Review of the current scenario of energy storage in Brazil

Emilly Caroline Costa Silva[1], George Harrison Gonçalves Fagundes[2], Kamila Aben Athar[3], Luísa Schiavon de Araújo[4], Melissa Fernanda Ribeiro Vale[5], Coautores: Guilherme William Caixeta Leite[6], Itiane Thayná Batista Almeida[7]

Resumo

A matriz elétrica brasileira é, em grande parte, limpa. De acordo com o Balanço Energético Nacional (BEN) 2020, a participação de renováveis alcançou 83% do total da matriz, com papel de destaque para as usinas hidroelétricas e rápido crescimento de novas fontes renováveis. Ainda assim, há desafios a serem superados, como alívio das redes de transmissão e distribuição, aumento da resiliência do sistema, redução de

Abstract

The Brazilian electrical matrix is largely clean. According to Brazilian Energy Balance (BEN) 2020, the share of renewables reached 83% of the total matrix, with the prominent role for hydroelectric plants and a rapid growth of new renewables sources. Nevertheless, there are challenges to be overcome, such as easing the transmission and distribution networks, increasing the system's

1 Engenheira de Energia pela UnB. Representou o Brasil como Youth Líder, no evento CEM-10/MI-4; e no programa GKS Partner, pela Chosun University. Atualmente, trabalha com Ciência, Tecnologia e Inovação para o Desenvolvimento Sustentável e faz parte da equipe técnica do CGEE.

2 Bacharel em Relações Internacionais pela UnB e assistente na Coordenação-geral de Atração de Investimento do Ministério do Turismo. É membro do Grupo de Estudos e Pesquisa em Segurança Internacional da UnB.

3 Graduanda em Relações Internacionais pela Universidade de Brasília (UnB) e estagiária no Centro de Gestão e Estudos Estratégicos (CGEE). É fundadora e primeira coordenadora-geral do Grupo de Estudos sobre China (Gechina-Asialac) na UnB.

4 Engenheira química pela Universidade de São Paulo (USP). Trabalha na Total Eren, empresa produtora independente de energia renovável. Representou o Brasil no evento CEM10-MI4, em Vancouver, Canadá, como delegada jovem em energia limpa.

5 Bacharel em Relações Internacionais pela UnB e graduanda em Direito pelo Centro Universitário de Brasilia. Participou da delegação brasileira na 22nd Youth Assembly, em Nova Iorque.

6 Graduando em Relações Internacionais pela UnB e estagiário da Assessoria de Cooperação Técnica Internacional do Senado Federal. É membro do Grupo de Estudos e Pesquisa em Segurança Internacional da UnB. Representou o Brasil na 18ª International Competition Quanta, em Lucknow, Índia.

7 Bacharel em Engenharia Eletrônica pela UnB. Atuou como estagiária no Corpo de Engenharia Clínica do Hospital Universitário de Brasília e, durante a graduação, foi colaboradora em projetos de saúde que envolviam Engenharia Biomédica.

emissões de gases de efeito estufa e mudanças no regime de chuvas. Tais problemas podem ser resolvidos, ou ao menos mitigados, por meio do desenvolvimento de soluções de armazenamento de energia. Nesse contexto, o artigo busca identificar o estado da arte da situação do armazenamento de energia no País e seus principais desafios políticos, econômicos, tecnológicos e socioambientais. Por fim, o artigo apresenta três estudos de casos brasileiros que apontam as principais tecnologias desenvolvidas no setor. O armazenamento de energia elétrica será uma importante peça para o futuro da transição energética mundial, que pode ser alcançada se forem consideradas as diferentes necessidades e características de cada país para a sua realização.

Palavras-chave: Energia renovável. Armazenamento de energia. Brasil. Estudos de caso

resilience, reducing greenhouse gas emissions and changes in the rainfall regime. Such problems can be solved, or at least alleviated, through the development of energy storage solutions. In this context, the article seeks to identify the state of the art of the situation of energy storage in Brazil and its main political, economic, technological and socio-environmental challenges. Finally, the article presents three Brazilian case studies that point out the main technologies developed in the sector. Energy storage will be an important part of the future global energy transition, which can be achieved considering the different needs and characteristics of each country for its realization.

Keywords: *Renewable energy. Energy storage. Brazil. Case studies.*

1. Introduction

Energy storage is considered one of the eight most important disruptive innovations that will influence the country's top 10 industries at the end of this decade, especially with the current increase in the share of intermittent sources in the power grid (CONFEDERAÇÃO NACIONAL DA INDÚSTRIA - CNI, s.d.). More than a climate change strategy, energy storage is a way of assuring more participation of the renewables in the energy supply, at the same time that does not require too much more installed power to do so with reliability. It is also an option to provide more inertia and frequency stability to the system (AL KEZ *et al.*, 2020). From the distributed generation point of view, energy storage also provides independence from grid connection and resilience for households that are distant from the greater centers (GUPTA; BRUCE-KONUAH; HOWARD, 2019; KLAIMI *et al.*, 2018). Furthermore, the concept of smart city itself, that is, a city that uses technology to tackle crucial development problems, counts on energy storage (DAMERI, 2013).

