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# Contradictory electric energy policies and its impacts on the renewability of the electric matrix: Brazil as a case study

Marcos Eduardo Melo dos Santos [a,*], Rui Castro [b], Hirdan Costa [c]

[a] HE/FFLCH, IEE, University of São Paulo, São Paulo, Brazil and Postdoc at INESC-ID/IST, University of Lisbon, Lisbon, Portugal
[b] INESC-ID/IST, University of Lisbon, Lisbon, Portugal
[c] IEE, University of São Paulo, São Paulo, Brazil

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ABSTRACT

This unprecedented analysis of the factors that determine the performance of Brazil electric energy contradictory policies identifies the irregular path followed by one of the largest national oil companies in the world. As high convenience comparative case study, the increase and decrease of production and investment within the context of the Brazilian electric matrix in the last 20 years can shed light on Petrobras' disparities in relation to itself and in relation to external variables over time such as policies and investment choices, international oil prices and exploration cost.

## 1. Introduction

This comparative case study evaluates the public policy strategies of the Brazilian government concerning thermoelectric plants. This quantitative and qualitative assessment considers political, economic, social, technological, legal and environmental factors for adopting different strategies according to the country's political orientation and stage of development of thermoelectric plants. Factors such as production, consumption, demand, cost per barrel of oil, investment, investment forecast, price and installed capacity provide quantitative criteria for strategically evaluating public policies.

From the beginning of the 2000s, developed countries reinforced the processes of replacing coal and oil with imported natural gas to reduce greenhouse gas emissions. For example, the United Kingdom, United States and Canada had the advantage of not being dependent on imports.[1] This trend was verified in Brazil but with a different motivation. According to the consolidated bibliography, in addition to having an electrical matrix with less use of hydrocarbons than developed countries, the country also started to have natural gas reserves available domestically.[2] Electricity production using natural gas as a source also gained momentum due to energy

* Corresponding author.
*E-mail addresses:* marcos.eduardo.santos@usp.br (M.E. Melo dos Santos), rcastro@tecnico.ulisboa.pt (R. Castro), hirdan@usp.br (H. Costa).

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shortages. The dry period caused the hydroelectric production to be reduced due to the decrease in the flow of the reservoirs.[3] As the increase in installed capacity through hydroelectric plants requires long-term projects, natural gas was used as a short-term solution.[4] In addition, the offshore production of gas associated with oil offered the opportunity to use this resource as a source of electrical energy. The development of technologies for exploration in deep and ultra-deep waters also offered Brazil this opportunity. Public policies and investment decisions through the national oil company (NOC), Petrobras, encouraged the growth of the installed capacity of Brazilian thermoelectric plants.

Among the countries with the highest installed capacity for electricity production using natural gas, it is possible to highlight four groups. The first is composed of countries with production surpluses for self-sufficiency with availability for export. The second group consisted of countries with a balance between production and consumption. The third group would be import dependent. The fourth group would be highly reliant on exports. In the second group, in 2022, Brazil occupied the 29th place in the ranking of installed capacity for producing electricity using natural gas. However, counting announced pre-construction and construction projects, it is now the 2nd country with more projects in the development of installed capacity, surpassed only by China.[5] The projects under development could elevate the country to 6th place in installed capacity over the next few years, behind only the United States, China, Japan, Russia and Iran. China and Brazil, respectively, tend to double and triple their installed capacity (see Table 1).

The countries with the highest installed capacity were divided by the authors by the *ratio* between consumption and production of natural gas. Countries with a ratio lower than 0.9 in the table were considered exporters (Russia, United Arab Emirates, Indonesia, Canada, Algeria, Malaysia, Australia and the Netherlands). The second group consisted of countries with a balance between input and output with a ratio between 0.91 and 1.1 (Brazil, United States, Saudi Arabia and Pakistan). The third group would be import dependent with a ratio above 1.11 (China, Iran, Mexico, Thailand, United Kingdom, Kuwait, India and Argentina). The fourth group would be highly dependent on exports with a ratio greater than 10 (Japan, South Korea, Italy, Egypt, Iraq, Taiwan, Germany, Spain and Turkey).

Brazil has one of the largest companies that produce electricity through natural gas, Petrobras. It is today the leading company in oil and gas production and exploration and in upstream technologies in deep and ultra-deep waters.[6] Controlled by the state since its origin, this NOC is among the 80 largest companies in the world in terms of installed capacity in 2022. However, within the group of companies that operate in the exploration and production of gas, as well as in the production of electricity through gas, it is in 5th place, ahead of *majors* such as Total and Shell. Among the ten largest oil companies producing electricity through natural gas, six can be classified as National Oil Companies (NOC). However, among the projects under development, ExxonMobil stands out, being the third company with the largest installed capacity under development. Thus, it can be concluded that the interest in producing electricity based on gas is not exclusive to NOCs, although it is predominant due to the demands of governments (See Table 2).

Tables 1 and 2 above also present two important trends in the Brazilian case. While the growth of installed capacity is undertaken by public companies, unlike the recent past, it is not today the main driver of growth in Brazil. This change deserves to be investigated since it seems to be related not only to the international context but also to political changes in Brazil. Petrobras owns almost 90% of the Brazilian Oil and Gas market.[7]

The expansion of the thermoelectric source in the Brazilian electrical matrix is motivated within a specific context that deserves to be analysed. Brazil (12%) is below the world average for using natural gas for electricity production (23%) in2021.[8] Nevertheless, it has the prospect of becoming the fourth largest consumer of this source, surpassing, for example, Germany and the United States and being surpassed only by China, Russia and Turkey. Thus, the development of Brazilian thermoelectric production deserves to be studied in a specific way. In addition, the country is the most relevant experience in the region due to its continental dimensions and the position it occupies today through Petrobras.[9] Throughout the 20th century, the federal government, through the national oil company (NOC) control, went through an intense industrialization process and became an important centre of the oil and gas industry, even becoming the leader in exploration technologies in deep and ultra-deep waters[10]. However, at the beginning of the 21st century, the company's results in electricity production presented a contradictory path over the years regarding the environment and development. The effects of strategy changes deserve to be evaluated. In the systematic bibliographical research carried out, no evaluations of the Brazilian strategy were found in articles published in high-quality journals.

In the electric energy segment, the company operates in the generation, commercialization and consumption markets, emphasising generation, having a mostly thermoelectric generating park and occupying the sixth position among the most significant agents in

[3] Colomer Ferraro, Marcelo, Hallack, Michelle. 2012. The development of the natural gas transportation network in Brazil: recent changes to the gas law and its role in coordinating new investments, Energy Policy, Vol. 50, 601–612.

[4] Raimundo, Danielle Rodrigues; dos Santos, Ivan Felipe Silva; Tiago Filho, Geraldo Lúcio; Barros, Regina Mambeli. 2018. Evaluation of greenhouse gas emissions avoided by wind generation in the Brazilian energetic matrix: A retroactive analysis and future potential, Resources, Conservation and Recycling, Volume 137, 270–280.

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[7] Ramírez-Cendrero, Juan M. and [12]. Oil fiscal regimes and national oil companies: A comparison between Pemex and Petrobras, Energy Policy, Elsevier, vol. 101, pp. 473–483.

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[9] Massi, E. and J. Nem Singh. 2018. "Industrial Policy and State-Making: Brazil's Attempt at Oil-Based Industrial Development." Third World Quarterly 39 (6): 1133–1150.

[10] [13]. Offshoring and the global geography of innovation. J. Econ. Geogr. 10 (4), 559–578; Rodrigues, Larissa Araujo, Sauer, Ildo [14]. Exploratory assesment of the economic gains of a pre-salt oil field in Brazil. Energy Policy 87, 486–495.

**Table 1**
External dependency in 2018 of the largest natural gas thermoelectric energy producers and projection of investments in development [3].

| Country | In Development | Operating | Total | Natural Gas consumption | Natural Gas production | Ratio consumption production | Country Group |
|---|---|---|---|---|---|---|---|
| United States | 37,436 | 532,529 | 569,965 | 846,600 | 831,800 | 1.02 | 2 |
| China | 92,910 | 105,208 | 198,118 | 307,300 | 161,500 | 1.90 | 3 |
| Russia | 12,396 | 106,672 | 119,068 | 444,300 | 669,500 | 0.66 | 1 |
| Iran | 25,658 | 67,564 | 93,222 | 223,600 | 60,180 | 3.72 | 3 |
| Japan | 11,237 | 77,505 | 88,742 | 108,100 | 4453 | 24.28 | 4 |
| Brazil | 48,126 | 14,231 | 62,357 | 38,300 | 40,857 | 0.94 | 2 |
| Mexico | 13,310 | 48,782 | 62,092 | 90,700 | 40,370 | 2.25 | 3 |
| South Korea | 19,918 | 41,817 | 61,735 | 49,400 | 188 | 262.77 | 4 |
| Italy | 13,791 | 43,298 | 57,089 | 72,100 | 5785 | 12.46 | 4 |
| Saudi Arabia | 550 | 55,868 | 56,418 | 113,600 | 112,100 | 1.01 | 2 |
| Thailand | 16,082 | 35,757 | 51,839 | 50,100 | 37,700 | 1.33 | 3 |
| Egypt | No data | 51,608 | 51,608 | 58,900 | 3610 | 16.32 | 4 |
| United Kingdom | 16,775 | 33,258 | 50,033 | 78,800 | 40,600 | 1.94 | 3 |
| United Arab Emirates | 6760 | 42,828 | 49,588 | 72,200 | 175,500 | 0.41 | 1 |
| Iraq | 10,963 | 29,214 | 40,177 | 19,900 | 1002 | 19.86 | 4 |
| Kuwait | 20,400 | 19,543 | 39,943 | 23,500 | 16,910 | 1.39 | 3 |
| Taiwan | 15,700 | 18,472 | 34,172 | 23,300 | 340 | 68.53 | 4 |
| India | 6245 | 26,485 | 32,730 | 54,200 | 26,210 | 2.07 | 3 |
| Indonesia | 12,740 | 18,407 | 31,147 | 39,200 | 73,200 | 0.54 | 1 |
| Germany | 6936 | 23,419 | 30,355 | 88,700 | 8730 | 10.16 | 4 |
| Canada | 5131 | 22,695 | 27,826 | 120,300 | 184,700 | 0.65 | 1 |
| Algeria | 5272 | 22,247 | 27,519 | 38,900 | 92,300 | 0.42 | 1 |
| Spain | No data | 26,939 | 26,939 | 32,000 | 62 | 516.13 | 4 |
| Turkey | No data | 24,608 | 24,608 | 51,700 | 381 | 135.70 | 4 |
| Argentina | 405 | 22,391 | 22,796 | 48,500 | 39,400 | 1.23 | 3 |
| Malaysia | 2600 | 17,517 | 20,117 | 42,800 | 72,500 | 0.59 | 1 |
| Australia | 4008 | 14,785 | 18,793 | 41,900 | 130,100 | 0.32 | 1 |
| Pakistan | 2442 | 15,819 | 18,261 | 40,700 | 39,300 | 1.04 | 2 |
| Netherlands | No data | 14,614 | 14,614 | 36,100 | 47,460 | 0.76 | 1 |
| World Total | 691,752 | 1,831,260 | 2,523,012 | – | – | – | |

Source: Global Gas Plant [1], Global Energy Monitor and CIA world [2]. Consumption and production in million $m^3$;/year, 2018. Power capacity installed in MW.

