



ISSN: 0067-2904

## An Economic Study of a Wind Energy Project Using Different Sources of Wind Data

Firas A. Hadi<sup>\*1</sup>, Samah Shyaa Oudah<sup>2</sup>, Rafa A. Al-Baldawi<sup>3</sup>

<sup>1</sup>Department of Renewable Energy Science, College of Energy and Environmental Sciences, Al-karkh University of Science, Baghdad, Iraq

<sup>2</sup>Green Horizon Organization For Relief and Sustainable Development, Baghdad, Iraq

<sup>3</sup>College of Energy and Environmental Sciences, Al-karkh University of Science, Baghdad, Iraq

Received: 8/4/ 2019

Accepted: 18/ 8/2019

### Abstract

In this study, a preliminary economic feasibility study of the project of wind power at the site of Al-Shehabi (Wasit-Iraq) was conducted using measured wind data at altitudes of 10, 30, 50 and 52 m per 10 minutes. For the purpose of comparison, data from NASA were used at the same location at 50 m height. The lowest unit cost of electricity from wind energy was found to be 0.028 \$/Kwh and 0.0399 \$/Kwh by using the standard methodologies of Levelized Cost of Energy (LCOE) equation and Net Present Value (NPV) procedure, respectively. Furthermore, RETScreen software was used to perform the economic prefeasibility study of a proposed wind farm. The study concludes that this site is economically feasible if a wind farm with 5.0 MW of ten wind turbines (EWT DW54) was established, with an NPV of \$11,309,956, after-tax IRR of 24.7%, a simple payback period of 6.1 years, and a capacity factor of 38.34%. Finally, this wind farm development will result in a reduction in greenhouse gases of 31876 tCO<sub>2</sub> per year. The sensitivity and risk analysis were performed and guarantee the safety of specified financial input parameters values.

**Keywords:** Wind energy, RETScreen, Windographer, LCOE, NPV.

### دراسة اقتصادية لمشروع طاقة الرياح باستخدام مصادر مختلفة لبيانات الرياح

فiras عبد الرزاق هادي<sup>1\*</sup>، سماح شياح عوده<sup>2</sup>، رافع عباس حسن<sup>3</sup>

<sup>1</sup>قسم الطاقات المتجددة، كلية علوم الطاقة والبيئة، جامعة الكرخ للعلوم، بغداد، العراق

<sup>2</sup>منظمة الاقح الاخضر للاغاثة والتنمية المستدامة، بغداد، العراق

<sup>3</sup>كلية علوم الطاقة والبيئة، جامعة الكرخ للعلوم، بغداد، العراق

### الخلاصة

في هذا البحث تم دراسة الجدوى الاقتصادية الأولية لمشروع طاقة الرياح في موقع الشهابي (واسط - العراق) باستخدام بيانات الرياح المقاسة على ارتفاعات 10 م و 30 م و 50 م و 52 م لكل 10 دقائق. ولغرض المقارنة، تم استخدام بيانات وكالة ناسا الفضائية لنفس الموقع وعلى ارتفاع 50 متراً فقط. تم العثور على أقل تكلفة لوحدة الكهرباء من طاقة الرياح (0.028 دولار / كيلووات ساعة و 0.0399 دولار / كيلووات ساعة) باستخدام معادلة المنهجية القياسية لتكلفة الطاقة (LCOE) وإجراءات القيمة الحالية الصافية (NPV) على التوالي. علاوة على ذلك، تم استخدام برنامج Rescreen لإجراء دراسة الجدوى الاقتصادية لمزرعة

\*Email: Firas.A.Hadi@kus.edu.iq

الرياح المقترحة. خلصت الدراسة إلى أن هذا الموقع مجدي اقتصاديًا إذا تم إنشاء مزرعة للرياح بقوة 5.0 ميغاوات من عشرة توربينات رياح (EWT DW54) مع NPV بقيمة 11,309,956 دولارًا ، بعد خصم الضرائب بنسبة 24.7٪ وفترة استرداد بسيطة تبلغ 6.1 سنوات وبنسبة 6.1.3٪. أخيرًا ، سيؤدي تطوير مزرعة الرياح إلى انخفاض في غازات الدفيئة بمقدار 31876 طن متري من ثاني أكسيد الكربون كل عام. بالإضافة إلى إجراء تحليل الحساسية والمخاطر وضمان سلامة قيم المعلمات المالية المحددة.

