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Wind Potential Assessment in the Department of Meta – Colombia

Solano R[1]*, Campo E[2], Ballesteros K[3], Rodríguez M[2]

[1]Nanomaterials and Computer aided process engineeringResearch Group. School of Engineering. Universidad de Cartagena. Cartagena, Colombia.
[2]Design of Processes and Use of Biomass Research Group, School of Engineering. Universidad de Cartagena. Cartagena, Colombia.
[3]Particles and Processes Modeling Research Group. School of Engineering. Universidad de Cartagena. Cartagena, Colombia.

Abstract : In this research, the assessment of eolic potential in the plane zone of department of Meta-Colombia was carried out, and economic prefactibility analysis was done about the electricity system from wind velocity data at a reference height (z =10m). Five different types of power turbines between 330 and 3000 kW were studied in order to analyze their technical and economic feasibility. The evaluated zone presented an energy potential of 4.9075 GWh/year, using a 3000 kW (Vestas V-112) turbine at a height of 90 m. The production cost of kWh under this condition was approximate 123.67$/Kw-h.

Keywords : air generator, wind energy, economic analysis, wind potential.

Introduction

Today, most of the electricity produced worldwide comes from fossil fuels, such as coal, natural gas, and petroleum derivatives; The energy production that comes from these sources has a considerable impact on the integrity of the environment and ecosystems, due to the generation of greenhouse gases and their consequent contribution to global warming[1]. However, in recent years, in the face of rising oil prices, the growing need to ensure energy supply and to lessen the effects of global warming, generated by the action of greenhouse gases, has driven the search for renewable energy sources[2].

The international scientific community has intensified efforts focused on the development of sustainable energy sources, within which are highlighted wind, solar, geothermal, and Tidal, among others[3]. Due to its excellent geographical location and its vast diversity of climates and ecosystems, Colombia presents itself as one of the countries with the greatest potential for the exploitation of these energies, a factor that has positively impacted the scientific and academic production in relation to these topics[4].Wind is an abundant resource available in nature that can be used by the mechanical conversion of wind energy into electricity, using wind turbines[5]. In the scientific literature there is a large number of studies related to the techno-economic

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evaluation of the production of electric energy from the wind; At the local level many authors have evaluated the potential of different areas of Colombia, within which are highlighted the area of the Department of La Guajira, the city of Cartagena de Indias and the San Andrés Islands[4]. However, there are still areas to be evaluated, which could meet the conditions necessary for the start-up of major wind projects.

The main objective of this work is to determine the wind potential of an area of the department of Meta-Colombia and to develop the analysis of economic prefeasibility of the electrical generation system from wind energy.

Experimental

Wind speed data for the department of Meta, Colombia

Wind velocity data for the studied area were measured using an anemometer. The information was supplied at 10 m height by the Institute of Hydrology, Meteorology and environmental Studies in Colombia (IDEAM)[6].

Rayleigh distribution

The function of Rayleigh describes in a precise way the distribution of wind velocity, from a modification of the model of Weibull (with k = 2), which is represented by the Ec. 1.

$$f(x/b) = \frac{x}{b^2} e^{\left(\frac{-x^2}{2b^2}\right)} \qquad Ec. 1$$

Where b represents the scale parameter (b > 1) and can be calculated from the Ec. 2[7].

$$b = \sqrt{\frac{1}{2n}\sum_{i=1}^{n} x_i^2} \qquad Ec. 2$$

Extrapolation of speeds

In general, the wind velocity is measured at a standard altitude of 10 m above the Earth's surface, for projects involving systems that take advantage of the kinetic energy of the winds, it is necessary to determine the wind velocity at various heights. Commonly this extrapolation is made from the Ec. 3[8].

$$v = v_{ref}\frac{ln\left(\frac{z}{z_0}\right)}{ln\left(\frac{z_{ref}}{z_0}\right)} \qquad Ec. 3$$

Where, v is the velocity of the wind at a height$z$, $v_{ref}$is the reference speed known to a reference height knownz_{ref}andz_0 is the length of roughness[9].Table 1 shows the roughness factor from the description of the terrain, where "x" represents the characteristic distance between obstacles and "H" is the height of the main obstacle[10].

