Global Journal of researches in engineering
Mechanical and mechanics engineering
Volume 11 Issue 7 Version 1.0 December 2011
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 Print ISSN:0975-5861

Economic Analysis Of The Wind Energy Generated In Cuba, Considering The Turbines Tested In The Country.

By Deivis Avila Prats, Ramón Alesanco García, Juan Veliz Alonso
University of La Laguna.

Abstract - In this study, the results of the analysis carried out about wind energy potentials in the western provinces of Cuba are shown. Wind characteristics were analyzed using the wind speed data collected from four meteorological stations, selecting for this study, the station with the maximum annual mean wind speed. A technical assessment has been made of electricity generation from three wind turbines having a capacity of (275 kW, 750 kW, and 850 kW), respectively. The yearly energy output for three different turbines was calculated, with the wind data of the meteorological station selected. The production cost of the kWh of wind energy generated with the different machines and the economical variables, such as the payback (PBA) and the net present value (NPV), have been determined for each one, taking for this economic analysis two different costs for kW of wind energy installed: national and international average. The conclusions show that, the production costs of the kWh of wind energy generated in this country is expensive, due to its high generation price, since they are conditioned by high installation costs and the use of turbines with low power of generation.

Keywords : Wind energy; Weibull distribution; Production cost; Payback; Net present value (NPV).

GJRE-A Classification : FOR Code: 091305

ECONOMIC ANALYSIS OF THE WIND ENERGY GENERATED IN CUBA, CONSIDERING THE TURBINES TESTED IN THE COUNTRY.

Economic Analysis Of The Wind Energy Generated In Cuba, Considering The Turbines Tested In The Country.

Deivis Avila Prats[α], Ramón Alesanco García[Ω], Juan Veliz Alonso[β].

Abstract - In this study, the results of the analysis carried out about wind energy potentials in the western provinces of Cuba are shown. Wind characteristics were analyzed using the wind speed data collected from four meteorological stations, selecting for this study, the station with the maximum annual mean wind speed. A technical assessment has been made of electricity generation from three wind turbines having a capacity of (275 kW, 750 kW, and 850 kW), respectively. The yearly energy output for three different turbines was calculated, with the wind data of the meteorological station selected. The production cost of the kWh of wind energy generated with the different machines and the economical variables, such as the payback (PBA) and the net present value (NPV), have been determined for each one, taking for this economic analysis two different costs for kW of wind energy installed: national and international average. The conclusions show that, the production costs of the kWh of wind energy generated in this country is expensive, due to its high generation price, since they are conditioned by high installation costs and the use of turbines with low power of generation.

Keywords : Wind energy; Weibull distribution; Production cost; Payback; Net present value (NPV).

I. Introduction

The electric production coming from the wind has had a significant growth at worldwide level, being wind energy, one of the biggest dynamic growths of all energy in the last years (WWEA, 2011).

Currently, Latin America is one of the regions of smaller development in this field, with only 1078 MW of wind energy installed until the year 2009 (LAWEA, 2010). Cuba is one of the many countries in this area that does not have large reserves of petroleum or natural gas, which poses a serious problem for the country, because the largest percent of the electricity is obtained from power plants, being only the 2% of the total energy produced by renewable energy sources (UNE, 2008). For this reason, the Cuban government considers wind energy the best choice from amongst the renewable energies, taking into account that it is one of the most abundant renewable energy resources of the national territory. The most significant results obtained in this field are the following:

Author [αΩβ] : Engineering Department; Nautical Technical School; University of La Laguna. C/ Padrón Albornoz s/n, P.O. Box 38001, S/C Tenerife, Spain. E-mail : deivisavila@yahoo.es, ralesanco@gmail.com, veliz24@yahoo.es

