

Review

Biomethane as a Fuel for Energy Transition in South America: Review, Challenges, Opportunities, and Perspectives

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Abstract: This review examines the current status of biomethane development in South America through a comprehensive comparative analysis of national legislation, scientific literature, and institutional data across all South American countries. The methodology consisted of a systematic review of technical and regulatory documents to assess the status of biomethane production, commercialization, and utilization throughout the region. The findings indicate that biomethane remains largely underdeveloped in most South American countries, primarily due to fragmented data, inadequate infrastructure, and a lack of targeted public policies. Brazil emerges as a regional leader, backed by robust legal frameworks such as the RenovaBio program, the Future Fuel Law, and specific regulations governing landfill waste treatment and biomethane quality standards. In contrast, other countries hold considerable biogas potential but lack the regulatory frameworks and financial incentives required to expand biomethane production. The principal contribution of this study is its comprehensive assessment of biomethane development in South America, providing a country-level analysis alongside direct comparisons with global leaders in both production and policy. By mapping legislation, infrastructure conditions, and energy strategies across the continent, this study offers a strategic reference to support future research, investment, and policy development.

Keywords: biomethane; biogas; South America; production; energy transition



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1. Introduction

The global energy sector has increasingly prioritized strategies aimed at reducing greenhouse gas (GHG) emissions in response to observed climate trends and international

environmental commitments. The continued reliance on petroleum-derived fuels across various sectors has contributed to increasing atmospheric carbon dioxide (CO₂) concentrations, rising from 410 ppm in 2019 [1] to 426.3 ppm by March 2025 [2]. In response to these developments, environmental regulations around the world have progressively introduced stricter emission limits for internal combustion engines (ICEs), aiming to improve engine efficiency and reduce fuel consumption [1,3,4]. At the 21st Conference of the Parties (COP21) held in Paris, 195 countries committed to setting progressive CO₂ reduction targets, particularly in the transportation sector, through the implementation of stricter regulatory frameworks [5,6].

Currently, natural gas is mainly utilized in spark-ignition (SI) engines that were originally designed for gasoline but later adapted to run on compressed natural gas (CNG) [7] or liquefied natural gas (LNG) [8], particularly in light-duty vehicles, taxis, and public transport fleets. Similarly to CNG, LNG can contribute to reductions in carbon monoxide (CO) and CO₂ emissions while leading to increased nitrogen oxide (NO_x) emissions [9].

Biogas and biomethane are renewable alternatives to natural gas, both consisting primarily of methane. They are produced through the anaerobic digestion of organic matter, which may originate from agricultural, industrial, urban waste, or sewage sources. Biogas contains a high concentration of CO₂, which can directly affect its use as a fuel. Consequently, biomethane is produced through a biogas upgrading process that removes CO₂, yielding a high methane content and physical properties comparable to fossil-based natural gas.

Global energy production based on biogas and biomethane reached over 1.6 EJ in 2022 [10]. The United States is currently the leading biomethane producer, contributing 38.0% of global output. California is notable for using biomethane in 97.0% of its gas-powered vehicle fleet [10]. When the total energy generated from biogas is considered, the European Union becomes the largest producer, followed by China, the United States, and India. The consumption patterns of biogas and biomethane vary by country and region, with nations such as India and China primarily using biogas for residential purposes, while the European Union employs a significant portion of its biogas and biomethane production for electricity and heat generation [10]. As shown in Figure 1, the use of biomethane as a vehicle fuel worldwide still accounts for only a small fraction of total global production—merely 7.0% in 2023 [10].

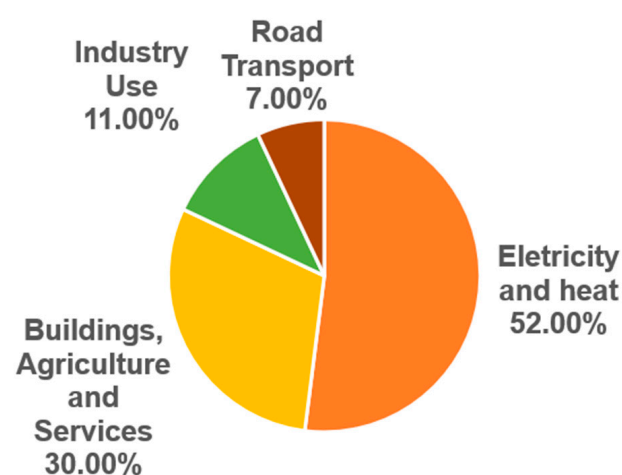


Figure 1. Global distribution of produced biomethane [10].

In the European Union, biomethane is primarily used in the industrial sector through its injection into the natural gas grid. However, its use as a fuel for internal combustion engines (ICEs) is also gaining attention and has been adopted in countries such as the

United States. Most research on the use of biogas and biomethane as fuels focuses on single-cylinder stationary spark-ignition (SI) engines [11–16], as well as on the effects of varying methane (CH_4) and CO_2 concentrations in biogas [17]. The CO_2 content in biogas influences engine performance and slows down the combustion process [13,17,18]. Notably, lower CH_4 concentrations have been associated with reduced NO_x emissions in engines [12]. Chandra et al. [13] compared CNG with biomethane containing 95% methane in a stationary engine for electricity generation. A decrease in engine power output was observed when operating on biomethane compared to CNG. Karlsson et al. [19] conducted tests on bi-fuel vehicles designed for CNG and gasoline operation, replacing CNG with biomethane containing 97% CH_4 . Emissions recorded during biomethane operation were found to be below the EURO-5 standard. Chassis dynamometer tests and driving cycle evaluations are also documented in the literature [20–22].

Several studies have also investigated engine calibration for biogas operation, focusing on modifications to the compression ratio and ignition timing [12,23]. Porpatham et al. [12] examined the effects of CH_4 and CO_2 concentrations in biogas used in an SI engine and found that a CO_2 concentration of 10% was sufficient to reduce HC emissions without significantly increasing the nitrogen monoxide (NO) emissions. The authors also concluded that ignition timing should be delayed by 5° before top dead center (bTDC) for biogas with 10% CO_2 compared to biogas with 41% CO_2 . Chandra et al. [13] identified the maximum brake torque (MBT) at an ignition timing of 35° bTDC, which also yielded a higher brake thermal efficiency. Roubaud et al. [24] studied variations in compression ratio and ignition timing in an engine operating on biogas. They observed that increasing the compression ratio, combined with optimized ignition timing, improved the thermal efficiency, although NO emissions increased under lean combustion conditions. Midkiff et al. [25] evaluated the different biogas purity levels and found that higher CO_2 concentrations required greater ignition advance while reducing NO_x emissions. Hotta et al. [15] tested an SI engine fueled with biogas (55.6% CH_4) under different compression ratios and ignition timing settings. A reduction in ignition advance was observed as the compression ratio increased, with the authors identifying a compression ratio of 12.0 and an ignition timing of 33.0° bTDC as the optimal condition for improvements in brake torque, specific fuel consumption, and brake thermal efficiency. Although most studies focus on spark-ignition (SI) engines, research on biogas use in compression-ignition (CI) engines—especially in dual-fuel configurations—also exists [26].

As highlighted by several studies, biomethane holds significant potential as a renewable energy source; however, it still faces challenges such as the lack of specific policies and financial incentives [27–29]. In Brazil, for instance, there are favorable conditions for injecting biomethane into natural gas grids, as well as supportive legislation. Nevertheless, further improvements are required, particularly regarding incentive mechanisms to enhance its competitiveness relative to natural gas [29,30]. Renato et al. conducted a study to assess the feasibility of using sewage as a feedstock for biomethane production in the state of São Paulo, Brazil [31]. The authors concluded that the energy potential is sufficient to replace approximately 10% of the state's current natural gas consumption, contributing to a reduction in CO_2 emissions. They further emphasize the need for public policies and incentive frameworks to foster the development of the biomethane market and improve its competitiveness.

Studies concerning the use of biomethane or synthetic natural gas for power generation can also be found in the literature. For instance, Cormos et al. [32] evaluated the application of biomass gasification in a 500 MWh power plant. The authors concluded that combining biomass gasification with CO_2 capture technologies could result in negative carbon emissions. However, the high process cost remains a major barrier, rendering the generated

energy more expensive than that produced from fossil natural gas. By way of comparison, the average electricity cost in Lithuania is approximately 44 to 45 EUR/MWh [33], whereas the estimated cost reported by Cormos et al. [32] was 53 EUR/MWh. Padi et al. investigated the economic feasibility of using biomethane for power generation on a farm, achieving a cost of 72 EUR/MWh [34]. The authors highlighted that biomethane could become competitive due to the volatility of the natural gas market in recent years, while also emphasizing the potential for distribution through existing natural gas grids. Regarding biomethane production costs, recent studies indicate that, in Europe, the cost is approximately 69 EUR/MWh, with a substantial portion attributed to the initial capital investment, since the feedstock for biomethane production is typically low-cost waste material [35]. In a study conducted by López-Aguilera et al. [36], the potential for biomethane production from agricultural waste, municipal solid waste, and wastewater sludge was assessed. The authors observed that, in the country, agricultural waste may become the primary feedstock for biomethane production, with an increase from 0.27 TWh in 2023 to 30.04 TWh by 2050. In order for biomethane to become competitive with natural gas in Spain, the authors emphasized the need for the implementation of regulatory and fiscal incentives, as well as advancements in waste management practices nationwide.

Despite studies highlighting the benefits of using biogas and biomethane for mobility, South America continues to lag behind the European Union and the United States in both biomethane production and utilization. South American countries have a large agricultural sector that could generate biomethane from waste products. However, a lack of tax incentives makes this fuel less economically attractive. Additionally, in some countries, the absence of specific waste management regulations results in CH₄ emissions being released into the atmosphere instead of being captured and utilized as biomethane in the transportation sector.

Given South America's vast potential for bioenergy production, this study aims to offer a detailed and structured overview of biomethane development in the region. The primary objective is to assess the current status of biomethane production, commercialization, and utilization across various countries, while identifying key barriers and opportunities for its expansion. To achieve this, a comprehensive review was carried out using national legislation, technical standards, scientific publications, and regulatory frameworks specific to each South American country. These sources were selected to ensure a balanced perspective that integrates academic insight with practical implementation considerations. However, in many countries, data availability remains limited and often outdated. The scarcity of scientific literature specifically addressing biomethane in South America reinforces the novelty and relevance of this research. While international studies on biogas and biomethane have advanced significantly, regional investigations are still fragmented, typically limited to technical case studies or pilot-scale evaluations. This paper presents a continent-wide, country-level comparative assessment of biomethane in South America, contextualized by reference to global leaders such as the European Union and the United States. Brazil is analyzed in greater detail due to its leading position in production capacity, number of authorized plants, availability of current public data, and favorable policy environment. National initiatives like the RenovaBio program and the Future Fuel Law further position Brazil as a reference point within the region. By consolidating these insights, this study provides a strategic foundation for supporting future regional dialogue and public policies that promote biomethane development and the broader energy transition in South America.

