THE BRAZILIAN ELECTRICITY SYSTEM: AN EVALUATION OF THE THERMOELECTRIC PLANTS UNDER THE ELETROBRAS PRIVATIZATION LAW[1]

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Discussions on the energy transition (ET) in the Brazilian electricity sector (sistema elétrico brasileiro – SEB) have often considered the insertion of natural gas (NG) thermoelectric plants (TPPs) as a solution to energy security. The SEB has a high penetration of renewable sources (84%). Its decarbonization is a mechanism that can contribute to Brazil's greenhouse gas (GHG) emission reduction targets and help mitigate the impacts of climate change by increasing the share of renewable sources. With this in mind, the aim of this paper is to analyse the requirement to contract 8,000 MW of new NG-fired thermal power plants – thermal-jabutis – based on Eletrobras' privatization law No. 14,182/2021 and its impact on the SEB. Methodologically, two guiding questions are used: i) does the SEB need new NG TPPs?; and ii) what are the impacts of implementing the new NG TPPs provided for in the Eletrobras privatization law? The results show that the compulsory contracting of NG TPPs in Brazil will result in: i) additional infrastructure costs for transporting NG to the TPPs; ii) a 40% increase in the SEB's annual GHG emissions; and iii) an increase in the demand for water resources, due to the

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consumption of water to operate the TPPs. On the other hand, in order to guarantee the increase in energy demand and the energy security of the SEB in the long term, the expansion of transmission networks and solar and wind generation are required as the most economical means of reducing GHG emissions from the electricity sector. It is necessary to guarantee the protection of biodiversity, the rights of communities affected by the implementation of these projects and the coordinated operation of these new plants with the Brazilian hydroelectric park, in order to guarantee the storage of energy in the form of water for periods of water scarcity and load control. Finally, we conclude that: i) it is essential to consider not only GHG emissions, but also environmental and social impacts when evaluating the expansion of power generation in Brazil; ii) the implementation of NG TPPs is a contradiction to the Brazilian TE, as it increases environmental impacts, the price of the energy tariff, delays the achievement of the decarbonization goals of the SEB and the 2030 Agenda; and iii) it goes against the scientific evidence, widely disseminated nationally and internationally, which recommends expanding the Brazilian supply of electricity from solar and wind sources. Therefore, the SEB does not need inflexible fossil TPPs.

Keywords: energy transition; energy planning; Brazilian electricity sector; natural gas; Brazil; Eletrobras.

O SISTEMA ELÉTRICO BRASILEIRO: UMA AVALIAÇÃO DAS TERMELÉTRICAS DA LEI DE DESESTATIZAÇÃO DA ELETROBRAS

As discussões sobre a transição energética (TE) no setor elétrico brasileiro (SEB) frequentemente consideraram a inserção de usinas termelétricas (UTEs) a gás natural (GN) como solução para a segurança energética. O SEB possui grande penetração de fontes renováveis (84%). A sua descarbonização é um mecanismo que pode contribuir para as metas brasileiras de redução das emissões de gases de efeito estufa (GEE) e ajudar a mitigar os impactos decorrentes das mudanças climáticas, a partir do aumento da participação das fontes renováveis. Nesse sentido, o objetivo do trabalho é analisar a exigência de contratação de 8.000 MW de novas UTEs a GN – térmicas-jabutis – a partir da Lei nº 14.182/2021 de desestatização da Eletrobras e seu impacto no SEB. Metodologicamente, utilizam-se duas perguntas norteadoras: i) o SEB necessita de novas UTEs a GN?; e ii) quais os impactos da implantação das novas UTEs a GN previstas na lei de privatização da Eletrobras? Os resultados demonstram que a contratação compulsória de UTEs a GN no Brasil resultará em: i) custos adicionais de infraestrutura para transporte de GN até as UTEs; ii) aumento em 40% das emissões anuais de GEE do SEB; e iii) aumento da demanda por recursos hídricos, devido ao consumo de água para operação das UTEs. Por outro lado, para garantir o aumento da demanda de energia e a segurança energética do SEB no longo prazo, exige-se a expansão das redes de transmissão e da geração solar e eólica como meios mais econômicos para reduzir as emissões de GEE do setor elétrico. É preciso garantir a proteção da biodiversidade, os direitos das comunidades afetadas pela implantação desses projetos e a operação coordenada dessas novas usinas com o parque hidrelétrico brasileiro, de forma a garantir o armazenamento de energia na forma de água para períodos de escassez hídrica e para controle da carga. Por fim, conclui-se que: i) é fundamental considerar não apenas as emissões de GEE, mas também os impactos ambientais e sociais ao avaliar a expansão da geração de energia no Brasil; ii) a implantação das UTEs a GN é um contrassenso à TE brasileira, pois aumenta os impactos ambientais, o preço da tarifa de energia, retarda o atingimento das metas de descarbonização do SEB e da Agenda 2030; e iii) vai na contramão das evidências científicas, amplamente divulgadas nacionalmente e internacionalmente, que recomendam expandir a oferta brasileira de energia elétrica a partir de fontes solar e eólica. Portanto, o SEB não precisa de UTEs fósseis inflexíveis.

Palavras-chave: transição energética; planejamento energético; setor elétrico brasileiro; gás natural; Brasil; Eletrobras.

EL SISTEMA ELÉCTRICO BRASILEÑO: UNA EVALUACIÓN DE LAS CENTRALES TERMOELÉCTRICAS EN LA LEY DE PRIVATIZACIÓN DE ELETROBRAS

Las discusiones sobre la transición energética (TE) en el sector eléctrico brasileño (setor elétrico brasileiro – SEB) consideraron frecuentemente la inserción de centrales termoeléctricas (CTE) de gas natural (GN) como una solución para la seguridad energética. El SEB tiene una alta penetración de fuentes renovables (84%). Su descarbonización es un mecanismo que puede contribuir a los objetivos brasileños de reducción de emisiones de gases de efecto invernadero (GEI) y ayudar a mitigar los impactos resultantes del cambio climático, aumentando la proporción de fuentes renovables. En este sentido, el objetivo del trabajo es analizar la exigencia de contratación de 8.000 MW de nuevas CTE de GN – Jabutis – con base en la Ley nº 14.182/2021 de privatización de Eletrobras y su impacto en el SEB. Metodológicamente, se utilizan dos preguntas orientadoras: i) ¿el SEB necesita de nuevas CTEs para GN? y ii) ¿cuáles son los impactos de la implementación de las CTEs prevista en la ley de privatización de Eletrobras? Los resultados demuestran que la contratación obligatoria de CTEs de GN en Brasil resultará en: i) costos adicionales de infraestructura para el transporte de GN a las CTEs; ii) aumento del 40% en las emisiones anuales de GEI de la SEB; y iii) aumento de demanda de recursos hídricos, debido al consumo de agua para la operación de las CTEs. Por otro lado, para garantizar el aumento de la demanda y la seguridad energéticas de SEB en el largo plazo, es necesario ampliar las redes de transmisión y generación solar y eólica como medios más económicos para reducir las emisiones de GEI del sector eléctrico. Es necesario garantizar la protección de la biodiversidad, los derechos de las comunidades afectadas por la implementación de estos proyectos y la operación coordinada de estas nuevas centrales con el parque hidroeléctrico brasileño, para garantizar el almacenamiento de energía en forma de agua durante períodos de escasez y para control de energía. Finalmente, se concluye que: i) es fundamental considerar no sólo las emisiones de GEI, sino también los impactos ambientales y sociales al evaluar la expansión de la oferta energética en Brasil; ii) la implementación de CTEs a GN es una contradicción con la TE brasileña, ya que aumenta los impactos ambientales, el precio de las tarifas energéticas, retrasa el cumplimiento de los objetivos de descarbonización de la SEB y de la Agenda 2030; iii) y contradice la evidencia científica, ampliamente difundida a nivel nacional e internacional, que recomienda la expansión del suministro de energía eléctrica a partir de fuentes solares y eólicas. Por lo tanto, el SEB no necesita CTEs fósiles inflexibles.

