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The crisis in the supply and distribution of electricity in Brazil in 2001: a panoramic analysis focusing on the prevention of future analogous events

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Abstract

Objective: By way of preventing future crises in the Brazilian electric sector, this study aimed to analyze, in detail, the strategies adopted by the Brazilian government to mitigate the crisis in the supply and distribution of electricity that occurred in the country in 2001.

Methodology: Case study, with a qualitative, exploratory, and descriptive approach, based on the review of arbitrated scientific manuscripts and technical reports correlated to the planning of the electricity sector in Brazil.

Originality/Relevance: In general, studies focused on understanding the crisis in the electricity sector in Brazil in 2001 collate analyses under the technical-economics aspect; the present work, however, considers, in addition to this aspect, public policy theories.

Results: The involvement of multiple interlocutors in the context of developing strategies focused on combating the crisis in focus could have made the measures adopted more effective; likewise, the reduction in electrical demand, especially during peak hours, is a unique opportunity to provide greater operational security to the electrical system and contributes to its expansion taking place under robust and sustainable bases.

Theoretical contributions: This study contributes to public policy management, particularly in terms of promoting sustainability in terms of the supply and distribution of electricity in Brazil.

Social contributions: There are subsidies for elaborating and implementing policies that make it possible to reduce the values of the electricity bill to the Brazilian population, which tends to be particularly relevant in the sense of mitigating poverty in the country.

Keywords: Brazilian electricity sector. 2001 crisis. Energy planning. Conjunctural and structural vulnerabilities.

A crise no fornecimento e distribuição de energia elétrica no Brasil em 2001: Uma análise panorâmica com foco na prevenção de eventos análogos futuros

Resumo

Objetivo: À guisa de prevenir futuras crises no setor elétrico brasileiro, objetivou-se, no presente estudo, analisar, de modo pormenorizado, as estratégias adotadas pelo governo brasileiro para mitigar a crise de fornecimento e distribuição de energia elétrica ocorrida no país, em 2001.
Metodologia: Estudo de caso, com abordagem qualitativa, exploratória e descritiva, baseado na revisão de manuscritos científicos arbitrados e de relatórios técnicos correlacionáveis ao planejamento do setor de energia elétrica no Brasil
Originalidade/Relevância: Em geral, estudos focados na compreensão da crise do setor de energia elétrica no Brasil em 2001 cotejam, centralmente, análises sob o viés técnico-econômico; o presente trabalho, porém, considera, além deste viés, teorias das políticas públicas.
Resultados: O envolvimento de múltiplos interlocutores no contexto de elaboração de estratégias focadas no combate à crise em foco poderiam ter conferido maior eficácia às medidas adotada; outrossim, a redução da demanda elétrica, em especial nos horários de pico, constitui oportunidade ímpar de se conferir maior segurança operacional ao sistema elétrico, além de contribuir para que a sua expansão ocorra sob bases robustas e sustentáveis.
Contribuições teóricas: Este estudo contribui para a área de gestão de políticas públicas, em particular no que tange à promoção da sustentabilidade no que tange ao fornecimento e à distribuição de energia elétrica no Brasil.
Contribuições sociais: Há, no presente estudo, subsídios para a elaboração e implementação de políticas que viabilizem redução nos valores da conta de eletricidade à população brasileira, o que tende a ser particularmente relevante no sentido de mitigar a pobreza no país.

Palavras-chave: Setor elétrico brasileiro. Crise de 2001. Planejamento energético. Vulnerabilidades. Sustentabilidade.

La crisis del suministro y distribución de energía eléctrica en Brasil en 2001: un análisis panorámico centrado en la prevención de futuros eventos análogos

Resumen

Objetivo: A modo de prevención de crisis futuras en el sector eléctrico brasileño, el objetivo de este estudio fue analizar, en detalle, las estrategias adoptadas por el gobierno brasileño para mitigar la crisis en el suministro y distribución de energía eléctrica ocurrida en el país, en 2001.
Metodología: Estudio de caso, con enfoque cualitativo, exploratorio y descriptivo, basado en la revisión de manuscritos científicos arbitrados e informes técnicos correlacionados con la planificación del sector eléctrico en Brasil.
Pertinencia: En general, los estudios enfocados en comprender la crisis del sector eléctrico en Brasil en 2001, cotejan análisis bajo el sesgo técnico-económico; el presente trabajo considera, además de este sesgo, teorías de política pública.
Resultados: La participación de múltiples interlocutores en el contexto del desarrollo de estrategias enfocadas a combatir la crisis en foco podría haber hecho más efectivas las medidas adoptadas; la reducción de la demanda eléctrica, especialmente en horas punta, es una oportunidad para brindar mayor seguridad operativa al sistema eléctrico y contribuye a que su expansión se lleve a cabo bajo bases robustas y sostenibles.
Aportes teóricos: Este estudio contribuye al área de gestión de políticas públicas, particularmente en términos de promoción de la sostenibilidad en términos del suministro y distribución de energía eléctrica en Brasil.
Aportes sociales: Existen subsidios para la elaboración e implementación de políticas que permitan reducir los valores de la factura eléctrica, lo que tiende a ser particularmente relevante en el sentido de mitigar la pobreza en el país.

