CONCENTRATING SOLAR POWER: A GLOBAL OVERVIEW AND THE POTENTIALITY IN BRAZIL FOR ELECTRICITY GENERATION

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Abstract:
The new renewable energies has been growing consistently in recent years in the world, indicating a process of global energy transition. In this context, use of technologies that take advantage of Concentrating Solar Power (CSP) for large-scale electricity generation is relatively recent. Compared to the installed global capacities of wind power and solar photovoltaic technologies, the installed capacity of CSP technologies is still very incipient and small. However, it has shown growth and is one of the promising renewable energy types. Thus, this work aims: to present an overview of the CSP technologies; to carry out an exploratory study on the current situation of CSP energy in the World and in the Brazil; and to show the possibility of implantation in Brazil. There are no still heliothermal power plants in commercial operation in Brazil, but there are some pioneer research power plants and there is a region, called the Solar Belt, with potential for implementation of these power plants. Results obtained The results found were: A great power potential to be explored by CSP in World and in Brazil is available; The CSP technologies are underused because your cost is yet high in comparison with wind and solar PV power; Until this moment, there is no politic and regulatory decision for help in the CSP commercial projects implantation in Brazil.

Keywords: Renewable Energy, CSP (or heliothermal energy), Brazilian Solar Belt.

1. INTRODUCTION

Societies and productive systems evolution implies in greater demand for availability energy to sustain the human progress. Consequently, world supply of energy is growing and diversifying continuously in terms of source types to attend demand. With the expansion of renewable energy use in recent years, a large-scale market has emerged. This allows for systematic investments in technological advances and feasibility of significant reduction in the costs of new technologies. This is making the renewable energy increasingly competitive and financially attractive for electricity generation. Wind and solar power sources have been the most expanding renewable energies in the world today.

In relation to solar energy, the electricity generation that most expanded was PV solar. However, there is also great global potential for the use of CSP (or heliothermal energy, or solar thermal concentration) in electricity generation. Brazil still does not have CSP commercial plants in operation, but there are some research power plants that are already in more advanced stages. In addition, there is a great power generation potential in large area in Brazil. This work presents an overview of the CSP technologies and your use in the World and in Brazil and the possibilities of implantation in Brazil.

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2. METHODOLOGY

The methodology used was an exploratory survey to collect data from national and international agencies and research technical-scientific articles available to the public. The three hypotheses presented are: (i) There is a great potential to be explored by CSP in World and in Brazil; (ii) CSP energy is underused; (iii) There is no yet politic decision about CSP energy implantation in Brazil.

3. LITERATURE REVIEW

Due to the worldwide population growth and industrialization, the demand of energy has been dramatically increasing. Renewable energy, which can be obtained from natural resources such as wind, solar, biomass and geothermal, has been encouraged by many countries due to the advantages of being sustainable and not contributing to the world's CO_2 GHG emissions [1]. Issues related to environmental preservation, climate change, advances in legislation, public opinion and sustainability have been influencing the expansion of the use of renewable sources. According to [2, 3], renewable energies are essential for an energy transition, reducing the consumption of fossil fuels and enabling a low carbon economy. [4] commented due to planning and energy security, several countries seek to diversify their available energy bases via alternative sources. China, Brazil, Spain, India and USA are some these countries.

With the growing concerns on energy security and climate change, countries across the world are undertaking measures to deploy Renewable Energy and promote Energy Efficiency. Apart from the direct benefits that these activities bring such as reduced greenhouse gas emissions, reduced energy use, etc., there are number of socio-economic benefits that these activities create; job creation being one of them. It is therefore interesting to see the economic effect of renewable energy adoption from an employment perspective [5].

The renewable energies (wind, solar, biomass, etc.) are alternatives that are economically viable and expanding more and more compared to traditional energies (fossil fuels) in several countries [6]. Among every renewable resources (e.g., wind, ocean, geothermal and solar), solar energy is showing encouraging promises due to the great quantities of solar irradiation flux arriving on earth [7].

The CSP technology makes use of the sun's right radiation. Thus it is important to evaluate their potential in the different places that are characterized as places with good measurements of right radiation. The ability to exchange heat with systems and eventually be stored is one of the great technical potentials of the technology. However costs are not yet competitive as countries do not manage incentive policies [8]. There are basically four CSP technologies: Fresnel linear reflectors; parabolic cylindrical concentrator (or parabolic trough collector); solar towers (with Central Receiver); solar parabolic dish Stirling. These to concentrate incoming sunlight on a relatively small target area using mirrors to produce enough thermal energy to drive a heat engine [9-21]. The investment costs for CSP plants depend on the technology/configuration used and their commercial maturity, the solar radiation of the project location and the capacity factor, which in turn depends on the size of the storage system and the size of the solar field. In addition, the investment cost also depends on the specific factors of each country, such as the cost of capital and labor [22]. These technologies, although they are still high costs and incipient in electric generation, are very promising and may represent a future strategic energy alternative. Spain [23, 24], USA [25], India [14, 20, 26, 27] and China [28, 29, 30] are countries that use CSP technologies.

Unlike PV systems which are capable of converting both diffuse and direct solar radiation into electricity, CSP technology relies only on DNI for effective operation [9, 31, 32]. Thus limiting its deployment and future dissemination to the subtropics between latitudes 15° and 40° where the skies are reliably clear and aerosol optical depths are low [9, 21].

CSP generates electricity from thermal heat, similar to fossil-driven thermal power plants, with the heat-source being inexhaustible concentrated solar irradiance. The thermal process, however, requires cooling, best achieved with a finite resource; water. CSP is ideally suited to areas of high solar irradiation, typically arid and water stressed. The need for water as a source of cooling is often neglected in the planning and development of CSP [33].

CSP plants bundle solar radiation using concentrating mirrors. The concentrated radiation is then transformed into thermal energy and used to power conventional steam and gas turbines or Stirling engines. CSP makes it possible to offer “power on demand” via heat storage and will be of particular interest for generation units between 200 and 400 MWel. It works as a regenerative alternative to conventional power generation technologies both for base load and peak load as well as for balancing varying power supply from wind and photovoltaic. Apart from producing electricity, the process heat emitted by CSP may be used to cool buildings and industrial processes, production of hydrogen or operation of facilities for the desalination of sea water [34].

The rapid global growth in the use of renewable energy to reduce GHG emissions and mitigate climate change, through the inclusion of large amounts of PV and wind in existing electricity grids, has highlighted certain challenges. Most critically, their intermittent supply, necessitates flexible dispatchability from other generators in the grid [33]. Some CSP technologies have a storage capacity for part of their produced energy that wind and solar PV technologies do not yet have. This allows for a better dispatch condition for CSP technologies with storage than wind and solar PV technologies.

CSP offers the value proposition of being a baseload and dispatchable renewable energy technology. CSP significantly lags behind solar PV and wind power by cumulative capacity and cost for a number of reasons including the complicated nature of the technology and the traditional inability of the technology to be economically viable at smaller scales. The scaling limitation itself has prevented the technology from learning faster due to limited market share, which has inhibited the learning rate and continued to make CSP project financing difficult due to finance quantum risks [35].

According to [28], the Chinese and Brazilian energy policies had not focused on CSP deployment. China and Brazil, emerging economies, have registered increases in energy demand and as growth of energy-related GHG emissions. However, since large scale deployment of CSP technologies still implies high LCOE. This could affect the competitiveness of national industry in global markets. Thus, there was no creation of national energy policies about large scale implantation of CSP. Consequently, the CSP has not benefited from the international demand that has boosted wind turbines and photovoltaic cells with their subsequent price reductions.