There is an international commitment to replace fossil energy sources with renewable ones, strengthened after COP 21 (HINRICHS-RAHLWES, 2017). Indeed, the use of resources that are not limited to a few reserves across the world is a more diligent way of managing what humankind has available. Besides, it is a way of ensuring future generations are able to meet their needs as well. Such an expected energy production shift increases the need to store it, since renewable sources have variable patterns of generation (CHASE; BERZINA, 2018). Therefore, it is necessary to absorb the surplus and release it when supply is low, but there is demand. It also limits the costly downtime of peak generators and helps reduce Greenhouse Gases (GHG) (CROSSLEY, 2013). Finally, it is an innovative technology to increase grid reliability by integrating new energy resources, replacing outdated infrastructure, and providing backup power during outages (UNION OF CONCERNED SCIENTISTS, 2018).

Considering Brazil's case, a country of continental dimensions and where there are long distances between centers of energy production and consumption, there is also a need to relieve transmission and distribution grids and support isolated systems. In such a scenario, energy storage and its solutions can provide the country more reliable and stable energy supply.

This article aims to address the challenges and opportunities of developing energy storage in Brazil. The present document will review important definitions for this field of study, then examine the current Brazilian storage environment, trends and provide case-studies.

2. The current situation of energy storage in Brazil

According to the Energy Research Office (EPE, 2019), the Brazilian grid is mostly composed of green energy. In the past few years, new renewable sources, such as wind and solar, grew fast in the country's power generation (LOSEKANN; TAVARES, 2019). In contrast with such a sustainable approach, energy storage is still underdeveloped (DELGADO; HAGE; LEITE, 2017). Energy storage is a global trend as it provides benefits across the entire value chain of energy systems, from the generation to the end user. The energy storage industry had a performance of 9.4 GWh (gigawatt-hours of power) of systems installed in the world by the end of 2020. For 2021, the projection is to reach 14.4 GWh, an increase of more than 50% from the previous year. Between 2023 and 2025, the projected growth is 125% per year (MACHADO, 2021).

For this matter, the energy sector requires a balance between demand and supply due to its centrality in other critical infrastructure sectors. Thus, public policies are strategic in creating the integration of energy storage systems nationwide.

An important step for this purpose is the R&D program created by the National Agency of Electric Energy (Aneel) [Agência Nacional de Energia Elétrica, acronym in Portuguese, Aneel] in 2000. The program is the main instrument of technological development in the Brazilian electric sector and seeks to efficiently allocate human and financial resources to demonstrate the originality, applicability, relevance and economic feasibility of products and services in the processes and end uses of energy (DE CASTRO *et al.*, 2020; ANEEL, 2021). Above all, this R&D project encourages the development of the Brazilian electricity sector by designing new equipment and improving the provision of services. It aims at securing electricity supply and tariff moderation, reducing technological dependency (ENERGY FUTURE, 2021).

Under this initiative, companies of the energy sector are obligated to invest 1% of their net operating revenue in R&D projects (ANEEL, 2021). About this discretionary, on the one hand, it has encouraged companies to conduct their research and innovation efforts. On the other hand, as they are part of a sector dominated by suppliers, they end up facing limitations regarding the generation of innovations, because often the results of R&D projects are not implemented. This condition reveals the absence of robust mechanisms to support companies in decisions that can help them generate research benefits (BIN *et al.*, 2015). Therefore, improving further capacity to foster interaction and dialogue between public and private sector institutions is crucial (ENERGY FUTURE, 2021).

The program also faces challenges to innovate from a systemic view. Although characterized by cooperative actions such as those that are the basis for the creation of the Electric Energy Research Center (Cepel) [Centro de Pesquisas de Energia Elétrica acronym in Portuguese, Cepel], and by internal efforts by state-owned companies, the R&D and innovation efforts in energy concessionaires have been restricted in terms of impacts on companies' economic performance (BIN *et al.*, 2015). Taking into account the relationship between the characteristics of Brazilian innovation ecosystems and the sectoral innovation standards and the policy of reasonable tariffs that tends to eliminate the gains of the innovator, this is another element that makes the interest in R&D on the part of the electricity sector still secondary.

Lastly, in interviews with several actors directly involved with the Program, De Castro *et al.* (2020) identifies that the R&D projects tend to focus on the solution of specific technical problems, whose solutions are not at the frontier of knowledge, instead of pursuing long-term and structural innovations. In this sense, many companies have a short-term view and prioritize the resolution of immediate internal problems, to the detriment of longer-term strategies that are more intensive in innovation, as they consider that the Program lacks incentives. As they see it, the most relevant factor that hinders or impairs innovation and R&D activities is the presence of excessive economic risks, which implicitly includes, among other factors, the risk of disallowance of projects, as it is a risk of economic loss.