## 1. Introduction

The renewable energy sources which include solar, wind, hydro, geothermal and biomass are becoming competitive to decrease the consumption and to replace the conventional energies throughout the last years. Clean energy has minimal negative effects along with non-polluting generation on the environment, and is currently replacing a portion of the fossil-based power generation in many parts of the world. Among the clean energy technologies, wind energy is one of the fastest growing in the global market. Due to the increase in populations and electricity demand, Iraq has a critical electricity leakage, while the traditional power systems cannot cover this demand. It became essential to solve the energy shortage by solar and wind energy sources which also provide an important source of income for the Iraqi government. The availability of wind is the most effective technical factor that affects the economic viability of the wind project. The deep knowledge of available wind resources is critical for investors to determine if a project is profitable in a specific site [1].

In the present work, two methods were used for the calculation of the unit cost of electricity produced from ten selected wind turbines. A proposed wind farm of 5.0 MW capacity of similar ten wind turbines (EWT DW54-500kw-50m height), located at AL Shihabi, was modeled using RETScreen software to demonstrate the financial viability of the construction.

## 2. Site Description

The proposed wind farm is located at AL Shihabi region near Kut city. The region is located at the position of 32.77°N 46.40°E. Figure-1 shows the location of the selected site in the eastern region near the border between Iraq and Iran.



Figure 1- Location of the proposed wind farm at AL- Shihabi region [1].

## 3. Wind Data Collection

The 10-minute time series wind data was collected from the meteorological station, which was installed at AL Shihabi region and measured at 10m, 30m, 50m and 52m from 11/29/2014 to 12/10/2015. The statistical analysis of the collected data, tabulated in Table- 1, shows that the total possible data points recorded were 54,288 data points, with 117 missing data points and a recovery factor of 99.78%. Windographer is a software that was used to download NASA hourly time series data for one year for the same time period of the data collected from AL Shihabi site. NASA hourly wind data were converted to 10 minutes time intervals for compatibility with the measured data via Windographer software.

**Table 1-** Mean wind speed at different heights (10, 30, 50, and 52 m)

Variable	speed 10m av	speed 30m av	speed 50m av	Speed 50m NASA	speed 52m av
Mean wind speed (m/s)	4.607	6.068	6.673	5.241	6.91
Median wind speed (m/s)	4.12	5.9	6.5	5.23	6.59
Min wind speed (m/s)	0.34	0.38	0.37	0.1	0.37
Max wind speed (m/s)	17.53	19.52	57.02	13.54	24.2
Possible data points	54,288	54,288	54,288	54,288	54,288
Valid data points	54,171	54,171	54,171	54,288	54,171
Missing data points	117	117	117	0	117
Data recovery rate (%)	99.78	99.78	99.78	100	99.78

#### 4. Wind Resources and Energy Output

Wind resource evaluation is the best approach to choose wind turbine sites, predict power output, and determine economic viability of placing turbines at a particular location. Examination was made for wind speeds using Weibull distribution function and its parameters (shape and scale factors) for all the heights (10m, 30m, 50m and 52m) as well as for NASA data at 50m, as shown in Table- 2 [2].