[29] affirmed that studying the economic performance is of great significance to the policy improvement and investment decisions making of CSP industry. In the case of China, your study developed a cost-benefit model to analyze the economic benefits of CSP industry, under the current technological level and policy system of China.

The results showed that: Firstly, the huge initial costs resulted in that the investment of CSP industry had to bear a long capital recovery period, which might add the investment risks; meanwhile it was still economically feasible because of better expected benefits. Secondly, for CSP industry, the internal rate of return mainly varied from 8% to 12%, and the average levelized cost of energy was $0.148/kWh; the economic performance of CSP industry was attractive from the multiple dimensions analysis, and the benchmark feed-in-tariffs could provide effective support for the CSP industry development of China. Thirdly, adopting solar tower CSP technology was better choice to improve the economic benefits of CSP industry, compared with parabolic trough and linear Fresnel CSP technologies. Lastly, the direct normal irradiation, initial costs, annual electricity production and loans ratio had important impacts on the economic benefits of CSP industry, and should be paid more attention in investment decisions [29]. As China's participation is normally a key factor in the fall in LCOE of a new renewable energy, the fact that it still does not have an energy policy aimed at the CSP hampers the expansion of the CSP worldwide. In general way, according to information of [36], the economic assessment of CSP yet need to more economic viability to development in large-scale in the world.

Still, for a sustainable market success without subsidies, their costs have to be further reduced. One key to cost reduction and for successful projects in general is ‘localization’. Localization here is defined as the process of adapting power plant type and design as well as system and component manufacturing methods to local conditions and production capabilities, and of increasing local capabilities [37]. In addition, [37-39] commented that desert regions are favourable to development of CSP power plants.

In countries like Brazil, the renewable energies are experiencing an important growth in recent years, mainly due to the current scenario of energy and water crisis in the Southern and Southeastern regions, which have been generating the need for development of Government programs aiming to ensure the maintenance of sustainable development [40, 41]. According to [42], the CSP was not competitive in the Brazilian electric power market in 2014. Until the present, the CSP is not yet competitive in Brazil.

4. SOLAR POWER POTENTIAL IN THE WORLD AND IN BRAZIL

Solar resource for potential energy generation is unevenly distributed across the surface of Earth. It is possible observe the existence of great potential available to CSP generation in the World and in Brazil with the Figure 1.

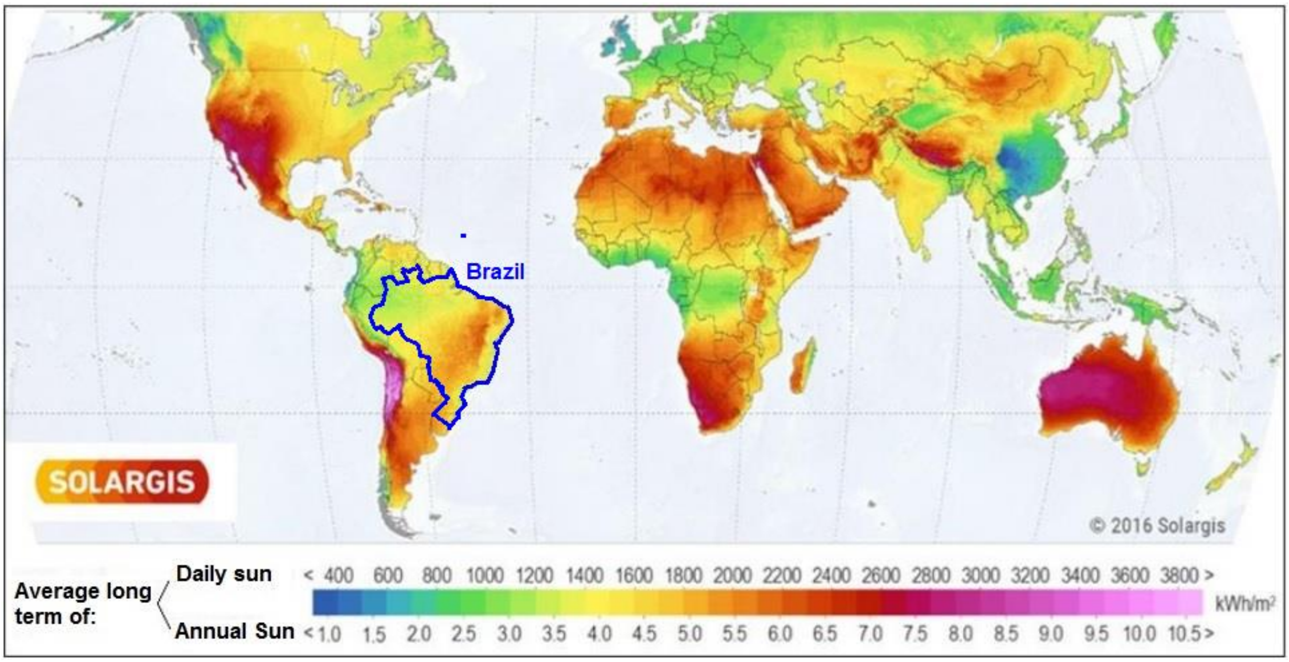

Fig. 1: Annual and Daily Normal Global Irradiation. Source: [43] (Adapted).

According to [44], there is a region in Brazil called “Solar Belt” (Figure 2) that presents conditions of ample potential for electricity generation through solar energy, due to the high irradiation rates.

In this solar belt there are extensive semi-arid regions with a daily direct normal irradiation in the order of 6 kWh/m², reaching 2,000 kWh/m² annually. [45], based in information of *Atlas Brasileiro de Energia Solar* [46] commented what Brazil has fairly uniform distribution of solar radiation, which varies little over the geography of the country. He said what an exception is the Amazon region, which has significant rainfall during the year and therefore isn´t attractive for large solar energy projects. He commented that in the Northeast, more specifically the semiarid, there is potential for CSP ventures. [47] commented that Northeast region contemplates the technical requirements for solar thermal energy exploitation in electricity generation of through CSP technology. Analyzed information indicates that "Solar Belt region", in the interior of Brazil, has adequate potential to receive CSP projects to generate electricity, with the semi-arid region being highlighted in the Northeast Region. [48] comments that there are immense areas of land available for solar thermal applications. For example, Januária and Itacarambi, in state of Minas Gerais, are two possible locations for CSP projects implementation, as they have: excellent topographic conditions; availability of water for cooling of power plants; road access; low wind speeds; and environment with moderate temperatures and little daily variation. These sites receive direct solar radiation between 1,800 kWh/m² and 2,300 kWh/m² annually and can accommodate solar thermal power plants on large scale. Still according to [48], the greatest potential is located in São Francisco River Basin and in Sobradinho-BA. Locations with great potential in Brazil are close to Equator Line, which offers an optical advantage since the radiation angle has lower annual variation. However, there is a need for further studies on efficient applications of each type of CSP technology and government actions to encourage its use.

