Research Article

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Growth in the Use of Photovoltaic Energy in Brazil

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ABSTRACT

In a world of ever growing interdependence, energy is increasingly becoming a subject of international dispute, both on economic and political level. Responding to this challenge, national and international decision-makers are seeking new strategies to diversify the energy mix of their home countries and arrange for a more sustainable production. Brazil has vast amounts of untapped renewable resources with a number of advantages over developed countries. However, the role that renewable energies plays in the Brazilian market is still quite small (except for hydro power). Drawing from the German example, this paper aims to develop a guideline for a Brazilian incentive program that encompasses the so far neglected photovoltaic technology, and takes into account the country's peculiarities. It highlights the potential and advantages that Brazil might have regarding gridconnected photovoltaic systems and makes a study of grid parity. This study was developed trough scenarios that identify when, how and in which regions of the country, photovoltaic generation would be competitive with conventional generation. The grid parity study of photovoltaic technology in Brazil was compared to a similar study developed in Europe. It showed, no matter the current cost of photovoltaic technology, it can be competitive with conventional generation in 2020 at the sunniest regions of Brazil, considering the worst scenario.

Keywords
Legislation, Projects in Brazil, Solar panels, solar resource.

Introduction
The search for diversification of energy resources in Brazil has become extremely necessary due to two main factors.

The first is the current water situation that the country is going through, with the scarcity of rain the generation situation through hydroelectric power plants has being compromised. Since the significant reduction in rainfall, power generation by hydroelectric plants has not been sufficient to supply the demand. Therefore, the need to use thermoelectric power plants has caused the price of energy to increase.

Secondly, the exploitation of renewable energy resources brings more comfort, security, flexibility and sustainability. In this scenario, photovoltaic solar energy presents itself as a technology in constant advance in Brazil and around the world.

Through a bibliographical review, this article aims to present the principle of the use of this energy, considering the equipment and materials applied to the system, as well as the efficiency they can achieve. In addition, there is a broader view of the use of sunlight to produce electricity through photovoltaic panels and the applications of this technology in specific situations, such as installation on street lights.

The use of photovoltaic energy is a reality that increasingly asserts in several countries. In Brazil, the implementation of photovoltaic systems needs to reach a high generation scale to reduce costs, because the tax is still high on the product. There are several uses for a system that generates electricity through solar modules, as in the battery bank and off and on grid systems.

Brazil is the most advanced country in South America, with respect to the development of renewable energies. This is mainly due to the large size (8,514,877 km²), which corresponds to 47% of the South American area [1], abundant natural sources and a favorable climate.

The country has excellent levels of solar radiation because it is located on a latitude range in which the incidence of solar radiation is much higher than in the rest of the world. This characteristic places the country at an advantage in relation to the industrialized countries with regard to the use of photovoltaic solar energy [2].

On the other hand, an energetic change of the country has been growing continuously. This generates overload in the network of large expansions, which consequently entails high investments. Thus, the main priorities and objectives of Brazil to encourage the use of renewable energy are:

- The use of local resources;
- The establishment of distributed generation in a country of continental currencies;
- The establishment of a local industry;
- The contribution to a generation of new jobs;
- The diversification of the energy matrix;
- The aid may not be necessary on national demand, through the use of a complementary source of energy;
- The contribution to the eradication of poverty, reinforcing or providing energy in local communities;
- The reduction of social and environmental impacts from the deployment of conventional energy sources.

The German Renewable Energy Energy Program

The pricing system introduced with the 1991 law, and continuously updated by law Renewable Energies Act of 2000 and the 2004 Renewal of Energy Sources Amendment, is the key to the success of renewables in Germany. The German mechanism is based on the obligation to buy from the network operator all the electricity generated by renewable sources, paying at a premium rate that is distinct for each technology. The funds raised through a double increase in the tariff of all products are deposited in a fund used for Reward (in the form of premium rate) those that need to be evaluated photovoltaic. In this case, the incentive is paid gradually, as a premium per kWh over several years, allowing consumers to recover their investments over a period of 10 to 12 years [3]. The objective of the program is to facilitate the sustainable development of energy supply by controlling global globalization, protecting the environment and In the list of renewable energies, there is no consumption of at least double until the year 2010.