**Table 2-** Average monthly values of Weibull parameters (shape and scale factors).

Hgt. Month	Weibull k					Weibull c (m/s)				
	10m	30m	50m	50m (NASA)	52m	10m	30m	50m	50m (NASA)	52m
Jan	1.239	1.503	1.372	2.22	1.811	4.05	5.732	6.269	4.686	6.857
Feb	1.215	1.509	1.533	2.256	1.784	4.748	6.423	7.147	5.187	7.578
Mar	1.201	1.604	1.525	2.393	1.946	3.707	5.381	5.777	5.47	6.281
Apr	1.448	1.823	1.818	3.184	2.132	5.539	7.24	7.898	6.405	8.275
May	1.905	2.643	0.443	3.344	2.799	4.992	6.616	6.066	5.807	7.474
Jun	2.189	2.75	2.832	3.935	3.125	8.972	10.89	11.78	8.037	12.09
Jul	1.548	1.849	1.857	3.358	2.14	6.692	8.518	9.353	7.093	9.78
Aug	1.895	2.388	2.32	3.585	2.566	5.756	7.595	8.424	7.009	8.704
Sep	1.512	1.83	1.656	2.869	1.982	4.372	6.13	6.633	5.952	7.02
Oct	1.508	1.821	1.667	2.715	1.989	4.489	6.14	6.737	5.685	7.092
Nov	1.453	1.743	1.593	2.332	1.999	3.753	5.238	5.752	4.399	6.169
Dec	1.216	1.54	1.435	2.417	1.852	3.652	5.274	5.835	4.948	6.349
All	1.363	1.693	1.63	2.531	1.932	4.975	6.715	7.349	5.896	7.771

The International Electro-technical Commission (IEC61400-1) created and published standards for wind turbines and its relation to wind regime viability [3]. The Wind Energy Resource Atlas of the United States was created and archived in the National Renewable Energy Laboratory (NREL) website [4]. The IEC classification of wind turbines along with the relevant wind speed and power density from NREL was introduced as wind power density classes, as shown Table-3 [1].

**Table 3-** Classes of wind power density at 50 m [1].

Wind Power Class	Rating	Annual Average Mean Wind Speed (m/s)	Wind Power Density (W/m <sup>2</sup> )
1	Poor	≤5.6	≤200
2	Marginal	5.6 - 6.40	200 - 300
3	Fair	6.4 - 7.00	300-400
4	Good	7.0 - 7.50	400-500
5	Excellent	7.5 - 8.00	500-600
6	Outstanding	8.0 - 8.80	600-800
7	Superb	8.8 - 11.9	800-2000

The wind resource maps estimate the resource in terms of wind power classes ranging from class 1 (the lowest) to class 7 (the highest). Areas designated at class 3 or greater are suitable for most wind turbine applications, whereas class 2 areas are marginal. Class 1 areas are generally not suitable, although a few locations as hilltops with adequate wind resource for wind turbine applications may exist in some class 1 area. Even if the site lies in class 3 or above area, an investigation will still be needed for assessment of the site's functionality, or at least must know there is some potential [3, 4]. The power density for the area of the study was calculated and shown in Table- 4. According to wind power density classes at 50m, the studied site lies in the third class, which fairly encourages the installation of a wind farm at that site.

**Table 4-** Wind energy at different heights.

Variable	speed 10m av	speed 30m av	speed 50m av	Speed 50m NASA	speed 52m av
Mean power density (W/m <sup>2</sup> )	144	257	346	339	359
Mean energy content (kWh/m <sup>2</sup> /yr)	1,260	2,255	3,027	2950	3,145

A comparison was made between the measured and simulated (NASA) wind data. The wind power density shows the expected electrical energy produced from the wind turbine by using the measured wind speed data which is best fitting with the expected Weibull distribution that matches the observed mean wind speed and mean wind power density at the selected site. In this study, ten models of wind turbines were considered from the library of Windographer software. The net energy depends on average wind speed at hub height and the energy production curve of the wind turbine. The following equation was used to calculate net energy ( $E_{net,annual}$ ) [2, 5]:-

$$E_{net,annual} = P_{net,overall} \times 8760hrs \quad (1)$$

Where:  $P_{net,overall}$  is the mean net power output over the entire data set (kW), 8760 is the number of hours in a year.

