grosso, Rio de Janeiro, and São Paulo	ICMS Agreement No. 24
2018	Ceará	Decree No. 32,600
2019	Rio Grande do Sul	ICMS Agreement No. 13
2019	Pará	ICMS Agreement No. 19
2019	Paraíba	Decree No. 39,110 and ICMS Agreement No. 06
2022	Mato Grosso do Sul	Decree No. 16,027
2022	Goiás	Statute No. 21,555

Table 1. Regulatory exemptions for biogas by state.

4. LEGISLATION ANALYSIS

Roitman (2018) highlights that there is no established worldwide standard or ideal model for public and private policies in the renewable energy sector. Brazil also does not present a model. This scenario is even more apparent when it comes to biogas and biomethane production, as in Brazil, this renewable energy source has been growing and developing with significant advancements only since 2010.

In Brazil, the production growth and the transition to renewable energy have been driven by specific government policies, environmental regulations, and tax incentives (EBA, 2017). The standards or regulations are important for developing and implementing these policies. Regulatory Agencies play a fundamental role in establishing these standards by regulating, controlling, and supervising the activities in specific sectors, ensuring appropriate application (Desclaux, 2019). The policies creation and standards about the issue is influenced by the context, needs, and territory maturity (Mito, 2022). The country is advancing in its energy transition to reduce dependence on fossil fuels by increasing renewable energy matrixes. Between 1970 and 2022, approximately 175 regulations related to the generation of energy from renewable sources were identified, of which 29 are specific to the production of biogas, and 8 bills are still under evaluation.

The biogas sector lies within the legal frameworks of renewable energy (electricity and natural gas sector), sanitation (management of urban solid waste and effluents), the environment, and climate change. It is also subject to some regulations related to the agricultural sector. The biogas legislative trajectory evidences that the growth in the number of standards and regulations related to renewable energies, especially those associated with biogas, is correlated with the significant increase in the implementation and this resource production. This increase is primarily attributable to the growing awareness of the population about the importance of sustainability and the environmental impacts resulting from the inadequate organic waste disposal, which has considerable potential as raw materials for the bioenergy production (Bharathiraja *et al.*, 2018).

Interest in biogas production in the country is being driven by the low cost of implementing biodigesters, an innovative technology internationally adopted to mitigate environmental impacts and providing benefits in waste and byproduct treatment (Esteves *et al.*, 2019).

In the twenty-first century, biogas production technologies have spread rapidly in Brazil, boosting research, policy development, and implementation of economic and fiscal incentives. Between 2000 and 2009, the interest and expansion of biogas production increased in Brazilian agriculture. However, specific regulations for biogas were not established, as it was not seen as a significant source of energy production, maintaining a subordinate position compared to traditional sources such as hydroelectricity and thermoelectric plants powered by fossil fuels. Thus, between 2007 and 2010, decrees related to the production of renewable energy prioritized biodiesel and ethanol. This occurred due to a larger volume of studies in the research, development, and production of these sources, which were also the most traded in the Brazilian and global markets (Sánchez *et al.*, 2017). However, regulations on renewable energy emphasize the individual support of each state, giving them autonomy to establish their own energy policies.

Since 2010, the transition through a gradual reconfiguration of legislation has been motivated by the development of renewable energies and as a solution to local issues, emission reduction, and waste management. In this scenario, the growing interest in biogas was driven by projects financed by several non-governmental institutions to acquire new knowledge and the global sharing of information in the sector. A notable example is the project developed by UNIDO, Itaipu Binacional, and Eletrobrás with the objective of preventing eutrophication in the Itaipu lake. Important events in 2010 include the World Energy Conference in Vienna and the launch of the first Refresher Course on Biogas Energies (CIBiogás, 2023). In turn, this year, the National Solid Waste Policy (PNRS) was instituted through Statute No. 12,305. Brazil has been slightly behind in enacting legislative to regulate the proper treatment and final disposal of waste, as other Latin American countries issued the corresponding laws years earlier: Mexico (2003), Colombia (2008), Peru (2000), and Argentina (2003). The delay in the creation and establishment of these statutes can be considered a barrier to the development of cleaner technologies, the production of renewable energy from waste, and the reduction of waste generated by society.