Palabras clave: Sector eléctrico brasileño. Crisis de 2001. Planificación energética. Vulnerabilidades. Sostenibilidad.

1 Introduction

The Brazilian electricity matrix has hydroelectric plants as the primary source of generation; this is due to the country's characteristics, such as high availability of water resources and a topography that is favorable to waterfalls (Castro et al., 2010; Goldemberg & Prado, 2003). According to data from the Brazilian Association of Small Hydroelectric Plants (PCHs) and Hydroelectric Generating Plants (CGHs), ABRAPCH, the Brazilian electricity matrix, is basically composed of hydroelectric plants (which generated, in 2019, about 62.4% of the electricity consumed in Brazil) represented by 704 large and 425 small hydroelectric plants (ABRAPCH, 2021).

However, this significant dependence on hydroelectric plants reduces the energy security of the electricity matrix and may harm the supply of electricity in events of sudden climate change, as it has occurred during the drought period in 2001 and 2002 and, more recently, between the years 2011 and 2013 (Aquila et al., 2017). Nevertheless, among these crises experienced by the Brazilian society, the one that occurred in 2001 was marked as the one that caused the most extensive rationing system in the recent history of the Brazilian electricity sector to be implemented.

Although evidence indicating an imbalance between electricity supply and demand had been identified a few years before the outbreak of the crisis in the electricity sector (Araújo, 2001; Goldemberg & Prado, 2003; Kelman, 2001), the Federal Government was not able to implement the necessary measures to avoid what at the time was called "blackout"[1].

Given the tendency of the availability of energy for consumption in the national electricity sector to be strongly correlated with hydroelectricity, which under normal conditions can supply the demand. However, in a scenario of abrupt climate changes may suffer volatility in its generation capacity, corroborating the instability of the electricity sector and affecting the country's economic and social development. In such context, the analysis of energy planning can be considered of utmost importance within the federal government's agenda to guarantee energy sovereignty and maintain sustained growth (Simões e Rovere, 2008; Vilar et al., 2020).

Thus, this work proposes an analysis of the process that culminated in the establishment of the crisis in the electricity sector and the solutions adopted by government institutions related to energy planning to mitigate the conflicts arising from this collapse.

Based on the constructed scenario, alternative ways of interpreting the problem are discussed, ones that could have enabled the formulation of a more inclusive agenda, capable of encompassing a set of solutions that would subsidize more adequate responses to the

[1] The term "blackout" (in Portuguese "*apagão*") is, despite being widely used, imprecise, insofar as there were, in fact, no untimely interruptions in the supply of electricity due to the low volume of reservoirs in 2001. More precisely, the rationing occurred due to the need to reduce electricity consumption established by the Government. This, however, did not mean abrupt interruptions in electricity generation. In this context, it appears that, from a practical point of view, the purpose of the rationing imposed on the Brazilian people was precisely to prevent the installation of such a scenario.

electric crisis foreseen by different actors inside the federal government (Kelman, 2001). It is hoped that, based on these findings, it becomes feasible to contribute to avoiding or alleviating possible future crises that may arise in the electricity sector.

Thus, this article is composed of 4 sections in addition to this Introduction. Section 2 identifies and analyzes the precedents and consequences inherent to the 2001 electricity sector crisis. Section 3 presents the agenda-setting process, in which context the public policies aimed at coping with the crisis were created - seeking to identify factors that contributed to the ineffectiveness of such policies. Then, in Section 4, alternative approaches to crisis management that could have resulted in more appropriate responses are discussed. In Section 5, finally, the conclusions are presented and commented.

2 The crisis in the supply and distribution of electricity in Brazil in 2001

Although the 2001 electricity supply crisis is a central part of the development of this work, the technical elements that contributed to its installation only constitute a background for the analysis of the formulation process of the problem in response to which the public policies discussed in this work were conceived. Therefore, it is not the objective of the present study to deepen the discussion on the reasons for its constitution or the responsibility that the institutions or government agents had in the process. Analyzes focused on these themes have already been extensively developed in other works, such as those conducted by Araújo (2001), Bastos (2011), Filho et. al (2002), França (2007), Goldemberg and Prado (2003), Kelman (2001), Pires, Giambiagi and Sales (2002), Sauer et al. (2003), Souza and Soares (2007), and Tolmasquim (2000).