The Net Capacity Factor (NCF) is expressed in equation 2 [2, 6]:-

$$NCF = (E_{net,annual} / (P_r \times 8760hrs)) \times 100 \quad (2)$$

Where,  $P_r$  is the rated power capacity of the wind turbines.

## 5. Economic Analysis

The viability of a wind energy project depends on its ability to generate energy at a low cost .The main parameters of the economics of wind energy project are included the following financial parameters [7-9].

- The installation costs of the electrical grid extension, grid reinforcement, foundation, roads, and cables. The installation costs constituted 30% of the turbine cost.
- Operation and maintenance costs.
- Annual energy production.
- Turbine life time.

The cost of the wind turbine which is set by the manufacturers varies widely from one manufacturer to another. The price index for wind turbines has gradually decreased over the last decade, reaching 0.79 million U.S. dollars per megawatt in the second half of 2019 as a benchmark .The cost of wind turbines has also decreased due to competition between manufacturers, growth in turbine heights and improved capacity. Costs of installing a commercial wind turbine depend on a variety of factors like the number of turbines, financing costs, purchase agreements, and location. Wind projects also vary depending on the components such as wind resource potential, utilities upgrades, transmission infrastructure, as well as maintenance and repair. However, economies of scale do play a part in wind systems and, therefore, larger systems tend to cost less per kilowatt than smaller systems. The cost of electricity is calculated by using the following two methods:-

### 5.1. Levelized Cost of Energy (LCOE) Method.

The applied LCOE method is a standard methodology [10, 11], which could be determined by four variables: capital expenditures, operational expenditures, annual energy production and the fixed charge rate (FCR; a coefficient that captures the average annual carrying charges including return on installed capital, depreciation, and taxes).The unit of LCOE is cents / kWh or \$/MWh, The LCOE and FCR are given by [5, 6]:

$$LCOE = \frac{(CapEx \times FCR) + OpEx}{(AEP_{net}/1000)} \quad (3)$$

$$FCR = \frac{d \times (1 + d)^n}{(1 + d)^n - 1} \times \frac{1 - (T \times PVdep)}{(1 - T)} \quad (4)$$

Where:

LCOE = levelized cost of energy (\$/MWh), FCR = fixed charge rate (%), CapEx is capital expenditures (\$/kW),  $AEP_{net}$  = net average annual energy production (MWh/ MW/yr) =  $MW_{net} \times 8,760 \times CF_{net}$ , OpEx is operational expenditures (\$/kW/yr) = LLC + OPER + MAIN, d is discount rate (weighted average cost of capital WACC) (%), n is economic operational life (yr), T is effective tax rate (%), PVdep is present value of depreciation (%),  $CF_{net}$  is net capacity factor (%), LLC is annual levelized land lease cost (\$/kW/yr), OPER is pretax levelized operation cost (operation and maintenance; O&M) (\$/kW/yr), MAIN is pretax levelized maintenance cost (O&M) (\$/kW/yr). The real rate of discount (d) adjusted for inflation can be obtained from the expression [10, 12] as:-

$$d_r = \frac{(d_{n+1})}{(i+1)} - 1 \quad (5)$$

Where:  $i$  is the inflation rate.

### 5.2. Net Present Value (NPV) Method

The net present value (NPV) is the difference between the value of all benefits (cash inflows) and costs (cash outflows) of the project, discounted back to the beginning of the investment. The benefits will necessarily include the sale income of electricity unit. NPV determines cash flow at a given discount rate of the project; it is an important factor of the feasibility of the project the depends on the relation of the benefit (B), the cost (C), the period (n) and the discount rate, as presented in 6 [13, 14]:-

$$NPV = \sum \frac{(B - C)}{(1 + r)^n} \quad (6)$$

For our calculations, we consider the retail wind energy sale price value as equal to 10 ¢/kWh.