Palabras clave: transición energética; planificación energética; sector eléctrico brasileño; gas natural; Brasil; Eletrobras.

JEL: O13; O21; Q21; Q35.

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1 INTRODUCTION

The Brazilian electricity system (SEB) is mostly renewable, 84% of the total installed capacity.[11] Its energy transition (ET), on the supply side, is aimed at further increasing the share of renewable sources, expanding its transmission network to allow the insertion of new generating parks distributed throughout the national territory, and carrying out decarbonization actions such as phasing

11. Available at: https://x.gd/uDSKB.

out fossil fuel sources, including the suppression of new fossil fuel thermoelectric projects. (Bugaje et al., 2022) resulting in a renewable SEB that meets the global goal of net-zero (EPE, 2021; IEA, 2021; 2023).

Even inserting natural gas (NG) thermoelectric plants (TPPs) into the SEB with environmental or mitigation technologies (Relva, 2022; Silva, 2022), such as carbon capture, usage and storage (CCUS), this solution still lacks technical, regulatory, and national infrastructure studies for its implementation. Pelissari, Relva and Peyerl (2023) studies are needed to map and address social, environmental and safety issues in addition to technical issues (Ciotta et al., 2020) and even determining their social acceptance and perception (Abreu Netto, Peyerl and Jacobi, 2023).

As this access is a fundamental asset for contemporary society (Grimoni et al., 2015; Ferreira et al., 2023) fair ET requires the inclusion of variables specific to each territory, taking into account socio-cultural, ecological-environmental and political aspects (Costa, 2022) as well as the availability of data and information (Relva et al., 2021) to plan and implement infrastructures to reduce regional asymmetries (Silva et al., 2021) and democratize access (Santos et al., 2023).

Therefore, it is clear that fair and democratic ET requires a multidimensional approach and the incorporation of all stakeholders and those involved in the process (Udaeta, 2012; Galvão, 2015; Bernal, 2018; Silva et al., 2021; Silva, 2022).

In this sense, the main objective of this paper is to analyze the requirement to contract 8,000 MW of new NG-fired TPPs under Eletrobras' privatization Law No. 14,182/2021 (Brazil, 2021), known as the thermal-jabutis of Eletrobras' privatization, through the lens of their impact on electricity generation in the SEB and on the environment.

To this end, this work is divided into seven sections, the introductory one presenting the context, objectives and justification. Section 2, the methodology for developing and analyzing the work is presented. Section 3, the main aspects of the law that privatized Eletrobras are presented, with a focus on the article that requires the contraction of NG TPPs. In section 4, discusses the current panorama of regulated auctions for the contraction of NG-fired TPPs and the progress made in implementing variable renewable sources in the SEB. Section 5, the impacts of current and projected greenhouse gas (GHG) emissions resulting from the contracting of TPPs are discussed, as well as the impacts of climate change on the SEB's energy supply. Section 6, the main results of the work are systematized and discussed. Finally, in section 7, the main conclusions and recommendations of the work are consolidated.

2 METHODOLOGY

The methodology of the work starts with the guiding questions: i) does the SEB need new NG-fired TPPs?; and ii) what are the impacts of implementing the new NG-fired TPPs provided for in the Eletrobras privatization law?

The paper then reviews the national and international literature, following the method used by Lim and Jiang (2010) and Bonalumi (2019) with the aim of identifying and analyzing the characteristics of different variables in planning the expansion of electricity supply. It also seeks to propose actions to reduce the socio-environmental impacts resulting from its expansion.

This review is carried out on portals and platforms that consolidate data on the operation and expansion of the SEB and technical-scientific papers that analyze the role of TPPs in the SEB, their possible socio-environmental impacts, and their role in climate change.

The information is gathered from research on scientific journal portals, state agencies, civil society organizations, trade associations, among others.

The review explores and systematizes, from a technical-environmental point of view, the Sustainable Development Goals (SDGs) of the 2030 Agenda, to directly achieve goal 07 – clean and affordable energy – and goal 13 – action against global climate change,[12] in the three dimensions defined by Peyerl, Relva and Silva (2022) (figure 1):

- time, relative to the duration of a TE, which can be long or short (Sovacool, 2016);
- impulse, comprising the territorial space related to the availability or not of energy resources and technologies (Udaeta, 2012; Schaffartzik, Brad and Pichler, 2017; Silva, 2022); and
- scale, also relative to the territory, can be sectoral - steel industry, electricity sector, transportation –, local – access to electricity in remote regions –, even on a global scale (Peyerl, Relva and Silva, 2022).

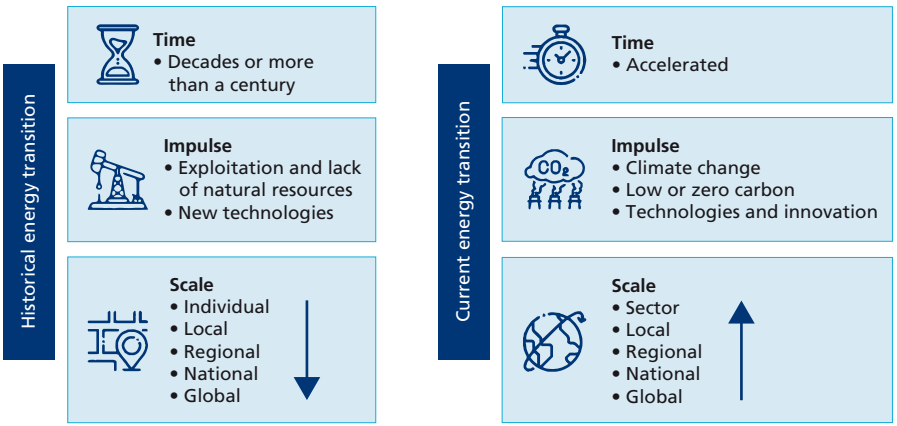
To demonstrate:

- the present role of sources in the SEB's energy supply mix;
- the current profile of the diversity of energy source expansion in the SEB;

12. Available at: https://brasil.un.org/pt-br/sdgs.

- the contextualization of Law No. 14.182/2021 (Brazil, 2021) in relation to the amendment requiring the contracting of NG-fired TPPs, through regulated auctions, to become part of the National Interconnected System (Sistema Interligado Nacional – SIN);
- the economic and environmental impact of implementing NG-fired TPPs; and
- the systematization of the data and results of this review.

FIGURE 1
Dimensions of the energy transition



Source: Peyerl, Relva and Silva (2022).

3 THE PRIVATIZATION OF ELETROBRAS AND THERMOELECTRIC PLANTS

Law No. 14.182 of July 12, 2021, provided for the Privatization of Eletrobras and regulated its privatization process (Brazil, 2021). The company in the electricity sector is responsible for more than a fifth of the installed capacity (IC) of electricity generation units and almost 40% of the SIN's transmission lines.[13]

The law included an amendment – the first paragraph of art. 1 – obliging the contracting of NG-fired TPPs through regulated auctions.

Paragraph 1, a 666-word section without periods, was strategically worded to make it impossible to partially veto it, resulting in the mandatory contracting of 8,000 MW of natural gas thermoelectric plants in locations mostly without gas

13. Available at: https://eletrobras.com/pt/Paginas/Sobre-a-Eletrobras.aspx.

supply infrastructure in the states of the North, Northeast and Southeast regions – and an established operating regime of at least 70% inflexibility per year.[14]

The sole paragraph explains how the private interests of the Brazilian gas sector, through lobbying in the legislature, override the public interests of Brazilian society, distorting a bill with the aim of directing a market reserve, in a clear demonstration of how Brazilian patrimonialism operates, by appropriating the state apparatus to legislate for its own benefit and that of its cronies (Faoro, 1958). The consequences will be the expansion of unnecessary projects, the burdening of electricity consumers with higher tariffs and an increase in SEB's GHG emissions.