2.1 Background

The genesis of the 2001 electricity crisis dates back to the 1990s, a period in which the government, in the context prevailing at the time of internationalization of the State and the advance of neoliberal policies, promoted a series of reforms in the Brazilian electricity sector. Four main measures summarize the structural changes intended to promote the sector at the time: (i) de-verticalization of its organizational structure, which became composed of four independent activities, namely: generation, transmission (both monopolists), distribution, and commercialization (both non-monopolists); (ii) increase in the participation of private companies through the implementation of a policy of privatization of assets and stimulus to invest in new projects; (iii) incentive of competition in the generation and commercialization sectors, resulting in increased efficiency and price reduction, and (iv) promotion of free access to transmission and distribution networks (Filho et al. 2002; Goldemberg & Prado, 2003; Sauer et al., 2003). França (2007) provides an accurate account of the political context within which

the electricity sector reform was conducted. Economically, at the time, Brazil was undergoing a process of economic restructuring, characterized by a rigid policy of fiscal adjustment and inflation control, and the main objective was to facilitate access to external financing, especially from the International Monetary Fund (IMF). As a result, investments by state-owned companies, which would be accounted for as federal government expenditures in the public account, were restrained (Tolmasquim, 2000; Pires et al., 2001).

Therefore, the loss of state leadership by Eletrobrás, responsible for concentrating all the strategic planning and operation of the electric sector until the beginning of the period in which its reform began, caused the failure of coordination between the new agents that were responsible for the sector, and the difficulty of developing a reliable free market. This led to poor governance of the Brazilian electricity system and, according to Goldemberg and Prado (2003), this situation contributed to the genesis of a “brainless system”.

Thus, as a result of the process of opening to private capital, investments aimed at expanding the electric generation and transmission sectors (admittedly capital-intensive) did not follow the intense growth in demand for electricity at the time the aforementioned restructuring was implemented (Souza & Soares, 2007; Tolmasquim, 2000). Leme (2009) (2016) highlights that the contribution of private resources for investments did not occur the way it should have, being insufficient instead.

During the 1990s, for example, the average annual growth rate of electricity consumption, equivalent to 4.1%, proved to be much higher than the Gross Domestic Product (GDP), equivalent to 2.6% (Pires et al., 2001). However, this inadequate rhythm of expansion of the hydroelectric system, responsible for the generation of 87% of the electricity used in Brazil in 2000 (EPE, 2016a), culminated in the gradual depletion of the levels of the reservoirs located in the Southeast/Midwest subsystem, which were responsible for about 70% of the country's total storage capacity at the time (Falcetta, 2015). Evidence of a probable electricity supply crisis had been picked up by different agents in the sector: the Ministry of Mines and Energy (MME), the National Electric Energy Agency (Aneel), and the National System Operator (ONS).

In as early as 1997 (Goldemberg & Prado, 2003), the federal government did not act to reverse the situation observed at the time. Reinforcing this analysis and contributing to an understanding of the lack of energy planning, in 2001, it was found that at the end of the rainy season, the reservoirs located in the Southeast region were at less than 34% of their total storage capacity, an insufficient amount for meeting the electrical demand expected in the drought season to come (Sauer et al., 2003). This made it possible to highlight the technical impossibilities resulting from underinvestments in high voltage transmission line systems that could take advantage of the electrical surplus available in other regions, such as the South Region where there was water abundance due to the different rainfall volume (Souza &

Soares, 2007; Tolmasquim, 2000). Faced with the high risk of not meeting the electricity demand in the country, the government was forced to adopt emergency containment measures, more specifically the obligation to reduce electricity consumption by 20% for all sectors of the economy, an action that characterized the rationing.

Therefore, two pieces of evidence stand out that illustrate the imbalance between electricity supply and demand that occurred at the time: (i) annual electricity consumption grew, on average, 0.8% more than supply between 1991 and 2000 (Sauer et al., 2003), and (ii) the average amount invested in the electricity sector in the 1990s corresponded to half of the amount invested in the previous decade (Souza & Soares, 2007).

2.2 Adopted measures and their consequences

As mentioned before, the gradual deterioration of the reservoir levels in the country's main hydroelectric plants was already a phenomenon recognized by the government since, at least, the year 1999. Given the not only real, but probable, perspective of inability to meet the electric demand in a short-term scenario, the Ministry of Mines and Energy (MME) sought to implement three measures aimed, basically, at minimizing the negative effects of the electric energy deficit, and increasing electric generation in the country: (i) contracting emergency generation (especially from thermal plants located on barges, and generators that could be rented); (ii) creating the Thermoelectric Priority Program (PPT), aiming at encouraging the construction of thermoelectric plants, mainly using natural gas transported by the recently inaugurated Brazil-Bolivia Gas Pipeline, based on the guarantee of financial and economic conditions; and (iii) holding “Capacity Auctions” to contract additional thermal capacity (Barros, 2005; Brasil, 2000; Kelman, 2001).