In 2004, there was an approximately 100% increase in photovoltaic energy installed in Germany [4], which at the end of 2005 was approximately 1.5 GWp connected to the public electricity grid [5]. Thus, renewable energies are the key contribution to leasing business and investments in the country. According to the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety [6], renewable energies in Germany contributed 72.6 TWh to the final supply of electricity in 2006. Data published by IIC - Invest in Eastern Germany 2006), indicate that in 2005 the German photovoltaic industry had a turnover of US $ 3 billion and generated around 30 thousand jobs. The photovoltaic market had a great growth, as it can be seen in Figure 1, mainly from the year 2000, where the German government implemented the Feed-in-Tariff and the Renewable Energy Sources Act.

Brazilian Incentive Program and Its Advantages In Relation To Germany

According to Holm and Arch [7], the price system is the most recommended mechanism to promote renewable energy not only in developed countries, but especially in developing countries. Since the poorest countries have basic needs to be met, it does not make sense to adopt a program of incentive to renewables where the government has to enter with a high initial investment. The advantage of the pricing system is that there is no such need for government investment.

The proposal for a Brazilian program is similar to that used by the German government, but would specifically contemplate photovoltaic technology. The program would follow the strengths of the Renewable Energy Sources Act and adapt the points that are not in accordance with the Brazilian reality. As in Brazil, there are 18 million residential consumers of income [8] the study of the principle that only residential class consumers average in Brazil would be paying for the photovoltaic energy incentive program.

Brazil has a number of advantages regarding the number of registrations in photovoltaic technology and mechanisms to encourage renewable energies.

It can be verified that even in the most favored region of Germany, in terms of solar radiation, presents approximately 1.4 times less radiation than the less sunny region of Brazil.

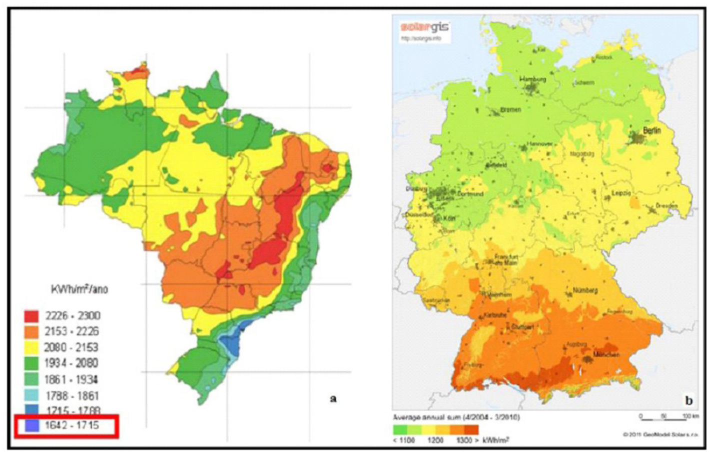

Figure 1: Solar irradiation - Brazil (a) / Solar irradiation - Germany (b). Annual average of the incident global cleaning without horizontal plane. Sources: SALAMONI and RÜTHER, 2007; GEOMODEL SOLAR.

If it is contrasted what consumes two countries (Tab.1), it can be observed that even Brazil has a significant larger language, a country has an energy consumption of approximately twice as much and a residential tariff approximately 30% more expensive than that of the Brazilian residential consumer. This causes Germany to raise more funds, for the tariffs of energy channels than Brazil would raise, in the case of an equivalent program.

As shown in Figure 2, of the German residential tariff, 3% goes to the Renewable Energy Sources Act. Therefore, Germany collected in 2006 only with residential consumers about 8.8 billion euros, which were destined to renewable energies. If this same percentage of 3% were applied to the tariff of middle-class residential consumers in Brazil in 2017 (Figure.3), the country could raise 3 billion euros.

