Hydro-Wind Power Complementarity: A Way to Implementing Wind Power in Brazil

Ricardo M. Dutra[1] & Alexandre S. Szklo[2]

1 - Electric Power Research Center – CEPEL - P.O. Box: 68007 – 21944-970, Rio de Janeiro, RJ, Brazil, Tel: 55 21 2598-6174, Fax: 55 21 2280-3537, Email: dutra@cepel.br
2 - Energy Planning Program, Graduate School of Engineering, Federal University of Rio de Janeiro, Centro de Tecnologia, Bloco C, Sala 211, Cidade Universitária 21941-972 Ilha do Fundão, Rio de Janeiro, RJ, Brazil, Tel: 55 21 2560-25628760, Fax: 55 21 2562-8777
Email: szklo@ppe.ufrj.br

Summary
The incentive policies for wind energy that has being implemented in Brazil, since the last decade, promoted the implementation of some projects, mainly through the Alternative Energy Sources Incentive Program (PROINFA), which started in 2002. After the first phase of PROINFA, the wind power sector in Brazil is still waiting for a new long-term program. By applying a GIS model to the available wind database, this paper evaluates a long-term incentive program to wind power in Brazil, according to specific target and criterion of optimizing the operation of Brazil's hydropower reservoirs. The optimization of the operation can be done through a wind-hydro complementary, present at northeast of Brazil. It is noteworthy that the São Francisco River is the most important resource of electricity generation to the northeast of Brazil, and the largest wind speeds occur exactly when the flow of water of São Francisco River is at a low level. A program based on Feed-in tariffs would result in the installed capacity of 15.5 to 65.4 GW, depending on the criterion for selecting the projects.

Keywords: Wind Power, Hydro Power, Policy, GIS

1. Introduction

As presented by the Atlas of Brazil´s Wind Power Potential [1] the wind potential is impressive in certain regions of Brazil, such as the northeast coastal region and parts of south and southeast. The Brazilian huge wind power potential has complementarities between wind and hydraulic resources that were identified in some regions which might optimize the use of hydropower reservoirs of the country[1].
The Alternative Energy Sources Incentive Program (PROINFA) was designed in 2002 to stimulate the electricity generation from three energy sources (wind, biomass and small-scale hydro) in Brazil. The Program was divided into two phases. The first one uses Feed-in tariffs for promoting the development of 3,300 MW in the short term. The second one that was originally based on feed-in tariffs was modified in 2003, in order to be based on biddings for renewables. As discussed by Dutra and Szklo [3], Brazil's power sector reform, which occurred in 2003, altered PROINFA'S second phase. The reform emphasized contract biddings, in order to control the excessive rise of the electricity tariff. Dutra and Szklo [3] also showed, by simulating different scenarios, that this revised version tends to penalize the highest-cost power option it promoted (wind power generation), which might have development problems in a bidding system that includes all three renewables as competitors.
Several wind power projects were proposed and assessed during the first phase of PROINFA, but the second phase of this program is still uncertain. However, this uncertainty is an opportunity to review the incentive policy [2].
According to specific targets and criterion, the wind power development in Brazil must be related to the

[1] Brazil's electric power system optimization is based on large reservoirs planned for multi-year storage (normally five years) and standby turbines for generating surplus power during rainy periods. In this way, Brazil's large hydropower plants are able to supply the load curve not only on a continuous basis, but also during peak and intermediate hours. In this system, thermal power plants primarily goal is to supplement hydropower during peak load or during the dry season. They are only dispatched during dry hydrological periods, when the hydropower units reservoirs stored water value is greater than the operating variable cost of thermal power plants, or when the optimal hydraulic dispatch cannot meet demand during the heavy load periods [2]

advantages of this technology to the country´s electric power system. Thus, a new incentive policy should focus on the reason for promoting wind power considering the country´s particular context. The wind-hydro complementarity is a very important natural phenomena present in some regions of Brazil. In this context, the wind power can provide an interesting power manager between two renewable sources.
In order to present the hydro-wind complementarity phenomena in Brazil, particularly at the northeast region, this article is divided into the following next sections. Section 2 presents the Brazilian wind potential and how hydro-wind complementarity can be observed at the northeast region. Section 3 processes the Brazilian wind database under GIS tools to size and locate the northeast region potential and evaluate the electricity that could be generate for hydro-wind complementarity. Section 4 presents the results and evaluates the most suitable incentive mechanism that could be applied to boost the interconnected power system through hydro-wind complementarity. Finally, Section 5 presents the conclusion of the paper.

