Renewable and Sustainable Energy Reviews xx (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Concentrated Solar Power deployment in emerging economies: The cases of China and Brazil

Luiz Enrique Vieira de Souza[a,b,*], Alina Mikhailovna Gilmanova Cavalcante[c]

[a] Centre for Environmental Studies and Research. Rua dos Flamboyants, 155 Cidade Universitária Zeferino Vaz, Campinas CEP 13083-867, São Paulo, Brazil

[b] School of Electrical Engineering, Beijing Jiaotong University, Nr. 3 Shangyuancun, Haidian District, Beijing, China

[c] Department of Social Science, Institute of Philosophy and Human Sciences (IFCH), UNICAMP R. Cora Coralina, 100 Cidade Universitária, Campinas, SP 13083-896, Brazil

ARTICLE INFO

Keywords:
Thermo Solar Energy
World-System Analysis
Levelized
Cost of Electricity
Elective Affinities
Climate Changes
Globalization

ABSTRACT

This paper debates the main reasons why Chinese and Brazilian energy policies have not focused on Concentrating Solar Power (CSP) deployment until now. Like most emerging economies, China and Brazil have registered large increases in energy demand, as well as considerable growth of energy-related greenhouse gas (GHG) emissions. On the other hand, both countries have played an important role on the expansion of renewable energy infrastructure and – considering that large portions of their territories present high levels of "Direct Normal Irradiation" (DNI) – CSP technologies might have figured as an important strategy for the mitigation of atmosphere pollution and global warming. Since large scale deployment of CSP technologies still implies high "Levelized Costs Of Electricity" (LCOE) that could affect the competitiveness of national industry in global markets, we argue that a comprehensive answer for this question must place national energy policies in the context of a "world-system" analysis. CSP has not benefited from the international demand that has boosted wind turbines and photovoltaic cells with their subsequent price reductions. Furthermore, we will discuss the "elective affinities" between thermal solar investments and the development of those regions that present the lowest performances in the Chinese and Brazilian socioeconomic realities.

1. Introduction

Global energy consumption data illustrates a geopolitical shift towards a more decisive role of the Global South in international affairs. According to its "New Policies Scenario", the IEA states that "the center of gravity of global energy demand moves decisively towards emerging economies", which are to be responsible for nothing less than 90% of net energy demand growth to 2035 [1]. China and India will continue to lead this trend, followed to a lesser extent by Southeast Asia and the Middle East. In the Western hemisphere, it is expected that Brazil will reinforce its position as energy producer due to the recently discovered enormous oil sands reserves. In addition, Brazilian internal energy consumption tends to increase from the current 267–480 Mtoe in 2035, while the figures for the electricity market indicate a 80% growth from 520 to 939 TWh in the same period [2,3].

Consequently, emerging economies are also to respond for most of the increase in energy-related CO2 emissions. China already ranks first place in atmosphere pollution and will remain highly dependent on coal and oil for the next decades, in spite of the large-scale efficiency measures implemented since the 11th Five-Year Plan [4]. Even though the Chinese government pledged to cap carbon emissions until 2030 in accordance with the agreement sealed with the USA at the 2014 APEC summit, one coal-fired power plant continues to be inaugurated every ten days [5]. This fact imposes not only a burden upon the country's public health [6], but makes it also hardly doubtful that international

Abbreviations: ANEEL, Brazilian Electricity Regulatory Agency; APEC, Asia-Pacific Economic Cooperation; BRL, Brazilian real; CC, Combined cycle; CO2, Carbon dioxide; CSP, Concentrating Solar Power; DNI, Direct Normal Irradiation; EPC, Engineering, Procurement, and Construction management; EPE, Energy Research Company; GDP, Gross Domestic Product; GHG, Greenhouse gas; GIZ, German Society for International Cooperation; GW, Gigawatt; HDI, Human Development Index; ISCC, Integrated Solar Combined Cycle System; IEA, International Energy Agency; kWh, Kilowatt hour; LCOE, Levelized Costs Of Electricity; LFR, Linear Fresnel Reflectors; MCTI, Ministry of Science, Technology and Innovation; Mtoe, Million Tonnes of Oil Equivalent; MW, Megawatt; PD, Parabolic Dish; PT, Parabolic Troughs; PV, Photovoltaic; R & D, Research and Development; RE, Renewable energy; ST, Solar Towers; STE, Solar Thermal Electricity

* Corresponding author at: Centre for Environmental Studies and Research. Rua dos Flamboyants, 155 Cidade Universitária Zeferino Vaz, Campinas CEP 13083-867, São Paulo, Brazil.

E-mail address: lenriquesol@yahoo.com.br (L.E. Vieira de Souza).

http://dx.doi.org/10.1016/j.rser.2016.10.027
Received 30 September 2015; Received in revised form 6 May 2016; Accepted 16 October 2016
Available online xxxx
1364-0321/

mitigation strategies will succeed in restraining global average temperature increase within the 2 °C limit.

The Brazilian energy mix differs from the Chinese mainly because the shares of renewable energy (RE) in its primary energy supply (43%) and in the generation of electricity (74.6%) are considerably above the world average [7]. However, the planned investments in the gas and oil sector have raised concerns on a "regressive process of carbonization" of the country's electricity supply. Such reversal is associated with the fact that much of the remaining potential for hydropower generation is located in the Amazon basin, and the political and ecological costs of standing for controversial projects like Belo Monte, Jirau and Santo Antônio have led the government to assign natural gas as a strategic resource. Such emphasis on the combination of hydropower and fossil fuels establishes a "vicious circle" in view of current changes in climate patterns: In the Brazilian case, global warming prospects indicate the likely increase in the frequency of drought phenomena similar to the observed in the Midwest and Southeast regions in 2013/2014 and, due to the drop in the level of reservoirs, the decrease in hydroelectric output is already being compensated by coal, oil and gas-fired power plants [8,9].

Nevertheless, the current bases of Chinese and Brazilian energy policies are characterized by a similar paradox: The counterpart of the environment unfriendly axiom "development first" is a major contribution from both countries in what refers to RE deployment – not only in their own territories, but also as key-players of the scaling-up process of renewables worldwide. In 2014, China provided the RE sector with US$ 83.3 billion, which represents an amount 117% higher than the investments made by the USA. Brazilian participation was only a ratio of the Chinese share, though at no means unimportant, for its US$ 7.6 billion input places the country among the ten major supporters of RE deployment, and right after China when solely emerging economies are considered [10].

Both Chinese and Brazilian public banks have been financing RE industry with low interest rates in order to enable the accomplishment of their respective goals on the expansion of alternative energy technologies. China's State Council announced the purpose of meeting 20% of the country's energy needs by 2030 from non-fossil fuel. On the Brazilian side, the US-Brazil Joint Statement on Climate Change affirms that 28–33% of its energy matrix (excluding hydropower) must derive from renewables by 2030 [11,12]. In this sense, the interactions between climate change mitigation goals and economic incentives for the RE industry has contributed for the highlighted position of these countries in the global value chain of alternative energy technologies. One in two wind turbines deployed worldwide in 2010 were produced in China, as well as 60% of the photovoltaic panels manufactured in the following year. Brazil has also become an exporter of wind turbines, supplying RE markets in the United States, Europe and Argentina [13–15].

In the light of such facts, the question that this article approaches focuses more specifically on the perspectives of Concentrating Solar Power (CSP) technologies in the Chinese and Brazilian energy markets: Why have these countries presented so meagre CSP deployment results until now, especially when compared to the evolution registered by them in other RE technology fields? Considering the escalation in Chinese electricity demand and the environmental pressures associated to it, a CSP roadmap that assigns merely 1 GW by 2015 and 3 GW until 2020 seems astonishingly modest.[1] This situation becomes even more puzzling when one remarks that—differently from its usual performance in the energy infrastructure sector, in which the targets are either achieved or surpassed—China is very distant from reaching the established goal for CSP expansion. The current operational capacity is limited to 2.18 MW, and even if all the projects under construction, development or planned are added, the total figure is still restrained to 567.5 MW [16].

