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Wind farm assessment at Triunfo-PE, in Brazilian northeast.

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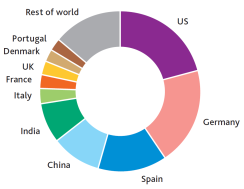
The propose of this paper is to present a technical and economic assessment of the TRI wind farm (with 20MW installed), simulated with WAsP program and situated in the region of Triunfo-PE, (Brazilian central northeast) using wind turbines with 850kW of power . The wind meteorological data's from Triunfo SONDA (Sistema de Organização Nacional de Dados Ambientais) meteorological station @ 50m during 30 months were used and the Triunfo wind's characterization shows a average wind speed (V) of 11,27 m / s, predominant Southeast wind direction, average wind power (P) of 1.672 W/m^2 and Weibull parameters shape (K) and scale (A) equal to 2,0 and 12,7 m/s respectively. From the TRI wind farm simulates results, the technical's results shoes and AEP (annual energy produced) 111,4 GWh, Cf (capacity factor) 62% and 5.462 hours of operation by year. The economical results, shows and Pay-back of 3 years,Internal Rate of Return (IRR) = 47% and Net Present Value (NPV) = 85.506k€ both @ 20 yeas time period.

Palavras-chave: *Wind speed, Wind energy, wind farm, Wind turbine, capacity factor, Brazil, Triunfo*

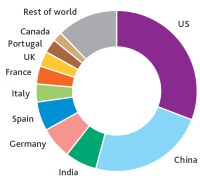
1. INTRODUCTION

In 2008 the world celebrate the 100GW mark in total installed wind energy capacity, Figs 1 and 2, shows the top 10 countries in wind energy capacity installed and new wind resources system installed in 2008 year respectively, according (GWEC,2008),



	MW	%
USA	25,170	20.8
Germany	23,903	19.8
Spain	16,754	13.9
China	12,210	10.1
India	9,645	8.0
Italy	3,736	3.1
France	3,404	2.8
UK	3,241	2.7
Denmark	3,180	2.6
Portugal	2,862	2.4
Rest of world	16,693	13.8
Total top 10	**104,104**	**86.2**
World total	**120,798**	**100.0**

Figure. 1 - Top 10 Total Installed Capacity 2008



	MW	%
USA	8,358	30.9
China	6,300	23.3
India	1,800	6.7
Germany	1,665	6.2
Spain	1,609	5.9
Italy	1,010	3.7
France	950	3.5
UK	836	3.1
Portugal	712	2.6
Canada	526	1.9
Rest of world	3,285	12.2
Total top 10	**23,766**	**87.8**
World total	**27,051**	**100.0**

Figure. 2 - Top 10 New Capacity 2008

Brazil has a total of 104, 7 GW (ANEEL,2009), of installed power, 68, 9% of this amount (energy matrix), comes from hydraulic resources and only 0, 37% (414.000kW) from wind energy resources. The first Brazilian wind atlas, published by the Electric Power Research Centre – CEPEL/ELETROBRAS in 2001 shows that the potential for onshore wind energy capacity is 143 GW in Brazil (at 50 meters high) and the best wind resources in terms of wind speed and capacity factor are in the Northeast, Southeast and Southern Regions (Camargo et al,2002).

Brazil's PROINFA program was initially passed in 2002 in order to stimulate the addition of over 1.400 MW of wind energy capacity and other renewable sources. In the first stage, 1.422.92 MW of wind farm projects have been already selected and awarded the 20-year power purchase agreement through ELETROBRAS with energy prices ranging from €77 to €87/MWh (equivalent to R$212 to R$241/MWh) in March 2007, depending on the capacity factor of the project. The Brazilian government is now looking at establishing an auctioning scheme to increase the country's wind capacity, and a first auction is expected in late 2009. The selection bidding process required some of the main pre-requisites for financing the projects: environmental licenses, qualified wind measurements, land clearance through lease or property ownership. According (Perreira et al, 2002), a total of 247MW wind energy resources are installed in the country and the perspectives or wind energy generation by 2017 is around 0,9% of total energy matrix (3 times the actual value).