### 6. Production Tax Credit

Production Tax Credit (PTC) was set by the USA Congress and used to know how to support the projects for 10 years from the beginning of wind energy operation. This will lead the investors to build wind farms and harvest as much energy from the source [8]. The proposed PTC which is considered in this research as Renewable Energy (RE) production credit escalation rate was 2.5 % [9], while the assumed applicable tax rate in Iraq for other life years of the project is 30% [15].

### 7. Depreciation Cost

Every year, the project would depreciate at a certain rate. The value of the project at the end of its useful life period is known as salvage value ( $S$ ), which is assumed to be 10 per cent of the initial cost at the end of 20 years of the project. The annual depreciation  $D_A$  is given by equation 7 [16]:-

$$D_A = \frac{C_i - S}{n} \quad (7)$$

Where:  $C_i$  = the capital investment,  $n$  = turbine life in years

### 8. Economic Analysis of a Wind Turbine Energy Production

The internal rate of return (IRR) is defined as the discount rate which sets the NPV of a series of cash flows over the project life as equal to zero. The rate which is produced by the solution is the project's (IRR). Simple payback period (SPB) represents the period to recoup the investment cost of the project.

The total initial cost (TIC) estimation is presented in eq. 8 [7]:-

$$TIC = FS + PD + E + PS + BM \quad (8)$$

Where,  $FS$  is prefeasibility study cost,  $PD$  is development project cost,  $E$  is engineering cost,  $PS$  is power system cost, and  $BM$  is balance system and miscellaneous cost. The renewable energy policy is still at its primary stage in Iraq. The adopted values of the input financial parameters in the RETScreen software were chosen in the acceptable range of the case study models as shown in Table- 5 [16].

**Table 5-** Input Cost parameters in RETScreen Model.

Input parameters	Selected value%	Acceptable range%
Feasibility study	1.0	Less than 2
Project Development	3	1 to 8%
Engineering cost	5	1 to 8%
Power System	71.3	67 to 80%
Balance of System & Miscellaneous	19.8	17 to 26%
O & M/ parts of labor	2	1 to 4%
Inflation rate (i)(%)	3	15%
Interest rate(%)	3	2 to 3%
Fuel cost escalation rate	8	
Electricity export escalation ate	2.5	
Discount rate(%)	5	
Debt ratio(%)	4.85	3.0 to 18.0%
Debt interest rate(%)	60	50.0 to 90.0%
Debt term ((year))	8	-
Project life ((year))	10	-
Turbine availability	20	20 to 30 years
	98%	98%

The initial costs of the implementation of the project include the costs for preparing a prefeasibility study, performing the project development functions, completing the necessary engineering, purchasing and installing the energy equipment, construction of the balance of plant and costs for any other miscellaneous items. The energy equipment and balance of the plant are the two cost categories showing the strongest dependence on the number of wind turbines that make up the wind farm. The O&M (operation and maintenance) cost was assumed as 3.0% of the total cost. The transmission and distribution power losses are in the range of 10% to 20.0%, while the assumed value was taken as 8% loss in this project.

### 9. Wind Power Results

The results showed that the wind turbine model (EWTDW54-500) had the highest power coefficient value 48 % which represents an excellent result from the viewpoint of wind energy production. The wind turbine manufacturers power curve and power coefficient at optimum rating which are shown in Figure-2 and Table-6 demonstrate the main characteristics of EWT DW54 wind turbine.