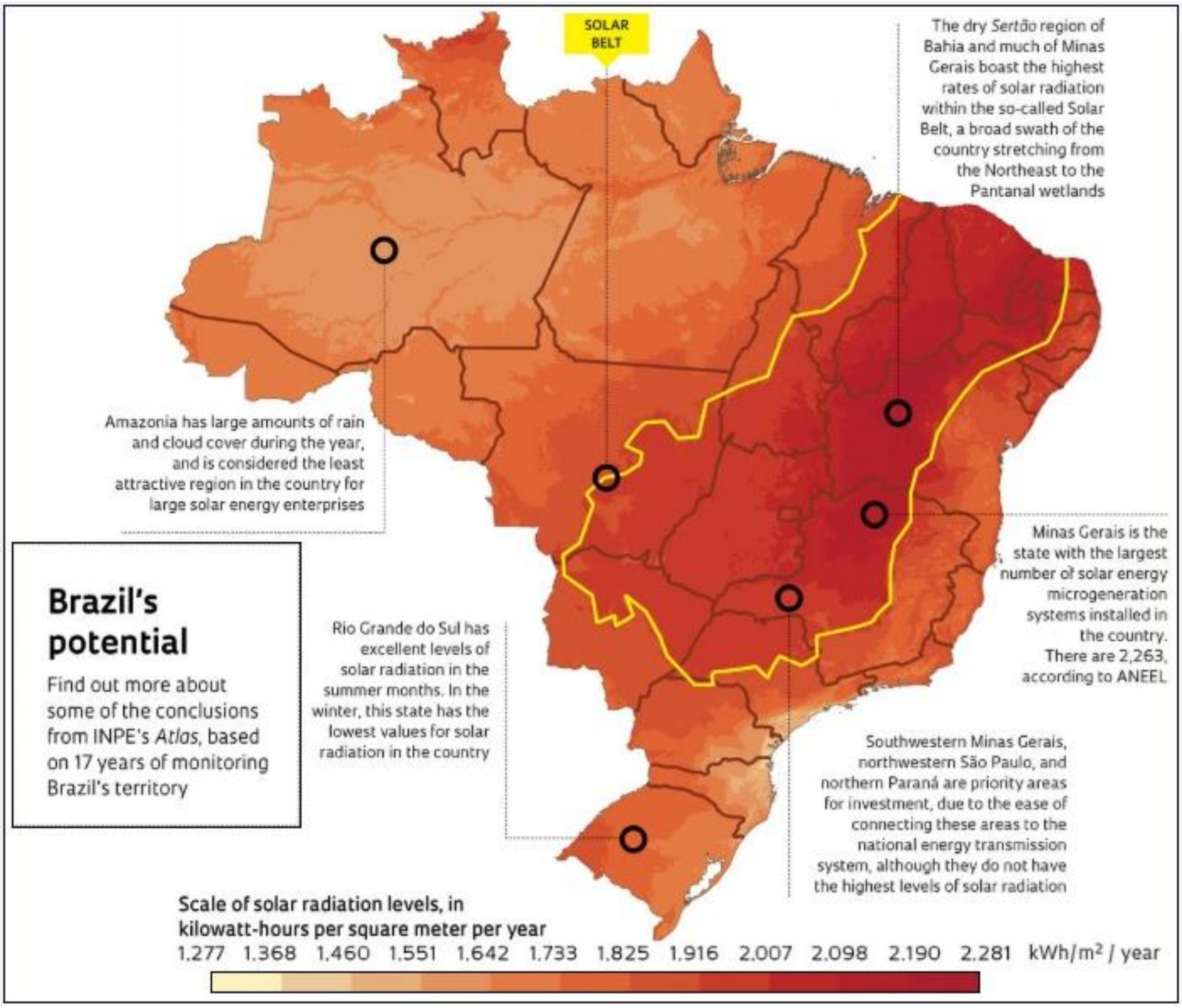

Fig. 2: Brazilian Solar Belt Region [44, 45] (Adapted).

According to [4, 6], there is energy complementarity of different sources in several regions of Brazil. This could be significantly increasing the gains in terms of efficiency and productivity of electricity generation from various sources, such as hydropower, wind and solar PV. That is, when certain energy sources are in periods of low productivity, other sources could partially or totally supply their energy deficits. Thus, heliothermal generation insertion can contribute to improve the global complementarity of renewable energies in the Brazilian electric sector since some CSP technologies have energy storage capacity.

5. COMPARISION OF WIND, PHOTOVOLTAIC AND HELIOTERMAL POWER GLOBAL COST AND INSTALLED CAPACITY EVOLUTION (2008–2018)

In the 2010-2018, [49] informed that the global weighted-average LCOE for commissioned onshore wind and PV solar power projects were more competitive than CSP cost range, even in the absence of financial support (Figure 3). The LCOE for fossil fuel costs projects was competitive and cheaper than CSP. So, there is economic preference of investment in wind and PV solar power. These are difficult factors to CSP technologies development and expansion in the World.

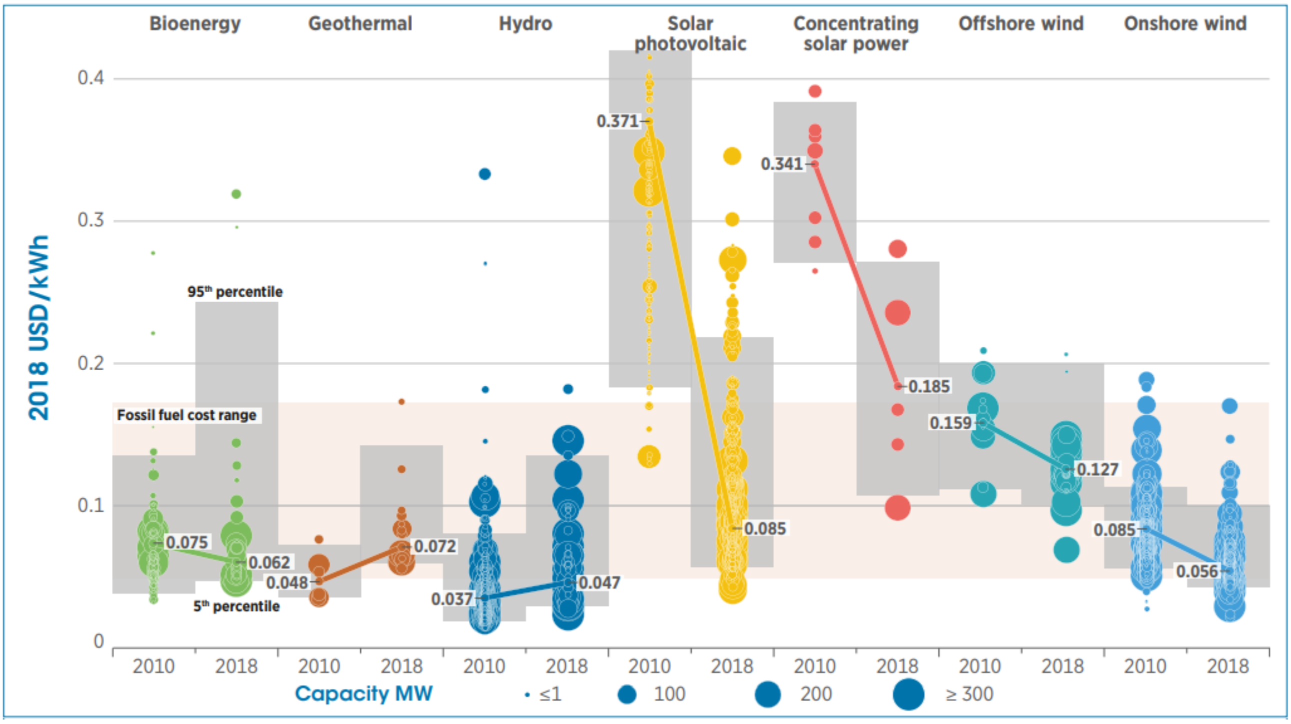

Fig. 3: Global LCOE (USD/kWh) of utility-scale renewable power generation technologies: 2010–2018. Source: [49].

