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Technical Analysis and Comparative Study of three Wind Turbines for a 50MW wind farm in Laayoune City Morocco

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Abstract. Wind energy is in the spotlight, it is nowadays the fastest growing source of energy in the world. The objective of this work is to examine wind power potential of Laayoune site using wind speed, wind direction, and other meteorological data collected during one year. This type of complete examination provides information of wind characteristics of potential sites and helps in choosing appropriate wind turbine. In the first part, we have been present a comparison of three methods for estimating parameters of Weibull distribution function wind speed data namely Standard Deviation , Least Squares and Mabchour's. The comparison has been done using Excel sheet and ALWIN software. In second part, we have been compare three various wind turbines: WES 18-100KW, XANT M-21 100KW and Northem Power NPS 21-100K for the production of a 50MW electric power from wind energy farm installed in Laayoune city. The criteria of turbine choice is based on the price per kilowatt hour and the higher annual production. The simulation results using HOMER and ALWIN software showed that the wind turbine: XANT M-21 100KW has the higher annual production with low cost of installation.

1 Introduction

In recent years the world has seen a huge increase in the consumption of electricity generation based on energy resources. There is a great need to use these renewable resources such as solar energy, wind energy, hydro energy, biomass… [1-2]. Currently, among the renewable energy sources, wind energy is discovered, this energy is clean and non- polluting, it is the most promising source in recent decades [3-4]. In addition, the development of wind turbines proposes a great investment in the field of technological research. These systems that produce electrical energy according to the principle of converting the wind kinetic energy that converts into mechanical energy and then into electrical energy with the help of wind turbines and electrical generators [5]. The general objective of this work is the choice of wind turbine technology to install in Laayoun city. The select Turbine is based on electricity production and technology cost. So it is necessary to choose an Equipment that gives a higher annual production but with a low cost. In this work, we will be interested in Processing meteorological data of Laayoune site and wind speed Data collected during twelve months to assess its potential, its direction and frequency. In order to know the properties of this site, we have used the most important exploited Weibull Distribution statistical [6]. In addition to determine the Weibull factors, we have used the following methods Standard Deviation, Least Squares and Mabchour's method the validation of these methods are executed using the Excel sheet and ALWIN software. In the simulation part, three medium-sized wind turbines: WES 18-100KW, XANT M-21 100KW and Northem Power NPS 21-100KW were compared by sheet and ALWIN software. To choose the higher annual energy production in that comparison we have used three different methods: Standard Deviation, Least Squares and Mabchour's method in order to confirm the most effectual method is evaluated with ALWIN software. Finally to choose the Wind turbine installed in the Laayoune city it is necessary to know the cost of KWh produced for each Wind turbine. The calculations are made by using Homer software. This paper is organized as follows: section 1 explains the study feasibility of dimension of wind farm by sheet excel and Alwin software, and at section 2, we present the results of dimensioning a wind farm of Laayoune , in section 3, we choose the wind turbines and calculate their annual energy production by Excel sheet, Homer, Alwin software. We compared in section 4 the results of the production of wind farm on Laayoune also the results the cost of KWh produced for each turbine.

2 Presentation of Site

Laayoune is the most important city in Western Sahara. It is located on the Atlantic coast, 500 km south of Agadir and 400 km west of Tindouf, on the road to Dakhla. Geographical coordinates: (Area: 21 km²; Contact information: located at 27° 09′ 13″nord, 13° 12′ 12″ouest; Climate: is characterized by its arid and temperate aspect).

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Table 1. Site meteorological data [7]

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
Average air Temperature (°C)	16.24	17.10	18.48	19.09	20.37	22.00	23.23	23.90	23.54	22.35	19.93	17.50	20.31

3 Mathematical Modelling of the Wind Frequency Distribution

3.1 Weibull distribution

The Weibull distribution is a continuous probability distribution used for statistical modelling of wind speeds [8-9]:

$$F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^k\right] \tag{1}$$

And the probability function is given by:

$$f(v) = \frac{dF(v)}{dv} = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1}\exp\left[-\left(\frac{v}{c}\right)^k\right] \tag{2}$$

$$f(v) \geq 0, v \geq 0, k \geq 0, c \geq 0$$

(v) is the Weibull probability density function. It represents the probability of observation of a wind speed$v$, in m/s. C is the scale factor of the Weibull law, in m/s. It is related to the average wind speed by the form factor, k is the form factor of the Weibull law, and it is generally between 1 and 3.

3.2 Weibull parameters Determination

Several methods are used to determine the Weibull parameters C and k from statistical wind data. Among the most used are [10, 11]:

3.2.1 Least squares method

With the help of this method the parameters are estimated with regression line equation by cumulative density function. From Equation 2, the cumulative density function of Weibull distribution function with two parameters can be written as:

$$\frac{1}{1-F(v)} = \exp\left[\left(\frac{v}{c}\right)^k\right] \tag{3}$$

$$\ln\left[\frac{1}{1-F(v)}\right] = \left[\left(\frac{v}{c}\right)^k\right] \tag{4}$$

The cumulative Weibull distribution function is transformed to a linear function like below:

$$\ln\ln\left[\frac{1}{1-F(v)}\right] = k\ln v - k\ln c \tag{5}$$

Equation (4) can be written as $y = ax$ +b.