- Inauguration of the first wind farm of Cuba, in the Turiguanó Island in 1999, with two wind turbines of 225 kW (Leiva, 1999).
- Creation of the National Wind Energy Group (GEN) in 2005, with the objective of settling down and to implement all necessary actions for the application of the wind energy in Cuba (GEN, 2007).
- Culmination of the Wind Potential Map of Cuba in 2006. The possible wind energy capacity in the territory of Cuba, could reach up to 3500 MW (Soltura and Roque, 2007).
- Inauguration of the experimental wind farm "Los Canarreos" (February 2007), with six folding wind generators of 275 kW, with an installed power equivalent to 1.65 MW (GEN, 2007).
- Culmination of the third wind farm "Gibara I" in 2008, with a power of 5.1 MW, having six wind turbines of 850 kW (Anon, 2008).
- Installation of small wind generators isolated from the National Electric System (SEN), with a total of 30 kW (Anon, 2008).
- Culmination and inauguration of the wind farm "Gibara II" in 2010, which have six turbines of 750 kW and a total power of 4.5 MW (Reve, 2010).

The potential sites of wind energy generation of Cuba have not been completely investigated in detail yet. The goal of this study is to carry out an economic analysis of the production costs of the wind energy by kWh generated in Cuba, analyzing the wind data of the meteorological stations in the western region of the country, the annual electric power generated by turbines of 275, 750 and 850 kW, and different investment costs by installed kW of wind power.

II. Methodology and Materials

a) Recoverable wind energy

Knowledge of wind speed frequency distribution is a very important factor to evaluate wind potential in windy areas. Wind data obtained with various observation methods has the widest ranges. Therefore, in wind energy analysis, it is necessary to have only a few key parameters that can explain the behaviour of a wide range of wind speed data. The simplest and most practical method for the procedure is to use a probability distribution function. The Weibull distribution is the most commonly used statistical distribution for describing wind speed data.

As indicated by Burton, et al. (2001), the Weibull distribution function which is a two-parameter distribution is a special case of generalized gamma distribution for wind speed and is expressed as:

$$f(v)=\frac{k}{c}\cdot\left(\frac{v}{c}\right)^{k-1}\cdot e^{-\left(\frac{v}{c}\right)^{k}} \qquad (1)$$

Where, k is the shape factor, c is the scalar factor, and v is the wind speed.

In order to estimate Weibull k and c parameters, numerous methods have been proposed over the last few years. In this study, the two parameters of Weibull are determined by using mean wind speed–standard deviation method (Ucar and Balo, 2008).

The speed at any height can be calculated using the hypothesis of a neuter atmosphere and is given by the expression (Ucar and Balo, 2008; Fawzi, 2009):

$$\frac{v_1}{v_2}=\left(\frac{z_1}{z_2}\right)^{\alpha} \qquad (2)$$

Where, v_1 is the actual wind speed measured at a height of z_1; v_2 the wind speed at the required or extrapolated height z_2. The exponent α depends on the surface roughness (z_o).

Another important aspect is to predict the distribution of speeds for any height (z), according to the principle of Weibull distribution, consists of being able to determine the parameters k and c for this height, starting from the knowledge of the parameters of another height, the empiric expression is expressed as follows (Villarrubia, 2004):

$$k_2=k_1\cdot\left[\frac{1-0.088\cdot\ln\left(\frac{z_1}{10}\right)}{1-0.088\cdot\ln\left(\frac{z_2}{10}\right)}\right] \qquad (3)$$

$$c_2=c_1\cdot\left(\frac{z_2}{z_1}\right)^{\beta} \qquad (4)$$

Where the coefficient β can be expressed as

$$\beta=\frac{0.37-0.088\cdot\ln c_1}{1-0.088\cdot\ln\left(\frac{z_1}{10}\right)} \qquad (5)$$

k_1, k_2 are the shape parameters and c_1, c_2 are the scale factor, for the height z_1 y z_2 respectively.

As displayed by Eskin, et al. (2008) and Hau (2006), it is well known that the power of the wind (P_w) that flows at mean wind speed (v_m) through a blade sweep area (A) increases as the cubic of its velocity and is given by using the following equation:

$$P_w=\frac{1}{2}\rho\cdot A\cdot v_m^{\;3} \qquad (6)$$

Where ρ is mean air density, $v_m^{\;3}$ is mean value of the third power of the wind speed and A is sweep area.