Except for some progress in Research and Development (R & D) conducted by scientists associated to public universities and electricity agencies, CSP evolvement in Brazil is almost inexistent. Cooperation ties between the Ministry of Science, Technology and Innovation (MCTI) and the German Society for International Cooperation (GIZ) have provided Brazilian scientists and policy-makers with German expertise in thermo solar energy and contributed to further research on the requisites for the deployment of CSP in Brazil. However, there is currently only 1 MW pilot plant under construction in Petrolina (PE) and other four commercial projects that amount to 130 MW, which find themselves in a very initial phase of development [17]. Furthermore, while in China the backward situation of thermal solar power does not apply to other branches of the solar industry (photovoltaic panels or solar water heaters), the abundant solar resources in the Brazilian territory are decidedly underused from the perspective of energy supply [18,19].

Rational energy planning might be defined as the development of the energy infrastructure that makes use of technological innovations to improve efficiency gains and explore renewable resources in order to meet the energy demands of a society in accordance to sustainability criteria. Following this definition, the adoption of specific technological innovations must be endorsed by their social acceptance and employed in a complementary perspective that explores different renewable energy resources conform to their geographical availability. Nevertheless, several barriers interfere as constraints for the accomplishment of rational energy planning, both within and beyond the limits of national sovereignty. Therefore, the next section is dedicated to a brief presentation of the theoretical framework and the methodological tools that oriented the assembly of original data for the analysis of our research problem. We will argue that the "World-Systems Theory", such as developed by Immanuel Wallerstein (2002, 2004), offers a comprehensive perspective that enables us to highlight the commonly neglected importance of electricity prices for determining the position of each country in a competitive world-economy [20,21].

In Section 3, we will give an overview of CSP technologies and emphasize their particular advantages in terms of energy conversion, storage and hybridization possibilities, as well as their life cycle assessment. In Section 4, the analysis of Direct Normal Irradiance (DNI) data will confirm that China, as well as Brazil, have large portions of their territories registering DNI values above the minimum necessary for an effective CSP performance. An important similarity between these countries will emerge from the analysis of solar resources data, for in both cases the places with higher DNI coincide to a great extent with the regions where the socioeconomic conditions are most critical. In this sense, it will be argued in Section 5 that, besides its environmental benefits, the large-scale deployment of CSP power plants in China and Brazil might also contribute for diminishing regional inequalities.

More attention will be paid to the economic viability aspects of Chinese and Brazilian CSP markets in Sections 6 and 7. We will provide an overview of the CSP value chain and demonstrate that thermal solar power plants demand regular industrial materials—e.g. steel, mirrors, steam turbines, electronic components—in which the Chinese manufacturing sector excels. Brazil also possesses a mature range of industries in the production of components and equipment for electrothermal conversion so that an important part of the value chain could be added locally [17,22].

The concluding remarks are intended to clarify the significance of the financial obstacles interposed by the high Levelized Costs of Electricity (LCOE) for CSP deployment in China and Brazil. From a sociological perspective, we criticize the limits of current explanations that point out solely the higher electricity prices imposed on consumers and the ensuing inflationary pressures. Beyond that, we indicate how

[1] Our analysis refers to the time frame of the 12th FYP. The 13th FYP was published when this article was being reviewed and we decided to write an appendix at the end with some further considerations and updated data regarding the 13th FYP.

the core of globalization and the struggle of national states for a bigger share of world markets are closely associated with the relative disadvantages of CSP technologies in face of other renewables. Finally, we refer to on-going researches on solar-hybrids to identify specific strategies that might enable an optimum adaptation of thermal solar power in the respective energy contexts of China and Brazil and thus overcome the existing economic constraints.

2. Theoretical framework and methodological approach

The main theoretical distortion in energy studies is the belief that energy planning might be explained solely by the interface between "national states" and "markets". A somewhat broader perspective includes a more extensive set of variables in order to analyse the different strategies established by the governments to meet their "energy security" concerns: a) support for the research and development of new technologies; b) the degree of internalization of environmental aspects and c) the economic efficiency of each State – might it be in terms of independently financing its energy policies or developing mechanisms to attract market actors. Nevertheless, the widespread epistemological inaccuracy in contemporary energy research lies in the assumption of the "national states" as the central analytical reference, despite the interconnected dynamics of globalized markets.

Even in the case of "comparative analyses", different national realities are contrasted more in the sense of emphasizing their respective singularities than with the purpose of establishing links of "interconnectedness" between them. The most evident consequence of such "*analytical insularization*"—methodological bias that restricts the investigation of socioeconomic issues within the limits imposed by the unquestioned tradition of representing such issues in a national framework— in energy studies is that explanations are reduced to the empirical causalities circumscribed within the national borders, completely disregarding the imbrication of global vectors in local decisions. In energy studies, the analytical insularization is usually expressed by research designs in which the energy infrastructure is analysed as the result of the guidelines developed by national governments through the institutions responsible for their energy planning and management. It is obviously not our intention to deny the fact that states indeed rely on the principle of "national sovereignty" to formulate strategies in the energy field that would ideally be more adequate to the pursuit of their respective national interests. In order to comprehensively understand such strategies, it is necessary, though, to take into consideration the whole range of transnational interdependencies, power relations and overlapping causalities that are in the very core of the decision-making processes of energy authorities, but cannot be properly identified without the methodological implosion of the national state as analytical reference.

In this sense, we argue that the deployment of CSP technologies in China and Brazil must be discussed not only on a cost-benefit basis that places the sole rational criteria on the comparison of its electricity prices in the view of other available technologies. In order to be comprehensive, energy studies must develop new analytical tools to determine to what extent the pressure for international competitiveness has become a central factor in energy planning.

Briefly, our theoretical framework will be based on selective elements of the contributions given by the "World-Systems Theory" and the "Methodological Cosmopolitism" to the sociology of globalization. "World-Systems Theory" is mainly associated to the theoretical work developed by Immanuel Wallerstein [20,21], who understands the world-economy as a single competitive matrix in which the different countries struggle for more privileged positions in the international flows of surplus-value. In order to understand such dynamics, Wallerstein referred his assertions to a typology that defines "core-nations" as those in control of high value-added economic activities, while "peripheral countries" are those where the agriculture and extractivism are the main economic sectors. Technology development plays a decisive role in the constitution of such asymmetrical relations and the "semi-peripheral countries" are located in-between this scale.

We suggest that the impact of energy planning on the prices of electricity is one of the variables that determine the conditions of insertion within this "world-system". Especially in energy-intensive industries, heat and electricity are important components for defining the final prices of a product and, consequently, its competitiveness in international markets. Hence, cheap sources of energy, such as coal plants or large hydropower stations, are common strategies for semi-peripheral countries that aim at upgrading their position in the international division of labour. On the other hand, energy planning might also be a tool for the accumulation of capital, when it contributes for the local manufacturing of energy technologies. We will show that the Chinese government considers the energy industry as a strategical focus for the restructuration of its economy towards higher value-added exports, while the Brazilian RE industry has also become a global player in the market of wind turbines.

Therefore, "World-Systems Theory" allows us to shift the analysis of energy planning from a narrow and unilinear national perspective to the more complex arena of international disputes within a competitive and globalized world-economy. Ulrich Beck's "*Methodological Cosmopolitanism*" [23,24] will further complement our analysis in virtue of its radical potential for questioning the rigid separation between the "inside" and the "outside" of national guidelines. The cosmopolitan features of the energy question are not only evident through the transnational value-chain of the energy industry and the interconnectedness of global energy markets, but also because energy planning in a globalized economy must deal with the interests of foreign actors as a core strategy for maximizing one own's "national" profits.

In regard to methodological approach, we based the arguments developed throughout this article both on primary and secondary data. The secondary data were obtained in scientific articles on the perspectives of thermo solar energy in China or Brazil. The existing literature raised a number of questions, though, that demanded the gathering of original information. Therefore, our primary data consist of four semi-structured interviews: In China, we interviewed an energy researcher from the Center for Renewable Energy Development and Research Institute/National Development and Reform Commission. In Brazil, we interviewed the general coordinator of technologies sector at the Brazilian Ministry of Science, Technology and Innovation, the director of the RE and efficiency energy sector of GIZ in Brazil as well as an expert of solar energy from the University of Brasilia.