2. Brazil's remaining wind power potential and the wind-hydro complementarity

According to the Atlas of Brazil´s Wind Power Potential [1] the wind-power technical potential reaches the impressive figure of 143.5 GW. Out of this total, 52% are located in northeast Brazil and 21% in the Southeast. In this report, it is assumed that the potential wind-power capacity covers only areas with average annual wind speeds above 7.0 m/s, with turbines installed in towers 50m-height, a land occupancy rate of 2MW/km^2 and an availability factor of 0.98, and does not include offshore potential (Figure 1 and Table 1).
So far, 247.0 MW (218.5 MW only by PROINFA till 2007) are installed in Brazil [4,5], accounting for less than 1% of the estimated technical potential. Therefore, the remaining potential wind-power use in Brazil is almost 100% for the entire analysis period.
Demonstration wind energy projects sum up 1.6MW, while the private investors backed projects add up to 81 MW in the northeast region and 164.4 MW in the south region [4]. Although the biggest wind project was installed at the southern region, the northeast region concentrates a large number of projects to be implemented under PROINFA´s program (805.6 MW at northeast region till 2008) [5].

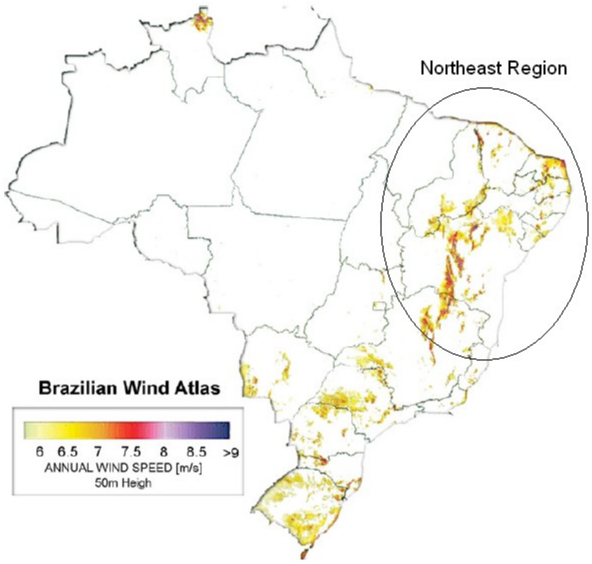

Figure 1: Annual average velocity distribution in the Brazilian Territory [1].

Table 1: Wind power technical potential in Brazil [1]

Wind (m/s)	Area (cumulative) (km^2)	Technical potential (GW)	Annual energy (TWh/year)
>6.0	667,391	1334	1711.62
>6.5	231,746	463	739.24
>7.0	71,735	143	272.20
>7.5	21,676	43	100.30
>8.0	6679	13	35.93
>8.5	1775	3	10.7

The huge concentration of wind power projects at northeast region, one of the best wind potential of Brazil, can provide more than a renewable energy generation. As discussed by Dutra and Szklo [3], a promising advantage of wind in Brazil is the hydro-wind power complementary, which is stronger in the Northeast region. This phenomenon, attested by Bittencourt et al [6] along the state of Ceará coast line, shows that using wind power generation in Northeast Brazil would optimize the regional power system, especially the unit commitment of Sobradinho, Itaparica, and Paulo Afonso I, II, III and IV hydroelectric power plants[2]. Figures 2 and 3 exemplify these complementarities, by simulating the monthly generation of a 3.0 GW wind park installed along the Ceará's state coast and the historical series of the flow at Sobradinho's Reservoir.

