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Technical and Economic Feasibility Study of Wind Farm in Aoulef Region, Adrar

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***Abstract*—This paper investigates the economic feasibility of predicted wind energy generation from 40.04 MW hypothetical wind farm at Aoulef region –Algeria. The fact that the first wind map of Algeria shows that this region is one of the windiest in country, three (03) sites were analyzed in this study; they were selected, two of them are close to the grid connection system. The results show that the wind farm consisting of 13 wind turbines of 3.08 MW rated power each is more feasible for site 2. The gross annual energy production without losses at this site was 87300MWh and the net annual energy production taking into consideration wake loss, availability loss and transmission line losses (about 5%) was found to be 82935MWh with the corresponding levelized cost of energy of 8.46 DA/kWh.**

***Keywords*— Aoulef, Economics, Levelized cost of energy, Windfarm. Geographical Information System, optimization, WindFarmer software.**

I. INTRODUCTION

Wind energy becomes today a promising option to complement the conventional energy source, especially in region where the existing power plants are not sufficient to match the increasing electricity demand. This success is principally due the rapid growth of the wind technology, which led the wind power to be more competitive by reducing the cost of electricity produced. This prompted the Algerian government to adopt a new energy policy by promoting and to supporting the development of this clean energy. An important result of this policy is the government intention to construct a wind farm in the southwest desert of Algeria. The choice of this region was justified by the existing of vast inhabited areas which are required for a large scale development of the wind energy, and also the fact that the first wind map of Algeria show that this region is one of the windiest in country [1,2].The Algerian wind map, related to measured data at 10 m above ground level, established by Kasbadji Merzouk, in 2006 [2] shows that a maximum of mean wind speed is reached in a South – West (Adrar region) of a country with a value of 6.5 m/s, (see Fig. 1). Within this context, some micro-climate studies have been established [4-5]. A first study done to identify a suitable site in Adrar region has been by Sebaa Ben Miloud F et al. in 2010, [6]. The authors did not consider the wind speed data inferior to 3 m/s and it is well known that this class of wind speed influences greatly the performance of the wind farm production.

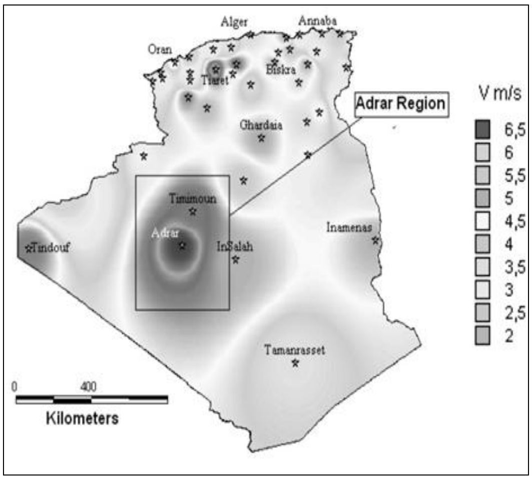

Fig. 1 Yearly mean wind speed map of Algeria [2]

Djamai et al. [3], have used GIS tools for wind resource mapping in order to evaluate and to determine the most suitable site for sitting a wind farm project. They presented the energy output of 10MW installed capacity wind farm in the south of the country, Adrar region in terms of gross annual energy production and net annual energy production using wind turbines of 2 MW. The wind resource mapping of a global region at a height of 80 meters is performed by WASP software with a resolution of 300 meters and for the entire area of interest as given in Fig. 2.

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It can see that the wind speed in the region vary between 8.75m/s to 9.28m/s, [3].

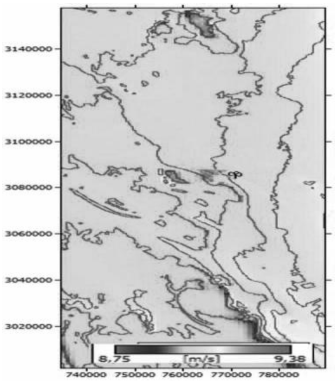

Fig. 2 Wind speed map at a height of 80m [3].