Table 1. Length of roughness from the description of the terrain.

z_0 (m)	Description of the Terrain
≤0.0002	Calm water, snowy plains
0.005	Snowy fields
0.03	Open and plain ground, grass, some isolated obstacles: x/H≥50
0.1	Low crops, big occasional hurdles: 50<x/H<50
0.25	High crops, scattered obstacles: 20<x/H<15
0.5	Parks, scrubs, numerous obstacles: 15<x/H<10
1	Forests: x/H<4
≥2	Irregular forests with clear

Simulation of the energy produced (E)

From the probability distribution of Rayleigh, presented in the EC. 1 The calculation of F (v) is made, which allows estimating the annual energy produced by the turbine (E), using the Ec. 4[11].

$$\boldsymbol{E = N_h \int_{vm}^{vM} g(v)F(v)dv\, Ec. 4}$$

Where, $\boldsymbol{N_h}$ the number of hours the turbine operates in one year, $\boldsymbol{vm}$ is the minimum speed of power generation and $\boldsymbol{vM}$ is the speed of the cut for safety.

Determination of the energy produced to the conditions of the area

The annual energy generated by a turbine must be corrected from the Ec. 5[12].

$$\boldsymbol{E_R = \frac{\rho}{\rho_0} E \quad Ec. 5}$$

Where $\boldsymbol{\rho_0}$it is generally expressed for an air density of 1,225 kg/m^3 (density under standard conditions: 288.16 K of air temperature and pressure of 101,325 KPa), $\boldsymbol{E_R}$is the production of energy to the density conditions of the study area (MWh/year), $\boldsymbol{\rho}$density of the Study Area (kg/m3) and $\boldsymbol{E}$energy produced per year at standard density conditions (MWh/year).

Ec. 6 was used to calculate the density of the air in the study area.

$$\boldsymbol{\rho = \frac{1}{T}\left[\frac{P}{R_0} - \emptyset P_W\left(\frac{1}{R_0} - \frac{1}{R_W}\right)\right] \qquad Ec. 6}$$

Where$\boldsymbol{P}$ is the barometric pressure (Pa), $\boldsymbol{P_W}$vapour pressure (PA), $\emptyset$ relative humidity (0 to 1 range), $\boldsymbol{T}$temperature (K), $\boldsymbol{R_0}$specific constant of dry air (287.85 J/kg k), $\boldsymbol{R_W}$specific constant of water vapour (461.5 J/kg k).For the Meta department 95.8587 KPa. The temperature and relative humidity data were acquired from the IDEAM. For the calculation of the vapour pressure was used the Antoine equation (Ec. 7).*A*, *B*and*C* are the constants of this equation for water, its values are: 16.2620, 3799.89 and 226.35, respectively[13].

$$\boldsymbol{lnP_W = A - \frac{B}{T + C} \qquad Ec. 7}$$

Characteristics of the turbines

To calculate the annual energy generated by a turbine, it is necessary to know its technical specifications, within which the speed at which it starts to generate electric energy (VM), the cutting Speed (VM), the price of the turbine and the curve of Characteristic power, among others. This information is collected through wind turbine catalogs. The relevant information for the turbines in question is summarized in Table 2. As far as the power curve is concerned, Figure 1 shows the power curve for the Vestas V-112 turbine.

Table 2. Length of roughness from the description of the terrain.

Turbine model	**ENERCON E-33**	**ENERCON E-53**	**WIN WIND WWD-1**	**ENERCON E -82**	**VESTAS V 112**
Nominal potential (kW)	330	800	1000	2000	3000
Rotor diameter (m)	33.4	52.9	64	82	112
Sweep area (m^2)	876	2198	2827	5281	9852
Height of the bushing (m)	44 – 50	73	70	70 – 138	84 -98
Number of shovels	3	3	3	3	3
Connection speed (m/s)	3	2	4	2	3
Cutting speed (m/s)	25	25	20	25	25
Price2017 (COP)	1.599.727.214	2.691.047.971	3.793.168.564	6.504.096.347	8.098.678.574

Results and discussion

Modeling for the wind profile from the distribution of Rayleigh

From the distribution of Rayleigh, the frequency F(v) was modeled for the ranges of velocities taken and compared with the real frequencies obtained by manipulating the data supplied by the IDEAM. In order to verify if the model was adequate to continue with the technical-economic prefeasibility, the Chi-square and square root of the mean quadratic error RMSE (root mean Square error) were used, based on the Equations 8 and 9, respectively[14]. In addition, Figure 1 shows that the method is suitable for modeling the frequency at 90 meters.