**Table 2**
Top 10 Oil Companies in ownership of gas plants (Installed Capacity in MW).

| Rank | Parent | Control | Development | Operating | Total | Country | Founded | Employees | Revenue in US$ billion |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Gazprom | Public | 1502 | 15,654 | 13,099 | Russia | 1989 | 468,000 (2022) | 138.7 (2021) |
| 2 | PetroVietnam | Public | 6170 | 2715 | 8885 | Vietnam | 1975 | 60,000 (2022) | 27.1 (2021) |
| 3 | CNOOC | Public | 2047 | 5305 | 7352 | China | 1992 | 98,750 (2011) | 98.5 (2017) |
| 4 | Saudi Aramco | Public | 0 | 6954 | 6954 | Saudi Arabia | 1933 | 66,800 (2018) | 424.8 (2021) |
| 5 | ExxonMobil | Private | 4662 | 2028 | 6690 | United States | 1870 | 63,000 (2021) | 285.6 (2021) |
| 6 | Eni SpA | Private | 532 | 5376 | 5908 | Italia | 1953 | 32,689 (2019) | 90.5 (2021) |
| 7 | Petrobras | Public | 257 | 5003 | 5260 | Brazil | 1953 | 45,532 (2021) | 83.9 (2021) |
| 8 | TotalEnergies | Private | 713 | 4497 | 5210 | France | 1924 | 101,310 (2022) | 205.8 (2021) |
| 9 | Shell | Private | 258 | 3395 | 3653 | United Kingdom | 1890 | 86,000 (2021) | 272.6 (2021) |
| 10 | NIOC | Public | 320 | 2073 | 2393 | Iran | 1951 | 87,500 (2019) | 110.1 (2018) |

Source: Global Gas Plant [1], Global Energy Monitor and Oil Companies Reports (several years).

installed capacity in the country (Table 3). In these links in the chain, Petrobras operates in a highly competitive market with a predominance of state agents among the largest producers. Petrobras is the sixth largest producer of electricity in Brazil and the only one whose main activity is not hydroelectricity and whose main source is thermoelectric plants.[11] (see Table 4)

When studying the case of this large national oil company (NOC), it is necessary to consider that Latin America historically has had cases of industrialization and modernization based on natural resources, especially oil.[12] Brazil is the most relevant experience in the region due to its continental dimensions and the position it occupies today through Petrobras.[13] Throughout the 20th century, the federal government, through the firm's control, went through a robust industrialization process and became an important centre of the

[11] Petrobras (Petróleo Brasileiro S.A.), Reports, 2000–2020. Available online at: ⟨https://www.investidorpetrobras.com.br/apresentacoes-relatorios-e-eventos/relatorios-anuais/⟩.

[12] De Oliveira, Adilson, 2012. Brazil's Petrobras: strategy and performance. In: Víctor, David G., Hults, David R., Thurber, Mark (Eds.), Oil and Governance. State-Owned Enterprises and the World Energy Supply, ed. Cambridge University Press, New York, 515–555.

[13] Massi, E. and J. Nem Singh. 2018. "Industrial Policy and State-Making: Brazil's Attempt at Oil-Based Industrial Development." Third World Quarterly 39 (6): 1133–1150.

**Table 3**
Top ten agents in the Brazilian electricity sector (2019).

| | Companies | Installed Capacity | % to the national total | Main source | Control |
|---|---|---|---|---|---|
| 1° | Companhia Hidrelétrica do S. Francisco - Chesf | 10,323 | 6.3% | Hydroelectric | Public* |
| 2° | Furnas Centrais Elétricas | 9443 | 5.7% | Hydroelectric | Public* |
| 3° | Centrais Elétricas do Norte do Brasil | 8907 | 5.4% | Hydroelectric | Public* |
| 4° | Norte Energia | 7566 | 4.6% | Hydroelectric | Public* |
| 5° | Itaipu Binacional | 7000 | 4,2% | Hydroelectric | Public |
| 6° | Petrobras | 6323 | 3.8% | Thermoelectric plants | Public |
| 7° | Engie Brasil Energia | 6188 | 3.8% | Hydroelectric and Thermoelectric (20%) | Private |
| 8° | Copel Geração e Transmissão | 5257 | 3.2% | Hydroelectric | Public |
| 9° | Rio Paraná Energia | 4995 | 3.0% | Hydroelectric | Private |
| 10° | Energia Sustentável do Brasil | 3750 | 2.3% | Hydroelectric | Public |
| | Total | 69,755 | 42.3% | | |

Sources: Banco de informações da geração (BIG), Agência Nacional de Energia Elétrica, ANEEL, Boletim de Informações [4], p. 8. * Private since 2022. Installed capacity in MW.

**Table 4**
PICO framework. Source: authors.

| Population or Problem | Intervention | Comparison | Results |
|---|---|---|---|
| Petrobras | Thermoelectric Industry | Companies in the oil and gas sector operating thermoelectric plants | Production, installed capacity, investment, costs, demand, emissions reductions and electric matrix share |
| Brazil | | Gas producing countries | |

oil and gas industry, even becoming the leader in exploration technologies in deep and ultra-deep waters.[14] The State even uses this as a driver of development.[15] However, at the beginning of the 21st century, the company's results in electricity production presented a contradictory path over the years, which justifies the comparison of the NOC's results with itself.

Numerous studies establish comparisons between oil companies such as in Latin America,[16] Europe,[17] and North America.[18] This study intends to establish a comparison of the case of Brazil and Petrobras with other companies of the same size. The differences in performance over time in the Petrobras case, as seen in the production of natural gas and electricity, present several indispensable factors to consider: the amount of investment, production cost, demand and production of gas and energy and even climatological factors.[19] National and international requirements concerning reducing emissions, especially in electricity production, are increasing[20]. International and national pressures and public opinion itself are relevant factors in reducing greenhouse emissions. In this context, electricity produced from natural gas is considered as a source of energy transition, as it presents lower levels of carbon emissions when compared to other fossil fuels.[21] Thus, the importance of this sector for the company is perceived, especially after finding large reserves of gas and oil associated with gas in the pre-salt reserves.[22]

However, these studies do not focus on thermoelectric production nor in the role of Petrobras specifically. Only two studies assess the

[14] Leal, Fernando I.; Rego, Erik E.; Ribeiro, Celma de Oliveira. 2019. Natural gas regulation and policy in Brazil: Prospects for the market expansion and energy integration in Mercosul, Energy Policy, Volume 128, 2019, 817–829.
[15] [15]. "Technology and Innovation in the Brazilian Oil Sector: Ticket to the Future Or Passage to the Past?" Journal of World Energy Law and Business 9 (4): 237–253.
[16] Luong, P. J. and J. Sierra. 2015. "The Domestic Political Conditions for International Economic Expansion: Lessons from Latin American National Oil Companies." Comparative Political Studies 48 (14): 2010–2043; Goldstein, A. and C. Baena. 2010. "Drivers of Internationalisation of Companies from Emerging Economies: Comparing Petrobras (Brazil) and PDVSA (Venezuela)." International Journal of Technological Learning, Innovation and Development 3 (4): 392–407; Dantas, E., 2006. The Development of Knowledge Networks in Latecomer Innovation Systems: The Case of PETROBRAS in the Brazilian Offshore Oil Industry. DPhil Thesis, SPRU, University of Sussex, Brighton.
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[19] Ramírez-Cendrero, Juan M. and [12]. Oil fiscal regimes and national oil companies: A comparison between Pemex and Petrobras, Energy Policy, Elsevier, vol. 101, pp. 473-483.
[20] [21]. Federal Environmental Protection and the Distorted Search for Oil and Gas. Working Paper.
[21] [22]. How international oil and gas companies respond to local content policies in petroleum-producing developing countries: a narrative enquiry. Energy Policy 73, 471–479.
[22] Costa, O.L.V., de Oliveira [23]. A robust least square approach for forecasting models: an application to Brazil's natural gas demand. Energy Syst 11, 1111–1135.

development of the electricity industry from a productive point of view.[23] Silva et al.[24] created a mathematical model to evaluate infrastructure development, considering technology maturity level, fuel and facilities costs, and the electricity market. However, the research was limited to the economic analysis of the pre-salt area in Southeast Brazil. They had have attempted to assess the strategy of the various public policies adopted by the federal government over the last few years. Furthermore, it does not establish a comparison with other markets. Aragão and Giampietro[25] created a qualitative analysis of the Energy System based on the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM). Although the study considers the technological factor of the natural gas industry and the quantitative data of the energy industry in Brazil, it did not create a mathematical model, did not focus on the thermoelectric source and is not a strategic analysis of public policies. Thus, the new perspective offered by the present study is evident.

Petrobras acquired its first thermoelectric plants in 2000. Six years later, it already held about 50% of the national thermoelectric production. As shown in Fig. 1, both Brazilian production and the company's production have an irregular path. Both productions peaked in 2014. However, from 2015 onwards, there is a decline in national production and in Petrobras' participation. In 2020, Petrobras' production is similar to that of 2006 and does not reach 20% of national production.

However, there is a reduction in this share due to the entry of other players in the market and due to the reduction in investments in the company's electricity production area. Petrobras is considerably more than a public company and therefore is a critical player in economic dynamics.[26] However, it is clear that, over these 20 years of analysis, there has been a change in strategy. As shown in Fig. 1, after an extremely high growth in production through the acquisition of thermoelectric plants and participation in electric production projects until 2014, the company abdicated its position as the national leader in electric energy production through thermoelectric plants. The company turned it into an alternative for electric production in periods of water scarcity and reduced production of hydroelectric plants, which today still correspond to the largest source within the Brazilian matrix.[27] This change contradicts the projections for an increase in the participation of natural gas in the Brazilian energy matrix due to environmental and budgetary restrictions for the expansion of the hydroelectric park. On the other hand, with the reduction in the cost of deployment and production of wind and solar energy, it appears that this matrix has replaced production from natural gas.

The company's strategic option tends to concentrate investments in the exploration and production of natural gas for sale to thermoelectric plants belonging to other players. This change is politically motivated and is explicitly defined in the company's reports and strategic plans.[28,29] These investment priority shifts must be analysed through quantitative and qualitative data in the company's reports and Brazilian regulatory agencies.

The literature still needs to deal adequately with the pros and cons of these different strategic decisions of the Brazilian government through its state-owned company. Studies have yet to analyse the relationship between gas production and electricity demand in the context of high and low economic growth, as experienced by Brazil, respectively, in the first decade and second decade of 2020. Studies published in high-level journals have yet to consider the consequences of the Brazilian government's change in strategy. The State went from being the main driving force behind thermoelectric plants to opening up the market to the private sector. The studies also did not assess the impact on the Brazilian electricity matrix.

Considering these aspects not yet fully addressed in previous studies[30], this paper will show the importance of some political and institutional factors to explain the company's productive performance in the electric energy area. It is necessary to explain how costs, including environmental, specific (and very different over time) condition performance and investment over the years. In addition to the costs, verifying the change in the company's direction is possible due to the control of the federal executive power. Thus, the political orientation of the executive power and the set of rules, laws, regulations and agreements in the environmental and industrial areas are causal factors in the strategic design of investment priorities.[31] However, this option deteriorated the Brazilian electric matrix from an

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[24] Silva, Liane Marcia Freitas; de Oliveira, Ana Camila Rodrigues; Leite, Maria Silene Alexandre; [24]. "Risk assessment model using conditional probability and simulation: case study in a piped gas supply chain in Brazil," International Journal of Production Research, Taylor & Francis Journals, vol. 59(10), 2960–2976.

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[31] Ramírez-Cendrero, Juan M. and [12]. Oil fiscal regimes and national oil companies: A comparison between Pemex and Petrobras, Energy Policy, Elsevier, vol. 101, pp. 473–483.