In the present study the feasibility of harnessing wind energy in the southeast Adrar region, Aoulef, was analyzed. Three (03) selected sites were identified and a preliminary analysis done regarding estimated annual energy production AEP, the technical installation of a wind farm including grid connection was discussed, and finally an economical analysis of the best site was performed. In order to select the eligible areas for wind farm sitting, an impact study was carried out.

II. Description of the Region

In Figure 3 is given the study area, located in the wilaya of Adrar and whose geographical coordinates are Longitude: between 1.7°W-3.37°E Latitude and between 25.5° N-30° N.

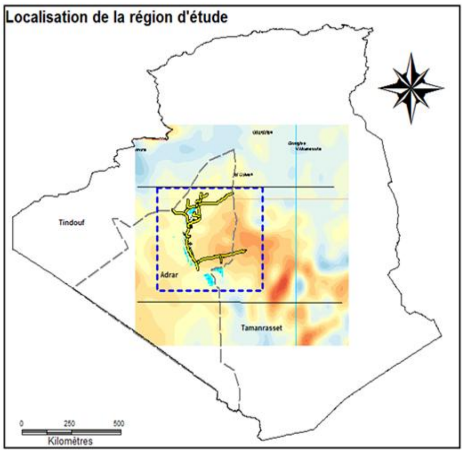

Fig. 3 Studied area

It was considered more efficient to remove constraints and establish feasibility studies on the favorable areas, presenting no problems related to the sites. By using GIS (Geographical Information System) tools, digital maps of energy and transportation infrastructures, natural, agricultural and urban areas, were superimposed on maps of the wind speed at 50 meters [7]. This has identified four (04) areas suitable for wind farms; the most interesting was that of Aoulef region (yellow in Fig. 4), three (03) sites are selected within the 20-40 km radius to the east of Aoulef, and where the wind speed exceeds 7 m/s.

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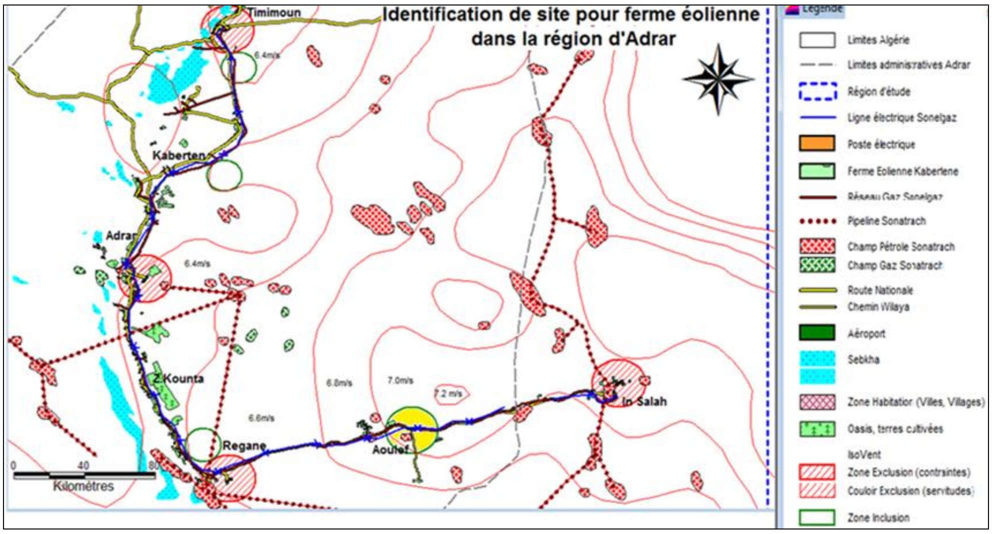


Fig. 4 Selected zone suitable for the wind farm [16].