3. Solar thermal technologies

Concentrating Solar Power (CSP) plants generate solar thermal electricity (STE) using mirrors to concentrate the sun's rays and produce heat for electricity generation via a conventional thermodynamic cycle [25,26]. The key distinction of CSP comparing with other renewables is the heat storage system to generate electricity even with cloudy skies or after the sunset. Unlike solar photovoltaic (PV), CSP uses only the Direct Normal Irradiation (DNI) and can provide carbon-free heat and power only in regions with high DNI (e.g. sunbelt countries). There are four main CSP plant in commercial use [25,27]:

3.1. Parabolic Troughs (PT)

PT usually rely on synthetic oil as the fluid that transfers heat (the heat transfer fluid) from collector pipes to heat exchangers, where water is preheated, evaporated and then superheated. The superheated steam runs a turbine, which drives a generator to produce electricity. They are the most established and proven CSP technology on a large-scale commercial basis.

3.2. Linear Fresnel Reflectors (LFR)

LFR use a series of ground-based, flat or slightly curved mirrors placed at different angles to concentrate the sunlight onto a fixed receiver located several meters above the mirror field. Compared to PT, LFR show worse performance, compensated however by lower capital investments. Hence, there is currently no clear advantage to either parabolic troughs or LFR systems.

3.3. Solar Towers (ST)

ST have a large number of computer assisted mirrors (heliostats) tracking the sun individually over two axes and concentrate the solar irradiation onto a single receiver mounted on top of a central tower, where the solar heat drives a thermodynamic cycle and generates electricity. In principle, ST plants can achieve higher temperatures than PT and LFR systems because they have higher concentration factors, increasing thus the efficiency and reducing costs.

3.4. Parabolic Dish (PD)

PD consists of a parabolic dish-shaped concentrator that reflects the sunlight into a receiver placed at the focal point of the dish. The main advantages of PD systems include high efficiency (up to 30%) and modularity (5–50 kW), apart from being particularly suitable for distributed generation (Fig.1).

3.5. Life cycle assessment

GHG emissions, water consumption and land use are the main environmental issues in the preliminary analysis of CSP plants. Although CSP plants have much lower GHG emissions (13.8 g/kWh) than natural gas-fired power plants (422.4 g/kWh), due to manufacturing process of the components, yet CSP plant consumes more water on-site per unit of electricity generated [29]. CSP needs water to cool and condense the steam cycle at the rate of 2–3 m^3 of water per MWh. Since water is often scarce in the regions with high DNI, CSP plants might use a “dry-cooling system” that is typically about 10% more expensive than the water-cooled one [25]. Regarding the land use, based on data from one of the largest CSP stations in the world (the Shams1 active in Abu Dhabi since 2013), a thermal solar power plant occupies 250 ha to produce 100 MW. Hence, CSP generates power at a “land cost” of 2.5ha/MW [22], while the land-use intensity range for photovoltaic energy varies between 2.5 ha/MW and 7.5 ha/MW [30].

3.6. Heat production

Thermal solar energy is suitable not only for generating electricity, but also the high-temperature heat steam necessary for several industrial processes. Taking into account that both Chinese and Brazilian industry sectors are energy-intensive, steam generated by CSP technologies could be used in a wide range of industrial activities that currently rely on coal or biomass for the production of heat. The use of combined heat and power could thus reduce thermal costs and facilitate the commercial viability of CSP technologies in emerging markets. In North-eastern Brazil, already four industrial enterprises are carrying out feasibility studies for using CSP heat for their industrial processes [31].

3.7. Hybrid

The “Integrated Solar Combined Cycle System” (ISCC) is a typical hybrid system that integrates solar heat and fossil fuels [32]. ISCC consists of a gas or coal-fired turbine, heat retriever, steam turbine and solar field. Steam generated in the solar field is fed into the water-steam cycle of the “combined cycle” (CC) plant, thereby increasing the power of the steam turbine. It can achieve efficiency rates around 67% (10% higher than a conventional CC plant) [33]. Moreover, it is also possible to combine the CSP plant with PV, wind or small hydropower plants, replacing the fossil fuel share for alternative sources in order to decrease the emissions of GHG. Following the example of Chile, the hybridization with PV could provide cheaper energy during the day, while CSP would start the generation in the afternoon with significant storage capacity, providing secure and stable energy power [34].

Many studies indicate a low cost approach for the introduction of CSP in a country's energy matrix through hybrid CSP plants associated to the use of sustainably managed biomass, gas or any other fossil fuel. Considering that biomass responds for 6.8% of Brazilian electricity needs [3], such hybridization mode would present a feasible path for CSP integration based on the context of local power generation. As an example, the association of solar fields to the consumption of sugarcane bagasse would make LCOE viable due to a reduction in the solar multiple and, consequently, enable the use of fewer collectors [35]. Since the participation of each component in the hybrid set is arbitrary, the solar share could be reduced until the level in which solar-biomass hybrid plants achieve competitive prices in the auctions. Although there is a problem regarding biomass availability in places with high DNI, Brazil presents the conditions for small scale projects in this hybrid modality [36,37].

Similarly, because the power sector in China relies heavily on coal-fired power generation, hybrid solar-coal plants could be an affordable beginning for the integration of CSP. Moreover, it allows the upgrading of existing small power plants to reduce the fossil cost and minimize the environmental impacts. These “solar boosters” would contribute for slowing down the frenetic rhythm in which new coal plants are constructed in China and, at the same time, take advantage of the existing energy infrastructure to reduce the LCOE about 20–30% in relation to the values expected for pure thermal solar plants [32].

4. Solar resources in China and Brazil

For an efficient performance, thermal solar plants require DNI

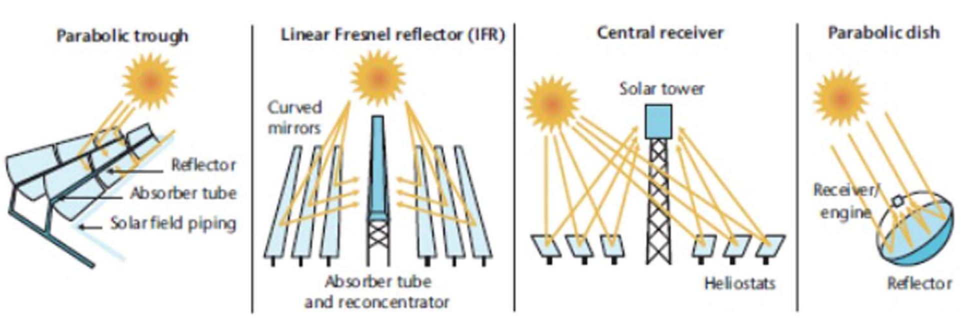

Fig. 1. Main CSP technologies.
Source: [28]