2. THE WIND FARM POTENTIAL ASSESSMENT REVIEW

The study and characterization of wind is a mandatory step to define the viability or not of a wind farm project, from this study the project's managers obtain the initial information's to simulate both, technical and economical aspects, to develop the road map to archive the projects targets. Many investigates were done in order to characterization the wind and the wind farm potential from one region. Chang et al (2008) present an assessment of wind characteristics and wind turbine characteristics in Taiwan, Jowder (2009) did a similar study in the Kingdom of Bahrain and Hrayshat (2007) presents the wind resource assessment of the Jordanian southern region including the behavior of wind turbines of 100, 22 and 4kW in 3 different heights. Ucar and Balo (2009) investigate the wind characteristics and energy potential in Uludag-Bursa Turkey, Shata and Hanitsch and Shata (2010) developed and work regarding the Electricity generation and wind potential assessment at Hurghada, Egypt, both including the economical aspects of the simulation. Ettoume et al (2008) did an investigation developing and Comparative simulation of wind park design and sitting in Algeria.

3. CHARACTERIZATION OF THE SITE AND EVALUATION OF THE WIND POTENTIAL

Triunfo (07º50'17" S, 38°06'06"W) is a city of Pernambuco state, in the arid Sertao region in Northeastern Brazil. Situated between mountains and at a lakefront, the city has a semi arid - hot and dries climatology with annual average temperature around 20.4 C and average elevation – 1.004 m. The population in 2008 was 15.724 and the area is 191,52 km² (IBGE,2009). Triunfo is one of the Brazilians cities who have a SONDA project base. The "Sistema de Organização Nacional de Dados Ambientais para o setor de energia" (Brazilian Depository System of Environmental Data for the energy sector) project is chiefly linked to the climatic area but is strongly oriented towards providing adequate support to activities in the area of renewable energy, chiefly in the assessment of the solar and wind energy resources (Ortega and Ulgiati, 2004)

The wind data's used in this project is obtained from SONDA project. The wind speed, direction and temperature were taken at height of 50m at each 10 minutes and validate according SONDA quality project procedures, to assure its reliability. A total of 30 months of measurements between 2004 and 2007 in Triunfo meteorological station (07° 49' 38" S, 38° 07' 20" and altitude of 1.123m), were use in the current study.

4. STATISTICAL DISTRIBUTION FOR WIND DATA AND WIND POWER GENERATION.

The Weibull law is the most frequently used model to describe the distribution of the wind speed (Takle and Brown, 1997; Nielsen et al, 1994). The distribution is also used in others sectors like automotive sector for analysis of survival data (Lima, 2006)

The probability density function (PDF) of the wind speed is given by:

$$f(V)=\left(\frac{K}{A}\right)\left(\frac{V}{A}\right)^{K-1}\exp\left(-\frac{V}{A}\right)^{K} \tag{1}$$

Where:

- f(v) is the probability density function of the wind speed;
- A is the Weibull scale parameter;
- K is the dimensionless Weibull shape parameter

According the value of K the Weibull distribution is similar to others kind of statistical distribution (k = 1,0: exponential, k = 2,0: Rayleigh, k = 3,5: Normal) (Duarte, 2008)

The cumulative distribution function F (V) is writing as follow:

$$F(V)=1-\exp(\left(-\frac{V}{A}\right)^{K} \tag{2}$$

The wind power available P (W) that can be obtain in cross sectional area A_T (circular area create by the wind turbine blades) perpendicular to the wind at speed V(m/s) with an given air density ρ (Kg/m^3) , is done by the follow equation:

$$P=\frac{1}{2}.\rho_{air}.A_T.V^3 \tag{3}$$

The amount of power, which can be extracted from the wind, depends on the available wind energy and on the operating characteristics of the wind energy extraction device (Omer,2008). However, wind machines cannot use 100% of this power due to the Berz limit. The previous equation can be rewrite adding a coefficient called Cp which defined the maximum efficiency of the Betz limit (0.593).

$$P = \frac{1}{2}.C_P.\rho_{air}.A_T.V^3 \tag{4}$$

To express the wind power in terms of area (Wind power density), independent of the wind turbine area, the Eq 4, cam is re write.

$$\frac{P}{A_T} = \frac{1}{2}.C_P.\rho_{air}.V^3 \tag{5}$$

The wind energy (E) that can be extracted by a wind turbine is defined by the follow equation.

$$E = T\int_0^\infty P(U).f(V).dU \tag{6}$$

Where:

- f(v) is the probability density function of the wind speed;
- P(U) is the power curve of the turbine
- T is the time period

