STORAGE OF ENERGY IN BRAZIL: TECHNOLOGIES, CONTEXT AND PERSPECTIVES

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ABSTRACT

The new models of electricity generation emerging since the last century, gather in their conceptions the environmental concern with the need to meet growing consumption in the most reliable way possible. In this context, the use of renewable sources has been an increasingly used and integrated option for energy systems. However, the intermittent nature of the availability of these resources can cause instability in these systems. In this way, the knowledge and the improvement of energy storage technologies become fundamental to obtain a stable and quality supply. In this sense, the present work is based on the exploratory research and the revision of the correlative bibliography to present the main energy storage technologies existing in the world today and in particular in Brazil. The country's electricity system (NIS - National Interconnected System) works in an integrated way, and the Brazilian energy matrix is strongly supported in hydroelectricity. Thermal generation also plays an important role, mainly in seasonal stabilization of supply, since, despite the presence of reservoirs, the flow regime generates fluctuations in the annual generation. Difficulties related to the construction of reservoirs, periods of rainfall and the insertion of non-controllable sources in the matrix - such as the wind and solar source - have represented important challenges for the sector. In this way, the paper seeks to present the current situation of the country and to address topics related to the Pumped storage hydroelectricity (PSH), which may constitute an alternative to the country. However, they still encounter some difficulties of difficult solution, such as the lack of regulatory bases. It is therefore sought to characterize the current national panorama by establishing pertinent discussions about promising paths to be adopted.

Keyword: Energy storage, renewable sources, regulatory bases, Brazilian scenario.

1 – INTRODUCTION

Ensure the proper functioning of the various systems that make up the supply of electricity is a challenge that has been faced for decades. The energy systems are always undergoing processes of improvement, aiming to attend to a growing consumption, which guarantees high levels of development to society.

The meeting the demands that arise over the years is no simple task. In the current scenario, an emerging and increasingly significant issue is the need to combine the increase in electricity supply through clean generation mechanisms, given the high levels of greenhouse gas (GHG) emissions that have been verified in recent years. The alternative adopted and indicated as the most adequate has been the incorporation of the sources of renewable generation to the electrical systems. These sources have the advantage of their low levels of GHG emission along their generation chain and the cheapening of generation systems, given the extinction of fuel expenses.

However, one of the main challenges to the use of these sources in energy systems is their intermittent nature, especially in the case of wind and solar energy, given the fluctuations in the availability of wind and solar radiation regimes. As the energy supply must be realized in order to meet a demand curve with instantaneous variations, the challenge of the incorporation of renewable sources is imposed on the whole electric sector. So, there is the need to invest in energy storage systems.

Energy storage can improve the efficiency of electrical systems - and also thermal - and play a key role in reducing GHG emissions by energy systems. Such systems are capable of:

- Improve efficiency in the use of resources in energy systems;
- Assist the integration of non-controllable renewable energy resources into the end use of the electricity sector;
- Increase the levels of energy generation in the places of consumption;
- Increase access to energy;
- Improve levels of stability, flexibility, adequacy and resilience of networks [1].

While some storage technologies are ripe or nearing maturity, many are still in the less advanced stages and have difficulty becoming competitive due to the high costs. In this sense, the design of the market is fundamental to accelerate the deployment. Current policy environments and market conditions often obscure the cost of energy services, creating significant price distortions and resulting in poorly equipped markets to compensate energy storage technologies for the set of services they can provide. Therefore, public market policies and incentives are fundamental to the viability of storage technologies in all its applications. Energy storage has positive implications in several spheres of system operation, as pointed out in Figure 1.

FUNCTIONALITY	POSSIBLE APPLICATIONS: National level / Streaming	POSSIBLE APPLICATIONS: Municipal level / Distribution	POSSIBLE APPLICATIONS: Unit level / Client
Balancing and supply of energy	Instant Fluctuations	Instant Fluctuations Performance in locations with momentary operational restriction (eg.: rush hour)	Instant Fluctuations
Network management	Frequency and voltage regulation	Frequency and voltage regulation	Offering services with small storage (backup)
Energy Efficiency	Efficiency in the generation mix with peak time management	Collective virtual power plants of distributed generation	Production and local use of energy Arbitrage of the energy value if there is an hourly charge

Figure 1: Possible storage applications and expected functionalities [2].