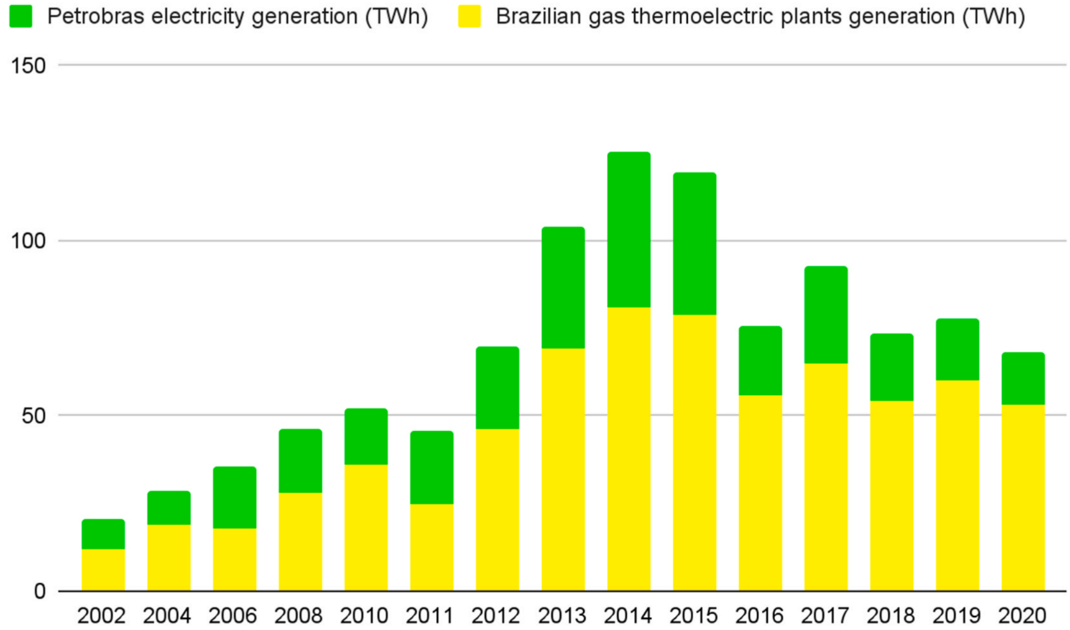


**Fig. 1.** Petrobras' participation in the Brazilian production of gas thermoelectric electricity (2002–2020).
Source: Petrobras and Aneel reports. Created by the authors

environmental point of view. The company's intention to be the leader in electricity production was also abandoned, and the company's electricity production sector was reduced to internal consumption or energy supply in times of crisis in the hydroelectric sector.

Based on this approach, our work aims to identify the specific characteristics of the policy and its influence on Petrobras' performance throughout the analysis period in terms of participation in the Brazilian electric matrix. This article tries to answer the following questions: What differences are there between the direction of Petrobras's electricity production policy? What are the impacts of these decisions on the Brazilian electricity matrix?

This paper is a strategic analysis study. This research tries to qualitatively evaluate the factors that motivate and impact the thermoelectric industry in the country. In addition, we study the impacts of Brazilian government policies on thermoelectric production and its impacts on the country's electrical matrix.

The context is restricted to the national electricity matrix and the role of the federal government, including through Petrobras. Data from other companies and countries will serve as comparative data. The qualitative analysis of the strategy will be carried out using the PICO, PESTEL and SWOT frameworks.

Public policies are also evaluated regarding other variables such as the international cost per barrel, investment, investment forecast, installed capacity, GDP, demand and reserves. The time frame is the years 2000–2020 to assess the political changes of the federal administration between the opposition parties Cardoso, Lula-Dilma, Temer and Bolsonaro. Data are broken down on an annual basis and correspond to national production.

In this paper, we conclude that between 2000 and 2012, Brazil expanded its electric capacity through Petrobras investments. After this period, the company reduced investments, and the installed capacity growth in this matrix is being carried out through the private initiative. Although natural gas is a less polluting source than coal and oil, this matrix tends to reduce the renewability of the Brazilian electricity matrix until 2020.

In this article, after describing the bibliography review (Section 2) and the methodology (Section 3), it was possible to divide the answer into two parts. The first deals with the growth trend between 2000 and 2013 (Section 4.1). This trend can be verified above all by the energy crisis and the rise to power of the Workers' Party with the developmental state model bias towards the company's administration. And it ends with the disinvestment trend between 2014 and 2020 (Section 4.2). This trend can be verified after the degradation of the developmental state model and the accession of governments with proposals closer to liberalism. The last part associates the investment with variations in the Brazilian electricity matrix (Section 4.3). Finally, some conclusions of the work carried out are presented (Section 5).

## 2. Bibliography review

The national oil company's creation was fundamental for countries with huge oil reserves.[32] This is mainly due to the strategic

[32] [25]. Changing relationships between multinational companies and their host regions? A case study of Aberdeen and the international oil industry. Scott. Geogr. J. 117 (1), 31–48.

nature of this industry and its potential for job creation and industrial chain production. In turn, States are strongly influenced by their performance.[33] The relationship between state development strategies and the NOC causes a conflict between "national goals" (Brazil) and "commercial goals" (Petrobras) and creates an insurmountable dichotomy.[34] The NOC can pursue its own goals to the point of acquiring the State, or the State can exercise its purpose to the point of inhibiting the NOC from operating effectively. This approach underlies the principle that it is impossible to reconcile commercial and national goals and that politics is a key determinant of this contradiction.[35] The resolution would only be possible in favour of one of the poles.[36]

From this, it is possible to identify that the policy determines the NOC's performance, especially in countries where they play a preponderant role in the gross domestic product.[37] The literature agrees to highlight local content public policies as the key to avoiding the resource curse.[38] In addition, most of these authors also agree that the analysis of these policies must include the analysis of the effects of these investments on the modification, expansion or diversification of the electric matrix. It is the joint analysis of the two elements that allow a more precise explanation of the relationship between public policies and the performance of the firm. Therefore, the analysis of public policies must include both dimensions. As noted, public policies consist of rules, laws, regulations and agreements that guide the distribution and use of revenues from the gas and electricity industry.[39]

However, the mechanism that allows these public policies to be linked to the productive performance of the firm is mainly how it affects its investment[40]. In the case of public companies, investment decisions can be clearly influenced by governments according to their development strategies.[41] Through its reports, it is possible to ascertain the main variables determining a company's production performance, such as consolidated financial data (nominal investments, profit, net debt, sector revenues and costs) and production data.[42]

Due to the size of Petrobras in the Brazilian market, such options have direct positive or negative impacts on the Brazilian electric matrix, both in the amount produced and in the relative shares of renewable and non-renewable sources. In this regard, the reports of national and international agencies present a wealth of data. In addition, non-renewable sources encourage fewer polluting alternatives than those derived from coal and oil, such as natural gas. Therefore, the critical question for analysis is whether public policies support or harm the investment and the energy matrix.[43] It is necessary to identify in each case the precise way in which this occurs. This is not to say that performance depends exclusively on public policies, but it is influenced by many other factors, both external and internal to the company, such as the case of popular expression in a democracy, international political pressure, variations in oil prices and shocks in demand for oil worldwide. However, public policies are a key variable that justifies the current analysis.[44]

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[35] [18]. An Empirical Investigation on the Effects of Political Risk on Technology Strategies of Firms. Paper Presented at the DRUID Summer Conference. Imperial College Business School. London, United Kingdom, 16–18 June.

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[39] De Oliveira, Adilson, 2012. Brazil's Petrobras: strategy and performance. In: Víctor, David G., Hults, David R., Thurber, Mark (Eds.), Oil and Governance. State-Owned Enterprises and the World Energy Supply, ed. Cambridge University Press, New York, 515–555.

[40] Ramírez-Cendrero, Juan M. and [12]. Oil fiscal regimes and national oil companies: A comparison between Pemex and Petrobras, Energy Policy, Elsevier, vol. 101, pp. 473–483.

[41] [15]. "Technology and Innovation in the Brazilian Oil Sector: Ticket to the Future Or Passage to the Past?" Journal of World Energy Law and Business 9 (4): 237–253; Massi, E. and J. Nem Singh. 2018. "Industrial Policy and State-Making: Brazil's Attempt at Oil-Based Industrial Development." Third World Quarterly 39 (6): 1133–1150.

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For this reason, public policies can be treated as an independent variable, not to quantify the degree of influence between them and the performance, but to illustrate how these variables are related throughout the analysis time (2000–2020). Therefore, given that space limitations prohibit comparisons with other companies, especially those located in developing countries, the analysis intends to situate the results obtained by Petrobras over the last few years and its relative role within the Brazilian electric matrix.

## 3. Methodology

This study implies using a mixture of methodologies to account for the complexities of qualitative evaluation of Brazilian public policy strategies. Quantitative data collection was based on institutional reports. Quantitative evidence empirically supports the analysis of the motivations and results of public policies. It avoids merely subjective explanations. The case was analysed comparatively to other countries and Petrobras concerning other state and private companies. This comparison helps to understand the change in the country scenario as a function of the international scenario to identify exogenous factors that may have influenced the performance of policies concerning thermoelectric plants in the country. As the energy area involves political, economic, social, technological, environmental and legal factors that influenced the adoption of public policies and their effects, the PESTEL framework was adopted.[45] This form of qualitative analysis of external factors influencing the system is widely used in high-level studies, including the case study of Brazil. The strategic analysis is evaluated according to one of the most used tools, the SWOT or TOWS.[46] This tool separates the strengths and weaknesses of a given policy and the opportunities and threats that may be present with adopting a given strategy.

Academic articles published in English in peer-reviewed journals between 2009 and 2023 were selected. The keywords followed the need to define the PICO framework. Huang et al.[47] recommended defining research questions regarding population or problem (P), intervention (I), comparison (C), and result (O).

The article seeks to answer the questions about differences in Petrobras's electricity production policy between 2000 and 2020 and the impacts of these decisions on the Brazilian electricity matrix. To answer these, let's conduct a structured case study.[48] This is an adequate methodology for analyzing the causal relationship proposed to federal public policies and the performance of the NOC when only one case is under study, and its performance is analysed over time. This methodology allows for a depth comparative examination of the elements that characterize the causal indicators among the variables over time.[49] To carry out this, a systematic review of the existing literature was carried out and used primary data from official databases or provided by the reports company[50].

The methodology for the literature review will consider qualitative and quantitative aspects of studies related to Petrobras' performance between 2012 and 2022. The purpose of this review is to identify the most appropriate references and methods to evaluate studies directed towards our objective. The data collected in December 2022 is treated in three stages. After an initial search through the Scopus database, limited to peer-reviewed articles from 2012 onwards, it was selected for 80 titles. The search wanted to map the bibliographic production in the last 10 years and revealed the need to develop the present study since there are no studies with the same object published in high-standard journals. Limited the search to research focusing on Petrobras and Brazil, it obtained a body of 32 articles. Then, the qualitative analysis was carried out, limited to texts published at Q1 levels in the Scimago Journal and Country Rank (See Table 5).

In the case of the gas industry in Brazil, whose main actor is the state-owned Petrobras, some researchers deal with the initiatives, results and obstacles of the Brazilian government in attracting national or international private capital,[51] and the advantages and disadvantages for the country due to the dominant role in the market of a national oil company.[52] Studies on the production and consumption of natural gas for industrial purposes and thermoelectric production have focused on Petrobras' role in industrialization

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and modernization based on natural resources, especially oil and gas.[53] The State even uses it as a driver of development.[54] The differences in performance over time in the Petrobras case, as seen in the production of natural gas and electricity, present several indispensable factors to consider: the amount of investment, production cost, demand and production of gas and energy and even climatological factors.[55] National and international requirements for reducing emissions are increasing, especially in electricity production.[56] International and national pressures and public opinion are relevant factors in reducing greenhouse emissions. In this context, electricity produced from natural gas is considered a source of the energy transition, as it presents lower levels of carbon emissions when compared to other fossil fuels.[57] Thus, the importance of this sector for the company is perceived, especially after finding large reserves of gas and oil associated with gas in the pre-salt reserves.[58]

The natural gas industry in Brazil is considered from many perspectives. Some studies consider the environmental consequences of the development of the industry as sustainability,[59] gas flaring[60], and underground storage of surplus gas not consumed or distributed.[61] Vahl et al.[62] point to this source as a path for the country's energy transition.

