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Land requirement scenarios of PV plants in Brazil

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Abstract. Wind and solar parks future development can be constrained by land requirements. Considering the expected rapid development of the photovoltaic (PV) sector in Brazil in the next years, we analyse in this paper the associated interactions between land requirement and possible impacts of the PV technology. Key data from selected PV plants in operation in Brazil are used as reference. Investigation is based on two electricity generation scenarios for the year 2050: 1) Base Scenario, developed according to governmental policies and current trends for the energy sector and 2) Energy Revolution Scenario, a projection developed by Greenpeace Brazil based on 100% renewable energy sources. Considering the 2050 - Base Scenario, PV installed capacity in Brazil is expected to require an area of 940 km^2. Considering the 2050 - Energy Revolution Scenario, PV installed power in the country is expected to use an area of 2000 km^2.

Key words

Energy scenario, PV sector development, Land requirement of PV plants.

1. Introduction

Considering the low energy density of decentralized renewable energy (RE) plants, such as wind and solar parks, future development of these electricity sources can be constrained by land requirements. This characteristic is site specific, since compatibility with other land uses will depend on many factors, such as population density, environmental and agricultural purposes.

This process is already being observed in the Brazilian wind sector development. The rapid expansion of wind power in the country, from 28.6 MW in 2005 to 12.2 GW in 2017, has led to social and environmental impacts, consequence of the relatively high land area required by wind energy converters (WEC) for a specific electricity production, particularly in the coastal area of the Brazilian Northeast region. This region concentrates ca. 80% of the country's total installed wind power [1], [2].

Brazil has very large annual solar irradiation (1500 to 2200 kWh/m^2) with low seasonal and inter-annual variability. As an additional advantage, considering the domain of large hydropower plants in the country, the solar resource is complementary to the seasonal hydro regimes, as the lowest irradiation levels occur during the rainy months, due to cloudiness.

The first recorded use of photovoltaic (PV) systems in Brazil describes stand-alone applications in rural areas, dated back to the 1980s [3]. A significant change in the Brazilian PV sector happened only in 2012. In this year, the National Agency of Electric Energy [4] resolution REN 482 regulated the access of micro-generation (up to 75 kW) and mini-generation (from 75 kW up to 5 MW) to the distribution grid and introduced a net metering system. Net metering is an incentive mechanism for RE use and permits consumers to subtract the self-produced electricity from measured consumption. Positive consequences of the mentioned resolution are being observed mainly in the PV sector: micro and mini-generation reached in 2016 an electricity production of 104.1 GWh with an installed power of 72.5 MW. The main contribution comes from PV plants, with a production of 53.6 GWh and a power of 56.9 MW [5]. Brazilian PV sector should receive investments of R$ 4.5 billion (ca. € 1.05 billion) in 2017 [6].

Considering the expected rapid development of the PV sector in Brazil in the next years, we analyze in this paper the associated interactions between land requirements of the PV technology and possible impacts. The investigation is based on two scenarios for the electricity generation in Brazil for the year 2050 [7]:

a) Base Scenario, developed according to the government policies and current trends for the energy sector;
b) Energy Revolution Scenario, a projection developed by Greenpeace Brazil based on 100% RE sources.

Considering the Brazilian territory area (ca. 16 times the area of Spain), an initial analysis can consider such impacts irrelevant. Large PV plants can be installed in the sunny central areas of the country, far away from the coast line characterized by a high population density. But this alternative has brought new challenges for the energy sector planners. The main challenge is related with the historically low electricity demand of rural areas. Hence, the electricity supply infrastructure in such areas is considered "weak" and need significant investments (transmission lines, substations…) to incorporate decentralized RE power. This lack of infrastructure has already canceled some solar and wind projects in rural areas, representing a restriction of areas in conditions to receive such power plants. Important to mention, for large ground-mounted PV plants, land is required in addition to the PV modules area for access, maintenance and to avoid shading [8]. Hence, this paper studies and analyses two land requirement scenarios of PV plants in Brazil. This study can provide policymakers and researchers with estimates of future land use claims by decentralized PV low carbon power source in Brazil, indicating priorities of investments in the sunny central areas to incorporate such RE power and comparing PV generation with other alternatives of electricity production, aiming to attend technical aspects, environmental protection and social demands.

