

## ENCIT-2018-0269 SOLAR ENERGY – BRAZIL’S ANALYSIS

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***Abstract.** Huge sized country, Brazil has a lot of natural resources. This paper aims to introduce an analysis of the national landscape related to renewable energy from investment to technical aspects. Gathering information from the most prestigious energy agencies and journals, the information provided below helps the reader to understand the situation where Brazil fits in when it comes to renewable energy, especially solar energy. Majority of power generation comes from hydropower however wind and solar started to push forward. It is not just about natural resources, investments, capacity factor and efficiency impact directly on the decisions to move on with new projects.*

***Keywords:** renewable energy, solar energy, LCOE, capacity factor.*

### 1. INTRODUCTION

Brazil is well known by its size and natural beauty. It is the fifth largest country in the world and it is still going through a phase of economic/industrial growing. Therefore it needs to provide a lot of energy and electricity for the industrial sector (it accounts for around a third of the total electricity consumption). Although Brazil is the 8<sup>th</sup> largest total energy consumer and 10<sup>th</sup> largest producer in the world (EIA, 2014), the country must increase its energy production, efficiency and energetic mix to provide a reliable electric grid.

Fortunately, Brazil is also well known when it comes to renewable energy as a rich country. This sentence is made by all kinds of people, after all you do not need to be an expert to observe the natural conditions offered by the country. The Brazilian “clean” power generation mix is basically a merge of hydraulic source (63.38%), wind (8.09%) and solar (0.81%). However the mix also includes power from thermoelectric plants and it reaches 26.06% (BIG, 2018). In spite of the large energy production, according to the Brazilian Photovoltaic Solar Energy Association (Associação Brasileira de Energia Solar Fotovoltaica – ABSOLAR) around 5% of the total energy consumed in Brazil comes from countries such as Paraguay, Uruguay and Argentina. On one hand there are the climate conditions favorable and on the other hand almost one quarter of the power generation is from a dirt and old process.

Looking at the clean three quarters of renewable and accounting for most of installed capacity, big hydroelectric power plants started to share Brazil’s landscape with wind and PV power plants. The recent beginning of decentralization generation along to the energy crises and climate change motivated the academy to seek beyond existing boundaries new renewable sources, more efficient and lower environmental damage (Guerra, et al., 2014).

Along with research and investments it is important to have mass awareness about renewables. In May, 2017, the Brazilian Energy Marketers Association (ABRACEEL) and the Brazilian Institute of Opinion and Statistic Intelligence (IBOPE Inteligência) did a research about energy and one of the questions was directly related to self-generation using a renewable source at home – 89% of Brazilian people would like to have it (2% max error and 95% confidence interval) (ABRACEEL, 2017). However, according to (ABSOLAR, 2017) distributed generation reaches only about 0.02% of consumers – the basic conclusion is that Brazilian people know about renewable energy and want to have it, however there is something on the way to get it done.

At the end of 2017, the renewables have the massive number 2179 GW installed. The trend to install solar energy is worldwide noticed, to tell the truth the solar energy capacity installed in 2017 increased 94 GW, meaning 56% of the total increased in renewables (IRENA, 2017a). Brazil is tagged as a “clean producer” and should keep it that way.

The Ministry of Mines and Energy releases annually the Decennial Expansion Energy Plan (MME/EPE, 2010). The 2019 plan (written in 2010) is supposed to have its results compared next year when the cycle is over. This report projected a decrease in gasoline consumption due to the increase in alcohol consumption (second largest producer and consumer of ethanol in the world according to EIA, 2014). The recent “truck driver” riot showed how fragile Brazil is and how much it depends on the road system; consequently showed the dependency of fossil fuels with prices reaching more than R\$ 4.98/liter (Gazeta, 2018). The report also predicts a decrease of the use of electricity, however an increase in per capita consumption. The Govern is planning on invest R\$ 175 billion to energy expansion programs, of which R\$ 108 billion for new power plants (70% hydraulic and 30% other renewables).

## 2. SOLAR ENERGY

Global investments in clean energy keep rising with global energy players seeking to develop a clean energy future. The most abundant form of energy and capable to generate world's energy consumption in a year in just an hour, the sun have been studied for a long time. Wind energy had a huge increase in capacity installed over the same time as well and in Brazil it was pushed forward through PROINFA (Incentive Program for Alternative Sources) – solar energy was not on the scope of this program but still have been growing as fast as wind.

Briefly, wind energy uses wind as the source to generate energy – it has a tower and at the top there are three blades mounted on a hub that contains the generator. Solar energy uses solar radiation to generate electricity through basically two processes: the photovoltaic effect (electrons jumping from one orbital slot to the high-energy next one) and concentrating the solar beams.

Sun is always shining and irradiating energy. This energy go through space and then reaches Earth, but before it happens there are several layers that decrease the amount of energy received by the ground. It can be called by atmospheric attenuation – it embraces atmospheric absorption and reflection. Solar beams are classified as direct and diffuse. Direct radiation is the solar beam coming straight down to the ground without any kind of interference and it can be concentrated. Diffuse radiation is all kinds of solar beams after they are scattered on the sky by the atmosphere or clouds. The first process mentioned before happens in photovoltaic (PV) cells and works with direct and diffuse radiation. The second process is used in concentrated solar power (CSP) plants and depends on direct radiation only. There are four CSP technologies: parabolic trough, parabolic dish, central tower and linear Fresnel. The basic configuration of a CSP power plant is: the solar field concentrates the radiation on the receiver. The heat transfer fluid absorbs the heat in the receiver and goes to the power block where a turbine generates electricity. If considered as a linear path, the energy storage is positioned in parallel with the input and output of the power block. A photovoltaic panel works with direct and diffuse solar irradiation; and CSP works only with direct solar irradiation, so the amount of energy that a PV panel gets is larger than a CSP panel, both having the same area. In order to select the best site to build the solar power plants, data from the solar irradiation must be collected on site and also satellites help to estimate the amount of energy received. Brazil has a program named SONDA (National Organizational System for Environmental Data) under the National Institute of Spatial Research (INPE) that has 17 stations to collect data from the sun spread nationally. A solarimetric station is responsible to measure the solar radiation and it has two main components: (a) the pyranometer that measures global solar radiation and (b) the pyrheliometer that measures direct solar radiation (SONDA, 2018). Also, there are several mathematical models to help predict the amount of net energy.