In more specific perspectives, Silva Neto et al.[63] studied the association of production from natural gas with sugar cane. There is also the relationship of the gas industry with other industrial sectors such as unconventional natural gas,[64] road transport for light vehicles,[65] heavy,[66] river transport in the Amazon.[67] Some studies are dedicated to the difficulties of public and private financing of the still-incipient distribution infrastructure for the internal and external market of the natural gas produced in the country.[68]

Some studies are dedicated to the development of models for the demand and consumption of natural gas in the regional scope,[69]

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**Table 5**
Bibliography selection. Articles written between 2012 and 2022 in Q1 of the Scimago Ranking.

| Authors | Year | Title | Source Title | Cited | Scimago | Methodology |
|---|---|---|---|---|---|---|
| Larizzatti Zacharias et al. | 2022 | Natural gas as a vehicular fuel in Brazil: Barriers and lessons to learn | Energy Policy | 0 | Q1 | Mathematical model |
| Paes et al. | 2022 | The power generation expansion planning in Brazil: Considering the impact of greenhouse gas emissions in an Investment Decision Model | Renewable Energy | 7 | Q1 | Computer model |
| Peyerl et al. | 2022 | Applying small-scale liquefied natural gas supply chain by fluvial transport in the isolated systems: The case study of Amazonas, Brazil | Energy for Sustainable Development | 0 | Q1 | Mathematical model |
| Rodrigues | 2022 | Decreasing natural gas flaring in Brazilian oil and gas industry | Resources Policy | 1 | Q1 | Mathematical model |
| Santos et al. | 2022 | Analysis of the Brazilian energy policies for natural gas using artificial neural networks | Journal of Natural Gas Science and Engineering | 1 | Q1 | Computer model |
| Gerber Machado et al. | 2021 | Natural gas vehicles in heavy-duty transportation – A political-economic analysis for Brazil | Case Studies on Transport Policy | 4 | Q1 | Mathematical model |
| Silva et al. | 2021 | Risk assessment model using conditional probability and simulation: case study in a piped gas supply chain in Brazil | International Journal of Production Research | 3 | Q1 | Mathematical model |
| Silva Neto et al. | 2021 | Potential impacts of vinasse biogas replacing fossil oil for power generation, natural gas, and increasing sugarcane energy in Brazil | Renewable and Sustainable Energy Reviews | 19 | Q1 | Mathematical model |
| Araujo and Leoneti | 2020 | Evaluating the Stability of the Oil and Gas Exploration and Production Regulatory Framework in Brazil | Group Decision and Negotiation | 5 | Q2 | Mathematical model |
| Costa et al. | 2020 | A robust least square approach for forecasting models: an application to Brazil's natural gas demand | Energy Systems | 4 | Q1 | Mathematical model |
| Gaudencio et al. | 2020 | Oil and gas companies operating in Brazil adhere to GRI-G4 essential sustainability indicators: a critical review | Environment, Development and Sustainability | 15 | Q1 | Mathematical model |
| Sakamoto et al. | 2020 | Energy and Environmental Contributions for Future Natural Gas Supply Planning in Brazil | Energy Technology | 3 | Q1 | Computer model |
| Araujo and Leoneti | 2019 | How attractive is Brazil's oil and gas regulatory framework to investors? | Extractive Industries and Society | 4 | Q1 | Computer model |
| García Kerdan et al. | 2019 | Modelling cost-effective pathways for natural gas infrastructure: A southern Brazil case study | Applied Energy | 13 | Q1 | Computer model |
| Leal et al. | 2019 | Natural gas regulation and policy in Brazil: Prospects for the market expansion and energy integration in Mercosul | Energy Policy | 12 | Q1 | Qualitative analysis without mathematical model |
| Almeida et al. | 2018 | Economic value of underground natural gas storage for the Brazilian power sector | Energy Policy | 12 | Q1 | Mathematical model |
| Assis et al. | 2018 | Will the shift from crude oil to natural gas burning for power generation at an oil refinery increase ozone concentrations in the region of Cubatão (SE-Brazil)? | Ecological Indicators | 6 | Q1 | Mathematical model |
| Raimundo et al. | 2018 | Evaluation of greenhouse gas emissions avoided by wind generation in the Brazilian energetic matrix: A retroactive analysis and future potential | Resources, Conservation and Recycling | 14 | Q1 | Mathematical model |
| Waterworth and Bradshaw | 2018 | Unconventional trade-offs? National oil companies, foreign investment and oil and gas development in Argentina and Brazil | Energy Policy | 14 | Q1 | Qualitative analysis without a mathematical model |
| Bruno et al. | 2017 | Optimization techniques for the Brazilian natural gas network planning problem | Energy Systems | 3 | Q1 | Mathematical model |
| Hourneaux Junior et al. | 2017 | Strategic aspects in sustainability reporting in oil & gas industry: The comparative case-study of Brazilian Petrobras and Spanish Repsol | Ecological Indicators | 29 | Q1 | Qualitative analysis without a mathematical model |
| Aragão and Giampietro | 2016 | An integrated multi-scale approach to assess the performance of energy systems illustrated with data from the Brazilian oil and natural gas sector | Energy | 15 | Q1 | Qualitative analysis without a mathematical model |
| dos Santos et al. | 2016 | Urea imports in Brazil: The increasing demand pressure from the biofuels industry and the role of domestic natural gas for the country's urea production growth | Journal of Natural Gas Science and Engineering | 7 | Q1 | Mathematical model |
| Vahl et al. | 2015 | Energy transition and path creation for natural gas in the Brazilian electricity mix | Journal of Cleaner Production | 21 | Q1 | Mathematical model |
| Brasil and Postali | 2014 | Informational rents in oil and gas concession auctions in Brazil | Energy Economics | 2 | Q1 | Mathematical model |
| Camargo et al. | 2014 | Major challenges for developing unconventional gas in Brazil - Will water resources impede the development of the Country [U+05F3]s industry? | Resources Policy | 11 | Q1 | Qualitative analysis without a mathematical model |

(*continued on next page*)

**Table 5** (*continued*)

| Authors | Year | Title | Source Title | Cited | Scimago | Methodology |
|---|---|---|---|---|---|---|
| Goldemberg et al. | 2014 | Oil and natural gas prospects in South America: Can the petroleum industry pave the way for renewables in Brazil? | Energy Policy | 35 | Q1 | Mathematical model |
| Mendes et al. | 2014 | Reforming Brazil's offshore oil and gas safety regulatory framework: Lessons from Norway, the United Kingdom and the United States | Energy Policy | 31 | Q1 | Mathematical model |
| Nogueira et al. | 2014 | Will thermal power plants with CCS play a role in Brazil's future electric power generation? | International Journal of Greenhouse Gas Control | 47 | Q1 | Computer model |
| Paz Antolín and Ramírez Cendrero | 2013 | How important are national companies for oil and gas sector performance? Lessons from the Bolivia and Brazil case studies | Energy Policy | 15 | Q1 | Qualitative analysis without a mathematical model |
| Vasconcelos et al. | 2013 | Network flows modeling applied to the natural gas pipeline in Brazil | Journal of Natural Gas Science and Engineering | 43 | Q1 | Mathematical model |
| Colomer Ferraro and Hallack | 2012 | The development of the natural gas transportation network in Brazil: Recent changes to the gas law and its role in co-ordinating new investments | Energy Policy | 6 | Q1 | Qualitative analysis without a mathematical model |
| Martins et al. | 2012 | Scenarios for solar thermal energy applications in Brazil | Energy Policy | 45 | Q1 | Qualitative analysis without a mathematical model |

national,[70] or continental.[71] Some of these studies focus on the aspect of emission predictions or based on present investment.[72]

Closer to the scope of the present study, there are evaluations of public policies for natural gas from an economic, environmental, or productive point of view. Araujo and Leoneti and Santos et al. evaluate the development and stability of exploration and production in the face of changes in the regulatory framework, pointing to its inefficiency for increasing production and consumption.[73] Brasil and Postali constructed a similar study considering the results of design auctions.[74] There are even comparisons of the legal framework with other countries with offshore production of a size similar to that of Brazil, such as Norway, the United Kingdom and the United States.[75] However, these studies do not focus on thermoelectric production.

Only two studies assess the development of the electricity industry from a productive point of view.[76] Like these highly qualified articles, this study is a case study, but it focuses solely on Petrobras Gas & Energy department. This is a point of view not explored in part of the high-level bibliography. These studies published in high-impact journals have the common deficiency of not using the breadth of qualitative and quantitative information in company and regulatory agency reports. Studies are often based mainly on interviews without properly contrasting with quantitative data. Interviews are necessary, but they are not the only means of analysis.

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[76] Silva, Vinícius Oliveira da; Relva, Stefania Gomes; Mondragon, Marcella; Mendes, André Bergsten; Nishimoto, Kazuo; Peyerl, Drielli. 2023. Building Options for the Brazilian Pre-salt: A technical-economic and infrastructure analysis of offshore integration between energy generation and natural gas exploration, Resources Policy, 81, 103305; Aragão, Amanda; Giampietro, Mario. 2016. An integrated multi-scale approach to assess the performance of energy systems illustrated with data from the Brazilian oil and natural gas sector, Energy, 115, Part 2, 2016,1412–1423.

Thus, this research assumes these analyses for a closer consideration of quantitative data from the company's annual reports and regulatory agencies.[77] The analysis is extended between 2000 and 2020 to show a medium-term perspective, which is necessary given the technological and productive particularities of the sector. The analysis in 2020 deals with the strong influence of exogenous factors (Pandemic included) on public policy (particularly the sharp drop in oil prices in 2014) as they affect oil revenues, investment and production.

The methodology is both quantitative and qualitative. In the first part of the article, data will be collected regarding the absolute and relative production of electric energy by the company concerning the Brazilian matrix and price. It was necessary to carry out extensive work of converting the measurement units referring to production and reserves and converting current values presented in Brazilian currency to the dollar. Then, a qualitative analysis was carried out, since international and national society and Brazilian and international legislation, require investment measures in less polluting forms of electricity generation and local content policies. The historiographical proposal to contextualize the aspects present in the reports, analyzing the primary sources and statistical data, within their culture, allows a better understanding of a certain broader historical context. The specialized field of economic history is broader than the conventional field of economics currently defined. It is possible to understand the trajectory of events, their causes and correlations, and their economic consequences on the Brazilian energy matrix. So, the study proposes to analyse the companies' data, taking into account the annual reports of the companies and governments to compare them to Brazil and Petrobras, based on company annual reports and the Brazilian regulatory agencies for oil and electricity.

This study has the limitation of not presenting a statistical model of data from Brazil and Petrobras compared to other countries. The study showed the increase and decrease of Petrobras' role in the thermoelectric market. The bibliographic survey was based on the Scopus platform and the evaluation of journals according to the Scimago ranking. The authors express this limitation since other platforms and rankings may present slightly different results.