[2] Bittencourt et. al.[6] also presents hydro-wind power complementary studies in the South and Southeast subsystems, and highlights the wind power generation in Palmas, in the state of Paraná.

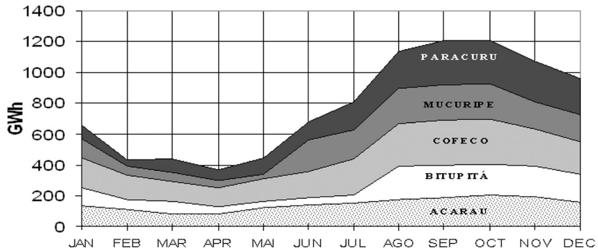

Figure 2: Simulated production of hypothetical 3GW wind farms in Northeast Brazil[6]

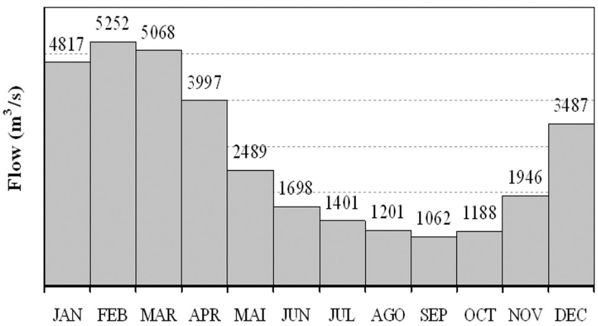

Figure 3: Natural water flow at Sobradinho's reservoir (from 1931 to 1992) [6]

As presented by Cebolo [7], the wind power projects contracted under PROINFA program has the same seasonal generation profile of the one simulated by Bittencourt et al.[6]. All 805.6 MW of wind power contracted by PROINFA at Notheast region can provide 2.2 TWh.year [5]

Additional studies are needed, in order to precisely evaluate the hydro-wind power complementary effect in the planning of expansion and operation of the Brazilian hidrothermal system.

3. Brazilian wind database under GIS tools – The case of Northeast Region

This paper revised the previous simulation of CEPEL [1], aiming at identifying Brazil's wind power potential at northeast region in terms of levelised costs per squares of 1km x 1 km. The database is the same that was used and produced by CEPEL [1], including: annual average wind velocity, roughness, and the shape and scale parameters of the Weibull distribution. This database was exported to a Geographic Information System - GIS model, which allowed the use of a spatial analysis and the crossover of all information. For instance, it allowed the adoption of spatial restrictions for selecting areas[3]

After analyzing Brazil's spatial restrictions according to wind velocities and the presence of natural reserves, this study selected the wind turbine model to be applied in the simulation. It adopted a 2 MW– model, which is the most common size of turbine that is commercialized worldwide, as of today [12]. The adopted turbine was Enercon E70 (2.3 MW and tower height around 100 m), since Enercon is the only factory in Brazil, and turbine E70 is the most modern equipment available at the Brazilian market. The availability of this equipment was fixed at 98% [1].

In order to define the wind turbine spatial configuration, a "5D x 10D" arrangement was adopted, where "D" is the diameter of the rotor area of the turbine. For instance, the turbine E70 has a diameter of 70 m. In this case, each turbine occupies 0.24 km^2. In the GIS model, the electricity generated by wind turbines was estimated inside areas of polygons (1 km^2) for an arrangement of turbines. This estimate provides the gross wind power potential results from the direct integration of the useful areas in the GIS model, considering the following restrictions: minimum wind speed, natural reserves, and existence of rivers, lakes and sea.

The estimates of the levelised costs for each polygon in the GIS model representing Brazil's territory were based on the figures proposed by [13,14,15]. According to these authors, fixed costs should vary between 800 and 1000 US$/kW, according to the impacts of the learning experience curve. In addition, [13,14,15] indicated O&M costs of 10 US$/MWh, according to the Brazilian experience. [16,17,18] presented figures from 12 to 15 US$/MWh, based on European countries. DEWI [19] collected data in Germany and found that O&M costs for the first six years were 3-4 US$/MWh, and then grew to 6-7 US$/MWh. This result agrees with [16] findings. Finally, IEA [20] collected data of projects implemented in 2005 and found O&M costs averaging 11 US$/MWh (onshore plants).