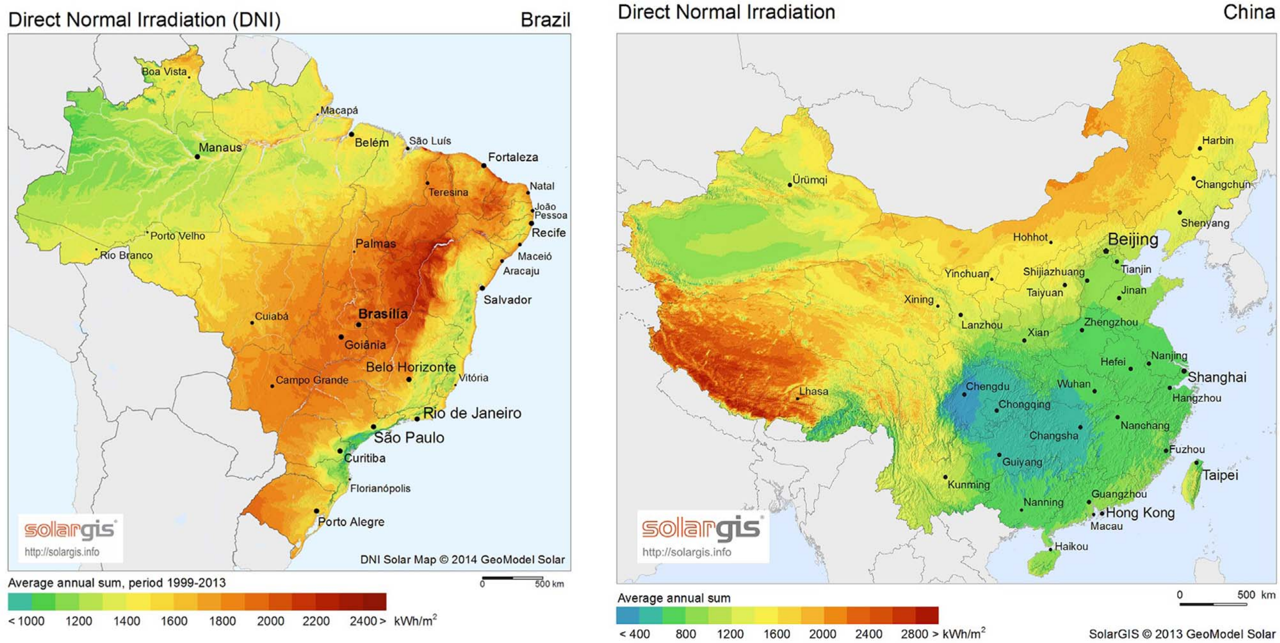

Fig. 2. Direct Normal Irradiation in China and Brazil.
Source: [41]

levels above 1800 kWh/m^2/y – which are registered mostly in desert and arid regions, such as the Middle East and North Africa (MENA), South Africa, Central Asia, India, Australia, North and South America.

China and Brazil offer a great potential for CSP technologies. As shown in Fig. 2, there are large areas in both countries with DNI above 2000 kWh/m^2/y. In Brazil, the DNI values in the Northeast semi-arid region reach 2000 kWh/m^2 annually, with the greatest potential located in the São Francisco River Basin and the area of Sobradinho. According to Soria (2011), Brazil possesses an area of 97,700.93 Km^2 suitable for CSP technology where 3664 TWh/y could be generated [38].

Based on DNI requirements, more than 700,000 Km^2 are suitable for CSP installation in China, with potential generation of more than 51,000 TWh/y – i.e., an amount of electricity more than ten times superior to the total electricity consumption of 4980 terawatt-hours in 2012. Due to appropriate solar irradiation, Gansu, Tibet, Qinghai, Xinjiang and Inner Mongolia would be convenient areas for the deployment of large scale CSP projects. Within these five provinces, Qinghai and Gansu stand out as ideal locations considering solar resources (over 2100 kWh/m^2), geographical conditions, slope and proximity to the consumption centres [39,40].

5. "Elective affinities" between CSP investments and regional development

The analysis of Chinese and Brazilian socioeconomic indices clearly reveals that they are structurally determined by regional disparities. Since the late 1980's, uneven economic growth has concentrated wealth in Chinese coastal cities, while rural inland territories have registered disadvantages in economic well-being. Indeed, Coastal and Northern provinces have a relatively bigger participation in the country's trade, and their per capita incomes are considerably higher than the national average. More specifically, the joined participation of Guandong and Jiansu in national GDP (20.63%) exceeds all the Western provinces combined [42], and the disposable income per capita in Shanghai is more than the double of the value perceived in Guizhou [43]. In Brazil, the financial, industrial and research centres are mostly located in the Southeast and Southern regions. São Paulo state alone responded for 33.5% of Brazilian GDP in 2009—while Piauí, Sergipe, Rio Grande do Norte, Paraíba, Alagoas and Ceará (all located in the Northeast region) had a combined result of 5.3% in the same year [44].

The comparison between solar resources and socioeconomic data evidences that both in China and in Brazil there is a coincidence between the territories with high DNI values and the most backward areas in terms of social development and participation in the national wealth. An assessment research indicates that Gansu, Tibet, Qinghai, Xinjiang and Inner Mongolia are the Chinese provinces that combine solar resources and lower demographic densities, placing them in a suitable condition for large-scale CSP deployment. However, except for Inner Mongolia, all these provinces present low *Human Development Index* (HDI) results, which vary from the 22nd (Xinjiang) to the last position (Tibet) among all the thirty-one Chinese provinces [45]. In the Brazilian case, the natural pre-requisites for the construction of thermal solar power plants are found in the semi-arid climate zone in the Northeast region. It suffices to say that, among this country's 1000 worst HDI conditions, 715 were municipalities located in semi-arid domains [45].

Hence, this article also highlights the "*elective affinities*" between CSP deployment and regional modernization in the sense that both in China and Brazil the areas that would be suitable for the operation of thermo solar plants are precisely those where socioeconomic conditions are below the national average. In other words, the construction of thermal solar power plants is in consonance to some of the guiding policies announced in the *12th Five-Year Plan* because it fits the purpose of increasing the participation of renewables in the energy matrix, as well as promoting "coordinated and interactive" regional development, especially in those Western provinces, whose socio-economic improvement is currently given "high priority" [46]. Similarly, CSP in Brazilian semi-arid regions might converge with other public policies aimed at reducing local poverty, not only because of all the direct and indirect jobs associated to the construction and maintenance of thermal solar plants, but also because CSP electricity might bring additional source of revenues if exported to the centres of electricity demand in South-eastern states. The existence of "elective affinities" between CSP deployment and regional development means that investments in thermo solar energy would meet environmental sustainability as well as social equality criteria.

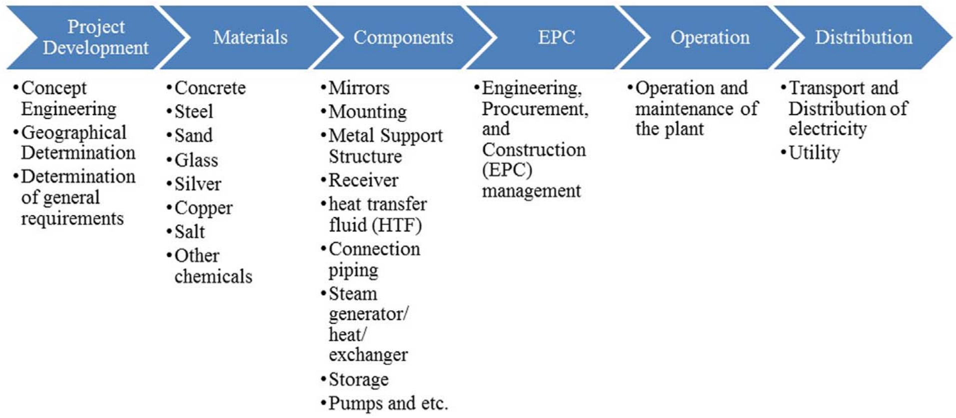

Fig. 3. Value chain of CSP plant.
Source: [48]

6. Value chain for CSP in China and Brazil

The question about the readiness of the national industry to supply the necessary equipment at a competitive price is crucial. Generally, CSP plants consist of various components that do not need highly specific industry know-how and could be produced with adoptions of slight changes on already existing production lines. The CSP plant could be divided in three parts: optical, thermal and electrical – and several sectors are involved along the value chain: steel and glass industry, chemical, petrochemical and construction companies [47].

As depicted in Fig. 3, the project development phase is followed by the raw material selection. Concrete, steel, and glass are the most required materials and, depending on the price, could be provided by Chinese and Brazilian local suppliers. The key components of the solar field are the metal support structure for the mounting, the mirrors and the receivers. Since the CSP market worldwide is still at a very initial stage, there are only a few companies that can supply these components. The main part of the power block is the steam turbine, which is the most complex item of the CSP plant and usually produced by specialized companies [48].

According to the results of our interviews, there is neither in China nor in Brazil any impeding barrier associated with the intellectual property rights of CSP technologies. The Chinese have been researching thermo solar technologies for some decades and several tests are being made in order to figure out which one out of the four CSP options would be more suitable for the Chinese conditions. If necessary, energy authorities are ready to sign cooperation agreements that would enable the use of Spanish and German technologies [49].

