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REPOWERING ANALYSIS OF THE GARGAÚ WIND POWER PLANT

Felipe Eduardo Ribeiro[a]
Gilberto Carlos dos Reis Junior[b]
João Gabriel Souza Soares[c]
Christian Jeremi Coronado Rodriguez[d]
Federal University of Itajuba - UNIFEI, Mechanical Engineering Institute, Av. BPS 1303, Itajubá, MG, Brazil.
feliperib1993@gmail.com[a]
gilbertocreisjr@gmail.com[b]
joaog0705@gmail.com[c]
christian@unifei.edu.br[d]

Resumo: *In the current Brazilian energy scenario, one of the energy's sources that has been highlighting is the wind power. Nowadays, according to ABEEOLICA (Wind Power Brazilian Association), the installed capacity is about 13 GW, with a big concentration in the northeast and south of Brazil. Even though it is the biggest load in the Brazilian electric system, the southeast region has only 3 wind farms in operation homologated by the responsible agency in the country (ANEEL). In this context, this present work proposes the case study of the southeast largest wind farm, the Gargaú Wind Power Plant, located at São Francisco de Itabapoana, RJ, with an installed capacity of 28MW, studying its arrangement, annual generation, and suggesting the replacement of the wind turbines, discussing the economic viability of this change and the possible gains with the new configuration. It was observed, at the end of the work, that the replacement of the wind turbines showed to be viable economically, due the energy generation increase presented by the new wind turbines installed.*

Keywords: *Wind Power. Repowering. Environmental Impacts. Energy use.*

1. INTRODUCTION

In the last years, the consumption of electricity has gradually increased, and with that, research and investments in the generation sector are necessary. Another factor that cannot be disregarded, is the pollution from the use of fossil fuels. As a result, the development of renewable energy sources (clean energy) is becoming increasingly necessary, and with that, the wind power generation has been highlighting in recent years. Figure 1 presents the historical evolution of wind power in the world.

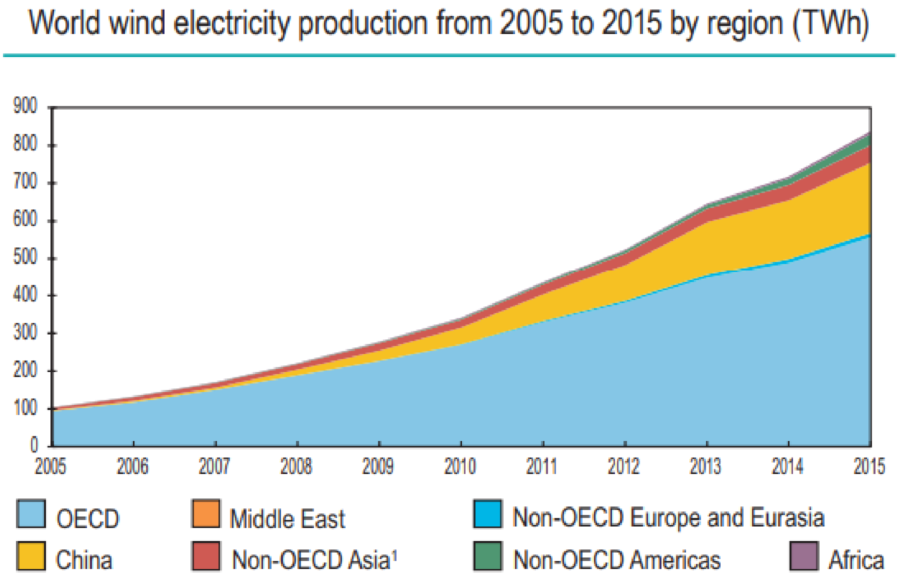

Figure 1 - Wind power historical evolution in the world scenario (KEY WORLD ENERGY STATISTICS 2017 IEA).

The present work consists of a case study of the Gargaú wind farm located at São Francisco de Itabapoana, RJ, with an installed capacity of 28MW, composed by 17 turbines of 1650kW, V-66 model (Vestas). Figures 2 and 3 present the arrangement of the aerogenerators.