Where $y = \ln\ln\left[\frac{1}{1-F(v)}\right], x = \ln(v), k = a, c = \exp\left(\frac{-b}{a}\right)$

By taking the logarithms xi=ln (v) and yi=ln [-ln (1-pi)], we obtain after a line $y = ax + b$whose coefficients are adjusted by linear regression. And we will have the parameters c and k, k= a and c=exp (-b/a).

3.2.2 Standard deviation method

The standard deviation method can be used for the K and C parameters determination based on the standard deviation calculation of the wind speeds variation and their average. According to this method [12], we have: The average wind speed can be expressed as:

$$\bar{v} = \int_0^\infty v f(v)dv = \int_0^\infty \frac{vk}{c}\left[\left(\frac{v}{c}\right)^{k-1}\right]\exp\left[-\left(\frac{v}{c}\right)^k\right]dv \tag{6}$$

$$x = \left(\frac{v}{c}\right)^k, x^{\frac{1}{k}} = \frac{v}{c}, dx = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1}dv$$

Equation (6) can be simplified as:

$$\bar{v} = c\int_0^\infty x^{\frac{1}{k}}\exp(-x)dx \tag{7}$$

By substituting a Gamma Function: $\Gamma(n) = \int_0^\infty e^{-x}x^{n-1}dx$

Into (7) and let $y = 1 + \frac{1}{k}$ then we have:

$$\bar{v} = c\Gamma\left(1+\frac{1}{k}\right) \tag{8}$$

The standard deviation of wind speed v is given by

$$\sigma = \sqrt{\int_0^\infty (v-\bar{v})^2 f(v)dv}$$

$$\sigma = \sqrt{\int_0^\infty (v^2 - 2v\bar{v} + \bar{v}^2) f(v)dv} \tag{9}$$

$$= \sqrt{\int_0^\infty v^2 f(v)dv - 2\bar{v}\int_0^\infty v f(v)dv + \bar{v}^2}$$

$$= \sqrt{\int_0^\infty v^2 f(v)dv - 2\bar{v}.\bar{v} + \bar{v}^2} \tag{10}$$

Using:

$$\int_0^\infty v^2 f(v)dv = \int_0^\infty v^2 \frac{k}{c}\left(\frac{v}{c}\right)^{k-1}dv = \int_0^\infty c^2 x^{\frac{2}{k}} \frac{k}{c}\left(\frac{v}{c}\right)^{k-1}dv = \int_0^\infty c^2 x^k \exp(-x)dx \tag{11}$$

Put $y = 1 + \frac{2}{k}$, then the following equation can be obtained:

$$\int_0^\infty v^2 f(v)dv = c^2\Gamma\left(1+\frac{2}{k}\right) \tag{12}$$

Hence, we get:

$$\sigma = \left[c^2\Gamma\left(1+\frac{2}{k}\right) - c^2\Gamma^2\left(1+\frac{1}{k}\right)\right]^{\frac{1}{2}} = c\sqrt{\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)}$$

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$$(\frac{\sigma}{\bar{v}})^2 = \frac{\Gamma(1+\frac{2}{k})}{\Gamma^2(1+\frac{1}{k})} - 1 \quad (13)$$

$$k = \left[\frac{0.9874}{\frac{\sigma}{\bar{v}}}\right]^{1.0983} \quad (14)$$

$$k = (\frac{\sigma}{\bar{v}})^{-1.086} \quad (15)$$

3.2.3 Mabchour's method

Mabchour's method (MMab). The proposed method by Mabchour (1999), was selected in the Assessment of wind energy potential k and c as [13]:

$$k = 1 + (0.483 * (\bar{v} - 2))^{0.51} \quad (16)$$

$$\bar{v} = c\Gamma(1+\frac{1}{k}) \quad (17)$$

4 Sizing techniques

4.1 Wind power turbine

$$p_i = \frac{1}{2} \times \rho \times s \times v_i^3 \quad (18)$$

ρ stands for the density of the air (kg/m3), v is the average wind speed in (m/s) and s the wind collector surface (m2). With i: class of wind speed [5, 7, 9]

4.2 Wind turbine energy

$$E = p_i(v_i) \times t_i \quad (19)$$

Where: E is the energy produced in kWh, ti is the time period pi (vi) is the power in kW given by the wind turbine generator at speedvi .with i: class of wind speed

5 Presentation of results

We processed and analysed the data of station in Laayoune of 369 days for an assessment of the wind potential using the menu under "Annual Review". We found the frequency distribution of wind speed as follows [8, 9, and 13].