In Section 2, the current state of biomethane development in each South American country will be presented. It is noteworthy that many countries still lack information regarding biomethane production and commercialization. However, data on biogas are available, which could serve as a foundation for future upgrading into biomethane. Regu-

lations and fiscal incentives will be discussed to provide context and support the analysis of the challenges and gaps still faced across the continent. To contextualize biomethane development in South America, Section 3 introduces the leading producers and examines the key regulations that have facilitated biomethane adoption. These regulations may serve as models for other South American countries seeking to fully develop their biomethane markets. Subsequently, Section 4 presents the results and discussions, positioning South American countries in relation to the world's leading biomethane producers. This analysis will facilitate the identification of development gaps and contribute to the formulation of effective policies to promote biomethane advancement in South America.

2. Biomethane Development and Regulatory Frameworks in South American Countries

2.1. Argentina

Argentina has a strong agricultural and agro-industrial sector and is a major producer of grains, meat, dairy products, and other commodities. This gives the country significant potential for biogas production from agricultural and industrial waste, which can be used for thermal and electrical energy generation or upgraded to biomethane. Argentina's energy matrix is heavily reliant on fossil fuels (89.3%), while renewable sources account for only 10.7% [37], as shown in Figure 2.

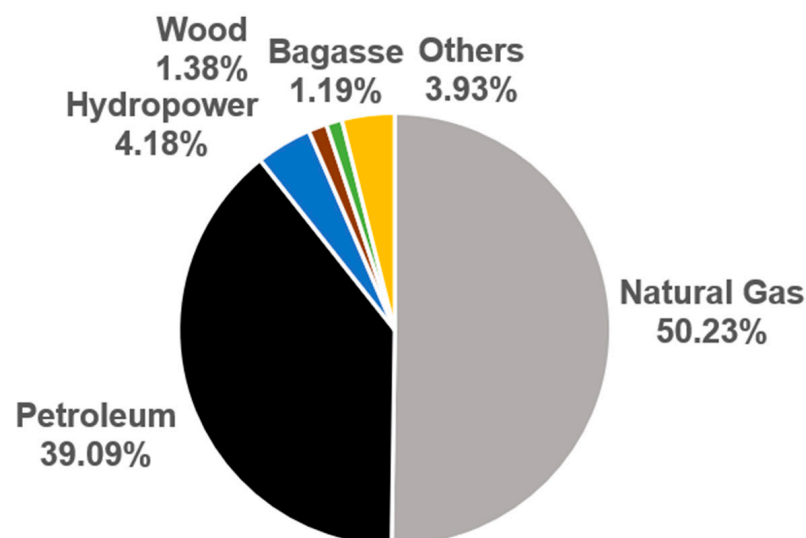


Figure 2. Argentine energy matrix [37].

Biogas development in Argentina began in the early 1980s. In 1993, a biodigester was installed at a school in Los Cerrillos, where the biogas produced was used to fuel the cafeteria ovens. In 1995, another biodigester was installed at a school in Alto Verde for the same purpose [38]. Also in 1995, a biodigester installed in Monte Vera marked the first documented case in Argentina of using urban solid waste (USW) for biogas production. The biogas produced was supplied to a poultry farm, helping reduce its gas consumption [38].

In the early 2000s, Argentina established its first urban solid waste treatment plant in Gobernador Crespo. This facility included a 150 m³ biodigester that produced biogas to serve a population of 10,000 [38].

To promote biogas production, Law No. 26093 was enacted in 2006 [39], classifying biogas as a biofuel of national interest across Argentina. That same year, Law No. 26190 [40] established a target requiring that 8.0% of the electricity matrix be supplied by renewable sources over the following decade.

Over the years, additional facilities were established. In 2008, the company Citrusvil inaugurated a biogas plant to process waste from lemon production, generating part of the gas needed for its industrial operations [38].

In 2016, the National Institute of Industrial Technology conducted a study identifying 105 biodigestion plants of varying sizes and technological levels across the country [38]. Of these, 62 were classified as medium- and large-scale facilities, with 53.1% operated by the private sector and 37.5% by the public sector. The main feedstocks for these plants include industrial waste (38.0%), urban waste (28.0%), and livestock waste (27.0%). Among the 62 highlighted plants, 44.3% of the biogas produced was used for thermal applications, while only 12.0% was used for electricity generation.

Law No. 27191, enacted in 2016 [41], set a new target requiring 20.0% of Argentina's electricity generation to come from renewable sources, such as wind, solar, and biomass. This law, along with the launch of the RenovAr Program, significantly boosted biogas production by securing government commitments to purchase electricity from renewable sources [42]. In 2017, the food company Adecoagro invested six million dollars in a biodigester with a capacity of 1.4 MW, supplying the generated electricity to the national grid [43].

In 2022, the Argentine government invested approximately USD 57 million in a biogas plant using USW from the Ecoparque Gualaguaychú landfill [44]. This landfill, inaugurated in 2001, receives an estimated 480 tons of waste per day [45].

Also in 2022, the National Institute of Agricultural Technology conducted a study aimed at quantifying greenhouse gas emissions in electricity generation [45]. This study analyzed the Bio 4 Bioelectric Complex, where the biogas produced is utilized for both electricity and heat generation. The facility reported an annual biogas production of 24,137,469 m³, with 57,202 MWh of electricity fed into the national grid and 26,316 MWh of thermal energy used in the ethanol biorefinery [45]. Among the findings, it was estimated that electricity production from biogas at this facility resulted in a 98.5% reduction in greenhouse gas emissions compared to energy generation from fossil fuels calculated based on the life cycle assessment, following the values established by the European Renewable Energy Directive (RED II) [45].

Despite the ongoing development of biogas for energy purposes, no biomethane applications have been identified in Argentina, either for pipeline injection or mobility use.

2.2. Bolivia

Biogas production in Bolivia began in the 1980s with the implementation of 65 domestic biodigesters between 1986 and 1992 [46]. However, no new biodigesters were reported in the country between 1992 and 2002 [46]. In 2003, the first digester above 4000 m of altitude was documented [47].

The Energy Development Program was one of the key initiatives promoting biogas development in Bolivia. Supported by countries such as the Netherlands, Germany, Norway, Australia, the United Kingdom, and Switzerland, the program began its activities in Bolivia in 2007, fostering small-scale projects. However, due to a lack of resources, the program ended in 2012 [46]. Currently, biodigesters in Bolivia are mainly small-scale installations found in households, schools, and educational institutions [46].

In Bolivia, fossil fuels receive strong government subsidies, while effective policies to promote biogas and other renewable energies are lacking. One example of fossil fuel incentives is that, for electricity generation, natural gas is priced at only 20.0% of the export price, with the government subsidizing the remainder [48]. This is a major reason why renewable energy accounts for only 8.0% of electricity production [48].

According to the Bolivian Energy Balance Report [49], published in 2023, biomass-based energy production accounts for 7.18%, while fossil fuels remain the dominant energy source in the country. Figure 3 illustrates this distribution.

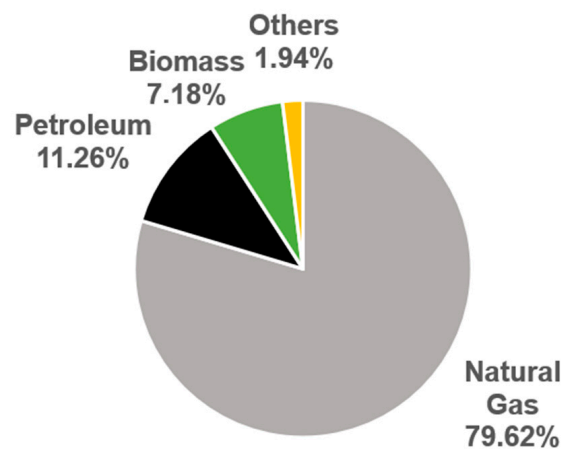


Figure 3. Bolivian energy matrix [49].

According to the Department of Environment of Bolivia, approximately 5470 tons of solid waste are generated daily, with the states that produce the most being Santa Cruz (30.6%), La Paz (27.4%), and Cochabamba (17.2%) [50]. Bolivia has few landfills, and detailed information about them is lacking. It is estimated that only 3.1% of urban waste in Bolivia is directed to landfills, with the remainder being disposed of in open-air dumps [51].

In a study conducted by Bautista and Calvimontes [50], the potential for landfills in three regions was evaluated: Santa Cruz, La Paz, and Cochabamba. Based on available data, electricity generation from biogas in these landfills was estimated at 550.4 GWh. Despite the potential production, the study highlights that the investment is still not attractive, mainly due to the lack of incentives for biofuels in the country.

Key challenges to implementing biodigesters for biogas and electricity production in Bolivia include logistics, transportation costs, limited public awareness of waste separation, and the strong incentives for natural gas production [52].

There has been progress in recent years regarding the construction of small systems for biogas production. This progress has been primarily driven by international institutions, along with Bolivian universities and research institutes [48]. Such involvement can provide technology transfer for future large-scale applications.

Even with the use of biogas for energy purposes, no references were found to the use of biomethane in Bolivia. The large-scale production of natural gas discourages incentives for biomethane production and commercialization in Bolivia.

2.3. Brazil

Biogas production in Brazil began with small domestic installations, where the gas was primarily used for thermal energy. Over the years, biogas has gained prominence in the country, especially for use in electricity generation. Figure 4 illustrates the recent growth observed over the last 10 years, showing an 87% increase in the volume of biogas produced.

Figure 5 illustrates the distribution of biogas production plants and the volume produced by sector in Brazil. Although most biogas plants are in the agricultural sector, their large number does not correspond to a high volume of biogas production. Many of these are small-scale installations using animal manure to produce biogas, mainly for on-site thermal energy needs. The plants utilizing sanitation waste, such as USW and sewage wastewater, stand out in terms of the volume produced. Despite the relatively small num-

ber of installations, biogas plants in this sector are usually large-scale and produce biogas for electricity generation. Biogas upgrading to biomethane has grown in Brazil in recent years, with larger plants leading in production and commercialization.

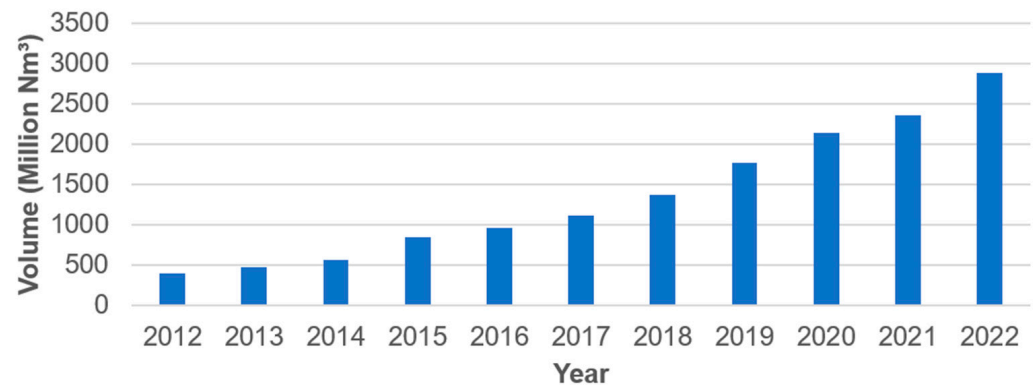


Figure 4. Use of biogas for energy purposes in Brazil [53].