## 4. Results and discussion

This session will address the political and financial factors that may have influenced investment decisions in Petrobras' electrical production area. In the first section, there is an analysis of the trend of increasing investment and production (4.1). In the second section, it is identified a reduction in investment and a trend towards stabilization or even a drop in production (4.2). Finally, there is an analysis of the consequences of this investment and production in the Brazilian energy matrix (4.3).

### *4.1. Expansion of electricity production using gas (2000–2014)*

The Petrobras foundation in 1953 took place in a context characterized by state development strategies mainly focused on industrialization (See Table 7). The electricity and oil industries in Brazil were born in very different contexts.[78] The electricity sector had abundant possibilities due to the country's hydroelectric capacity. The oil company began its journey in the scarcity of reserves and even investments restricted to the state monopoly that was only broken in1997.[79] Petrobras had support from the Brazilian government through tax benefits and other resources. This fact, together with the state development strategy, determined investments in the hydroelectric matrix, transforming the country into one of the largest energy producers from this source.

During the Brazilian energy supply crisis of the years 2000–2001, with rationing and blackouts, thermoelectric plants began to gain a relative share in the generating complex, stimulated by the construction and operation of the Bolivia-Brazil gas pipeline (GASBOL), by the Priority Thermoelectric Program (PPT) and by Petrobras' acquisition of thermoelectric plants. The beginnings of the natural gas industry date back to 1940 with the first gas discoveries in Northeast Brazil, but its participation in the national energy matrix increased by 2.7% around the year 2000 (Table 6).

This table contains information on the share of energy sources in the Brazilian electricity matrix, analysed throughout this paper. In this context, Petrobras was used to contain the energy crisis by acquiring thermoelectric plants to supply a short-term demand after years of lack of investment in infrastructure. Petrobras is no longer an energy importer and has become a producer within the National Interconnected System (SIN).

The Lula government (2002–2010) brought with its strong tendency to the economic developmental model investing most of the capital into the oil industrial sector.[80] It starts to encourage the productive sector in favour of increasing employment and the population's income. Chinese demand also increased the prices of commodities that Brazil exported.[81] This environment had an impact on energy demand. Between 2002 and 2014, the supply and production of electricity started to grow at average rates of 4.2% and 4.6%, respectively. Before the 2000s, coal and oil derivatives already suffered a tendency to lose participation within the Brazilian matrix, being surpassed by natural gas in 2002, when it reached 4% of the matrix. This source had a growth of 2%–18% of the matrix between

[77] [15]. "Technology and Innovation in the Brazilian Oil Sector: Ticket to the Future Or Passage to the Past?" Journal of World Energy Law and Business 9 (4): 237–253; Ramírez-Cendrero, Juan M. and [12]. Oil fiscal regimes and national oil companies: A comparison between Pemex and Petrobras, Energy Policy, Elsevier, vol. 101, pp. 473–483.

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[81] [40]. Comparing innovation systems: a framework and application to China's transitional context. Research Policy 30, 1091–1114.

the years 2000 and2013.[82]

Petrobras is the main player in this process, using imported Bolivian gas transported by pipeline.[83] Still, from the discoveries and increased production in the Pre-salt and Uruçu fields, this source becomes to be seen as a replacement for the hydroelectric system in periods of drought, especially after 2012.[84] Within this context of expansion, Petrobras has a decisive role, accounting for about 7% of the Brazilian electricity matrix (2013–2015). The State maintains its influence over the company's investment strategy to achieve functionality within the general energy and industrial policy.[85] An indicator of this influence appears to be a change in firm investments. It is possible to verify a significant growth in nominal investment in all sectors (Table 8).

But the refining and gas, and energy sectors gain a share in the company's total investment amount. It was a strategy of verticalization of production. In addition, it aimed to make the country independent from the import of petroleum derivatives, strengthening the petrochemical sector and the naval industry simultaneously.[86] These changes occurred during the Cardoso administration (1994–2002), through the intensification of exploratory investment through the development program to achieve self-sufficiency. PROCAP (Petrobras Technological Program in Ultra-[5]) initiative is an excellent example of this attempt.[87]

During the Lula government (2003–2010), the country finally achieved energy self-sufficiency and developed offshore production.[88] Petrobras adapted its strategy to developmental policies, characterized by the promotion of refining and biofuels, or the attempt to revitalize the national industry. For this, the company intensified investments in Exploration, Refining, Gas and Energy. Between 2004 and 2009, investments in the refining area grew at an average rate of 46%, against 11.8% between 1997 and 2003.[89]

This optimistic and expanding context culminated in the discovery of traces of oil in the pre-salt, announced by Petrobras in 2006.[90] In 2008, Petrobras confirmed the discovery of light oil associated with gas in the sub-salt layer and extracted oil from the sub-salt layer for the first time in the coast of Southeast Brazil. At the time, these reserves were estimated at more than 80 billion barrels, making it the holder of one of the 10 largest reserves in the world.[91] This euphoric environment was accompanied by economic growth and, consequently, by increased demand for industrial and residential electricity. Due to the 2009 economic world crisis (also called the subprime crisis), the federal government adopted countercyclical measures such as the tax reduction (IPI) for cars and white goods, which impacted the consumption of these goods and electricity. Energy consumption increased 2.5% per year following the average growth of 3% in GDP between 2010 and 2013.[92]

Within this perspective of increased demand and with the objective of consolidating its leadership in the production of thermoelectric energy in the country, Petrobras is starting a series of investments to expand its installed capacity, either through the purchase of units or by increasing its stakes, even through its subsidiaries. In this sense, the increase in participation in the share capital of a company that generates electricity [6]. In 2010, Petrobras' Brazilian production of natural gas supplied 50% of the natural gas consumed in Brazil by natural gas distribution companies, and thermoelectric power plants, among other consumers. In relation to the electric energy market, Petrobras had 5.6% of the total installed capacity of Brazilian generation or the equivalent of 51% of the installed capacity of thermoelectric generation.[93]

This policy was extended until the beginning of the second Rousseff government (2010–2016). In 2015, in the midst of the water crisis, Petrobras generated the highest historical value of thermoelectric energy for the National Interconnected System (SIN). The company had a 7.5% share in the country's thermoelectric generation and around 54% of this market. Petrobras' thermoelectric generating complex, with an installed capacity of 6676 MW, was then made up of 21 owned and leased plants powered by natural gas or fuel oil. Including plants with generation from renewable sources and projects in which Petrobras had a minority stake, the installed capacity totalled a record 7028 MW.

Some financial data deserve to be considered to evaluate the company's performance (Fig. 2).

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[84] Petrobras (Petróleo Brasileiro S.A.), Reports, 2000–2020. Available online at: ⟨https://www.investidorpetrobras.com.br/apresentacoes-relatorios-e-eventos/relatorios-anuais/⟩.

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[92] EPE (Empresa de Pesquisa de Energia), Annual Report, 2010–2019. Available online at: ⟨https://www.epe.gov.br/pt⟩.

[93] Petrobras (Petróleo Brasileiro S.A.), Reports, 2000–2020. Available online at: ⟨https://www.investidorpetrobras.com.br/apresentacoes-relatorios-e-eventos/relatorios-anuais/⟩.

**Table 6**
Brazil and petrobras production, 2000–2020.

| | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Petrobras installed capacity | – | – | 5223 | 5443 | – | 5284 | 6553 | 7028 | 6885 | 7001 | 6500 | 6100 | 6100 | 6010 | 6447 | 6427 |
| Petrobras total electricity | – | 8.6 | 9.7 | 17.7 | 18 | 16 | 20.8 | 23.6 | 34.8 | 44.2 | 40.6 | 19.7 | 27.7 | 19.3 | 17.7 | 15.3 |
| Petrobras' participation in the thermoelectric market (%) | – | 51 | 51 | 98 | 64 | 44 | 83 | 50.6 | 50.4 | 54.5 | 51.3 | 35.1 | 42.6 | 35.7 | 28.5 | 28.8 |
| Petrobras' participation in Brazilian matrix (%) | | 2.4 | 2.5 | 4.4 | 3.9 | 3.1 | 3.9 | 4.2 | 6.1 | 7.5 | 7 | 3.4 | 4.7 | 3.2 | 2.8 | 2.4 |
| Petrobras Oil production | 447 | 530 | 519 | 616 | 647 | 675 | 759 | 801 | 748 | 749 | 775 | 771 | 783 | 780 | 822 | 844 |
| Petrobras gas production | 81 | 95 | 102 | 107 | 131 | 137 | 143 | 171 | 197 | 180 | 172 | 177 | 182 | 179 | 188 | 190 |

Sources: Authors' calculations based on Petrobras annual reports (lifting cost and investment), EPE, ANEEL, ANP (production and O&G prices) and IEA. Installed capacity in MW, electricity production in TWh, Oil production in barrels/year and gas production in Bboe/year.

**Table 7**
Brazilian politics, petrobras and brazilian electric sector.

| Period | Petrobras and Brazilian Electric Sector |
|---|---|
| 1953–1964 - Populist years (Getúlio Vargas, Juscelino Kubitschek, Jânio Quadros, João Goulart) | - Beginning of commercial production of natural gas in Brazil (1940).<br>- Creation of the first state refinery (1950).<br>- Petrobras was created as state-owned (1953). The company was already created with mixed capital.<br>- Eletrobras was created as state-owned (1962). |
| 1964–1985 - Military dictatorship | - Construction of large-scale refineries and tripling of refining capacity 1960–1981.<br>- The confirmation of the offshore discoveries took place in the Guaricema field (1968).<br>- The Oil Shock made the Brazilian state invest heavily in offshore reserves (1974).<br>- Beginning of commercial exploration in Campo de Garoupa, in the Campos Basin, in deep water, using a floating platform (1977).<br>- Offshore production surpasses onshore production (1983).<br>- Petrobras reached the production milestone of 0.5 million barrels per day (1984). |
| 1985–1993<br>Restoration of civilian government (New Republic) and the 1988 Constitution. | - Petrobras receives the first achievement OTC award. The award recognizes the innovations developed to achieve production from Campos Basin (1992).<br>- Petrobras reached the production milestone of 1 million barrels per day (1997).<br>- Brazilian production covers for the first time more than 50% of national consumption (1998). |
| 1994–2002 - Fernando Henrique Cardoso (Brazilian Social Democracy Party, PSDB) | - Production in deep water surpasses production in shallow waters (1995).<br>- Law 9.478 broke Petrobras's monopoly and created the national petroleum agency (Agência Nacional do Petróleo, ANP, 1997).<br>- Beginning of operation of the Brazil-Bolivia Gas Pipeline (1999).<br>- Petrobras set a world record for oil exploration in shallow waters (2000)<br>- Occurrence of blackouts due to droughts that affected the performance of hydroelectric plants (2001).<br>- Petrobras receives the first achievement OTC award. The award recognizes the innovations developed to achieve production from the Roncador and Marlim fields (2001).<br>- Import of Gas From Bolivia (2001)<br>- Petrobras acquires the first thermoelectric plants (2002)<br>- Incentive Program for Alternative Sources of Electric Energy (2002).<br>- Brazil exceeded 2 billion dollars in crude oil exports for the first time (2002). |
| 2003–2010<br>Luis Inacio Lula da Silva (Workers' Party) | - Petrobras surpassed 2 million barrels of oil equivalent of daily production (2003).<br>- Brazilian production covers for the first time more than 75% of national consumption.<br>- Pre-Salt discoveries doubled the current Brazilian oil reserves (2007).<br>- Brazil has become self-sufficient in oil production (2007).<br>- Brazil exceeds 10 billion dollars in crude oil exports for the first time (2008).<br>- Highest capitalization in history (until 2010)<br>- Beginning of the pre-salt exploration (2009).<br>- Beginning of the Urucu-Coari-Manaus gas pipeline operation (2009).<br>- Increase in Petrobras' indebtedness (2006–2016) |
| 2010–2016<br>Dilma Rousseff (Workers' Party) rowhead | - The Brazilian government made significant legal changes in its oil sector, inverting the previously undertaken market reforms and intensifying state interference. The main goal was to increase governmental strategic resource control to guarantee that future Brazilian generations could take advantage of the proceeds of the oil reserves (2010).<br>- Brazil exceeded 20 billion dollars in crude oil exports for the first time.<br>- Petrobras reached the maximum of its installed electrical production capacity and began selling assets (2012).<br>- Droughts in Brazil affect the performance of hydroelectric plants requiring the activation of thermoelectric power (2014–2016).<br>- Operation Car Wash (2015–2017).<br>- Petrobras receives third achievement OTC award. The award recognizes the innovations developed to achieve production from the pre-salt (2015).<br>- From 2002 to 2016, the installed wind energy capacity increased from 22 MW to 10074 MW. |
| 2019–2022<br>Jair Bolsonaro (Liberal Party) | - Wind energy has become the second-largest source of electricity (2018).<br>- Petrobras reached the production milestone of 2,8 million barrels per day (2018).<br>- Oil production in Brazil reaches 3 million barrels per day (2019).<br>- Pandemic (2020).<br>- Production of oil and natural gas exceeded, for the first time, 4 million barrels of oil equivalent per day (2020).<br>- Petrobras receives the fourth achievement OTC award. The award recognizes the innovations developed to achieve production from the pre-salt (2021).<br>- Upsurge of Attacks and Sanctions in the Russian-Ukrainian War (2022).<br>- Privatization of Eletrobras, the largest public electricity production company (2022) |