The extrapolated measurement of wind speed at 30m hub height was found to be 6.06 m/s, while it was 6.67m/s at 50m. The wind speed of NASA at 50m was 5.241m/s, which is lower than the extrapolated measured wind speed within 13.5% and gives inaccurate indications about the viability of wind power. The maximum net annual energy production (Net AEP) values were 2,191,918 (kWh/yr), 2,084,388 (kWh/yr), 1,679,169 (kWh/yr) from wind turbine models of Gamesa G58- 0.85 MW, EWT DW54-900 and EWT DW54-500, respectively. The other wind turbines were less productive than Net AEP. The results also showed that the wind turbine EWT DW54-500 (50m) gives the maximum Net Capacity Factor (NCF) of 38.34% which means the maximum compatibility with the site, as shown in Table- 7. Table- 8 shows the monthly turbulence intensity (TI) at 10m, 30m, 50m, and 52m heights. For EWTDW54 wind turbines, it was found that the variation of TI ranged from a minimum value of 0.13 to a maximum value of 0.2 at 50m hub height, which is compatible with the selected wind turbine class IIIA depending on IEC61400-1 edition 3 definition [1].

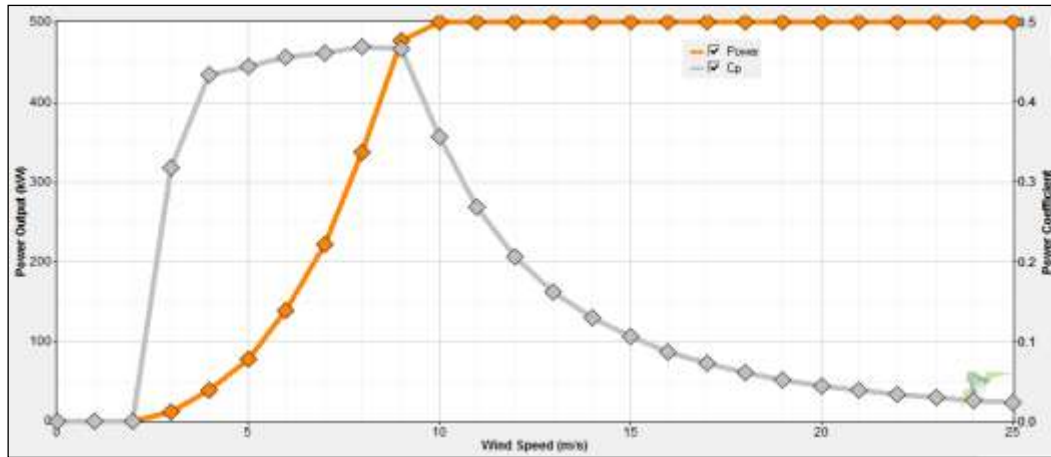


Figure 2- Power curve of EWT DW54 wind turbine [17].

Table 6- Main characteristics of EWTDW54 wind turbine [17].

Parameter	Unit	Parameter	Unit
Rotor diameter	54m	Rated wind speed	10m/s
IEC wind class	IIIA	Cut-out wind speed	25m/s
Rotor speed variable	12-24rpm	Survival wind speed	52.5m/s
Nominal output power	500kW	Power output control	Pitch controlled
Hub height	40 and 50m	Generator	Synchronous multi-pole
Cut-in wind speed	2.5m/s	Power converter	IGBT-controlled

Table 7- The extrapolated wind speed at different heights and the calculated Net Power, Net AEP and NCF for different turbines

Turbine	Hub Height m	Rated Power (kW)	Hub Height Measured Wind Speed m/s	Speed 50m NAS A	Net Power (kW)	Net AEP (kWh/yr)	NCF (%)
Bergey Excel-S	30	10	6.06	-	2.1	18,115	20.68
Eocycle EO 25/12	30	25	6.06	-	6.7	58,701	26.8
Northern Power 100	30	100	6.06	-	21.2	185,678	21.2
Northern Power 100-24	30	100	6.06	-	23.9	209,010	23.86
Northern Power 60-23	30	60	6.06	-	18.8	165,091	31.41
Seaforth AOC 15/50	30	50	6.06	-	15.8	138,597	31.64
Gamesa G58- 0.85 MW	50	850	6.67	5.241	250.2	2,191,918	29.44
Enercon E-33 / 330 kW	50	330	6.67	5.241	94.8	830,134	28.72
EWT DW54-500 (50m)	50	500	6.67	5.241	191.7	1,679,169	38.34
EWT DW54-900 (50m)	50	900	6.67	5.241	237.9	2,084,388	26.44

Table 8- Turbulence intensity characteristics at 10m, 30m, 50m, 52m heights at the studied site.