According to [50], the global installed capacities of wind, PV solar and heliothermal technologies were presented in the Figures 4, 5 and 6. Comparing the information on installed capacity Wind (591 GW), PV (505 GW) and CSP (5.5 GW) in 2018, it is possible to note that the installed capacity of wind and PV were, respectively, 107.5 and 91.8 times greater than the CSP. It can see than incipience and smaller proportion in relation to the first two. However, heliothermal energy has shown growth, indicating a promising future for its technologies if there is LCOE reduction. Figure 6 pointed Spain and USA are the main countries with installed capacity in the World in 2018. [51] show a LCOE case study applied to Chile in comparation with Spain and USA and results poitd to LCOE redution.

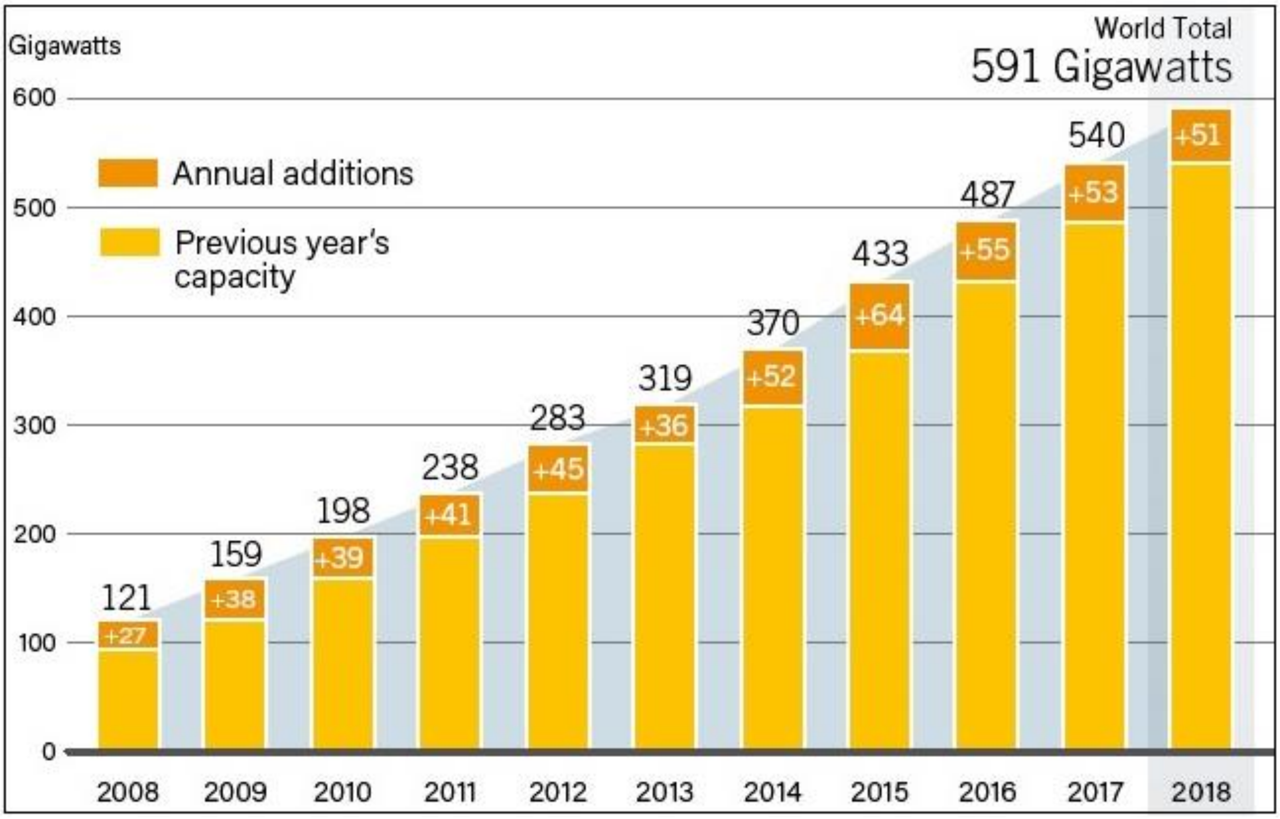

Fig. 4: Wind Power Global Capacity and Annual Additions 2008-2018. Source: [50] (Adapted).

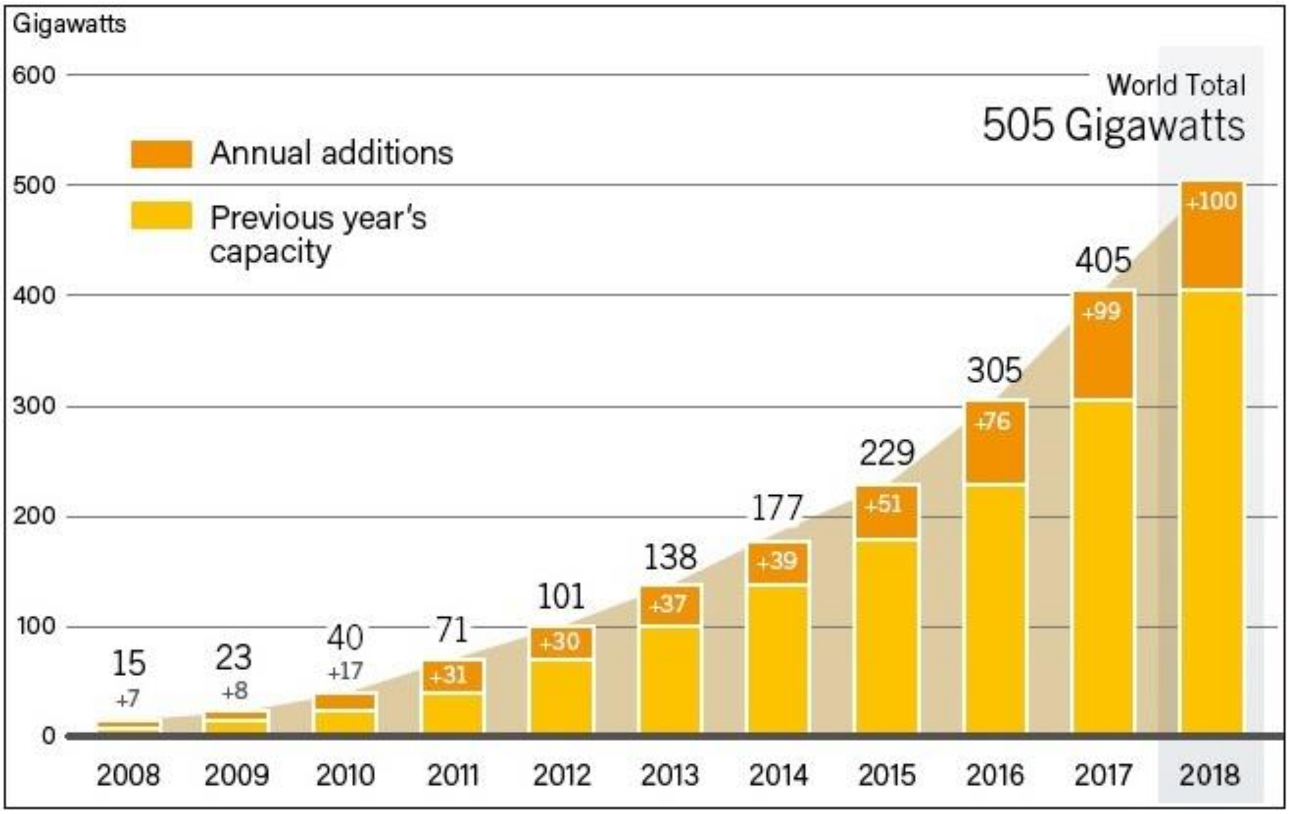

Fig. 5: Solar PV Global Capacity and Annual Additions 2008-2018. Source: [50] (Adapted).