In turn, the government created the Electricity Compensation System (SCEE – *Compensação de Energia Elétrica*) that authorized Brazilian consumers to generate their own electricity from renewable sources (SAPATEL, 2020). This begins to further open the market for energy produced from renewable energies.

In state terms, the first specific regulation for biogas was created in 2012 in São Paulo through Decree No. 58,659/2012, establishing the São Paulo Biogas Program.

The legal economic incentives began with the creation of the ICMS Agreement 112/2013. This agreement allowed for a reduction in the tax burden for projects, connections,

transportation, and electricity generation from biogas and biomethane (LIMA, 2022). Other states, including Goiás, Minas Gerais, and Bahia, have created specific laws related to ICMS taxation and special tax regimes to benefit biofuel producers.

However, agreements can generate a distortion in competition between companies in the sector, as not all have access to the same tax incentives, which can favor some to the detriment of others (GOV, 2022). The agreements are not clear and specific about who can obtain the tax benefits and do not establish amounts and percentages related to the acquired benefit. In this sense, regulatory frameworks provide greater clarity in defining who can participate in the markets, how they can participate, and under what conditions.

No statute guarantees that the government grants the benefits to the producer or buyer for a specific time. In addition, there is a risk that companies will use these incentives only to reduce costs and not to invest in technological and environmental improvements, compromising the quality and sustainability of biogas and biomethane production. Another point to consider is that these agreements are only temporary and can be revoked or modified at any time, which can generate legal uncertainty for investors (PCD, 2020; GOV, 2022). All these points are examples of the ambiguity in the legislation becoming important barriers to the development of the sector, causing negative impacts on competition, quality, and sustainability of the production of this bioenergy and legal certainty.

This chapter highlights that several statutes, decrees, and agreements in Brazil regulate biogas production, but the lack of standardization at both the state and federal levels is evident. The generalization of the term “renewable energy” in standards and programs makes it difficult to determine which technologies or resources are included in the definition when sources are not specified, which may result in gaps or inconsistencies in the implementation and compliance with energy policies. The lack of clarity could create uncertainty for investors, developers, and others interested in the industry. Therefore, renewable energy-related standards and programs must specify which technologies and resources are covered by the definition to provide a solid foundation for consistent implementation of related policies and regulations and to avoid misunderstandings or misinterpretations. Regulatory frameworks are fundamental to define the business environment and market models. This aspect is considered a challenge that prevents the biogas use as an energy source (Santos *et al.*, 2018).

According to BEP (2021), the diversity of the legal framework can lead to a lack of standardization and harmonization between standards. Therefore, it is crucial to identify which standard to apply and understand how it ensures compliance with all project requirements. Some state or federal standards have limited reach and scope, resulting in conflicts with other standards or not meeting the specific demands of each region or sector. In addition, the standards may have different technical requirements, administrative procedures, jurisdictions of the agencies responsible for the license, and mitigating and compensatory measures required for the environmental licensing of biodigesters with energy recovery from biogas.

From 2019 to the end of 2020, the years of the COVID-19 pandemic were stagnant years for many sectors, including the legislative sector. This period helped in understanding the importance of renewable energies, with an increase in regulations related to the area encouraging their generation.

In 2020, the Bill 2193/2020 was proposed, aiming to establish the Federal Policy for Biogas and Biomethane, seeking to encourage the production, research, and consumption of gases produced from organic waste (PCD, 2020). This bill is considered one of the most relevant for biogas and biomethane in the country until today. However, there is still a long way to go because, after more than 20 years of technological development in the country, the statute has only been proposed but not approved yet. Approval by the National Congress may result in changes or vetoes of the original text, which means that it is unknown when it may be approved, delaying the process of institutionalizing biogas production in subsequent chains.