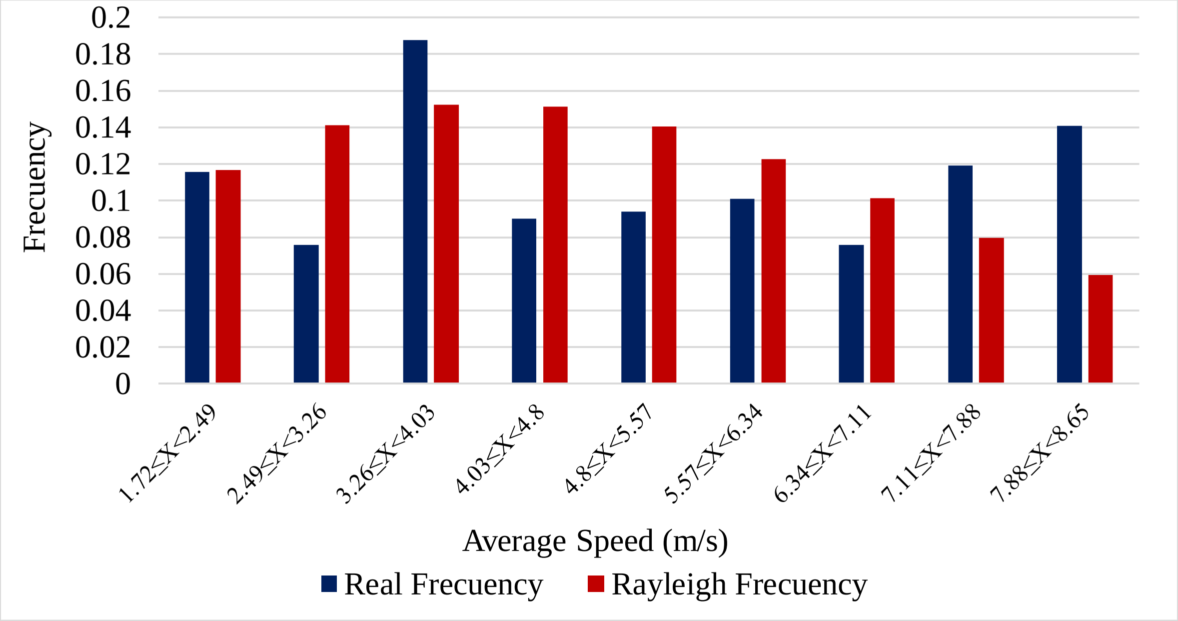

Figure 1. Real frequency and frequency calculated by means of the distribution of Rayleigh to 90 meters of height according to the ranges of selected speeds.

$$X^2 = \frac{\sum_{i=1}^{N}(y_i - x_i)^2}{N - n} \qquad Ec.8$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2\right]^{1/2} \qquad Ec.9$$

Where the i-th value of the probability of the actual data isy_i, $x_i$is the i-th value of the estimated data with the distribution of Rayleigh, N is the number of observations and n is the number of constants (1 for this case).The values obtained for the statistical criteria are shown in Table 3, and it is observed that they are very close to zero (0), which allows us to verify the accuracy of the model.

Table 3. Chi-square and RMSE for the Rayleigh model for a height of 90 m.

Criteria	**Value**
Chi-square	0.0025
RMSE	0.047

Selection of the wind turbine with the lowest rate of $/kWh

El costo de los kWh de energía se calculó dividiendo el valor presente de los costos (Ec.10), entre la cantidad de energía producida en el tiempo de vida útil de los aerogeneradores[15].

$$VPC = I + C_{om}\left[\frac{1+i}{r-1}\right] \times \left[1-\left(\frac{1+i}{r+1}\right)\right] - S\left[\frac{1+i}{r+1}\right]^{t} \qquad Ec.10$$

Where (i) is the initial investment, (C_{om}) operating and maintenance costs, (r) interest rate, (i) Rate of inflation, (S) salvage value and (t) life of the wind turbine. In this study the initial investment was estimated on the basis of the distribution of the capital costs of a typical wind project in Europe (Figure 2). This procedure is speculative, but it can serve as a good approximation of the investment budget needed for the implementation of a wind turbine.