	BRAZIL	GERMANY
Number of inhabitants	184 million	82 million
Number of residential consumers	48.3 million	44 million
Number. of middle-class residential consumers	30.3 million	N.A.
In the case of low-class residential consumers	18 million	N.A.
Total Power Consumption	336 TWh / year	616 TWh / year
Total residential energy consumption	85 TWh / year	140 TWh / year
Residential energy consumption low class	13.7 TWh / year	N.A.
Middle class residential energy consumption	71.3 TWh / year	N.A.
Residential Rate	€ 0.14 / kWh	€ 0.19 / kWh
Maximum annual solar radiation	2226-2300 kWh / m²/ year	1150-1200 kWh / m 2 / year
Minimum annual solar radiation	1642-1715 kWh / m ² / year	900-950 kWh / m 2 / year

Table 1: Comparative data between Brazil and Germany.
N.A * = no data available.

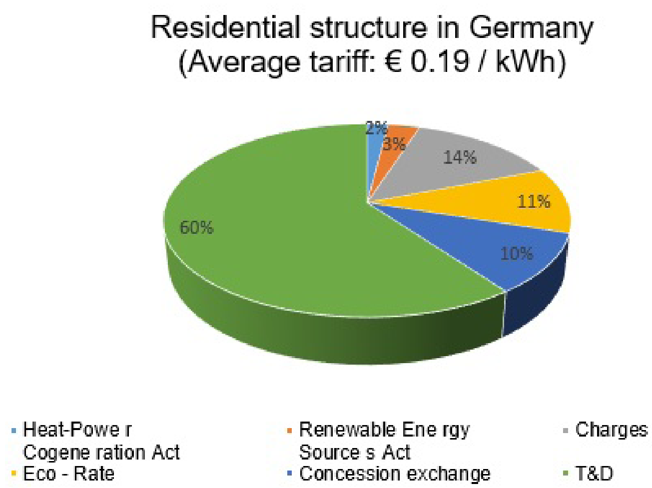

Figure 2: Residential tariff in Germany (0.19€ / kWh).

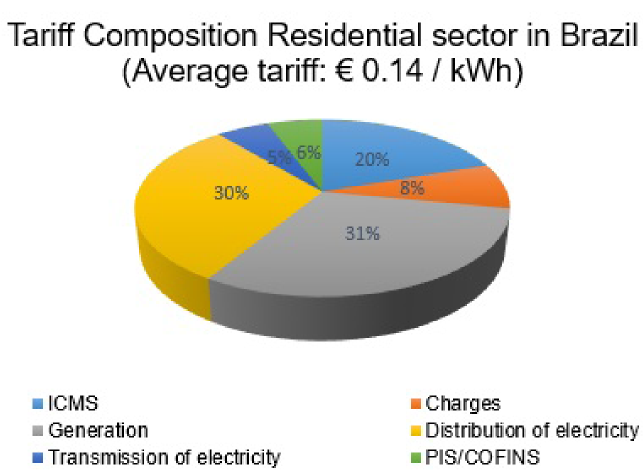

Figure 3: Residential tariff in Brazil (0.14€ / kWh).

According to the above data, it can be seen that the same photovoltaic power installed in Germany would have in Brazil an energy generation and a significantly higher demand supply impact, since Brazil has higher solar radiation levels and an energy demand approximately twice as low as Germany's. This leads to a lower investment cost, for the same energy benefit generated in Germany.

Solar Energy in Brazil

According to the Solar Irradiation Atlas of Brazil [9] in the Northeast, where solar energy is more efficient, it is daily between 4.5 kWh / m² and 6.3 kWh / m² in the country.

According to the official website of ANEEL - Agência Nacional de Energia Elétrica [10]. Brazil has 3407 agents investing in the electric energy market, of which 249 are self-produced and 70 are public transport.