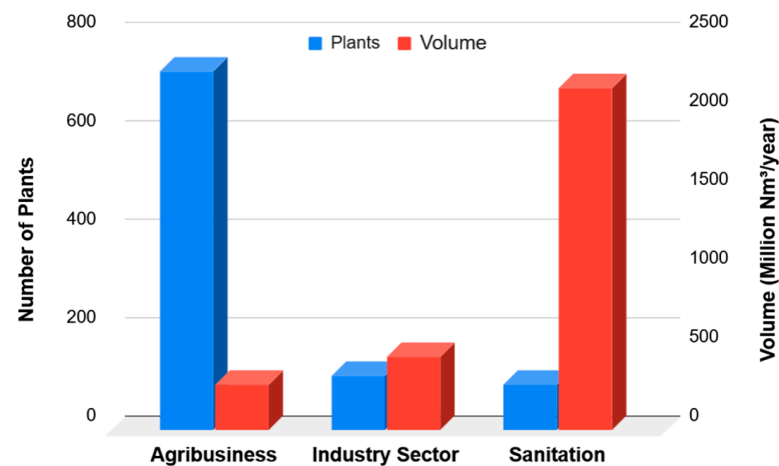


Figure 5. Biogas production by sector in Brazil [53].

One of the key legislations that promoted biogas, and consequently, biomethane, in Brazil, was Law No. 12305 of 2010, which initially set a four-year deadline for the end of illegal waste disposal in the country [54]. Later, this legislation was amended, and by 2020, six years after the original deadline, Law No. 14026/2020 modified the deadlines according to the population of cities, extending them until 2024 [55]. Significant progress has been made in Brazil's waste management since 2010, with the country's leading biomethane producer now using urban solid waste (USW). However, delays in policy implementation have resulted in Brazil still failing to ensure the proper disposal of all municipal solid waste.

Law No. 13576 of 2017 addresses the national biofuel policy (RenovaBio) [56]. This law set out guidelines for gradually reducing emissions in the national fuel matrix, with parameters for emissions and the commercialization of carbon credits. Subsequently, Law No. 15082 of 2024 amended Law No. 13.576/2017 to include independent feedstock producers [57].

Decree No. 11033 of 2022 established strategies to encourage the sustainable use of biogas and biomethane [58]. This decree outlined guidelines for the use of methane credits, the installation of biodigesters, and the use of biomethane in light and heavy-duty vehicles.

In 2023, through Law No. 14993/2023, known as the "Future Fuel Law", Brazil plans to encourage the gradual replacement of natural gas with biomethane through annual targets for reducing greenhouse gas emissions, governed by the National Energy Policy

Council [59]. Initially, the law outlines a 1% reduction (capped at 10%) in emissions from the natural gas sector starting in 2026.

According to the Brazilian National Agency of Petroleum, Natural Gas, and Biofuels (ANP) [60], Brazil currently has 12 authorized plants to commercialize biomethane, with a total production capacity of 696,967 Nm³/day. Table 1 presents relevant information about authorized biomethane plants for production and commercialization in Brazil.

Table 1. Authorized biomethane production and commercialization plants in Brazil [60].

Company	Location	Raw Material	Authorization Date	Authorized Biomethane Production (Nm ³ /day)	Current Production (Nm ³ /day)
Adecoagro Vale do Ivinhema S.A.	Ivinhema-MS	Sugarcane and USW	12/2024	8000	0
Cocal Energia S.A.	Narandiba-SP	Agroforestry Waste	07/2022	27,112	22,000
Cri Geo Biogás S.A.	Elias Fausto-SP	Agroforestry Waste	02/2025	23,694	0
Engep Ambiental LTDA	Jambeiro-SP	USW	03/2023	30,000	30,040
Essencis Biometano S.A.	Caieiras-SP	USW	09/2024	67,200	51,869
Gás Verde S.A.	Seropédica-RJ	USW	07/2020	204,000	387,298
Geo Elétrica Tamboara Bioenergia LTDA.	Tamboara-PR	Agroforestry Waste	12/2024	31,200	0
GNR Dois Arcos Valorização de Biogás LTDA.	São Pedro da Aldeia-RJ	USW	07/2020	16,000	32,554
GNR Fortaleza Valorização de Biogás LTDA.	Caucaia-CE	USW	01/2020	110,000	118,542
Metagás Biogás e Energia S.A.	São Paulo-SP	USW	06/2022	30,000	7574
Raízen-Geo Biogás Costa Pinto LTDA.	Piracicaba-SP	USW	08/2024	130,368	20,965
Zeg Biogás Aroeira SPE LTDA	Tupaciguara-MG	Agroforestry Waste	03/2025	16,912	0

In addition to the authorized and operational biomethane plants in Brazil, 35 new plants are under construction or in the process of obtaining authorization. Table 2 presents the main details. It is noteworthy that three of these plants have already completed their construction and are expected to begin operation in the near future, adding 41,320 Nm³/day. All 35 plants are expected to be completed by 2027, potentially adding 1,467,333 Nm³/day to Brazil's biomethane production capacity.

Table 2. Plants in the process of authorization for biomethane commercialization in Brazil [60].

Company	Location	Biomethane Production Capacity (Nm ³ /day)	Estimated Completion Date
AE H&T SPE LTDA.	Harmonia-RS	11,712	03/2026
Agric Adubos E Gestão De Resíduos Industriais E Comerciais S.A.	Campos Novos-SC	31,440	08/2025
Atvos Biometano Santa Luzia S.A.	Nova Alvorada do Sul-MS	110,101	12/2026
Bioenergia Santa Cruz LTDA.	Américo Brasiliense-SP	75,000	07/2025
Biometano São Leopoldo S.A.	São Leopoldo-RS	36,744	06/2026
Biometano Sul S.A.	Minas do Leão-RS	70,000	06/2025
Biometano Verde Paulínia S.A.	Paulínia-SP	225,840	12/2025
CH4 Energia S.A.	Sabará-MG	72,000	06/2026
Cocal Energia Ppt Participações Ltd.a.	Paraguaçu Paulista-SP	54,000	07/2025
Folhito Ltd.a	Estrela-RS	10,000	Construction completed. The authorization process is ongoing.
Ga Energia S.A.	Sabará-MG	36,000	08/2026
Geo Agrovale Biogás Ltd.a.	Juazeiro-BA	55,000	08/2025
Geriba Energy Gas Desc S.A.	Descalvado-SP	3360	04/2026
H2A Soluções Ambientais Ltd.a	Rio Verde de Goiás-GO	4320	Construction completed. The authorization process is ongoing.
H2A Soluções Ambientais Ltd.a. Scp	Videira-SC	6720	04/2026
H2A Soluções Ambientais Ltd.a. Scp 1	Videira-SC	20,000	10/2025
H2A Soluções Ambientais Ltd.a. Scp 2	Papanduva-SC	6720	08/2025

Table 2. Cont.

Company	Location	Biomethane Production Capacity (Nm ³ /day)	Estimated Completion Date
H2A Soluções Ambientais Ltd.a. Scp 3	Papanduva-SC	6720	11/2025
Mele Biogás Brasil LTDA.	Toledo-PR	24,756	09/2026
Orizon Itapevi Limitada	Itapevi-SP	32,400	09/2026
Orizon Biometano Jaboatão Dos Guararapes Limitada	Jaboatão dos Guararapes-PE	162,000	Awaiting schedule update.
Orizon Biometano Rosario Do Catete Limitada	Rosário Do Catete-SE	60,000	05/2027
Orizon Biometano Tremembé Limitada	Tremembé-SP	43,200	12/2026
Scalon & Cerchi Ltd.a	Sacramento-MG	10,800	Awaiting schedule update.
Scbio Energias Renováveis Spe Ltd.a.	Campos Novos-SC	4320	Awaiting schedule update.
Spe Bioo Paraná Ltd.a.	Toledo-PR	36,000	07/2026
Spe Bioo Passo Fundo Ltd.a.	Passo Fundo-RS	36,000	12/2026
Spe Central De Tratamento Integrado Resíduo Zero Ltd.a.	Triunfo-RS	36,000	Construction completed. The authorization process is ongoing.
Translurean Transportes Ltd.a.	Carambei-PR	31,440	01/2027
Tropical Biogás Ltd.a.	Edéia-GO	17,300	03/2026
Uisa Geo Biogás S.A	Nova Olímpia-MT	27,600	01/2026
Uvb Marca Ltd.a.	Cariacica-ES	25,000	07/2025
Valorgás Energia Igarassu I Aluguel De Equipamentos Para Sistema De Valorização Energética E Manutenção Spe Ltd.a.	Igarassu-PE	45,760	10/2026
Valorgás Feira De Santana Ltd.a.	Feira de Santana-BA	21,400	11/2026
Zeg Biogás Pindorama Spe Ltd.a.	Penedo-AL	60,000	12/2026

According to the Biogas Overview in Brazil [61], seven plants in Brazil produce biomethane as a secondary product, in addition to those referenced by the ANP. These plants are mostly located in the southern region of the country. Besides the commercial plants, notable examples include the Foz do Iguaçu-PR plant, operated by Itaipu Binacional, producing 70 Nm³/day for its bus fleet [62], and the Sabesp plant in Franca-SP [63], which powers its vehicle fleet with the generated biomethane.

Information on plants already producing biomethane in Brazil, whether for internal consumption or commercialization, is available. Table 3 illustrates six plants with publicly available information on biomethane production that are not included in the list of those authorized by the ANP (Table 1). Of note is the São Mateus-SP plant, whose authorization was revoked in 2022 [60], and the Franca-SP plant, which is currently undergoing authorization.

Table 3. Biomethane plants in Brazil.

Location	Start	Capacity	Source
Patos de Minas-MG	2016	4995 kW of electricity production	[64]
Foz do Iguaçu-PR	2017	70 m ³ /day (consumption in the internal fleet)	[62]
Concórdia-SC	2018	Consumption in the internal fleet	[65]
Franca-SP	2018	Consumption in the internal fleet	[63]
Paulínia-SP	2022	110,000 Nm ³ /day	[66]
São Mateus-SP	2021	90,000 Nm ³ /day	[67,68]

The regulation of biomethane for commercialization in Brazil is governed by ANP Resolution No. 906, dated 18 November 2022 [69], which establishes the limits for the composition of biomethane, as shown in Table 4. Therefore, for biogas to be classified as biomethane in Brazil and be commercialized, it is required that the upgrading process be conducted until the methane concentration exceeds 90.00%, and the volumetric concentration of CO₂ is limited to a maximum of 3.00%. Given Brazil's vast territory and regional disparities, quality specifications are defined regionally, as outlined in Table 4.

Table 4. Regulation of biomethane composition in Brazil [69].