Replacing the equation (1) into (6), we obtain the wind energy in terms of Weibull distribution.

$$E = T\int \left(\frac{K}{A}\right)\left(\frac{U}{A}\right)^{K-1}.\exp\left(-\left(\frac{U}{A}\right)^{K}\right).P(U).dU \tag{7}$$

The capacity factor (Cf), is one element in measuring the productivity of a wind turbine or any other power production facility. It compares the plant's actual production over a given period of time with the amount of power the plant would have produced if it had run at full capacity for the same amount of time and cam be calculate by the follow equation being expressed in %.

$$C_f(\%) = \frac{Wind\ Energy\ \Pr oduced\,(Wh/year)}{Max\ Wind\ Energy\ \Pr oduced\,(Wh/year)} \tag{8}$$

An equivalent hour (Eh) is the parameter used to express wind farms exploitation. It constitutes the equivalent relationship between the operational time of the machine and its nominal potential. The best placed wind frames in Spain register an operational average of 2.830 hours; some frames exceed 3.000 hours/year of real generation (EGA, 2009). The value of Eh is being expressed by the follow equation:

$$Eh(h) = 8760h\ x\,FC(\%) \tag{9}$$

5. WIND ASSESSMENT

The data were analyzed using the WAsP program. WAsP is a PC program for predicting wind climates, wind resources and power productions from wind turbines and wind farms. The predictions are based on wind data measured at stations in the same region. The program includes a complex terrain flow model, a roughness change model and a model for sheltering obstacles. The Fig 3, show the wind speed and wind air temperature profile (monthly average) from Triunfo meteorological station, the maximum observed value of wind speed average was in July / 05 (21,9 m/s) and the minimum value in March /05 (6,86m/s). The final mean wind speed from data calculate with WAsP is 11,83 m/s and the mean speed from the derived Weibull distribution is equal to 11,27m/s with 4,72% of discrepancy in comparison with the mean wind speed from data. The highest wind temperature was detected in Dec-04 (22,31ºC) at Summer time (south hemisphere) and the lowest in Jun-05 (17, 1ºC) winter time (south hemisphere) with average of 20,20ºC during the studied period.

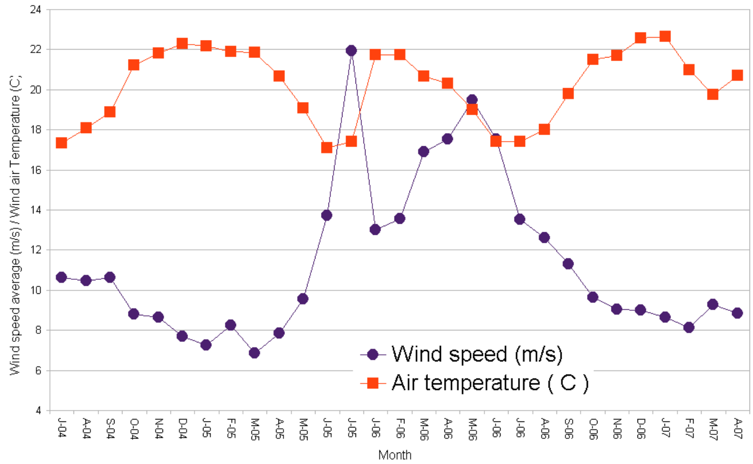


Fig. 3. Monthly wind speed and wind air temperature average @ 50m from Triunfo meteorological station

Regarding the wind direction, Triunfo region has southeast predominant wind direction, as showed in the wind rose in Fig. 4. The expressive wind direction of Triunfo is very beneficial to wind energy prospection because the amount of energy lost in the wind turbines due to the wind direction changes is reduced.