Jointly with the German Society for International Cooperation (GIZ), the Brazilian Ministry of Science, Technology and Innovation (MCTI) actively works to create the conditions for developing and disseminating the CSP technology in Brazil. The project has many approaches as capacity-building, scientific and industrial cooperation, as well as the construction of the pilot plant “Petrolina”. In face of the industrial and academic cooperation with German companies and universities, the work is aimed at the adaptation of the national industry and the development of CSP technology in Brazil. Brazilian universities are working for the development of heliostats and concentrating Fresnel mirror, and the glass industry is expected to launch new products in this sector [34].

In Brazil, steel and glass industries, as well as chemical and petrochemical companies, are already present and could locally supply many components for a plant construction. Thus, local share of around 70% could be achieved with an annual increase of approximately 250 MW or more of CSP installed capacity. But it has also been considered that, without any adaptations in the different industry sectors, only a small local share would be achieved [47]. The cooperation between the MCTI and GIZ could provide further support for the technology transfer and – except for the optical components, which would need to be imported in the beginning – the other elements of the value-chain might be added locally [31].

China already has the manufacturing abilities to produce most of the key components for centralized tower and would be able to export some of the key CSP components. The Institute of Electrical Engineering (IEE), a leading research institution within the National Solar Thermal Energy Alliance, has developed its own patented CSP technique and manufacturing abilities [50]. Comparing to Brazil, the Chinese industries have more experience with thermal power and such experience provides some relative advantages for technology adaptation. In Beijing, there is 1 MW demo plant and in Qinghai a 10 MW commercial scale plant. This figure is expected to increase in the near future because there are 317.5 MW under construction [16].

Although the Chinese CSP industry sector has recently emerged, it is dominated by the so-called “Big 5 Utilities”: *China Guodian, China Huaneng, China Power Investment, China Datang and China Huadian;* which operate in China as project developers, electric power companies and EPC (Engineering, Procurement, and Construction management). Within the industry, some local equipment suppliers like *Himin* or *Huiyin*, besides some of the first European CSP players like *Siemens, Schott* or *Abengoa,* have been trying to establish themselves in the Chinese market [40].

The development of national produced renewable energy technology might contribute for the reduction of the electricity price. However, China's policy approach to renewable energies has placed priority on developing the renewable energy manufacturing industry and only secondly on renewable energy itself. In contrast to the wind industry which was pulled by domestic market, PV industry was boosted by overseas market, mainly by the European Union [13]. Therefore, the low DNI levels in some of the main importers of Chinese renewable energy products (e.g. Germany) might be a hindrance to the development of the Chinese thermal solar industry.

Differently from China, Brazil has given priority to the national deployment of renewable energy, compassing 74.6% of renewable energy sources in its energy mix [7], but the renewable energy technology manufacturing is not as developed as in the Asian country. To date, Brazil still does not have the technology to manufacture photovoltaic cells active in the country, although the sector is growing every year. For Chinese PV companies, Brazil is an auspicious new market, and, as example, one of the largest Chinese PV modules' manufacturer (BYD) is already planning to invest US$ 50 million for setting up the manufacturing facility in Campinas [51].

7. Cost analysis of CSP technology in China and Brazil

Levelized Cost of Electricity (LCOE) is an important tool for the comparison of various generation options, as it demonstrates the per-kilowatt hour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle [52]. In contrast to fossil fuel sources, LCOE for renewables has been falling continuously for decades. Nevertheless, due to CSP embryonic deployment, its LCOE is still relatively high compared with other renewable technologies, registering prices in the range of 20–35 US$c/kWh [53]. Future cost reductions can be expected if deployment accelerates, but policy uncertainty is negatively affecting the prospects of growth.

As 85% of all CSP projects are dominated by parabolic troughs technology, data available on operating experience and cost information refers usually to PT systems. PT plants without storage in non-OECD countries have been able to achieve lower capital costs between US$ 3500/kW and US$ 7300/kW. Plants with storage usually require higher capital investments, but they allow greater capacity factor resulting in lower LCOE [53]. The high initial capital investment is indeed a serious impediment for the competitiveness of CSP, but thermal solar energy still has a large cost-reduction potential, with future opportunities for wholesale power supply, industrial heat production and desalination [54].

In Brazil, the real LCOE for CSP plants will be known when the only CSP auction is held, whereupon the experts expect the cost decrease, as it happened for the wind turbines or PV [31,34]. Moreover, the Electricity Regulatory Agency (ANEEL) will announce in 2016 the results of the first R & D auction for CSP plants, where 5–7 projects are expected to be presented. Due to capacity building in Brazilian government by the German Cooperation for Sustainable Development (GIZ), ANEEL has already permitted the participation of CSP plants in national energy auctions, although the presented projects were not able to compete with other sources. Previously, the same path has been taken for wind and PV, when the exclusive commercial auction was announced only after the R & D auction had already been held. Moreover, the Energy Research Company (EPE) is prepared to introduce the CSP share in its next energy forecasts, as was confirmed by the interviewees, implying the future announcement of exclusive commercial auctions by the government.

There are currently few available data for the CSP technology costs in the country and no projects exist that could indicate the LCOE for CSP plant in Brazil. However, there are some studies that have been done, simulating various scenarios for CSP development in Brazil. Following the results of a research developed at Federal University of Rio de Janeiro [35], in the base (business-as usual) scenario, CSP was not able to compete with biomass and gas-fired. In the alternative scenario, in which specific auctions for CSP might be adopted, the optimization indicated the impacts caused by the hypothetical mandatory use of CSP in the grid. In such case, the costs would be about 144 billion dollars dearer than the base scenario, but the Northeast could become an energy independent region and even an exporter of electricity to the Southeast and South regions. The LCOE is estimated to be in a wide range from 39 to 82 US$c/kWh in the base scenario and around 19–39 US$c/kWh in the alternative scenario [38].

Comparing with the average price of electricity for the industry of 0.38 BRL/kWh or 10.7 US$c/kWh (taxes included, 2015), we could observe that CSP is not competitive in Brazil yet [55,56]. However, the hybridization of CSP with biomass could decrease the LCOE to 11 US $c/kWh and thus make thermal solar electricity also feasible and competitive from the economic point of view [38]. As we pointed in Section 3, the local availability of biomass would restrain the scale of these hybrid projects, but, if adequately managed, it might indeed contribute to a certain degree for the reduction of initial costs.

CSP in China has already 2.18 MW installed capacity or 567.5 MW including the projects under construction and development. However, there is a lack of clear and ambitious “feed-in tariff” (FIT) policy to boost investments into the emerging CSP sector. In 2011, a 50 MW solar thermal power generation project in Inner Mongolia won a first FIT price of 0.94 RMB/kWh or 15 US$c/kWh [40]. After the experts claimed the price was too low and unprofitable, the government established a higher “feed-in tariff” of 1.2 RMB/kWh (19 US$c/kWh) for the CSP plant Supcon's Delingha [57], but this incentive was still not sufficient to make CSP projects viable in China. Moreover, the Asian Development bank (ADB) provided preferential loans for CSP projects, enabling Supcon's Delinghua to achieve the lowest electricity generation costs in comparison with other CSP projects in China, that vary in a range of 19–43 US$c/kWh [39,58].

> “For the PV and wind power, the Chinese government formulated the FIT for several years, and the market for such technologies has developed favourably. But for CSP – because there are no commercial large scale projects operated at present– the government hesitates to formulate the FIT and to set the price level for CSP. The pilot developers set up the CSP plans first and then establish the price policy. However, the developers hope the government can set the policy first. The government waits for the prices and the developers wait for the government. That is why the CSP is not on the normal road to achieve the target”, Energy researcher at the Center for Renewable Energy Development and Research Institute, Shi Jingli [49].