Determining the best storage technology for a given application is a function of, among other things, the cost of this technology, its storage capacity and its discharge time. Broadly speaking, smaller technologies are associated with distribution systems while larger ones are associated with large centralized generation systems. This paper briefly presents the current storage technologies and then describes the current scenario of Brazil in terms of the storage of large energy, given the characteristics of its interconnected system. Challenges exist in the Brazilian scenario, which seek to guide possible alternative solutions, in terms of elaboration and proposal of public policies, at national and state level.

2 - TYPES OF STORAGE TECHNOLOGY

The storage systems are designing to enhance power offerings at different time horizons, accumulating power when production exceeds demand at a given time, allowing it be used when the situation reverses, reducing losses and increasing the overall efficiency of systems. Storage requires the conversion of energy into kinetic, potential, chemical or thermal before conversion [3]. The following are the main types of technology currently available.

Pumped storage hydroelectricity (PSH): This power plants store energy by accumulating water in reservoirs. During off-peak periods, the electricity is used to pump water from a lower-level reservoir to an upper-level reservoir. In moments of increased demand, the stored water is turbinated for the generation of energy. PSH plants operate by generating or consuming energy, by turbinating or pumping water, and, in general, consumption levels are always higher than generation. It is the most common type of technology used for large-scale energy storage worldwide: there are about 127,000 MW installed in about 200 large-scale plants. Its advantages include low cost, reliability and the ability to provide high energy levels for several hours. However, due to the fact that the construction of large reservoirs is allied, the expansion of this type of technology is subject to geographic constraints [4].

Compressed air systems: Compressed air systems use gas turbines. Energy is stored by compressing the air in caves or tanks. Subsequently, this air is heated and expanded in high pressure turbines. The residual compressed gas can still be expanded in low pressure turbines. Generally, this systems use the excess energy of the periods of production out of peak to the compression of the gas, for its use in the peaks of consumption [1]. These systems are most commonly used in scales ranging from 10 MW up to 100 MW [4].

Flywheels: Mechanical devices are accelerated at high speeds, storing electricity as rotational energy during peak periods. Subsequently, the energy is harnessed for electricity generation. This type of technology has been used in buses and trucks, and units ranging from 5 MW to 50 MW are in development [4].

Liquefied Air Storage: This type of system uses electricity to promote air cooling until it changes phase and liquefies for later storage in tanks. At times when power generation is required, it is brought back to the gaseous state by exposure to process waste heat and used in turbines to generate electricity [1,4].

Hot water storage systems: These are systems characterized by the storage of hot water in insulated tanks for later use [1].

Batteries: Batteries can transform, through chemical reactions, chemical energy into electrical energy and vice versa, with low value of environmentally damaging emissions, without noise, and require little maintenance. There is a wide range of types of batteries used in storage systems: lead – acid, nickel – cadmium, nickel – metal hydride, sodium – sulphur, lithium – ion, lithium – polymer, and others [4].

Concentrating Solar Power (CSP): These plants operate by concentrating solar energy through mirrors for steam generation and turbine drive. These systems use molten salts for the storage of thermal energy, which can later be converted into electricity [1].

Storage in solid media: These systems use solid media to store energy for later use in heating or cooling [1].

Chemical storage of hydrogen: uses hydrogen as an energetic vector, for example, through the electrolysis process.

Magnetic superconductors: Energy storage in magnetic superconductors is achieved by induction of direct current (DC) in a coil composed of superconducting cables with near zero resistance, usually made of titanium niobium (titanium) niobium (NbTi) filaments Operate at very low temperatures (-270 ° C). The current increases during the load and decreases during the discharge, in which case an alternating current (AC) conversion system [4] has to be used.

Supercapacitors: The energy storage in supercapacitors is performed in the form of an electric field between two electrodes. This is the same principle used in conventional capacitors, except that the insulation material is replaced by an ionic conducting electrolyte in which the ions move through an electrode made of porous carbon-based material with a large specific surface [5].