The process of discussing Law No. 14,182/2021 was widely criticized by different actors in the electricity sector, from the presentation of the provisional measure by the executive to its debate in Congress and later in the Senate.

The main point of this criticism was the interference of the legislature in the planning process of the electricity sector. Despite several points that require to adequately incorporate socio-environmental aspects of projects, this process has at least worked with transparency and clear rules on the economic criteria for contracting power plants through auctions regulated by the National Electric Energy Agency (Agência Nacional de Energia Elétrica – Aneel).

In addition, there are environmental considerations, depending on the type of auction and the specifics of each edition, such as criteria for GHG emissions and pollutants, environmental licensing requirements, socio-environmental commitments based on social responsibility actions and environmental education programs.[15]

Since their contracting is determined by law, NG-fired TPPs do not go through a process of competition with other sources in these auctions, in which the plants with the lowest energy prices are contracted.[16]

In the case of the auctions established for contracting NG-fired TPPs, only NG-fired projects take part. In addition, specific regions are established for the implementation of these thermal plants, i.e. exclusive agents (NG thermoelectric generators) compete directly in capacity reserve auctions – contracting power and

14. The TPPs will be obliged to generate energy for at least 70% of the total hours in a year (6,132h out of a total of 6,760h), and payment for this energy will be guaranteed by the country's captive consumers.

15. Available at: https://www.epe.gov.br/pt/leiloes-de-energia/leiloes.

16. In a conventional auction, electricity generation agents compete with each other, regardless of the type of source, renewable or not, and the region where the plant is located. A base price is set at the start of the auction and the generation agents compete with each other by bidding lower than the established price, with the lowest bid winning. Energy auctions are the mechanism that enables distributors to contract electricity to meet the electricity demands of captive consumers – the Regulated Contracting Environment (Ambiente de Contratação Livre – ACL) – and at the same time guarantee predictable revenue for generators. Available at: https://www.ccee.org.br/web/guest/mercado/leilao-mercado; and https://www.epe.gov.br/pt/leiloes-de-energia/leiloes.

associated electricity – in pre-established regions, making it impossible for agents unable to access the region or the NG supply reserves and infrastructure for the TPPs to participate.

In this sense, the forced contracting of fossil TPPs promotes a shift in the electricity supply towards non-renewability and a reduction in tariff modicity. Since the energy that could once be contracted from renewable sources and with cheaper energy prices is now limited to generation from more expensive NG (IEMA, 2021; 2022b). Moreover, this overlooks the market trend in which the winners in conventional auctions have been solar photovoltaic and wind power, while NG-fired TPPs have been contracted and operated on a reduced regime due to high operating and fuel costs (IEMA, 2022b).[17]

Currently, there are attempts by the executive branch to reverse or amend the privatization law regarding art. 3, III, point a, which governs the amendment of the company's bylaws,[18] no clear position has been taken by the federal government in relation to the decision to compulsorily contract TPPs.

4 AUCTIONS FOR NG-FIRED TPPs AND THE ADVANCE OF RENEWABLES

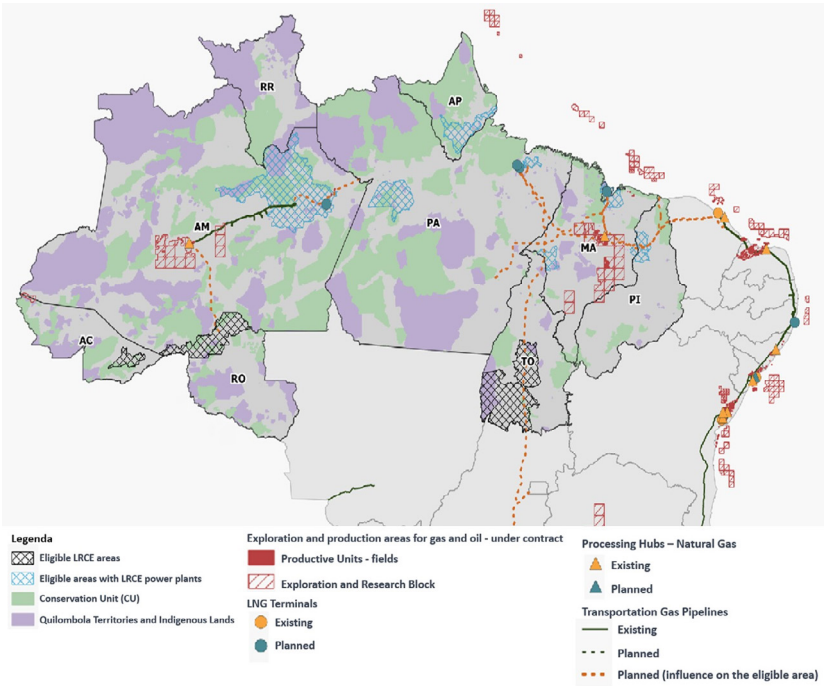
After two years since the publication of Law No. 14,182/2021, only one auction has been held, making three different areas available for the implementation of the auctioned NG-fired TPPs: 1,000 MW in the North region, 700 MW in the State of Piauí and 300 MW in the state of Maranhão. In the states of Maranhão and Piauí, where there is little or practically no infrastructure for transporting gas, there were no bids, indicating a lack of interest even from generators. In the North, three plants with a total CI of 754 MW were contracted, all located in the state of Amazonas (IEMA, 2022b).

The expansion of this thermoelectric park will require the construction of transportation pipelines to supply NG to regions lacking infrastructure and demand for other end uses. To supply NG to the North and Northeast regions, the expansion will total 7,476 km (IEMA, 2022a) almost doubling the length of Brazil's current gas pipeline network, which currently stands at 9,409 km (Brazil, 2022b). According to IEMA (2022a) this new infrastructure will require investments of almost R$ 57 billion and a right-of-way of approximately 150 km², resulting in environmental impacts due to changes in land use and an increase in GHG emissions. In addition, it will be necessary to cross sensitive areas such as conservation units, quilombola territories and indigenous lands (figure 2).

17. Available at: https://www.ccee.org.br/mercado/contas-setoriais/conta-de-desenvolvimento-energetico-cde.

18. It prohibits any shareholder or group of shareholders from voting more than 10% of the number of shares into which Eletrobras' voting capital is divided (Brazil, 2021). Even the federal government, which owns 43% of the shares, cannot have a voting weight greater than the 10% established.

FIGURE 2
Eligible areas for setting up a TPP and existing and planned infrastructure for the NG chain



Source: IEMA (2022a).
Obs.: Figure displayed in low resolution and whose layout and texts could not be formatted and proofread due to the technical characteristics of the original files (Publisher's note).

At the time of the auction, the Institute for Energy and the Environment (Instituto de Energia e Meio Ambiente – Iema) pointed out weaknesses in the licensing processes of the participating plants, including recent licensing processes, without enough time for a real analysis of socio-environmental impacts, lack of environmental impact studies and difficulty in accessing public data on the processes, including for the winning plants (IEMA, 2022a).

This lack of public data restricts civil society's assessment of the socio-environmental impacts of this type of project, which range from global and national impacts, such as GHG emissions, to regional and local impacts, such as pollutant emissions, changes in land use and competition for water resources (Relva, 2022). In the case of water resources, during the operation of TPPs, around 70% to 80% of the abstracted water does not return directly and immediately to the watershed, but evaporates during the cooling process. In terms of local competition, for example, an NG-fired TPP can consume 1,000 liters of water per MWh. If it operates annually, its daily consumption is equivalent to

the water supply of a city with approximately 156,000 inhabitants, totaling 24 million liters per day (Baitelo, 2021).