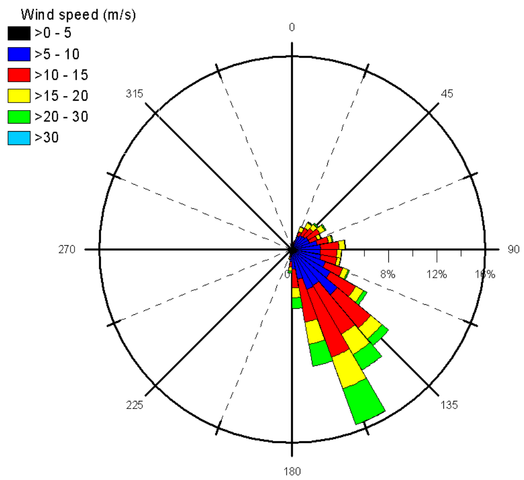


Figure. 4. Triunfo meteorological station wind rose @ 50m

Using the Weibull distribution (1), we could obtain the scale (A) and shape (K) parameter for each month (monthly average). Those values were calculated by WAsP program (as a output of is wind analyze and prediction) using the wind monthly values, obtain from SONDA project. Fig. 5. Represents the distribution of both parameters during the studied time period, obtain from the WAsP analyze using the

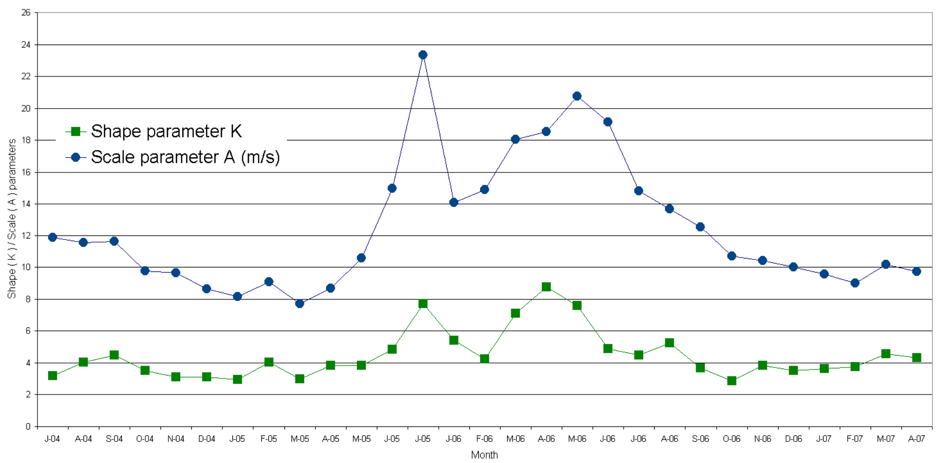


Figure. 5. Monthly shape (K) and scale (A) Weibull parameter average @ 50m from Triunfo meteorological station

The final values of K and A parameters are 2,0 and 12,7m/s respectively. Due to the fact that the K parameters is 2,0, the Rayleigh distribution can also be used (as the Weibull distribution) to characterized the wind distribution in the studied zone The wind power density monthly average estimation is obtain from (5). The mean power density from data using WAsP is calculated as 1.671W/m^2 and the mean power density derived from Weibull is 1.672,3 W /m2 with a 0,14% of discrepancy. The WAsP program uses a constant air density value (1,225kg/m3) in order to calculate the mean power density. This approach facility the final calculation of wind assessment because it does not correlate the wind power calculation with the influence of its associate air temperature and altitude values. In regions with hot climate, as the Brazilian northeast and in special Triunfo, which has associated with this climate an important altitude (1004m overseas in average), the impact of temperature and altitude in the air density is important an must be take in consideration for a more accurate value of power energy.

Fig.6 represents the two power density curves, one with air density constant and equal @ 1,225kg/m^3 and another with the air density value calculated according the base altitude 1040m and the monthly air average temperature, the values of power density with constant density are 16% higher.

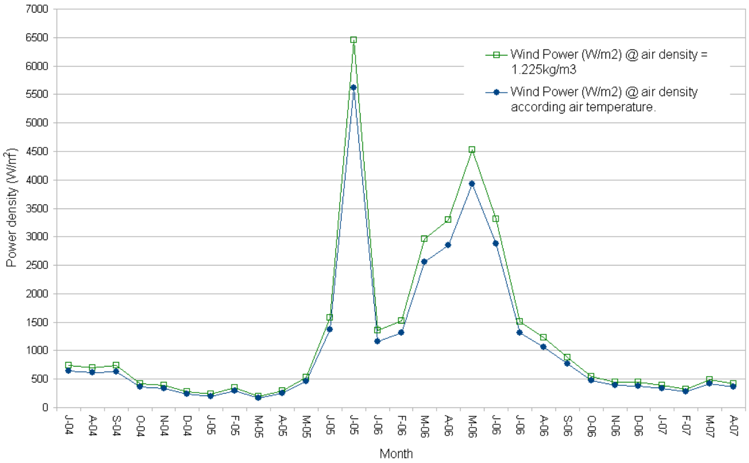


Figure. 6. Monthly wind power average @ 50m with air density changes from Triunfo meteorological station