Despite these efforts, none of the adopted measures had the expected outcome within the planned deadline (Kelman, 2001). Regarding emergency generation, differences in interpretation between Eletrobrás and ANEEL on how the costs arising from the program would be equated ended up creating an impasse that prevented its execution (Kelman, 2001). The PPT, similarly, was also hampered by the lack of interest from the private sector in investing in this type of asset, and by the lack of understanding between the different actors involved in its execution (Ministry of Finance, MME, ANEEL, and Petrobras, in particular) about the form of compensation for the increase in costs arising from the importation of natural gas due to exchange rate variations (Barros, 2005; Kelman, 2001). Finally, the “Capacity Auctions” were not even carried out due to the impasse caused by the delay in the start of generation at the Angra II plant, which resulted in the stoppage of the Wholesale Energy Market (MAE) (ANEEL, 2001; Kelman, 2001; Magalhães & Parente, 2009).

Thus, by analyzing the implementation process of the three measures, it is clear that, more than technical obstacles, the lack of clear attributions for the different agents of the electric sector resulted in a picture of institutional paralysis that prevented the adequate treatment of the scenario installed in the electricity sector. In fact, Goldemberg and Prado (2003) state that the divergence of opinions and purposes among government entities, without the central coordination of Eletrobrás, culminated in the failure of these measures.

Faced with the failure of initiatives to mitigate the mismatch between electricity supply and demand, in May 2001, through Provisional Measure No 2.147, the Electric Energy Crisis Management Chamber (GCE) was instituted, and its main goal was (Brasil, 2001): “to propose and implement measures of an emergency nature to match the demand and supply of electricity, in order to avoid untimely or unforeseen interruptions in the supply of electricity”.

This measure was successful for engaging in a single effort, coordinating the various government agents involved, directly or indirectly, in the crisis: MME, Ministry of Finance, Ministry of Planning, Attorney General of the Union, ANEEL, ONS, National Bank for Social and Economic Development (BNDES) and Eletrobrás. This way, it was possible to bypass the precarious institutional dialogue mentioned above (Pires, Giambiagi, and Sales, 2002). The first measure adopted by the GCE was the imposition of rationing onto society, and it has marked the period characterized, (imprecisely, as previously pointed out), as “blackout”. Between June 2001 and February 2002, residential and commercial consumers had to reduce electricity consumption by 20%; for the industrial sector, this number varied between 20% and 25% (EPE, 2007; Pires et al., 2002). Three additional measures, two of them aimed at increasing electric generation (like the initiatives that marked the “pre-rationing” phase of the crisis), and one focused on the search for structural solutions for the electric sector, were also adopted, successfully this time. Information on the mechanisms through which these measures were implemented and precise data on their effect on the electricity sector can be accessed in Pires et al. (2002).

3 Government actions from the perspective of public policy theories

According to Kingdon (2011), the process of formulating a public policy is composed of four main steps: 1) establishment of an agenda; 2) identification of solutions to deal with the issue that motivated the establishment of the agenda; 3) selection of the solution(s) considered most appropriate amongst those identified in the previous step; and, finally, 4) the implementation of the selected solution(s). The goals of the present work, interpreted from this systematization, relate to the three initial phases of the described process. In order to assign the breadth normally required by the discussion we intend to promote, it was deemed appropriate to also look at what would be the first phase in the formulation of the public policies discussed, that is, the establishment of the governmental agenda related to the Electric Crisis of 2001, and not just the phases directly related to the solutions deemed appropriate by the government (exposed in Item 2.2). The last phase, referring to the analysis of the implementation process of these solutions in the period that preceded the rationing and the justifications for their failure, is beyond the scope of this work. Detailed information on these topics can be found in Kelman (2001), Pires, Giambiagi, and Sales (2002), and Sauer *et al.* (2003).