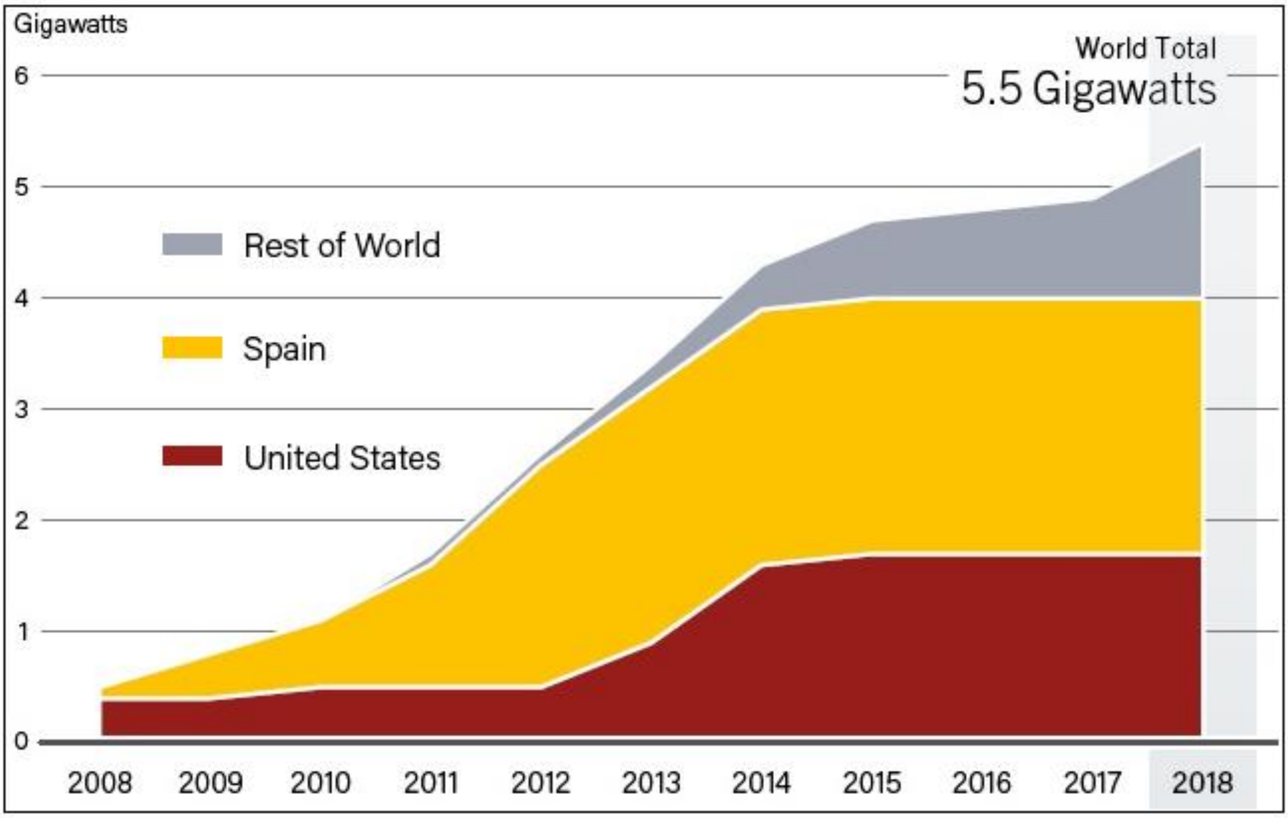

Fig. 6: Growth of Concentrating Solar Power Global Capacity 2008-2018. Source: [50] (Adapted).

6. CONCENTRATING SOLAR POWER TECHNOLOGIES

The Figure 7 presents a comparison between functional principles each four CSP technologies existents.

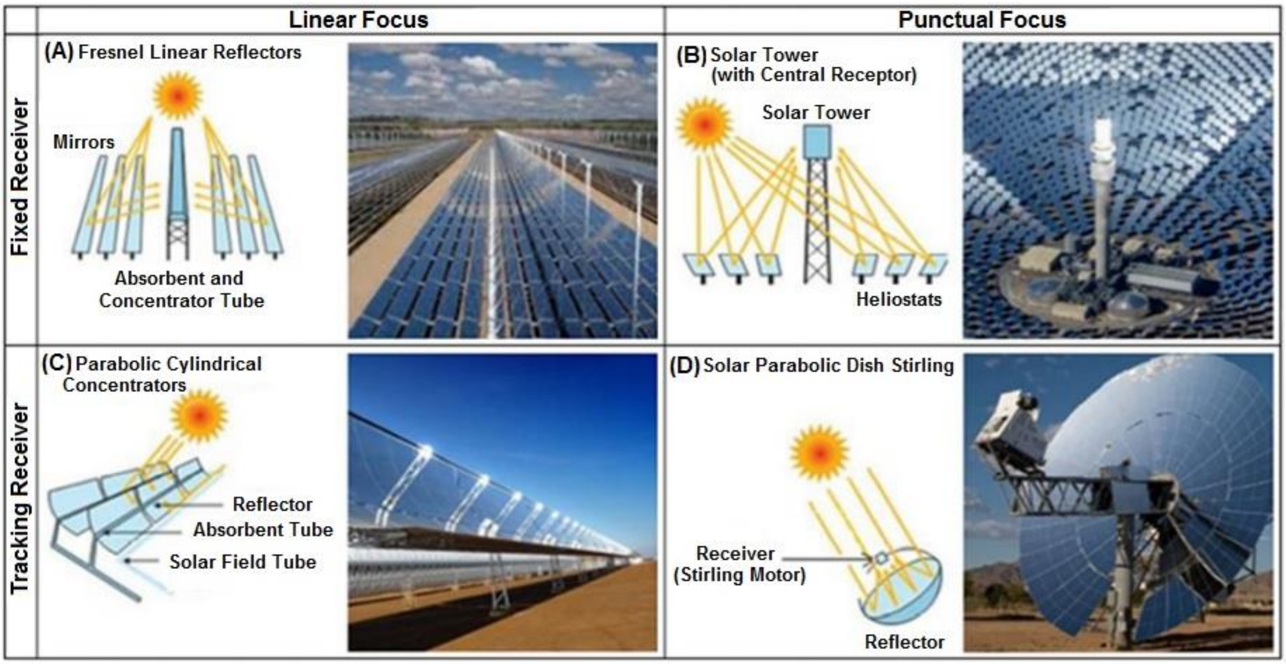

Fig. 7: CSP Technologies: (A) Fresnel Linear Reflector; (B) Solar Tower with Central Receiver; (C) Parabolic Cylindrical Concentrator; (D) Solar Parabolic Dish Stirling. Source: [10, 13, 16, 17, 20; 21] (Adapted).