Concerning the lack of a solid regulatory framework in energy storage, Dantas *et al.* (2018) argue that the country's regulations still focus on pre-defined remuneration with energy contracts, which impacts negatively on the promotion of innovation in the electricity sector, and, thus, on the attractiveness of investments. Another issue is ancillary services, essential in maintaining frequency, voltage, and power quality on the electric system, making energy storage projects feasible, which also do not have a regulatory framework in Brazil (WEISS; TSUCHIDA, 2015).

Moreover, in terms of economic aspects, in May 2020, the Brazilian Revenue Service (Receita Federal do Brasil, acronym in Portuguese, RFB) determined that storage systems should fall under the same Common Mercosur Nomenclature (NCM) codes as the accumulators (cells and batteries) they use. According to Vlasits (apud BADRA, 2021) and Malluf (apud MACHADO, 2021), the tax burden of these codes is extremely high (more than 80%), and jeopardizes the development and implementation of such technologies, even with the drop in battery prices. Also, companies face high costs and a significant scarcity of resources to transform concepts and technologies with potential into effective innovations associated with a business model.

About the technology dimension, according to Mass Clean Energy Center (2016), the energy storage technologies can be classified into five groups according to the form of storage: mechanical, electrical, thermal, electrochemical and chemical (hydrogen). **Mechanical** energy storage has PHS, which, according to Barbour *et al.* (2016), is a process that pumps water from a lower to a higher reservoir in periods of low demand. There are also mechanisms to store energy by compressed air. In the **electrical** energy storage, there are the Supercapacitors, which present highly porous carbon materials, and SMES, devices which have superconductivity properties (SERRA, 2016). **Thermal** energy storage (TES) presents the Heat-sensitive systems, which are based on increasing the temperature of materials, without undergoing phase changes. In the Latent heat systems, the storage is based on the absorption/emission of heat during the change of phase of the material. Also, in the thermal energy storage category, there is the Cryogenic Energy Storage, a type of storage made at low temperatures (LOPES, 2015). About **electrochemical** energy storage, there are the Conventional batteries which the most popular ones are of lead acid (PbA) and lithium ions (Li-ion). Another type of this kind of storage is the Flow batteries as zinc bromide (ZnBr) and vanadium redox (VRB) (EVANS *et al.*, 2012). Finally, **chemical** energy storage presents fuel cells or hydrogen storage which uses hydrogen as a fuel to react with oxygen (SERRA, 2016). The concept of P2G is to feed electrolysers with cheap surplus renewable electricity to produce hydrogen and inject this into the gas grid (ZHANG *et al.*, 2016).

As consolidated in the literature, innovation is understood as an essentially uncertain activity and having a technology or concept with potential does not mean that subsequent steps are less uncertain (DOSI, 1988; DE CASTRO *et al*., 2020). Despite its continental dimension, Brazil is recognized internationally for its integration capacity of energy systems due to the National Interconnection System (SIN) [Sistema Interligado Nacional, acronym in Portuguese, SIN]. Hydropower has been the mainstay of the energy grid, although its share has decreased for the last two decades. The share of this source with large reservoirs can convey the false idea that the country does not need much more energy storage. However, the effective storage capacity of hydropower has been decreasing, primarily due to the growing demand for supply and the dramatic reduction in the level of precipitation in the past few years, especially in the semi-arid Northeast region (EPE, 2019).

Ion-lithium batteries are the most used technology for energy storage nowadays in Brazil, after hydraulic storage. Although it will not likely to assume prominence soon, the Brazilian conjuncture is moving towards the enlargement of this market due to the following factors: South America having 60% of the lithium reserves known in the world (BRAZILIAN ASSOCIATION OF STORAGE AND ENERGY QUALITY -ABAQUE, 2016); the process of liberalization of the national economy is ongoing (REN21, 2020); and the temporary measure of reducing to zero the tax of imports for lithium and lead-acid batteries is in course (BRASIL, 2020).

There is a current need to store electricity generated by non-dispatchable energy sources that becomes essential for use whenever necessary. Recently, Industry 4.0 has been used to make storage "smarter" in Brazil, leading to a better grid balance during periods of high intermittent generation and low demand and vice-versa. Artificial intelligence (AI) is gradually being used as well for predictive maintenance of fleets of intermittent sources, increasing reliability, and reducing downtime (REN21, 2020). Through the Internet of Things (IoT), it is already possible to measure the use of traditional batteries, allowing their connection to the users, and delivering performance and functioning reports, as well as allowing the remote monitoring and real-time of all batteries (ASSOCIAÇÃO BRASILEIRA DE INTERNET DAS COISAS - ABINC, 2019).

The question of the influence of storage technologies also assists in the process of relieving the electricity transmission and distribution networks, as it allows the decentralization of production, promoting the self-sufficiency potential of consumer units (SHIRLEY, 2019)

However, in order to maximize its energy storage potential, Brazil must also overcome challenges in terms of maintenance and strengthening of a low-carbon approach brought by international alliances and the use of "alternative" technologies such as batteries for energy storage in large scale. The most important commitment signed recently was the Paris Agreement, in which

Brazil states it will reduce its GHG by 37% in 2025 and 43% by 2030. This pledge encompasses the Brazilian economy, wildlife and indigenous areas (UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE - UNFCCC, 2016). That is because, at the same time the country needs new and clean power plants, there are a series of impacts in creating a larger system capacity, such as relocation of populations, destruction of the local nature, water pollution, etc. (LEROY; MALERBA, 2010). This raises the urgent challenge of keeping the Brazilian energy production at a low carbon-intensive level, considering that energy storage is yet to be further developed in the country (LOSEKANN; TAVARES, 2019).