An important technical aspect for all kinds of energy generation is efficiency – it can be directly related to environmental damage, as shown by Turconi, et al. (2013). The topic efficiency is cited by several energy reports and the energy production processes are emphasized (Bloomberg New Energy Finance, 2016; IEA, 2016a, 2016b, 2016c, IRENA, 2016, 2017b). According to IRENA (2016), Latin America has the biggest potential to reduce greenhouse gases (GHG) emissions under the indicator “energy efficiency”. In 2016, the Paris Agreement was signed and 143 countries plus Brazil mentioned efficiency as one of the goals (Brazil established an increase of 10% in energy efficiency) (United Nations Framework Convention on Climate Change, 2015). Brazil is also involved in other organizations and recent news highlighted the possibility of the country to join the International Solar Alliance (ISA) and the International Renewable Energy Agency (IRENA), two very important credentials (Ministry of International Affairs, 2018).

The Energy Research Company (EPE) has a tool named “Calculadora 2050” (<http://calculadora2050.epe.gov.br/calculadora.html>) that simulates several scenarios until 2050. The standard scenario is defined as no addition in energy offer and no efforts to decrease the energy demand – the internal energy output will increase around 3.16 times and the greenhouse gases emissions will increase 3.6 times. There are several options available for the user to define the scenario and the best set up could increase the internal output 2.3 times and the greenhouse gases emissions up to 2 times. It shows that there is a solution for the current situation and the path is already set to reach the goals for energy demand, energy consumption, energy efficiency and consequently greenhouse gases emissions.

## 3. ECONOMICS

The Brazilian market is going very well in the renewable sector, the predictions are the startup of 31 new PV power plants until 2021 and an increase of 1 GW year from 2020 until 2026 of wind energy generation (ANEEL, 2018). According to the predictions of Bloomberg's Climatescope (2016), the global energy demand will keep rising 2% annually and by 2040 20% of Brazil's generation could be provided by rooftop PV panels. The investment until 2026 is estimated on R\$ 174.5 billion (MME/EPE, 2017). Other investments are on the edge, such as the R\$ 5 billion Chinese and R\$ 385 million Spanish. Furthermore almost R\$ 3.2 billion will be available to finance the installation of PV panels in the North, Northeast and Central East regions (ABSOLAR, 2018, EPowerBay, 2018). With all this money coming in Brazilian authorities need to rush and push the regulatory questions related to distributed generations and energy efficiency. According to Tomalsquim (2016) there are more issues to solve in order to expand the national grid, pointing out cost reduction, local industry development, credit lines, quality control of new plants and intermittency in generation.

Nowadays cost reduction is following the trend set by technology progress. Generally a power plant has three main economic indicators: capital expenditure (CAPEX), operation and maintenance cost (O&M) and Levelized Cost of Electricity (LCOE). Capital expenditure includes almost everything used to build the power plant, such as the purchase of equipment, land preparation, power block, etc. Upgrades are also taking into account here. Operation and maintenance embrace fixed and variable costs. The most important indicator is the LCOE – it represents the cost of a unit of generate electricity through the project life time and it can directly compared different technologies. It take into account CAPEX, O&M costs and all the other costs plus interest rates. This value is not the price paid by the final consumer because it does not includes taxes or the profit margin add by the distributor.

For many years the prices have been falling, as an example, the PV panel price dropped 30% in the last five years (Taylor, 2015) and the decrement projected for LCOE (in PV) is 66% by 2040 (Bloomberg New Energy Finance, 2017) and 50% for the period 2010 – 2020 from CSP (SETO, 2018). The energy auctions around the world shows the cost reduction every time that there is a record price. In Brazil the last two auctions realized were in 2017 and April 2018. Both of them had the spotlight turned to solar energy with 85% and 76% of the offer bought from solar energy, respectively as Figure 1 shows. Furthermore the price of the latest auction was smaller than the previous one, confirming the decrease prices. There is one more formalized auction for 2018: the new energy auction “A-6” expected to happen in the second quarter of the year. According to the terms established in a federal decree, the Ministry of Mines and Energy (MME) must published by March 30<sup>th</sup> the schedule for all the auction to be realized in 2018 (EPowerBay, 2018 apud MME Social Media Advisory).