With regard to new auctions, a capacity reserve auction was scheduled for the end of the first half of 2023,[19] but after this period, no notice or date has been released.

Even though the first auction was cancelled, Aneel had already predicted that 2023 would be a record year for the increase of IC in the SEB, with the entry of 10,300 MW of new plants, 90% of which would be new solar photovoltaic and wind power plants (Aneel, 2023).

In fact, the growth of these two renewable sources over the last two years has been 93%, totaling 58,000 MW of IC and corresponding to an average generation capacity of 15,000 MWmed (Aneel, 2023).[20] Both IC and electricity generation are more than enough to cover the compulsory contracting of the 8,000 MW of NG-fired TPPs, with a combined generation potential of 5,600 MWmed, considering the 70% inflexibility provided for in Law No. 14,182/2021 (Brazil, 2021). And they neutralize the need for importing liquefied natural gas (LNG) and set up new terminals and gas pipelines, which would otherwise be used to supply these new TPPs.

Suspending the contracting of these NG-fired TPPs also has a direct impact on the moderateness of electricity tariffs, since the average contracting price for TPPs was 440.00 R$/MWh (IEMA, 2022b) while solar and wind sources obtained average prices of 175.66 R$/MWh and 171.20 R$/MWh, respectively, in the last auction.[21]

The compulsory contracting of the 8,000 MW provided for in Law No. 14,182/2021 could result in a 41% increase in the monthly operating cost of Brazilian thermal power plants, from R$ 1.7 billion to R$ 2.4 billion[22] an increase of more than 12% in the cost of energy consumed by Brazilians (IDEC, 2022). The inflexibility of 70% of these TPPs, on the other hand, would result in greater spillage from the UHEs' reservoirs. According to PSR (2023) this operation makes no economic sense, as it prioritizes more expensive thermoelectric generation and spills water from the reservoirs, restricting the possibility of cheaper, renewable hydroelectric generation.

19. Available at: https://www.gov.br/mme/pt-br/assuntos/noticias/mme-define-cronograma-de-leiloes-de-energia-para-o-trienio-2023-2013-2025.

20. Available at: https://www.absolar.org.br/mercado/infografico/; https://x.gd/Yr8b4; and https://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/carga_energia.aspx.

21. Available at: https://www.ccee.org.br/documents/80415/26037005/Resultado_Consolidado_Setembro_2023.xlsx/6b764c4b-b523-d6b8-8120-2afcb8a7e3e8.

22. Available at: https://idec.org.br/termicas-jabuti?gclid.

Furthermore, as determined by Werlang et al. (2021) the expansion of NG-fired TPPs distributed throughout the territory, as determined by the law, would result in operating and investment costs 16% higher than in a scenario with TPPs concentrated in the Southern region of Brazil.

With regard to security of supply, the current scenario differs from two years ago. In 2021, the activation of gas-fired thermoelectric plants reached 11,053 MWmed, a national record, as a result of the drought that impacted the generation capacity of HPPs. In 2022, this generation reached 7,714 MWmed at the start of the year, falling sharply to a minimum of 1,086 MWmed and stabilizing between 2,000 and 3,000 MWmed. By 2023, the low tendency for NG-fired TPPs to be inserted into the SIN resulted in generation in the range of 1,500 to 3,000 MWmed (ONS, 2023a) as a result of the increase in rainfall and, consequently, the stored energy capacity (energia armazenada – EAR)[23] in the form of water in the reservoirs of the hydroelectric power plants (HPPs). In terms of comparison, in September 2021, the EAR reached its lowest rate, just over 16%. In July 2023, the EAR exceeded 86%.[24]

The decline in TPPs generation, with a 47% reduction compared to 2021 (EPE, 2023). The peak of 42 million m³ per day (MMm³/day) in January 2021 fell to a level of 24 MMm³/day in 2022, a reduction of 60%. In the case of LNG imports, this decline was even greater, from over 20 MMm³/day in January 2022 to just over 1 MMm³/day in December 2022; a reduction of 95% (Brazil, 2022a).

The infrastructure for supplying imported and domestic NG is being expanded. The planning of five new terminals and the construction of six new pipelines for the transportation and flow of NG onshore and offshore will increase the supply of this fuel from the current 116 MMm³/day to 182 MMm³/day in 2032, or an increase of 57%. However, it is important to note that the supply of this gas does align with the demand from TPPs, which will rise from a consumption of 40 MMm³/day in 2022 to 49 MMm³/day in 2023, an increase of 23% (EPE, 2023). In this case, the expansion of this infrastructure could result in investments that become idle and require public resources to maintain.

5 SEB, GHG EMISSIONS AND CLIMATE CHANGE

According to data from the System of Estimates of Emissions and Removals of Greenhouse Gases (Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa – SEEG), Brazil's GHG emissions were at their highest level in almost two decades in 2021, with emissions of 2,420 Mt CO_{2e}.[25]

23. EAR in the SEB refers to the amount of energy stored in the form of water in the reservoirs of HPPs that can potentially be converted into electricity.

24. Available at: https://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/energia_armazenada.aspx.

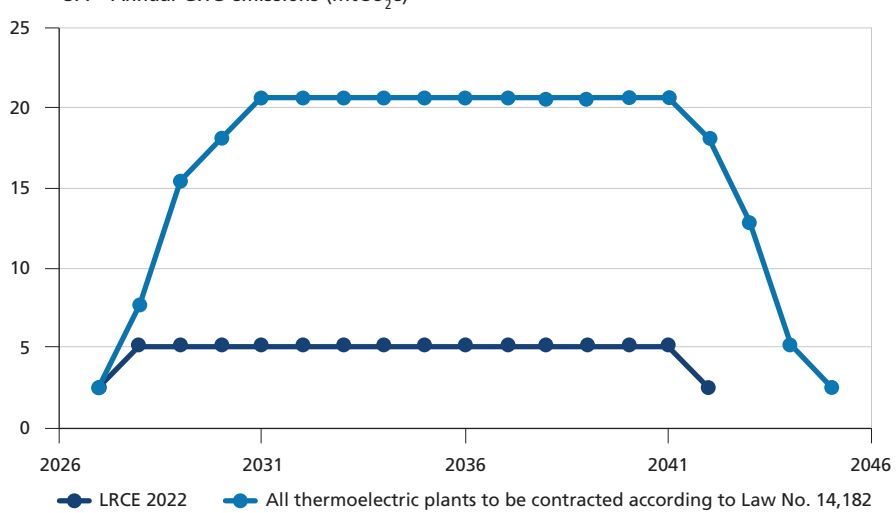
25. Available at: https://plataforma.seeg.eco.br/total_emission.