Data Column	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
TI at 10m	0.22	0.23	0.29	0.24	0.26	0.17	0.24	0.24	0.3	0.25	0.23	0.23	0.24
TI at 30m	0.15	0.16	0.21	0.17	0.17	0.13	0.18	0.17	0.21	0.18	0.15	0.15	0.17
TI at 50m	0.13	0.15	0.2	0.16	0.17	0.12	0.17	0.16	0.2	0.17	0.14	0.13	0.16
TI at 52m	0.12	0.13	0.15	0.13	0.14	0.11	0.14	0.13	0.16	0.14	0.12	0.12	0.13

## 10. Economic Results

The results of the unit cost of electricity that could be generated from the used wind turbines are presented in table 9 by using Levelized Cost of Energy (LCOE) and Net Present Value (NPV) Methods. It was found that the wind turbine model EWT DW54-500 could produce electricity at lowest cost value of 0.028 \$/kWh and 0.061 \$/kWh in both methods, respectively, and these results are acceptable based on the LCOE results [10, 16]. The other models of wind turbines were found to produce electrical wind energy with higher unit costs as compared to EWT DW54-500 model and, therefore, they were excluded.

**Table 9-** Unit cost of electricity from the wind farm.

Unit cost of electricity produced from wind energy \$/kWh			
Turbine model	Pr (kw)	LCOE Method	NPV Method
Bergey Excel-S (30m)	10	0.052021898	0.075567717
Eocycle EO 25/12 (30m)	25	0.040134609	0.068743388
Northern Power 100 ARCTIC (30m)	100	0.050753276	0.074839419
Northern Power 100-24 (30m)	100	0.045087636	0.071586853
Northern Power 60-23 (30m)	60	0.034249354	0.065364744
Seaforth AOC 15/50 50Hz (30m)	50	0.033997009	0.065219876
Gamesa G58- 0.85 MW (50m)	850	0.036544259	0.066682217
Enercon E-33 / 330 kW (50m)	330	0.037461941	0.067209045
EWT DW54-500 (50m)	500	0.028060805	0.061811983
EWT DW54-900 (50m)	900	0.040690074	0.069062273

## 11. Sensitivity Analysis Results

Sensitivity Analysis worksheet was operated in RETScreen software to test the effect of key financial parameters (initial cost, electricity export rate, debt ratio, debt interest rate, CE production credit rate) on the financial indicators (NPV, IRR and SPB). The key financial parameters varied with the base case within values of  $\pm 10\%$  and  $\pm 20\%$ . as shown in Table-7.