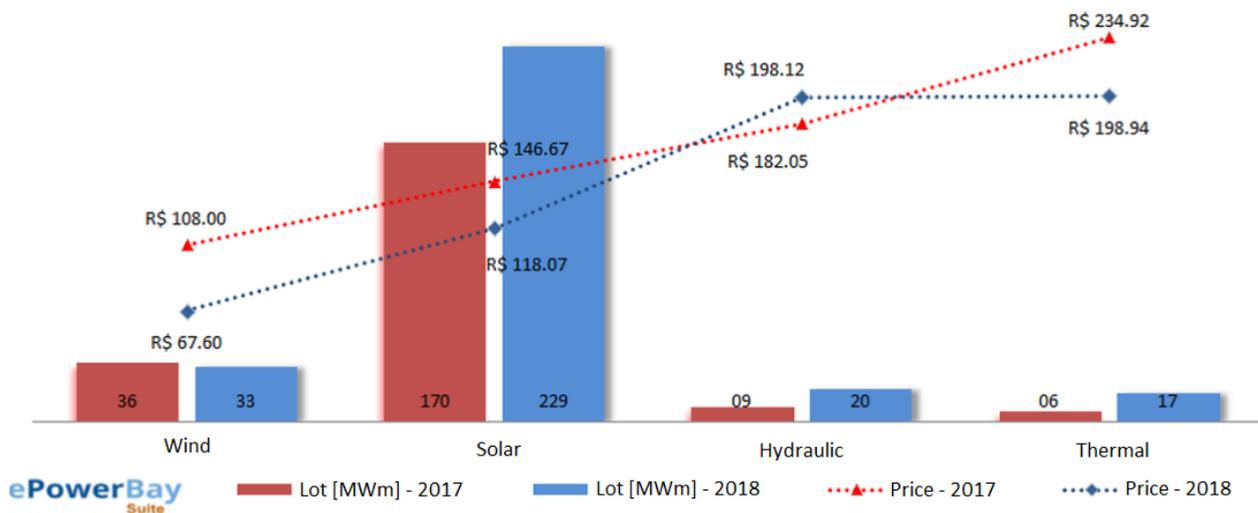


Figure 1 - A comparison between the A4 Auction realized in 2017 and 2018. Edited from EPowerBay, 2018.

The auctions can stimulate the market but they need the rules and other incentives to settle down as good investments. ANEEL regulates the energy market in Brazil and since the beginning of decentralized generation they guide the producers through resolutions. As an example, there is the REN 482/2012 (ANEEL, 2012) and the REN 687/2015 (ANEEL, 2015) – both are related to the same purpose and the second it is sort of an update of the first – it established the main frame and overall conditions for distributed micro generation and distributed mini generation to access the distributed electric system and compensation electric system. The main points for this topic are:

- a. The generation must come from hydraulic, solar, wind, biomass or qualified cogeneration;
- b. The definition of micro and mini generation: micro is generation less than 75 kW and mini is from 75 kW to 5 MW;
- c. It is forbidden to split the generation systems in order to fit into the limits of distributed generation;
- d. Compensation system is a free loan of active energy from the consumer to the distributor and subsequently compensation from the distributor to the consumer;
- e. Complex with several final consumers is characterized by an unique generation system with several consumers at the same property, each one of them using a fraction of the produced energy;
- f. Shared generation is characterized by the union of several consumers under the same permission each one of them with its own generation system functioning as only one.
- g. Self-remote use is characterized by several spread unities under the same ownership using the same generation system;
- h. The consumer has a maximum of 60 months to use the energy credit;
- i. There is a minimum charged for each group of consumers defined by the REN 687/2015;

- j. The distributor is technical and financially responsible for the measurement system for distributed micro generation;
- k. The costs for the measurement system and connection of distributed mini generation systems are responsible of the consumer.

Other two important regulation marks are: Covenant ICMS 16/2015 (CONFAZ, 2015) and Law 13169/2015 (Casa Civil, 2015). The first one authorizes exemption of ICSM (Tax on Circulation of Goods and Transportation and Communication Services) for energy under the REN 482/2012. The second authorizes exemption of PIS/COFINS (Programa de Integração Social and Contribuição para Financiamento da Seguridade Social) for energy under the REN 482/2012.

Within the solar topic, electric vehicles (EV) are moving the technology development towards better efficiency and fast charge/response. In 2017 the EV sales growth was around 50% globally, led by China (EV-Volume, 2018) – it could mean that the consumption peak hours will be spread throughout the day because of the number of cars charging while people are working. Brazil is also moving forward with the EV regulations and recently ANEEL approved the minimum requisites for electric recharge stations (ANEEL, 2018).

Shifting to local industry development, credit lines and quality control – those are delicate issues. The industry is supposed to be developed from the investments but then if the national product does not have quality, the investor will prefer to import main assets. Even taking into account the numbers mentioned before, the taxes and interest rates are higher than other countries with less natural resources. As an example, Spain was pioneer in CSP and its regulations, subsidized the industry. Luis Crespo, president of the European Solar Thermal Electricity Association (ESTELA) said that “In the summer months CSP is supplying 4% of the country’s needs. Very often we provide 8% or even a record 10% of the demand (SolarPACES, 2018).” There are almost ten years of data about CSP in Spain and the numbers show this technology ability to help the grid year after year. The Brazilian scenario is slowly changing and starting to show progress regarding the development of technology – the first national heliostat was designed at University of São Paulo (USP) in Pirassununga by the SMILE team (Solar-Hybrid Microturbine Systems for Cogeneration in Agro-Industrial Electricity and Heat Production). This project has two power plants and strong partnerships such as the German Aerospace Center (DLR) (Solar Thermal World, 2018). Along with national technology development, some installations are pushing forward the use of solar energy such as: Solar Park Nova Olinda (Ribeira do Piauí, PI), Solar Park Lapa (Bom Jesus da Lapa, BA) and Blue City Power Plant (Tubarão, SC).

A study by Assunção and Schutze (2017) gathered information about solar radiation in Brazil and PV panels; further along with IBGE database they plotted the graph shown bellowed that correlates it. Figure 2 shows that the majority of PV panels are installed where it is known that GDP (Gross Domestic Products) is above average and the solar radiation below average. In summary, in Brazil the region where there is more solar radiation is where people need more external investments because GDP is below average and they cannot manage to pay for a PV system.