The average wind power density ($P_{d,w}$) or energy output, based on Weibull probability density function can be expressed as follows:

$$P_{d,w}=\frac{1}{2}T\cdot\rho\cdot C_p\cdot A\cdot\sum_{x=1}^{J}f_{(v)}\cdot v_x^{\;3} \qquad (7)$$

Where C_p is the capacity factor of the wind generator, T is the time analyzed (one year), v is the wind speed, and J is the class number of the data.

b) Economic evaluation

In spite of the fact that wind energy has one of the biggest dynamic growths of all energy per year, it only represents a small portion of the whole energy that is produced at world level. This is given mainly by their high production costs per kW, which makes the projects unfeasible in much of the cases. A deep economic analysis of all the proposals will be necessary. In order to do so, it can use for them many different criteria as: Unitary cost of electricity production (c_u), Payback (PBA) and Net present value (NPV).

i. *Unitary cost of electricity production*

In an economic study of wind energy systems it is necessary to know the unitary cost of electricity production, as well as their profitability for payment of the generated kWh.

It is possible to determine the unitary production cost of electricity generated with the wind (c_u), updating all costs of the project along their useful life and to add them to the initial investment of the year zero. The quotient among the resulting quantity in constant monetary units of the zero year and the total electric power that will produce the project, allows a reasonable estimate of the unitary cost of production (\$/kWh) (Villarrubia, 2004). In this way, the unitary cost of electricity production (c_u) will be determined according to the formula:

$$c_u=\frac{I-V_R\cdot(1+r)^{-n}+\sum_{j=1}^{n}(OM_j+F_j)\cdot(1+r)^{-j}}{\sum_{j=1}^{n}P_{d,w}} \qquad (8)$$

The variables of the expression are:

c_u : unitary production cost of electricity (\$/kWh) in constant monetary units (year 0).

n : lifetime of the system (year).

I : capital cost of the installed wind power system, in the 0 year ($).
V_R : residual value of the installation at the end of their useful life ($).
OM_j: operation and maintenance costs in the j year ($).
F_j : financing cost of the j year ($).
$P_{d,w}$: energy output in the year j (kWh/year).
r : market discount rate (includes the inflation effects).

ii. *Payback (PBA) and Net present value (NPV)*

Wind turbine projects are generally characterized by high initial investment and low operating costs. Thus the basic economic problem is one of comparing an initial known investment with estimated future operating savings. Several economic criteria have been proposed for evaluating and optimizing systems, and there is no universal agreement on which should be used (Tsoutsos, et al., 2003). For the needs of the current study, the two following criteria are used:

- payback period (PBA)
- net present value (NPV)

The payback (PBA) is a financial balance inside the horizon of the project (years). It is possible to obtain it through the expression

$$PBA = \frac{\log\left[\frac{I}{E_j}\cdot\frac{i}{100}+1\right]}{\log\left[1+\frac{i}{100}\right]} \quad (9)$$

Where I: capital cost of the installed wind power system ($); i: energy inflation (the change of energy prices relative to general inflation), E_j: energy saving ($/yr).

The net present value (NPV) in dollars ($) units, is a sequence of cash flows take as input the cash flows and a discount rate or discount curve and outputs a price.

$$NPV = Y\frac{1}{r-i}\left[1-\frac{1+i}{1+r}\right]^n - I \quad (10)$$

Where Y: yearly benefits ($/yr), r: market discount rate, i: energy inflation, n: lifetime (yr), I: capital cost of the installed wind power system ($).
The yearly benefits (Y) represent an expression of the annual costs for any system, wind power or non-wind power systems to meet energy needs.

Economic assumptions

The basic assumptions made during the economic evaluation are:

- cost by kW of wind energy installed equal to 1000 $/kW or 1400 $/kW
- operation and maintenance costs (OM_j): 3% of the capital cost.
- lifetime of the system (n): 20 yr.
- market discount rate (r): 7 %
- energy inflation (i): 3%
- residual value of the installation at the end of their useful life (V_R): not considered.
- financing cost:5%

The determination of the capital cost, or total investment, generally involves the cost of the wind turbines and the cost of the remaining installation (Manwel and Rogers, 2009). In relation to the criteria used in this study, the average value cost per kW of wind energy installed in Cuba (1400 $/kW) (Leiva, 1999; UNE, 2008; INEL Project, 2009) and the average cost in the world (1000 $/kW) (Villarrubia, 2004) are used.