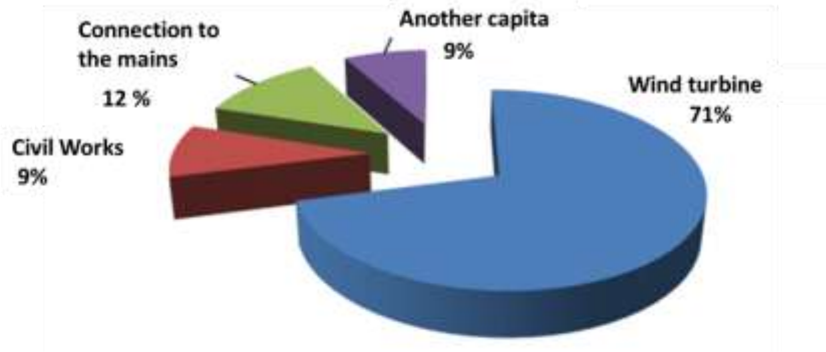

Figure 2. Distribution of capital costs of a wind project.

The evaluation was carried out for a specific case in which interest rates (R) were considered from 0-40%, an inflation of 5.6% (percentage in Colombia for this indicator in 2016 according to the DANE), operating and maintenance costs (CO&M) equivalent to 25% of the cost Annual turbine, a salvage value (S) of 10% at the cost of the plant and a lifespan (t) for wind turbines of 20 years[13].

Figure 3 shows the cost per kWh of energy produced for the five selected turbines, for different heights. It is observed that the cost of kWh is lower in all these cases for the Vestas turbine V-112 (3000 KW), with values of \$151.69/kWh, \$134.46/kWh and \$123.67/kWh, to 50, 70 and 90 m, respectively, so this turbine was selected for the development of the analysis of prefactibility Techno-economic in the flat of the Department of Meta, Colombia.

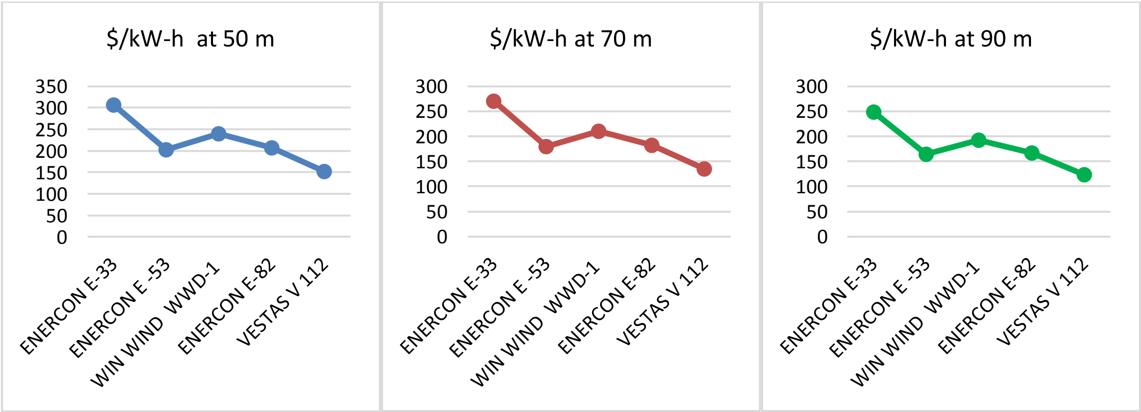

Figure 3. Specific cost of energy generated by five wind turbines at 50, 70 and 90 meters high.