Finally, the wind map of Triunfo region was developed using WAsP program using the NASA geographical database with counter curves at 50. The coordinates (597.324, 9.134.745 - 38,00°N 7,00°E) and altitude 1.103m altitude of Triunfo meter station were defined and also the height of wind data collection (50m). Figs 7 and 8 shows the wind speed and power density maps simulated with a grid of 45 rows by 45 columns with 500m of resolution covering an area of 506 km^2 in the proximity of Triunfo meteorological station.

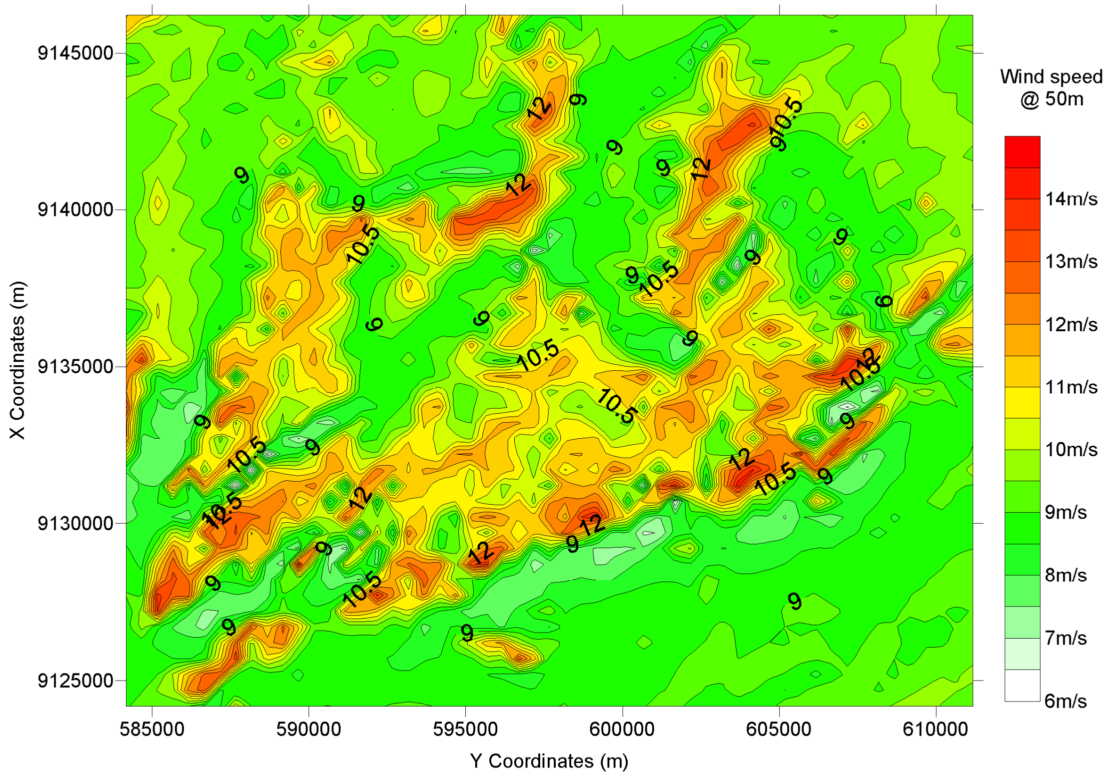


Figure. 7. Triunfo wind speed map @ 50m (45 rows X 45 columns with 500m of resolution) covering 506 km^2.