The final report of the Commission of Analysis of the Hydrothermal Electric Energy System, which was instituted by a presidential decree in May 2001, precisely summarizes the main conclusions of the works focused on the electricity sector crisis mentioned above, by characterizing it as an "imbalance between energy supply and demand" in Brazil (Kelman, 2001). Although the question, posed in this way, prompts actions aimed both at increasing electricity generation and at reducing consumption, none of the measures that preceded the imposition of rationing was focused, as indicated in the previous section, in the second option. Rationing itself, the only measure to control electricity demand discussed and implemented by the Government during the crisis, only came to be seen as an option when an emergency context, characterized by the failure of previously adopted measures aimed at the expansion of generation, was installed. Therefore, in practice, it would be more realistic to characterize the agenda established at the time, given the strategy adopted by energy planners, as an insufficient expansion of electricity supply rather than an imbalance between electricity supply and demand. At first, this discussion may seem to cover a purely semantic issue. However, the way in which objective elements, such as those that, as discussed in the previous section, impacted the expansion of electricity generation in the years prior to the onset of the crisis under analysis, are translated and guide a political agenda can decisively impact the search for solutions to the problem represented by it. It should also be noted that the Commission of Analysis of the Hydrothermal Electric Energy System aimed to "evaluate, within sixty days, the energy production policy and identify the structural and circumstantial causes of the imbalance between the demand and supply of energy" (Kelman, 2001).

In the context of the 2001 electricity sector crisis, all these objective elements were associated with the supply of electricity (e.g., insufficient investment in generation, delays in the construction of hydroelectric plants and transmission lines, etc.), and were detected, as expected, by the governmental institutions belonging to the electric sector expansion planning nucleus (MME, ANEEL, ONS, Eletrobrás). These same agents were consequently the ones who guided the establishment of the crisis agenda with the federal government. It seems reasonable, therefore, that the solutions proposed as a response to the problems identified, elaborated, and selected by the same institutions that carried out the previous stages of this process, were limited to the context of their performance. From the perspective of the defense coalitions model, as theorized by Sabatier and Jenkins-Smith (1999), it is observed that the process of mitigating the 2001 crisis was conducted by a group composed of institutions belonging only to the electricity sector, living out a discussion about different strategies, whether conflicting or complementary. On the one hand, this uniqueness, associated with the endogenous character of the decision-making process, allowed public policies considered necessary for reversing the crisis to be taken quickly[2].

On the other hand, the absence of coalitions defending different interests may have made the debate focused on the search for solutions to the crisis less diverse in terms of potentially applicable public policy options and, therefore, excessively dependent on the success of those indicated by the electricity sector. As analyzed throughout Section 2, the 2001 rationing was imposed on society precisely due to the failure of previously adopted public policies and unilateral governance processes. The proposition, and eventual adoption, of multiple strategies to combat the crisis, resulting from the involvement of different coalitions

[2] The failure of the measures identified as adequate for mitigating the crisis in the electricity sector, discussed in Section 2, is mainly attributed to the lack of coordination between the institutions that make up the planning nucleus of the electricity sector. There are no indications that delays in the implementation of certain measures contributed to the worsening of the crisis.

with the established agenda, could have made the response given by the government to the signs of stagnation in the electricity supply verified in 1999 much more effective. As will be discussed in Section 4, some of the measures that could have been adopted were complementary and non-conflicting to those that were, in fact, implemented.

As pointed out by França (2007), referring to electricity supply failures occurring at the time, no events related to the electricity sector led to coordinated public demonstrations, indicating that if the government did not avoid it, they, at least, did not promote a public debate about the reasons behind the gradual deterioration of conditions in the electricity sector and the measures required to reverse that situation. This dialogue, as evidenced now, was restricted to governmental institutions directly associated with the planning for electric generation expansion in the country. An example of a complementary action focused on reducing electricity demand, rather than expanding its supply, is discussed in the next section. It is not intended to end the debate on the list of measures that could have been adopted, but to offer indications that the involvement of different sectors of society could have increased the chances of successful reversal or mitigation of the crisis, as previously argued.

4 Complementary public policies

The replacement of incandescent light bulbs with compact fluorescent bulbs was, along with the change in personal habits related to electric consumption, the most forceful measure to reduce electricity use adopted by residential consumers after the beginning of rationing imposed on society in the wake of the 2001 electricity crisis (Bastos, 2011). The fact that these two technologies share the same electrical installation infrastructure (e.g., nozzles, wiring, etc.) allowed the transition between them to occur with ease despite the lack of planning[3].

> In addition to lighting, other energy end uses also represent relevant opportunities for reducing electricity consumption in the residential sector. This is the case, for example, with water heating. Since the 1960s and 1970s, a period in which Brazil experienced a situation of abundant electricity due to the strong growth of hydroelectric generation capacity, until today, electric showers have prevailed as the main water heating system in the country's residential sector (Martins, Abreu, & Pereira, 2012). The most recent data available on the subject indicates that approximately 75% of households in Brazil that heat water for bathing use these appliances, which account for a significant 24% of the electricity used in households (Johann et al., 2019)). It should also be noted that about 80% of Brazilian households have some water heating system for bathing in Brazil (Johann et al., 2019).