Considering the provisions of Complementary Statute No. 205/2017, ARSESP Resolution No. 744/2017, Bill No. 3865/2021, Statute No. 5420/2021, Statute No. 2656/2022, Statute No. 11,190/2022, and Resolution No. 16/2022, the biogas that can be injected into the gas network and commercialized is exclusively biomethane. Thus, only facilities with a biogas purification process and access to the natural gas distribution network can sell the excess gas produced. This can cause economic problems for farmers, as many are in decentralized areas without access to gas pipelines, electricity, studies, and knowledge of technologies that can improve the current situation to meet the basic needs of the farm.

Power plants that can sell excess biogas or energy to the national distribution network are mostly considered large-scale enterprises because these systems require the integration of anaerobic digestion plants with the biogas purification steps and transformation into energy. This implies substantial investments in this production chain to achieve these products and economic benefits through the sale of energy, biomethane, and biofertilizer, in addition to obtaining environmental gains by avoiding the consumption of products from the national network.

On the other hand, farmers with low raw material production or more rudimentary and less technological biogas production technology could not reap an economic benefit from the sale of their products. In turn, their location far from centralized areas or gas pipeline and electricity grid connections makes it difficult to distribute biomethane and energy produced.

The projects developed on a large and small scale with farmers have faced a common difficulty – the lack of technical knowledge about the production process and skilled labor. Brunel (2023) identified that political instability, the lack of motivational factors, and limited environmental awareness are global causes for the shortage of professionals with skills to work in the energy sector. Although there are initiatives in Brazil to enter, enhance, and delve into the biogas sector, it is crucial to invest in the training and improvement of knowledge among the workforce, farmers, and the interested population, as well as allocate economic

resources for this purpose. Technological knowledge stands out as one of the most relevant aspects in the decision-making process for its implementation.

For the different investments made in the area, national development banks have been the major loan providers for the large-scale development of renewable energy in some Latin American countries, offering particularly attractive conditions and covering a large part of the funding required by project developers (Brunel, 2023). According to Lonnqvist *et al.*, 2018, the desired scale for implementation includes macroeconomic and macro-political factors, such as energy prices and plant infrastructure. The abolition of fossil fuel subsidies, which lower the costs of generated energy and purchased material, would put pressure on the socio-technical system of biogas production.

Evaluating the installed capacity of small biogas power plants is crucial. Larger power plants generally have lower relative installation and maintenance costs (Lima *et al.*, 2018), generally making their economic feasibility higher. This is why investments of resources are mostly made for large-scale production projects rather than small projects, especially not micro and mini power generators from biogas. Legislation for the latter is more focused on other renewable sources. An example of this is Decree No. 16027/2022, which grants ICMS deferral in operations involving machinery and equipment for the capture, generation, and transmission of solar or wind energy, as well as for the energy generation from biogas. Thus, it was not written for small producers, as technologies purchased outside the country may be more expensive than more basic technologies created in the national territory.

Usually, small-scale production is the least developed in the legal framework. However, this is precisely where the potential biogas producer is in Brazil. If small producers had access to the national energy distribution and transmission system, they could acquire greater socioeconomic benefits, considering that 79% of Brazil's total registered power plants are small (CIBiogás, 2021).

Thus, the legislation related to the production of biogas and biomethane in the country is still in transition to a suitable configuration. With this transition, different legislation must undergo transformations. This type of change is increasingly focused on properly educated energy producers with stable production. This could be considered an aspect that has direct environmental effects for the country, because the most abundant raw material comes from the agricultural sector, which is the second-largest generator of GHG emissions in the country. Thus, small and medium-sized farms and ranches could reduce their emissions with adequate waste management to reach the emission reduction targets, consequently increasing the participation percentage of renewable sources from biomass in the Brazilian energy matrix, as well as providing benefits from the co-products generated from the production of biogas (energy and biofertilizer).