The use of these technologies in the world are distributed as illustrated by the

Figure **2**. A Table 1 presents relevant criteria that can be taken into account when determining the most suitable storage technology for a particular application.

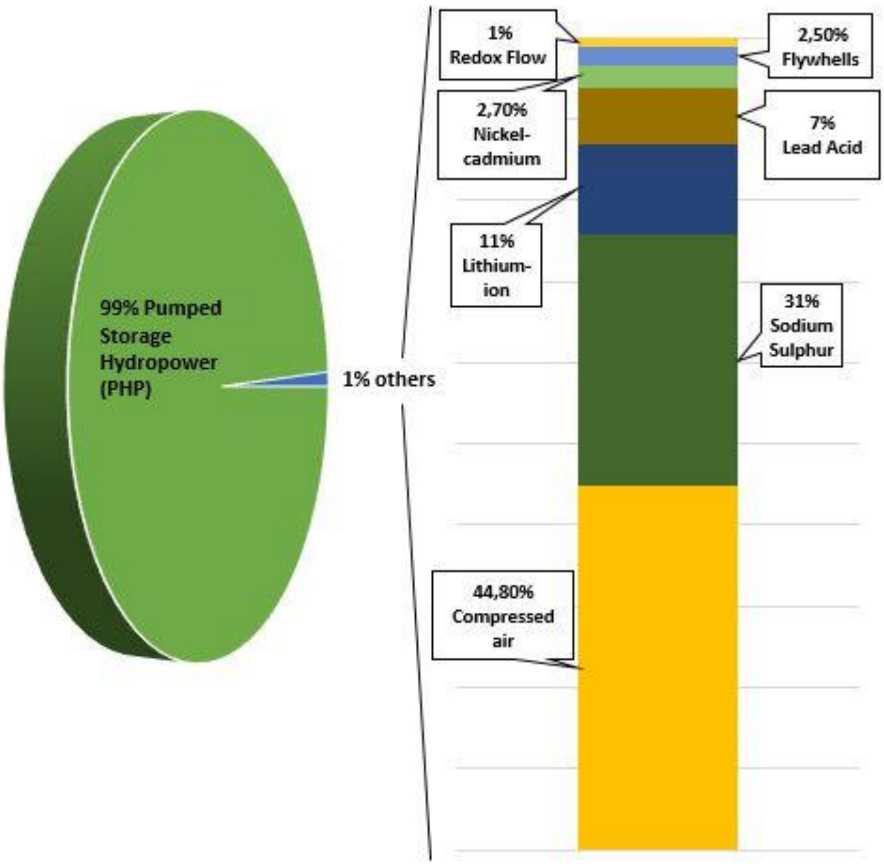

Figure 2: Installed capacity of storage technologies in the world [4].

Table 1: Criteria (short term) for the determination of the most appropriate storage technologies for deployment [1].

Power Storage	Technology examples	They can provide greater short-term benefits in areas such as:
Large-scale electricity	Reversible plants, compressed air.	Developed electrical networks or systems that can accommodate centralized energy resources more easily.
Large-scale thermal energy	Storage in solid media, molten salts	Significant amounts of residual heat, demands concentrated by heat or cooling, or large amounts of concentrated solar energy.
Small-scale electricity	Batteries	Remote or isolated communities
Small scale thermal energy	Hot water storage systems, liquefied air storage	Highly variable demand

3 - STORAGE OF ENERGY IN THE NATIONAL SCENARIO AND DISCUSSIONS

The national electricity system is strongly marked by the hydraulic source of generation allied to the reservoirs, which make possible the stabilization of afluent flows and, therefore, the supply of hydropower in the dry period. Large reservoirs are the main form of energy storage in Brazil; however, their construction has been unfeasible by the requirements related to environmental legislation. Thus, despite the expected increase in installed capacity of hydroelectric plants in the next ten years, the increase in national storage capacity is only 2.6 GW in the same period, which corresponds to approximately 1% of the total existing in 2015 .The importance of the large reservoirs installed in the Southeast / Center-West region, representing approximately 70% of the SIN storable energy at the beginning of 2015, while the Northeast, South and North regions account for 18%, 7% and 5%. On the other hand, market growth is approximately 45%, as well above the growth of storable energy [6]. Figure 3 illustrates a comparison between the growth of SIN's maximum storable energy and the growth of the energy market, according to the Decennial Energy Expansion Plan 2024 [7].