The Table 1 presents characteristics comparative about the four CSP technologies and the four respective largest CSP power plants in operation in 2018:

Table 1: Comparison about CSP Technological and the largest CSP Power Plants in the World.

Characteristics	4 main existing CSP technologies			
	Fresnel Linear Reflectors	Solar Tower with Central Receptor	Parabolic Cylindrical Concentrator	Solar Parabolic Dish Stirling
Typical Installed Capacity	10 MW - 200 MW	10 MW - 200 MW	100 MW - 300 MW	0,01 MW - 0,025 MW
Receptor	Movable	Fixed	Movable	Movable
Operating Temperature	390°C	250°C - 565°C	350°C - 450°C	550°C - 750°C
Efficiency	18%	25% - 35%	14% - 20%	30%
Land Use (hectare/MW)	2.02 a 3.64	1.21 a 3.64	2.02 a 3.64	3.24 a 3.64
Land Declivity Maximum	<3%	<5%	<3%	<5%
Energy Storage	Yes	Yes	Yes	No
Water consumption	Yes	Yes	Yes	No
Thermodynamic Cycle	Rankine St	Rankine Sp	Rankine Sp / Bryton	Stirling / Bryton
Technologic Maturity	Intermediary	Low	Intermediary	Low
Implementation cost of plant in US$/MWh Millions (in 2017)	5,714	3,222	-	5,832
Largest CSP power plant in operation until 2018	Dhursar	Ivanpah Solar Eletric Generating System	Mojave Solar	Maricopa Solar
Country	India	USA	USA	USA
Installed Capacity	125 MW	392 MW	280 MW	1.5 MW
Number of CSP power plants in respective coutry in 2017	2	32	96	2

Source: Data from [10, 52-60].

6.1. Overview about CSP ventures with Fresnel Linear Reflectors

According to [10], the *Fresnel Linear Reflectors* (Figure 7-A) are flat mirrors in multiple rows, tracked on one axis. These mirrors focus the sunbeams on absorbers fixed above the mirrors. The absorbers are tubular receivers and parabolic mirrors what collect the sunbeams from the mirrors that don´t reach the reflector directly Fresnel linear reflectors are less commonly used than solar tower and parabolic cylindrical concentrator technology. CSP power plants with Fresnel linear reflectors have the advantage of being simple and using low cost components. This technology enables the use of a steam storage system or molten salt. Despite a relatively lower performance, this can be offset by the lower cost of investment, operation and maintenance. [61] considered that Fresnel lens technology is a promising alternative of reflectors in concentrated solar power. The Table 2 presents some largest existing ventures in the world in 2018:

Table 2: Examples of Fresnel Linear Reflectors CSP Power Plants in 2018.

	Fresnel Linear Reflectors Plant Names	Country	Start Operation	Capacity (MW)	DNI (kW/m²/year)	Land Area (ha)	Land Use (ha/MW)	Number of Reflectors	Solar Field Area (m²)	References
1	Dhursar	India	2014	125	–	340	2.72	–	–	10, 11
2	Puerto Errado 2 Thermosolar Power Plant	Spain	2012	30	2.100	70	2.33	28	302,000	10, 11
3	Dadri ISCC	India	2017	14	–	–	–	–	–	10
4	Liddell Power Station	Australia	2014	9	–	36	4	4	18,490	11
5	Kimberlina Solar Thermal Power Plant	USA	2008	5	–	5	1	3	25,988	10, 11, 19

[54] informed that there are almost 200 MW installed with this type of technology and the first pilot plant was built in Australia, soon afterwards plants appeared in France, USA, Spain, India and other countries. Among mills using Fresnel linear reflector technology, Dhursar power plant (India) is currently the largest in operation in the world, with 125 MW installed capacity. It was designed and built by the company Areva Solar, occupies an area of approximately 340 hectares, generating about 280,000 MWh/year. China is building 3 projects with 50 MW installed capacity each: Zhangjiakou, Zhangbei, Urat. In France, SUNCNIM is building eLLO Solar commercial plant with 9 MW, which will occupy 36 hectares [10].

Although CSP technology with linear Fresnel reflectors is cheaper and simpler, there were no CSP commercial projects to use this technology in Brazil until 2019. There are only researches with simulations in Brazilian universities.

6.2. Overview about CSP developments with Solar Towers with Central Receivers

According to [10], the *Solar Towers with Central Receptor* (Figure 7-B), also called "central receiver systems" or "power towers", are structures that concentrate the irradiation at a single point through the reflection of several linear mirrors (heliostats), being individually traced to concentrate sunbeams in a single point at the top of the tower. At this point, there is the receiver, where there is a heat transfer substance (e.g., molten salts, etc.) which is heated. Solar tower technology with central receiver enables the use of thermal storage, thus having a high operating temperature, which improves the efficiency of the Rankine Cycle. Among CSP technologies, solar tower is the second most used, the first being parabolic cylindrical concentrators. Some of the largest CSP solar power plants are located in the USA, South Africa and Spain in 2018, as listed in Table 3.

Table 3: Examples of Solar Tower CSP Power Plants in 2018.

N°	Solar Tower (with Central Receptor) Plants Names	Country	Start Operation	Capacity (MW)	DNI (kW/m^2/year)	Land Area (ha)	Land Use (ha/MW)	Number of Reflectors	Solar Field Area (m^2)	References
1	Ivanpah Solar Eletric Generating Sistem	USA	2014	392	2717	3500	8.9	173,500	2,600,000	10, 11
2	Crescent Dunes Solar Energy Project	USA	2015	110	–	–	–	–	–	10
3	Khi Solar One	South Africa	2016	50	–	–	–	–	–	10
4	Planta Solar 20	Spain	2009	20	2012	80	4	1255	150,000	10, 11, 19
5	Gemasolar Thermosolar Plant	Spain	2011	19.9	2172	195	9.8	2650	304,750	10, 11

[55] informed that the largest CSP plant with solar tower is from Ivanpah Solar Electric Generating System, with 392 MW of installed capacity. According to the company Ivanpah [62], the plant has 173,500 heliostats, 3 solar towers and its total cost was around 2.2 billion dollars, in addition to occupying an area of around 1,416 hectares, located in the desert of Mojave, at the base of Clark Mountain in California (USA) and being developed by Bright Source Energy and Bechtel. Ivanpah obtained final approval of the project in 2010. However, in 2011, the USA Fish and Wildlife Service issued a report stating that the project would risks to wildlife. The construction was suspended due to a possible impact on the desert fauna. Subsequently, the works were resumed and the plant went into operation in February 2014 [10].

There are no CSP plants with solar towers in commercial operation in Brazil, but [63] informed that exist ongoing pilot-project called SMILE. SMILE project foresees the construction of two solar plants with central tower for electricity generation and heat cogeneration integrated into two agro-industrial activities (Dairy and Slaughterhouse). CSP plants will be built in Pirassununga, state of São Paulo, and in Caiçara do Rio do Vento, state of Rio Grande do Norte. The towers will have installed capacity 100 kW each and will be used to supply the electrical and process heat needs, using the air as thermal working fluid. At first, there will be no thermal storage, but both plants will be built with implementing possibility this technology in a future stage. To assist production at low or no solar radiation availability, auxiliary boilers powered by biodiesel will be used in a hybrid generation system. This project is financed by BNDES and industrial partners, is coordinated by GREEN/USP, executed in partnership with German Aerospace Center DLR, Elektro Electricity and Services S/A and Solinova Renewable Energy Company. Forecast was for construction of power plants to start in January 2016, and to start operations in December 2016 [10]. However, there was a delay and project had not yet been completed until 2019.