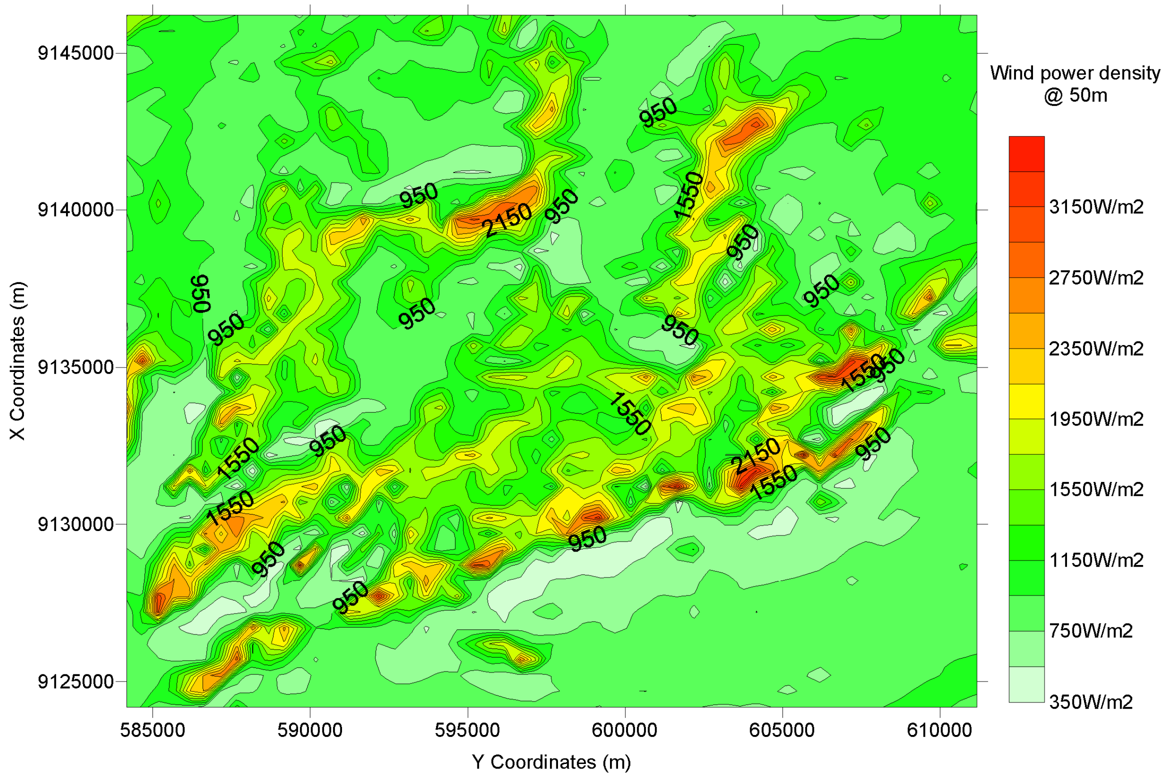


Figure. 8. Triunfo wind power density map 50m (45 rows X 45 columns with 500m of resolution) covering 506 km^2.

6. WIND FARM SIMULATION.

Wind farms or wind parks, as they are sometimes called, are locally concentrated groups of wind turbines that are electrically and commercially tied together (Manwell et al, 2002). Several steps are involved in the successful planning and development of a wind farm (Mathew, 2006). They are:

1. Preliminary site identification
2. detailed technical and economical analysis
3. Environment, social and legal appraisal and
4. micro-sitting and construction

In this study, the wind farm simulated (called TRI wind farm) has a hypothetical installed capacity 20MW installed. The wind turbine selected for this study was a Vestas V52 with 850kW of installed power with blade diameter of 52m, area swept of 2,124 m^2 cut-in wind speed of 4 m/s, nominal wind speed of 16 m/s and cut-out wind speed of 25 m/s installed at 55m of height. A total of 24 wind turbines will be installed in the wind farm.

When installing a cluster of machines in a wind farm, certain spacing between the wind towers must be maintained to optimize the power cropping. The spacing depends on the terrain, the wind direction, the speed, and the turbine size. The optimum spacing is found in rows 8 to 12-rotor diameters apart in the wind direction, and 1.5 to 3-rotor diameters apart in the crosswind direction. Using the wind turbine rotor diameter of 52m, we obtain the minimum distance between turbines in X and Y dimension of 200m by 624m respectively, those values will be confirmed during the software simulation and maybe change in order to archive the maximum improvement from wind farm.

The initial arrangement of wind turbines are in an array form of 8 X 3 turbines in the first simulation. The iteration consists into move the wind turbines with lower values of AEP, annual electric energy produced (GWh), to places with higher values of wind power (P); the final result is presented in Table 1.