Interest rate influence on VPN for Vestas wind turbine V-112 at 90 m height

In order to determine the VPN for the different interest rates, the Ec. 11 was used[13] and the results are summarized in Figure 4. The project would be attractive (15% interest rates) only if the sales price exceeds \$300.

$$VPN = -I + (P_v E_{g-} C_{om}) \left[\frac{1+i}{r-1}\right] \times \left[1 - \left(\frac{1+i}{r+1}\right)\right]^t - S\left[\frac{1+i}{r+1}\right]^t \quad Ec.11$$

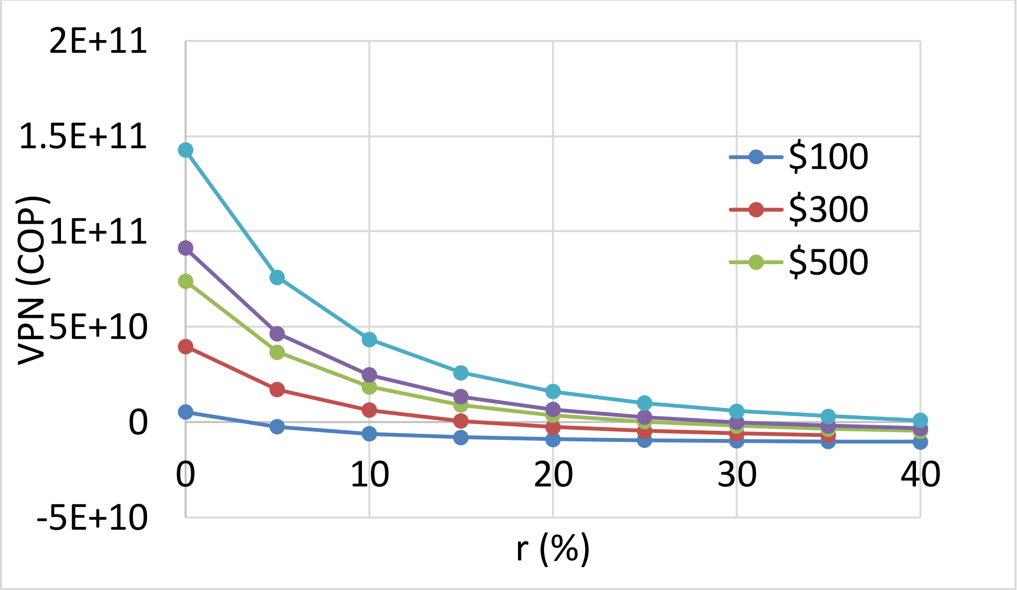

Figure 4. VPN variation depending on interest rate at different energy selling prices at 90 meters high.

Interest rate influence on investment recovery time (TRI)for Vestas V-112

The time of recovery of the investment (TRI), was calculated, applying the Ec. 11[13].

$$TRI = \frac{log\left[1 - I \times \left[\frac{r-i}{P_v E_g}\right]\left[\frac{1}{1+i}\right]\right.}{log\left(\frac{1+i}{1+r}\right)} \quad Ec.11$$

Figure 5 shows that it is possible to recover the investment made in times less than 15 years (time less than the life of the turbine Vestas V-112 3000 KW) for attractive interest rates for investors (15-25%), for sales prices higher than $300 Colombian pesos.

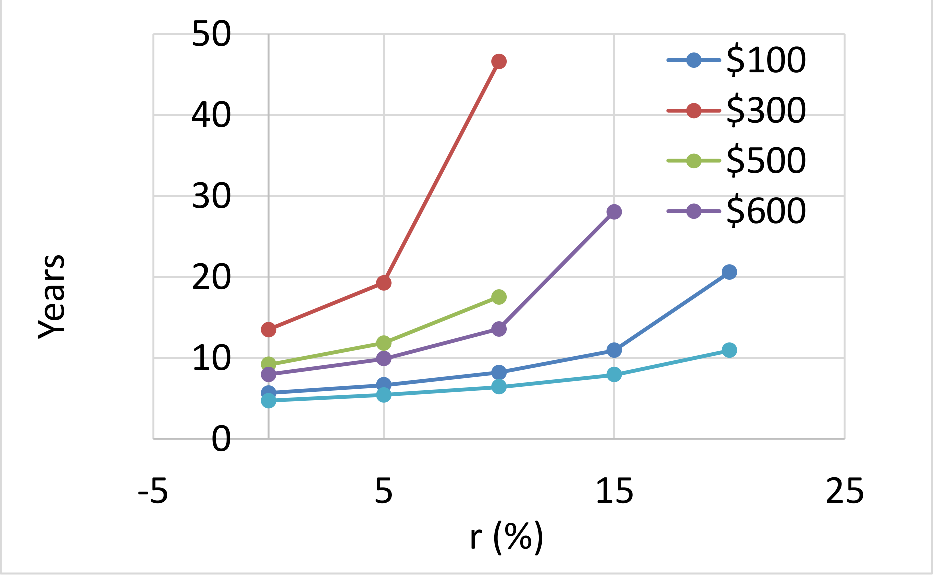

Figure 5. Variation of the TRI depending on the interest rate at different energy sales prices at 90 meters height.