Figure 2 - Wind turbines arrangement at Gargaú wind farm (GOOGLE EARTH).

Figure 3 - Frontal view of the wind turbines arrangement at Gargaú wind farm (OMEGA ENERGIA, 2017).

The city of São Francisco de Itabapoana is part of the Northern Fluminense Meso-region, whose economic base is the oil activity, due to the various oil and gas wells located in the Campos Basin. In addition, it has large plantations fields of sugar cane, among other agricultural activities.

The Gargaú wind farm is currently managed by Omega Energia Renovável S/A. The energy generated in this park was commercialized through the Incentive Program for Alternative Energy Sources (Proinfa), and Omega's acquisition took place in 2012 (OMEGA ENERGIA, 2017).

2. METHODOLOGY

A political initiative was used by the state government of Rio de Janeiro to encourage the insertion of renewable energy into the Brazilian energy scenery in 2002, through the state energy company, Marine and Petroleum Industry (SEINPE), and the Sociedade Fluminense de Energia LTDA (SFE), created the Wind Atlas of the State of Rio de Janeiro (ATLAS, 2002).

Between the different informations contained in this document, the most important used in this work are the air density maps, formation factor and wind potential inte the varied heights and times of the year.

Using the Wind Atlas (ATLAS, 2002), the data from the winds and the shape factors were extracted for the different heights and seasons of the year in San Francisco de Itabapoana, the data are presented in the table below.

Table 1 - Values of k for different heights and seasons.

Averare Speed		Shape factor	Season
75 m	100 m	[k]	
7.25	7.25	2.15	Summer
6	6.5	2.55	Autumn
6	6.25	2.15	Winter
8.25	8.5	2.25	Spring

Through the values presented in Table 1, the Weibull distribution for the locality was constructed (using the “WEIBULL.DIST” function of excel). Figures 4 and 5 present, respectively, the average Weibull distribution at 75 and 100 meters of height.

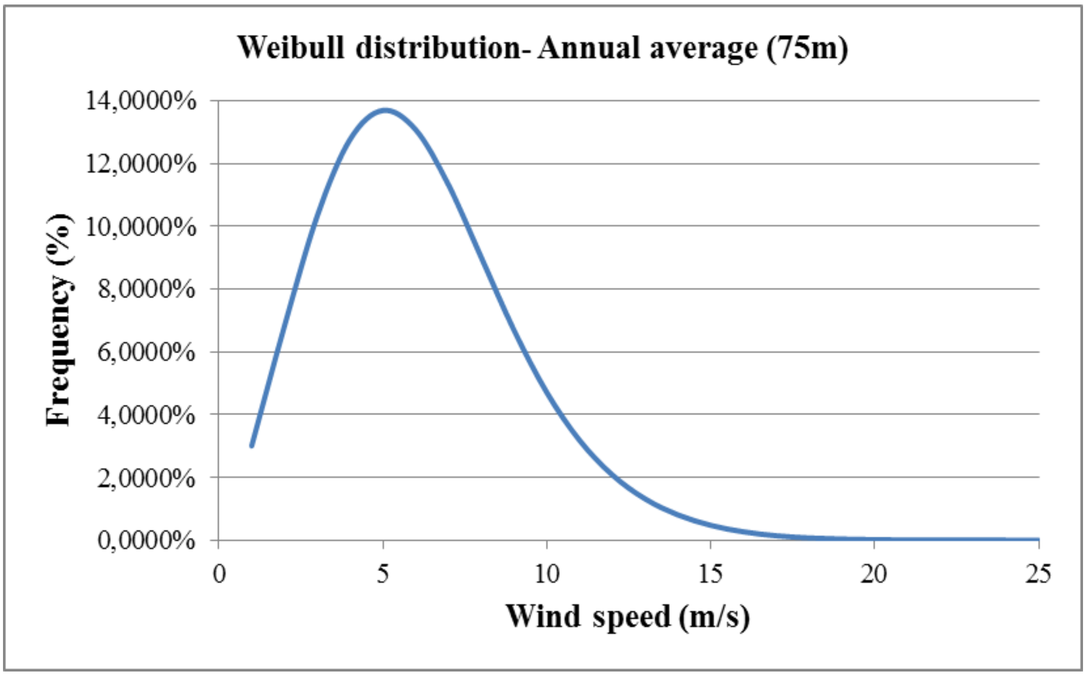

Figure 4 - Weibull distribution at 75 meters of height.