The operation cost can include a cost of insurance of the wind turbine, taxes, and the land rental cost, while the maintenance cost can include the following typical components: routine checks, periodic maintenance, periodic testing, blade cleaning, electrical equipment maintenance, and unscheduled maintenance cost (Manwel and Rogers, 2009).

c) Acquisition of wind speed data.

In the study, wind speed data are obtained from four of the meteorological stations placed by the Institute of Meteorology of Cuba (INSMET), for the estimate of the wind energy resource under different physical-geographical conditions of the Cuban archipelago (Roque, et al., 2009). The meteorological stations are located in the western region of Cuba; the more industrialized and inhabited regions of the country.

Table 1 shows the geographical coordinates of the meteorological station and the height level over floor (HLF) of the four stations used in the study. Fig. 1 samples the geographical localization of the studied meteorological stations and the wind farms of the island.

Table 1 : Geographical coordinates of the meteorological stations used in the study (Source: Roque, et al., 2009).

Stations	Longitude (deg)	Latitude (deg)	(HLF) (1) (m)
Guanito TV	83° 46' 54"	22° 27' 08"	75
S/C del Norte	81° 55' 58"	23° 09' 00"	60
Jagüey	81° 05´44"	22° 33´39´´	50
El Brinco	81° 03'14"	22° 04' 18"	50

(1) (HLF) - height level over floor (m)

Table 2 shows some parameters of the meteorological stations mentioned before, as power of wind per unit area (P_u), parameters k, c of the Weibull distribution and the mean wind speed (v_m).

Fig. 1 : Distribution of the meteorological stations used in the study. Localization of the wind farms of Cuba.

Table 2 : Wind data of the stations used in the study. (Source: Roque, et al., 2009).

Stations	**Weibull parameters *k, c***	**Mean wind speed. v_m (m/s)**	**Power of wind (P_u) (W/m^2)**
Guanito TV	k =2.55 c=6.4	5.7	175
S/C de l Norte	k =2.29 c =7.4	6.6	292
Jagüey	k =2.81 c=5.8	5.2	124
El Brinco	k =2.63 c=6.7	6.0	197

III. Results and Discussion

a) Selection of the optimum location

To compare the wind energy potentials of the different meteorological stations that appear in Table 2, can introduce errors in the analysis, because measurement of wind speed has been carried out at different heights over the floor level. Given these circumstances, the parameters of wind speed of all stations are extrapolated to a height of 55 meters over the floor level (HLF), predetermined study height. The obtained values are shown in Table 3.

Table 3 : Wind data of the stations used in the study, 55 meters high over the floor level.

Stations	**Weibull parameters *k, c***	**Mean wind speed v_m (m/s)**	**Power of wind (P_u) (W/m^2)**
Guanito TV	k=2.47 c=5.92	5.46	141
S/C de l Norte	k =2.27 c=7.25	6.5	276
Jagüey	k=2.84 c = 5.94	5.27	132
El Brinco	k=2.66 c =6.85	6.1	209

The obtained results show that the power exerted by the wind per square meter in the four stations to a height of 55 meters over the floor level, is between 132 and 276 W/m^2, being Santa Cruz del Norte, in Havana, the station with the biggest potentials. Fig. 2 samples the probability of Weibull distribution of wind speeds analyzed in the period of one year in the four meteorological stations studied at this height.