III. Wind Resources

A. Wind Energy Estimation

Based on wind data (speeds and directions) obtained from the ONM station located at the airport of In-Salah (27° 12'N, 02° 28' E), the Wind Resources at 10m height, was studied using the Wasp software Tools. The wind rose (see Fig. 5) indicates that the best direction of wind is northeast.

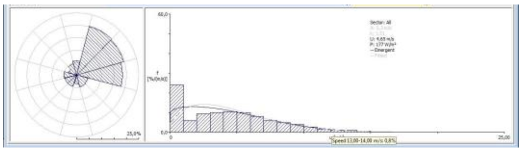


Fig. 5 Wind rose and histogram of speeds at In-Salah Station [16].

The digital terrain model was established using two (02) boards, downloaded from topographical data generated by Shuttle Radar Topography Mission of NASA (SRTM) in

	In-Salah station	Aoulef Area
Shape factor,k	1.51	1.51
Scale factor, C, m/s	5.3	8.6
Average speed, U, m/s	4.65	7.78
P, W/m^2	177	774

2000), [16].

Using Global Mapper software, the file contours with an interval of 10m was generated. The file is shown in Fig. 6, where we notice a small change in altitude from 250 to 400m.

The regional wind atlas covering the entire region was developed taking into account the topography, roughness and obstacles. Then a 'Resource Grid' was generated (.WRG File) in order to be used for calculations and optimization under WindFarmer software.

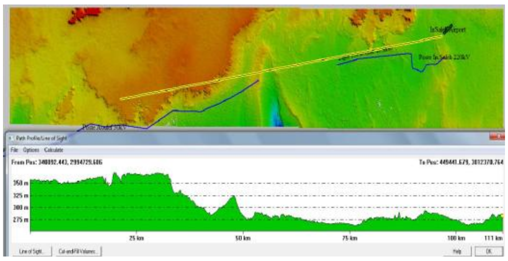


Fig. 6 Digital terrain model of the study area [16].

The Weibull parameters obtained after horizontally extrapolation, from In-Salah to Aoulef region (100km far) and vertically from 10m to 80m height, are presented in Table 1.

TABLE 1

Weibull Parameters Obtained after Extrapolation, Horizontally from In-Salah to Aoulef Region, [16]

B. Selection of Wind Turbines (AEP Simulation)

By consulting WTG library available under Wasp, four turbines with a rated power ranging between 2.5 and 3 MW were chosen and tested (Nordex N90-2500 LS, Power Wind

90-2500, Vestas 90-3.0MW VCS and Vestas V112-3.0MW, [16].

By simulating the Annual Energy Power of each in the site1 of Aoulef (taken as reference), the V112-3.0MW was selected. The calculation of the Capacity Factor (CF) for four (04) machines has shown that V112 -3.0 MW has the highest CF (26%) compared to the other ranging from 19% and 23%. Characteristics of Wind Turbines are given in Table 2.

TABLE 2

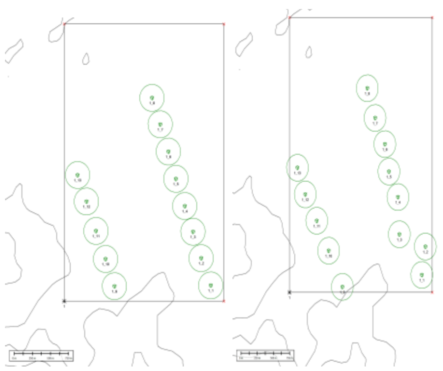
CHARACTERISTICS OF PRESELECTED WIND TURBINE

Description	
Wind turbine type	W112-3.0MW
Nominal Power, MW	3.0
Diameter, m	112
Turbine height, m	84
Cut-in speed, m/s	3.0
Cut off speed, m/s	25.0

C. Optimization of Wind Farm by WTG Best Position

Using WindFarmer, [16], file lines level wind speed of the study area is loaded. WindFarmer allows, first, test of the legality of the wind farm by checking that the slope is not too great, the wind turbines are not too close to each other and the limits of noise are not exceeded.