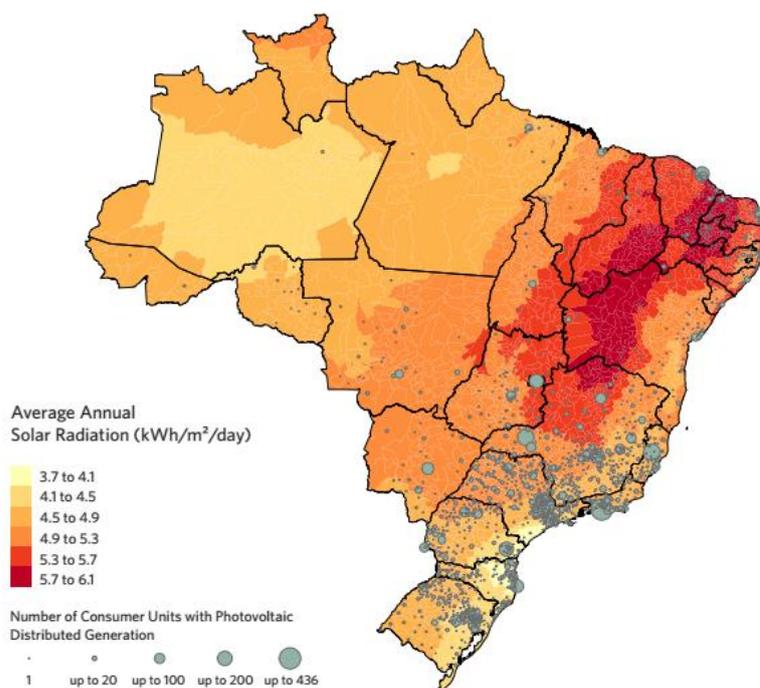


Figure 2 – An infographic showing the average annual solar radiation and the number of consumer units with PV distributed generation (ASSUNÇÃO; SCHUTZE, 2017).

Directly connected to wind and solar energy, the intermittency is a critical factor to blend in these sources due to high fluctuation of generation. There are several models to predict with high precision the wind and radiation however they cannot change it. So if there will be a lot of variation predicted for that day, there are great chances of curtailment. The reason for curtailment can be basically two: the lack of energy (or high variation) and excess in generation.

The fluctuations, the grid management and the response to the demand together create the grid flexibility. This is how the system reacts if there is variation and what speed it does (ramp in response). The generators and the cycle used by the power plants help to increase the flexibility – gas fired turbines and internal combustion engines are considered to be the best (high speed to start, low cost and wide range of operation). High flexibility allows wind and solar energy to increase its share of contribution and decrease the LCOE. Decentralized generation also helps to increase flexibility and it can work as a so called “smart grid”. This kind of systems uses local network (power lines, substations, transformers, etc.) and technology to communicate between the utility and its customers so it can shift loads and prevent blackout.

Solar panels help to create this decentralized generation and electric vehicles along smart grids could be used to normalize the energy delivered. As an example, Figure 3 shows how decentralized generation helps to do it. If the grid is smart and flexible, there are great chances to decrease the LCOE. Another feature that helps to decrease LCOE is energy storage.

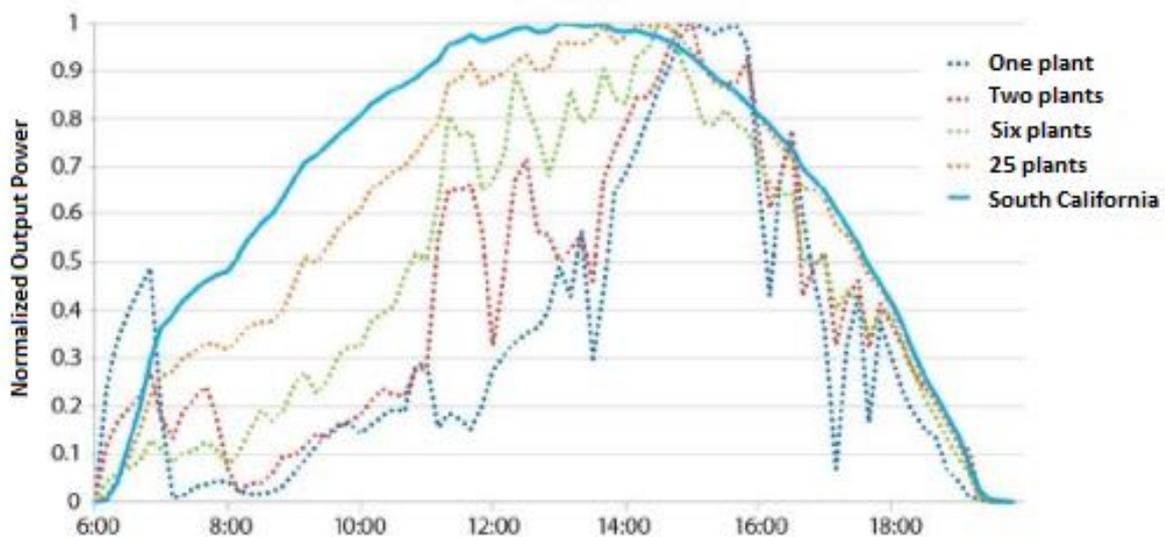


Figure 3 – Normalized output power from solar PV power plants in South California, U.S.A. Edited from (TOLMASQUIM, 2016 apud Lew et al., 2013).