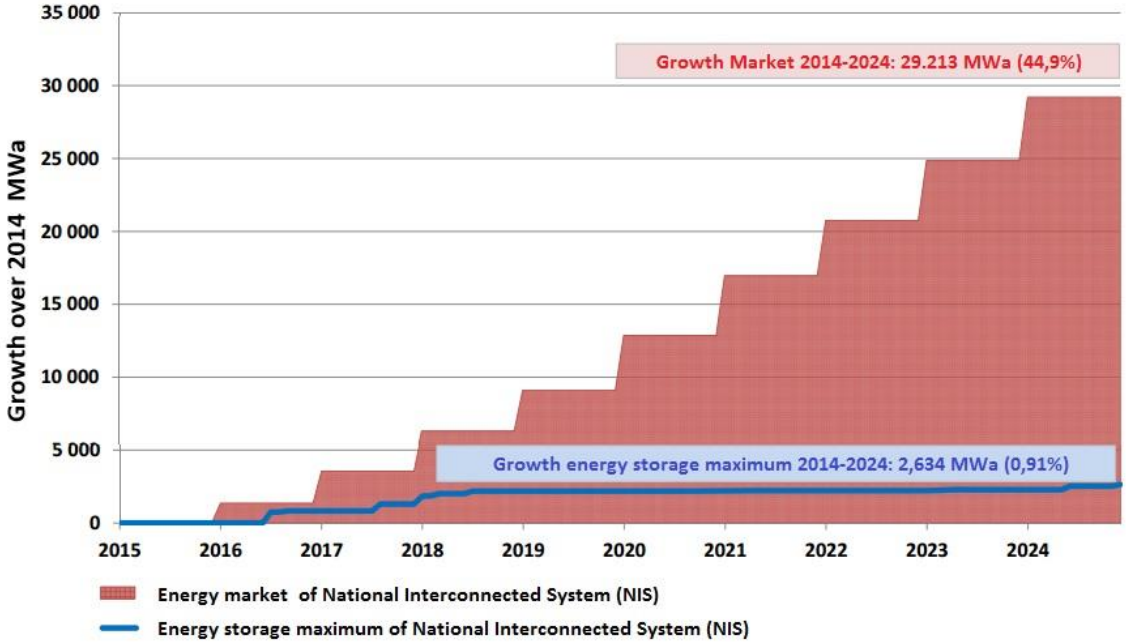

Figure 3: NIS energy market growth × maximum storable energy [7].

Figure 4 presents the main reservoirs in Brazil and the subsystems of operation of the NIS. The strong concentration of the reservoirs in the southeast and central-west regions is evident, which shows how difficulties for periods of rainfall under this region can lead to the supply of electricity demand. Figure 5 presents the evolution of NIS storage capacity between 1996 and 2017. It can be seen that the critical year was 2001, when the period of energy crisis and energy rationing in the country was recorded. Among the causes that led to the outbreak of this crisis are, among others, the lack of planning and investment in energy generation and transmission, and the scarcity of rainfall. In subsequent years there was a significant increase in storage capacity, which once again returned to critical values in the years 2014 and 2015, again due to a period of rainfall scarcity. Figure 6 presents the energy stored in the annual horizon of the years between 2013 and 2017, highlighting once again the lowest values of the years 2014 and 2015.