The electricity sector has seen the biggest rise in GHG emissions in 50 years as a result of the record start-up of TPPs. Even though the use of TPPs decreased in 2022[26] the high levels of GHG emissions due to deforestation and farming persist.[27]

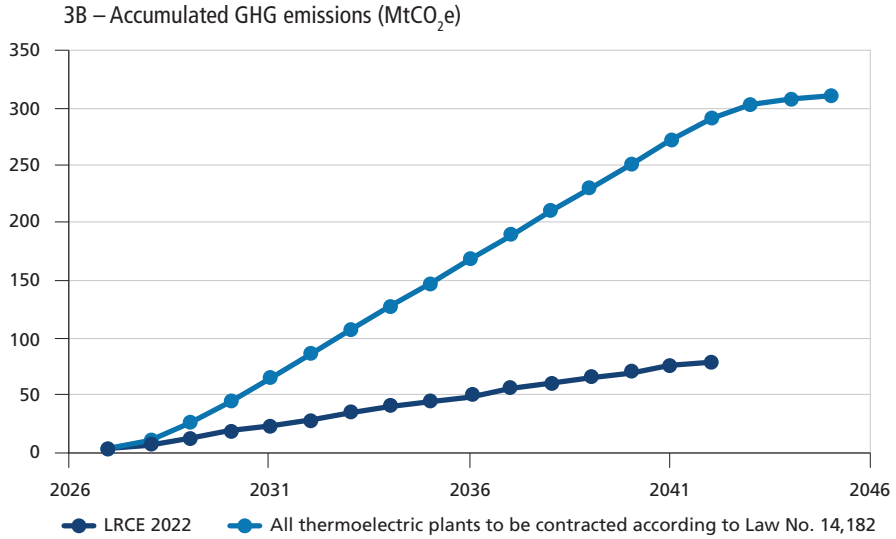
Even though deforestation emissions tend to fall with the resumption of actions to combat deforestation and fires (Rovere et al., 2014) the urgency of reducing global emissions leaves no room for growth in emissions from TPPs. Once land use emissions are under control, the energy sector will have a greater share of the country's total emissions, becoming an even more important bottleneck for the country to achieve carbon neutrality.

Emissions from all NG-fired TPPs to be contracted in accordance with Law No. 14,182/2021 (Brazil, 2021). In the period between the first 1,000 MW going into operation in 2026 and the final CI (8,000 MW) in 2045, it was calculated that these TPPs will emit an accumulated total of GHG in the order of 310 $GtCO_{2e}$ (figure 3), equivalent to 50 years of emissions from coal-fired TPPs in Brazil, increasing SEB's annual emissions by 36%.[28]

FIGURE 3
GHG emissions from the TPPs under Law No. 14,182/2021 and the TPPs contracted under LRCE 2022



26. Available at: https://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/carga_energia.aspx.
27. For more information, see footnote 25.
28. For more information, see footnote 25.



Source: IEMA (2022a).

ClimaInfo (2023) show the relationship between the water crisis and the energy crisis in Brazil, through extensive bibliographic research. They conclude that it is not advisable to consider historical rainfall patterns when planning the SEB; otherwise, the expected average annual rainfall may not be realized due to climate change.

The projected trend is for a decrease in the physical guarantee[29] of the HPPs in the long term, due to the seasonal change in the rainfall regime. The reduction in rainfall in regions with a densification of HPPs is aggravated by the increase in the intensity of extreme events and a greater sequence of dry days in the North and Northeast regions (ClimaInfo, 2023).

These results corroborate those found by de Jong et al. (2019) who utilized data from three global climate models to estimate future wind speed and average solar radiation for the 2030s and 2080s, comparing them to reference data from the last century. The results show that, due to climate change, the potential for photovoltaic generation in the Northeast and Southeast will increase slightly and the potential for wind generation will increase by more than 40%. The latter effect is also determined by Pereira et al. (2013) and Borba et al. (2023).

29. The physical guarantee determines the amount of marketable energy of a plant and defines the percentage of participation of the HPPs in the Energy Reallocation Mechanism (Mecanismo de Realocação de Energia – MRE) – an instrument that shares the financial risk associated with the sale of electricity from HPPs dispatched centrally by the National Electric System Operator (Operador Nacional do Sistema Elétrico – ONS) among the sector's agents, according to CCEE (2018) and EPE, available at: https://www.epe.gov.br/pt/areas-de-atuacao/energia-eletrica/garantia-fisica#:~:text.

And, according to Lucena et al. (2009) based on long-term climate projections using the Intergovernmental Panel on Climate Changes (IPCC) emissions scenarios, there will be an increase in the energy vulnerability of the country's lower-income regions, i.e. climate vulnerability also increases the social vulnerability of the poorest part of the Brazilian population and both the generation of HPPs and the production of biofuels (mainly biodiesel) could be harmed.

The scenarios analyzed show that there will be an increase in wind intensity and solar radiation incident on the earth (ClimaInfo, 2023). These two characteristics strengthen the implementation of wind and solar farms which, acting optimally, would avoid the use of water from HPPs which, in turn, could store energy in the form of water for longer, compensating for periods of drought. At the same time, this triad avoids the dispatch and contracting of new fossil-fuel TPPs in the SEB.

In this sense, the main recommendation, based on the references analyzed, is to diversify the supply of electricity through a hydro-solar photovoltaic-wind system, making it possible to mitigate the adverse effects of climate change in a more efficient way, making the SEB more resilient and secure (Lucena et al., 2018).

Although the diversification of electricity supply in the SEB over the last two decades has been due to the advance of renewable sources, further progress is needed to balance the proportion between HPPs and solar photovoltaic and wind generation. To this end, ClimaInfo (2023) suggest increasing the installed power (ballast measured in MW) from renewable sources in the SIN and greater energy storage, either centrally in modernized and repowered HPPs, or through new technologies such as batteries together with photovoltaic generation, hydrogen and reversible hydroelectric plants (ClimaInfo, 2023; PSR, 2023).

According to the IEA (2023) national actions must be more robust and accelerated, including, in addition to expanding and accelerating the implementation of renewable sources such as solar photovoltaics and wind power, the adoption and intensification of energy efficiency programs in all sectors of the economy and cutting GHG emissions through the electrification of industrial processes and transport. To this end, the expansion of transmission and distribution networks, together with incentives and the intensification of energy efficiency programs and demand-side management, is fundamental and unavoidable in SEB planning. Its neglect will be the bottleneck for the modernization and transition of the entire energy chain, from generation to the end use of energy.

Variable sources can be complemented by solutions such as additional biomass thermal plants, improved energy demand management, tapping into the

energy efficiency potential of consumer sectors, and, above all, the utilization of various storage systems. Proof of this is the free-run scenario included in the 2031 Ten-Year Energy Plan (Plano Decenal de Expansão de Energia – PDE), which only takes into account the TPPs that have already been contracted, indicated that the SEB could be served with an expansion of the transmission networks and a large share of renewable sources (19,300 MW), modernization of existing hydroelectric plants (4,300 MW) and flexible thermal plants, without the need for inflexible thermal plants (EPE, 2022).

The publication *Scenarios for inserting storage resources into the National Interconnected System* shows that by 2026 – the year in which part of the NG-fired TPPs will be in operation – unconventional storage systems will already be on a par with NG-fired thermal plants. In addition to avoiding the emission of atmospheric pollutants and GHGs, the response time of these systems[30] is fully compatible, in order to compensate for variations in wind farms and solar power plants (Absolar, 2021).

Furthermore, according to Cunningham (2023) the use of NG will reach a peak by the end of this decade, followed by a subsequent significant decline. The acceleration of this movement for this decade was prompted by the Ukraine War, which deregulated the supply of NG around the world and contributed to accelerating the deployment of renewable sources in various markets.[31]

GIZ (2019) analyzed the security of the electricity system with high penetration of renewable sources, concluding that: i) the seasonal complementarity between wind and inflows in the Northeast region of Brazil reduces the need for seasonal storage in the region; and ii) the expansion of the national transmission network is fundamental to enable the integration of variable renewable sources and allow the national hydroelectric park to act as a beacon of flexibility, stability and security of system operation.

In other words, the electricity system needs to be adapted to this new reality by strengthening the transmission system in order to support the increase and spread of wind generation in the Northeast, as well as solar photovoltaic plants in the Southeast and Northeast, coupled with regulatory improvements for the various types of storage systems implemented throughout the SEB chain.