Unlike with lighting, the potential for reducing electrical consumption associated with water heating cannot be achieved by increasing the efficiency of electricity use, but by replacing it with another energy input. Thus, the energy efficiency of electric showers and gas

[3] Despite having contributed to numerous households reaching the established targets for reducing electrical consumption, the widespread use of fluorescent lamps, which are significantly more efficient than incandescent lamps, has had undesired impacts on the environment and on the electrical system itself, such as controlled mercury in inappropriate places and the generation of harmonic waves in the electrical network.

heaters corresponds to approximately 95% and 85%, respectively (Inmetro, 2016). However, the assessment of the global efficiency of water heating (here understood as the integrated efficiency of all the processes of conversion, transmission, distribution, and final use of a certain form of energy to provide this service), as proposed by Santos, Fagá and Santos (2013), indicates that, according to the local electrical matrix, gas heaters can present a much higher energy performance. In general terms, this understanding is associated with the fact that electricity generation processes, its subsequent transmission and distribution, and, finally, the final conversion of this energy vector into heat include significant efficiency losses that are avoided when a primary energy source is converted into heat directly at the point where it is demanded (for example, the burning of combustible gases to heat water). Furthermore, electric showers typically have high energy efficiency, close to the theoretically possible limit. However, the final use provided by them for water heating, analyzed from a systemic point of view and covering all related energy conversion processes (an unfortunately not very common practice in the context of energy policy planning), presents a certain intrinsic inefficiency, which is related to non-structural changes in the national electricity matrix. Such inefficiency, both in Brazil and in any other country, if effectively mitigated, tends to lead to universal access to electricity and, at the same time, a more rational consumption of natural resources (Farrel, 2011).

As thermal sources take up more space in an electrical matrix, electrothermia, the name given to the use of electricity to generate heat, tends to be, from the point of view of end uses efficiency, more harmful. While thermal power plants can generate electricity with a maximum efficiency of approximately 55% (in the case of combined cycle power plants), hydroelectric plants typically operate at an efficiency greater than 85%. In the case of Brazil, evidence indicates that the increase in generation capacity in the country in the coming years should occur mainly through the increase in thermal generation, especially from non-renewable fuels such as natural gas (NG) and uranium. The depletion of a large part of the environmentally and economically usable water potential and the gradual decrease in the capacity to store potential energy in reservoirs, resulting from the prioritization of the construction of run-of-river plants, are the main determining elements of this transition. Issues related to these types of plants, their impacts on the operation of the electrical system, and other determinants of the expansion of thermoelectric generation in Brazil have already been extensively discussed and can be accessed at IEA (2013), Castro, Brandão, and Dantas (2010), Nogueira et al. (2014) and Santos et al. (2013).

In this setting, the use of fuel gases (a term that, in the context of this work, designates natural gas and liquefied petroleum gas - LPG) for water heating represents not only a reduction in electrical consumption, but also significant gains in energy efficiency. In terms of access to these energy sources, if the natural gas distribution networks were still restricted to

some of the large urban centers in 1999, LPG was already widely disseminated in the country, being present in approximately 90% of households[4] (IBGE, 1999).

Since the infrastructure necessary to enable water heating from the combustion of combustible gases (gas networks, hot water networks, and the gas heater itself) is normally not available in households that use electricity for this purpose, replacing electric showers for gas heaters involves technical challenges significantly more complex than those related to replacing incandescent lamps with fluorescent ones. Such a measure, therefore, would require coordinated actions between a set of institutions from different areas (network installers, manufacturers and importers of heaters, equipment, and accessories) to be adopted on a national or, at least, regional scale. Despite this, the time interval between the detection of the first signs of the coming crisis and the establishment of rationing (more than two years, as discussed above), would have been long enough for a plan containing the strategies necessary to overcome or mitigate the barriers for the wide dissemination of residential water heating technologies based on combustible gases to be structured.

The potential for electricity conservation associated with this technology replacement is so significant that, in retrospect, it is surprising that no action aimed at this measure was carried out, or even suggested, at the time when other crisis mitigation measures were implemented, and electric rationing was debated and established. If we consider that the residential sector accounted for 22.6% of all electricity used in Brazil in 1999 (EPE, 2016a), and that the proportion of this electricity directed to water heating at the time was 24%, as pointed out by Eletrobrás (2007), it is observed that just over 5% of all electricity demand in Brazil, at the end of the 1990s, was originated by electric showers.

If the use of gas heaters for heating water had been encouraged when the first signs of crisis were identified, instead of after the failure of previous attempts, it could have contributed greatly to the elaboration of a more robust strategy to mitigate the risk of shortage, and with greater chances of success.