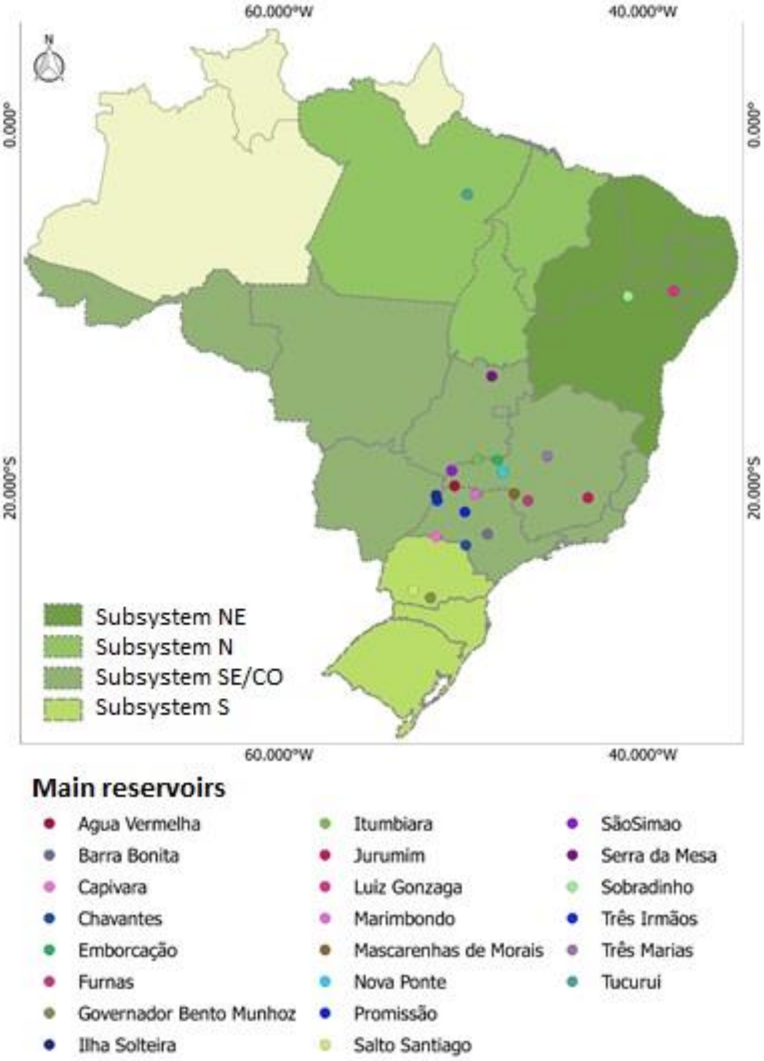

Figure 4: Brazilian subsystems and main reservoirs [8].

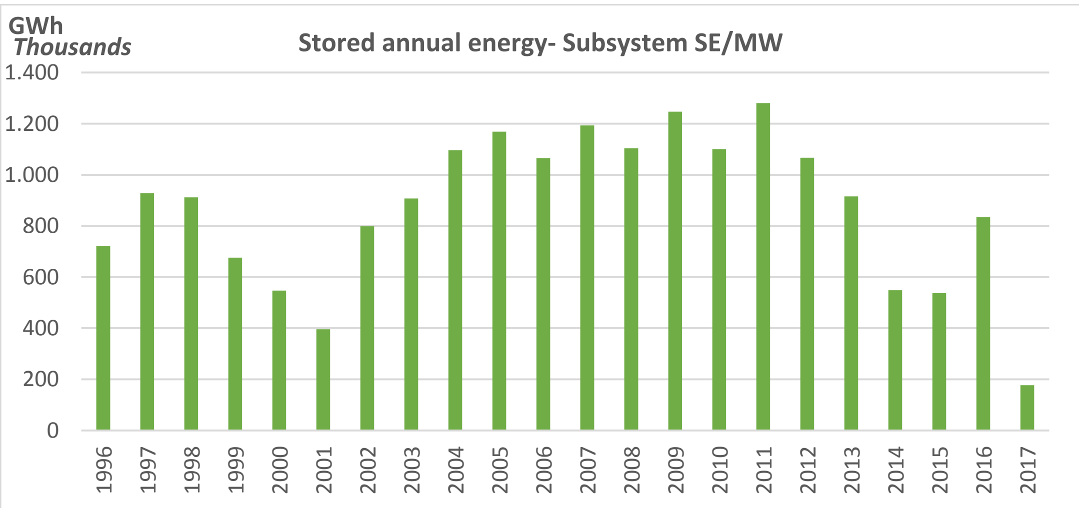

Figure 5: Evolution of stored energy - Annual horizon [8].