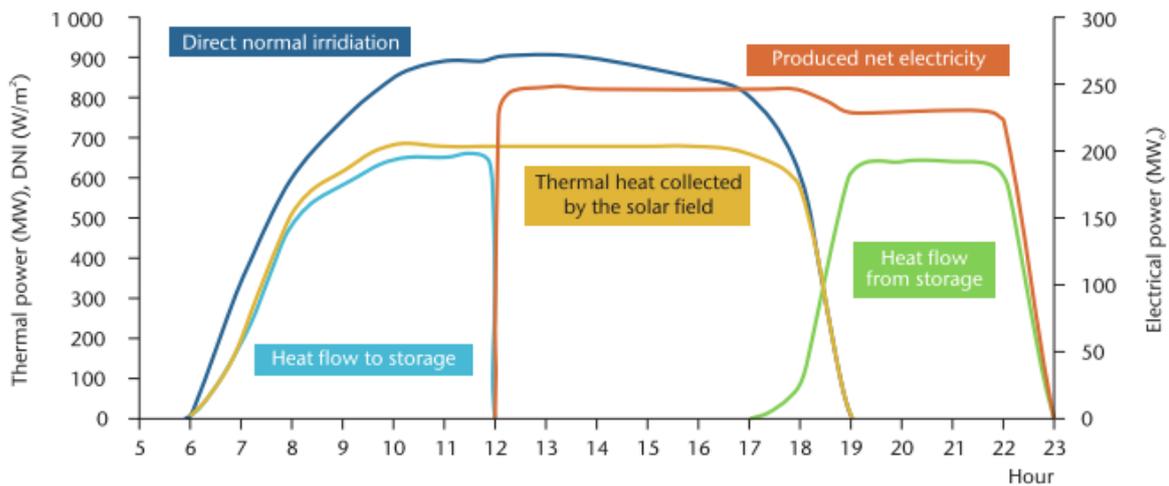
#### 4. ENERGY STORAGE

Energy storage is the basic back-up for variations of generation in power plants and high demand off-peak production. Therefore it has to be fast enough to provide extra power when needed and large enough to cover the demand. The power plant should be able to manage between production and storage – it also has directly relation with how the power plant is operating and integrated in the grid. This is why the management of the grid is very important and the variations should be as low as possible – as an example, the wind and PV plants could be used during the day to cover the basal energy demand while the CSP plant stores the energy to provide it by the afternoon and night due to the large storage. It is important to plan ahead how to operate the power plant because of two main reasons: first is to avoid partial demand (low efficiency) in the power block, and second to avoid several start/stop operations (high cost). The second point controversial by reason of solar power plants are totally dependent on the sun and its radiation. Wind power plants does not have energy storage and it has becoming a must have for all new solar power plants.

There are several ways to storage energy, such as mechanical mechanisms, magnetic mechanisms, chemical reactions, biological mediums and thermal energy. Usually PV technology is coupled with chemical energy storage (battery). A battery usually have a super-fast response but it does not have a large energy density (if compared with molten salt). Therefore it has to be stack by the hundreds to provide a reliable large storage. Recently the world’s largest lithium-ion battery was installed in Australia – 100 MW facility powered by Tesla technology (The Verge, 2017). In the first month of operation they register an efficiency around 80%. Logan Goldie-Scot, BNEF’s head of storage says in the clean energy predictions for 2018 that “Lithium-ion battery pack prices will continue to drop in 2018, but at a slower pace than in previous years. We expect average pack prices to decline by 10-15%, driven by economies of scale, larger average pack sizes and energy density improvements of 5-7% per year.” These predictions are even more optimistic by Ericson et al.,

(2018) when mentioned battery prices – the forecast is to decline 50% from 2016 levels by 2020 (apud D'Aprile et al., 2016), and total capital costs for battery storage projects are estimated to decrease by 38% between 2016 and 2021 (apud Lazard, 2016a).

CSP stores energy as thermal energy (TES). Heat can be stored as sensible heat, latent heat and thermo-chemical. Water, thermal oils, molten salt, liquid metals and solid mediums (concrete blocks and packed beds) are some ways to store sensible heat which depends on the temperature difference. Molten salt is the most consolidated option however it has some drawbacks such as the need for an auxiliary boiler to avoid freezing the molten salt and the maximum temperature of operation. Phase change materials have become a trend topic in the academic world as a way to store latent heat. Specific latent heat is higher than specific sensible heat therefore, for the same mass, the temperature gap to released/absorbed the same amount of energy of a phase change is very high. Thermo-chemical heat storage happens only through reversible reactions. Unfortunately CSP technology is not a reality in Brazil yet however there are a couple initiatives, to mention: Helioterm (Petrolina, PE), SMILE (Pirassununga, SP), Solar Thermal Laboratory (UNIFEI, SP) and Projeto Energia Heliotérmica (Brazil-Germany). Large scale TES proved itself as cheaper and more efficient than most electric storage systems (Esence et al., 2017 apud (Philibert, 2011; Sabihuddin et al., 2015). The theory behind thermal energy storage is simple: the excess heat during the day is channeled to the storage material and later on is used, as shown in Figure 4. When the same heat transfer fluid is used to produce and store energy it is called direct storage and when there is an extra heat exchanger it is called indirect storage.



Notes: the graph shows on left scale the DNIR and the flows of thermal exchanges between solar field, storage and power block, and on the right scale electricity generation of a 250-MW (net) CSP plant with storage. Courtesy of ACS Cobra.

Figure 4 – The framework behind thermal storage - it shows the produced net electricity based on how the heat is used. (IEA, 2014).

TES systems are usually have the following functions: (i) mitigate short fluctuations during cloud covered periods and low radiation; (ii) shift the generation from off-peak to on-peak demand periods and; (iii) extend the generation time (Alva et al., 2018; Liu et al., 2016). As main consequences there will be an increase of the capacity factor, which is the ratio between the operational hours and the total operational hours possible, and the decrease in LCOE. The design of TES must considered capacity and size of storage, intended power, operating temperature range, efficiency and cost (Cabeza, 2014; Kuravi et al., 2013). As mentioned before the LCOE can be the base for comparison among several technologies and the capacity factor shows how storage can improve the efficiency. It is very hard though to gather reliable information.

An important definition to understand how storage and capacity factor can be modified is the solar multiple (SM): the ratio of the designed thermal energy from solar field and the designed load of power block (Lodi, 2011 apud Cardemil e Colle, 2010). This value represents how big is the solar field in comparison to the size it would be if designed to generate only the designed capacity of the power block. Example: if the solar multiple is two, it means that the solar filed can generate twice as the rated power of the power block. Usually the SM is above one because the solar field rarely operates at its designed capacity and it is higher if storage is used. Table 1 and Table 2 show a simple comparison among some renewables and configurations. As expected, Table 1 shows a higher capacity factor for the CSP baseload which has a SM of three and 15 hours of storage. The solar label in Table 2 only represents PV. Hydropower still holds the maximum capacity factor followed by CSP Baseload.