Regarding the incentives for the generation of energy, the content of Article 7 II of Normative Resolution ANEEL3 nº 482/2012, states that "if the energy injected is greater than that consumed, the excess energy will be equal to the difference between the amount of energy injected and the amount of energy consumed ".

The resolution also informs about the invoice, which should show the positive energy balance in kWh (kilowatt-hour) and the cost of adequacy of the metering system, which is required by the energy compensation system, is the responsibility of the company or person concerned, but the repairs and maintenance of the equipment are the responsibility of the distributor. With Resolution ANEEL Regulation 482, the small producer can introduce the energy obtained by the renewable system, but will not be remunerated. What happens after this generated surplus becomes credits that expire in 60 months.

Several advantages are known for the use of this energy, such as reduction of transmission and distribution losses and reduced value in transmission and distribution line investments.

Network Parity Analysis

In the course of the research, network parity scenarios for photovoltaic technology were developed for the years 2007, 2010, 2015 and 2020. Network parity is achieved when the costs of photovoltaic and conventional energy are the same for the end user. This study was compared with a similar model, developed for Europe, by Sinke [11].

On the map of Brazil lines of solar radiation were drawn with different colors. These radiation ranges and their respective colors are based on the solarimetric atlas of Brazil (Figure. 1Taking as an example the rate of growth of residential rates in the Southeast region of Brazil over the years (Table 2), it is possible to observe that there was not linear growth in the evolution of residential rates over the years. In this way, scenarios were developed considering four annual percentages of residential tariff evolution: 4% p.y, 8% p.y, 12% p.y and 16% p.y.

The study by Sinke (2006) considered a percentage increase in the residential tariff in the Europe of only 1% py.

2012	2013	2014	2015	2016	Δ% (2016/2015)	Δ% (2016/2012)		
292,85	254,45	276,97	395	419,09	6,1	143,1	292,85	Brazil Average
321,17	276,68	303,53	372,93	419,75	12,6	130,7	321,17	North
297,09	250,52	269,05	340	367,64	8,1	123,7	297,09	Northeast
294,78	260,24	282,22	413,04	441,65	6,9	149,8	294,78	Southeast
277,23	235,15	264,27	409,28	415,1	1,4	149,7	277,23	South
290,41	257,74	273,63	398,07	419,38	5,4	144,4	290,41	Midwest

Table 2: Average Rates by Region (R $ / MWh). Source: Statistical Yearbook of Electric Energy 2017.

In the European analysis, the author used an IRR of 4% py, which in the case of Brazil would not attract potential investors. For this, an internal rate of return of 12% py was used in the analysis for Brazil, which is more in keeping with the Brazilian reality. For both analyzes, a cost reduction percentage of photovoltaic technology of 5% per year was considered, based on the learning curve [12-15]. This model analyzes and predicts how the costs of photovoltaic production decline proportionally to the increase in production volume.

The cost of photovoltaic energy in Brazil was calculated according to Equation below. It has been considered that the efficiency of the generator is 839 kWh / kWp at a radiation of 1000 kWh / m² / y. This value was based on field experiments and measurements. The European analysis considered a yield of 750 kWh / kWp at a radiation of 1000 kWh / m² / y. For both analyzes, 1% was considered as an expense.

$$C = \$x \, \frac{\left[\frac{\mathrm{TIR}\ \mathrm{x}(1+\mathrm{TIR})^t}{(1+\mathrm{TIR})^t} + D\right]}{R}$$

The values for solar radiation in Brazil were placed to the right of the maps. Each colored band represents an index of solar radiation. In order to simplify the process, it is considered that all the regions contained within these bands have the radiation index equivalent to the same. The values referring to the energy tariff for the residential sector were inserted on the map within each state.

The cost of photovoltaic energy was placed to the left of the map. In each band of solar radiation, the cost of photovoltaic energy is different. This cost is valid for all regions within the same radiation range. The cross-sectional areas represent the regions that would reach network parity, that is, that would cost the photovoltaic generation at least equivalent to the cost of conventional generation for the residential consumer. They were presented in this article only the maps for the simulations that resulted in network parity.