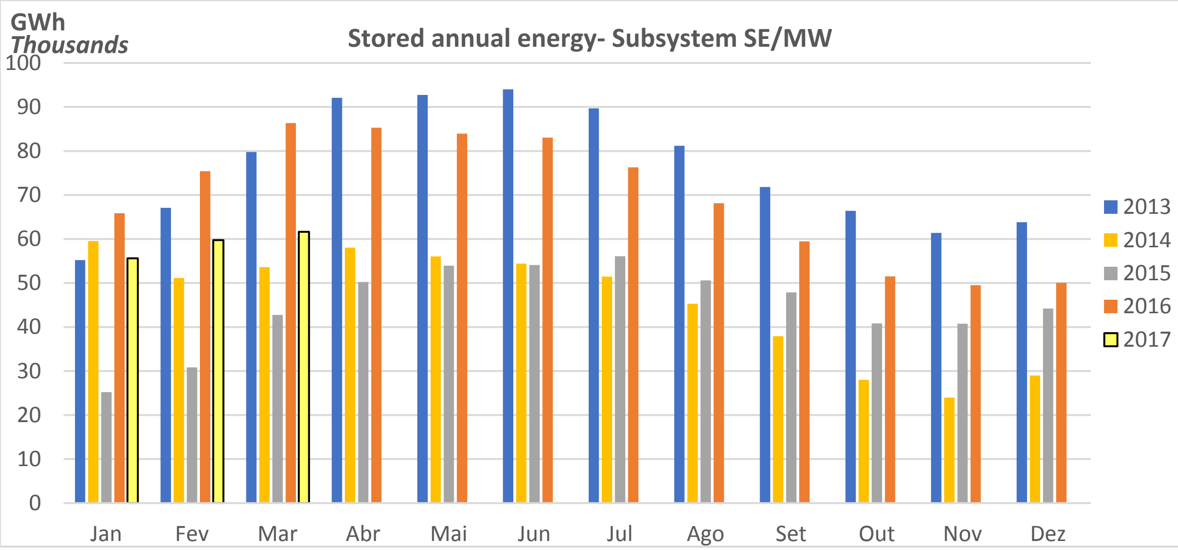

Figure 6: Evolution of stored energy - Monthly horizon [8].

Although it is well known that the market variation is much greater than the variation of the storage capacity, the facts gathered, however, do not point to a decrease in the security of the national energy supply, given the participation of the other sources that compose the electrical matrix . In addition, existing storage structures, hydroelectric plants with stock capacity, and the presence of thermal plants, make the system predominantly composed of controllable sources, although there is a need to increase storage capacity. Therefore, system operation challenges are established. A significant insertion of non-controllable renewable sources in the energy supply, such as wind, solar, small hydropower and biomass, is assumed, which presupposes the incorporation of varied generation profiles, dependent on natural stochastic events. When this occurring below the expectation, impose the challenge of meeting the demand by means of the dispatch of thermal plants, economically more expensive, or by means of hydroelectricity, which can become a difficult decision especially in periods of low affluence. This is the emerging issue of meeting the demand for electricity in the horizon of hourly consumption. The change of operational profile presented above requires a change in planning as well. With this new behavior, the guarantee of maximum service demand of the system is no longer enough to supply the demand at other times of the day. In addition, the large variation in the generation of intermittent sources, which may occur in a few hours or even minutes, will require a greater participation of controllable sources with operative flexibility, to "follow" the system's net hourly charge (curve of total charge discounted from the expectation of hourly generation of non-controllable plants). These flexible sources, on the other hand, tend to present higher operating costs, requiring planning to properly define the amount required so as not to overburden the system.

Therefore, a pertinent discussion is started regarding the appropriate alternatives that the country should use to increase its energy storage capacity. According to Canales et al [3] for large-scale applications (in terms of capacity and power), the main technology applied in the world is the PSH, which are based on the gravitational energy storage of water through a difference in elevation, based on the same principles of converting power from conventional hydroelectric plants. They are, therefore, technologies mature and highly compatible with the Brazilian scenario, given the predominance of the hydraulic source in this.

The Table 2 presents the main reversible plants in operation in Brazil and worldwide.

Table 2: Main PSH plants in Brazil and in the World [3, 9, 10].