One important parameter for differentiating wind power projects inside the country is the distance of the plant from the Brazilian shore. This is due either to the quality of the Brazilian roads or to the increasing difficulties faced by the transportation of larger turbines inside roads not sized for this type of service. Therefore, the GIS model also identified the areas according to its distance from the coast; and an average cost factor (an additional cost to the fixed cost) was included in the simulation (Table 2). Table 3 summarizes the main parameters used

[3] For more details about GIS, see [8,9,10,11]

for estimating levelised costs for each area of polygons in the GIS model.
Finally, Figure 4 and Figure 5 present the results of the GIS model for the Northeast Region, according to the levelised cost. The results are given for fixed costs varying between 800 and 1000 US$/kW.

Table 2: Additional cost according to the distance to the coast

Distance	Additional cost
Up to 100 km	0%
100 km - 200km	10%[1]
200 km - 400km	15%
400 km - 600km	20%
600 km - 800km	25%
1000 km - 1200km	30%
Above 1200 km	40%

(1) in this case, the fixed cost should be multiplied by 1.10.

Table 3: Economic parameters of the analysis

Fixed cost	1000 US$/Kw
Additional cost	f(distance) – see Table 2
Interest rate	15 %
Construction period	1 year
Useful life	20 years
O&M	10 US$/MWh

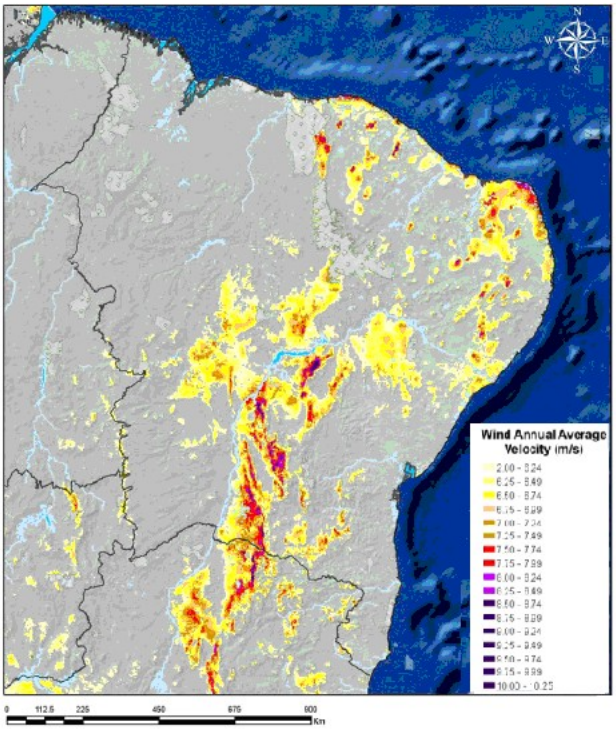

Figure 4: Wind velocity annual average at Northeast Region of Brazil (gross potential)