Therefore, the different actions to further increase the renewability of the electricity supply, guarantee energy security and mitigate the impacts of climate change on the SEB must be coordinated between the various actors working in the SEB to allow for predictability in the expansion of renewable generation

30. Time between giving the drive command to inject electricity into the electrical system and it actually happening.
31. Available at: https://www.iea.org/data-and-statistics.

and transmission networks, regulated auctions, legal frameworks and, above all, the availability of financial resources to guarantee the implementation of the necessary infrastructures for the adequate expansion and resilience of the SEB in the short, medium and long term.

6 CONSOLIDATION OF DISCUSSIONS AND RESULTS

The contextualization and in-depth understanding of Law No. 14,182/2021, specifically the amendment that determines the obligation to contract NG-fired TPPs through regulated auctions, added to the analysis of the specialized literature, allows us to determine that, as follows.

1) The compulsory contracting of NG-fired TPPs leaves both the locational criteria and the economics of the projects in the background. When determining the contracting in specific regions, no account was taken of the existing infrastructure for transporting NG to the plants, which will possibly require the approval of more public resources for the construction of new gas pipelines and specific LNG terminals to serve them, without any regional planning to enable the use of this NG for other sectors of the economy as a substitute for other fuels.

2) There will be an increase in GHG emissions, as the inflexible operation of NG-fired TPPs for a period of at least 15 years will result in the emission of more than 300 $MtCO_{2e}$ or $20MtCO_{2e}$ per year. In comparative terms, in 2019, the entire Brazilian electricity generation sector emitted 53.4 $MtCO_{2e}$ (IEMA, 2020). This means that NG-fired TPPs alone have the potential to account for almost 40% of the annual GHG emissions of the entire SEB.

3) The SEB's climate resilience must be achieved by expanding electricity transmission networks, modernizing, and repowering existing HPPs and maintaining the growth of solar photovoltaic and wind generation. These are the most economical and have the largest annual deployment scale to meet the necessary pace of decarbonization in the electricity sector and potentially aid in the decarbonization of sectors such as transport and industry.[32]

4) The expansion of transmission and distribution networks and generation from renewable sources must respect biodiversity, protected territories and ensure the application of Convention No. 169 of the International

32. Due to the electrification of part of the fleet and the use of renewable fuels, and industrial, due to the electrification of production processes and the use of green hydrogen, for the new hydrogen production market and its subsequent use in other production processes in the steel industry. (E+ Energy Transition Institute, 2022; Agora Industry and Wuppertal Institute, 2023) ammonia and green fertilizer, among other semi-finished products and chemicals.

Labor Organization (ILO)[33] of which Brazil is a signatory, and which guarantees free, prior, and informed consultation with Indigenous peoples, traditional communities, and the individual affected by the implementation of these new infrastructures.

5) The installation of transmission networks involves altering the landscape of large continuous areas, ranging from tens to hundreds of kilometers. This change in land use also occurs in the implementation of solar photovoltaic and wind farms, which require deforestation of the area where the equipment will be installed and for the service areas. Therefore, in addition to considering the impacts of GHG emissions, air pollutants and pressure on water resources, it is necessary to provide transparency and consider other impacts on the country's socio-biodiversity.

Furthermore, the characteristics presented show that the discussions on electricity generation in Brazil are of a technical and economic nature and take little account of the fundamental aspect of one of the SDGs, access to clean, quality energy. Thus, based on the conceptual framework and the collection of data and information on the inclusion of NG-fired TPPs in the SEB, the implementation of this infrastructure is evaluated in terms of the three dimensions of energy efficiency and SDGs 7 and 13, as follows.

1) Time: although the TE to mitigate the effects of climate change requires rapid and robust action, the operation of fossil fuel TPPs lasts for the long term. In this case, the relative period for phasing out fossil fuels and achieving Brazil's potential decarbonization and sustainable development goals would be long.

2) Impetus: global actions and targets to reduce GHG emissions and decarbonize the global energy sector are part of the SEB's discussions. Extensive literature shows that the sector will be affected by these changes, negatively in relation to hydroelectricity and positively in relation to solar and wind sources. However, the limit on the implementation of new fossil-fired TPPs has not been compromised by the legislature, which included the requirements for NG-fired TPPs in the Eletrobras privatization law, compromising Brazil's participation in meeting the global decarbonization target.

3) Scale: the current TE has a global scale, covering all its levels. The NG phase-out in the SEB, on the other hand, has a sectoral scale, since it represents a sector of the Brazilian economy.

33. Available at: https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C169.

4) SDGs 7 and 13: the implementation of NG-fired TPPs makes both objectives unfeasible, since the implementation of the plants and their chain puts negative pressure on various natural resources in the air, land and water environments. They also reduce national mitigation actions to reduce the impacts of climate change.

7 CONCLUSION

By answering the two guiding questions: i) does the SEB need new NG TPPs? and ii) what are the impacts of implementing the new NG TPPs provided for in the Eletrobras privatization law? The conclusion is that, as follows.

1) The short-term outlook for the Brazilian electricity sector indicates a scenario of low growth in electricity demand, combined with a high reservoir level and exponential growth in the IC of renewable energy sources, with average energy generation higher than that generated by NG TPPs during the period of water scarcity between 2020-2021.

2) The current situation is ripe not only for reviewing the obligation to contract NG TPPs, but also for correcting actions to create artificial demands for the NG market, in a clear demonstration of Brazilian patrimonialism. However, despite criticism of Law No. 14,182/2021 from civil society and the federal government, so far there has been no political movement to reverse the contracting of NG TPPs.

3) NG-fired TPPs will cause negative systemic impacts, such as an increase in environmental impacts – GHG emissions and pressure on local water systems –; an increase in electricity tariffs; spillage of turbinable water from TPPs; economic inefficiency in the operation of the SIN; and the requirement for resources to set up NG transportation infrastructure in places without demand for other end uses.

Despite the advance of renewable sources in Brazil's electricity supply, the compulsory contracting of NG-fired TPPs will distance Brazil from meeting its climate target and the SDGs of the 2030 Agenda by jeopardizing SEB's potential to reduce GHG emissions.

Furthermore, this compulsory nature, a type of legal recourse, sets a precedent for the legislature to interfere in the planning and operation of the SEB, putting the public interest at the expense of the private interest of a tiny section of society with political influence.

Instead of hiring new thermal power plants, transmission lines should be extended and existing ones reinforced, thus allowing the expansion of the renewable park spread throughout the country.

Therefore, in view of all the data, information and indicators presented, the implementation of inflexible fossil TPPs is a contradiction in terms for Brazil's electricity grid and goes against the scientific evidence regarding the negative impacts of their operation.

As a recommendation for future work, we suggest further modeling, analysis and discussion of the role of the expansion of transmission network systems (transmission and gas pipelines), the readjustment of the distribution service, the insertion of new technologies on the supply and demand side, the role of hydroelectric plants in the operation and pricing of electricity, as well as the composition of sector charges. Coadhering in the discussions on a new SEB, a decarbonized SEB while maintaining security of supply and tariff modicity.

REFERENCES

ABREU NETTO, A. L., PEYERL, D.; JACOBI, P. R. Social acceptance and perceptions of energy transition technologies in Brazil. In: PEYERL, D.; RELVA, S. G.; SILVA, V.O. da (Ed.). **Energy transition in Brazil**. 1st ed. Switzerland: Springer Nature, 2023. p. 75-90. (The Latin American Studies Book Series). Retrieved from: https://doi.org/https://doi.org/10.1007/978-3-031-21033-4_5.

ABSOLAR – ASSOCIAÇÃO BRASILEIRA DE ENERGIA SOLAR FOTOVOLTAICA. **Estudo de inserção de tecnologia de armazenamento ao SIN**. São Paulo: Absolar, 2021.

AGORA INDUSTRY AND WUPPERTAL INSTITUTE. **15 insights on the global steel transformation**. Berlin: Agora Industry and Wuppertal Institute, 2023. Retrieved from: https://www.agora-energiewende.de/en/publications/15-insights-on-the-global-steel-transformation-1/.