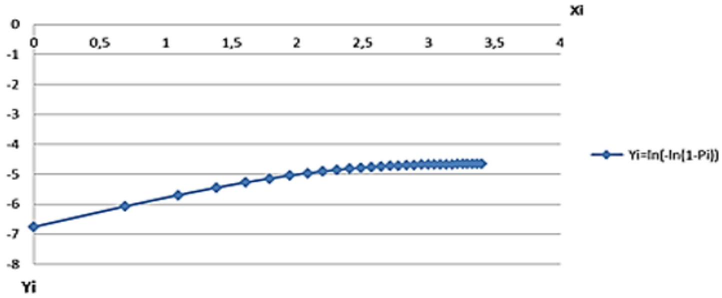
5.1 Least squares method Result

Least squares method can be used to determine the parameters k, c by numerical of the equations (4, 5).

Weibull parameters for the Laayoune site by the least squares method :(k = 2.95 and c = 6.93).

Table 2. Plot of the least squares line of Laayoune site and calculations by the Excel sheet.

Vi	Frequency	Frequency/100	cummulative frequency	Xi=Ln(Vi)	Yi=ln(-ln(1-Pi))
1	0,116	0,00116	0,00116	0	-6,75875
2	0,114	0,00114	0,0023	0,693147181	-6,07369
3	0,105	0,00105	0,00335	1,098612289	-5,6971
4	0,094	0,00094	0,00429	1,386294361	-5,44931
5	0,082	0,00082	0,00511	1,609437912	-5,27399
6	0,071	0,00071	0,00582	1,791759469	-5,14353
7	0,061	0,00061	0,00643	1,945910149	-5,04355
8	0,052	0,00052	0,00695	2,079441542	-4,96552
9	0,044	0,00044	0,00739	2,197224577	-4,9039
10	0,037	0,00037	0,00776	2,302585093	-4,85488
11	0,031	0,00031	0,00807	2,397895273	-4,81555
12	0,026	0,00026	0,00833	2,48490665	-4,78371
13	0,022	0,00022	0,00855	2,564949357	-4,75753
14	0,018	0,00018	0,00873	2,63905733	-4,73680
15	0,015	0,00015	0,00888	2,708050201	-4,71949
16	0,012	0,00012	0,009	2,772588722	-4,70601
17	0,01	0,0001	0,0091	2,833213344	-4,69491
18	0,008	0,00008	0,00918	2,890371758	-4,68612
19	0,007	0,00007	0,00925	2,944438979	-4,67848
20	0,005	0,00005	0,0093	2,995732274	-4,67307
21	0,004	0,00004	0,00934	3,044522438	-4,66876
22	0,004	0,00004	0,00938	3,091042453	-4,66446
23	0,003	0,00003	0,00941	3,135494216	-4,66125
24	0,002	0,00002	0,00943	3,17805383	-4,65912
25	0,002	0,00002	0,00945	3,218875825	-4,65699
26	0,001	0,00001	0,00946	3,258096538	-4,65593
27	0,001	0,00001	0,00947	3,295836866	-4,65487
28	0,001	0,00001	0,00948	3,33220451	-4,65381
29	0,001	0,00001	0,00949	3,36729583	-4,65275
30	0,001	0,00001	0,0095	3,401197382	-4,6516



5.2 Standard deviation method Result

Standard deviation method used to determine the parameters k, c by numerical of the equations (14, 15).

Table 3. Calculation of the Weibull parameters using the standard deviation method for the Laayoune site.