**Table 8**
Nominal investment.

| | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Exploration and Production | 2.8 | 2.8 | 4.3 | 7 | 14.2 | 18.6 | 20.4 | 21.9 | 27.5 | 25.5 | 19.1 | 13.5 | 12.3 | 10.7 | 8.4 | 6.5 |
| Refining | 0.5 | 0.8 | 1.3 | 1.9 | 6.5 | 16.1 | 16.1 | 14.7 | 14.2 | 7.8 | 2.5 | 1.1 | 1.2 | 1.1 | 1.4 | 0.9 |
| Gas and Energy | 0.1 | 0.2 | 0.2 | 0.7 | 3.9 | 3.9 | 2.2 | 2.1 | 2.7 | 2.5 | 0.7 | 0.7 | 1.1 | 0.4 | 0.5 | 0.3 |
| International | 0.3 | 2 | 0.7 | 3.2 | 3.3 | 2.7 | 2.6 | 2.5 | 2.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Distribution | 0 | 0.1 | 0.4 | 0.2 | 0.3 | 0.5 | 0.6 | 0.6 | 0.5 | 0.4 | 0.2 | 0.1 | 0.1 | – | – | – |
| Others | 0.2 | 0.2 | 0.3 | 2.2 | 0.6 | 1.5 | 1 | 0.8 | 0.6 | 0.5 | 0.3 | 0.3 | 0.1 | 0.3 | 0.3 | 0.2 |
| Total | 4.1 | 6.4 | 7.4 | 15.4 | 29 | 43.4 | 43.1 | 42.9 | 48 | 37 | 23 | 15.8 | 15 | 12.6 | 10.7 | 8 |

Note: Investments in the international area were nominally reallocated in other areas as of 2014. The gas and energy area is the company's newest, with a US$12 million nominal investment as of 1997. Nominal investment in current Values (US$ billions).

The company's profits also increased, from US$ 3 in 2000 to US$ 19.4 in 2014, having remained above US$ 10 billion between the years 2006–2013, with the exception of 2009 due to the subprime crisis. International oil and natural gas prices were also a stimulus for expansion during the period. Prices nearly tripled: gas went from 80 to 236 US$/thousand $m^3$ and Brent from 28 to 111 dollars. Between 2000 and 2013, oil production rose from 447 to 748 billion barrels per year, with a peak of 801 in 2012. Gas production had an even more surprising result, from 81 billion barrels corresponding to 197 billion.

### *4.2. Divestment policies (2014–2020)*

The company's divestment policies are presented in the reports since 2012 due to the increase in the company's debt and a series of interventions by the federal government in the price of fuel, prohibiting the company from increasing the price according to the international market.

This attempt was intended to avoid the resurgence of inflationary trends in the second government of President Rousseff (2010–2016).[94] However, a series of factors led Petrobras to establish a policy of reducing investments or even applying divestment strategies, both through the sale of subsidiaries and participation in industrial fields or projects. Such measures resulted in a drop in production costs. Among the external causes, perhaps the most significant is the sharp drop in the international price of oil and natural gas. Brent has gone from an average of US$111 in 2012–2013 to US$52 in 2015, reaching US$43 in 2016 (Fig. 2). This is a reduction of almost a third of the value. The company's price and profit curve blames for the financial blow.

This reduction would have a direct relationship with the North American energy policy and the reduction in Chinese growth and be accompanied by a reduction in commodity prices, which in the case of Brazil, account for the majority of exports.[95] In addition, the Petrobras corruption scandals can be singled out as one of the causes of the 2014 political-economic crisis in the country, which would have culminated in Rousseff's impeachment in 2016.[96] These events not only reduced economic activity, with poor economic performance between 2014 and 2020, including a severe gross domestic product recession in 2015 and 2016.[97] The impact of the corruption cases investigated by Lava Jato was profound on the company and on the Brazilian government, even generating the process of impeachment of Rousseff. The Federal government for 14 years in the hands of the Workers' Party passed into the hands of centre-right and right-wing politicians from 2016 onwards. Liberal economic policies took the place of neo-developmental ones.

For Petrobras, the global and national context resulted in staggering numbers. The reduction in fuel prices directly impacted the company's finances, which posted a loss for four consecutive years (2014–2017). The most serious thing is that production costs had an upward trajectory between 2006 and 2014 due to the requirements inherent to the pre-salt exploration.[98] Despite Petrobras' retention of a large part of oil revenue, the ambitious investment program launched after the discoveries in ultra-deep waters greatly increased the company's indebtedness, underlining one of the most vulnerable points in the model.[99] On another hand, the drastic reduction experienced in international oil prices increased Petrobras' internal problems associated with the corruption scandals, also significantly altering the conditions, causing a drastic deterioration in Petrobras' rating and increasing financing costs.

The drop in oil prices also hampered the local content policies implemented by the Rousseff government. Such policies resulted in cost increases for Exploration and Production (E&P), thus reducing the company's operating profit. As seen above in Fig. 2, the cost increased every year between 2000 and 2013, more steeply after 2006. This increase was influenced by the increasing involvement of offshore versus onshore E&P. Such requirements have driven industrial development, but there is great heterogeneity in the competitiveness of different industrial branches. Local content requirements and the industrial policy that covers them have not managed to achieve positive effects in the branches with the greatest potential competitiveness, as happened in the successful experiences of Norway.[100]

The combination of factors such as the drastic fall in international prices, negative financial years, increase in net debt, and local content and price control policies implemented by the federal government in 2015 certainly forced the Board of Directors to approve the Plan of Business and Management for 2015–2019 with even stronger divestment trends in less profitable areas. In this, divestments were foreseen for an "efficient integration". In the Business plan, the company had the objective of "reducing Petrobras' risk, adding

[94] Massi, E. and J. Nem Singh. 2018. "Industrial Policy and State-Making: Brazil's Attempt at Oil-Based Industrial Development." Third World Quarterly 39 (6): 1133–1150.

[95] Massi, E. and J. Nem Singh. 2018. "Industrial Policy and State-Making: Brazil's Attempt at Oil-Based Industrial Development." Third World Quarterly 39 (6): 1133–1150.

[96] Maragno, L. and J. A. Borba. 2019. "Unearthing Money Laundering at Brazilian Oil Giant Petrobras." Journal of Money Laundering Control 22 (2): 400–406.

[97] Ramírez-Cendrero, Juan M. and [12]. Oil fiscal regimes and national oil companies: A comparison between Pemex and Petrobras, Energy Policy, Elsevier, vol. 101, pp. 473–483.

[98] [44]. A crise no setor de petróleo e gás natural no brasil e as ações para o retorno dos investimentos, *in*: IPEA, Desafios da Nação, Ernesto Lozardo, Alexandre Xavier de Carvalho Ywata, Adolfo Sachsida e Helena Karla Barbosa de Lima (coord.), Brasília, 597–627; Massi, E. and J. Nem Singh. 2018. "Industrial Policy and State-Making: Brazil's Attempt at Oil-Based Industrial Development." Third World Quarterly 39 (6): 1133–1150; Rodrigues, Larissa Araujo, Sauer, Ildo [14]. Exploratory assesment of the economic gains of a pre-salt oil field in Brazil. Energy Policy 87, 486–495.

[99] [15]. "Technology and Innovation in the Brazilian Oil Sector: Ticket to the Future Or Passage to the Past?" Journal of World Energy Law and Business 9 (4): 237–253.

[100] [16]. The evolution of Norway's national innovation system. Sci. Public Policy 36 (6), 431–444; [42]. The overhaul of the Brazilian oil and gas regime: does the Adoption of a production sharing agreement bring any advantage over the Current Modern Concession System? OGEL 8 (4), 1–85.

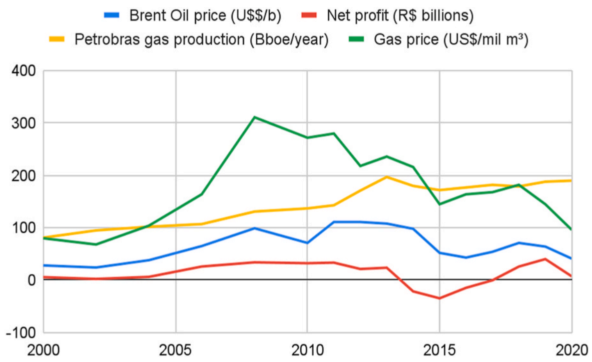


**Fig. 2.** Financial indicators and selected costs (2000–2020).
Source: Petrobras, ANEEL, EPE, several annual reports (2000–2020). Created by the authors. The units were converted without harming the absolute quantitative measures so that they could be compared on the same axis and could be associated

value in its activities in E&P, Refining, Transport, Logistics, Distribution and Commercialization through active portfolio management through partnerships, acquisitions and divestments". It was a measure related to policies to control the growing public debt during the Temer government (2016–2018).

This explains the drop in Petrobras' total investments in 2014, although the drop in E&P and Gas and Energy investment was reduced. This situation deteriorated further as prices continued declining, as seen with E&P investments worldwide.[101] In the Energy and Gas area, there was also a drop in investment to the point of falling to values below the year 2006 (Table 3).

In 2020, the nominal investment values in the Energy and Gas area were lower than in 1998, without the correction of values. There was, therefore, a tendency for operating costs to fall with a slight increase in production. As of 2018, the company became profitable again, remunerating shareholders and reducing net debt. In 2011, it presented the best profit of the selected period. It concentrated its operations in offshore oil exploration in the so-called Pre-Salt and reduced its participation in Brazilian oil production by around 5% points. On the other hand, during the Bolsonaro government (2018-current), fuel prices are in line with international prices, making the company's profits resounding. However, fuel prices have had the effect of boosting inflation. These factors have harmed the population and caused the president's popularity to decline, evidencing the contradiction between the interests of the company and the Brazilian State.