Lastly, less than 1% of the Brazilian population does not have access to electricity from the Brazilian Interconnected System (SIN) (WORLD BANK, 2018). Therefore, alternative ways of generation and storage of energy in distant locations of the country may facilitate the access of millions of people to energy and all the technologies that require it. This is an infrastructure investment with positive externalities on the short-term in Brazil and in countries alike. Therefore, it is important to highlight that energy storage constitutes an important opportunity for Brazil to develop national technologies. The alternative forms of energy generation and storage to be developed in the country will serve as vectors for the improvement of the industrial sector, the National Science, Technology and Innovation (SNCTI) [Sistema Nacional de Ciência, Tecnologia e Inovação, acronym in Portuguese, SNCTI] ecosystem, the negotiation model in the international market, and Brazilian society.

3. Case studies of energy storage in Brazil

After conducting a survey of the main Brazilian companies involved with energy storage, it is noticeable that energy storage is expected to become an increasingly strong trend in the coming years (CNI, s.d.). Experts in the energy sector point to this system as the most viable solution to allow the full operation of energy generation through renewable sources, such as wind and solar, which occur at intervals (BOLT, 2019).

Energy storage contributes to solving the great challenge of intermittent renewable sources. With the use of storage systems, it is possible that the operator of the electrical system uses electrical energy in a more flexible way, that is, that which would be lost, can be used at other times (BOLT, 2019). In this section, the article explores some types of storage technologies being developed in Brazil by analyzing the case studies of some large companies from the country.

3.1. Battery (CEMIG/Alsol)

CEMIG is the Minas Gerais Energy Company, one of the main electric energy concessionaires in Brazil. On the other hand, Alsol Energias Renováveis is a specialized company in distributed generation of different renewable energy sources. Alsol was a pioneer in Brazil in photovoltaic systems and energy storage and currently has 500 projects in operation (ALSOL, 2020). In May 2018, these two companies opened together the first photovoltaic plant with a storage capacity of 1 MW (megawatt) in Brazil. The plant has 1,152 solar panels, and has a generation potential of approximately 480 thousand kWh/year, which is enough energy to serve around 250 homes with an average consumption of 150 kWh/month per year (CANALENERGIA, 2019).

In Brazil, plants that had this type of operation before this project generated energy only during the day, and wouldn't supply active energy during the night (CANALENERGIA, 2019). In this new plant, the logic is reversed, since it has a mixture of sending energy to the grid and storage throughout the day with the presence of the sun. An important piece of information is that this technology allows its potential of 1 MW to be injected into the network for up to three hours. This is a first prototype, but the idea is for another six energy storage units to be installed (UFPB, 2019).

3.2. Biogas (Itaipu Binacional)

Itaipu Binacional is a company founded in 1966. At the time, Brazil and Paraguay united to construct a hydroelectric power plant between both countries with an installed capacity of 14 GW. This plant produces 11.3% of Brazil's total energy consumption and 88.1% of Paraguay's (ITAIPU, 2020). However, the company has been investing in new forms of storage, focusing on rural producers, who may use the farm's waste to produce biogas (ITAIPU, 2016). The project is enrolled in farms in Paraná, and followed by the research center CIBiogás, supported by Itaipu Binacional (CIBIOGÁS, 2020). Such initiatives not only help these farms have access to clean energy, but it also decreases their carbon footprint and gives them another product: bio-fertilizers.

The use of biogas in small bioreactors, installed in farms in southern Brazil, has shown Itaipu Binacional good results (ITAIPU, 2016) and studies show this is a viable scenario (FREITAS *et. al*, 2019). With further research on the topic, this could be extended to larger producers.

In Brazil, around 41% of the territory is dedicated to agricultural projects (IBGE, 2017). The country owns the world's second-largest cattle herd (USDA, 2019) and it is a top exporter of pigs and chickens. Thus, biogas from animal manure is a significant possibility of using a resource already available in the country. Biogas should appear more in the discussions about energy storage and become more available and affordable, so it can have a more significant place in the future of Brazilian energy market.

3.3. Hydrogen (Furnas/Senai)

Eletrobras Furnas is a subsidiary of Eletrobras that operates in the generation and transmission of energy all over the country with 21 hydroelectric, 2 thermoelectric and 1 wind plants (FURNAS, s.d.). Furnas's energy storage project comes from an R&D program launched by Aneel in August 2016 for the proposition of energy storage systems in an integrated and sustainable way, seeking to create conditions for the development of technological bases and national production infrastructure.