ANEEL – AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA. **Primeiro semestre de 2023 tem crescimento de 5,1 GW na matriz elétrica brasileira**. [s.l.]: Aneel, 5 jul. 2023. Retrieved Aug. 28, 2023, from: https://www.gov.br/aneel/pt-br/assuntos/noticias/2023/primeiro-semestre-de-2023-tem-crescimento-de-5-1-gw-na-matriz-eletrica-brasileira#:~:text.

BAITELO, R. L. Ênfase nas termelétricas: risco para o bolso e para o meio ambiente. **Gazeta do Povo**, 22 jun. 2021. Retrieved from: https://www.gazetadopovo.com.br/opiniao/artigos/enfase-nas-termeletricas-risco-para-o-bolso-e-para-o-meio-ambiente/.

BERNAL, J. L. de O. **Modelo de integração de recursos energéticos com consideração de delimitadores de potenciais de recursos energéticos visando o plano preferencial do planejamento integrado de recursos**. 2018. Tese (Doutorado) – Escola Politécnica, Universidade de São Paulo, São Paulo, 2018. Retrieved from: https://doi.org/10.11606/T.3.2018.tde-22052018-140626.

BONALUMI, D. Considerations on CO2 and pollutants emissions of modern cars. In: ATI NATIONAL CONGRESS: ENERGY CONVERSION – RESEARCH, INNOVATION AND DEVELOPMENT FOR INDUSTRY AND TERRITORIES, 74., 2019, Modena, Italy. **Proceedings**… New York: AIP Publishing, 2019. Available at: https://doi.org/10.1063/1.5138757.

BORBA, P. C. S. et al. Enhancing drought resilience and energy security through complementing hydro by offshore wind power: the case of Brazil. **Energy Conversion and Management**, v. 277, p. 116616, 2023. Retrieved from: https://doi.org/10.1016/j.enconman.2022.116616.

BRAZIL. Lei nº 14.182, de 12 de julho de 2021. Dispõe sobre a desestatização da empresa Centrais Elétricas Brasileiras S.A. (Eletrobras); altera as Leis nºs 5.899, de 5 de julho de 1973, 9.991, de 24 de julho de 2000, 10.438, de 26 de abril de 2002, 10.848, de 15 de março de 2004, 13.182, de 3 de novembro de 2015, 13.203, de 8 de dezembro de 2015, 14.118, de 13 de janeiro de 2021, 9.648, de 27 de maio de 1998, e 9.074, de 7 de julho de 1995; e revoga dispositivos da Lei nº 3.890-A, de 25 de abril de 1961. **Diário Oficial da União**, Brasília, 13 jul. 2021. Retrieved from: https://www.planalto.gov.br/ccivil_03/_ato2019-2022/2021/Lei/L14182.htm.

_____. Ministério de Minas e Energia. **Boletim mensal acompanhamento da indústria de gás natural**. Brasília: MME, n. 190, 2022a. Retrieved from: https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/publicacoes-1/boletim-mensal-de-acompanhamento-da-industria-de-gas-natural/2022-2/12-boletim-de-acompanhamento-da-industria-de-gas-natural-dezembro-de-2022.pdf.

_____. Ministério de Minas e Energia. **Boletim mensal acompanhamento da indústria de gás natural**. Brasília: MME, n. 184, 2022b. Retrieved from: https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/publicacoes-1/boletim-mensal-de-acompanhamento-da-industria-de-gas-natural/2022-2/06-boletim-de-acompanhamento-da-industria-de-gas-natural-junho-de-2022.pdf.

BUGAJE, A.-A. B. et al. Rethinking the position of natural gas in a low-carbon energy transition. **Energy Research and Social Science**, v. 90, p. 102604, 2022. Retrieved from: https://doi.org/10.1016/j.erss.2022.102604.

CCEE – CÂMARA DE COMERCIALIZAÇÃO DE ENERGIA ELÉTRICA. **Mecanismo de Realocação de Energia**. São Paulo: CCEE, 2018. Retrieved from: https://www.ccee.org.br/ccee/documentos/CCEE_076159.

CIOTTA, M. et al. An overview of carbon capture and storage atlases around the world. **Environmental Geosciences**, v. 27, n. 1, p. 1-8, 2020. Retrieved from: https://doi.org/10.1306/eg.10221919015.

CLIMAINFO. **Vulnerabilidade do setor elétrico brasileiro frente à crise climática global e propostas de adaptação**. São Paulo: ClimaInfo; Coalizão Energia Limpa, 2023. (Sumário Executivo). Retrieved from: https://climainfo.org.br/wp-content/uploads/2023/05/SumarioExecutivo_RelatorioCoalizaoEnergiaLimpa-1.pdf.

COSTA, J. Popular energy transition, from and for the people. In: ARÉVALO, T. R. (Ed.). **Sociedade e energia**: construindo a transição energética de e para as pessoas e comunidades – casos: Brasil, Peru e Bolívia. 1. ed. São Leopoldo: Casa Leira, 2022. p. 228. Retrieved from: https://fmclimaticas.org.br/wp-content/uploads/2022/07/Livro-SOCIEDADE-E-ENERGIA.pdf.

CUNNINGHAM, N. Gas demand could peak sooner than thought, research shows. **Gas Outlook**, Aug. 13, 2023. Retrieved Aug. 15, 2023, from: https://gasoutlook.com/analysis/gas-demand-could-peak-sooner-than-thought-research-shows/.

E+ ENERGY TRANSITION INSTITUTE. **Scoping paper on the Brazilian decarbonization**: steel industry. Rio de Janeiro: E+ Energy Transition, 2022. Retrieved from: https://emaisenergia.org/wp-content/uploads/2022/09/EDecarbonization_Steel_Industry.pdf.

EPE – EMPRESA DE PESQUISA ENERGÉTICA. **Plano Nacional de Energia 2050**. Rio de Janeiro: EPE, 2021.

_____. **Plano Decenal de Expansão de Energia 2031**. Rio de Janeiro: EPE; MME, 2022. Retrieved from: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/Documents/PDE 2031_RevisaoPosCP_rvFinal_v2.pdf.

_____. **Estudos do Plano Decenal de Expansão de Energia 2032**: energia e meio ambiente. Rio de Janeiro: EPE; MME, 2023. Retrieved from: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-689/topico-640/Caderno%20Energia%20e%20Meio%20Ambiente%20-%20PDE%202032.pdf.

FAORO, R. **Os donos do poder**: formação do patronato político brasileiro. 10. ed. São Paulo: Globo; Publifolha, 1958. v. 2.

FERREIRA, A. L. et al. **Sistemas fotovoltaicos na Amazônia Legal**: avaliação e proposição de políticas públicas de universalização de energia elétrica e logística reversa. São Paulo: Iema, 2023. Retrieved from: https://energiaeambiente.org.br/wp-content/uploads/2023/04/IEMA_UniversalizacaoAmazonia20230427.pdf.

GALVÃO, M. D. **Inclusão da análise da dimensão política no planejamento do setor elétrico**. 2015. Dissertação (Mestrado) – Escola Politécnica, Universidade de São Paulo, São Paulo, 2015. Retrieved from: https://doi.org/10.11606/D.3.2016.tde-15072016-163341.

GIZ – DEUTSCHE GESELLSCHAFT FÜR INTERNATIONALE ZUSAMMENARBEIT. **Sistemas energéticos do futuro**: integração de fontes variáveis de energia renovável na matriz energética do Brasil. Brasília: GIZ; MME; EPE; ONS, 2019.

GRIMONI, J. A. B. et al. **Iniciação a conceitos de sistemas energéticos para o desenvolvimento limpo**. 2. ed. São Paulo: Edusp, 2015.