According to [10, 65], another pilot-project foreseen, but not completed, in Brazil is PETROBRAS project to reduce electricity consumption with a CSP power plant located in Vale do Açu, in state of Rio Grande do Norte. Heliothermal power plant is being designed with 3 MW installed capacity, with solar tower technology. Project will be carried out in partnership with CTGAS-ER, UFSC and UFRN.

6.3. Overview about CSP developments with Parabolic Cylindrical Concentrators

Parabolic Cylindrical Concentrators (Figure 7-C) are parabolic mirror rails, where the surfaces of the mirrors are covered by layers of maximum reflection. Sunbeams are reflected through them and hit tubular receivers in the focus line. The receivers are black tubes with antireflective coating, high absorptivity capacity and low emittance of thermal irradiation. The collectors are tracked along axes parallel to the gutter line [10]. Of the four collector systems, the parabolic trough collector type dominates the market since it has been proven to be commercially mature due to its simplicity, easy operation and cost-effectiveness [21, 22]. According to [64], the solar parabolic trough collector is used for air heating system, desalination, refrigeration, industrial heating purposes and power plants.

CSP projects are well accepted by the world, especially in terms of parabolic cylindrical concentrators. Some of the largest CSP power plants with parabolic cylindrical concentrators in operation today are described in Table 4:

Table 4: Examples of parabolic cylindrical concentrators CSP Power Plants.

N°	Parabolic Cylindrical Concentrator Plants Names	Country	Start Operation	Capacity (MW)	DNI (kW/m^2/year)	Land Area (ha)	Land Use (ha/MW)	Number of Reflectors	Solar Field Area (m^2)	References
1	Mojave Solar Project	USA	2014	250	–	714.3	2.86	–	–	10, 11
2	Solana Generating Station	USA	2013	250	–	780	3.12	3232	2,200,000	11, 56
3	Shams 1	UEA	2013	100	1.934	250	2.50	768	627,840	10, 11
4	KaXu Solar One	South Africa	2015	100	–	1100	1.10	1200	800,000	10, 11
5	Martin Next Generation Solar Energy Centre	USA	2010	75	–	202	2.69	1136	464,908	10, 11

Data from [56] report that the Mojave Solar project is the largest CSP plant with parabolic troughs currently in operation, with 280 MW installed capacity. This plant belongs to Abengoa Solar and is located in the USA. Spain stands out as a country with more parabolic cylindrical concentrators power plants with 50 MW each: Andasois 1, 2 and 3; Arcosol 50; Arenales; Astexol II, Astes 1A and 1B; Casablanca; Helios I and II; Ibersol Ciudad Real (Puertollano); La Africana; La Dehesa; La Florida; La Risca (Alvarado I); Lebrija 1; Majadas I; and Manchasois 1 and 2.

In Brazil, according to [63], an ongoing project is the parabolic cylindrical concentrators power plant with 1 MW installed capacity in Petrolina, state of Pernambuco. This project aims to introduce solar technology into the Brazilian market and evaluate the potential of the Northeast region (solar belt). Your execution is responsibility of CEPEL and CHESF/ELETROBRÁS. The parameters used to determine the plant location were: normal direct irradiation, infrastructure in the region, water resources, among others. Initial design doesn´t provide storage capacity, however, in later phases of project, a storage tank can be coupled to the system. [65] informed that cost of implementing of project is R$ 45 million. According to [66], CEPEL has already signed a contract with the German company Enolcon for technical consultancy in the preparation of a bidding document for the hiring of an EPC company to execute the pilot plant of this CSP plant. This project is called "Helioterm" and will be carried out with resources mainly from the FINEP/MCTIC. Institutions that too are participating this initiative: UFPE, as a co-executor; the SECTI of state of Pernambuco, as intervening institution; and CHESF, partner institution. This is first phase regarding the construction of an experimental research platform for development of CSP in the country. It will be covering several types of technologies, similar to research platforms existing abroad.

According to [60], other ANEEL R&D project with parabolic cylindrical concentrators power plant (0,5 MW) is "thermo solar power generation integration y nationalization and implantation of the pilot power plant in the renewable energy complex of Porto Primavera Hydro power plant. The project aims an integrated operation of hydro, wind, PV solar with heliothermal energy. Forecast was for start operations in 2018 and has predicted 48 months for conclusion.

In 2018, according to [67], Eletrosul Electricity Company signed the service order for implementation of the solar-thermal power plant of Laguna, in state of Santa Catarina/Brazil. Power plant will be CSP with parabolic cylindrical, will have a 250 kW installed capacity, and has an estimated budget of R$ 16.5 million to be made possible by ANEEL R&D Program. The project will be executed by companies Eudora Energy and Facto Energy and will occupy an area of 2.8 hectares. Power plant's start-up is scheduled for 2019 and the total duration of the project will be three years, including academic-scientific studies.

6.4. Overview about CSP ventures with Solar Parabolic Dishes Stirling

Solar Parabolic Dishes Stirling (Figure 7-D) works with a point-focusing technology, where a parabolic mirror concentrates sunbeams at a point in front of collector. At this point there is a receiver mounted and heating a certain fluid [10]. Dish Stirling is a promising technology since eighties of the last century. It has some interesting advantages like efficiency and environmental care. Nevertheless, its reliability depends on some important parameters as Energy loses reliability of the Stirling engines, dispatchability and LCOE [68]. The power plants of solar parabolic dishes Stirling are more difficult to find compared to the other types of CSP described in this article. The Table 5 presents 2 examples of these types of power plants in operation:

Table 5: Examples of Solar Parabolic Dish Stirling CSP Power Plants

N°	Solar Parabolic Dish Stirling Plants Names	Country	Start Operation	Capacity (MW)	DNI (kW/m²/year)	Land Area (ha)	Land Use (ha/MW)	Number of Reflectors	Solar Field Area (m²)	References
1	Maricopa Solar Project	USA	2010	1.5	–	6,25	–	60	–	10, 19
2	Tooele Army Depot	USA	2013	1.5	–	6.9	4.6	429	–	10, 11

According to site of [69], 60 solar parabolic collectors, called SunCatcher, were installed at Maricopa solar power plant in Peoria, USA. Each parabolic collector unit has installed capacity 25 kW and total installed capacity for electric generation is 1.5 MW. Dishes Stirling technology also captures heat using a mirrored parabolic dish that moves constantly to keep up with the movement of the Sun. However, instead of heating liquids to make steam and moving turbines and electricity generators, heat is directed to a piston containing hydrogen gas which drives a Stirling engine to produce electricity.

In Brazil, solar parabolic dishes Stirling technology is less known, researched or supported by public and private sectors. According to [70], as a result of a ANEEL R&D project, a Solar Thermal Laboratory for research was built 2016 at the UNIFEI (state of Minas Gerais), with two dishes Stirling systems, a system type ORC and a gas/power system with installed capacity of 6 kWe.