Photovoltaic solar energy has been conquering consumers and expanding in Brazil. Only in 2016 the sector grew 300% and has bigger prospects for the next years. According to the Brazilian Association of Photovoltaic Solar Energy (ABSOLAR), the country has 12,520 solar photovoltaic pairs connected to the grid, bringing economic and environmental engagement to 13,897 consumer units, totaling over R $ 850 million in investments calculated since 2012.

Results

According to the scenarios, considering an evolution in residential tariffs of 4% py, Brazil would reach network parity in 2020, in the state of Mato Grosso and part of Minas Gerais (Figure. 4).

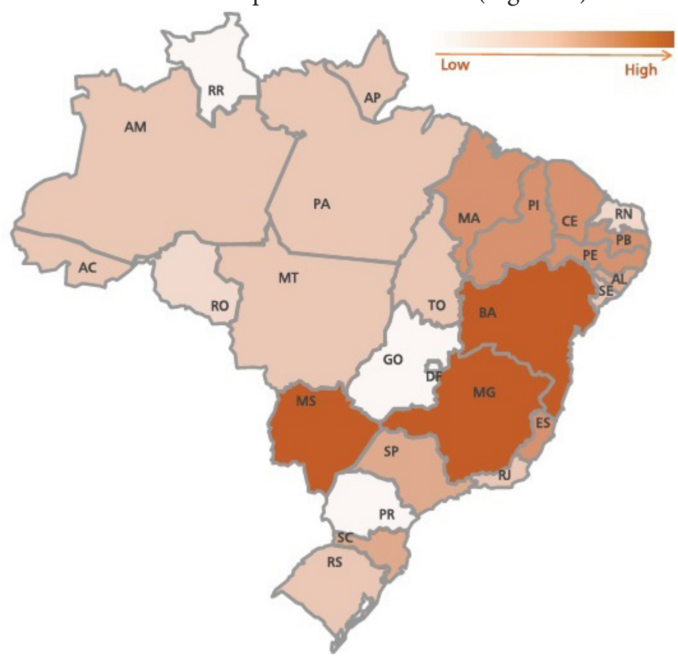

Figure 4: Network parity for the year 2020, based on a tariff growth rate conventional residential power of 4% p.y.

In this case, photovoltaic energy would be costing 0.24 € / kWh, while the conventional tariff for the residential sector would be costing approximately 0.25 € / kWh.

BRAZIL		
	STATES	**DATA**
1	BA	0,37
2	PE	0,32
3	ES	0,32
4	CE	0,32
5	RJ	0,27
6	SE	0,27
7	SP	0,30
8	AC	0,27
9	MA	0,32
10	RS	0,27
11	PA	0,27
12	GO	0,22

13	RO	0,25
14	MS	0,37
15	SC	0,30
16	RN	0,25
17	PR	0,22
18	DF	0,22
19	MG	0,37
20	PB	0,32
21	TO	0,27
22	AL	0,30
23	AM	0,27
24	PI	0,32
25	MT	0,27
26	AP	0,27
27	RR	0,22

Table 3: Growth in the conventional residential energy tariff of 4% per year.

Final Considerations

Brazil is a country rich in renewable energy sources and has the necessary and sufficient conditions to establish a law to encourage distributed generation, in particular to the generation of photovoltaic solar energy connected to the grid, like the one established in Germany.

Although Brazil is a developing country, it presents a portion of consumers with the possibility of assuming the costs of a considerable photovoltaic program. Besides this factor, the energy demand of Brazil is significantly lower and the country presents excellent levels of solar radiation. The sunniest region of Brazil is about 1.4 times more radiation than in the less sunny region of Germany. As it is written on Magazine Exame (edition of March 15yh, 2018), "for now, in Brazil, the sun is strong, but it is not yet for everyone".

Brazil is able to expand its generation in terms of natural resource supply and be a potential in photovoltaic energy.

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