Characteristic	Unit	Limit		
		North	Northeast	Central-West, Southeast, and South
Higher heating value	MJ/m ³	34.00–38.40		35.00–43.00
	kWh/m ³	9.47–10.67		9.72–11.94
Wobbe Index	MJ/m ³	40.50–45.00		46.50–53.50
Methane, min.	% mol.		90.00	
Ethane	% mol.		note	
Propane	% mol.		note	
Butanes and heavier	% mol.		note	
Oxygen, max.	% mol.		0.80	
CO ₂ , max.	% mol.		3.00	
CO ₂ + O ₂ + N ₂ , max.	% mol.		10.00	
Total sulfur, max.	mg/m ³		70.00	
Hydrogen sulfide (H ₂ S), max.	mg/m ³		10.00	
Water dew point at 1 atm, max.	°C	−39.00		−45.00
Hydrocarbon dew point	°C	15.00		0.00

Brazil stands out in South America for having legislation and incentives that are comparable to those in the world's largest biomethane producers. The Future Fuels Law (Law 14993/2023) and RenovaBio are examples of measures that encourage the production and commercialization of biomethane. With 12 biomethane plants in operation and another 35 in development, Brazil has the potential to become one of the top five global biomethane producers in the future.

Furthermore, Brazil already has infrastructure for injecting biomethane into the natural gas grid, allowing the fuel to be used more widely in the transportation sector and industry. Another notable factor is the partnership between companies in the sugar-energy sector and the government, which has facilitated the growth of biogas production from agricultural waste.

2.4. Chile

Chile shows promising development in the biogas sector, largely driven by legislation implemented since the early 2000s. Government incentives have supported the growth of renewable energy, particularly biogas and biomethane.

In 2005, Law No. 20018 [70] introduced amendments to the general electricity services law, encouraging non-conventional methods of electricity generation. Law No. 20527 of 2008 required companies with capacities over 200 MW to supply at least 5.0% of their electricity from renewable sources [71]. In 2013, with Law No. 20268 [72], incentives were provided to expand renewable sources in Chile's energy matrix. Law No. 21118 of 2018 [73] allowed users with equipment generating energy from non-conventional renewable sources or cogeneration to inject energy into the distribution network.

Thus, Chile's energy matrix has evolved in recent years, reaching a total of 39.3% from renewable sources, as indicated in the energy balance released in 2023 [74]. Biogas still accounts for a small share of the energy matrix (0.4%), as shown in Figure 6.

According to a survey conducted by the Ministry of Energy of Chile in 2017, 107 biogas plants were registered [75]. Among these, the La Farfana Biogas Plant, inaugurated in 2008, stands out as it is the only one producing biomethane and injecting it directly into the medium-pressure network. The plant produces an estimated 4113.5 m³ of biogas per hour.

In 2021, the Chilean government launched the national organic waste program aimed at encouraging biogas production in the country. The program aims to raise the landfill gas collection requirement from 5.0% to 30.0%.

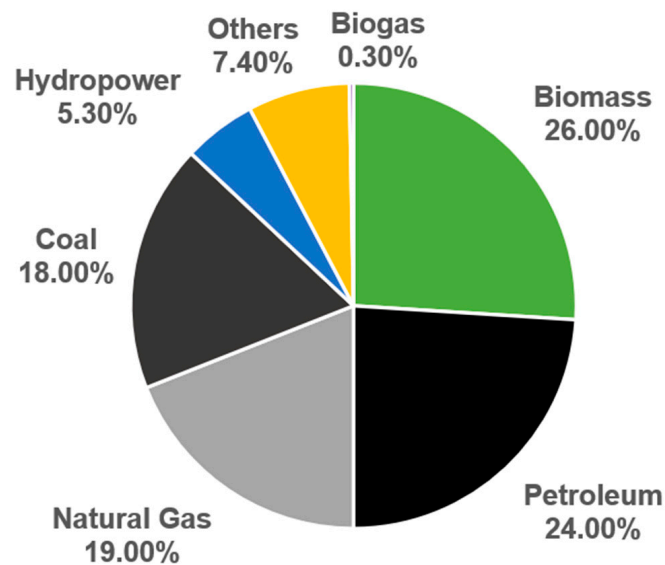


Figure 6. Chilean energy matrix [74].

In 2022, the HAM Group and CycleØ signed a contract for the construction of the first bio-LNG plant in Chile [76]. This plant is located in the Ñuble region and will have the capacity to produce between 7500 and 16,500 m³ of biogas per day. The plant aims to purify biogas to achieve methane concentrations above 99.0%.

2.5. Colombia

Colombia has biomass production and favorable climatic conditions for biogas development. However, its development has lagged behind other South American countries such as Brazil. Collaborative efforts among universities, the private sector, and the government are essential to unlock the country's biogas potential [77].

According to a survey conducted by the Mining and Energy Planning Unit (UPME) [78] in 2025, it is estimated that 63,791 TJ of electricity could be generated from biogas, considering agricultural residues, livestock waste, and industrial by-products.

Examples of operational biogas plants in Colombia include the Bogotá Botanical Garden [79], the San Fernando wastewater treatment station, the La Pradera landfill in Medellín [80], the biogas plant at the International Center for Cleaner Production Lope in Nariño, and the Guayabal landfill in Cúcuta, which can generate 2 MW of electricity from solid waste for self-consumption.

With government support in disseminating renewable energy sources through the Mineral Energy Planning Unit (UPME), the implementation of biogas in Colombia has intensified. An example of this initiative is the implementation of a biogas plant at Huevos Kikes [81], which can generate 800 kW of energy from chicken manure.

Electricity in Colombia is mainly generated by hydroelectric (67.99%) and thermal (30.99%) power plants using coal and fuel oil. Although Colombia's energy matrix has a significant contribution from renewable sources, most of it is concentrated in hydraulic generation. Only 1.04% of the total energy produced in Colombia comes from unconventional renewable sources, such as solar and biomass.

Among the unconventional renewable sources, most of the energy comes from syngas obtained through the gasification of sugarcane bagasse. Biogas contributes only 5.55 MW, generated by three plants connected to the national grid. It is important to note that the previously mentioned examples of biogas usage are for internal consumption and are not connected to the electricity distribution grid. Therefore, they are not accounted for in Figure 7.

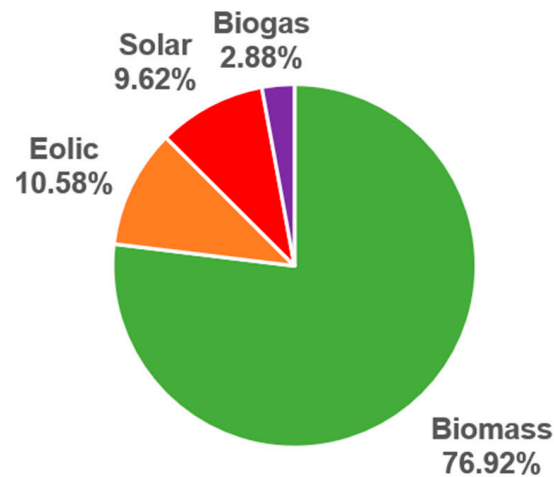


Figure 7. Contribution of non-conventional sources in the Colombian energy matrix [79].

The Doña Juana biogas plant in Bogotá processes approximately 6700 tons of urban solid waste daily. It began operations in 2009 but only started generating electricity from biogas in 2016. Currently, the site hosts three central units with a total capacity of 24.68 MW. Regarding the produced biogas, the average concentration is 52.5% methane and 38.1% CO₂, with a flow rate ranging between 6000 Nm³/h and 8000 Nm³/h [82].

Despite its limited current participation in the Colombian energy matrix, the government has been seeking alternatives for biogas use since 2009. Based on Resolution CREG-056 from 22 May 2009 [83], a study was conducted to analyze the national and international landscape in search of viable biogas applications in Colombia.

In 2014, through Law No. 1715 of 13 May 2014 [84], the integration of renewable energy sources, particularly non-conventional ones, was regulated to encourage the deployment of these energy sources to meet the energy demand. This law was significant because it established a legal framework to incentivize investments in non-conventional renewable energies in Colombia.

In 2016, rules for the use of biogas and biomethane as fuel gas were implemented through Resolution No. 240 of 6 December 2016 [85]. This resolution established a regulatory framework aimed at promoting the injection of biomethane directly into the natural gas grid.

Even though biogas is currently used for electricity generation or in thermal form, there is still the potential to upgrade biogas to biomethane. Although not yet implemented in Colombia, this process could significantly help mitigate the depletion of natural gas reserves in the medium term.

2.6. Ecuador

Ecuador's 2024 energy balance [86] reported a 14.0% decrease in biomass energy production compared to 2021. Regarding electricity generation, biogas accounts for only 0.1% of the total, as shown in Figure 8. The latest energy balance [86] also indicates that a significant share of Ecuador's electricity matrix relies on fossil sources, particularly natural gas.

Biogas-based electricity generation in Ecuador began in 2016, mainly using internal combustion engines. The main biomass sources in Ecuador come from the banana, palm oil, sugarcane, rice, and corn sectors [87]. Currently, only the palm oil and sugarcane sectors utilize residual biomass for electricity generation, with the main use still being in the form of cogeneration [87]. The installed capacity for electricity generation from biomass is 143 MW, with the sugarcane sector accounting for 136.4 MW.

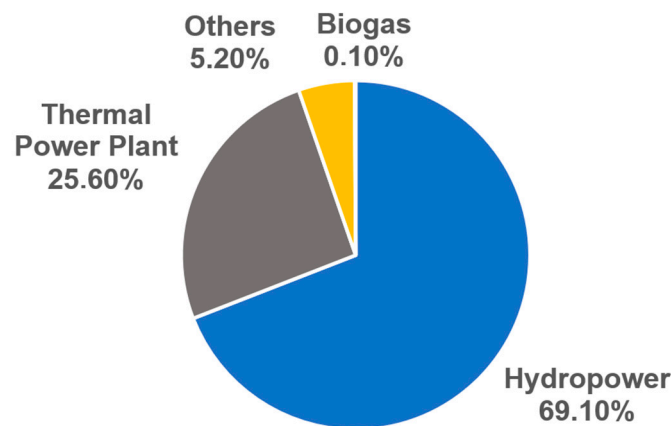


Figure 8. Ecuadorian energy matrix [86].

The 2009 Constitution of Ecuador [88] proposed that the government should promote the use of technologies and energy sources with low environmental impact. Additionally, it established that municipal governments would be responsible for managing urban solid waste.

With the National Law for Autonomy and Territorial Decentralization in 2010 [89], municipalities were required to gradually implement systems for the collection and treatment of urban solid waste.

There are only two projects for the reuse of urban solid waste to generate electricity from biogas produced. The first is the El Inga plant in Quito, which has an installed capacity of 5 MW. Built by Gasgreen SA and EMASEO, the plant receives approximately 2000 tons of waste daily. The biogas collected at the landfill is used in internal combustion engines for electricity generation, which is distributed to the national grid.

The second project in Ecuador is the Pichay plant in Cuenca. This plant receives approximately 490 tons of urban solid waste daily and has an installed capacity of 1 MW [87]. Built by the Dutch company BGP Engineers in partnership with EMAC, the plant has been injecting electricity into the grid since 2015 and plans to double its capacity in the near future [90]. The biogas produced at the Pichay plant has a methane concentration of around 55.0% and is used to fuel internal combustion engines.

Both projects benefit from CONELEC Regulation 004/11 [91], which guarantees a feed-in tariff of 11.05 USD/kWh for electricity from non-conventional renewable sources. However, the regulation applies only to projects registered before the end of 2012 and excludes new installations [90].