With regard to capital investments, the 50 MW Qinghai Delingha concentrated solar thermal power project amounted to US$ 322.26 million of capital expenditures, representing an average of 6400 US $/kW. Due to the high initial CAPEX, the current electricity cost generated by the CSP is therefore still much higher than that of conventional technologies. While the current electricity price for major industrial use in China (taxes incl.) is around 0.61 RMB/kWh (10 US $c/kWh) [59], it is unlikely that CSP might become a competitive alternative in China.

Comparing LCOE estimates in Brazil and in China with electricity price of 10–11 US$c/kWh it remains to be an expensive option for developing countries, guided by the principle of affordable electricity price. Yet, it must be considered that first projects in the countries are usually more expensive than the ones that follow, meaning that the price would be reduced in the future. Moreover, as a result of its high DNI rates and relatively inexpensive costs of labour and materials, it was estimated that LCOE for CSP technologies might be at least 20% cheaper in China than in Europe [50,53]. Nevertheless, even in face of such “comparative advantages”, thermal solar electricity would still represent a financial burden in contrast to fossil fuels or other more established and competitive renewable technologies (Table 1).

8. Concluding remarks: CSP deployment in the framework of globalized competitive markets

Both China and Brazil have several options for alternative energy planning. However, their energy guidelines might be regarded as very

Table 1
LCOE estimates per technology and country (US$c/kWh)[*].

Technology	Brazil[**]	China	USA	Europe
CSP	N/A	19–46	20–49	20–49
PV	6.5–8.4	7.9–14.9	11–23	10–25
On-shore wind	3–5	4.9–9.3	6.1–13.6	7.1–11.7
Hydro	3	3	9	10
Coal	3.6	3.5–3.9	7	12–17

Source: Elaborated by the authors based on [53,60].

[*] Note: the given range is an average scenario range and does not reflect actual maximum and minimum values.

[**] The data on energy sources in Brazil is based on auction prices from ANEEL site [56] (auction results from 2005 to 2015).

conservative in the sense that they are largely focused on thermal and hydro power plants, while more environmental friendly RE are considered merely as "complementary" sources. In Brazil, it is even relatively common for CSP enthusiasts to criticize energy planners as "electrosaurs" for their short-sightedness and inability to analyse thermo solar perspectives in the long run [31].

Nevertheless, we demonstrated along this article that the impediments for CSP deployment in China and Brazil are not only the result of what might be called "energy conservatism", but mostly associated with the comparatively more expensive LCOE of thermo solar energy. The high initial expenditures for the construction of the solar fields would raise the inflationary pressures on the electricity prices and thus reflect negatively upon the input costs of the industrial sector, specially its energy-intensive branches. In the light of the growing liberalization of international markets, the logical consequence of higher production costs (raw materials, labour and electricity) would be a more disadvantageous position of China and Brazil in the increasingly competitive world-economy.

The industrial sector accounts for 71% of total Chinese energy consumption, and the prevalence of coal for electricity and heat generation was decisive for the astonishing growth rates registered in the last three decades [61]. The central government has relied on coal for developing its macroeconomic strategies [26], and the strictly regulation of electricity tariffs has had an importance similar to currency devaluation in assuring the increase of Chinese manufactures and their growing share in the world trade. Therefore, the first obstacle to the large-scale replacement of coal-fired plants for thermal solar power is related to the expenses on CSP infrastructure and its reverberation on the electricity prices, especially when one takes into consideration the role of energy intensive sectors—including chemicals, primary aluminium, cement, iron, paper and glass—in terms of employment and industrial value-added for the Chinese economy.

Although the contribution of the industry sector to the Brazilian GDP decreased in the last decade, and the country experienced a process of "reprimarisation" pushed up to a great extent by the Chinese demand for "commodities", the high LCOE is also an important part of the explanation on the backward stage of CSP integration in the national energy mix. In order to assure low electricity prices, the Brazilian legislation establishes that the contracts for the expansion of power capacity are defined in specific auctions. After the institutionalization of the "Incentive Program for Alternative Sources of Electricity" (PROINFA, Decree nr. 5025, 2004), goals were set for the deployment of alternative technologies, as a form of compensating to a certain degree the environmental and time consuming limitations for the construction of new large hydropower plants. Though CSP investors have taken part in auctions, the prices offered could not compete yet with other RE bids [31].

The CSP hybrid modalities and the application of combined heat and power in industrial processes were presented as viable strategies for reducing the costs and enabling the incorporation of thermo solar technologies in the Chinese and Brazilian energy matrices. Another incentive for including CSP policies in their respective energy planning might be the decision to boost the local industries that could take part in the manufacture of some CSP components and thus become global-players in this field. Indeed, this is an oligopolized branch of the global energy industry, mostly dominated by Spanish and German companies. This strategy would ratify the dynamics analysed by Wallerstein [21], according to which developing countries might attract a bigger share of the global surplus-value with strong State measures for inserting their national companies in oligopolized markets of high-technology products.

From the economic point of view, both PV and CSP deployment require high initial costs that tend to diminish throughout scaling-up processes and learning curves. Nevertheless, the Chinese government provided large subsidies and bank loans at lower rates (US$30 billion only in 2010) to boost the PV industry, drastically reducing the prices of PV panels and contributing in a decisively manner to make them competitive worldwide [19]. The advantages of PV over CSP were intimately connected to the perception of the Chinese government that the former presented greater profit opportunities in the overseas market. More specifically, China was attentive to the energy debate and the incentives given in the last fifteen years to the deployment of alternative technologies in the European Union. After the implementation of FITs in Germany, the country was inundated by "made-in-China" PV panels and, in a very short period of time, more than 300 Chinese cities were involved in the production of photovoltaic cells, with about 2000 PV industries active in the country [13]. Therefore, Chinese PV manufacturing capacity was pushed up by external demand, and local deployment was subsequently favoured by economies of scale and their positive effects on the production costs.

The contextualization of Chinese energy policies within a "World-Systems" framework provides key elements for understanding why initially expensive PV infrastructure was given priority in detriment of the investments on CSP technologies. However, it also presents a scenario in which developments in thermal solar energy might overcome the current lethargy and follow a similar path. As we showed previously, the Chinese industrial sector is already capable of integrating all the stages of the CSP value chain, and the low costs of national production would place the country as a global CSP player. It is also worth mentioning that China Electric Power Research Institute – a subsidiary of the state-owned State Grid Corporation of China – joined the Desertec Industrial Initiative in 2013 [62] and, in the same year, a delegation of Chinese policy-makers visited Morocco and Egypt, as part of a South-South knowledge exchange project to learn from these countries' experience with CSP pilot projects and their perspectives for the scaling-up process of thermal solar energy [63]. It remains unclear, however, if massive exports of CSP components will be a feasible strategy in the short and mid-term, for the Southern countries located at regions with high DNI levels are mostly developing nations with poorer budgets than the developed countries that pushed the Chinese PV manufacture.

The perspectives for CSP deployment in the next decade are less advantageous in Brazil than in China, for the South-American country is a latecomer in the field of solar energies. Even though Brazil has privileged DNI rates, thermal solar energy still does not figure as an important component of the plans for the expansion of the power sector. The experts stated the on-going work with Energy Research Company (EPE) to introduce CSP in the next ten-year energy plan, which is likely to occupy a small share in the Brazilian energy matrix [31,34]. Yet, the competition with other renewable energy sources seems to leave CSP aside. The Brazilian government is initially focusing on solar water heaters (SWH) and on the manufacture of solar panels. It is expected that PV will have substantial growth in the next period and reach 9 GW of capacity until 2035 [64]. The government's intention is to reproduce the path of the wind industry, using the legislation to create incentives for the national deployment of PV stations as a step for upgrading the industry competitiveness and thus achieve a profitable share of the PV world market [65].

Even if this goal is accomplished, current figures indicate that PV will then represent only 3% of the country's total electricity capacity [64], which is inferior to the world average (8%), although more auspicious perspectives are placed for the long-term scenario. Brazil will also continue to foster the manufacture and exports of RE technologies, but, in the light of current energy guidelines, its contribution to the mitigation of global warming will be largely outweighed by the commercialization of the oil-sand reserves.