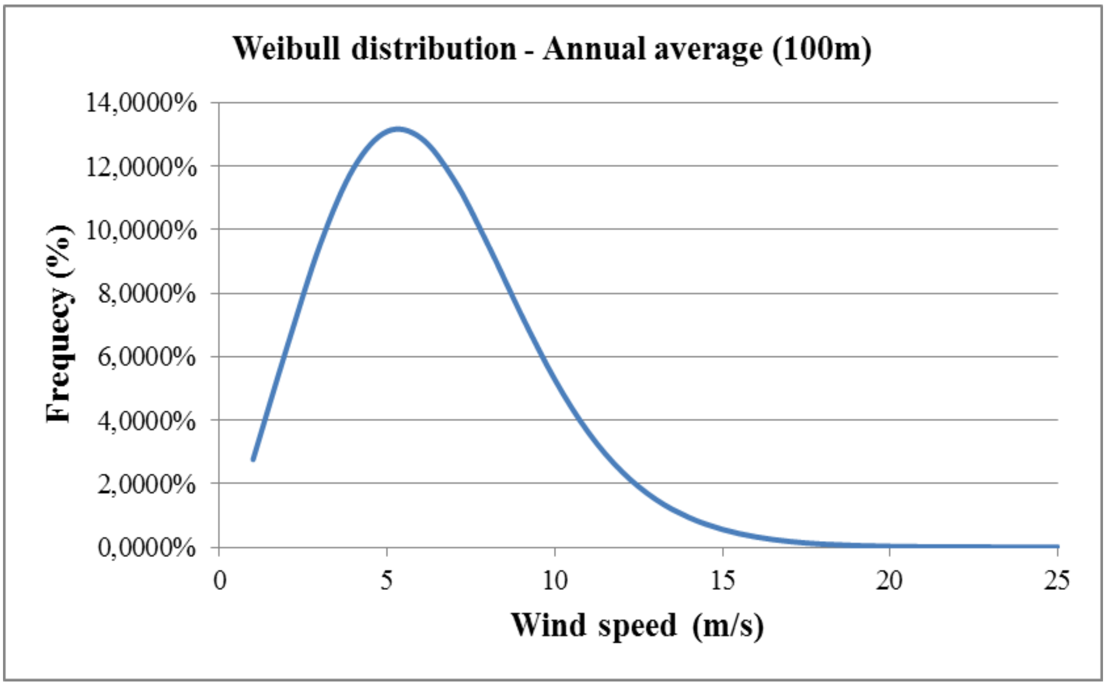

Figure 5 - Weibull distribution at 100 meters of height.

Based on the Weibull distribution theory we can estimate the generation of electricity from the wind power plant, using as input parameters, the Weibull distribution, the wind speed energy generation data provided by the manufacturer for each wind turbine, and the number of hours of machine availability.

In the present work, 3 types of wind turbines were chosen, which 2 were manufactured by Wobben, an important manufacturer of wind turbines in Brazil and the third one is made by Vestas, which is the machine that was used at the time of the plant implantation. Some characteristics of the selected wind turbines are presented below.

Table 2 - Main Wind Turbines characteristics.