2.7. Guyana

Similarly to other South American countries, Guyana began using biodigesters in the 1980s. The Guyana National Energy Authority, together with the Latin American Energy Organization, financed the installation of small-scale biodigesters in rural areas [82]. The Chinese-type biodigester model, with adaptations, became the most commonly adopted model in the country due to its suitability to the local climate. The adapted Chinese model was installed on the Alliance farm in Coverden and the Guymine farm in Linden, but these systems are no longer in operation today [92].

The Guyana Energy Agency estimates that around 30 biodigesters are currently operational in the country [93]. A survey conducted in 2020 identified that the energy matrix of Guyana is largely based on fossil sources (92.0%) [94]. Biomass contributes 7.0% to the energy mix, but there is no evidence of its use for biomethane production [94]. Consequently, there is no available information on biomethane production or commercialization in Guyana.

2.8. Paraguay

A significant share of Paraguay's gross domestic product originates from the primary sector, especially agriculture (7.1%) and grain production (2.5%). The study [95] aimed to evaluate the potential for biogas production from agricultural waste. The sugarcane sector shows greatest potential, followed by the poultry, cattle, and pig sectors. The agricultural sector is estimated to have a theoretical potential of 315 million m³ of biogas, which could generate 300 MW of thermal energy and 120 MW of electrical energy [95]. Moreover, using biogas for energy could reduce firewood consumption in Paraguay, thus decreasing deforestation and pollutant emissions.

The utilization of USW is still limited when compared to neighboring countries such as Brazil. In 2022, an investment of approximately 170 million dollars was announced for the proper treatment of the Cateura landfill in Asunción. However, according to ORD. No. 9/22 [96], which outlines the landfill recovery plan, the intended use of the biogas remains unspecified. There is a risk that the biogas may be flared instead of being utilized for electricity generation.

In 2023, the law N° 6977/2023 [97] was enacted, regulating the promotion of electricity generation from non-conventional renewable energy sources. The law stipulates that only individuals and entities based in Paraguay may generate electricity from these sources.

2.9. Peru

The use of biodigesters in Peru began in the 1980s, with the Industrial Technology Research Institute and Technical Standards promoting the installation of small-scale biodigesters, with capacities ranging from 10 to 12 m³. Over time, however, biogas production has remained limited to small-scale installations. In the private sector, some notable investments include the dairy plants in Arequipa and the poultry company La Calera, which operates four biodigesters with a daily biogas output of approximately 7000 m³ [98].

The use of biogas to generate the electrical energy distributed through the national grid began in 2011 with the operation of the Huaycoloro power plant, with an installed capacity of 4.8 MW. Subsequently, the La Gringa V plant, with a capacity of 3.2 MW, was inaugurated in 2015, and the Doña Catalina plant was launched in 2018. The Callao thermal power plant, with an installed capacity of 2.4 MW, started operations in 2020 [99]. Biogas consumption in Peru has grown in recent years, increasing by 39.0% compared to 2020 [99]. Nevertheless, biogas still accounts for less than 1.0% of Peru's energy matrix, as illustrated in Figure 9 based on the 2022 energy balance of Peru [100].

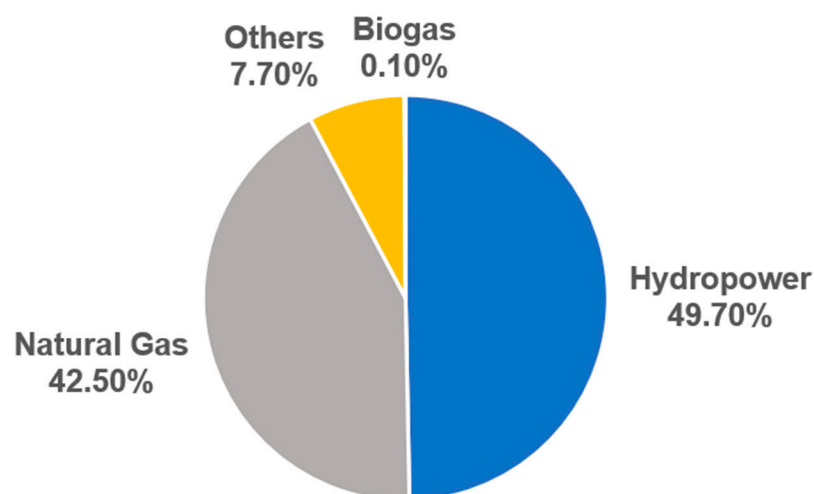


Figure 9. Peruvian energy matrix [100].

According to [101], Peru generates 21,000 tons of USW daily, of which 55% can be considered organic compounds with high energy potential [102,103]. As a result, Law No. 30754 [104] was enacted to promote the adoption of renewable energy sources. This law paved the way for the utilization of USW for biogas generation in landfills. However, in Peru, only 48.0% of the waste is disposed of in 12 landfills [103]. The proper disposal of waste remains a major challenge in Peru, with estimates suggesting that only 1% of generated organic waste is utilized in technologies like biodigestion for energy production [105,106].

2.10. Suriname

Regarding the energy matrix of Suriname, hydroelectric plants have a significant share (59.6%), followed by fossil sources (40.0%) [107]. Estimates suggest that biomethane could fully substitute natural gas consumption in Suriname [108]. Furthermore, biomethane use could potentially reduce emissions by around 60.0% instead of traditional fossil sources [108]. However, no data are currently available on the use of biogas or biomethane in Suriname.

2.11. Uruguay

In Uruguay, some companies utilize biodigestion for energy purposes, such as breweries, dairy industries, and wool factories. Some industries present favorable conditions for the implementation of biogas-based energy systems. However, the agricultural sector faces difficulties in capturing biogas. Although biogas exploitation remains underdeveloped, the growing concern about renewable energy sources may stimulate further development in Uruguay.

A study conducted at the Universidad de la República investigated the biogas production potential in Uruguay [109]. The results indicate that biogas could contribute up to 2.1% of Uruguay's total primary energy supply if repurposed for electricity generation.

According to a study [110], only 18.0% of the methane emissions generated in the industrial sector in Uruguay are utilized. The main industries that treat effluents for biogas generation and utilization include the meat, dairy, and beverage industries. Only nine facilities in Uruguay currently operate effluent treatment systems for biogas production. Based on this information, the study suggests that there is potential to reduce methane emissions by over 30.0% if biodigestion systems are implemented in the country's industries to capture the biogas generated for thermal purposes or electricity generation.

The government is exploring ways to promote the use of renewable energy, especially wind power and biogas, through tax exemptions for investments in the sector. However, there are no specific regulations for the development of biogas and biomethane in the country, forcing biodigestion technologies to compete directly with conventional energy sources.

According to the latest energy balance report released (2023), illustrated in Figure 10, there are only five plants in Uruguay that generate electricity from biogas [111]. The first is the Las Rosas plant in Maldonado, which has utilized biogas from USW since 2005. The second plant was only accounted for in 2014, using effluent treatment from a wool washing plant to produce biogas. The third plant began operation in 2019, generating biogas from effluent treatment. The most recent one began operation in 2022, but it is classified as a cogeneration plant.

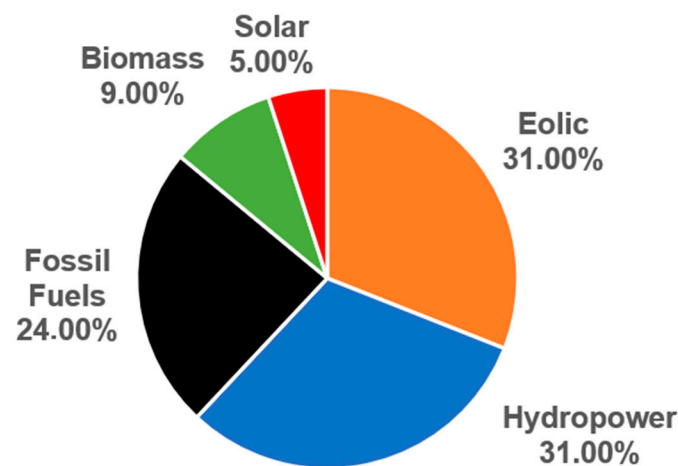


Figure 10. Uruguayan energy matrix [111].

Despite the limited number of operational biogas plants, biomass accounts for 14.0% of Uruguay's installed energy capacity.

2.12. Venezuela

In Venezuela, the effective implementation of policies for the promotion and utilization of biogas has been limited due to the lack of a cohesive legislative and regulatory framework. Although the "Organic Law on Unconventional Alternative Energies" was proposed in 2021 [112], its approval is still pending. The absence of a national climate change policy is a key barrier to the effective use of biogas. The introduction of tax incentives and policies to stimulate the adoption of clean technologies and renewable energies is essential to drive the development of biogas projects and enable participation in the international carbon market by valorizing landfill waste [113].

With the largest natural gas reserves in South America and the eighth largest in the world, Venezuela has underutilized waste as a biogas source, heavily relying on its natural resources. Although some small and medium-scale biogas applications exist, especially in the livestock sector, much of the potential remains untapped. The lack of treatment and the utilization of biogas in landfills, such as in Santa Eduvigis, has led to environmental hazards and unregulated air pollution [113]. The largest landfill in the country, La Bonanza, generates biogas with 35.0% methane, but it is currently flared without utilization [114,115]. In 2007, a natural gas line was connected to the La Bonanza landfill for USW treatment [116].

Although companies providing biogas infrastructure exist, project development has been minimal. However, successful cases, such as the "Carnes El Pazo" slaughterhouse biodigester, demonstrate the potential of biogas [117]. With a capacity of 15,000 m³, it has a system for treating wastewater and organic waste from the slaughterhouse. The biogas produced in the biodigester is utilized as an alternative fuel source for the facility's boilers [117].

3. Current Status of the Biomethane Sector

Global biomethane production has shown steady growth in recent years, driven primarily by the United States and the European Union. As illustrated in Figure 11 [118], these two regions account for approximately 90% of global biomethane production, exceeding 9 billion Nm³ annually.

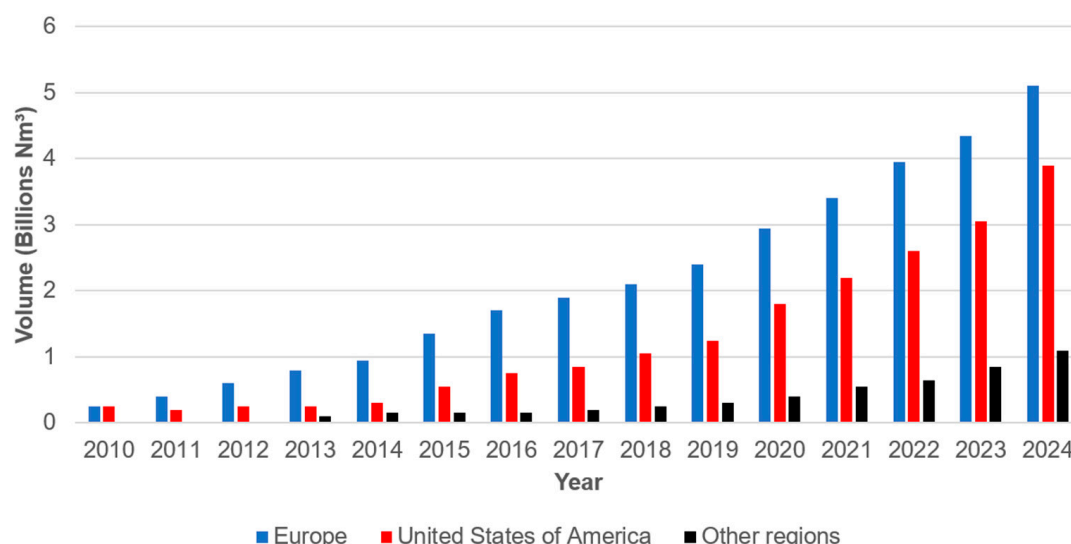


Figure 11. Biomethane production worldwide [118].