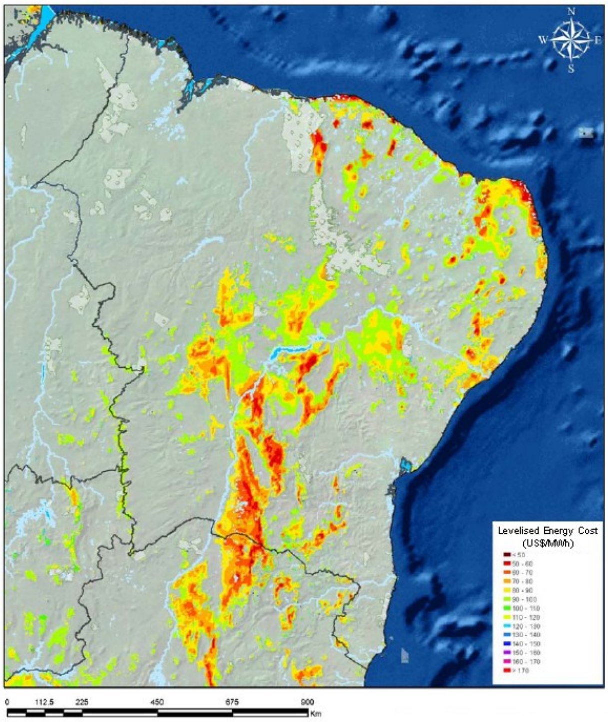

Figure 5: Levelised energy cost at Northeast Region of Brazil (gross potential)

4. Results

Based on the findings of Bittencourt et. al. [6], wind power potential was calculated along the whole Northeastern Brazil coast line, up to a maximum distance of 100 km from the shore. (Table 4).

Table 4: Achievable wind power potential for the Northeast Brazil (up to 100km from the shore)

Wind [m/s]	Area [km²]	Achievable Potential [GW]	Electricity Generation [TWh/year]
6.0 – 6.5	2312.4	21.1	47.7
6.5 – 7.0	1084.3	9.8	26.1
7.0 – 7.5	434.0	4.1	12.9
7.5 – 8.0	216.6	2.1	7.3
8.0 – 8.5	60.5	0.6	2.2
> 8.5	16.6	0.2	0.6

The levelised energy cost based on the northeastern wind power potential was also calculated, using the fixed cost of 1000 US$/kW. As discussed in section 2, the investment in the Brazilian wind power generation grows in direct proportion to the distance to the shore. For a full achievable potential estimated in 37.9 GW (96.9 TWh/year), the average levelised cost for using the whole northeastern wind power potential corresponds to 74.90 US$/MWh (Table 5).

Table 5: Levelised costs of wind power in the Brazilian Northeast Coast Region (up to 100 km from the shore)

Levelised Costs [US$/MWh]	Northeast Region		
	Area [km^2]	Installable Potential [GW]	Electricity Generation [TWh/year]
40.00 - 50.00	28	0.3	1.2
50.00 - 60.00	420	4.0	14.3
60.00 - 70.00	627	7.4	17.9
70.00 - 80.00	1136	14.6	27.8
80.00 - 90.00	1257	12.2	25.2
90.00 - 100.00	544	5.6	8.8
100.00 - 110.00	73	0.7	1.2
110.00 - 120.00	15	0.2	0.2
120.00 - 130.00	13	0.1	0.2
130.00 - 140.00	4	0.0	0.1

5. Conclusion

The main hypothesis behind this paper is that any wind power incentive program to succeed should emphasize the reasons why this alternative should be promoted in the country's power system during the long term. This paper showed that Brazil's wind power potential is large enough to comply with others possible targets, at reasonable levelised costs.

Several papers discussed the two main incentive mechanisms internationally adopted for promoting renewable energy sources: Feed-in tariffs and quota/green certification [21-27]. The efficient application of one of those mechanisms is direct associate with the main goal of the incentive to the renewable energy source.

In order to optimize the hydroelectric system, the most suitable mechanism is the one that allows the continuous and reliable growth of wind power plants at the selected sites. Therefore, Feed-in tariffs is a adequate mechanism for such a scheme, as describe above. Additional studies are needed, in order to precisely evaluate the hydro-wind power complementary effect in the planning of expansion and operation of the Brazilian hidrothermal system. It is also necessary to evaluate the inner workings of the wind power turbines in high salinity and abrasivity conditions that are common in the Brazilian shore[28]. The application of small wind turbines in remote or rural Brazilian areas (for instance, for water pumping) is another interesting field of study, which could be addressed in another work.

Finally, there is much to be learned by looking at the international experience. When promoting wind resources in Brazil, it is worth being aware to:

- The tariff offered and the guaranteed contract time limit.
- The grid capacity near the wind sites.
- The planning approval process for the project that is low cost and efficient with a reasonable guarantee of success.

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