Acknowledgments

The authors acknowledge the support of Jiang Jiuchun (Dean of the School of Electrical Engineering, Beijing Jiaotong University - China), Leila da Costa Ferreira (Full Professor at University of Campinas –

Brazil) and Valeriano Mendes Ferreira Costa (Assistant Professor at University of Campinas – Brazil). We are also thankful to Eduardo Soriano, Shi Jingli, Rafael Shayani and Torsten Schwab for providing us with valuable information. The São Paulo State Research Foundation (FAPESP) and the National Council for Scientific and Technological Development (CNPq) contributed for the accomplishment of this research.

Appendix A. The 13th chinese five-year plan – A turnpoint for CSP investments in China?

During the period in which this article was being reviewed, the Chinese government announced its 13th FYP with considerably more ambitious goals for CSP development. The following paragraphs will bring a short presentation of the newest roadmap, as well as information collected from three interviews with CSP companies and technology researchers in China.

Even though China did not achieve the target of 1 GW established by the 12th FYP, Beijing finally reached an agreement with project developers on the FIT for CSP plants: RMB 1.15/KWh ($0.22/KWh). Hence, the government declared the purpose of reaching 10 GW of installed capacity for CSP by 2020. In this case, China would be responsible by then for nothing less than 2/3 of CSP deployment worldwide [66].

The 13th FYP directives for CSP investments are intended to contribute for decreasing the participation of fossil fuels in the Chinese energy mix, as well as providing further incentives for the RE industry. The approval of the FIT – associated with the “competitive advantages” of the Chinese industry in a “World-System” economy – are likely to develop the country as a manufacturing hub for CSP components. A variety of national companies will benefit from the incentive policies and other US and European firms (SolarReserve, BrightSource Energy, 247 Solar, Cleanergy, Frenell) have announced that they will take part into the Chinese CSP program, possibly moving part of their manufacture plants to China and developing joint-ventures with stakeholders from the Chinese industry [67].

If Beijing is successful in achieving its new CSP target, then it will represent a turnpoint not only for China, but for any country that intends to develop CSP projects. Indeed, the deployment of 10 GW will be a major contribution for scaling-up CSP production and thus promote a global reduction of costs. China might also contribute with some technological breakthroughs, specially in the area of thermal storage, where most Chinese R & D efforts are concentrated [68].

However, there are still some barriers to overcome in order to successfully implement the new CSP goals. In Western provinces with sufficient DNI levels for making CSP projects feasible, the authorities have built some PV plants with high percentages of registered power curtailment [69]. Besides, the transmission lines that would connect these provinces to important consummer centres in Coastal cities are still being developed, which means that the achievement of 10 GW by 2020 will also depend on the socioeconomic development of such provinces so that at least part of the power production can be consumed locally and thus avoid further curtailment.

Another decisive point is the question whether the agreed FIT will be really sufficient for enabling the progress of CSP investments. Even though the institution of FIT for CSP plants already represents a positive sign, many stakeholders of the Chinese industry consider RMB 1.15/KWh a low price and suggest skeptical views on the market feasibility of the government's CSP program [70].

References

[1] International Energy Agency (IEA). World Energy Outlook 2013. Paris; 2013.
[2] M. Luomi Sustainable Energy in Brazil: Reversing Past Achievements or Realizing Future Potential. n.d.
[3] Ministério de Minas e Energia (MME) and Energy Research Company (EPE), Plano Decenal de Expansão de Energia, 2022; 2013
[4] Wang C, Cai W, Liao H, Lin J. China's carbon mitigation strategies: enough?. Energy Policy 2014;73:47–56. http://dx.doi.org/10.1016/j.enpol.2014.05.041.
[5] D Nakamura, Mufson S. China, U.S. agree to limit greenhouse gases. Washington Post. ⟨https://www.washingtonpost.com/business/economy/china-us-agree-to-limit-greenhouse-gases/2014/11/11/9c768504-69e6-11e4-9fb4-a622dae742a2_story.html⟩; 2014, [accessed 10.05.15].
[6] The Guardian. Air pollution in China is killing 4000 people every day, a new study finds. ⟨http://www.theguardian.com/world/2015/aug/14/air-pollution-in-china-is-killing-4000-people-every-day-a-new-study-finds⟩; 2015, [accessed 04.09.15].
[7] Empresa de Pesquisa Energética (EPE). Balanço Energético Nacional 2015: Ano base 2014. Rio de Janeiro; 2015.
[8] Instituto de Energia e Meio Ambiente (IEMA). Análise da evolução das emissões de GEE no Brasil (1990–2002); 2014.
[9] Roman M. Energy Policy in Brazil: Perspectives for the medium and long term. Östersund: n.d.
[10] Frankfut School and United Nations Environment Programme Colaboration Centre (FS & UNEP). Global Trends in Renewable Energy Investment 2015 | FS UNEP Centre; 2015.
[11] State Council . China's Energy Policy. Beijing: 2012; 2012.
[12] Painel Brasileiro de Mudanças Climáticas. US-Brazil Climate Change Declaration; 2015.
[13] Zhang S, Andrews-Speed P, Zhao X, He Y. Interactions between renewable energy policy and renewable energy industrial policy: a critical analysis of China's policy approach to renewable energies. Energy Policy 2013;62:342–53. http://dx.doi.org/10.1016/j.enpol.2013.07.063.
[14] Silva NF, da, Rosa LP, Freitas MAV, Pereira MG. Wind energy in Brazil: from the power sector's expansion crisis model to the favorable environment. Renew Sustain Energy Rev 2013;22:686–97. http://dx.doi.org/10.1016/j.rser.2012.12.054.
[15] Li J, Wang X. Energy and climate policy in China's twelfth five-year plan: a paradigm shift. Energy Policy 2012;41:519–28. http://dx.doi.org/10.1016/j.enpol.2011.11.012.
[16] CSP World. CSP World Map. CSPWorld.org. ⟨http://www.cspworld.org/cspworldmap?Field_country_map_tid%5B%5D=466⟩; 2015, [accessed 05.07.15].
[17] Pereira E, Charbel A, Aroreir I, Mesquita L. Mapeamento básico das precondições gerais para tecnologias heliotérmicas no Brasil; 2014.
[18] Ministério de Minas e Energia (MME) and Energy Research Company (EPE). Brazilian Energy Balance; 2014.
[19] Liu L, Wang Z, Zhang H, Xue Y. Solar energy development in China—A review. Renew Sustain Energy Rev 2010;14:301–11. http://dx.doi.org/10.1016/j.rser.2009.08.005.
[20] Wallerstein I. The Itinerary of World-Systems Analysis; or How to Resist Becoming a Theory. In: Berger J, Zelditch JR, M, editors. New dir contemp sociol theory lanham. MD Rowman Littlefield; 2002.
[21] Wallerstein I. World-systems analysis: an introduction. Durham Duke Univ Press; 2004.
[22] Mathews JA, Hu M-C, Wu C-Y. Are the land and other resources required for total substitution of fossil fuel power systems impossibly large? Evidence from concentrating solar power and China. Renew Sustain Energy Rev 2015;46:275–81. http://dx.doi.org/10.1016/j.rser.2015.02.045.
[23] Beck U. The Cosmopolitan Society and Its Enemies. Theory, Cult Soc, 19; 2002. p. 17–44. ⟨http://dx.doi.org/10.1177/026327640201900101⟩
[24] Beck U. Toward a new critical theory with a cosmopolitan intent. Constellations. Int J Crit Democr Theory 2003;10:453–68. http://dx.doi.org/10.1046/j.1351-0487.2003.00347.x.
[25] International Energy Agency (IEA) and International Renewable Energy Agency (IRENA). Concentrating Solar Power: Technology Brief. IEA & IRENA; 2013.
[26] International Energy Agency. Technology Roadmap Solar Thermal Electricity; 2014. ⟨http://dx.doi.org/10.1007/SpringerReference_7300⟩.
[27] International Energy Agency (IEA). Technology Roadmap Concentrating Solar Power; 2010. ⟨http://dx.doi.org/10.1177/02632764020190010110.1787/9789264088139-en⟩.
[28] International Energy Agency (IEA). Technology Roadmap Solar Thermal Electricity - 2014 edition. Paris; 2014.
[29] Klein SJW, Rubin ES. Life cycle assessment of greenhouse gas emissions, water and land use for concentrated solar power plants with different energy backup systems. Energy Policy 2013;63:935–50. http://dx.doi.org/10.1016/j.enpol.2013.08.057.
[30] Calvert K, Mabee W. More solar farms or More bioenergy crops? Mapping and assessing potential land-use conflicts among renewable energy technologies in eastern Ontario, Canada. Appl Geogr 2015;56:209–21. http://dx.doi.org/10.1016/j.apgeog.2014.11.028.
[31] Interview with Eduardo Soriano - General coordinator of sector techonologies. Brazilian Ministry of Science, Technology and Innovation; 14 of April 2016.
[32] Hong H, Peng S, Zhao Y, Liu Q, Jin H. A typical solar-coal hybrid power plant in China. Energy Procedia 2013;49:1777–83. http://dx.doi.org/10.1016/j.egypro.2014.03.188.
[33] Price T. Integrated solar combined cycle plants: Right place, right time. CSP Today n.d. ⟨http://social.csptoday.com/technology/integrated-solar-combined-cycle-plants-right-place-right-time#sthash.lITKs7si.dpuf⟩.[accessed 06.05.15].
[34] Interview with Torsten Schwab. Director of the RE and efficiency energy sector of GIZ in Brazil; 18th of April 2016.
[35] Malagueta D, Szklo A, Soria R, Dutra R, Schaeffer R, Moreira Cesar , Borba BS. Potential and impacts of Concentrated Solar Power (CSP) integration in the Brazilian electric power system. Renew Energy 2014;68:223–35. http://dx.doi.org/10.1016/j.renene.2014.01.050.
[36] Soria R, Portugal-Pereira J, Szklo A, Milani R, Schaeffer R. Hybrid concentrated