3.1. Global Biomethane Production: Key Players

The Renewables 2024 report [10] indicates that Europe currently contributes nearly 50% of the world's biomethane output. In response to growing concerns about natural gas dependency, the European Union launched the REPowerEU plan in 2022, aiming to achieve 35 billion Nm³ of annual biomethane production by 2030. Projections from individual member states suggest that production will likely reach between 30 and 32 billion Nm³ per year by 2030 [118].

Using the world's largest biomethane-producing region as a reference, Table 5 summarizes the key regulations governing the biogas and biomethane sector within the European Union, which are summarized in Table 5, highlighting a regulatory progression that started with mandatory organic waste collection, advanced to the integration of renewable energy in transport, and ultimately established a clear target for annual biomethane production.

Table 5. Key regulations for the biogas and biomethane sector in the European Union.

Legislation	Year	Description	Source
Waste Framework Directive (WFD) (EC/2009/98)	2009	Makes separate collection of organic waste mandatory starting in 2024	[119]
Renewable Energy Directive II (RED II) (EU/2018/2001)	2018	Requires fuel suppliers to include a minimum share of renewable energy in the transport sector, including biomethane.	[120]
REPowerEU plan (COM/2022/230)	2022	Set the target of producing 35 billion Nm ³ of biomethane per year by 2030 to reduce fossil fuel imports.	[121]
Renewable Energy Directive III (RED III) (EU/2023/2413)	2023	Expanded the final use of biomethane, making its use less restrictive.	[122]

Germany, Europe's top biomethane producer—contributing around 20% of global output—aims to increase its reliance on more sustainable feedstocks, such as urban solid waste (USW). A key application is the injection of biomethane into the natural gas pipeline network, along with its use in internal combustion engines (ICEs) in agricultural and rural contexts. Germany promotes biomethane adoption by taxing CO₂ emissions in the

transport sector, from which biomethane is exempt. Recently, biomethane production in Germany has shown signs of stagnation, with only modest annual growth. This trend has raised concerns about economic sustainability, primarily because many plant contracts are expiring, highlighting the need to evaluate new incentive mechanisms [123].

In recent years, the United States has seen a substantial rise in biomethane production, positioning it as the world's leading producer (also referred to as renewable natural gas in the country), with an estimated output of 3.5 billion Nm³ in 2024 [10]. In the USA, biomethane use is particularly prominent in the transport sector, which consumes approximately 56% of national production. Table 6 illustrates some of the key legislations and initiatives that have driven biomethane in the USA, such as the tax credit of the 1 USD/gallon of biomethane used in heavy-duty vehicles for 10 years. In California, 97% of the natural gas vehicle fleet runs on biomethane, underscoring how policy incentives and mandates have established it as a key energy carrier in transportation.

Table 6. Key regulations for the biogas and biomethane sector in the USA.

Legislation	Year	Type	Description	Source
Renewable Fuel Standard (RFS) program	2005	Federal	Establishes a minimum of renewable fuels in transportation sector fuel.	[124]
California Low Carbon Fuel Standard (LCFS)	2011	State: California	Sets a 20% reduction in carbon intensity in the transportation sector by 2030.	[125]
Inflation Reduction Act (IRA)	2022	Federal	Establishes investment credits and protection for renewable fuel projects initiated before 2025, with a duration of 10 years.	[126]
California Renewable Gas Standard (RGS) procurement program D.22-25-025	2022	State: California	Establishes a mandatory target for purchasing biomethane from landfills for gas utilities.	[127]
Set Rule Implementation (RFS)	2023	Federal	Updated targets for the years 2023–2025.	[128]
Renewable Natural Gas Incentive Act	2023	Federal	Introduction of a credit of 1 USD/gallon of biomethane used in heavy-duty vehicles.	[129]

China also plays a significant role in the global biogas and biomethane landscape. During the early 2000s, the Chinese government introduced multiple incentives to support small-scale biodigester construction, peaking at 42 million units by 2015 [10]. After 2014, this expansion slowed as government incentives shifted toward industrial-scale biogas applications via medium- and large-scale facilities. In 2019, the Chinese government published its guidelines to promote biomethane development, known as bio-natural gas (BNG), setting targets to produce 10 billion cubic meters by 2025 and to double this production by 2030. China's primary incentives include financial aid and tax exemptions for companies engaged in biogas or biomethane utilization. This support covers all end uses, including electricity generation, thermal energy production, vehicle fuel, and industrial applications. Despite considerable potential and supportive policies, the expansion of China's biogas and biomethane industry remains limited. This is mainly attributed to the difficulties in accessing the natural gas grid and the elevated cost of feedstock. Table 7 summarizes the main legislations related to biomethane in China.

By analyzing the annual growth in biomethane production in Europe and the United States, as shown in Figure 11, alongside the main legislative frameworks implemented during the reported period (Tables 5 and 6), it is possible to establish a direct relationship between specific regulations and biomethane production levels. Europe experienced an

average annual growth of approximately 25%, while the United States showed a similar growth rate of about 24% between 2010 and 2024.

Table 7. Key regulations for the biogas and biomethane sector in China [10].

Legislation	Year	Description
Chinese Rural Household Biogas State Debt Project	2003	Aimed to reduce pollution from agricultural wastes and solve energy shortage in rural areas.
Working Plan of Upgrading and Transforming Rural Biogas Projects	2015	Promoted BNG pilot projects by the central government for the first time.
Guidelines for Promoting Development of the Biomethane Industry	2019	Targeted 10 bcm (billion cubic meters) by 2025 and 20 bcm by 2030.
14th Five-Year Plan for the Development of Renewable Energy	2021–2025	Introduced support for large-scale biomethane industry.

The years with the highest growth rates in Europe were 2011 compared to 2010 (nearly 60%) and 2012 compared to 2011 (nearly 50%). The main regulation enforced during this period was the Waste Framework Directive, which makes the separate collection of organic waste mandatory starting in 2024. In other words, a short-term impact was observed in the region following the implementation of legislation directly targeting waste and organic matter management. During the same period, the United States implemented California's Low Carbon Fuel Standard (LCFS), which established a target for reducing carbon intensity in the transport sector. This regulation may have directly influenced biomethane production, which experienced a growth in 2012 compared to 2011 that exceeded the average rate observed through 2024.

More recently, from 2022 to 2024, the United States introduced significant legislation regarding biomethane, including the establishment of future consumption targets and the creation of a direct credit for its use in heavy-duty vehicles. As a result, biomethane production in 2024 grew by 27.87% compared to 2023. The direct effects of the USD 1.00 per gallon biomethane credit are expected to become more evident in the coming years; however, such incentives already contribute to making biomethane more economically attractive than other fuels, increasing its utilization and, consequently, boosting its production.

3.2. Biomethane for Sustainable Transport

When applied as a fuel in the transportation sector, biomethane accelerates the decarbonization process [130]. Biomethane presents a lower environmental impact not only when compared to fossil fuels but also relative to bioethanol and electric vehicles, as demonstrated by Orecchini et al. [131]. The authors found that the consumption of non-renewable primary energy for biomethane was approximately three times lower compared to natural gas, while the reduction reached 55% and 69% when compared to bioethanol and electric vehicles, respectively. Moreover, the use of biomethane resulted in significant reductions in CO₂ emissions, reinforcing its environmental benefits.

Meena et al. investigated a multi-cylinder spark-ignition engine operating with biomethane blended with other fuels in different proportions [132]. The authors demonstrated that biomethane can significantly reduce emissions compared to the other alternative fuels evaluated. Aggarangsi et al. assessed three different biomethane purity levels in a light-duty pickup truck and compared the results with the same vehicle operating on natural gas and gasoline [133]. They found that biomethane led to lower emission levels and achieved a reduction in fuel cost per kilometer traveled of up to two times compared to gasoline. Noussan [134] evaluated the urban bus fleet in Turin, Italy, and analyzed the feasibility of replacing natural gas and diesel with biomethane. The author concluded that the adoption

of biomethane could lead to a substantial reduction in emissions, achieving a 71% decrease compared to the current scenario.

Among the advantages of biomethane over conventional fossil fuels, it is worth noting that biomethane is non-toxic, non-carcinogenic, does not present an increased risk potential compared to diesel, and has a higher autoignition temperature than liquid fuels such as diesel and gasoline [135]. Additionally, the tailpipe emissions of harmful gases can be reduced by up to 30% in vehicles powered by biomethane compared to those fueled by gasoline and diesel [135].

A major challenge for biomethane in the transportation sector is its viability as a fuel for heavy-duty transport. Freight transport accounts for a significant share of emissions and represents a hard-to-decarbonize sector due to the operational demands and continuous use of large diesel engines [136]. There is a growing interest in the use of natural gas and, consequently, biomethane in heavy-duty vehicles. However, the requirement to convert engines to spark ignition poses some barriers, such as reduced driving range compared to diesel-powered vehicles [137]. Therefore, to ensure the competitiveness of biomethane-fueled spark ignition engines in the heavy-duty vehicle market, strategies to improve efficiency must be implemented [138].

Another research direction that has been gaining attention involves the use of biomethane enriched with green hydrogen [139]. Hydrogen has the potential to increase flame temperature, which consequently leads to higher NO_x emissions [139–141].

3.3. Biomethane—A Renewable and Circular Resource

Municipal waste management is considered one of the cornerstones of the circular bioeconomy in the European Union. Key initial measures to support this framework include improving the quantity and quality of waste sorting, implementing fiscal instruments such as pay-as-you-throw systems, and providing incentives for the construction of anaerobic digestion plants [142]. Equally important is the need to raise public awareness through information and education campaigns, which are essential to the success of waste valorization strategies.

The literature highlights the negative impacts associated with inadequate waste management, including the emission of greenhouse gases, unpleasant odors, the spread of diseases, and the proliferation of pests [143,144]. These problems emphasize the environmental, social, and economic benefits of deploying anaerobic digestion technologies for biomethane production. This approach not only mitigates environmental issues but also fosters local job creation and strengthens regional economies.

A key advantage of biomethane production lies in the fact that its feedstock consists of organic waste from various sources. This characteristic enhances feedstock flexibility, strengthens the circular economy, and minimizes competition with food production systems [145,146]. In this context, biomethane production does not exert direct pressure on the food supply chain. Furthermore, since biomass captures CO₂ during its growth, only a portion of this carbon is re-emitted into the atmosphere during biomethane production, resulting in a net reduction in global emissions when evaluated through a life cycle assessment (LCA) [138].