5 Discussing the signs of vulnerability observed within the electricity sector in the years 2014, 2015, and 2016

Despite its relative maturity since the implementation of the reforms that marked the end of the 1990s, there are still inherent weaknesses in the Brazilian electricity sector that could, eventually, cause new imbalances between electricity supply and demand. For representatives of financial capitalism, the delay in the environmental licensing of transmission line projects, for example, means an obstacle to the use of electricity generated in hydroelectric plants under construction in the Amazon Region; in turn, under a more preservationist and

[4] Most households without access to LPG (Liquefied Petroleum Gas) are located in the North Region, where water heating, due to the high average local temperature, is not characterized by relatively significant electricity consumption in households.

non-neoliberal view, it is precisely this “delay” that makes it possible to move towards sustainability and a more economically resilient model for the energy sector, even if under capitalism, albeit in a medium to long term (Lozornio et al., 2017; Werner, 2019). Furthermore, despite the prospect of increasing the share of thermal generation in the electricity matrix, hydraulic plants still account for a relevant share of electricity generation - more precisely 64% in 2015 (EPE, 2016b), which means that periods of low rainfall more severe than expected also pose potential threats to the balance between electricity supply and demand in the country. Based on this, it is perceived that the considerations present in this work should not be taken only as a belated reflection exercise on the 2001 electrical crisis, as they can inspire the adoption of mitigation strategies for possible analogous or similar situations in the future.

During 2014 and 2015, for example, the electrical system found itself at risk due to unexpectedly low levels of rainfall and delays in the construction of transmission lines. Again, doubts arose as to the ability of the electricity generation system to be able to adequately meet the demand of consumers connected to the grid. Although the country then had a broader and more well-structured thermoelectric park than the one existing at the beginning of the 2000s, the significantly low level of reservoirs in the main Brazilian hydroelectric plants, even lower than the levels observed during the 2001 crisis, caused the implementation of a new electricity rationing scheme to be considered probable, or even inevitable, by many professionals in the area (Abbud, 2014; Rochas, 2014). The fact that the Marginal Operating Cost (CMO) has exceeded the Deficit Cost at some points throughout the years 2014 and 2015 (Vilar et al., 2020) reinforces the understanding that the electricity sector went through an extremely unfavorable situation in the aforementioned biennium[5].

However, the electricity consumption of the National Interconnected System (SIN), observed in 2015, was about 2% lower than that of the previous year (EPE, 2016a). This reduction, associated with a general deceleration of economic activity, especially felt in the industrial sector (ONS, 2015), relieved the pressure on the system and contributed to making the measure unnecessary.

It is interesting to note that the main factors associated with the “near crisis” context of the electricity sector in 2014 and 2015 (i.e., water scarcity and insufficient electricity transmission capacity) are not different from those that, as already discussed in this work, contributed to the installation of the 2001 electricity sector crisis, among others. This means that, despite the seriousness of the situation observed then, the public agents directly involved in the selection of mitigation measures adopted by the government (MME, ONS, and ANEEL, in this case) were not able to develop mechanisms to avoid the exposure of the electricity

[5] The Deficit Cost represents, in general terms, what would be the cost for the economy in an eventual electricity rationing. From the point of view of the electric sector's operating model, there is an evident inconsistency in the fact that the cost of meeting the electric demand has exceeded the Deficit Cost of the electric system.

sector, around 15 years later, to the same factors that contributed to the onset of the crisis. These agents, it is worth remembering, are the same who have been planning the expansion of the electricity generation system since the sector reform in the 1990s.

The difficulty in avoiding events of imbalance between electricity supply and demand, or at least drastically reducing the chances of these events occurring, explains the challenges inherent to planning in the sector. While the process of making hydroelectric and thermoelectric projects feasible can take about ten and five years, respectively, between the planning and construction phases, electricity consumption, which is strongly influenced by the country's economic activity, is likely to present significant variations (both positive and negative) in annual cycles, as was evidenced in 2015. Thus, permanent measures aimed at reduction and efficiency of electricity consumption (e.g., ANEEL's Energy Efficiency Program - PEE) are relevant complementary tools for energy policy focused on the electric sector. These initiatives, however, can have their results expanded if they are developed from a broader, permeable, and inclusive approach (in the sense of aggregating contributions from all segments of the energy sector), one that allows an integrated analysis of the fulfillment of demands for end uses from different energy inputs. For example, actions focused on the most reprehensible electrical end uses from a thermodynamic point of view, such as electrothermia (i.e., the use of electricity for heating, as exemplified in Section 4) would not only contribute to the reduction of electricity consumption, but could increase the rationality of energy consumption in Brazil. However, the fragmented approach to energy policies in Brazil often prevents available resources from being directed to actions of this nature. The impossibility of promoting the replacement of electric showers with gas heaters using PEE resources, for example, adds to the unintended consequences of a partial view of the electrical issue.