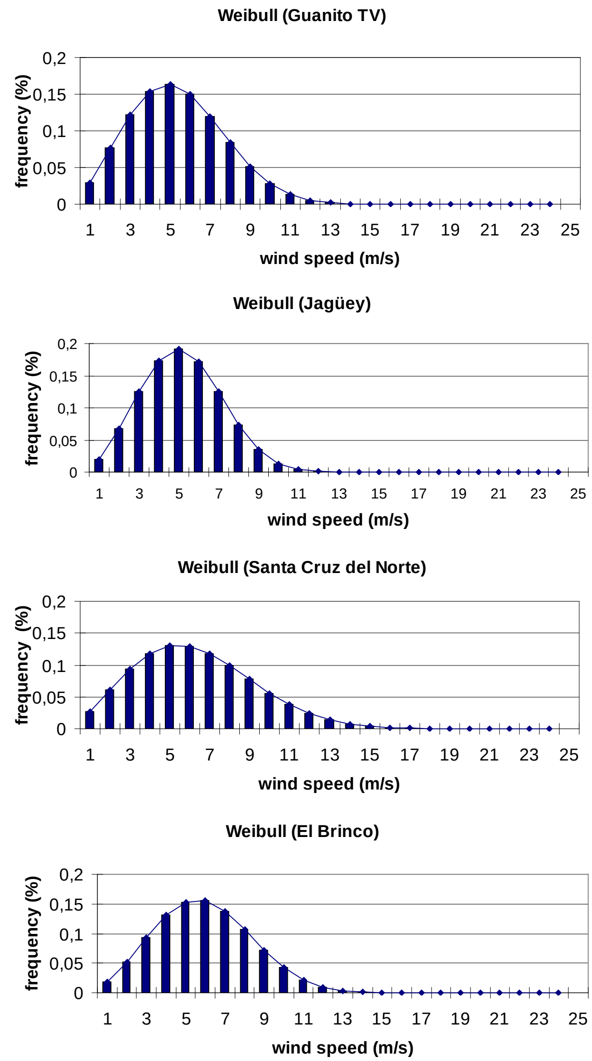

Fig. 2 : Weibull distribution of the analyzed wind speeds, in the meteorological stations studied at a height of 55 meters over floor level.

Known the wind energy potentials of the different meteorological stations analyzed, Santa Cruz del Norte is selected as the best candidate for the study, for its wind potentials, as well as for its climatic and infrastructure conditions.

The area where the meteorological station is located one characterized by mountainous elevations, with a very low occurrence probability of severe meteorological events (hurricanes, tornados and storms, etc) (Limia and Pérez, 1999) and located near ports, electricity transmission grids, industrial centres and good roads.

b) Production of energy by wind turbines

The characteristics of the selected wind turbines are shown in Table 4. The selection of the different machines is based on the wind turbine technologies used in the different wind farms (Los Canarreos, Gibara I, Gibara II) in Cuba. The power curves of turbines with different rated power are shown in Fig. 3. The rated powers of these turbines were 275 kW, 750 kW and 850 kW, respectively. The annual electric power and the annual equivalent hours obtained in the modelling of the wind speeds in the meteorological station of Santa Cruz del Norte, is shown in Table 5.

Table 4 : Main characteristics of three different wind turbines.

Characteristics	GEV-MP275	G52-850	S50/750
Rated P ower (kW)	275	850	750
Hub height (m)	55	55	55
Diameter (m)	32	52	48.4
Sept area (m^2)	805	2 124	1 840
Cut-in wind speed (m/s)	4	4	4
Cut-off w ind speed (m/s)	20	25	25

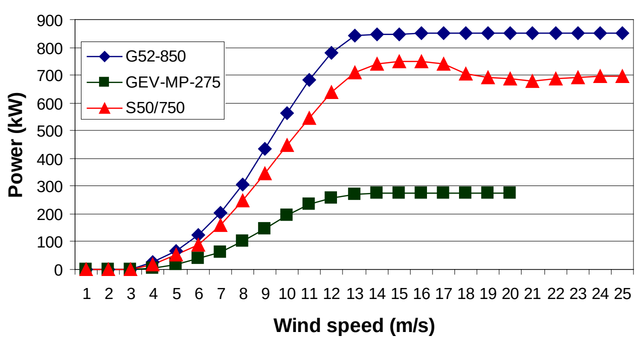

Fig. 3 : Power curves of the selected wind turbines.

Table 5 : Energy generated by the wind in one year.