Second, WindFarmer used for optimization, stochastic optimization model to maximize energy production of the wind farm while respecting the constraints of engineering, hearing and vision already determined. The wake model (Park Modified) recommended by the program has been selected; it is designed to better reflect the influence of a wind turbine or a row of wind turbines or following rows. The optimization (see Fig. 7), taking into account the wake effect, allowed a 0.2% increase in energy (after 146 iterations).



a) Before b) After

Fig. 7 Position of WTG (before and after optimization with Windfarmer).

To detect the most advantageous site in terms of cost and performance, a wind farm with a nominal capacity of 40 MW has been installed on three separate sites in the Aoulef region, where the distance from 30kV transmission Aoulef post is respectively 13 km north east, 05 km north-east and 0.5 km north West. The turbines were installed on the same altitude on an area (08) km². Figure 8 show position of the selected sites.

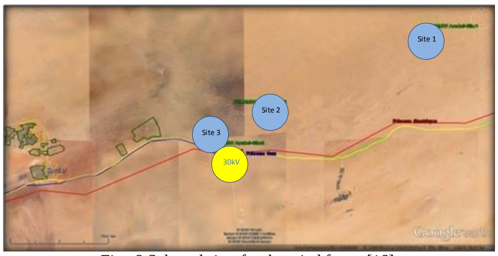


Fig. 8 Selected sites for the wind farms [16].

The availability of wind turbines is described as the time that the wind turbine is available for energy production, so the availability of the wind farm at the selected sites is set fixed at 95%, this is explained by mandatory downtime due to unexpected malfunction and maintenance (5% availability losses). However, the net annual energy production AEP must be calculated after deducting all the losses that occur during the production and transportation phases of the electricity generated. The AEP estimated for the three (03) sites is shown in table 3. Comparing the net annual energy production, it is clear that the site1 is the best site with 88 GWh /year

TABLE 3

AEP OPTIMIZATION RESULTS FOR THE THREE (03) SITES

	Capacity Factor, %	Weak Effect, %	Net AEP, GWh	Optimization %
Site 1	25.0	95.10	88.0	1.9
Site 2	24.8	94.10	87.3	0.2
Site 3	24.2	93.80	85.2	0.3

IV. ECONOMIC ANALYSIS OF WIND ENERGY

The levelized cost of energy for wind power is dependent on the wind resource at each site and the wind project. The source data such as investment cost CAPEX, Operation and Maintenance cost, wake loss, availability loss and transmission line losses, discount rate and grid connection cost have been identified based on literature from report, publications and documents[8]. The estimated values are represented below in table 4. The operation and maintenance cost OPEX account for 3% of total investment cost [8]. The key finding in the reports showed that the investment cost of onshore wind farm is about 1300 € / kW installed capacity.

The economic feasibility study is performed in terms of the Internal Rate of Return (IRR) and Net Present Value (NPV). They are the key evaluation methods used to choose the suitable sites. So the analysis of the selected sites will consist in ranking them depending on different parameters such as IRR, NPV and LCOE.

TABLE 4
ASSUMED ECONOMICAL PARAMETERS GIVEN BY THE LITERATURE,[8]

Item	Value	References
Investment cost CAPEX	150MDA*	[9-10-11]
O&M cost (OPEX)	2%	[12,13]
Economic Lifetime	20 years	According to the practice in the wind
Wake loss, availability and transmission line losses	5%	According to the practice in the wind energy industry
Discount rate	8%	According to the practice in the implementation
Grid connection cost	11 MDA/km	[14]

*1 MDA = 9021 Euros according Rate Exchange June 2015)

A. Levelized Cost of Energy

The levelized cost of energy LCOE is defined as the present value of all costs divided by the present value of all energy produced over the energy project's lifetime. The equation is given as follow [15]:

$$\frac{\sum_{t=1}^{n}\frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{n}\frac{E_t}{(1+r)^t}} \qquad (1)$$

Where n is lifetime of the project in years, r is the discount rate for the project, E_t is the AEP, F_t is the fuel expenditure, M_t is the operation and maintenance cost (OPEX) and I_t is the capital expenditures (CAPEX). All of them are calculating year t.