A report Exploring the Potential Competitiveness of Utility-Scale Photovoltaics plus Batteries with Concentrating Solar Power, 2015 – 2030, written in 2016 commissioned by the National Renewable Energy Laboratory (NREL) models different scenarios where the deployment of PV and CSP with storage is compared based on the LCOE for the same

output capacity and solar multiple/inverter loading ratio (ILR) – it is the PV compatible for SM – it measures “the ratio of the PV modules to the inverter AC rating. By increasing the ILR, a greater amount of energy is collected, and sent either to the grid or to storage” (Feldman et al., 2016). The conclusion shows how the different scenarios interact and topics like the penetration of solar in the generation grid, the storage size and how the power plant operates.

Table 1. Capacity factor and annualized net grid cost (approximations) for different configurations of PV and CSP for the same capacity. Edited from (Mehos et al., 2017)

Technology	Capacity Factor (%)	Annualized Net Grid Cost (\$/kW-yr)
PV + Combustion Turbine	12.0	220
PV + Battery	43.9	From 400 to 1500
CSP Peaker (SM = 1, 6 h TES)	24.5	380
CSP Intermediate (SM = 2, 9 h TES)	47.9	400
CSP Baseload (SM = 3, 15 h TES)	67.8	580

Table 2. Capacity factor of the plants from the last A-4 auctions in Brazil. Edited from EPowerBay, 2018.

A-4 2017			A-4 2018		
Source	Capacity (MW)	Capacity Factor (%)	Source	Capacity (MW)	Capacity Factor (%)
Wind	64	59.4	Wind	57.2	53
Solar	75	26.4	Wind	57.2	47.9
Solar	240	34.0	Solar	30	34
Solar	90	29.1	Solar	210	34
Solar	57	31.2	Solar	30	34
Solar	112	24.3	Solar	179.9	28
Biomass	25	34.4	Solar	90	30.3
Hydraulic	1512	60.2	Solar	79.9	27.9
Hydraulic	10	85.9	Solar	120	25.8
			Solar	66.9	26.5
			Biomass	40	60.5
			Biomass	21.8	47.2
			Hydraulic	22.4	50.5
			Hydraulic	12.2	51.4

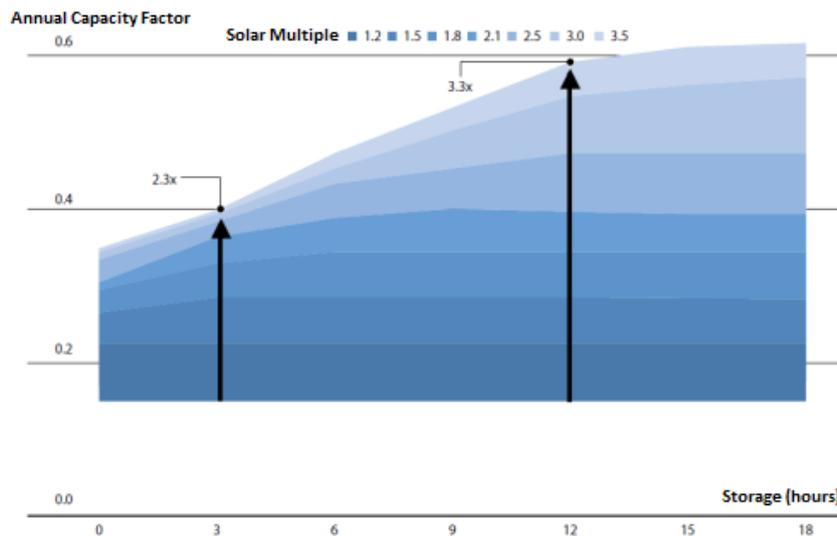


Figure 5 – Variability of capacity factor as function of storage and solar multiple. Edited from (TOMALSQUIM, 2016).

Figure 5 shows how three very important technical indicators are related – all kinds of combinations could be done based on this graph. It is important to notice that the limitation for annual capacity factor is due to several reasons, such as physical space of the site, temperature, storage medium and available radiation. Physical space is a problem when the

topic is decentralized generation and it is also a problem when the land to build the power plant is extremely expensive. The high energy density of the storage system can help to save space because they are usually very big in the case of batteries. As it shown in Figure 5, the increase in storage hours leads to an increase in capacity factor. The temperature plays an important role – if it is very high the performance of the PV panels are decreased and also the heat transfer between the panel and the environment. In the concentrated solar power plant, the temperature does not prejudice the performance of the mirrors, however the heat transfer fluid has to be cooled down every cycle and if the temperature difference is not high, it will return to the system hotter meaning less radiation absorbed from the sun.

The radiation absorbed from the sun also depends on how much is available. In Brazil there is a range covering from Midwest to Northeast as shown previously on Figure 2. The average radiation for a CSP power plant is 5.4 kWh/m<sup>2</sup>/day and there is no restriction for PV panels (Lodi, 2011). A study made by Shayani and Mathyas (2016) estimated that only 0.41% of the Federal District region is enough to cover the demand of the federal capital.

## 5. CONCLUSIONS

The analysis made showed that Brazil is moving forward the expansion of grid flexibility. Among the renewables, hydropower is dominant followed by wind and photovoltaic (PV). Other than PV, concentrated solar power (CSP) had a big initiative with Projeto Energia Heliotérmica – a partnership between Brazil and Germany had great output encouraging the academy to study this topic. It accomplished four national congresses, nine technical visits and 14 research and development project, among others. Still, CSP is not mentioned yet in reports about solar energy.

The benefits about the use of renewable energy is very clear and it is spread nationally. Future and contemporary structures of buildings are more environmental friendly and some of them have the internationally recognized green building certification LEED (Leadership in Energy and Environmental Design). Shapes and materials are developed every semester with astonishing results for the smallest to the largest applications.