2. Scenarios for installed capacity in Brazil for electricity generation

Figure 1 shows the installed electrical power in Brazil for the year 2017. Hydropower (HP) is the main electricity source, with almost 63% of the total power, corresponding to 96.9 GW. In the last years, the country is diversifying its electricity generation matrix, the most significant increase rates being observed in the wind and PV sectors. Particularly the wind energy program is a successful public-private initiative, attractive for investors in RE [1].

Figure 2 shows the installed capacity for electricity generation in Brazil for the year 2050 - Base Scenario, a scenario developed according to the government policies and current trends for the energy sector. Comparing to the electricity matrix in 2017, HP grows to 137 GW but its per cent participation is smaller (ca. 44%). PV and Concentrated Solar Power (CSP) represent almost 16% of the matrix (50 GW). Wind increases its installed capacity to 52 GW, representing 17% of the matrix. Nuclear, NG and Coal increase their installed power, but the per cent participation is kept nearly the same.

Figure 3 shows the installed capacity in Brazil for 2050 - Energy Revolution Scenario, a projection developed by Greenpeace Brazil based on 100% RE sources. According to this scenario, Nuclear, NG, Fuel Oil, Coal and Diesel have no participation in the matrix. HP, PV and Wind become the main sources in the country, with 32.2%, 28.7% and 24.4 % of the electricity matrix, respectively. PV has the most expressive increase in the period, from 0.1 GW in 2017 to 100 GW in 2050. Wind installed capacity increases from 12.2 GW to 85 GW in the same period. According to Greenpeace, the main results of the mentioned scenario are:

- Use of 100% RE sources;
- Increase in energy efficiency;
- Electrification of the energy mix;
- Diversification and decentralization;
- Significant changes in the transport sector;
- Cheaper electricity;
- Large number of jobs.

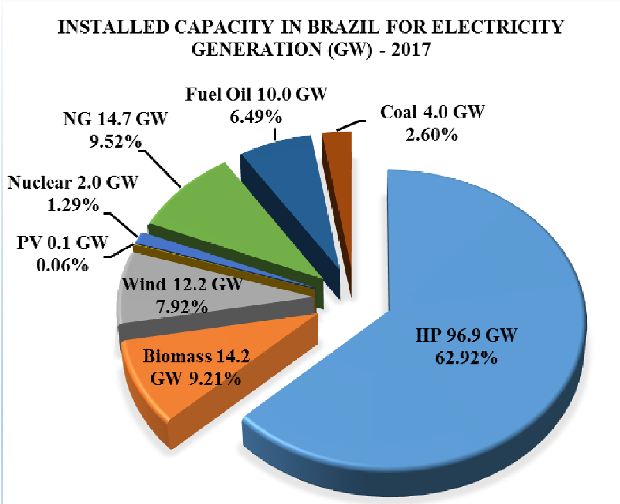

Fig. 1. Installed capacity in Brazil for electricity generation (GW) 2017; Hydropower (HP); Natural Gas (NG)

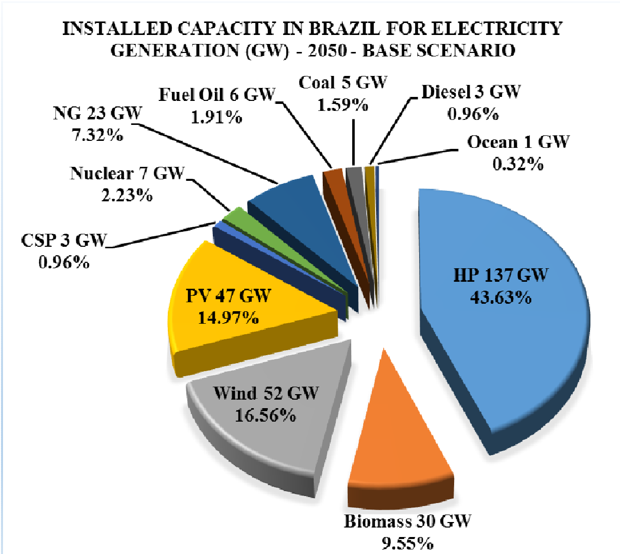

Fig. 2. Installed capacity in Brazil for electricity generation (GW) – 2050 – Base Scenario; Concentrated Solar Power (CSP)