Table 1 – TRI wind farm optimization result

TRI wind farm				
Iteration	**AEP Net [GWh]**	**Improvement (%)**	**Capacity Factor - C_f (%)**	**Equivalent Hours Eq (h)**
1	93,20	-	52%	4.571
2	102,6	9%	57%	5.030
3	107,8	13%	60%	5.283
4	110,2	15%	62%	5.401
5	111,4	16%	62%	5.462

As a final result, TRI wind farm has 111,4 GWh of AEP net, 62% of capacity factor that represents 5.462 hours of annual energy production. The final emplacement of wind turbines is represented in Fig.9

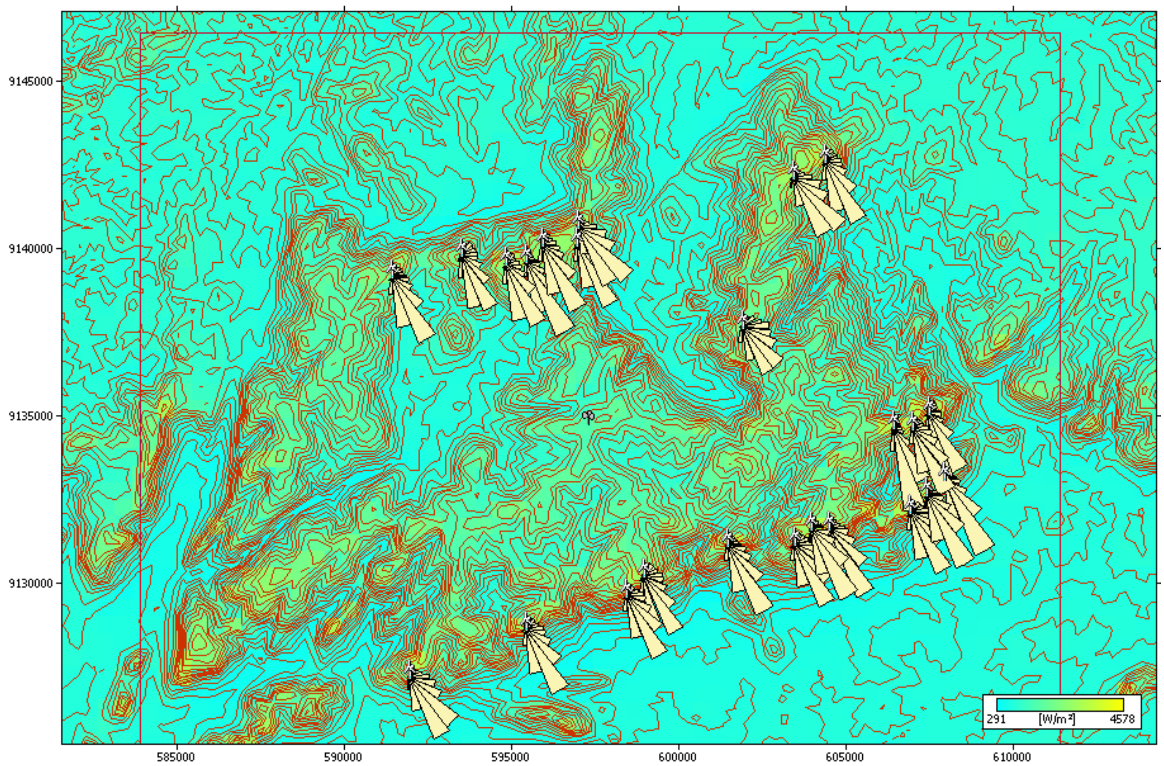


Figure. 9 –TRI wind farm turbine sites final location with each individual AEP rose.

7. WIND FARM INITIAL FEASIBILITY.

Once we obtain the AEP values from TRI wind farm, and feasibility study, involved economical, technical and environmental aspects must be done in order to support the final wind farm project. In this topic we present the economical (IRR, NPV and Payback), electrical energy extraction and logistic feasibilities for TRI wind farm.