It is the main metric for comparing the profitability of energy investments. If LCOE is lower than the wholesale price of electricity, profits can be made in a margin.

B. Net Present Value

The net present value NPV of a project can be defined as the difference between the sum of discounted cash inflows and outflow. It is calculated by discounting all cash flows as given in the following formula [15]:

$$\sum_{n=0}^{N}\frac{C_n}{(1+r)^n} \qquad (2)$$

Where : is the after-tax cash flow in year n. Positive values of NPV demonstrates that the project is feasible.

C. Internal Rate Of Return

The internal rate of return IRR is the discount rate that causes the NPV of the project to be 0. It is calculated by solving the following equation for IRR [15]:

$$0 \; \frac{C_n}{(1+IRR)^n} \qquad (3)$$

Where N is the project life in years and C_n is the cash flow for year n. If the internal rate of return of the project is greater than the discount rate (8%) then the project will likely be considered financially acceptable.

V. COST ANALYSIS

The hypothetical wind farm of 40.04 MW installed capacity at Aoulef, if developed, could produce 90 GWh of electricity annually. Assuming that the cost per MW of installed wind power capacity is around 150MDA/MW, so the investment cost (excluding grid connection costs) is approximately 6006 MDA [16].The grid connection cost was estimated separately since; it becomes a big factor of the cost of setup for locations far from the electricity grid. The capital expenditures including grid connection cost for the three sites is resumed in the table 5.

TABLE 5
RELATIONSHIP BETWEEN CAPEX AND GRID CONNECTION COST

	CAPEX excluding grid connection cost, (MDA)	Distance to the grid connection 220 kV (km)	Grid connection cost (MDA)	CAPEX including grid connection cost, (MDA)
Site 1	6006.00	13	143.00	6149.00
Site 2	6006.00	5	55.00	6061.00
Site 3	6006.00	0.5	5.50	6011.50

VI. RESULTS AND DISCUSSION

The LCOE for all the sites namely site1, site 2 and site 3 is shown in table6.Lower value of energy cost of 8.91 DA/kWh is obtained at site 2, while they rise between 8.96-9.05 DA/kWh at two other sites. Although the site 1 giving the highest AEP production of energy and surpasses site 3 which is the best location due to shorter distance to grid [16].The site 2 was chosen for profitability study based on economical aspects.

TABLE 6
SUMMARY OF ANNUAL ENERGY PRODUCTION AND LEVELIZED COST OF ENERGY FROM 40.04 MW

Item	Site 1	Site 2	Site 3
Total rated power (MW)	40.04		
Gross AEP (MWh)	88000	87300	85200
Wake loss, availability loss and transmission line losses (%)	5		
Net AEP (MWh)	83600	82935	80940
Economic Lifetime (year)	20		
Discount rate (%)	8		
Depreciation rate (%)	10.185		
Investment cost-wind farm-(MDA)	6006		
Grid connection cost (MDA)	143	55	5.5
Capital expenditure CAPEX (MDA)	6149	6061	6011.5
Operating and maintenance fees (%)	2		
Operating and maintenance costs (MDA)	122.98	121.22	120.23
Levelized Cost Of Energy LCOE (DA/kWh)	8.96	8.91	9.05

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Rank	2	1	3

The economical calculation, with results presented as NPV and IRR, done by a program created in Excel is shown in tables for different values of discount rate. The study considers two (02) discount rate scenarios and one adjusted AEP scenario. For each scenario, the results are compared as IRR, NPV and LCOE.

A. Scenario 1: discount rate at 8%

The annual energy production net, the sale price, the revenue, the operating and maintenance cost, the net cash flow and investment are listed in table 7. The net present value was found to be negative -83.08 MDA this implies that the project is less profitable while the internal rate of return of 7.78 % was found to be lower than the required rate of 8%. This rate is considered to be satisfactory since the assumptions taken into account at the outset are very severe, so the risk of project is virtually zero.