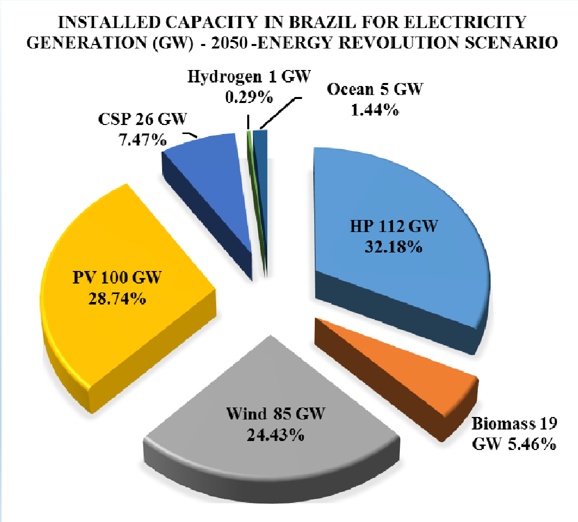

Fig. 3. Installed capacity in Brazil for electricity generation (GW) – 2050 – Energy Revolution Scenario.

3. Scenarios for land use of PV plants in Brazil

Table 1 summarizes some key data of selected PV plants in operation in different states in Brazil: PV technology, power, area, power per area, area per power. As mentioned, grid connected PV plants in the country is a relative recent process, with the main actors in a learning process. Hence, the number of installations is very small compared to the potential. The considered Brazilian states are Rio de Janeiro (RJ), Ceará (CE), Piauí (PI), Bahia (BA), Santa Catarina (SC) and Pernambuco (PE). The dominant PV technology uses crystalline silicon. Table 1 does not include Building-integrated photovoltaics (BIPV).

Table 1. Key data of selected PV plants in operation in different states in Brazil

Site	PV Technology	Power (kWp)	Area (m^2)	Wp/m^2	m^2/Wp	Source
Cabo Frio, RJ	a-Si	9.00	139.49*	64.52	0.015	[9]
	a-Si/µSi	8.95	99.19*	90.19	0.011	
	p-Si	8.93	60.53*	147.53	0.007	
	m-Si	8.84	59.47*	148.65	0.007	
	CIGS	8.88	80.96*	109.68	0.009	
	CdTe	8.96	80.64*	111.11	0.009	
Tauá, CE	p-Si	1000	12000	83	0.012	[10]
Pindoretama, CE	m-Si	2983.5	60000	49.73	0.020	[11]
Tabuleiro do Norte, CE	p-Si	1060	35000	30	0.033	[12]
Nova Olinda, PI	p-Si	292000	6900000	42	0.024	[6]
Ituverava, BA	p-Si	254000	5500000	46	0.022	[6]
Tubarão, SC	NA	3000	100000	30	0.033	[13]
São Lourenço da Mata, PE	a-Si	11.22	299	37.53	0.027	[14]
	p-Si	23.04	360	64.00	0.016	
	m-Si	980.50	14000	70.04	0.014	
	CIGS	10.68	337	31.69	0.032	

a-Si: amorphous silicon; a-Si/µSi: microcrystalline silicon; p-Si: polycrystalline silicon; m-Si: monocrystalline silicon; CIGS: copper indium gallium diselenide; CdTe: cadmium telluride.
*Only array area; NA = Not Available

Considering the 2050 - Base Scenario, PV installed capacity in Brazil is expected to grow to 47 GW_p. Using a value of 0.02 m^2/W_p as reference, this results in an area requirement of 940 km^2. This reference uses an average area/power of plants using crystalline modules, mentioned in table 1 and excluding plants that consider only array area. The corresponding average power/area is 50 W_p/m^2. Comparing with other sources in Brazil, the average reservoir area per unit of firm power from the Brazilian hydroelectric plants is 0.815 m^2/W [15].

Considering the 2050 - Energy Revolution Scenario, PV installed power in Brazil is expected to grow to 100 GW_p. Using the same reference, an area requirement of 2000 km^2 is calculated.