It will be a hybrid energy storage system consisting in lithium-ion batteries and hydrogen obtained by electrolysis and stored in pressurized tanks, powered by surplus electrical energy from floating photovoltaic panels located on the reservoir lake of the Itumbiara Hydroelectric Plant owned by Furnas in the state of Goiás. The system also includes a 300 kW fuel cell for power generation based on the stored hydrogen (CEPEL, 2019), through catalyzed electrochemical reactions that have only heat and water as by-products.

The entire solar plant located in Itumbiara will have a 1000 kWp power, of which 200 kWp will come from the floating panels located in the plant's reservoir and 800 kWp from the other panels on the ground. The energy won't be commercialized, it will power the plant's auxiliary services system, such as lighting, sockets, ventilation, etc. The surplus energy will be injected into the grid through the existing infrastructure.

3.3.1. Other cases of hydrogen in Brazil

The Australian company Enegix signed a partnership with the government of Ceará to build a huge plant for the production of hydrogen. According to the company, the guaranteed contract to date is 3.4 GW of renewable sources to feed the electrolysers with the possibility of reaching 100 GW according to the scale of the plant design. The Australians reported an investment of US $ 5.4 billion to be raised (CLIMAINFO, 2021).

Also in 2021, Fortescue Metals Group Ltd (Fortescue), and Porto do Açu Operations SA (Porto do Açu), a subsidiary of Prumo Logística SA (Prumo), signed a Memorandum of Understanding (MoU) to develop green industrial projects based on hydrogen in Rio de Janeiro. The MoU will allow companies to conduct feasibility studies for the installation of a green hydrogen plant in Porto do Açu, the largest private industrial port complex in Latin America. Subject to the completion of feasibility studies and approvals, the project includes the construction of a green hydrogen plant with a capacity of 300 megawatts, with the potential to produce 250 thousand tons of green ammonia per year (PORTO DO AÇU, 2021).

4. Conclusion

The market is pointing to the direction that energy storage is and will be a strong component of the future world energy scenario, as the tendency is for decentralized energy production and bigger use of renewables for the grid supply. Indeed, to "clean" the energy and goods production, thus the air and the environment, we need to be able to store energy somehow and have it available in a dynamic way, fulfilling the needs of a growing global population. In addition, it is noticeable that the current trend is directed to the hydrogen production for energy storage, though batteries are still the most direct option and more applied today.

In a local analysis, one can see that the current attempts in increasing the participation of energy storage in the Brazilian market are still shy and punctual, despite the promising worldly perspective. The existing technologies are already satisfactory to make this possible at a lower cost than before and by using resources already available. However, the recent instability caused by the pandemics, as well as conservative measures being taken in the Brazilian economy for the past years, push the country to small development in this domain, especially if the subject is not considered in the near future as a way to fulfill our international commitments of lowering GHG emissions. In addition, in order to shift our energy consumption and production to a cleaner and inclusive one, the country needs an infrastructure (transmission lines, gas storage, transportation, etc.) that is able to fit the need for sustainability the world has.

It was identified during this study the key-role of the Brazilian government in continuing with the energy transition in the country. It must now reinforce the importance of the development of different technologies in energy storage, as well as set the regulatory ground for them to flourish. Moreover, cooperation and regulation are going to be key to accelerate the process of energy transition in the country and in the world. National development needs energy, and if the decisions made in this sector are guided by sustainability values, the whole chain of production also becomes cleaner. However, there is no single solution: different needs and local-specificities require different approaches, using what best fits their strengths and weaknesses.

References

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA - ANEEL. **Programa de Pesquisa e Desenvolvimento Tecnológico do Setor de Energia Elétrica**, 2021. Disponível em: *https://www.aneel.gov.br/programa-de-p-d/*. Acesso em: 15 mai. 2021.

AL KEZ, Dlzar *et al*. A critical evaluation of grid stability and codes, energy storage and smart loads in power systems with wind generation. **Energy**, v. 205, 117671, 15 aug. 2020. *https://doi.org/10.1016/j.renene.2020.09.124* Acesso em: 01 jul. 2020.

ALSOL ENERGIAS RENOVÁVEIS S/A - ALSOL. **Nossos negócios**. 2020. Disponível em: *http://grupoenergisa.com.br/paginas/nossos-negocios/alsol-energias-renovaveis.aspx*. Acesso em: 23 jun. 2020.

ASSOCIAÇÃO BRASILEIRA DE ARMAZENAMENTO E QUALIDADE DE ENERGIA - ABAQUE. **Mercado brasileiro para armazenamento de energia é de 95GW, estima ABAQUE**, 31 mai. 2016. Disponível em: *http://abaque.com.br/index.php/2016/05/31/31052016-mercado-brasileiro-para-armazenamento-de-energia-e-de-95-gw-estima-abaque/*. Acesso em: 26 jun. 2020.