Turbines.	Rated Power (kW)	Annual power (kW h/ yr)	Annual equivalent hours (h/ yr)
GEV-MP275	275	644 803	2 345
G52-850	850	1 976 090	2 325
S48/750	750	1 574 448	2 100

The annual energy output of the different wind turbines changes due to the capacity of each one. In the case of wind turbines with a capacity of 275 kW the annual energy output is 644 803 kW h/year, with 2 345 equivalent hours. The annual energy generated by a wind turbine of 750 kW is 1574448 kW h/year and 2 100 equivalent hours. The wind turbine of 850 kW is the maximum producer, with 1976090 kW h/year and 2 325 equivalent hours.

c) The wind farms

Currently wind farms are the more viable options for the reception of wind energy and, from the technical point of view, as economic. This is due to the fact that the connection of a group of wind turbines, reduces maintenance expenses, simplifies the requirements for interconnection and compensates the interruptions caused by local fluctuations in the speed of the wind.

Taking as reference the proposition of the Cuban Electric Union (UNE) to develop 10 MW from wind energy power in the western region of Cuba (UNE, 2008), the number of the necessary wind generators to cover this power with a wind farm have been calculated, always in excess, as it is shown in Table 6 .

Table 6 : Number of wind generators by wind farms.

Variants	Turbine	Rated Power (kW)	Nº of turbines	Wind farm Power(MW)
1	GEV-MP275	275	37	10.175
2	G52-850	850	12	10.2
3	S50/750	750	14	10.5

The number of wind turbines by wind farms goes from 37 machines necessary to produce 10.175 MW, with turbines of 275 kW, up to 14 machines of 750 kW necessary to produce 10.5 MW and the 12 of 850 kW required to generate 10.2 MW.

With the obtained wind farm proposals an economic analysis will be developed with the aim of determining the production cost of the kW of wind energy that is supposedly generated in each one. Other criteria (payback, net present value) will be used too to determine the viability of the projects.

d) Economic analysis

The economic analysis of the different wind farm propositions with different wind turbines models will be carried out following these two investments:

1. Cost per kW of wind energy installed equal to 1400 $/kW (average value for kW of wind energy installed in Cuba, it can be bigger in some cases) (Leiva, 1999; UNE, 2008; INEL Project, 2009).
2. Cost per kW of wind energy installed equal to 1000 $/kW (average value for kW of wind energy installed in the world) (Villarrubia, 2004).

i. *First investment*

The economic variables that appear in Table 7 have been obtained establishing a cost per kW of wind energy installed equal to 1400 dollars. The reckoning is carried out from an initial investment in the wind farm, to which are added the costs in which the project incurs in the analyzed period (20 years). In this way the cost of production of the wind energy kW for the different proposals is obtained.

The values of production costs per kW of energy generated in the wind farms (different wind turbines models) are between 5.8 and 6.34 c$/kW. It is assumed as a possible price to pay for the generated electricity a value equal to 7 c$/kW.

It is calculated the payback (PBA) and the net present value (NPV) in this first investment proposition of all turbines. The economic curves for the three turbines with different rated power are shown in Fig. 4.

Table 7 : Production cost of the kW of wind energy (with a cost per kW of wind energy installed equal to 1400 dollars).

Variable	Wind farm with GEV-MP275	Wind farm with G52-850	Wind farm with S48/750
Initial investment ($)	14 245 000	14 280 000	14 700 000
Production cost (c$/kW)	6.34	5.8	6.3

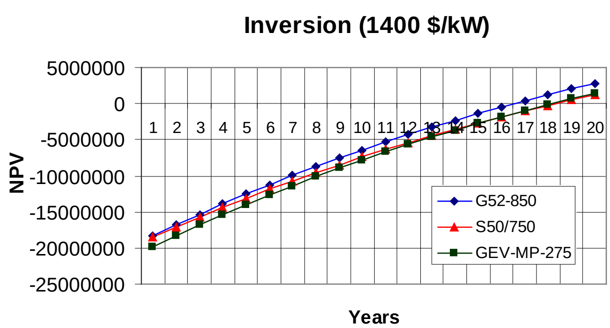

Fig. 4 : Net present value (NPV) with a cost by kW of wind energy installed equal to 1400 $/kW.