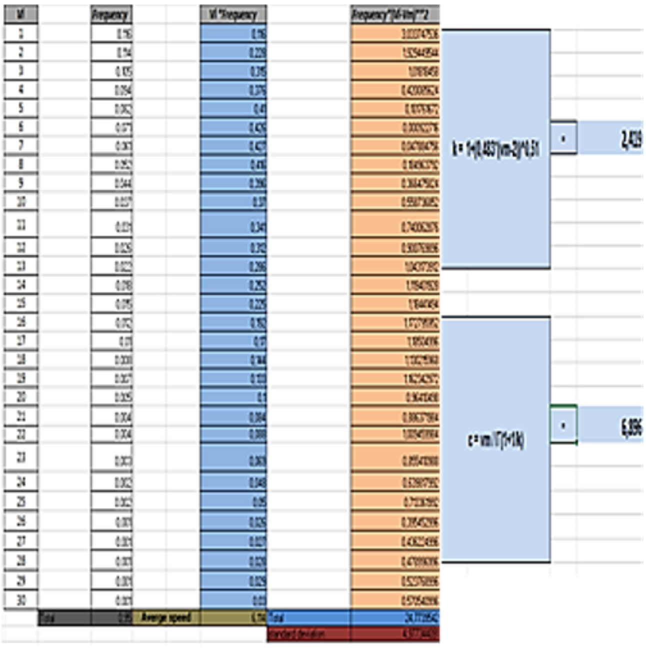
Vi	Frequency	Vi*Frequency	Frequency*(Vi-Vm)**2			
1	0,116	0,116	2,83374536	$k = (\sigma/vm)^{1.086}$	=	2.9
2	0,114	0,228	1,52944544			
3	0,105	0,315	1,1781458			
4	0,094	0,376	0,43085624			
5	0,082	0,41	0,01176672			
6	0,071	0,426	1,10082276			
7	0,061	0,427	0,84784756			
8	0,052	0,416	1,16496792			
9	0,044	0,396	0,36647824			
10	0,037	0,37	0,55873652			
11	0,031	0,341	0,74086376			
12	0,026	0,312	0,90076896			
13	0,022	0,286	1,04317312			
14	0,018	0,252	1,15940928			
15	0,015	0,225	1,18441494			
16	0,012	0,192	1,02795952			
17	0,01	0,17	1,18504896			
18	0,008	0,144	1,10021568			
19	0,007	0,133	1,62342872			
20	0,005	0,1	0,96410498			
21	0,004	0,084	1,18637884			
22	0,004	0,088	1,03458884	$c = vm / \Gamma(1+1/k)$	=	6,86
23	0,003	0,069	1,35541088			
24	0,002	0,048	1,52967932			
25	0,002	0,05	0,71336892			
26	0,001	0,026	0,38545296			
27	0,001	0,027	0,43622496			
28	0,001	0,028	0,47896896			
29	0,001	0,029	0,52376896			
30	0,001	0,03	0,57054896			
Total	1,55	Average speed 6,74	Total 24,7738542			
			standard deviation 4,97734429			

Weibull parameters for the Laayoune site by the least squares method :($k = 2.9$ *and* $c = 6.86$).

5.3 Mabchour's method

Mabchour's method can be used to determine the parameters K, C by numerical of the equations (16, 17).

Table 4. Calculation of the Weibull parameters using the Mabchour's method for the Laayoune.



Weibull parameters for the Laayoune site by Standard deviation method (k = 2.419 *and* $c = 6.89$).

5.4 Wind potential of the of Laayoune

Wind potential of Laayoune site of 369 days for an assessment of the wind potential using the menu under "Annual Review".

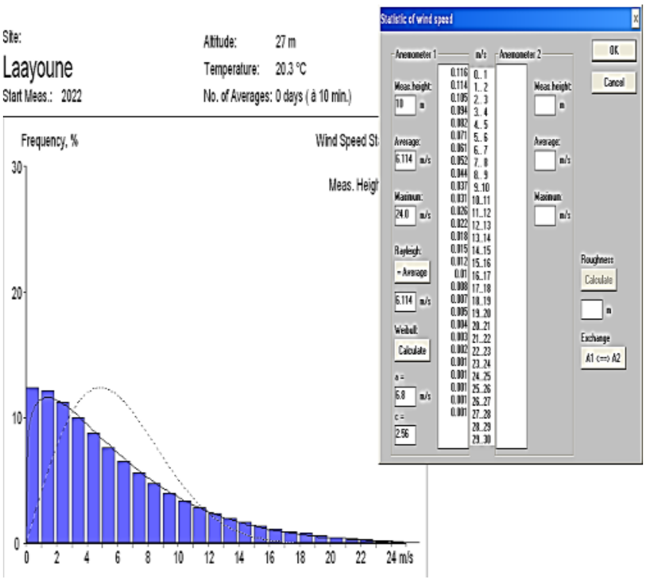


Fig. 1. Wind potential of the site of Laayoune.

The annual balance of the wind speed frequency distribution gives the following information:

- The average speed of the site is 6.114 m/s.
- The maximum speed of the site is 24.0 m/s.
- The predominant speeds at the site vary between 3 m/s and 10 m/s.

Weibull parameters for the Laayoune site by ALWIN (k=6.8 and c=2.56)

We consider k and c obtained by ALWIN as reference parameters, we can see that the Weibull parameters K and C calculated by the Mabchour's method.

6 Calculation of the energy production of the 50 MW Laayoune park

6.1 Calculation of energy production using HOMER

For the estimation of the energy production of the 50MW Laayoune park. The three average wind turbines: WES 18-100KW, XANT M-21 100KW and Northem Power NPS 21-100KW were selected using HOMER software.

Fig. 2. The results by HOMER of WES 18 - 100KW.