7. HELIOTHERMAL ENERGY BRAZILIAN CONTEXT

Brazil changed your Framework Regulation in 2004 and beginning to contracted power energy by auctions. The energy hydro, wind, biomass and PV solar were contracted until 2020. However, there were no supports or incentives by public police for viability the contracting of CSP commercial projects in Brazilian auctions. So, there are no large-scale CSP plants for electrical generation implemented in Brazil until 2020. [45, 48] affirm that the costs for CSP projects are still very high for their implementation in Brazil when compared to other options of energy sources (wind and PV solar) and which would require specifics and adequate public policies.

In 2010, MCTI and MME signed an agreement to build a research platform on heliothermal energy in the Brazilian semi-arid region. Currently, the *Energia Heliotérmica* Brazilian government site

[71], which originated under the Heliothermal Energy Project, is being developed by: MCTIC, German Cooperation for Sustainable Development through GIZ GmbH and KfW Development Bank.

In 2013, CNPq launched the first national call for research on heliothermal energy, encouraging Brazilian universities to carry out studies in this area. Since then, research and development (R&D) projects in some Brazilian universities have already begun to be developed, highlighting the states of: Santa Catarina, Rio de Janeiro, São Paulo, Paraíba, Pernambuco, Ceará and the Federal District.

In 2015, according to [60], the ANEEL [72] launched other national call for R&D strategic project on CSP technologies (ANEEL Nº19/2015), "National Development technology of Heliothermal power generation" [67] and the "International Cooperation Project on Heliothermal Energy", originated of cooperation between MCTIC, German Cooperation for Sustainable Development through GIZ GmbH and KfW Development Bank.

Regarding the nationalization potential, it appears that the Brazilian industry has the capacity to manufacture all components of the solar thermal plant, except for the solar concentrators [73]. The Brazilian industry already has part of the production required for CSP technology production chain of in thermal generation, such as steam turbines, power generators, substations, transformers and civil appliances. However, it is necessary to develop the technological part of energy capture and of maintenance of the thermal cycle. This is strategic because mirrors and solar concentrators would need to be imported and equipment that is still exclusively foreign technology and supply [10].

The Solar Belt region offer ideal location conditions for CSP project implantation: high solar irradiation and high land availability. [74] did a study to obtain indices for installation of heliothermal power plant in a region with a normal direct radiation high index in Bom Jesus da Lapa, state of Bahia. This study had as simulation a solar tower power plant and presented good performances, such as factor of capacity and annual production. Thus, heliothermal energy will don´t have conditions to make up a significant portion of the Brazilian electricity matrix without incentive public policies. This attests that Brazil has great climatic characteristics for the implementation of this type of power plant. However, study showed that costs are very high, which makes CSP ventures unfeasible [75].

According to [74], it was verified that a CSP power plant (solar tower) with a storage period of 7.5 hours obtained a LCOE of USD 272,60/MWh (using a quotation of 1 USD = 2.27 BRL in 08/13/2014), which is higher than LCOE in the USA, whose LCOE is around USD 150,00/MWh. Compared to some wind power projects in Brazil in 2014, which LCOE was USD 57,26/MWh, LCOE was higher yet [10].

Table 6: Comparison of LCOE/MWh, with the USD and BRL values in 05/13/2014.

Energy	Country	LCOE in 2014	
		USD/MWh	BRL/MWh
Heliothermal	United States	150,00	340,50
Heliothermal	Brazil	272,60	618,80
Wind Power	Brazil	57,26	129,97
Quotation USD (U$) x BRL (R$) in 2014	U$1 = R$ 2,27 in 08/13/2014.		

Source: [10; 74].

The solar thermal energy is advantageous mainly when associated with thermal storage, since it complements the intermittency of other renewable sources such as wind and solar photovoltaic [73]. Investments in CSP technology with storage, at this point, should be considered in part as learning investments, necessary to reduce the costs of this technology at a young age. They therefore need support, which can be obtained in several ways. However, recognizing the true value of the CSP in time and on site and fully rewarding it is an important step, as it will reduce the extra burden of subsidies in any support schemes. It will also drive the development and deployment of technology to maximize its value for the entire system [60].

8. COMMENTS AND CONCLUSIONS

The hypotheses presented in this paper were confirmed. There is a great potential to be explored by CSP in World and in Brazil. The CSP technologies are underused. There is no yet politic decision about CSP energy implantation in Brazil.

CSP energy is no yet very representative in terms of global installed capacity and few large plants are in operation in comparison with wind and solar PV power because it has high LCOE. However, the use of these technologies is very promising and could be developed as one of the options in renewable energies. In the future, this potential for expansion will can be similar to that of wind and solar PV energy if: there is greater technological maturity and completeness of productive chain and reduction of costs compared to other renewable energy sources. Thus, heliothermal technologies could will commercially viable.

Brazil still does not have CSP commercial plants in operation, but there are some pilot-projects ongoing. In addition, some agreements and partnerships are being signed with leading countries in the use of concentrated solar energy, such as Spain, Germany and the USA. Thus, CSP technologies are still very embryonic stage when compared to other countries, mainly Spain and the USA. However, Brazil has a significant potential for use of solar energy (Figure 2), as well as high potential from other renewable sources (e.g. wind, hydro, etc.) operated in the country.

Brazil basically exist ANEEL R&D project, so the heliothermal knowledge is very incipient. However, in the region known as Brazilian Solar Belt there is a lot of potential and areas available for future heliothermal power plant deployments. Future results of the pilot projects will be useful for a better knowledge of these technologies in the Brazilian reality.

In addition, heliothermal plants could act in an integrated way and complementary other renewable energy sources, improving national energy security. Currently, there is no exist effective public policies and initiatives by the Federal government to enable and encourage the implementation of heliothermal ventures in Brazil. However, it would be advisable for the Government to act to make the use of heliothermal energy in Brazil possible as a further option energy. So, it is need of creation of public polices for development of CSP power plants in Brazil.

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NOMENCLATURE

ANEEL – National Electric Energy Agency
BNDES – National Bank for Economic and Social Development
CEPEL – Electric Energy Research Center
CHESF – São Francisco Hydroelectric Company
CNPq – National Council for Scientific and Technological Development
CSP – Concentrating Solar Power

CTGAS-ER – Center for Gas Technologies and Renewable Energy
DNI – Direct Normal Irradiance
ELETROBRÁS Brazilian Power Plants S.A.
EPC – Engineering, Procurement and Construction
FINEP – Financing of Studies and Projects
GHG – Greenhouse Gases
GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GREEN/USP – Researching Group on Recycling, Energy Efficiency and Numerical Simulation of University of São Paulo
IRENA – International Renewable Energy Agency
IEA – International Energy Agency
LCOE – Levelized Costs of Electricity
MCTI – Ministry of Science, Technology and Innovation
MME – Ministry of Mines and Energy
MCTIC – Ministry of Science, Technology, Innovation and Communications
NREL – National Renewable Energy Laboratory
ORC – Rankine Organic Cycle
PETROBRAS – Brazilian Petroleum S/A
PV – Photovoltaic
REN21 – Renewable Energy Policy Network for the 21st Century
R&D – Research and Development
SECTI – Secretary of Science, Technology and Innovation
SMILE – Solar-hybrid micro-turbine systems for cogeneration in agro-industrial electricity and heat production
UAE – United Arabian Emirates
UFPE – Federal University of Pernambuco
UFSC – Federal University of Santa Catarina
UFRN – Federal University of Rio Grande do Norte
UNIFEI – Federal University of Itajubá
USA – USA of America

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