The expansion of biofuels can significantly contribute to the circular economy if based on sustainable biomass sources, including agricultural byproducts, municipal solid waste, industrial residues, and forestry waste [147]. In addition to producing a renewable and efficient fuel, anaerobic digestion yields valuable co-products, such as organic fertilizers and fibrous materials, which further contribute to resource recovery and waste minimization.

In economic terms, the biomethane market has the potential to generate thousands of direct and indirect jobs, contributing to social welfare and local economic development [148].

However, it is crucial to ensure that biomethane production prioritizes waste and residual biomass rather than dedicated energy crops. Only under this condition can its benefits to the circular economy be fully realized, avoiding conflicts with food production and promoting a truly sustainable bioeconomy model [149,150].

4. Discussion

The analysis of the biomethane landscape in South America, in comparison to the world's leading producers, reveals substantial differences—particularly in legislation, tax incentives, and infrastructure. These disparities directly affect South America's capacity to produce and commercialize biomethane, highlighting both challenges and opportunities for regulatory and strategic progress.

It is important to highlight that biomethane can directly replace natural gas without requiring modifications to the existing infrastructure, including storage and distribution systems [151]. Since biomethane can be produced wherever there is waste generation and surplus biomass, it has the potential to become a key vector in the energy transition. With appropriate incentives, biomethane can stimulate local economies by fostering the emergence of entrepreneurs dedicated to its production and commercialization [152].

4.1. Key Regulatory Advances in South America

Drawing on the historical development of major biomethane-producing countries, Table 8 outlines the key legislative measures that have promoted biomethane production and use. The leading producers—namely the USA, EU, and China—have adopted similar legislative frameworks in comparable chronological sequences, fostering biomethane development in recent years.

Table 8. Key legislations for the promotion of biomethane.

Legislation	Expected Timeframe	Countries
Mandatory selective waste collection and/or sanitary landfills	Medium to long term	Brazil and Chile
Minimum share of biofuels in the transport sector and/or energy matrix	Short, medium, and long term	Argentina, Brazil, and Chile
Investment and/or utilization credits for biomethane	Short to medium term	Brazil and Ecuador

A pivotal piece of legislation for biomethane development is the requirement for formal waste collection, which effectively eliminates open dumping practices. The solid waste present in municipal refuse can thus be recovered through anaerobic digestion, enhancing the value of biogas that would otherwise be freely emitted into the atmosphere. With proper upgrading, landfill biogas can be injected into natural gas distribution networks or used in the transportation sector as a renewable substitute for fossil natural gas. However, this initiative is a long-term undertaking, as evidenced by the European Union's Waste Framework Directive (WFD-EC/2009/98), which allowed a 15-year timeline for the full implementation of waste disposal regulations. In South America, a similar initiative was introduced in Brazil under Law No. 12305 of 2010, which originally set a four-year deadline for directing all waste to sanitary landfills, later extended to 2024—resulting in a 14-year transition period. In 2021, Chile launched a program to raise its waste collection rate from 5% to 30%; however, no specific timeline was set for achieving comprehensive waste management. In Peru, Law No. 30754 aimed to promote the use of landfill-generated biogas; nonetheless, only 48% of waste is currently directed to landfills. In several other South American countries, no legislation specifically mandates comprehensive waste disposal control, and waste management practices remain limited.

Once effective waste disposal regulations and compliance deadlines are in place, legislation setting renewable energy targets for the energy mix and transportation sector can drive biomethane development. In the United States, the Renewable Fuel Standard (RFS) of 2005, and in the European Union, the Renewable Energy Directive II (RED II-EU/2018/2001), mandate the minimum usage of biofuels in the transportation sector. As a renewable alternative to fossil natural gas, biomethane can benefit from such legislative measures, even when not directly mentioned. In Argentina, Law No. 27191 of 2017 mandates that at least 20% of the energy matrix must originate from biofuels. In Brazil, Law No. 14993 of 2023 encourages the replacement of natural gas with biomethane by setting a target of a 10% reduction in transport sector emissions starting from 2026. In Chile, Law No. 20527 of 2018 requires that energy companies with capacities above 200 MW to produce at least 5% of their energy from renewable sources.

It is noteworthy that many South American countries already derive a substantial share of their energy from renewable sources—such as Colombia (62%), Ecuador (61%), Peru (56%), Suriname (60%), and Uruguay (76%). However, these countries have yet to establish specific regulations promoting biomethane or set targets to encourage its adoption, such as reducing fossil natural gas consumption. It is also noteworthy that Argentina (10.7%), Bolivia (8%), and Guyana (8%) still have a low participation of renewable sources in their energy matrices, indicating substantial potential for rapid development through renewable and biofuel targets.

Moreover, legislation that provides fiscal incentives for biomethane production and use can further accelerate its development. In the United States, the Inflation Reduction Act (IRA) of 2022 and the Renewable Natural Gas Incentive Act of 2023 established benefits for both biomethane plant construction and its use as a fuel. These incentives directly support biomethane and increase corporate interest in this biofuel. In South America, Brazil's Law No. 13576 of 2017 establishes guidelines for issuing carbon credits, while Ecuador's CONELEC 004/11 introduced preferential tariffs for renewable energy—though limited to facilities commissioned prior to 2012. In other countries, besides the absence of fiscal incentives for biomethane, some nations continue to promote fossil fuel subsidies, particularly among major natural gas producers, which discourages biomethane production and commercialization.

In addition to existing laws, some countries have expressed interest in drafting legislation to support biomethane development. In Colombia, Resolution No. 240 of 2016 set forth regulations for injecting biomethane into natural gas networks. In Brazil, Decree No. 11033 of 2022 defined strategies for the use of biomethane in the transportation sector, while ANP Resolution No. 906 of 2022 set technical limits for the composition of Brazilian biomethane.

4.2. Lack of Legislation on Waste Collection

One of the primary barriers to expanding biomethane production in South America is the absence of specific legislation governing the collection and management of USW. In the United States and the European Union, mandatory organic waste separation and methane capture in landfills have been key drivers of biogas—and consequently biomethane—production.

In South America, countries such as Bolivia and Venezuela discard large volumes of organic solid waste improperly, missing opportunities for energy recovery. Paraguay and Peru face similar issues, exhibiting very low rates of urban waste recycling and reuse. This situation severely restricts biogas and biomethane production, as USW is a primary feedstock for biomethane.

Moreover, the lack of effective waste management policies impedes sector development, resulting in lost energy potential and higher greenhouse gas emissions. Many landfills across South America still lack biogas capture systems, whereas in developed nations, such technologies have been legally mandated for decades.

4.3. Tax Incentives

The world's leading biomethane producers employ tax incentives as a strategy to foster the economic and commercial viability of the biogas industry. In the United States, the Inflation Reduction Act (IRA) of 2022 provides tax credits to support renewable fuel projects. The European Union also offers subsidies and tax incentives to stimulate biomethane production and usage.

In South America, Brazil stands out for implementing policies such as *RenovaBio* and Decree No. 11033/2022, which offer tax incentives for biogas projects. Chile has also introduced initiatives focused on renewable energy, including biomethane production. However, such incentives remain limited or absent in many other countries across the region.

Conversely, the absence of tax incentives in several South American countries poses a major barrier to sectoral growth. Argentina, for example, holds significant biogas production potential but lacks policies that render biomethane competitive with fossil fuels. In Venezuela and Bolivia, heavy subsidies for natural gas further undermine the economic viability of biomethane.

Despite its sizable agricultural sector, Paraguay has yet to implement specific incentives for biogas development. In Colombia, although there is considerable production potential, the fiscal framework to support the sector remains in its early stages.

4.4. Biomethane Potential in South America

The integration of biomethane into South America's energy matrix offers a promising path toward greater energy sustainability and reduced environmental impact. Given the region's diverse energy landscape, countries with a greater reliance on fossil fuels, particularly natural gas, can significantly benefit from the adoption of biomethane.

Biomethane, derived from organic waste, exhibits similar physicochemical properties to natural gas, making it a viable replacement for conventional fossil-based methane in existing infrastructure. This feature enables the smooth integration of biomethane into existing energy distribution systems without the need for significant modifications. Countries such as Argentina and Bolivia, where natural gas constitutes a significant portion of the energy supply, can leverage biomethane to diversify their energy sources while reducing greenhouse gas emissions.

From an environmental perspective, biomethane offers a significantly lower carbon footprint compared to fossil-based natural gas. The closed carbon cycle of biomethane production ensures that combustion emissions are offset by carbon absorption during biomass growth. Furthermore, the use of organic waste for biomethane production reduces methane emissions from landfills and agricultural processes, further contributing to climate change mitigation.

Economically, the development of a biomethane industry in South America has the potential to increase energy security by reducing dependence on imported natural gas and fostering local job creation in the bioenergy sectors. Countries with well-developed agricultural and livestock sectors, such as Brazil and Argentina, have abundant feedstock for biomethane production, supporting the viability of large-scale deployment.

Currently, the United States is the largest producer of biomethane worldwide, with an annual production of 3.5 bcm. Germany represents the largest biomethane market in

Europe, with an estimated production of approximately 1 bcm per year. France has a production volume comparable to Germany (around 1 bcm per year), with projections indicating that, by 2025, it will surpass Germany as the largest producer in Europe. Denmark follows closely, with an annual biomethane production of approximately 0.8 bcm.

As highlighted in Section 4.1, Brazil is the country with the most advanced regulatory framework supporting biomethane development. This regulatory maturity helps explain Brazil's leadership position in biomethane production compared to its South American neighbors. Currently, Brazil has 12 operational plants producing approximately 0.25 bcm of biomethane annually. This figure may increase to 0.27 bcm per year by the end of 2025, as three new plants are expected to commence operations shortly. By 2027, Brazil could reach a production capacity of 0.8 bcm per year, supported by the construction of an additional 32 plants already underway. These projections are based on data available at the beginning of 2025 and may increase further with the advancement of legislative frameworks and growing interest in biomethane. Consequently, Brazil could position itself among the world's leading biomethane producers, approaching Denmark's current production levels.

4.5. Political and Social Drivers of the Biomethane Sector

The development and deployment of biomethane are intrinsically linked not only to technological advancements but also to the implementation of effective political and social instruments. As highlighted in the present study, biomethane stands out as a key enabler for the circular economy, contributing to waste management, GHG mitigation, and energy diversification. However, its large-scale implementation heavily depends on coordinated public policies and social engagement strategies.

From a political perspective, successful biomethane expansion observed in countries such as Germany, France, and Italy has been strongly driven by structured regulatory frameworks that include feed-in tariffs, tax incentives, carbon pricing mechanisms, and subsidies for infrastructure development (e.g., anaerobic digestion plants and grid injection systems). In addition, clear targets for renewable gas integration into national energy matrices and long-term policy stability have been crucial for investor confidence and market growth.

In contrast, in developing countries such as Brazil, although there is a favorable legal framework for biomethane injection into natural gas grids, the lack of consistent financial incentives and specific subsidy programs still limits competitiveness compared to fossil natural gas. Expanding biomethane production in Brazil would benefit from mechanisms such as differentiated taxation, carbon credit systems, and public financing lines dedicated to renewable energy projects.