B. Scenario 2: Discount Rate at 7 %

The scenario 2 is used to demonstrate the profitability of a project, the fact that the economic evaluation is very sensitive to this discount rate. The results of calculation are shown in table 7 where the NPV becomes positive +311.36MDA which is an indicator of potentially feasible project. The IRR remains constant 7.78% while NPV increase (-83.08 to +311.36 MDA) The levelized cost of energy of 8.36 DA/kWh was found to be lower than the wholesale price of electricity of 10.48 DA/kWh.

C. Scenario 2: adjusted of5 %

This scenario is based on adjusted AEP, indeed being consistent with the results of ONM over a period 1981-1985, shows an underestimate of 10% of wind speed, in the strong wind cases, then the AEP increases 5% at site 2.

The calculations were redone with the corrected AEP and the results are given in table 7. It is noticed that the IRR (8.70%) was found to be higher than the required rate of 8%, the NPV was also found to be positive (+265 .92MDA) this means that the project is acceptable and feasible. The LCOE (8.46 DA/kWh) was found to be above the price of electricity in scenario 2 (8.36DA/kWh).

VII. Conclusion

This paper focuses on techno-economic feasibility study of wind farm, in the south east Adrar region Aoulef, which technical aspects of wind energy and the cost of wind-generated electricity were discussed. The study led to identify the best sites for a wind farm in the region taking account of geographical constraints and the wind energy potential.

The technical optimization led to the identification of the best sub-region taking into account the geographical constraints, the energy potential of wind and terrain characteristics.

Three sites were studied and the estimated annual energy production is slightly different, where the highest elevation site (360m) in the sub region Aoulef is the best, however it is the farthest from the power grid (220kV). The investment cost and therefore the cost per kWh are affected by the cost of connecting to the network.

The energy potential also play a key role on the cost per kWh produced. Indeed, despite its distance of five (05) km of the connection point, the Site2 proved more favorable than nearby, namely Site3.

Electricity generation by wind path is interesting in energy and cost, as the investment return will be established over a period of 9 years and a half, and the estimated cost per kWh to 8.91 DA is competitive with other renewable energy sectors, which encourage the development of wind energy in Algeria.

It concludes that the wind farm consisting of 13 wind turbines of 3 MW rated power each is more feasible for site 2. The levelized cost of energy is lowest at site2 with and an expected annual energy production of 82935MWh.

Table 7
The NPV and IRR for different discount rate of 8%, 7% and for adjusted AEP of 5%

Mis en forme : Anglais (États-Unis)

Period year	Production MWh	Sale price (Feed In Tariff) DA/kWh	Revenue MDA	O&M cost MDA	Net Cash Flow MDA	Investment, MDA	Total MDA
NPV and IRR for discount rate of 8%							
0	0			6 061		6 061	- 6 061
1- 5	82 935	10.48	869. 16	121 .22	747. 94	0	747 .94
6 - 20	82 935	7.64	633. 62	121.22	512 .40	0	512 .40
Net Present Value NPV (MDA)							**-83.08**
Internal Rate of Return IRR (%)							**7.78**
NPV and IRR for discount rate of 7%							
0	0			6 061		6 061	- 6 061
1- 5	82 935	10.48	869 .16	121. 22	747. 94	0	747. 94
6 - 20	82 935	7.64	633 .62	121 .22	512 .40	0	512.40
Net Present Value NPV (MDA)							**311.36**
Internal Rate of Return IRR (%)							**7.78**
NPV and IRR for adjusted AEP of 5%							
0	0			6 061		6 061	- 6 061
1- 5	87 300	10.48	914. 90	121.22	793. 68	0	793 .68
6 - 20	87 300	7.64	666 .97	121 .22	545. 75	0	545 .75
Net Present Value NPV (MDA)							**265.92**
Internal Rate of Return IRR (%)							**8.70**

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