The first wind farm that begins to recover the investment is the one calculated with the machines of 850 kW, which begins to the 16 years and seven months, with a net present value of 2 814 985 dollars. The wind farm with the wind turbines of 275 kW begins to recover the investment to the 18 years and two months with NPV of 1 480 030 dollars. The last one in recovering the investment would be the proposal with the turbines of 750 kW, which would begin the recovery in 18 years and five months. The values obtained in the analysis with 1400 $/kW of wind energy installed and a payment of 7 c$/kW by wind energy generated, are not considered a good economic option.

ii. *Second investment*

In this second investment proposition, the data will be processed with a cost for kW of wind energy installed equal to 1000 dollars, the calculations were carried out in the same way that in the first proposal, the obtained results are shown in Table 8.

The production costs per kW of energy generated with the wind in different wind farms, taking as reference the data of wind speed from the station of Santa Cruz del Norte and an investment of 1000 $/kW of installed wind energy, are between the 4.15 and the 4.52 c$/kW. The money pay by the generated wind energy will remain equal in this second proposition, 7 c$/kW. The economic curves are shown in Fig. 5

Table 8 : Production cost of the kW of wind energy (with a cost per kW of wind energy installed equal 1000 dollars).

Variable	Wind farm with GEV-MP 275	Wind farm with G52-850	Wind farm with S48/750
Initial investment ($)	10 175 000	10 200 000	10 500 000
Production cost (c$/kW)	4.52	4.15	4.5

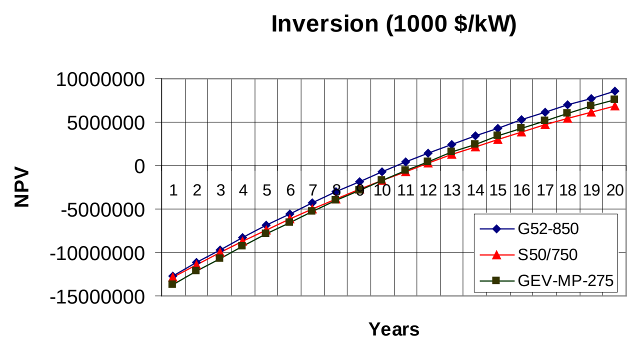

Fig. 5 : Net present value (NPV) with a cost by kW of wind energy installed equal to 1000 $/kW.

With an investment of 1000 $/kW and a payment by the produced electricity equal to 7 c$/kW, the results show that the first wind farm begin to recover the investment is that of the wind turbines of 850 kW in 10 years and eight months with a net present value of 8 523 080 dollars, followed by the wind farm with machines of 275 kW, which take around 11 years and seven months to recover their investment (having a NPV of 7 646 700 dollars). The last one to recover the investment is the wind farm with turbine of 750 kW, which takes one month more than the previous one in recovering the investment, 11 years and eight months with a NPV of 6 903 870 dollars.

IV. Conclusions

Taking in consideration all aspects analyzed in the study of the wind energy potentials in the western region of Cuba, have been reached the following conclusions:

1. The meteorological station located in the region of Santa Cruz del Norte, Havana, has the biggest power mean of wind by square meter in the four stations analyzed in the western region of Cuba, with a value of 276 W/m2 at height of 55 meters over the floor.

2. The biggest electricity production obtained with the analyzed wind turbines is obtained with a machine of 850 kW of power, with 1 976 090 kWh/year, to a hub height of 55 meters and 2 325 annual equivalent hours.
3. The production cost of the kW of wind energy generated in the different wind farms with an investment of 1400 $/kW of wind energy installed is between 5.8 and 6.34 dollar cent, being smaller the costs of the wind farm with turbines of 850 kW of power.
4. The production costs of the kW of wind energy generated in the different wind farms with an investment of 1000 $/kW of wind energy installed is between 4.15 and 4.52 dollar cent, being smaller the costs of the wind farm with machines of 850 kW of nominal power.
5. Taking an investment of 1400 $/kW of wind energy installed and with a payment for the generated electricity of 7 c$/kW, the results show that the wind farm that first begins to recover the investment is the one with turbines of 850 kW, which begins the 16 years and seven months, with a net present value (NPV) of 2 814 985 dollars.
6. With an investment of 1000 $/kW for wind energy installed and with a payment for the generated electricity of 7 c$/kW, the first wind farm that begins to recover the investment is the proposition with turbines of 850 kW, which begins the 11 years and seven months, with a NPV of 7 636 875 dollars.
7. The wind energy is not economically viable in Cuba, due to its high generation prices, which are conditioned by the high installation costs and the use of turbines with low power of generation.