Social instruments also play a critical role, particularly due to the decentralized nature of biomethane production. A significant share of biogas production in Brazil originates from small-scale producers, including family farming operations. This characteristic highlights the importance of social policies aimed at supporting rural communities, promoting technological training, and facilitating access to credit for small- and medium-sized enterprises (SMEs) engaged in biomethane production. Furthermore, public awareness campaigns about the environmental and economic benefits of biomethane are essential to fostering societal acceptance and encouraging broader adoption.

The integration of biomethane into the energy transition goes beyond environmental benefits; it also contributes to rural development, job creation, and income diversification. By transforming organic waste from sectors such as agriculture, wastewater treatment, and urban solid waste management into renewable fuel, biomethane strengthens local economies and reduces dependence on centralized fossil fuel infrastructures. This socio-economic dimension is particularly relevant in regions with high levels of agricultural activity

and waste generation, providing a unique opportunity for the deployment of distributed energy systems.

4.6. Future Challenges

Argentina has only 10.7% of its energy matrix sourced from renewables. In contrast, 50.23% comes from natural gas, indicating a significant potential market for biomethane. Over the years, some regulations have been implemented to establish biofuel targets within the energy matrix (Law No. 26190 setting an 8% target in 2006 and Law No. 27191 in 2016 setting a 20% target). Although still modest, these targets create an opportunity for biomethane to emerge as a fuel for the future. Moreover, biogas production in the country is primarily concentrated in small- and medium-scale private facilities, mainly focused on thermal energy generation. Consequently, the upgrading of biogas to biomethane is not yet regarded as a viable energy alternative, either for power generation or fuel use. Despite the existing potential, there is still no comprehensive legislation for the management and use of solid waste for biogas or biomethane production. Additionally, the establishment of biomethane use targets and the implementation of direct fiscal incentives could promote the development of biomethane in the country, especially considering that current biogas production could be upgraded to biomethane if it became competitive with other fuels, such as natural gas.

In Bolivia, natural gas accounts for 79.62% of the energy matrix, which theoretically suggests significant potential for biomethane. However, the main barrier to biomethane adoption in the fuel market is the substantial fiscal incentive currently granted to fossil fuels. Therefore, biomethane should be directly incentivized through credits and tariffs, while governmental support for natural gas should be gradually reduced to allow fair competition. A clear potential for energy generation through biogas recovery from landfills has been identified in three regions of the country (approximately 550.4 GWh), but the absence of legislation for waste management continues to hinder the development of both biogas and biomethane.

In Brazil, its regulatory maturity helps explain its leadership in biomethane production in South America. Legislation has been enacted to prohibit open dumping of waste, which has acted as a driver for biomethane development. Most biomethane plants in the country rely on municipal solid waste (MSW) from sanitary landfills, highlighting the benefits of Law No. 12305 from 2010, which banned open dumping by 2014, later extended to 2024. The country also has a long-standing tradition of biofuels such as ethanol and biodiesel, widely used in the transportation sector. According to data from ANP, Brazil is projected to become one of the world's leading biomethane producers by 2027, reaching 0.8 bcm, equivalent to Denmark's current production. Law No. 14993/2023 is a recent example that confirms the country's intent to enhance biomethane competitiveness.

In Chile, the majority of the energy matrix is still based on fossil fuels. Biomass accounts for a relevant share (26%) of the matrix but is not exclusively used for biomethane production. While there are a significant number of biogas plants (107), only one facility currently upgrades biogas to biomethane. The National Organic Waste Program, launched in 2021, may boost interest in biogas and biomethane, as it mandates an increase in landfill gas collection from 5% to 30%. Despite the lack of full-scale waste control, this legislation could be considered a precursor to biomethane development in the country. Setting future targets for biogas and biomethane utilization could further stimulate these biofuels, considering the notable share of biomass in Chile's energy mix.

In Colombia, there is a clear energy generation potential from biogas estimated at 63,791 TJ per year, considering only agricultural, livestock, and industrial residues. While a large part of the energy matrix comes from renewables, hydropower dominates (67.99%).

Biomass is mainly used for gasification and syngas production. In the absence of comprehensive waste disposal legislation, biogas facilities traditionally produce electricity directly, with little interest in upgrading to biomethane. In 2016, Resolution No. 240 established a legal framework for injecting biomethane into the natural gas grid. Although promising, the lack of waste control still hampers biomethane development. Fiscal incentives and mandatory usage targets could make biomethane a viable option in Colombia and encourage biogas plants to invest in upgrading technologies.

In Ecuador, most of the energy matrix is based on renewable sources, but biogas represents only a minor share (0.1%). In 2010, the National Law for Autonomy and Territorial Decentralization assigned municipalities the responsibility of gradually implementing waste collection and treatment. However, no subsequent legislation has set explicit targets for complete waste control. Only two facilities in the country currently treat MSW for electricity generation via biogas. These facilities benefit from Ecuadorian fiscal incentives, although they are only applicable to installations operational before 2012. As such, Ecuador still lacks specific control measures for waste valorization. Renewed incentives for biogas and biomethane use, which ended in 2012, and regulations establishing biomethane utilization targets are both necessary. Combined, these policies could make biomethane competitive and promote its widespread adoption.

In Guyana, 92% of the energy matrix is based on fossil fuels, severely limiting the penetration of renewables. First, proper waste management must be established to ensure sufficient MSW availability for biogas production. Next, a minimum utilization target for biogas or biomethane should be introduced to stimulate production. Finally, fiscal incentives directly supporting biomethane use are essential to make it competitive against fossil fuels.

In Paraguay, there is significant potential for agricultural waste utilization in biogas production (315 million Nm³). However, in the absence of specific incentives and regulations, there is little interest in utilizing this resource. Furthermore, no legislation exists for the control and reuse of waste. Although several regulations have been implemented in recent years, none have explicitly addressed biogas or biomethane. Therefore, Paraguay needs specific legislation mandating waste management and subsequently setting targets for biogas upgrading to biomethane. To make biomethane attractive compared to other fuels, direct tax incentives or credits for producers and users should also be considered.

As in other South American countries, Peru's energy matrix relies heavily on hydropower. Biogas is mainly used for electricity generation, though it represents a negligible share of the matrix (0.1%). It is estimated that only 1% of MSW is currently used for biogas production. Thus, there is an urgent need for legislation addressing waste disposal and establishing targets for MSW reuse via biogas production. Subsequently, clear biomethane usage targets should be set. Finally, direct credits and incentives are essential for making biomethane attractive and supporting its growth in the country.

In Suriname, there are estimates of replacing natural gas with biomethane. However, similarly to most analyzed countries, biomethane is not yet competitive. Therefore, waste management and treatment must be regulated, and both biomethane utilization targets and incentives must be established to promote its production and usage.

In Uruguay, there are significant challenges in utilizing agricultural residues for biogas production. Similarly, only 18% of methane generated by industries is directly reused. As a result, just five facilities in the country produce electricity from biogas. Legislation establishing biomethane usage targets could make it more attractive and boost production, given the existing biogas plants. Waste management should also be prioritized, as MSW is one of the primary feedstocks for biogas generation worldwide. Additionally, interest in

biomethane could be enhanced through direct credits and fiscal incentives for its production and use.

Venezuela faces a situation similar to Bolivia, as it is a major natural gas producer. Thus, biomethane is unlikely to be competitive unless targeted policies are implemented. Fiscal benefits for biomethane production and mandatory utilization targets are crucial. Moreover, waste management must be regulated through legislation, as it is common for landfills in the country to release biogas without proper utilization.

In summary, the main actions that should be implemented in South America to foster biomethane development are given as follows:

- Implementation of legislation that encourages the collection and separation of organic waste.
- Establishment of emission reduction targets and carbon credit systems.
- The creation of financial and tax incentives for biogas plants.
- Expansion of infrastructure for biomethane injection into the natural gas grid.
- Development of public–private partnerships for financing biogas projects.
- Development of environmental education initiatives and promotion of the circular economy to raise public awareness about the significance of biomethane.

5. Conclusions

One of the key innovations of this review lies in its systematic comparison between South American countries and the world's major biomethane producers, offering not only a diagnostic of the current situation but also strategic references for regulatory and investment development. By consolidating fragmented and scarce data, the study contributes practical value for decision makers, investors, and researchers aiming to structure the biomethane market within the continent.

Key barriers hindering the advancement of biomethane in South America include the lack of comprehensive waste management regulations, limited fiscal incentives specifically targeting biomethane production, and a lack of integration with national energy strategies. Conversely, opportunities such as the agricultural and urban waste potential, the expansion of renewable energy goals, and the ongoing global decarbonization agenda offer fertile ground for biomethane development.

It is initially recommended to implement legislation focused on waste management, as such measures have proven beneficial in other regions of the world. Brazil already has legislation focused on waste disposal control, which helps explain the country's prominent position in the South American biomethane market. It is important to emphasize that the regulation of waste disposal constitutes a long-term initiative, typically requiring more than ten years to achieve full implementation, but it should be one of the first regulatory measures adopted to promote biomethane development. Subsequently, establishing targets for the participation of biofuels in the energy matrix and/or the mobility sector is a medium-term strategy that can further stimulate biomethane production and utilization. It is noteworthy that short-, medium-, and long-term targets are feasible and can be implemented progressively. In addition, specific legislation and goals focused on biomethane should be adopted, considering that many South American countries already have a significant share of renewable energies in their energy matrices. Finally, legislations establishing fiscal incentives and credit mechanisms for biomethane production and utilization should be implemented in the medium term, as these measures would enhance the competitiveness and market attractiveness of this biofuel.

Future research should prioritize the techno-economic assessment of biomethane projects in South America, particularly their integration into the existing natural gas grid, and the creation of carbon credit markets tailored to biomethane. In addition, further inves-

tigations are recommended to explore biomethane applications in mobility and distributed energy systems, which remain underexplored in the region.

The paper also highlights Brazil as the largest biomethane producer in South America. With legislation supporting biomethane development that is comparable to that of the world's leading producers, Brazil has the potential to become one of the largest biomethane producers globally, reaching 0.8 billion cubic meters (bcm) by 2027, provided that all plants currently under construction become operational. Brazil thus serves as an example for other South American countries, which could follow this model to also become key players in the global biomethane market.

By answering the initially stated goals—namely, assessing the state of biomethane production, commercialization, regulatory frameworks, and mapping barriers and opportunities—this paper provides a strategic basis to foster regional cooperation, encourage targeted public policies, and stimulate scholarly interest and investment in the biomethane sector, contributing decisively to the energy transition in South America.

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Abbreviations

The following abbreviations, acronyms, and symbols are used in this manuscript:

ANP	Brazilian National Agency of Petroleum, Natural Gas, and Biofuels
bcm	Billion cubic meters
BNG	Bio-natural gas
bTDC	Before top dead center
CH ₄	Methane
CNG	Compressed natural gas
CO	Carbon monoxide
CO ₂	Carbon dioxide
COP21	21st Conference of the Parties in Paris
GHG	Greenhouse gas
HCs	Unburned hydrocarbons
H ₂ S	Hydrogen sulfide
ICEs	Internal combustion engines

LNG	Liquefied natural gas
MBT	Maximum brake torque
N ₂	Nitrogen
NO	Nitrogen monoxide
NO _x	Nitrogen oxides
O ₂	Oxygen
SI	Spark ignition
UPME	Mineral energy planning unit
USA	United States of America
USW	Urban solid waste

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