Analysis of the internal rate of return

The internal rate of return indicates the value of the interest rate for which the VPN equals zero[13]. In Table 4 It is observed that the project is interesting for sales prices higher than$300/kWh, since the TIR can exceed the TMAR, depending on the considerations made by the investor[15].

Table 4. TIR obtained for each sales price studied.

Energy selling price ($/kWh)	**TIR (%)**
100	2.95
300	15.75
500	25.45
600	29.96
900	43.07

Conclusions

The Rayleigh distribution function allows to model the wind velocity profile for the Meta Department (Colombia). The economic analysis determined that the turbine with lower cost of electricity generation was the Vestas V-112 (3MW).

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References

1. Recalde, M., Bouille, D., Girardin, L. (2015) Limitación para el desarrollo de energías alternativas en Argentina. Problemas del Desarrollo, (46), 89-115.
2. Campo, E, Romero, M. (2015). Análisis Termodinámico Del Sistema Metanol – Glicerol- Biodiesel A Partir De Jatropha curcas. Tesis de pregado, Universidad de Cartagena, Cartagena.
3. Pandey, V., Singh, K., Singh, J., Kumar, A., Singh, B., Singh, R. (2012). Jatropha curcas: A potential biofuel plant for sustainable environmental development. Renewable and Sustainable Energy Reviews, 16, 2870–2883.
4. Realpe, A., Diazgranados, J., Acevedo, M. (2011). Generación Eléctrica Y Evaluación Del Potencial De Energía Eólica En Regiones De Colombia. Portal Revistas Unacional. ISSN: 0012-7353.
5. Al-Nassar, W., Alhajraf, S., Al-Enizi, A., Al-Awadhi, L. (2005). Potential wind power generation in the state of Kuwait. Renewable Energy, 30, 2149–2161.
6. IDEAM, Databases of wind, solar and hydrological. Available at:http://institucional.ideam.gov.co, 2011.
7. Pishgar-Komleh, S.H., keyhani, A., Sefeedpari, P. (2015). Wind speed and power density analysis based on Weibull and Rayleigh distributions (a case study: Firouzkooh county of Iran). Renewable and Sustainable Energy Reviews, (42), 313-322.
8. Safari, B., Gasore, J. (2010). A statistical investigation of wind characteristics and wind energy potential based on the Weibull and Rayleigh models in Rwanda. Renewable Energy, (35), 2874-2880.
9. Gualtieri, G., Secci, S. (2014). Extrapolating wind speed time series vs. Weibull distribution to assess wind resource to the turbine hub height: A case study on coastal location in Southern Italy. Renewable Energy, (62), 164-176.
10. Marrero, M. (2011). Parámetros de rugosidad representativos de terrenos naturales. Tesis de Maestría. Universidad de Granada, España.
11. Realpe, A., Chamorro, B., De Ávila G. (2016). Modeling and Assessment of Wind Energy Potential in the Cartagena City. International Journal of ChemTech Research, 9(5), 614-623.

12. Jafarian, M., Ranjbar, A.M. (2010). Fuzzy modeling techniques and artificial neural networks to estimate annual energy output of a wind turbine. Renewable Energy, 35(9), 2008-2014.
13. Tafur, A.M., Pizza, A.D. (2013). Modelación y evaluación del potencial eólico como una fuente de generación de energía eléctrica en la zona costera de Cartagena. Tesis de pregrado. Universidad de Cartagena, Colombia.
14. Serrano, J.C. (2013). Comparación de métodos para determinar los parámetros de Weibull para la generación de energía eólica. Scientia et Technica Año XVIII, 18(2), 315-320.
15. Baca, G. (2006).Evaluación de proyectos. México: Mc Graw Hill.

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