To calculate area per electricity production ratio, measured capacity factor (CF) data from a 1.5 kWp grid connected PV plant installed at the Laboratory of Alternative Energies of the Federal University of Ceará (LEA-UFC), in Fortaleza, Brazil, are used. Fig. 4 shows the mentioned CF measurements in the period of September 2016 to August 2017. CF development shows clearly the local meteorological conditions: most rainfall (some 80% or more of the precipitation) occurs within the rainy season (January-June), and very little more falls during the rest of the year [16]. An average CF value of 20% is calculated for the mentioned period.

Data from a PV plant in Pindoretama, CE (Table 1) are used as reference for large plants, due to the relative small distance between the two sites (ca. 50 km). Hence, irradiation conditions and CF development can be considered the same for Fortaleza and Pindoretama. Based on this assumption, a yearly electricity production of 5178.48 MWh is estimated for the mentioned plant. Considering the plant area (60000 m^2), this production leads to an electricity production per area ratio of 0.09 MWh/m^2, corresponding to an area per electricity production ratio of 11.59 m^2/MWh.

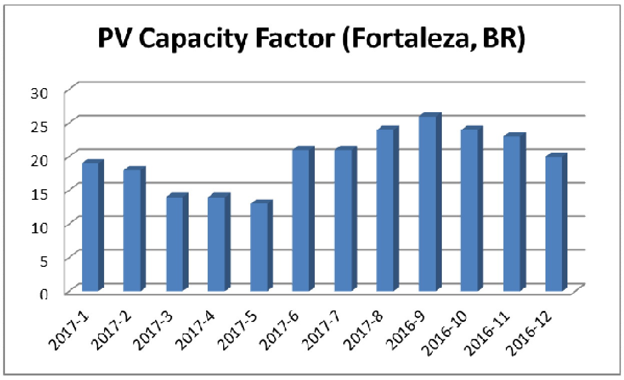

Fig. 4. Capacity factor data from a 1.5 kWp grid connected PV plant installed in Fortaleza, Brazil

Immobilized area per electricity production ratio for different energy sources, except PV sector, can be found in [15]. Table 2 shows these ratios, including the calculated value in this paper for PV plants. The "immobilized area over time" concept, expressed in m^2.year, express the occupation and recovery time of energy sources for generating electricity. Area downtime, considering both plant operating time and time to recover the site, is taken as the associated parameter of this variable. In the present analysis, a life time of 25 years is assumed as PV plant operating time, a period usually informed by PV module companies.

Important to mention, data from [15] represent mean values of several power generation plants found in the literature, characterized by large variations.

Table 2. Immobilized area per electricity production for different energy sources

Energy source	Immobilized area per electricity production (m^2.year/MWh)
Biomass	21,320
Coal	33
Wind	1,129
Natural gas	11
Hydropower	186
Nuclear	346
Oil	11
PV	290

Source: [15], except PV data

4. Conclusion

Two scenarios for electricity generation in Brazil for 2050 are considered in the present analysis: 1) Base Scenario, proposing a mix of fossil fuels and RE sources and 2) Energy Revolution Scenario, proposing a matrix based on 100% RE sources. Using these scenarios as reference, area requirements for PV plants are calculated: 940 km^2 for 47 GWp (Base Scenario) and 2000 km^2 for 100 GWp (Energy Revolution Scenario). For comparison, PV area for the first scenario corresponds to 1.6 x area of Madrid, Spain largest city. PV area for the second scenario is ca. 3.3 x area of Madrid. Considering area per power ratio of PV and hydroelectric plants, Brazil's main electricity source, HP requires ca. 40 x the value of PV installations.

Considering immobilized area per electricity production, a value of 290 m^2.year/MWh is calculated, assuming a life time of 25 years for the PV plant. This ratio is found using data from a large PV plant in the neighborhood of Fortaleza (latitude: −03° 43′, longitude: −38° 32′). Hence, additional investigation is needed aiming to collect data of large PV plants in different regions of the country.

Land requirement of large grid connected PV plants in Brazil should be considered as an important challenge for definition of energy policies. That is particularly true for the sunny rural areas in Brazilian Northeast region, characterized by a "weak" electricity infrastructure requiring significant investments. Hence, energy planners should concentrate efforts to examine the scale and pace of land use change that will be necessary to realize the widespread use of utility-scale PV plants in Brazil. Optimization strategies should be investigated, aiming to attend technical aspects (grid connection points), environmental protection and social demands.

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