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Assessing incentive policies for integrating centralized solar power generation in the Brazilian electric power system

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HIGHLIGHTS

- We assess the impacts of promoting centralized CSP and PV by auctions in Brazil.
- We simulate energy scenarios with and without solar power.
- Our solar scenario leads to 17 GW of solar capacity installed between 2020 and 2040.
- This solar scenario is some USD$ 185 billion more expensive than the base case.

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ABSTRACT

This study assesses the impacts of promoting, through auctions, centralized solar power generation (concentrated solar power – CSP, and photovoltaic solar panels – PV) on the Brazilian power system. Four types of CSP plants with parabolic troughs were simulated at two sites, Bom Jesus da Lapa and Campo Grande, and PV plants were simulated at two other sites, Recife and Rio de Janeiro. The main parameters obtained for each plant were expanded to other suitable sites in the country (totaling 17.2 GW in 2040), as inputs in an optimization model for evaluating the impacts of the introduction of centralized solar power on the expansion of the electricity grid up to 2040. This scenario would be about USD$ 185 billion more expensive than a business as usual scenario, where expansion solely relies on least-cost options. Hence, for the country to incentivize the expansion of centralized solar power, specific auctions for solar energy should be adopted, as well as complementary policies to promote investments in R&D and the use of hybrid systems based on solar and fuels in CSP plants.

1. Introduction

The Brazilian power system is hydrothermal, with thermal plants operating with, and complementing, hydroelectric plants to increase the system's firm energy[1] (Borba et al., 2012). As of 2012, hydroelectric power plants account for some 80% of all electricity produced in the country and new hydro plants are still expected to be built in the near to medium terms (MME/EPE, 2011, 2012). However, the remaining potential for hydroelectric expansion is concentrated in regions that are environmentally sensitive, which has justified investments in run-of-river plants as well as the greater environmental costs associated with the successive stages of environmental licensing (MME/EPE, 2011).

Among the renewable alternatives to meet the growing electricity demand in Brazil, solar and wind power stand out. Solar power is the conversion of solar energy into electricity, using either Photovoltaic panels (PV) or concentrated solar power (CSP).

Worldwide, grid-connected PV is currently the fastest growing power-generation technology, which grew in existing capacity by 58% per year from end-2006 through 2011, followed by CSP, which increased almost 37% annually over this same period (REN21, 2012).

The installation of CSP plants is usually recommended (as economically feasible) in regions with direct normal irradiation (DNI) above 6 kW h/m²/day, or 2000 kW h/m²/year (Arvizu et al., 2011; Viebahn et al., 2011; IEA, 2010a; Clifton and Boruff, 2010; Lovegrove et al., 2011; NREL, 2005). Estimates of CSP potential were done in countries with good DNI areas, and with existing or planned CSP plants, such as United States of America (Fthenakis

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[1] The firm is defined as the greatest amount of energy the hydroelectric system can provide 100% of the time or given the worst or critical hydrological conditions (Lucena et al., 2010).

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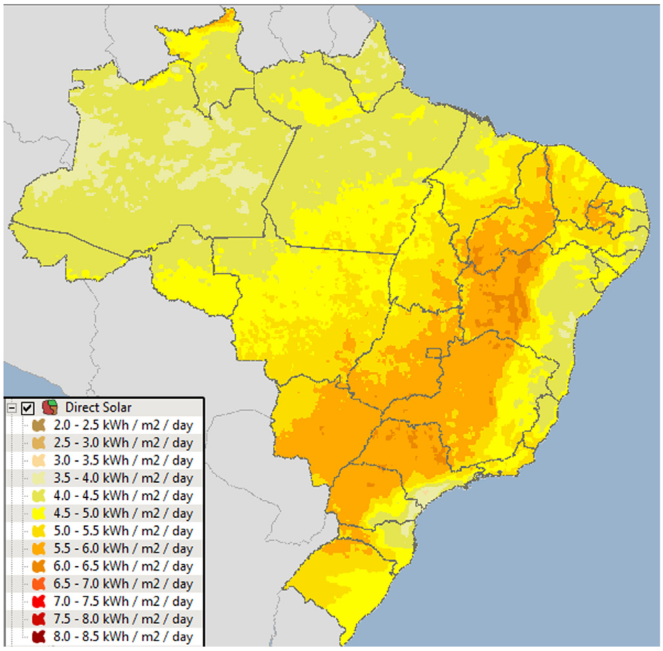

Fig. 1. Direct Normal Irradiation (DNI). .
Source: Geospatial Toolkit (2012).

et al., 2009; NREL, 2005; Wiser et al., 2011), India (Beerbaum and Weinrebe, 2000; Lovegrove et al., 2011), China (Wang, 2010; Hang et al., 2008; Li, 2009), Chile (Larraín et al., 2010) and United Arab Emirates (Vidican et al., 2012). In the case of Brazil, DNI assessments are summarized in different studies (Martins and et al., 2007; Martins and et al., 2008a; Martins and Pereira, 2011; Viana et al., 2011; Martins et al., 2012). These studies do not emphasize the modeling of the integration of large CSP power plants into the power grid, however. They focus on the assessment of Brazil's solar resource and, in the case of Viana et al. (2011) and Martins et al. (2012), on the evaluation of technical potentials for high concentrating photovoltaic systems (HCPV) and CSP systems, respectively.