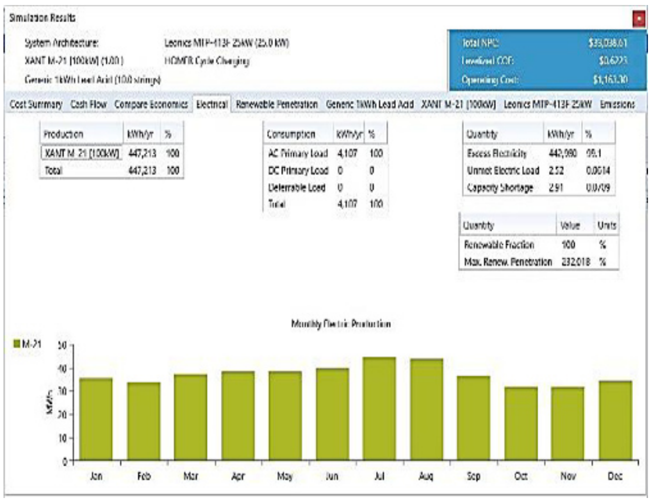


Fig. 3. The results by HOMER of XANT M-21 100KW.

Fig. 4. The results by HOMER of Northem Power NPS 21-100KW

The main characteristics of these wind turbines are presented in the table below.

Table 5. Principal characteristics of the wind turbines

characteristics	WES 18	XANT M-21	NPS 21
Hub Height (m)	30	31.8	29
Nominal power KW	100	100	100
Rotor diameter	18	21	21
Number of blades	2	3	3
Rotor surface m^2	255	347	347

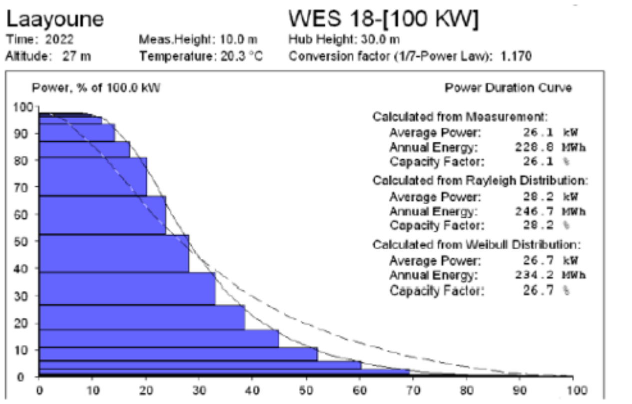
From the figures (2, 3 and 4) we can say that turbine XANT M-21 100KW has a good Monthly Electric Production.

6.2 Calculation of the production by Excel

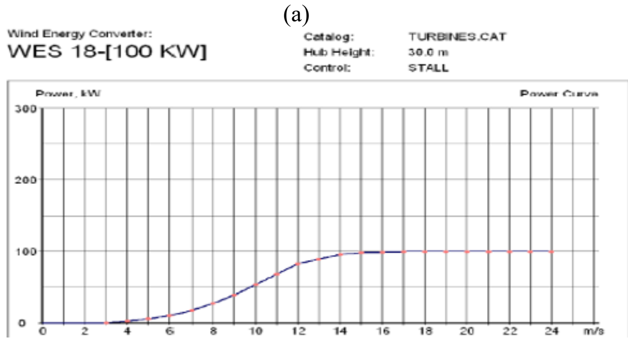
The tables 6, 7 and 8 represent the annual production for the XANT M-21 100KW turbine calculated by Excel.
We can see that: The annual production measured by method 1 is: 441.39 MWh.
The annual production by method 2 is: 449.96 MWh.
The annual production by method 3 is: 436.57 MWh.
It can be seen that the annual production by method 3
Is almost identical with the measured annual production.

6.3 Calculation of the production by ALWIN

The graph below represents the annual production for the WES 18 - 100KW turbine calculated by ALWIN.
The choice of WES 18 - 100KW with a nominal power of 100KW allows the production of 288.8 MWh (From Measurement) or, 246.7 MWh (from Rayleigh) and 234.2 MWh (From Weibull) annually by each wind generator. Knowing that the power of the installed park is 50MW, 500 wind turbines are needed.



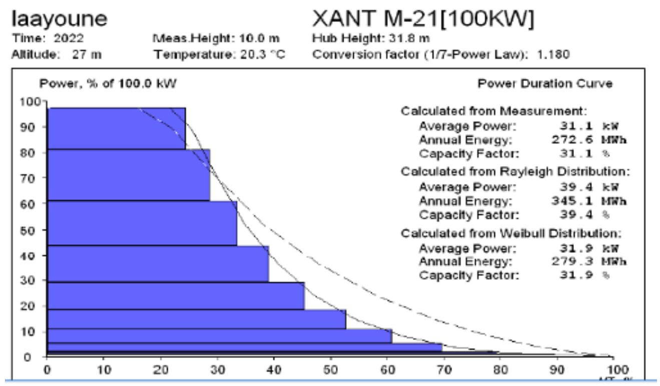
(a)



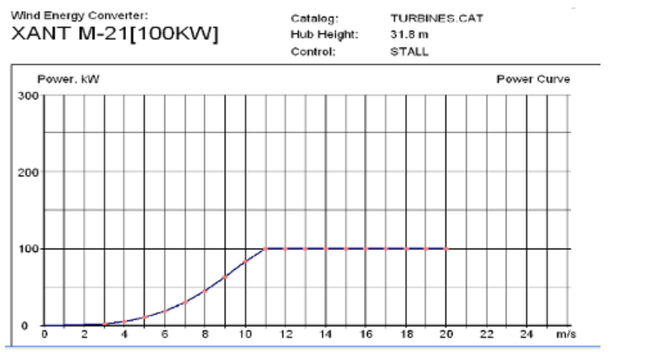
(b)

Fig. 5. (a) and (b) Annual production for the turbine WES 18-100KW calculated by ALWIN.