In order to increase the share of other renewables in the generation mix there are some gaps and challenges that are worth mentioned: (a) to map the local industry upgrading old manufacturing plants, leading the transformation towards an industry with high technology and designed to serve the renewable infrastructure; (b) to increase the number of energy auctions in the renewable sector in order to motivate big players to move their pieces and install facilities in Brazil; (c) to increase quality and volume of transmission lines with the purpose of decrease losses in transmission and increase the range of the current grid because several solar/wind projects are based on locations where there is no infrastructure around; (d) to have a solid policy framework for renewables along heavy academic/governmental studies to predict the demand and necessity; (e) to promote research and development, and support from investors by doing all the points mentioned before. By the end of the process it is important to have a competitive LCOE, as shows the Figure 6. The comparison is from 2010 and the hatched area is the LCOE for fossil fuels. Since 2014 a lot has changed therefore the update of those information helps to track how good/bad the topics mentioned above are doing, as well the technical studies behind it.

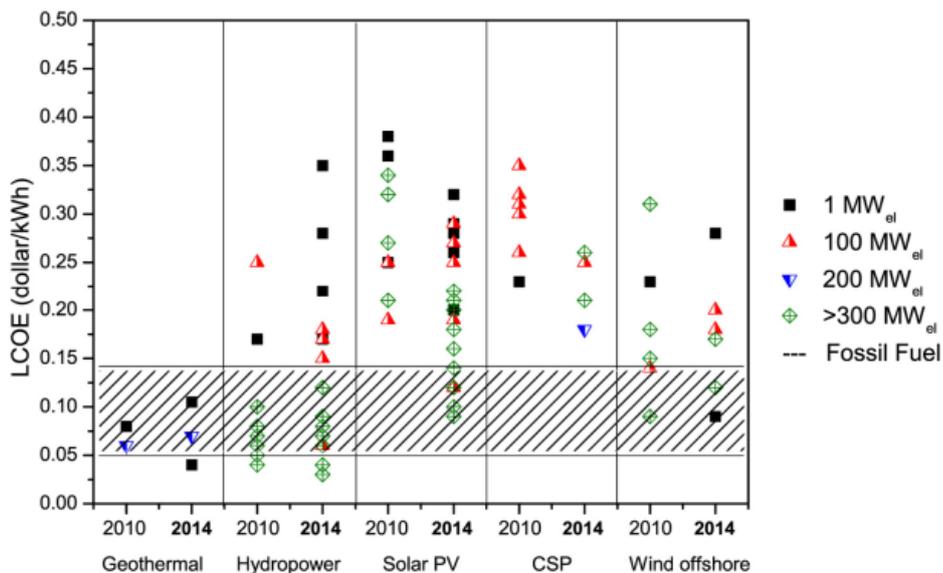


Figure 6 – LCOE for several technologies. (Zhang et al., 2016 apud Bilgili et al., 2013).