7.1 ECONOMICAL FEASIBILITY

The Table 2 presents the typical breakdown of cost for a 10MW wind farm [22]

Table 2 – TRI wind farm cost breakdown

Element of wind farm	% of cost
Wind turbines	65
Civil works	13
Wind farm electrical infrastructure	8
Electrical network connection	6
Project development and management cost	8

The economical feasibility takes in consideration the follow criteria's.

a) Cost of installed MW = 1.000K€ [21];

b) 111,4 GWh of Annual Energy production net (as conclusion of item 6)
c) 5.462 hours of annual energy production (as conclusion of item 6)
d) Useful life to economical retour of investment = 20 years :
e) Useful life (technical and technological) of wind farm = 30 years:
f) Energy purchasing price = 87€/MW (price assured by Brazilian government @ 20 years):
g) Maintenance yearly price = 1% of wind farm annual incomes;
h) Interesting taxes = 5,8 %:

The internal rate of return (IRR) is a rate of return used in capital budgeting to measure and compare the profitability of investments. The net present value (NPV) or of a time series of cash flows, both incoming and outgoing, is defined as the sum of the present values (PVs) of the individual cash flows. The payback can be easily defined as the optimized time when the incomings become positives, after all initial investment amortization.

The overall

Table 3 – TRI wind farm final economical balance

Economical Criteria's	Results
Pay back @ 20 years (years)	3
NPV @ 20 years (€)	85.506 k €
IRR @ 20 years (€)	47%

7.2 ENERGY EXTRACTION FEASIBILITY.

The energy extraction of a wind farm is one of the points that define the success or not of a project. May regions with important wind energy potential are not explored due to the fact that is placed in regions without any linkage with the current electrical grid. TRI wind farm final site is placed in a zone with a relative easy connection to the current northeast electrical grid in both lines and substations at 500KV or 250KV as presented in Fig. 10.

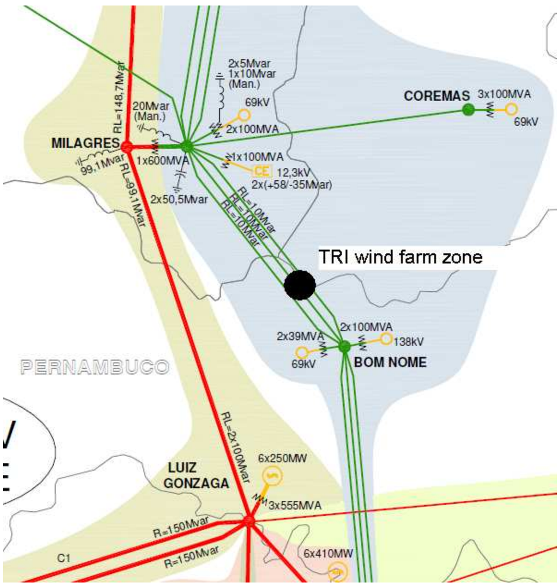


Figure. 10 – Northeast electrical grid near from TRI wind farm

8. CONCLUSION

As a conclusion of this paper we conclude the follow:

- Triunfo region has a important and significant wind resources with wind speed mean (V) 11,27 m/s , Weibull scale parameter (A=12,7m/s), Weibull shape parameter value (K = 2,0) and mean wind power density (P / A_T) 1.672 W/m^2 must be considerate as an potential area for future prospection's;
- The wind direction , extremely predominant, to southeast impact positively for future wind energy prospection;
- The wind (air) average temperature has a strong impact on the air density value: 1,052kg/m3 instead of 1.225kg/m3 (WAsP default value) given and reduction in the final power energy calculate in the order of 6%;
- Weibull shape parameter (K = 2,0) allow the use of Rayleigh distribution to characterize the wind speed distribution of Triunfo region;

- TRI wind farm (20MW installed) with AEP 111,4 GWh, Cf = 62% and 5.462 of operative yearly hours shows the tremendous potential for wind prospection in this region;
- The approximate economics feasibility simulate for TRI wind farm, shows a pay-back of 3 years, IRR = 47% and NPV = 85.506k€ @ 20 years time period, resulting in a feasible project from the economic point of view.
- The current wind energy grid near from TRI zone allow the energy extraction from the wind farm with low impact cost in power lines;
- The wind farm was optimized in order to archive the highest value of Cf. these criteria impose the final emplacement of wind turbines in sites with higher values of wind power density (Fig 08). Certainly that the final wind farm turbines final configuration (turbine sites) maybe change, if others factors related with the wind farm such as construction (relieve , construction permissions, machines accesses, electrical power lines, etc) , economical (cost of land, const of electrical connections, etc) and legal (environmental permission) were take in consideration..
- The precision and quantity of data's from SONDA project become the final results reliable;
- The WAsP program shows robust and reliable tool to make wind characterization and wind energy potential assessment.

9. ACKNOWLEDGEMENTS

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11. RESPONSIBILITY NOTICE