The annual energy of the park is therefore:
500x288.8=144.400GWh (from Measurement)
500x246.7=123.350GWh (Rayleigh)
500x234.2=117.100GWh (Weibull).
The graph below represents the annual production for the XANT M-21 100KW turbine calculated by ALWIN.



(a)



(b)

Fig. 6. (a) and (b) Annual production for the XANT M-21 turbine [100KW] calculated by ALWIN.

The choice of XANT M-21 [100KW] with a nominal power of 100KW allows the production of 272.6MWh (From Measurement) or 345.1MWh (from Rayleigh)
And annually and 279.3 MWh (From Weibull) by each wind generator. Knowing that the power of the installed park is 50MW, 500 wind turbines are needed. The annual energy of the park is therefore: 272.6x500=136GWh (From Measurement) or, 500x345, 1=172.550 GWh (Rayleigh) and 500x279, 3=139.650GWh (Weibull).
The graph below represents the annual production for the Northem Power NPS 21-100KW turbine calculated by ALWIN.

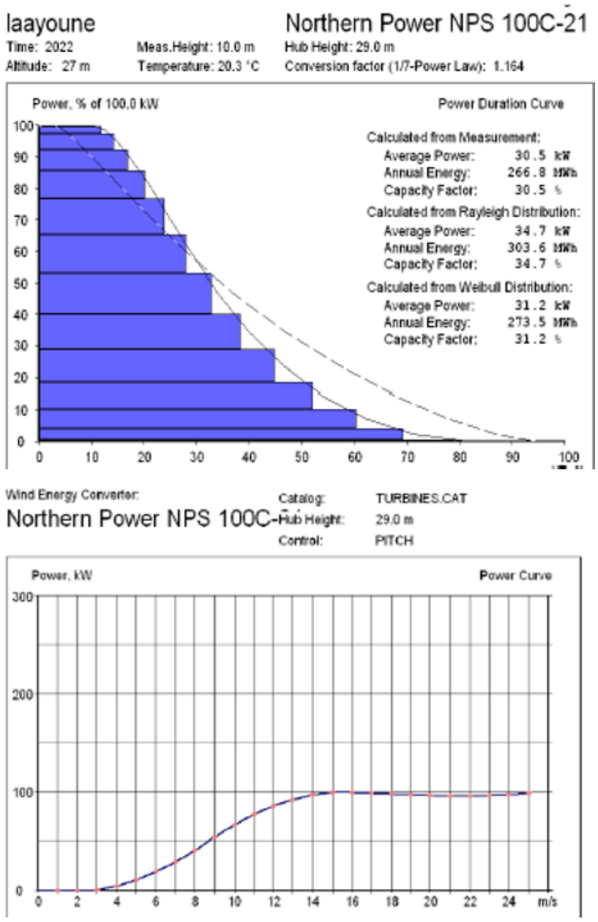


Fig. 7. Annual production for the Northem Power NPS 21-100KW calculated by ALWIN.

The choice of Northem Power NPS with a nominal power of 100KW allows the production of 266.8MWh (From Measurement) or 303.6MWh (from Rayleigh)

And annually and 273.5 MWh (From Weibull) by each wind generator. Knowing that the power of the installed park is 50MW, 500 wind turbines are needed. The annual energy of the park is therefore: 266.8x500=133.400GWh (From Measurement) or,

500x303.6=151.800GWh (Rayleigh) and 500x273.5=136.750GWh (Weibull).

For the other medium-sized wind turbines: WES 18-100KW and Northem Power NPS 21-100KW it is the same principle. So we obtain the following results:

Table 9. Annual production of a single wind turbine for each technology.

Production annual	Methods	WES- 18 [100K W]	XANT M- 21 100K W	Northem Power NPS 21-100K
Production annual MWh Excel	Method 1	293.24	441.39	213.92
	Method 2	298.68	449.96	218.36
	Method 3	299.85	436.57	223.11
Production annual MWh ALWIN	Measurement	228.3	272.6	266.8
	Rayleigh Distribution	246.7	345.1	303.6
	Weibull Distribution	233.5	279.3	273.5

It can be seen that the annual production by Method 3 is almost identical with the measures annual production.

7 Calculation of the cost per KWh produced by each technology

According to figures 5, 6 and 7 estimated with the help of HOMER software we find:

Table 10. Result by HOMER.