With regard to the area of electricity, the plan foresaw restructuring the Electric Energy business, seeking an alternative that maximizes value for the company. The reports are no longer present excerpts with the company's intention to expand installed capacity or even export electricity. Thermoelectric plants, previously with the objective of draining the surplus of natural gas often found associated with oil and making Petrobras a leading player in the electric energy market, have their objective formally changed.[102] In terms of generation costs, hydroelectric power is cheaper in Brazil than Petrobras' natural gas-fired thermoelectric power plants. This mainly impacts captive consumers, who depend exclusively on energy distributors. The impact on the account thus falls mainly on residential consumers. Although the government's priority is the use of energy from hydroelectric plants, periods of water Scarcity end up reducing the productivity of the units, making Petrobras' thermoelectric plants an alternative to supplying the demand.

The divestment policy gained a new impetus under the Bolsonaro administration and alignment with the Washington Consensus. In 2020, Petrobras' Board of Directors approved the Strategic Plan for the 2021–2025 five-year period. In 2022, the installed capacity of Petrobras' thermoelectric plants is officially 5369 MW in 14 units (Table 9). The difference between the numbers is due to the sale of 7 units during the beginning of the Bolsonaro government (6,323 MW in 2019). In addition to the name change, the capacity of most units was increased between 2014 and 2022.

The reports indicated the Company's intention to completely abandon the previous policies for increasing the production of electricity and biodiesel in order to concentrate assets in the pre-salt.[103] The first steps in this direction are the sale of the entire interest in five electricity generation companies. Petrobras signed a contract to sell its entire stake in its wind unity. In the title of the Strategic Plan, "Energy transition", the company presented the intention "to develop research aimed at acting, in the long term, in petrochemical

[101] IEA (International Energy Agency), Report, Several years. World Energy Investment. Available online at: ⟨http://www.iea.org/⟩; IEA, Offshore oil production in deepwater and ultra-deepwater is increasing, 2016. Available online at: https://www.eia.gov/todayinenergy/detail.php?id=28552#.

[102] Petrobras (Petróleo Brasileiro S.A.), Reports, 2000–2020. Available online at: ⟨https://www.investidorpetrobras.com.br/apresentacoes-relatorios-e-eventos/relatorios-anuais/⟩.

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**Table 9**
Petrobras thermoelectrics (2014 and 2022).

| Unit in 2022 | State | Installed capacity | Unit in 2014 | State | Installed capacity |
|---|---|---|---|---|---|
| TermoCeará | CE | 220 | TermoCeará | CE | 220 |
| Termobahia | BA | 186 | Rômulo Almeida | BA | 138 |
| Vale do Açu | RN | 323 | Celso Furtado | BA | 186 |
| Ibirité | MG | 226 | Jesus Soares Pereira | RN | 323 |
| Juiz de Fora | MG | 87 | Aureliano Chaves | MG | 226 |
| Três Lagoas | MS | 386 | Usina Termelétrica de Juiz de Fora | MG | 87 |
| Termomacaé | RJ | 923 | Luiz Carlos Prestes | MS | 386 |
| Termorio | RJ | 1058 | Mário Lago | RJ | 923 |
| Seropédica | RJ | 386 | Governador Leonel Brizola | RJ | 1058 |
| Piratininga | SP | 190 | Barbosa Lima Sobrinho | RJ | 386 |
| Cubatao | SP | 219 | Piratininga | SP | 219 |
| Nova Piratininga | SP | 386 | Fernando Gasparian | SP | 576 |
| Canoas | RS | 249 | UEG Araucária | PR | 484 |
| Baixada Fluminense | RJ | 530 | Sepé Tiaraju | RS | 161 |
| Total [7] | | 5369 | Tambaqui | AM | 95 |
| | | | Jaraqui | AM | 76 |
| | | | Arembepe | BA | 150 |
| | | | Cuiabá | MT | 529 |
| | | | Bahia I | BA | 32 |
| | | | Muricy | BA | 152 |
| | | | Baixada Fluminense | RJ | 344 |
| | | | Total [8] | | 6751 |

Sources: Petrobras Website. Consulted 30/08/2022. Installed capacity in MW.

and renewable energy businesses with a focus on wind and solar in Brazil".[104] There is, however, no reference to the amount invested or investment perspective. In 2021, Petrobras Biocombustível (PBio), its subsidiary company dedicated to the production of biodiesel and ethanol, is being offered for sale in 2021 through a teaser announced by the company. These facts, together with the reduction in investment, make us believe that Petrobras will restrict itself to producing electricity for its own industrial activities and selling electricity to the national system in times of water scarcity.

### *4.3. Impacts of policies on the Brazilian electricity matrix*

The installed capacity of the Brazilian electricity matrix is one of the cleanest in the world. As of 2002, this matrix more than doubled, reaching 174,737 MW of installed capacity. In the national electricity sector, there was a reduction in electricity production due to the internal political and economic crisis (2015–2016), caused by the drop in prices of commodities exported by Brazil, with a reduced impact of around 2.4% of energy demand. Between 2017 and 2019, there was a modest annual growth of the economy, in the order of 1.2%. Consequently, the demand for electricity remained stagnant, mainly due to the stagnation of industrial activity. During the period of 2015 and 2017, the economic recession caused a reduction in the supply and demand of energy, returning to the level of growth in 2018. In 2019, the country's electric production reached its peak, having a slight drop due to the COVID-19 pandemic in 2020. Fig. 3 shows this growth and the participation of the main sources. As of 2006, national reports present production capacity from natural gas separately from other fossil sources. Hydroelectricity is losing ground to fossil fuels, especially to gas, but in the last five years, biomass, especially from sugar cane, wind and solar take the share that hydroelectricity has lost to fossil fuels.

If the results seem positive from a productive point of view, they do not seem to be when considering the Brazilian energy matrix (Fig. 3). Non-renewable sources for electricity production rose from 15% in 2000 to 26% in 2014. The reduction to 10% in 2004 can be explained by the fact that precisely in the base year for comparison, Brazil was going through an electricity supply crisis, as mentioned above. The share of renewable sources fluctuated from over 90% in 2000, reaching the lowest level in 2014 (73%), recovering year after year until reaching 84% again in 2020.[105] This variation is directly related to the seasonality of the main source of the electrical matrix, hydraulics, and expansion through smaller amplitude reservoirs. In the first years of the hydroelectric crisis, electricity generated by gas-fired thermoelectric plants reached 18% and 17% in 2013 and 2014, respectively. That was the highest proportion in history. As of 2015, there has been an increase in production from wind energy, which rose from 3.7% in that year to 9.2% in 2020. In the case of wind energy, its period of greater productivity coincides exactly with the dry period that affects Brazilian hydroelectric

[104] Petrobras (Petróleo Brasileiro S.A.), Reports, 2000–2020. Available online at: 〈https://www.investidorpetrobras.com.br/apresentacoes-relatorios-e-eventos/relatorios-anuais/〉.

[105] Petrobras (Petróleo Brasileiro S.A.), Reports, 2000–2020. Available online at: 〈https://www.investidorpetrobras.com.br/apresentacoes-relatorios-e-eventos/relatorios-anuais/〉.

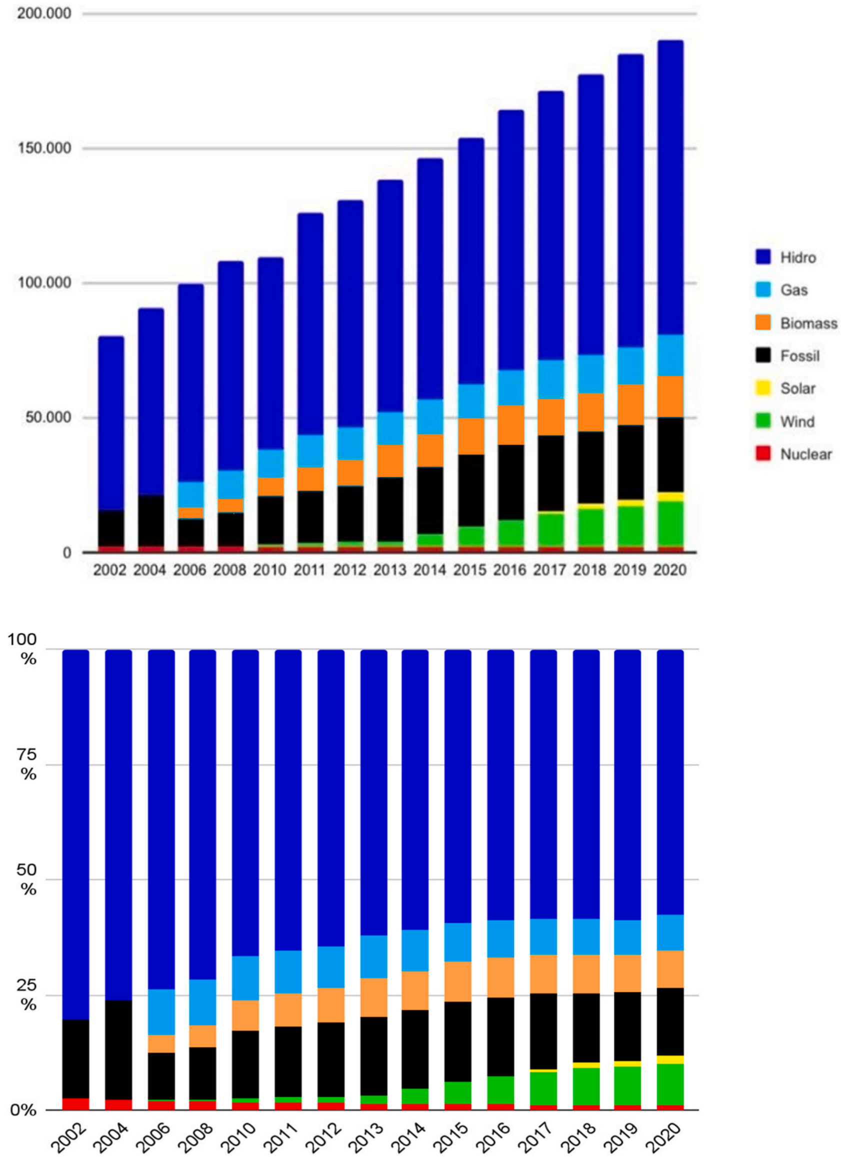


**Fig. 3.** Brazil: Electric Installed capacity, relative and absolute values by source, 2002–2020.
Sources: Authors' calculations based on EPE annual reports. Installed capacity in MW. In 2002 and 2004 the installed capacity in gas thermoelectric plants was not counted separately.

plants. Solar energy, which corresponded to less than 0.1% of the matrix in 2016, it rose to 1.7% in 2020. This 7.2% increase in the matrix corresponds exactly to the loss of share of natural gas, which in 2020, began to supply 9% of demand. The increase also corresponded to the loss of participation of the hydroelectric matrix in the Brazilian matrix, which went from 87% in 2000 to 63% in 2020 with the lowest proportional value in 2015 and 2017, 61% and 62%, respectively. If before 2000, the production of electricity from biomass, from sugarcane bagasse and bleach, was no more than 2% of the Brazilian matrix, it would reach 8.8% of national production in 2020, with annual growth exceeding 10%. In the years from 2013 to 2015, there was a hydroelectric crisis in Southeast Brazil, which forced the activation of thermoelectric plants. Not without reason, between these years, hydroelectric plants provided 68%, 63% and 61% of generation in Brazil, much lower values compared to the highest in the selected period, 87% in 2000. The replacement of hydroelectric energy was through thermoelectric plants, which went from 2% of the matrix in 2000 to a peak of 18% in 2013. With regard to the production of electricity from renewable sources, it went from 89% in 2000 to only 63% in 2014, the lowest value not only of the selected period but of the last 50 years of the history of electric energy production in Brazil.[106]