On the other hand, biogas and biomethane production in the country could also be a strength by using raw materials from landfills and sewage treatment. This production is mainly linked to large-scale production, because the production of these raw materials is higher and continuous throughout the year.

Prior to the distribution stage of the surplus energy generated and the barriers that this stage covers, the acquisition of technology to purify biogas into biomethane or transform it into energy can be considered one of the main barriers due to its economic viability (dos Santos *et al.*, 2018).

Before addressing the distribution phase of the surplus energy generated and the barriers associated with this stage, it is essential to highlight that the technology acquisition for the biogas purification into biomethane or its conversion into energy can be considered one of the main barriers and is influenced by its economic viability (dos Santos *et al.*, 2018) and the purchasing power of the producer.

According to the biogas panorama report of CIBiogás (2021), Brazil has 811 biogas plants, of which 755 are currently in operation. In comparison, developing countries such as China, India, Bangladesh, and Nepal have achieved remarkable success in their biogas programs with the installation of millions of domestic digesters (Mukeshimana *et al.*, 2021). This is due to key factors, including favorable government policies, adequate financial support, technological advances, training, efficient quality control, raw materials availability, financial and technical support from donors, and effective coordination between institutions and partners (Mukeshimana *et al.*, 2021). In essence, well-designed policies make the biogas market prosper as a source of renewable energy. Along with maintaining these long-term policies, fixed objectives, and continuous review and evaluation for the commercialization of biogas and biomethane is necessary.

5. BARRIERS AND SUSTAINABILITY OF THE SYSTEM

The sustainability of the biogas production system currently depends on different factors and the main economic activities in each country. Although countries may face some common barriers. The adoption of biogas systems can also be influenced by specific geographic location, climate, culture, and economic situation (Mukeshimana *et al.*, 2021).

Legislation has a direct influence on the sustainability of the biogas and biomethane production process. The **sustainability economic aspect** (Mukeshimana *et al.*, 2021) includes the costs associated with acquiring the equipment and materials necessary to install biodigesters, and these costs are reflected in the construction, operation, and maintenance of the technology. Another economic aspect is the lack of clear financial mechanisms from the government (tax exemptions, discounts, and subsidies), including a framework that regulates prices and maintains price stability, preventing price fluctuation from directly affecting the economy of the farmer or energy producer (Lonnqvist *et al.*, 2017). According to Thrän *et al.* (2020) fiscal incentives, subsidies, and financing to shape renewable energy generation are essential for its development.

Due to the lack of price stability and standardization (Nevzorova and Kutcherov, 2019), products from the biogas production chain entails high economic risks, with long

periods and low rates of return on the amount invested. This is a delicate aspect, as not all farmers, ranchers, or rural producers have the same purchasing power to buy and maintain the plants in operation.

In general terms, the uncertainties and instability that the legislation generates (Martin, 2015; Ammaenberg *et al.*, 2018) are among the reasons why project financiers related to renewable energies are not interested in this type of renewable source

Finally, a barrier directly linked to the economic and social aspects is the lack of knowledge about the economic benefits of acquiring the technology and possible sale of products obtained from anaerobic digestion (Yasar *et al.*, 2017; Scheftelowitz *et al.*, 2018). Energy from biogas can supply the energy demand of small properties, reducing the energy consumption from the national grid and fossil fuels (Oehmichen *et al.*, 2017) and consequently increasing family income, generating savings in the annual budget.

Beside this, considering **sustainability social aspect**, there is lack of awareness, social acceptance, knowledge of biogas production technology and the benefits that its installation can provide directly affect the performance of installed plants (Mukeshimana *et al.*, 2021). In turn, this lack of knowledge affects national scopes related to increasing the percentage share of renewable energy sources in the energy matrix, consequently reducing greenhouse gas emissions from the proper management of waste generated by human activities, and thereby boosting the national economy through small-scale production units.