Turbine	Total NPC	Levelized cost	Operating COE
WES 18-100KW	$107,037.00	$2.01	$2,864.97
XANT M-21 100KW	$33,038.61	$0.6223	$1.163.30
Northem Power NPS21-100KW	$48,993.05	$0.9226	$2,060.47

Total NPC: total net present cost of a system is the present value of all the costs the system
Levelized cost: HOMER defines the levelized cost of energy.

$$COE = \frac{C_{ann,tot} - C_{boiler} H_{served}}{E_{served}} \tag{20}$$

$C_{ann,ot}$=$total\ annualized\ cost\ of\ the\ system$ [\$/yr]
C_{boiler} = $boiler\ marginal\ cost$ [\$/kWh]
H_{served}= $total\ thermal\ load\ served$ [kWh]
E_{served}= $total\ electrical\ load\ served$ [Kwh]

Operating cost: The operating cost is the annualized value of all costs and revenues other than initial capital costs. HOMER uses the following equation to calculate the operating cost

$$C_{operating} = C_{ann,tot} - C_{ann,cap} \tag{21}$$

$C_{ann,ot}$ = $the\ total\ annualized\ cost$ [\$/yr]
$C_{ann,cap}$ =The total annualized capital cost [\$/yr]

From Homer's results we can observe that the XANT M-21 100KW wind turbine has the lowest cost.

Table 6. Annual production for the XANT M-21100KW turbine by method 1 calculated by Excel.

Méthode 1 XANT M-21 [100KW]					
Vi	frequence	freq/Somme	nbr h	Puissance (kW)	Energie (kWh)
1	0,010849934	0,010850333	95,04891415	2	190,0978283
2	0,0395222	0,039523652	346,227189	5,6	1938,872259
3	0,080192545	0,080195491	702,5124995	11	7727,637495
4	0,123055917	0,123060438	1078,009438	19	20482,17931
5	0,155431119	0,15543683	1361,626629	30,1	40984,96152
6	0,166359266	0,166365378	1457,360711	45	65581,23202
7	0,152140675	0,152146264	1332,801275	62,6	83433,3598
8	0,118755785	0,118760148	1040,338896	83,1	86452,16229
9	0,078646786	0,078649676	688,9711603	100	68897,11603
10	0,043806374	0,043807983	383,7579333	100	38375,79333
11	0,020310596	0,020311342	177,9273555	100	17792,73555
12	0,007749761	0,007750046	67,89040368	100	6789,040368
13	0,00240434	0,002404428	21,06279289	100	2106,279289
14	0,000598984	0,000599006	5,247292965	100	524,7292965
15	0,000118301	0,000118305	1,036353132	100	103,6353132
16	1,82839E-05	1,82845E-05	0,160172508	100	16,01725076
17	2,18249E-06	2,18257E-06	0,019119324	100	1,911932423
18	1,98564E-07	1,98571E-07	0,001739482	100	0,173948174
19	1,35876E-08	1,35881E-08	0,000119032	0	0
20	6,90091E-10	6,90116E-10	6,04542E-06	0	0
21	2,56684E-11	2,56694E-11	2,24864E-07	0	0
22	6,8998E-13	6,90005E-13	6,04445E-09	0	0
23	1,32261E-14	1,32266E-14	1,15865E-10	0	0
24	1,78406E-16	1,78412E-16	1,56289E-12	0	0
25	1,67107E-18	1,67113E-18	1,46391E-14	0	0
26	1,07258E-20	1,07262E-20	9,39612E-17	0	0
27	4,65542E-23	4,6556E-23	4,0783E-19	0	0
28	1,34849E-25	1,34854E-25	1,18132E-21	0	0
29	2,57257E-28	2,57267E-28	2,25365E-24	0	0
30	3,19009E-31	3,19021E-31	2,79462E-27	0	0
	0,999963262				441397,9348

Table 7. Annual production for the XANT M-21 100KW turbine by method 2 calculated by Excel