solar power (CSP)–biomass plants in a semiarid region: a strategy for CSP deployment in Brazil. Energy Policy 2015;86:57–72. http://dx.doi.org/10.1016/j.enpol.2015.06.028.

[37] Deloitte. Macroeconomic impact of the Solar Thermal Electricity Industry in Spain; 2011. p. 126.

[38] Soria R. Cenários de geração de eletricidade a partir de geradores heliotérmicos no Brasil: a influência do armazenamento de calor e da hibridização. Universidade Federal do Rio de Janeiro; 2011.

[39] Asian Development Bank (ADB). Proposed Loan People's Republic of China: Qinghai Delingha Concentrated Solar Thermal Power Project; 2013.

[40] Wiesenberg R, Hernández C, Serrano E. Market outlook for csp projects in china. SolarPaces Conference; 2012.

[41] Solar GIS. Solar radiation map - DNI n.d. ⟨http://solargis.info/doc/free-solar-radiation-maps-DNI⟩ [accessed 05.07.15].

[42] Levinger H. China's provinces: Mapping the way forward. Frankfurt Am Main, Germany: n.d.

[43] Statista GmbH. China: disposable income per capita by region 2014 | Statistic 2014. ⟨http://www.statista.com/statistics/278854/available-income-per-household-in-china-by-region/⟩; 2014, [accessed 24.04.16].

[44] Instituto Brasileiro de Geografia e Estatística (IBGE). Contas Regionais do Brasil (2005–2009). Rio de Janeiro; 2011.

[45] United Nations Development Program (UNDP). China National Human Development Report 2013 – Sustainable and liveable cities: Toward ecological civilization. Beijing; 2013.

[46] National Development and Reform Commission (NDRC). XII Five-Year-Plan (2011–2015); 2011.

[47] Schlipf D et al. CSP in Brazil. Perspectives for industrial development; 2014.

[48] Fraunhofer. Middle East and North Africa region assessment of the local manufacturing potential for Concentrated Solar Power (CSP) Projects; 2011.

[49] Interview with Shi Jingli. Energy researcher at the center for renewable energy development and research institute/national development and reform commission; 20th of November 2015.

[50] Chinese Academy of Sciences. The feasibility and policy study on developing concentrating solar power in China; 2010.

[51] Portal Brasil. Brasil instala primeira fábrica de paineis solares. ⟨http://www.brasil.gov.br/economia-e-emprego/2015/05/brasil-instala-primeira-fabrica-de-paineis-solares⟩; 2015, [accessed 06.09.15].

[52] International Energy Agency (IEA). Levelized cost and levelized avoided cost of new generation resources in the annual energy outlook. Paris; 2015. n.d

[53] International Renewable Energy Agency (IRENA). Renewable power generation costs in 2014; 2015.

[54] REN 21. 10 years of renewable energy progress: 2004–2014; 2014

[55] Associação Brasileira de Distribuidores de Energia Elétrica (ABRADEE). Tarifas de Energia. ⟨http://www.abradee.com.br/setor-de-distribuicao/tarifas-de-energia/tarifas-de-energia⟩; 2015, [accessed 16.04.16].

[56] Agência Nacional de Energia Elétrica (ANEEL). Banco de Informações de Geração (BIG) n.d. ⟨http://www.aneel.gov.br/area.cfm?IdArea=15⟩ [accessed 10.07.15].

[57] Energy Trend. CSP Focus China 2015 March 30–31 Beijing. ⟨http://pv.energytrend.com/event/20150129-8183.html⟩; 2015, [accessed 12.11.15].

[58] Zhu Z, Zhang D, Mischke P, Zhang X. Electricity generation costs of concentrated solar power technologies in China based on operational plants. Energy 2015;89:65–74. http://dx.doi.org/10.1016/j.energy.2015.07.034.

[59] Bendibao. Beijing electricity price list. ⟨http://bj.bendibao.com/cyfw/2011324/72937.shtm⟩; 2015, [accessed 05.07.15].

[60] J.Salvatore, World Energy Perspective - Cost of Energy Technologies, Bloomberg New Energy Finance, London, 2013, https://www.worldenergy.org/wp-content/uploads/2013/09/WEC_J1143_CostofTECHNOLOGIES_021013_WEB_Final.pdf

[61] Hu Y, Rodríguez C. Monroy Chinese energy and climate policies after Durban: save the Kyoto Protocol. Renew Sustain Energy Rev 2012.

[62] Willis B. State Grid Corporation of China joins Desertec initiative. 13 of December. PV-Tech Rev. ⟨http://www.pv-tech.org/news/state_grid_corporation_of_china_joins_desertec_initiative⟩; 2013, [accessed 15.04.16].

[63] Y. Song China visits Morocco, Egypt & finds the light of the future. 10 of January. Voices Views Middle East North Africa. ⟨http://blogs.worldbank.org/arabvoices/closer-sun-china%E2%80%99s-vision-solar-future⟩; 2012 [accessed 16.04.16].

[64] Empresa de Pesquisa Energética (EPE). Demanda de Energia 2050. Rio de Janeiro: EPE; 2014.

[65] Associação Brasileira da Indústria Elétrica e Eletrônica (ABINEE). Propostas para Inserção da Energia Solar Fotovoltaica na Matriz Elétrica Brasileira; 2012.

[66] National Renewable Energy Laboratory NREL. On the Path to Sunshot: Advancing Solar Power Technology, Performance and Dispatchability. US Department of Energy, ⟨http://www.nrel.gov/docs/fy16osti/65688.pdf⟩; 2016, [accessed 20.10.16].

[67] CSP today, China to install 1.4 GW CSP capacity by 2018, 30th September 2016 ⟨http://social.csptoday.com/markets/china-install-14-gw-csp-capacity-2018-south-africa-backs-redstone-ppa⟩; 2016, [accessed on 10.15.16].

[68] Interview with Jiao Jiwen. Director of oversea sales at the Tsinghua Solar company; 15th of October 2016.

[69] Interview with Richard Yang, Beijing Zeta Energy Technology; 16th of October 2016.

[70] Interview with Professor Wang Zhifeng, Chinese Academy of Sciences; 17th of October 2016.