The lack of acceptance, awareness, and knowledge about biogas production technology directly affects public and political support, directly influencing decision-making on implementation of the technology at different levels. To correct this barrier, the government must provide the necessary support to the community so that this lack of knowledge and acceptance ceases to be a hindrance.

For the **sustainability environmental aspect**, the generation of GHG emissions from inadequate management of agriculture should be considered where no anaerobic digestion technology has been implemented**.** Thus, implementing technologies for the agricultural waste use in the production of agro-energy would also help the country meet its emission reduction targets (Hollas *et al.*, 2022). Finally, the non-implementation of the system in rural areas with a large production of organic waste from potentially polluting activities keeps the producer from having a more sustainable production chain. Biogas production is an opportunity to produce cleaner energy, earn environmental seals, sell carbon credits, and consequently reduce GHG emissions (Oehmichen *et al.*, 2017). The latter is a critical characteristic that directly affects the economic and social aspects of the Brazilian industrial and agricultural production chains.

In general terms, the three pillars of sustainability are correlated in different aspects, which can easily and directly affect the sustainability of the biogas production system (Thrän *et al.*, 2020).

CONCLUSIONS

The biogas sector in the country is covered in the legal contexts of renewable energy (electricity and natural gas sector), sanitation (management of urban solid waste and effluents), the environment, and climate change. The analysis of the legal framework revealed the enormous interest of the country in this renewable energy source. Thus, biogas technology has been driven and disseminated by government initiatives in collaboration with various organizations, but it is still in the process of development and transition. Therefore, crucial factors must be better structured and analyzed to obtain better results in the adoption of biogas in the Brazilian energy matrix, such as clear and detailed government support policies, technical training of the community about the technology, its benefits, and its regulations, and technological standardization for small- and large-scale operations.

Legislation strongly influences the sustainability of the biogas and biomethane production system, as the gaps within each regulatory framework can directly affect any of the three pillars of sustainability.

In the economic aspect, the costs of acquiring biodigester equipment impact its construction, operation, and maintenance. The absence of clear government financial mechanisms, like tax exemptions and subsidies, leads to price instability, affecting farmers. Fiscal incentives and financing are crucial for renewable energy development. Additionally, the lack of price stability and standardization in biogas products poses high risks and low returns on investment.

In the social aspect, the lack of knowledge about the economic benefits of biogas technology and its potential sale impacts social acceptance and the performance of installed plants. In turn, the lack of awareness and social acceptance of the technology affects public and political support, hindering decision-making on its implementation.

In the environmental aspect, the use of agro-pastoral waste in agroenergy reduces greenhouse gas emissions. However, not implementing the system in rural areas with significant organic waste misses the chance for a more sustainable production chain. Biogas production offers opportunities for cleaner energy, environmental certifications, and reduction of greenhouse gas emissions.

The legal framework related to biogas favors large-scale renewable energy producers, facilitating the equipment acquisition and inputs (national and international) for their generation. However, this benefit is less accessible to small-scale agricultural producers located in decentralized areas of the country, which represent the majority of production. This discrepancy slows the development of the sector and prioritizes the production of other renewable energy sources, such as solar and hydroelectric.

Despite initiatives in Brazil to improve and strengthen the biogas sector, the state and federal governments need to enhance mechanisms to improve the knowledge of the workforce, farmers, or the interested population, as well as directing fixed and detailed

economic funding for this purpose. Therefore, the transition of the sector will take longer than expected, even though Brazil is one of the richest countries in raw materials for biogas production.

The legislative framework for biogas and biomethane should undergo continuous evaluation and renewal to keep pace with evolving technologies and practices. Specific parameters need to be established for biogas and biomethane production in rural areas, given the often-precarious conditions, as these sources of energy directly impact the country's economy.

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