ASSOCIAÇÃO BRASILEIRA DE INTERNET DAS COISAS - ABINC. **Baterias Moura lança produto pioneiro para medir o uso de baterias tradicionais usando Internet das Coisas via Rede Sigfox da WND Brasil**, 13 nov. 2019. Disponível em: *https://abinc.org.br/baterias-moura-lanca-produto-pioneiro-para-medir-o-uso-de-baterias-tracionarias-usando-internet-das-coisas-via-rede-sigfox-da-wnd-brasil/.* *Acesso em 26 de junho de 2020.*

BADRA, Mateus. Armazenamento de energia no Brasil: o que falta para decolar?. **Canal Solar**, 2021. Disponível em: *https://canalsolar.com.br/armazenamento-de-energia-no-brasil-o-que-falta-para-decolar/*. Acesso em: 16 mai. 2021.

BARBOUR, Edward *et al*. A review of pumped hydro energy storage development in significant international electricity markets. **Renewable and Sustainable Energy Reviews**, v. 61, p. 421–432, 2016. Retrieved from: *https://doi.org/10.1016/j.rser.2016.04.019* Available on June 16th 2020.

BIN, Adriana *et al*. Da P&D à inovação: desafios para o setor elétrico brasileiro. **Gestão da Produção**, São Carlos, v. 22, n.º 3, p. 552-564, 2015. http://dx.doi.org/10.1590/0104-530X1294-14. Disponível em: *https://www.scielo.br/pdf/gp/v22n3/0104-530X-gp-0104-530X1294-14.pdf* Acesso em: 16 mai. 2021.

BOLT. 4 tendências para o mercado de energia do Brasil. **Bolt Energy**, 2019. Disponível em: *http://boltenergy.com.br/blog/4-tendencias-para-o-mercado-de-energia-do-brasil/* Acesso em: 01 jul. 2020.

BRASIL. Presidência da República. **Camex zera tarifas de importação de 25 insumos para combate ao coronavírus**, 06 abr. 2020. Disponível em: *https://www.gov.br/pt-br/noticias/financas-impostos-e-gestao-publica/2020/04/camex-zera-tarifas-de-importacao-de-25-insumos-para-combate-ao-coronavirus.* Acesso em: 26 jun. 2020.

CANALENERGIA. **Usina solar em Uberlândia recebe sistema de armazenamento de Energia**. 2019. Disponível em: *https://www.canalenergia.com.br/noticias/53090598/usina-solar-em-uberlandia-recebe-sistema-de-armazenamento-de-energia* Acesso em: 20 jun. 2020.

CENTRO DE PESQUISA DE ENERGIA ELÉTRICA - CEPEL. **Cepel detém ampla experiência na área de células a combustível: uma tecnologia de geração limpa e promissora**. CEPEL, 2019. Disponível em: *http://www.cepel.br/pt_br/sala-de-imprensa/noticias/cepel-detem-ampla-experiencia-na-area-de-celulas-a-combustivel-uma-tecnologia-de-geracao-limpa-e-promissora.htm* Acesso em: 26 jun. 2020.

CHASE, Peter; BERZINA, Kristine. **Transatlantic policy challenge of the digital energy nexus**. Report. Washington, D.C.: German Marshall Fund of the United States, 2018, p. 7-28. Disponível em: *http://www.jstor.org/stable/resrep18948.4* Acesso em: 01 jul. 2020.

CIBiogás ENERGIAS RENOVÁVEIS. **Gestão de energia**. CIBiogás, 2020. Disponível em: *https://cibiogas.org/gestao-de-energia/* Acesso em: 21 jun. 2020.

CLIMAINFO. Ceará anuncia usina de hidrogênio verde em parceria com australianos. **Climainfo**, 2021. Disponível em: *https://climainfo.org.br/2021/02/21/ceara-anuncia-usina-de-hidrogenio-verde-em-parceria-com-australianos/* Acesso em: 16 mai. 2021.

CONFEDERAÇÃO NACIONAL DA INDÚSTRIA - CNI. **Indústria 2027**: Inovações disruptivas, s.d. Disponível em: *http://www.portaldaindustria.com.br/cni/canais/industria-2027/inovacoes/* Acesso em: 15 jun. 2020.

CROSSLEY, Penelope. Defining the greatest legal and policy obstacle to “energy storage”**. Renewable Energy Law and Policy Review**, v. 4, n.º 4, 2013, p. 268-281. Disponível em: *http://www.jstor.org/stable/24324568* Acesso em: 01 jul. 2020.

DAMERI, Renata. Searching for Smart City definition: a comprehensive proposal. **International Journal of Computers & Technology**, v. 11, n.º 5, 2013, p. 2544-2551. Disponível em: *https://www.researchgate.net/profile/Renata_Dameri/publication/283289962_Searching_for_Smart_City_definition_a_comprehensive_proposal/links/5630cd6608ae2df441bb7e5d.pdf* Acesso em: 01 jul. 2020.

DANTAS, Guilherme *et al.* Public policies for smart grids in Brazil. **Renewable and Sustainable Energy Reviews**, v. 92, 2018, p. 501–512. Disponível em: *http://gesel.ie.ufrj.br/app/webroot/files/publications/51_Artigo%20de%20SG%20na%20RSER.pdf* Acesso em: 17 jun. 2020.