## 6. REFERENCES

- ABRACEEL, 2017. Pesquisa de Opinião Pública Sobre Energia Elétrica.
- ABSOLAR, 2018. "Associação Brasileira de Energia Solar Fotovoltaica". 28 March, 2018. <<http://www.absolar.org.br>>.
- Alva, G., et al., 2018. An overview of thermal energy storage systems. In *Energy*, v. 144, p. 341–378.
- ANEEL, 2018. "Agência Nacional de Energia Elétrica". 19 June, 2018. <<http://www.aneel.gov.br>>.
- ANEEL, 2012. Resolução Normativa No 482. 25 June, 2018. <<http://www2.aneel.gov.br/cedoc/bren2012482.pdf>>.
- ANEEL, 2015. Resolução Normativa No 687. 25 June, 2018. <<http://www2.aneel.gov.br/cedoc/ren2015687.pdf>>.
- Assunção, J. and Schutze, A., 2017. Developing Brazil's Market for Distributed Solar Generation. *Developing Brazil's Market for Distributed Solar Generation*. <[https://climatepolicyinitiative.org/wp-content/uploads/2017/10/Working\\_Paper\\_-\\_Distributed\\_Solar\\_Photovoltaic\\_Generation\\_in\\_Brazil.pdf](https://climatepolicyinitiative.org/wp-content/uploads/2017/10/Working_Paper_-_Distributed_Solar_Photovoltaic_Generation_in_Brazil.pdf)>.
- BIG, 2018. "Banco de Informações de Geração". 28 March, 2018. <<http://www2.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm>>.
- BNEF. "The Force Is With Clean Energy: 10 Predictions for 2018". *Bloomberg New Energy Finance*. 09 Feb., 2018. <<https://about.bnef.com/blog/clean-energy-10-predictions-2018>>.
- Bloomberg New Energy Finance, 2016. "Climatescope 2016". 10 May, 2017. <<http://global-climatescope.org/en/>>.
- Bloomberg New Energy Finance, 2017. "New Energy Outlook 2017". 16 June, 2017. <<https://about.bnef.com/new-energy-outlook/>>.
- Cabeza, L. F., 2014. *Advances in Thermal Energy Storage Systems*. Woodhead Publishing, 1st edition.
- Casa Civil, 2015. 27 June, 2018. <[https://www.planalto.gov.br/ccivil\\_03/\\_ato2015-2018/2015/lei/l113169](https://www.planalto.gov.br/ccivil_03/_ato2015-2018/2015/lei/l113169)>.
- CONFAZ, 2015. 27 June, 2018. <[https://www.confaz.fazenda.gov.br/legislacao/convenios/2015/CV016\\_15](https://www.confaz.fazenda.gov.br/legislacao/convenios/2015/CV016_15)>.
- EIA, 2014. "Brazil." *Energy Information Administration*. 22 June, 2018. <<https://www.eia.gov/beta/international/analysis.php?iso=BRA>>
- Ericson, S. et al, 2018. Power couples: The synergy value of battery-generator hybrids. *The Electricity Journal*, v. 31, n. 1, p. 51–56, 2018.
- Esence, T. et al., 2017. A review on experience feedback and numerical modeling of packed-bed thermal energy storage systems. In *Solar Energy*, v. 153, p. 628–654.
- EpowerBay, 2018. 25 March, 2018. <<http://www.epowerbay.com>>.
- EV-Volume, 2018. 28 June, 2018. <<http://www.ev-volumes.com>>.
- Feldman, D. et al., 2016. Exploring the Potential Competitiveness of Utility-Scale Photovoltaics plus Batteries with Concentrating Solar Power, 2015 – 2030. 10 May, 2017. <<https://www.nrel.gov/docs/fy16osti/66592.pdf>>.
- Gazeta, 2018. 20 June, 2018. <<https://www.gazetaonline.com.br/noticias/economia/2018>>.
- Guerra, J. P. M. et al., 2014. Comparative analysis of electricity cogeneration scenarios in sugarcane production by LCA. In *International Journal of Life Cycle Assessment*, v. 19, n. 4, p. 814–825.
- IEA, 2014. "Technology Roadmap: Solar Thermal Electricity". 15 June, 2015. <[https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarThermalElectricity\\_2014edition.pdf](https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarThermalElectricity_2014edition.pdf)>.
- IEA, 2016. "Energy Matters 2016". 24 May, 2017. <[http://www.antisce.org/sites/antisce.org/files/an\\_tasice\\_energy\\_matters\\_2016.pdf](http://www.antisce.org/sites/antisce.org/files/an_tasice_energy_matters_2016.pdf)>.
- IEA, 2016. "Energy Efficiency Market Report 2016". 25 May, 2017. <[https://www.iea.org/eemr16/files/medium-term-energy-efficiency-2016\\_WEB.PDF](https://www.iea.org/eemr16/files/medium-term-energy-efficiency-2016_WEB.PDF)>.
- IEA, 2016. "Energy and Air PollutionWorld Energy Outlook - Special Report". 25 April, 2017. <<https://www.iea.org/publications/freepublications/publication/WorldEnergyOutlookSpecialReport2016EnergyandAirPollution.pdf>>.
- IRENA, 2016. "Renewable Energy Market Analysis: Latin America". 10 May, 2017. <<http://www.irena.org/publications/2016/Nov/Renewable-Energy-Market-Analysis-Latin-America>>.
- IRENA, 2017a. "Renewable Capacity Highlights." 10 June, 2018. <[http://www.irena.org/DocumentDownloads/Publications/RE\\_stats\\_highlights\\_2017.pdf](http://www.irena.org/DocumentDownloads/Publications/RE_stats_highlights_2017.pdf)>.
- IRENA, 2017b. "Planning for the Renewable Future". 9 May, 2017. <[http://www.irena.org/DocumentDownloads/Publications/IRENA\\_Planning\\_for\\_the\\_Renewable\\_Future\\_2017.pdf](http://www.irena.org/DocumentDownloads/Publications/IRENA_Planning_for_the_Renewable_Future_2017.pdf)>
- Kuravi, S. et al., 2013. Thermal Energy Storage Technologies and Systems for Concentrating Solar Power Plants. In *Progress in Energy and Combustion Science*, v. 39, n. 4, p. 285–319.
- Liu, M. et al., 2016. Review on Concentrating Solar Power Plants and New Developments in High Temperature Thermal Energy Storage Technologies. In *Renewable and Sustainable Energy Reviews*, v. 53, p. 1411–1432.
- Mehos, M. et al., 2017. "Concentrating Solar Power Gen3 Demonstration Roadmap NREL/Tp-5500-67464". 10 Jan., 2018. <<http://www.nrel.gov/docs/fy17osti/67464.pdf>>.
- Ministério de Relações Exteriores, 2018. "Brasil dá início a processo de adesão à IRENA." 20 Feb., 2018. <<http://www.itamaraty.gov.br>>.
- MME/EPE, 2010. "Plano Decenal de Expansão de Energia 2019". 10 Jun., 2018. <<http://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-40/PDE2026.pdf>>.

- MME/EPE, 2017. "Plano Decenal de Expansão de Energia 2026. 20 Dec., 2017. <<http://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-40/PDE2026.pdf>>.
- Shayani, R. A. and Mathyas, A. Da M, 2016. "Potencial da Energia Solar Fotovoltaica de Brasília". 10 June, 2018. <[https://www.wwf.org.br/informacoes/noticias\\_meio\\_ambiente\\_e\\_natureza/?55102](https://www.wwf.org.br/informacoes/noticias_meio_ambiente_e_natureza/?55102)>.
- SETO, 2018. "Solar Energy Technologies Office". 20 Feb., 2018. < <https://www.energy.gov/eere/solar/concentrating-solar-power>>.
- Solar Thermal World, 2018. 25 June, 2018. <<http://www.solarthermalworld.org>>.
- SONDA, 2018. 23 June, 2018. < <http://sonda.ccst.inpe.br>>.
- Taylor, M, 2015. "Renewables: The True Costs". 23 Oct., 2017. <<http://www.irena.org/-/media/Files/IRENA/Costs/Videos-and-Webinar/IRCA-and-Coalition-WebinarEnglishUpload.pdf?la=en&hash=2634FDF115A878706B2424C44A634C8D09C1330C>>.
- The Verge, 2017. 21 March, 2018. < <https://www.theverge.com>>.
- Tomalsquim, M. T., 2016. Energia Renovável: Hidráulica, Biomassa, Eólica, Solar, Oceânica. Empresa de Pesquisa Energética. Rio de Janeiro, Brazil.
- Turconi, R. et al., 2013. Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations. In Renewable and Sustainable Energy Reviews, v. 28, p. 555–565.
- United Nations Framework Convention on Climate Change, 2015. "Paris Agreement". 25 May, 2017. <[http://unfccc.int/files/essential\\_background/convention/application/pdf/english\\_paris\\_agreement.pdf](http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf)>.
- Zhang, H. et al., 2016. Thermal Energy Storage: Recent Developments and Practical Aspects. In Progress in Energy and Combustion Science, v. 53, p. 1–40.

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