IDEC – INSTITUTO BRASILEIRO DE DEFESA DO CONSUMIDOR. **Assessment of the impact on electricity consumers of provisions that are not related to the main purpose of the Eletrobras capitalization law**. São Paulo: Idec, 2022.

IEA – INTERNATIONAL ENERGY AGENCY. **Net zero by 2050**: a roadmap for the global energy sector. 3rd ed. Paris: IEA, 2021. p. 70. Retrieved from: https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf.

_____. **Net zero roadmap**: a global pathway to keep the 1.5 °C goal in reach – 2023 update. Paris: IEA, 2023. Retrieved from: https://iea.blob.core.windows.net/assets/9a698da4-4002-4e53-8ef3-631d8971bf84/NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach-2023Update.pdf.

IEMA – INSTITUTO DE ENERGIA E MEIO AMBIENTE. **As emissões brasileiras de gases de efeito estufa nos setores de energia e processo industriais em 2019**. [s.l.]: IEMA, 1 dez. 2020. Retrieved Aug. 20, 2023, from: https://energiaeambiente.org.br/as-emissoes-brasileiras-de-gases-de-efeito-estufa-nos-setores-de-energia-e-de-processos-industriais-em-2019-20201201.

_____. **Análise prévia do Leilão de Energia Nova (LEN) A-5, de 30 de setembro de 2021**. 2. ed. São Paulo: Iema, 2021. (Boletim Leilão de Energia Elétrica). Retrieved from: https://energiaeambiente.org.br/wp-content/uploads/2021/10/boletim-energia-iema-set-2021-2.pdf.

_____. **Análise prévia do Leilão para Contratação de Potência Elétrica e de Energia Associada, de 30 de setembro de 2022**. 4. ed. São Paulo: Iema, 2022a. (Boletim Leilão de Energia Elétrica). Retrieved from: http://energiaeambiente.org.br/produto/analise-previa-do-leilao-para-contratacao-de-potencia-eletrica-e-de-energia-associada-de-30-de-setembro-de-2022.

_____. **Termelétricas contratadas no leilão de energia referente à privatização da Eletrobras devem gerar aumento de emissões no estado do Amazonas**. [s.l.]: IEMA, 30 set. 2022b. Retrieved Aug. 20, 2023, from: https://energiaeambiente.org.br/termeletricas-contratadas-no-leilao-de-energia-referente-a-privatizacao-da-eletrobras-devem-gerar-67-de-aumento-de-emissoes-do-setor-eletrico-do-amazonas-20220930.

JONG, P de et al. Estimating the impact of climate change on wind and solar energy in Brazil using a South American regional climate model. **Renewable Energy**, v. 141, p. 390-401, 2019. Retrieved from: https://doi.org/10.1016/j.renene.2019.03.086.

LIM, J.-U.; JIANG, J. N. Bibliography review on applications of correlation analysis in power system operation and planning. **European Transactions on Electrical Power**, v. 20, n. 2, p. 114-122, 2010. Retrieved from: https://doi.org/https://doi.org/10.1002/etep.294.

LUCENA, A. F. P. et al. The vulnerability of renewable energy to climate change in Brazil. **Energy Policy**, v. 37, n. 3, p. 879-889, 2009. Retrieved from: https://doi.org/10.1016/j.enpol.2008.10.029.

LUCENA, A. F. P. et al. Interactions between climate change mitigation and adaptation: the case of hydropower in Brazil. **Energy**, v. 164, p. 1161-1177, 2018. Retrieved from: https://doi.org/10.1016/j.energy.2018.09.005.

PELISSARI, M. R.; RELVA, S. G.; PEYERL, D. Possibilities for Carbon Capture, Utilization, and Storage in Brazil. In: PEYERL, D.; RELVA, S. G.; SILVA, V. O. da (Ed.). **Energy transition in Brazil**. 1st ed. Switzerland: Springer Nature, 2023. p. 141-157. Retrieved from: https://doi.org/10.1007/978-3-031-21033-4_9.

PEREIRA, E. B. et al. The impacts of global climate changes on the wind power density in Brazil. **Renewable Energy**, 49, p. 107-110, 2013. Available at: https://doi.org/10.1016/j.renene.2012.01.053.

PEYERL, D.; RELVA, S. G.; SILVA, V. O. da. Introdução aos aspectos teóricos-conceituais da transição energética. In: PEYERL, D.; MASCARENHAS, K. L.; SANTOS, E. M. dos (Ed.). **Transição energética, percepção social e governança**. 1. ed. Rio de Janeiro: Synergia, 2022. p. 21. Retrieved from: https://www.researchgate.net/publication/369625549.

PSR. **Energy Report**. Rio de Janeiro: PSR, n. 197, 2023.

RELVA, S. G. **Mapeamento energoambiental**: modelo de apoio ao planejamento eletroenergético no contexto do planejamento integrado de recursos energéticos. 2022. Tese (Doutorado) – Escola Politécnica, Universidade de São Paulo, São Paulo, 2022. Retrieved from: https://doi.org/10.11606/T.3.2022.tde-22032023-085909.

RELVA, S. G. et al. Enhancing developing countries' transition to a low-carbon electricity sector. **Energy**, v. 220, p. 119659, 2021. Retrieved from: https://doi.org/10.1016/j.energy.2020.119659.

ROVERE, E. L. la et al. Climate change mitigation actions in Brazil. **Climate and Development**, v. 6, n. 1, p. 25-33, 2014. Retrieved from: https://doi.org/10.1080/17565529.2013.812952.

SANTOS, A. A. dos et al. Democracy and energy justice: a look at the Brazilian electricity sector. In: PEYERL, D.; RELVA, S. G.; SILVA, V. O. da (Ed.). **Energy transition in Brazil**. 1st ed. Switzerland: Springer, 2023. p. 57-73. Retrieved from: https://doi.org/10.1007/978-3-031-21033-4_4.

SCHAFFARTZIK, A.; BRAD, A.; PICHLER, M. A world away and close to home: the multi-scalar "making of" Indonesia's energy landscape. **Energy Policy**, v. 109, p. 817-824, 2017. Retrieved from: https://doi.org/10.1016/j.enpol.2017.06.045.

SILVA, V. O. da. **Como inserir recursos energéticos importados no planejamento energético nacional?** Modelo de determinação de recursos energéticos para integração energética transnacional. 2022. Tese (Doutorado) – Escola Politécnica, Universidade de São Paulo, São Paulo, 2022. Retrieved from: https://doi.org/10.11606/T.3.2022.tde-19012023-091237.

SILVA, V. O. da et al. Desafíos e incertidumbres del desarrollo sostenible en la planificación de la energía eléctrica: um enfoque brasileño. **enerLAC**: Revista de Energía de Latinoamérica y el Caribe, v. 5, n. 1, p. 50-75, 2021. Retrieved from: http://enerlac.olade.org/index.php/ENERLAC/article/view/152.

SOVACOOL, B. K. How long will it take? Conceptualizing the temporal dynamics of energy transitions. **Energy Research and Social Science**, v. 13, p. 202-215, 2016. Retrieved from: https://doi.org/10.1016/j.erss.2015.12.020.

UDAETA, M. E. M. **Novos instrumentos de planejamento energético e o desenvolvimento sustentável**: planejamento integrado de recursos energéticos na USP. 2012. Tese (Livre-Docência) – Escola Politécnica, Universidade de São Paulo, São Paulo, 2012. Retrieved from: https://doi.org/10.11606/T.3.2014.tde-05052014-125907.

WERLANG, A. et al. Reliability metrics for generation planning and the role of regulation in the energy transition: case studies of Brazil and Mexico. **Energies**, v. 14, n. 21, p. 7428, 2021. Retrieved from: https://doi.org/10.3390/en14217428.