	Name	**Instaled power (MW)**	**Location**
Brazil	Pedreira (construída em 1939)	78.5	Sao Paulo
	Traição (construída em 1940)	7.3	Sao Paulo
	Vigário (construída em 1952)	88	Rio de Janeiro
	Edgard de Souza (construída em 1955 e desativada em 1982)	-	São Paulo
World	Bath County	3003	U.S
	Guangzhou	2400	China
	Huizhou	2400	China
	Okutataragi	1932	Japan
	Frades II	191.6	Portugal
	Ludington	1832	U.S
	Turlough Hill	292	Ireland
	Goldisthal	1060	Germany

Despite the strategic advantages of using reversible plants in the Brazilian scenario, its installation still faces significant obstacles that keep the debate open on the main alternatives for increasing national storage capacity.

One of the main difficulties faced by the UHR in Brazil today is the fact that the contracting of energy occurs always considering its physical guarantee, that is, the energy that the new plants can offer to the system. Thus, the commercial viability of these projects becomes a challenge because, in the case of UHR, the balance of energy generated is often negative, since the energy spent in the pumping is higher than that generated in the turbine [11-12]. Therefore, a clear lack of public policies and regulatory bases can establish a legal framework that guides investment in this type of enterprise, taking into account its characteristics and the systemic gain of its use. Still in this sense, Zuculin et al [12] point out that:

> "It is verified that the viability of these plants in other markets is related mainly the differentiated values of energy, for the different load levels, which does not apply to the NIS.
>
> [...] We recognize at least three difficulties for the PSH regulatory proposition in the brazilian model: (i) The lack of a power market or ancillary services, which could be a reference; (ii) The small differentiation, where it exists, of short-term prices between heavy, medium or light loads and (iii) The absence of verticalized companies, where there would be financial compensation for investments in PSH, given their benefits not only in the generation component, but in the other segments (transmission and distribution)".

As alternatives, the authors point to regulatory bases that establish the sale of energy and the acquisition of pumping by special tariffs.

It is interesting to note the case of the China, which is one of the countries with greatest installed power in PSH plants (Table 2), despite this; it pointed out that this capacity might be insufficient in the current scenario where there is massive insertion of the wind generation. Over the years incentive policies have varied in terms of tariffs (Feed in tariffs, differentiation between generation and pumping tariffs, tariffs for installed capacity, etc.), construction and operational strategies of the plants, however, PSH plants have been positioned as operational tools of the grid company and little consideration has been given to their economic uniqueness. Instead, government regulations and policies have required that PSH plants be constructed and managed by the grid company and that the operating cost be integrated into the grid company operating cost. Although the recently revised policies have made improvements with regard to the PSH tariff regime, more policy changes are needed to support the development of PSH in China. In this regard, it is pointed possible alternatives:

(a) To examine those PSH operational and tariff mechanisms currently implemented to good effect in other economies, particularly in the EU member countries;
(b) To comprehensively assess the value of ancillary services and their benefits to all relevant parties so as to provide the basis for pricing ancillary services as well as revenue sharing;
(c) To examine the institutional constraints to the development of creative PSH policies;
(d) Remove the restrictions on investments in PSH: under the current regulations, the grid company and its subsidiaries dominate the investment in new PSH capacity. This is consistent with the current approach to treat the PSH plant as an integral part of the transmission system. However, the PSH plant has its own unique economic value and at least some of these economic benefits can be translated into financial revenues. This would enable PSH plants to be treated as distinct corporate entities with a defined revenue stream and create interest from commercial enterprises to invest in new PSH capacity;
(e) Establish time-of-day tariffs for generators;
(f) Establish a market for ancillary services: Growing wind power penetration results in an increased demand for ancillary services such as spinning reserve, contingent reserve, load following capability and frequency regulation. PSH plants have the technical capability to offer these ancillary services in an economically competitive manner compared to thermal power plants [13].

The use of renewable energies associated to the PSH so that the energy associated with the non-controllable sources could be used in support of the pumping systems. The importance of this type of system can be illustrated by the case of India, where authors [14] point out that the major constraint for PSH operation in India, for example, was the deficit of off-peak power available for pumping in all the regional grids except the north-east region.