However, this result has serious externalities. In 2014, there was the worst performance in the participation of renewable energies in the last 70 years of the Brazilian electricity sector history.[107] That year, non-renewable energies reached 26% of the electricity market, with a special emphasis on natural gas (17%), after reaching 18% in the previous year. The thermoelectric production using natural gas in the country was more than twenty times what was produced in 2000. It was well known that both the image of Petrobras and the Lula-Rousseff government could be damaged by the degradation of the Brazilian energy matrix, one of the most sustainable in the world. Not without reason, a series of investments were made in the areas of renewable energies such as biodiesel, ethanol, palm oil and other vegetable oils, as well as the production of electricity from renewable sources. However, the sum of installed capacity in these sources of electricity never exceeded more than 5% of the company's total [9].

| | |
|---|---|
| SWOTrowhead | |
| Strengths | - Lower implementation price compared to hydroelectric plants |
| | - Non-dependence on drought cycles |
| | - Inputs do not depend on imports |
| | - Growing demand for both natural population growth and economic growth |
| | - Know-how of the expansion of installed capacity |
| | - Possibility of state investment through Petrobras |
| | - High ability to attract private investment to expand installed capacity. |
| | - Lower greenhouse gas emissions when compared to oil and coal. |
| | - Proximity to consumer centres, including the possibility of being accessible to places isolated from the national system |
| Weaknesses | - non-renewable source |
| | - Increased emissions when compared to renewable sources |
| | - Gas pipeline distribution infrastructure still does not cover most of the national territory. |
| | - No possibility of distributing LNG in systems isolated from the national system. |
| | - Infrastructure for export unable to respond to external demand |
| Opportunities | - Use of surplus gas production associated with oil in the pre-salt layer. |
| | - Avoid reinjection of gas in production fields |
| | - Give economic value to gas associated with oil. |
| | - Be a factor that helps make the expansion of LNG terminals and gas pipelines viable. |
| | - Increase energy security through the variety of available sources. |
| | - Production does not depend on climatic factors |
| | - Productive association with other industrial and fertilizer sectors. |
| Threats | - Decreased partitioning of renewable sources in the electrical matrix |
| | - Investments and state subsidies could be directed towards wind and solar sources. |
| | - The international oil price can influence cost in an international parity policy (IPP) scenario |
| | - Natural gas leaks and flaring gas. |
| | - Difficulties in obtaining environmental licenses. |
| | - Legal Uncertainty in Brazil |
| PESTELrowhead | |
| Political | - Brazil offers a general scenario of institutional instability |
| | - Impacts from the political alternation in the federal government and the economic development model through private or State investment |
| | - Scenario of public debt or the NOC can intervene in state investment |
| | - Investment priority of the state-owned company can be changed by the presidency appointed by the federal government |
| | - Parliament can enact laws that favour or inhibit the industry |
| Economic | - Security of energy supply due to the variety of sources |
| | - Impact by the international price of oil and cost of production |
| | - Investments can be impacted by energy demand. |
| | - The growth of the national economy impacts energy demand. |
| | - Abundance of natural resources |
| | - Brazil's political, economic and social instability can negatively impact GDP growth and forecast demand. |
| Social | - Using natural gas can increase the value and availability of energy, impacting the number of jobs and income. |
| | - The industrial chain linked to natural gas and energy can generate jobs and income and reduce poverty. |
| Technology | - The country has enough technology for the deployment of thermoelectric plants |
| | - Research can develop ways to reduce pollutants or accidents and leaks. |
| | - Research tends to reduce the cost of implementing installed capacity and production from renewable sources such as wind and solar. |
| Environment | - Impacted by the gas emission targets agreed upon by Brazil |
| | - Negatively impacts emissions when compared to renewable sources |
| | - Risk of gas leaks and work accidents. |
| | - Decrease in the share of renewable sources in the Brazilian electricity matrix |

(*continued on next page*)

[106] EPE (Empresa de Pesquisa de Energia), Annual Report, 2010–2019. Available online at: ⟨https://www.epe.gov.br/pt⟩.

[107] EPE (Empresa de Pesquisa de Energia), Annual Report, 2010–2019. Available online at: ⟨https://www.epe.gov.br/pt⟩.

(*continued*)

| | |
|---|---|
| | - Climatic cycles can increase demand from this source. |
| Legal | - Brazil offers a general scenario of legal instability in labour relations, extraction of natural resources, logistics, and the environment.<br>- Impact the environmental licensing of power plants and natural gas or electricity distribution infrastructure<br>- Impact the price of production through subsidies or tariff increases<br>- Impact the entry of private agents in the sector |

## 5. Conclusions and policy implications

The present study sought to assess the performance of Petrobras for 20 years in the production of electricity. This paper tried to answer the following questions about differences on the direction of the Petrobras Gas and Energy sector and their impact on the Brazilian electricity matrix. Petrobras' production, even in terms of electricity, has a high carbon footprint. However, company annual reports present socio-environmental action to compensate for this fact, such as reforestation projects, offsetting carbon credits, adoption (or creation) of an environmental reserve. It is noted that these initiatives were more highlighted in the annual reports during the government of the Workers' Party than in subsequent governments.

Following the trend of developed countries, Brazil has left the new thermoelectric projects in the hands of the private sector. Although Brazil already has one of the NOCs with the highest production of electricity through gas, the private sector has controlled the projects under development. This tendency is verified in the countries that host the *majors*.

It was found that the company's electric power sector started with a specific nominal investment in 1997. It gained more importance after the acquisition of thermoelectric plants in 2000. This acquisition was determined by the federal government, majority controller of the public company, to solve the problem of the energy supply at the beginning of the period considered. These thermoelectric plants made up almost the entirety of the thermoelectric park in Brazil. In 2002, Petrobras owned about 50% of the Brazilian thermoelectric park and reached more than 90% of the thermoelectric production using gas in 2006. This share has been decreasing with the entry of other players in the sector, some of which are private. On the other hand, Brazil is the second country with the most projects under development and will have the sixth largest installed capacity. The company's thermoelectric market share was reduced to around 28% in 2020. With the conclusion of the projects under development, Petrobras' share in this market should go from 90% to less than 10%. Private initiative tends to definitively control the installed capacity in Brazil.

During this period, Petrobras remained the sixth Brazilian largest company in electricity production and the largest producer of energy with natural gas thermoelectric plants. Its contribution to the national energy matrix was 2.4% of the market in 2020, after a peak of 7.5% share in 2014. This period coincided with the greater use of fossil fuels for the production of electricity in the last 70 years. Consequently, in the 2014–2016 triennium, renewable energies had the smallest share of the Brazilian energy matrix. After this period of water crisis, the share of thermoelectric sources fell from 18% in 2013 to 9% in 2016. This proportion remained at this level until 2020. The share was gradually replaced by other renewable energies with significant growth such as wind, solar and biomass. This growth has not been carried out by Petrobras, but by other players, including those from the private sector, as the Brazilian government gave up on carrying out large infrastructure initiatives under the Temer and Bolsonaro governments. The growth of renewable sources of electricity led Brazil to reach 84% in 2020, a rate like that of 2002, close to the historic peak of 89% in 2000. In addition, it is remarkable how there was a reduction in the hydroelectric source from 87% in 2000 to 63% in 2020. The Coronavirus pandemic did not have such a great impact on the aspects studied in this article, since economic recovery maintained the trend of increasing demand for electricity.

This result is related to a series of state policies for production during the Lula and Rousseff governments, which bore fruit throughout the period analysed. In addition to public policies, the fact that wind energy has become the third largest source of energy in Brazil is related to the development of technology at an international level and the respective reduction in implementation costs.

The Petrobras crisis, with consequences for the Energy and Gas sector, seems to have been motivated by several factors exogenous to the Brazilian economy, such as the reduction in the price of oil, the reduction in the growth prospects of the Chinese GDP, the change in the North American energy policy, the reduction in commodity prices, as well as several endogenous factors, such as the political and economic crisis that Brazil went through between 2014 and 2016. Such externalities undoubtedly deepened the company's crisis, which was already suffering from poor results due to the consequences of corruption scandals. This environment favoured the divestment policy in the electricity sector as of 2015 and the decision to withdraw from the electricity sector as of 2020 totality up to the date of analysis of this study. Without a doubt, these consequences deserve to be studied in future analyses. The company's Gas and Energy sector was used by the State in situations of reduced supply of hydroelectric energy over these 20 years.

During these years, relevant company resources were dedicated to research through the Company Research Centre to the development of electricity production through wind, photovoltaic and biomass projects from sugarcane bagasse. It generated studies on the Brazilian wind potential and developed technologies and patents related to electricity production. However, the amount of energy produced by renewable sources within the company's installed capacity never exceeded more than 5%, which also made it seem like a mere marketing strategy of the company and the government itself. The most recent strategic plans even mention the beautiful intention to encourage renewable energies, but they do not indicate the amount of investment or more concrete measures. This aspect can be explored in further studies.

From the present analysis that considered the last 20 years of Petrobras' Energy and Gas sector, the company tends to remain with the gas sector in order to sell it to Brazilian distributors and does not tend to increase its thermoelectric park any further. The company, although still a leader in the production of energy from natural gas, has abdicated its intention to expand its installed capacity and formally declared the sale of part of its thermoelectric park. It seems to restrict itself to being a self-producer of electric energy and contributing to the National Interconnected System in periods of the collapse of hydroelectric production. However, this purpose may be unjustified as the source seems to give way to electricity produced from the wind and solar matrix.

Based on these conclusions, it is appropriate to propose the following policies for the conservation of the Brazilian energy matrix and the maintenance of development based on the oil industry.

1. The Brazilian government should continue to encourage the growth of installed capacity by the private sector, in line with the trend observed in developed countries.
2. State and Petrobras investment, as well as encouraging private investment for production from renewable sources, especially through solar, biomass and wind sources.
3. Use of wind energy as a substitute for hydraulic energy in periods of water scarcity with the maintenance of the thermoelectric park for national energy security.
4. Transformation of oil and coal thermoelectric plants to gas, taking advantage of the pre-salt potential, including the improvement of the gas distribution system for large urban centres not yet connected to the national system.
5. Return of the business model that used the national oil company as an investment inducer, but inserted in energy transition policies or, at least, reduction of emissions using natural gas, abundant in the pre-salt.
6. Substitution of imports of electricity and natural gas for national production.

Future studies should investigate the characteristics of private investors gaining greater participation in production. The constitution of a mathematical and computational model can be developed in specific research in the future. A future study could also compare the performance of countries with thermoelectric production similar to that of Brazil and that of thermoelectric production, as is the case of Iran, the United Kingdom, Egypt, Turkey and Mexico.

## Author contribution statement

Marcos Eduardo Melo dos Santos, Rui Castro, Hirdan Katarina de Medeiros Costa: conceived and designed the experiments; performed the experiments; analysed and interpreted the data; contributed reagents, materials, analysis tools or data; wrote the paper.

## Data availability statement

Data will be made available on request.

## Additional information

No additional information is available for this paper.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Marcos Eduardo Melo dos Santos reports financial support was provided by Univesp. Hirdan Katarina de Medeiros Costa reports financial support was provided by University of São Paulo. Hirdan Katarina de Medeiros Costa reports financial support was provided by Fundação de Amparo a Pesquisa do Estado de São Paulo. Hirdan Katarina de Medeiros Costa reports financial support was provided by Shell Brazil Oil. Rui Castro reports financial support was provided by Fundação para a Ciência e a Tecnologia. Marcos Eduardo Melo dos Santos reports a relationship with University of Lisbon that includes: non-financial support.

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