DE CASTRO *et al.* **Programa de P&D da ANEEL**: avaliação & perspectivas. Rio de Janeiro: Publit, 2020, 424 p. Disponível em: *http://www.gesel.ie.ufrj.br/app/webroot/files/publications/29_livro_ped_aneel.pdf* Acesso em: 16 mai. 2021.

DELGADO, Marco; HAGE, Fabio; LEITE, Nelson. Os Desafios do armazenamento de energia no setor elétrico. **FGV Energia Caderno de Opinião**, 2017, 8 p. Disponível em: *https://bibliotecadigital.fgv.br/dspace/bitstream/handle/10438/19255/Coluna%20Opiniao%20Janeiro%20Nelson%20Leite.pdf* Acesso em: 30 jun. 2020.

DOSI, Giovanni. Sources, procedures, and microeconomic effects of innovation. **Journal of Economic Literature**, 1988, ed. 26, p. 1120-1171. Disponível em: *https://www.jstor.org/stable/2726526*

ENERGY FUTURE. **Consulta Pública para aprimorar o Programa de P&D da ANEEL recebe sugestões. Energy Future**, 2021. Disponível em: *https://hub.energyfuture.com.br/2021/02/10/consulta-publica-para-aprimorar-programa-de-pd-da-aneel-recebe-sugestoes/#:~:text=Os%20principais%20desafios%20relacionados%20%C3%A0,dos%20setores%20p%C3%BAblico%20e%20privado* Acesso em 15 de maio de 2021.

EMPRESA DE PESQUISA ENERGÉTICA - EPE. **Balanço Energético Nacional 2019**: ano base 2018, 2019. 303p. Disponível em: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-377/topico-494/BEN%202019%20Completo%20WEB.pdf. Acesso em: 26 jun. 2020.

EVANS, Annette *et al.* Assessment of utility energy storage options for increased renewable energy penetration. **Renewable and Sustainable Energy Reviews**, v. 16, p. 4141–4147, 2012. Disponível em: *https://doi.org/10.1016/j.rser.2012.03.048* Acesso em: 14 jun. 2020.

FREITAS, Flavio *et al.* The Brazilian market of distributed biogas generation: Overview, technological development and case study. **Renewable and Sustainable Energy Reviews**, v. 101, p. 146-157, 2019. Disponível em: *https://econpapers.repec.org/article/eeerensus/v_3a101_3ay_3a2019_3ai_3ac_3ap_3a146-157.htm* Acesso em: 15 jun. 2020.

FURNAS. *Geração.* **Eletrobrás Furnas**, s.d. Disponível em: *https://www.furnas.com.br/geracao/?culture=pt* Acesso em 16 de maio de 2021.

GUPTA, Rajat; BRUCE-KONUAH, Adorkor; HOWARD, Alastair. Achieving energy resilience through smart storage of solar electricity at dwelling and community level. **Energy and Buildings**, v. 195, 2019, p. 1-15. Disponível em: *https://www.sciencedirect.com/science/article/abs/pii/S0378778818330482 Acesso* em: 01 jul. 2020.

HINRICHS-RAHLWES, Rainer. Renewable energy: What could and should happen after 2020? Implementing the Paris commitments requires a system change for renewable energy. **Renewable Energy Law and Policy Review**, v. 8, n.º 2, 2017, p. 38-49. Disponível em: http://www.jstor.org/stable/26377526 Acesso em: 02 jul. 2020.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. **Censo Agropecuário 2006/2017. 2017**. Disponível em: *https://censoagro2017.ibge.gov.br/templates/censo_agro/resultadosagro/pdf/estabelecimentos.pdf* Acesso em: 21 jun. 2020.

ITAIPU BINACIONAL - ITAIPU. **Geração**. 2020. Disponível em: *https://www.itaipu.gov.br/energia/geracao* Acesso em: 21 jun. 2020.

ITAIPU BINACIONAL - ITAIPU. **Propriedades rurais no Oeste do Paraná geram a própria energia**. 2016. Disponível em: *https://www.itaipu.gov.br/sala-de-imprensa/video/biogas* Acesso em: 21 jun. 2020.

KLAIMI, Joelle *et al*. A novel loss-based energy management approach for smart grids using multi-agent systems and intelligent storage systems. **Sustainable Cities and Society**, v. 39, may 2018, p. 344-357. Disponível em: *https://www.sciencedirect.com/science/article/abs/pii/S2210670717307552* Acesso em: 01 jul. 2020.

LEROY, Jean Pierre; MALERBA, Julianna. **IIRSA, energia e mineração**: ameaças e conflitos para as terras indígenas na Amazônia brasileira. Rio de Janeiro: Federação de Órgãos para Assistência Social e Educacional (FASE), 2010. Disponível em: *https://fase.org.br/wp-content/uploads/2010/10/IIRSA.pdf* Acesso em: 16 mai. 2021.