Characteristics	**Vestas V-66**	**Wobben E-82**	**Wobben E-92**
Rated Power [kW]	1650	2000	2350
Rotor Diameter [m]	66	82	92
Cube Height [m]	60/78	78/84/85/98/108/138	78/84/85/98/108/138
Blade Material	GFK/Epoxy	PRFV	PRFV
Power Supply	Thyristor	Inverter Enercon	Inverter Enercon

Given the possibilities of installation of the wind turbines in relation to the height of the hub, there are 5 possible configurations, the three models at 75m or the Wobben at 100m.

In order to calculate the energy generation of each wind turbine, the weibull distribution was used for the respective height and power curve of each wind turbine. The curves of each wind turbine are presented below.

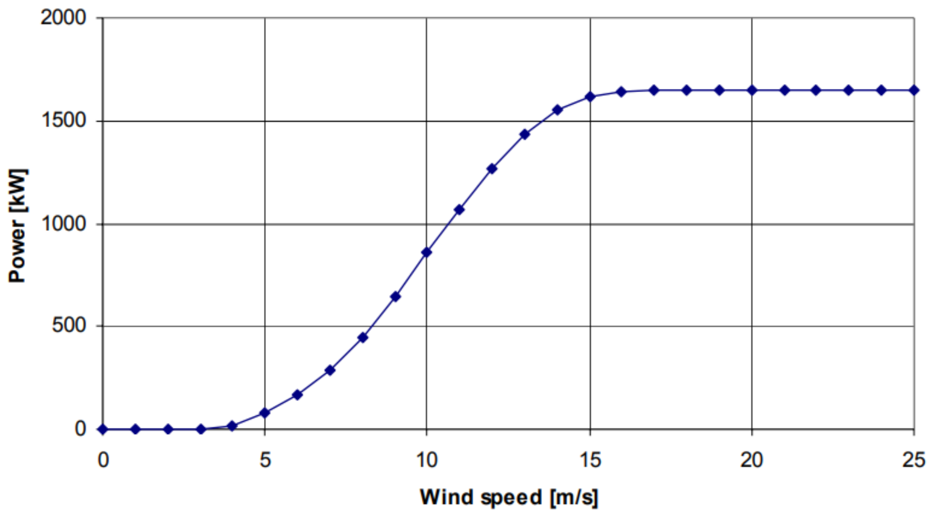

Figure 6 - Vestas V-66 power curve (VESTAS, 2017).

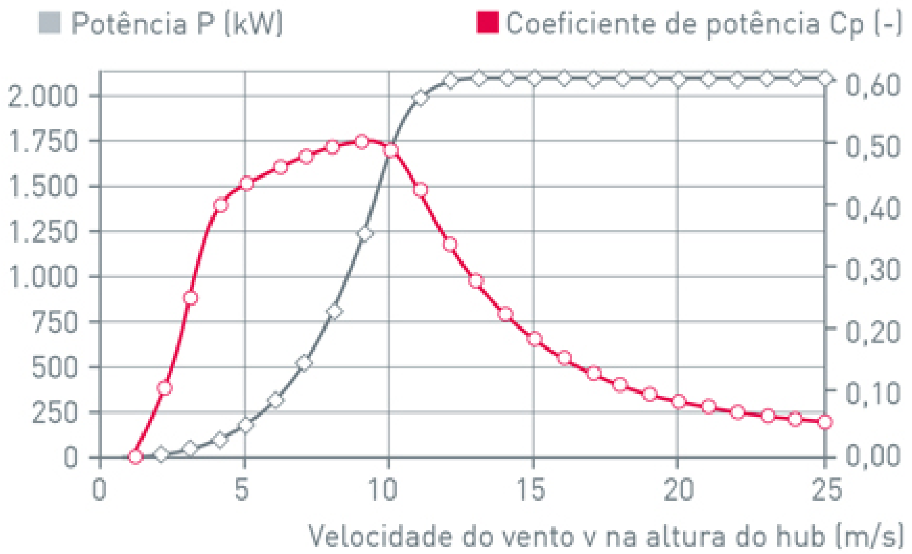

Figure 7 - Wobben E-82 power curve (WOBBEN, 2017).