V. Nomenclature

A	sweep area (m^2)
c	Weibull scale parameter (m/s)
C_p	capacity factor (dimensionless)
C_u	unitary production cost of the electricity ($/kWh)
E_j	energy saving ($/yr)
F_j	financing cost ($)
i	energy inflation (dimensionless)
I	capital cost of the installed wind power system($)
J	class number (dimensionless)
k	Weibull shape parameter (dimensionless)
n	lifetime of the system (years)
NPV	net present value ($)
OM_j	operation and maintenance costs ($)
PBA	payback (years)
P_u	power of wind per unit area (W/m^2)
P_w	power of wind (kW)
$P_{d,w}$	energy output (kW h/ year)
r	market discount rate ($)
T	time (h)
v	wind speed (m/s)
v_m	mean wind speed (m/s)
V_R	residual value of the installation ($)
Y	yearly benefits ($/yr)
z	height (m)
z_o	Surface roughness (m).
ρ	air density (kg/m^3)

References Références Referencias

1. Anon., 2008. Wind farm Gibara 1. Energy & you, January – March, 41. ISSN: 1028-9925.
2. Burton, T. et al., 2001. Wind Energy Handbook. England: John Wiley and Sons Ltd., 617 p. ISBN: 0 471 48997 2.
3. Eskin, N. et al., 2008. Wind energy potential of Gökceada Island in Turkey. Renew Sustain Energy Rev, 12, pp. 839–51.
4. Fawzi, A.L., 2009.Wind power analysis and site matching of wind turbine generators in Kingdom of Bahrain. Apply Energy, 86, pp. 538-45.
5. GEN (National Wind Energy Group), 2007. Ten Questions and Answers about Wind Energy. CUBASOLAR, ISBN: 9789597113379.
6. Hau, E., 2006. Wind Turbine, Fundamentals, Technologies, Application, Economics. Berlin: Springer, pp. 81-88. ISBN: 103540242406.
7. INEL Project, 2009. Wind farm Gibara 2, [online] Available at: <http://www.cdmbazaar.net> [Accessed 5 November 2010].
8. LAWEA (Latin American Wind Energy Association), 2009. Wind energy in Latin America. Infopower, October, 120, pp. 11-16. ISSN: 11385073.
9. Leiva, G., 1999. Wind farm of Turiguanó. Energy & you. April-June, 6. ISSN: 1028-9925.
10. Limia, M.; Vega, R. y Pérez, R., 1999. Climatology of the tropical Hurricanes that have affected Cuba and their provinces. CITMA.
11. Manwel, J. F., Mcgowan, J.G., Rogers, A.L., 2009. Wind energy explained, Theory, Designed and Application. England: John Wiley and Sons Ltd., pp. 506-520. ISBN: 978- 0 -470- 01500-1.
12. Reve, 2010. Wind energy in Cuba - next launch of Gibara II wind farm. [online] Available at: <http://www.evwind.es> [Accessed 10 February 2011].
13. Roque, A. et al., 2009. Network of meteorological towers for the Cuban winds program. VI International workshop of Renewable Energy, Saving Energy and Energy Education, Havana, Cuba.
14. Soltura, R. and Roque, A., 2007. Wind resource map of Cuba. Energy & you, January – February, 37. ISSN: 10289925.
15. Tsoutsos, T. et al., 2003. Solar cooling technologies in Greece. An economic viability analysis. Appl. Therm. Eng. 23, pp.1427-39.

16. Ucar, A. Balo, F., 2008. Evaluation of wind energy potential and electricity generation at six locations in Turkey. Apply Energy, 86, pp. 1864- 72.
17. UNE (Electric Union of Cuba), 2008. Wind Energy Program. [online] Available at: <http://www.energia.inf.cu/eventos/memorias6/pdfs/PROG_EOLIC_JUN08.pdf > [Accessed 22 September 2010].
18. Villarrubia, M., 2004.Wind Energy. Barcelona: CEAC, 322 p. ISBN: 8432910627.
19. WWEA (World Wind Energy Association), 2011.World Wind Energy Report 2010.