Fig. 1 presents a DNI map for Brazil, in which the total area above the recommended DNI is of approximately 97,700 km².

There are some studies on grid-connected PV in Brazil as well (Mitscher and Rüther, 2012; Rüther and Zilles, 2011). However, there is no specific published study whose focus is on the integration of centralized PV into Brazil's power grid. In 2011, Brazil's total installed PV capacity reached around 31.5 MWp (30 MWp in isolated systems and 1.5 MWp in grid connected) (ABINEE, 2012). Even though Brazil's PV installed capacity is low, its potential is huge. Actually, the annual sum of daily horizontal global solar irradiation in any country's region hovers between 1500 and 2500 kWh/m^2, greater than those of the majority of the European countries such as Germany (900–1250 kWh/m^2), France (900–1650 kWh/m^2) and Spain (1200–1850 kW h/m^2) (Martins et al., 2008b).

In addition, there are only a few studies on the integration of variable renewable energy into the Brazilian power system (for example, see Borba et al., 2012, for an analysis of wind power integration in the country). According to Denholm and Hand (2011) and Strbac et al. (2007), the high penetration of intermittent renewable energy requires the appropriate modeling of the power system.

Usually, scientific papers devote particular attention to evaluate and propose policies for promoting renewable energy. The cases of United States and Spain are normally highlighted when it comes to discussing the promotion of solar technologies due to their relative success on high solar technologies deployment (Arvizu et al., 2011; CSP TODAY, 2011; Solangi et al., 2011; Torres et al., 2010). The most used policy for incentivizing renewable energy, specifically solar, in the United States and Spain was the feed-in tariff scheme. In the United States, the starting point is the PURPA act of 1978, which established a feed-in tariff incentive for qualifying facilities (QFs), set at the avoided costs of power utilities (Hirsh, 1999; Margaret, 2008; Solangi et al., 2011; Wiser et al., 2011). This policy was in force until 2005, when an amendment, aiming at establishing quotas for renewable energy for power generation in each state, was introduced (Wiser et al., 2011). This is the so-called renewable portfolio standard (RPS). In Spain, Law 54/1997 defined the Special Regime (RE), that guaranteed an incentive to solar energy based on feed-in tariffs for self-producers up to 50 MW of installed capacity (González, 2008; Fernández-García et al., 2010; Gobierno de Espana, 1997).

In the case of Brazil, the policy for promoting some renewable electricity generation options, especially wind, biomass and small scale hydro, is based on specific auctions.[2] In this case, the electricity distribution companies of the National Interconnected System must contract new power capacity in order to supply their market through auctions (CCEE, 2011; Ministério de Minas e Energia Do Brasil, 2007). The power contracting model based on bid for auction led to the success of wind power deployment in large scale in Brazil (Ricosti and Sauer, 2013; Moreno et al., 2010; Rego and Parente, 2013).

Therefore, Brazil does not adopt the feed-in tariff as a major policy to foster renewable energy, as oppose to happens in the United States and Spain. Instead, Brazil adopts an auction-based incentive policy. This policy is assessed in this study in order to, firstly, identify its impacts on the Brazil´s electric power system. This was done by running scenarios in an integrated optimization model, which allowed the identification of the electricity generation options displaced or complemented by solar alternatives, the impacts on transmission and the additional costs. Then, this study recommends some improvements in the Brazil´s current policy in order to promote solar energy in the country.

The remainder of this paper is divided as follow: Section 2 presents the technologies chosen for the technical-economic simulations. Section 3 details the methodology developed and used in the study, which is divided into three parts: the first indicates Brazilian radiation maps and justifies the selected cities for simulations (Bom Jesus da Lapa and Campo Grande for CSP plants, and Recife and Rio de Janeiro for PV plants); the second presents the inputs and the methodology for simulating CSP and PV plants with Brazilian meteorological data. Each plant is simulated in the software SAM, which allows to model solar plants operating in specific sites on hourly basis for the 365 days of the year; SAM is also capable of calculating the financial performance of each plant. In the third part of Section 3 (Section 3.3), the outputs from SAM become inputs to a least-cost optimization model adapted to the Brazilian interconnected power system. This model is a Brazilian updated version of MESSAGE, which is able to simulate the expansion and operation of all power generation plants in the Brazilian grid, according to two scenarios: a business as usual scenario without policies for centralized solar power; and an alternative scenario, where solar plants are

[2] In Brazil, electric power generation expansion is based on a competitive bidding mechanism, where energy blocks are sold from lower to higher prices until the total capacity amount, stipulated for every single round, is reached. In general, the bidding mechanism does not deny a source, but for several reasons the regulatory body can define a more restricted round—as occurred for alternative sources. In 2007 and 2008, in the specific alternative energy sources auctions only small-hydro and biomass won shares of requested capacity. In 2009, the first wind power exclusive round was accomplished, and thenceforward the source demonstrated its competitiveness in renewable-exclusive rounds (2010 and 2011). Nowadays, wind competes in ordinary rounds—opened to any source.