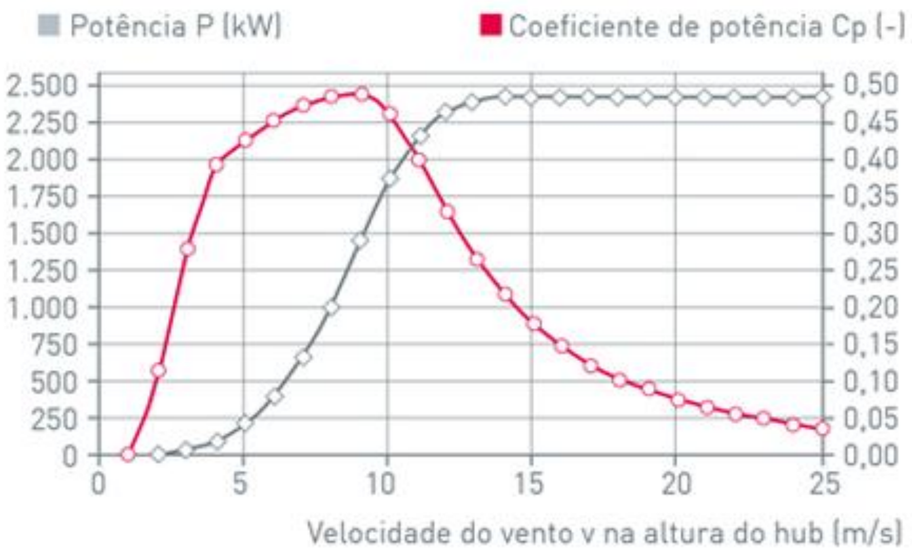

Figure 8 - Wobben E-92 power curve (WOBBEN, 2017).

After calculating the energy produced by each wind turbine, the graph presented in Figure 9 was plotted.

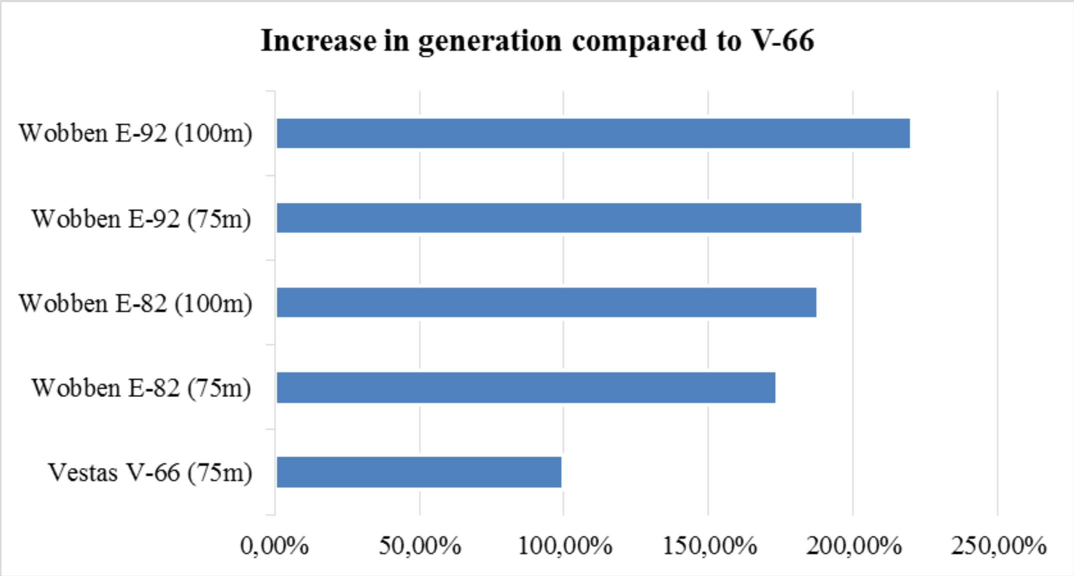

Figure 9 - Relation of Generation between different Wind Turbines.