LOPES, Sérgio Augusto Seixas. **Tecnologias de armazenamento de energia para fornecimento de serviços de sistema**. 107 f. (Mestre em Engenharia Eletrotécnica e de Computadores) - Faculdade de Ciências e Tecnologia, Universidade de Coimbra, 2015. Disponível em: *https://estudogeral.sib.uc.pt/bitstream/10316/40488/1/Tecnologias%20de%20Armazenamento%20de%20Energia%20para%20Fornecimento%20de%20Servicos%20de%20Sistema.pdf* Acesso em 14 de junho de 2020.

LOSEKANN, L.; TAVARES, F. **Política energética no BRICS**: desafios da transição energética. Brasília: Instituto de Pesquisa Econômica Aplicada, 2019, 60 p. (Texto para Discussão, 2495). Disponível em: *https://www.ipea.gov.br/portal/index.php?option=com_content&view=article&id=34933* Acesso em 20 jun. 2020.

MACHADO, Nayara. **Mercado de armazenamento de energia vai deslanchar, mas tributação é empecilho no Brasil, diz diretor da BYD**. EPBR, 2021. Disponível em: *https://epbr.com.br/mercado-de-armazenamento-de-energia-vai-deslanchar-mas-tributacao-e-empecilho-no-brasil/* Acesso em: 16 mai. 2021.

MASS CLEAN ENERGY CENTER - MassCEC. **Energy storage study**. Massachusetts: Massachusetts Energy Storage Initiative, 2016. Disponível em: *https://www.mass.gov/service-details/energy-storage-study* Acesso em: 15 jun. 2020.

PORTO DO AÇU. *Fortescue* **Future Industries e Porto do Açu unem forças para desenvolver planta de hidrogênio verde no Brasil**. Porto do Açu, 2021. Disponível em: *https://portodoacu.com.br/fortescue-future-industries-e-porto-do-acu-unem-forcas-para-desenvolver-planta-de-hidrogenio-verde-no-brasil/* Acesso em: 16 mai. 2021.

REN21. **Renewables 2020 global status report**, 2020. Disponível em: *https://www.ren21.net/gsr-2020/* Acesso em: 26 jun. 2020.

SERRA, Eduardo *et al*. **Armazenamento de energia**: situação atual, perspectivas e recomendações. Comitê de Energia da Academia Nacional de Engenharia Brasil, 2016. Disponível em: *https://energiasroraima.com.br/wp-content/uploads/2020/01/ACUMULACAO-DE-ENERGIA-_Armazenamento-de-Energia-Fev-2017.pdf* Acesso em: 15 jun. 2020.

SHIRLEY, Rebekah. Decentralizing energy for a high-demand, low-carbon world. **One Earth**, v. 1, n.º 4, 2019, pp. 388-391. Disponivel em: *https://reader.elsevier.com/reader/sd/pii/S2590332219302271?token=5BE5946958000F41DABB1CDD1A55CFE13760E1251886CC7D4EC458D8B0ABA9EEECF15B5B0E97A8CFA3488BC0B183636F&originRegion=us-east-1&originCreation=20210516184326* Acesso em: 16 mai. 2021.

UNION OF CONCERNED SCIENTISTS. **Union of concerned scientists**, 2018. doi: *10.2307/resrep24152*

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE - UNFCCC. **Paris Agreement**: Brazil’s Nationally Determined Contribution (NDC). 2016. Disponível em: *https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Brazil%20First/Brazil%20First%20NDC%20(Updated%20submission).pdf* Acesso em: 16 mai. 2021.

UNITED STATES DEPARTMENT OF AGRICULTURE - USDA. **Brazil once again becomes the world’s largest beef exporter**. Washington D.C.: White House, 2019. Disponível em: *https://www.ers.usda.gov/amber-waves/2019/july/brazil-once-again-becomes-the-world-s-largest-beef-exporter/* Acesso em: 21 jun. 2020.

UNIVERSIDADE FEDERAL DA PARAÍBA - UFPB. **Projeto de energia solar da UFPB recebe menção honrosa em prêmio na Inglaterra**. 2019. Disponível em: *https://www.ufpb.br/ufpb/contents/noticias/projeto-de-energia-solar-da-ufpb-recebe-mencao-honrosa-em-premio-na-inglaterra*. Acesso em: 20 jun. 2020.

WEISS, Jurgen; TSUCHIDA, Bruce. **Integrating renewable energy into the electricity grid**: Case studies showing how system operators are maintaining reliability. The Brattle Group, jun. 2015. 39 p. Disponível em: *https://info.aee.net/hubfs/EPA/AEEI-Renewables-Grid-Integration-Case-Studies.pdf* Acesso em: 26 jun. 2020.

WORLD BANK. **Access to electricity (% of population)**, 2018. Disponível em: *https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?view=chart* Acesso em: 26 jun. 2020.

ZHANG, Fan *et al*. The survey of key technologies in hydrogen energy storage, **International Journal of Hydrogen Energy**, v. 41, n.º 33, 7 set. 2016. p. 14535-14552. Disponível em: *http://dx.doi.org/10.1016/j.ijhydene.2016.05.293* Acesso em: 17 jun. 2020.