The Figure 7 allows to observe the significant values of wind and solar potential in Brazil. The Decennial Energy Expansion Plan 2024 points to the fact that the reservoirs are more requested during the dry period of the year, causing a greater commitment of their levels. The dry period, however, is that it records the highest wind speed values. The high potential of these renewable resources in Brazil is a good indication of the technical feasibility of their use with the PSH, however, the strategic advantages of this alternative should be evaluated in the light of experts and public initiative, responsible for proposing relevant policies.

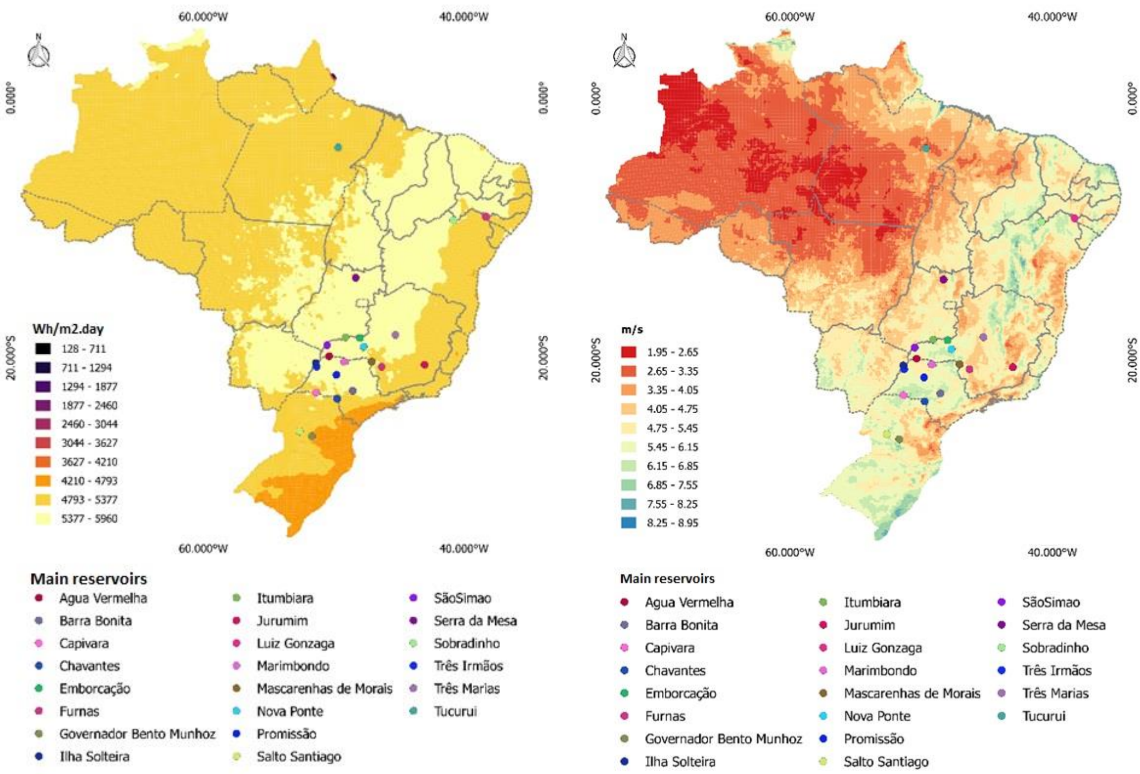

Figure 7: Solar (left) and wind potential (right) of Brazil [15].

4 – CONCLUSION

This work aimed to present a general picture of the situation of the storage of electric energy in Brazil, presenting the main characteristics of its matrix. The challenge presented to NIS was the attendance to a growing demand, with an increase in the share of non-controllable renewable sources, together with an expressive storage capacity it was pointed out that, given the characteristics of the Brazilian matrix, strongly supported in the water source, a promising alternative for the country would be the adoption of PSH. However, the current market and regulatory model lacks the bases that can make these projects feasible, since at present the viability of generation projects is achieved through the contracting of the generated energy, which in the case of the PSH is compromised in its final balance by energy expenditure in pumping. Regulatory alternatives have been presented, however, the lack of public policies in support of these systems is still something that should be discussed by the public, technical and academic community.

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