This is why a strategy of energy planning that involves diversification of energy sources is extremely important. In this context, the Brazilian government, after the 2002 majority election, started a new cycle of restructuring the national industry that sought to circumvent these obstacles and expand the universalization of use and diversification of the energy matrix, as in the case of small hydroelectric plants, solar and wind. The introduction of these new forms of energy occurred, according to the analysis of De Melo et al. (2016), through the adoption of governance mechanisms and actors at different federal, state, and municipal levels, meaning in a more expanded, multilevel way, and with different instruments. In this sense, it can be seen that Brazil has advanced in energy diversification; however, these policies are not being carried out strategically to significantly incorporate other potentials in the composition of the energy matrix effectively. At the level of anticipated energy planning (as it should always be), both within the scope of the public sector and private sector, this energy diversification is analyzed in more detail only when water conditions are insufficient (Falcetta, 2015; Johann et al., 2017; Lozornio et al. 2017).

6 Conclusions

The analysis of the period before the 2001 electrical crisis and the solutions proposed by public institutions related to it suggest that the involvement of multiple interlocutors in the context of elaborating strategies focused on combating the crisis could have made the measures adopted more effective. This thesis is reinforced by the reoccurrence, in 2014 and 2015, of some of the factors that contributed to the 2001 crisis, as discussed in Section 5 of the present study. Furthermore, the complexity involved in the management of the electricity sector, evidenced throughout this work, justifies the need to engage actors from different segments of the energy market. And this, not only in the management of moments of crisis but also in planning actions for permanent mechanisms and ongoing operations that address the operational sustainability of the electricity sector from a long-term perspective. It is crucial to take into account that the electricity sector is considered a monopoly, with high verticalization of the production chain and low domain in the coordination of these links, which, in general, depending on how effective the plans are (strategic, energetic, and governmental, in particular), compromises the reliability of supply.

It must be considered, however, that there is no concrete evidence of actors in the fuel gases segment attempting to participate in the process of searching for solutions to the crisis. Borrowing concepts from the public policies branch of studies, the 2001 crisis can be characterized as a “window of opportunity” for the performance of the various segments of the energy sector that could have, in some way, contributed to its mitigation. Therefore, attention is drawn to the lack of protagonism of consolidated sectors (such as fuel gases), which, by proposing and eventually implementing solutions to the identified problem, could have expanded their operations in the market in which they operate. Future investigations exploring why these and other actors remained oblivious to events in the electricity segment could generate lessons related to strategies for involving different sectors representing society in similar situations.

For the paradigm shift discussed in this work (that is, the inclusion of a wide range of segments of the energy segment in the electric sector planning process) to become viable, traditional practices and concepts of this sector must be reassessed and, eventually, overcome. The promotion of broader participation, under the terms discussed herein, in the debate on issues related to the supply and demand for electricity in Brazil, both in the short, medium, and long term, may imply an eventual reduction in electricity consumption to the extent that the replacement of electricity by alternative forms of energy in certain end uses becomes part of the list of energy planning tools usually adopted; this tends to induce sustainability, especially if such alternative energy sources are renewable. Contrary to being interpreted solely as a burden for the electricity sector (due to loss of revenue), the possible

reduction in electricity demand, especially at peak times, constitutes a unique opportunity to provide greater operational security to the electricity system, mainly in the electricity transmission and distribution networks, and it contributes to their expansion taking place on robust and sustainable bases.

It is worth noting, therefore, that electric showers account for a relevant portion of residential consumption at peak hours, with an evident impact on the load curve of the national electrical system. Thus, it is important to adopt public policies that encourage the use of renewable technologies that are typically less dependent on the SIN, such as water heating using natural gas and based on solar energy.

The initiatives to bring segments that were previously peripheral to the electricity sector closer, however, are only justified if there are willingness and, more importantly, conditions, so that the responsibilities attributed to them are carried out. In the specific case of the energy transition discussed in this work, meaning the replacement of electricity by combustible gases for heating water, the broad market actions necessary for its viability (promoting the certification of the workforce and the availability of equipment and energy inputs themselves) impose challenges that can only be overcome if there is high cohesion and coordination between the main actors in the sector (government, natural gas distributors, heater manufacturers, and technical training centers, in particular).

Thereby, from the accomplishment of the present study, it was possible to identify some obstacles between planning and implementation. Thus, for future work, it is recommended that the governance structure and its instruments for the Brazilian electricity sector are closely looked at, seeking to correlate the concentration of decision-making power and its related conflicts of interest and their impacts on society in short and long terms.

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