It can be seen from the graph shown in Figure 9 that, for wind turbines with larger rotor diameter and higher hub height, the power generation had a significant increase when compared to the current scheme. Highlight for the model Wobben E-92 at 100 meters of height, which the generation increase reached more than 100%.

It is worth to mention that in this work it was considered that the energy generation limit for the plant was 30MW, falling under the law 114/2007, which limits the generation to this value so that the enterprise has a reduction in the tariffs of TUST and TUSD.

3. PRELIMINARY RESULTS

Through the calculation of the energy generation, it was possible to estimate the income of the enterprise. The amount of 178.88 R$/MWh was used based on the auction of new energy A-3 2015. It was adopted as expenses: the costs of implementation of R$ 9,179,280.93 per wind turbine (for 75 meters of height) and R$ 9,338,614.96 per aerogenerator (for 100 meters of height), (these values were estimated through the auction of new energy 2014 dividing the investment value by the installed power); the operation and maintenance costs of approximately R$ 57/kW. We used 50% financing of the total investment with an interest rate of 7% a.a. (BNDES, 2017), considering the financing time of 12 years, and a 30-year horizon of the project (in this work the cost of dismantling the plant was not considered in the economic analysis). Through these data, the following economic results were obtained.

3.1. Wind Turbine Vestas V-66 at 75 meters of height

Using the values presented previously, the economic parameters for the plant were calculated using the V-66 at 75 meters of height. It can be seen from the results presented in Table 3 that for this situation the enterprise is not feasible, since, it presents negative NPV.

Table 3 - Economic results V-66 (75m).

Economic Analysis Summary	
Project Investment	R$ 156,047,775.81
Installed Power (kW) – 17 Wind Turbines	28050
Tariff (R$/kWh)	R$ 0.1788
Total Admission	R$ 7,227,278.13
Maintenance Costs	R$ 2,552,896.19
MRA	10%
IRR	6.42%
NPV	-R$ 42,274,246.91

3.2. Wind Turbine Wobben E-82 at 75 meters of height

Using the values presented previously, the economic parameters for the plant were calculated using the E-82 at 75 meters of height. It can be seen from the results presented in Table 4 that for this situation the enterprise is feasible, since, it presents positive NPV.

Table 4 - Economic results E-82 (75m).

Economic Analysis Summary	
Project Investment	R$ 128,509,933.02
Installed Power (kW) – 14 Wind Turbines	28700
Tariff (R$/kWh)	R$ 0.1788
Total Admission	R$ 10,337,862.99
Maintenance Costs	R$ 3,651,650.11
MRA	10%
IRR	10.79%
NPV	R$ 8,951,573.01

3.3. Wind Turbine Wobben E-82 at 100 meters of height

Using the same procedures presented previously, the economic parameters for the plant were calculated using the E-82 wind turbine at 100 meters of height. It can be seen from the results presented in Table 5 that for this situation the enterprise becomes even more feasible than in the previous case.

Table 5 - Economic results E-82 (100m).

Economic Analysis Summary	
Project Investment	R$ 130,740,609.44
Installed Power (kW) – 14 Wind Turbines	28700
Tariff (R$/kWh)	R$ 0.1788
Total Admission	R$ 11,194,563.21
Maintenance Costs	3,954,262.89
MRA	10%
IRR	11.36%
NPV	R$ 15,880,998.29

3.4. Aerogerador Wobben E-92 at 75 meters of height

Adopting the same procedure, the economic parameters for the E-92 model at 75 meters of height were obtained. It can be seen from Table 6 that the economic attractiveness of the enterprise continues to increase.

Table 6 - Economic Results E-92 (75m).

Economic Analysis Summary	
Project Investment	R$ 110,151,371.16
Installed Power (kW) – 12 Wind Turbines	28200
Tariff (R$/kWh)	R$ 0.1788
Total Admission	R$ 10,383,954.88
Maintenance Costs	R$ 3,667,931.18
MRA	10%
IRR	12.27%
NPV	R$ 22,869,359.25

3.5. Aerogerador Wobben E-92 at 100 meters of height

Likewise, the results for the E-92 model at 100 meters of height were obtained. Table 7 presents the results.