Method XANT M-21 [100KW]					
Vi	frequency	freq/Sum	nbr h	Power (kW)	Energy (kWh)
1	0,008987039	0,008987038	78,72645361	2	157,4529072
2	0,03519996	0,035199956	308,3516129	5,6	1726,769032
3	0,074805092	0,074805084	655,2925363	11	7208,217899
4	0,118994398	0,118994385	1042,390812	19	19805,42542
5	0,154791208	0,154791191	1355,970835	30,1	40814,72214
6	0,169574625	0,169574606	1485,473552	45	66846,30984
7	0,157590244	0,157590227	1380,490392	62,6	86418,69853
8	0,123874347	0,123874333	1085,139161	83,1	90175,06426
9	0,081680486	0,081680477	715,5209796	100	71552,09796
10	0,044668296	0,044668291	391,2942328	100	39129,42328
11	0,019991967	0,019991965	175,1296102	100	17512,96102
12	0,007217363	0,007217362	63,22409246	100	6322,409246
13	0,002069637	0,002069637	18,13002162	100	1813,002162
14	0,00046395	0,00046395	4,064201813	100	406,4201813
15	7,99819E-05	7,99819E-05	0,70064145	100	70,06414503
16	1,0428E-05	1,0428E-05	0,091349126	100	9,134912551
17	1,01097E-06	1,01097E-06	0,008856066	100	0,88560664
18	7,16408E-08	7,16408E-08	0,000627573	100	0,062757345
19	3,64727E-09	3,64727E-09	3,19501E-05	0	0
20	1,311E-10	1,311E-10	1,14844E-06	0	0
21	3,26946E-12	3,26946E-12	2,86405E-08	0	0
22	5,55848E-14	5,55848E-14	4,86922E-10	0	0
23	6,32979E-16	6,32979E-16	5,54489E-12	0	0
24	4,74351E-18	4,74351E-18	4,15532E-14	0	0
25	2,29823E-20	2,29823E-20	2,01325E-16	0	0
26	7,07223E-23	7,07223E-23	6,19527E-19	0	0
27	1,35789E-25	1,35789E-25	1,18952E-21	0	0
28	1,59803E-28	1,59803E-28	1,39988E-24	0	0
29	1,13232E-31	1,13232E-31	9,91916E-28	0	0
30	4,74532E-35	4,74532E-35	4,1569E-31	0	0
	1,000000107				449969,1213

Table 8. Annual production for the XANT M-21 100KW turbine by method 3 calculated by Excel

Method 3 XANT M-21 100KW					
Vi	frequency	freq/Sum	nbr h	Power (kW)	Energy (kWh)
1	0,022438956	0,022455283	196,7082778	2	393,4165556
2	0,057608052	0,057649969	505,0137246	5,6	2828,076858
3	0,094213123	0,094281675	825,9074695	11	9084,982164
4	0,123904371	0,123994526	1086,192051	19	20637,64897
5	0,140400733	0,140502891	1230,805325	30,1	37047,24027
6	0,140967915	0,141070486	1235,777455	45	55609,98548
7	0,127044298	0,127136738	1113,717823	62,6	69718,73571
8	0,10340729	0,103482531	906,5069687	83,1	75330,7291
9	0,076224089	0,076279551	668,2088659	100	66820,88659
10	0,050925881	0,050962936	446,4353203	100	44643,53203
11	0,030829661	0,030852093	270,2643331	100	27026,43331
12	0,016895411	0,016907704	148,1114887	100	14811,14887
13	0,008370318	0,008376409	73,37734121	100	7337,734121
14	0,003742626	0,003745349	32,80925873	100	3280,925873
15	0,001507604	0,001508701	13,21621724	100	1321,621724
16	0,000546065	0,000546462	4,787005807	100	478,7005807
17	0,000177496	0,000177626	1,555999613	100	155,5999613
18	5,16716E-05	5,17092E-05	0,452972495	100	45,29724952
19	1,34448E-05	1,34545E-05	0,117861757	0	0
20	3,12043E-06	3,1227E-06	0,027354849	0	0
21	6,44706E-07	6,45175E-07	0,00565173	0	0
22	1,18339E-07	1,18425E-07	0,0010374	0	0
23	1,92597E-08	1,92737E-08	0,000168837	0	0
24	2,77383E-09	2,77585E-09	2,43164E-05	0	0
25	3,52841E-10	3,53098E-10	3,09314E-06	0	0
26	3,95658E-11	3,95946E-11	3,46849E-07	0	0
27	3,90378E-12	3,90662E-12	3,4222E-08	0	0
28	3,38275E-13	3,38521E-13	2,96544E-09	0	0
29	2,56968E-14	2,57155E-14	2,25268E-10	0	0
30	1,70818E-15	1,70942E-15	1,49745E-11	0	0
	0,99927291				436572,6954

8 Conclusion

This project presents a study relating estimation of the wind potential on the site of Laayoune and on the other hand the estimation of the annual energy production. The analysis of the results shows that the site of Laayoune has a significant wind potential and is more favourable to the exploitation of this type of energy for electricity production. To install a 50MW wind farm in Laayoune, we can use on the one hand medium wind turbines: 500 turbines type WES-18 [100KW] whose annual production of the wind farm is about 117.10GWh (according to the results of Weibull ALWIN). Then we can install 500 XANT M-21 100KW turbines with an annual production of 139.65GMWh, and finally we can choose 500 Northem Power NPS 21-100K turbines with an annual production of 136.7GWh.

The choice of the installed technology is based on the costs of the technology. Therefore, it is necessary to choose a technology that gives a higher annual production but with a low cost.
According to the results obtained by the different methods, we can conclude that the annual energy production obtained by the XANT M-21 100KW turbine is generally good compared to the other turbines.

In addition to that, the electrical production of the XANT is superior with a very low total cost. Therefore, for the Laayoune site, the XANT M-21-100KW turbine is the most efficient, the most profitable and the best suited to the climatic variables of the site.

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