Table 7 - Economic Results E-92 (100m).

Economic Analysis Summary	
Project Investment	R$ 112,063,379.52
Installed Power (kW) – 12 Wind Turbines	28200
Tariff (R$/kWh)	R$ 0.1788
Total Admission	R$ 11,234,293.14
Maintenance Costs	R$ 3,968,296.73
MRA	10%
IRR	12.87%
NPV	R$ 29,966,612.38

Thus, for better visualization of the results, the Figure 10 was plotted, presenting the IRR for each type of wind turbine studied.

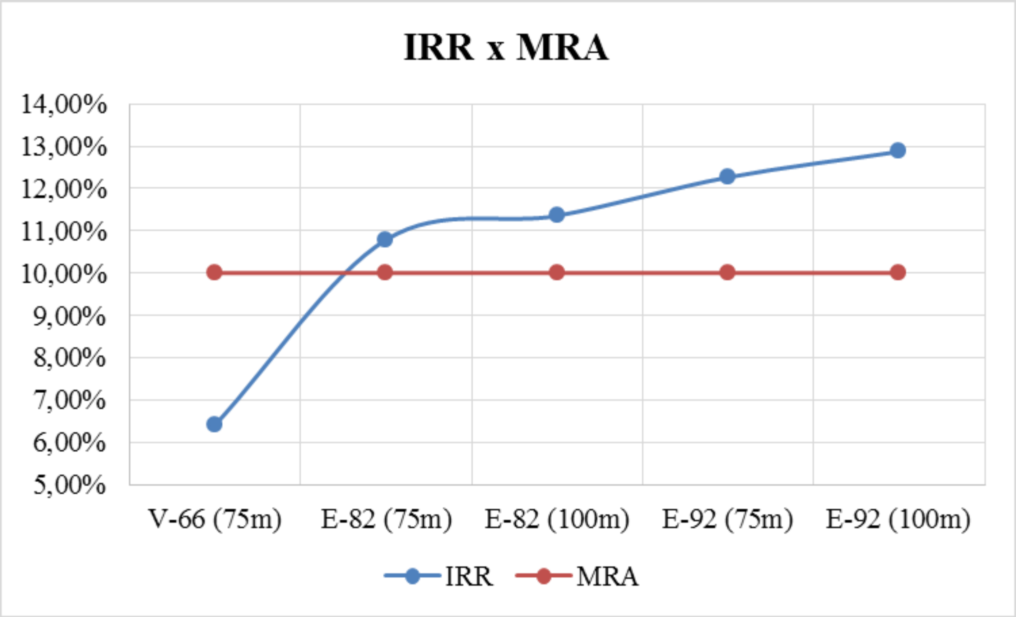

Figure 10 - Comparison of IRR for the different cases analyzed.

As can be seen in Figure 10, the IRR is lower than the Minimum Attractiveness Rate considered in the case of using Vestas V-66 turbines, which shows that this investment is not economically attractive. With the increasement of the machines, the TIR also increases, where the best case is using the turbine Wobben E-92 to 100 meters of height.

The graph shown in Figure 10, justifies the growing number of investments in wind power, since that the advancement of technology leads to better economic returns.

4. CONCLUSION

New technologies, along with government incentives tto generate clean energy, have made wind farm implementations more and more widespread. Based on the results analysis, it is evident that the progress in the development of new wind turbine models has increased the economic attractiveness of projects such as the Gargaú Plant.

It is noteworthy that with the rates used, the implementation of the Gargaú plant project would not be economically attractive. However, the place chosen for installation can be considered a milestone for the sector, since it is the first and only medium-sized plant in the region.

It is suggested as future studies, repowering analysis of the old wind farms (nationally and worldwide), increasing generation through more efficient wind turbines, increasing energy generation.

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6. RESPONSIBILITY STATEMENT

The authors are solely responsible for the printed material included in this article.