- When the electricity export rate was decreased to -20% of base case, this caused decreasing NPV to 7,414,931\$ (-34.4%), increasing SPB to 7.6 years (+19.7%) and decreasing IRR to 21.5% (-14.8%). When the electricity export rate reached +20%, it caused an increase in the NPV to 15,204,982\$ (+25.6%), decrease in the SPB to 5.1 years (-19.6%) and increase in the IRR 31.1% (+20.5%).
- When debt ratio reached -20% of the base case (60%), it caused a slight increase of NPV value to 11,348,917\$ (+0.34%), a slight increase of IRR to 26.3% (+6%) and a null decrease of SPB. The impact of increasing the debt ratio to +20% of the base was a null decrease of both NPV and IRR and a null increase of SPB.
- When clean energy (CE) production credit rate was increased by +20% of the base case, then NPV increased to 11,649,387\$ (+2.9%), IRR increased to 25.7% (+3.9%) and SPB decreased to 5.9 years (-3.3%). The impact of varying the CE production credit rate to -20% was a slight decrease for both NPV and IRR values, while slightly increasing the payback period .
- Increasing the project cost by +20% caused reductions in NPV by -4.57% and IRR by -9.38%, while it caused an increase in SPB by (+6.1%), and vice versa in the case of decreasing the cost by -20%.
- The variation of financial parameters with  $\pm 10\%$  of the base case led to the same procedure results, but still less than, those when using  $\pm 20\%$ . When two key input parameters varied simultaneously, e.g. the initial costs to +10% higher than estimated and electricity export rate to +20% higher than estimated, IRR was increased to 28.5%.
- When the discount rate was changed below and higher than the selected value of 4.85%, as shown in the table 8, it affected the value of NPV but not the values of IRR and SPB.



- It was found that the estimated values (base case) of financial parameters were represented as optimum case and adopted in economic evaluation of the project. The energy price is not too high, while the NPV was positive with suitable payback period. Therefore, the results showed suitable wind resources and economic analyses outcomes.
- The financial parameters with the strongest effects on the economic indicators were the total initial cost, electricity export rate and discount rate.

**Table 7-** Effects of financial parameters on financial indicators

Financial parameters	Base case value	Variation from Base case	Changeability of Economic indicators		
			NPV	IRR	SPB
Electricity export rate	100\$/MWh	-20%	-34.4%	-14.8%	+19.7%
Electricity export rate	100\$/MWh	+20%	+25.6%	+20.5%	-19.6%
Debt ratio	60%	-20%	+0.34%	+6%	Null decrease
Debt ratio	60%	+20%	Null decrease	Null decrease	Null increasing
(CE) production credit rate	0.021\$/kWh	+20%	+2.9%	+3.9%	-3.3%
(CE) production credit rate	0.021\$/kWh	-20%	decrease	decrease	increase
Initial cost	8,565,650\$	+20%	-4.57%	-9.38%	+6.1%
Initial cost	8,565,650\$	-20%	+4.5%	+8.95%	-7%
Initial cost	8,565,650\$	+10%	-9.5%	-18.7%	+12.8%
Initial cost	8,565,650\$	-10%	+8%	+17.67%	-17.3%

**Table 8-** Effects of discount rate on financial indicators

Discount rate value%	NPV \$	After-tax IRR - equity IRR %	SPB years
4	12,767,843	24.7	6.1
4.85	11,309,956	24.7	6.1
5	11,071,205	24.7	6.1
6	9,606,478	24.7	6.1
7	8,337,985	24.7	6.1
8	7,236,007	24.7	6.1

## 12. Prefeasibility Results and Discussions

- The studied site lies in the 3<sup>rd</sup> class according to the IEC classification, which implies the suitability of AL Shihabi site for wind energy project construction.
- The total initial cost analysis value is \$8,565,650 as related to EWT DW54 wind turbine. The required minimum After-tax IRR - equity value was evaluated as 24.7% if the wind turbine EWT DW54 was installed.
- The emission analysis worksheet shows the greatest amount of annual net emission reduction (32,613 tCO<sub>2</sub>) from the proposed wind farm when using EWT DW54 wind turbine.
- The financial worksheet provides the following results:-
- The NPV is \$11,309,956; this positive value of NPV indicates that the project is feasible for the model of EWT DW54 at a discount rate of 4.85%. the negative value is unacceptable. The results of the economic feasibility are illustrated in fig.3, which summarizes the yearly cash flow rate and describes the cumulative cash flows during the life of the project.

- The benefit –cost ratio was found to be 4.30, which implies that the project is acceptable. The electricity exported to grid was 13,703 MWh per year at an overall wind plant capacity factor of 38.34%. The simple payback period was found to be 6.1 years and the equity payback was 5.0 years.

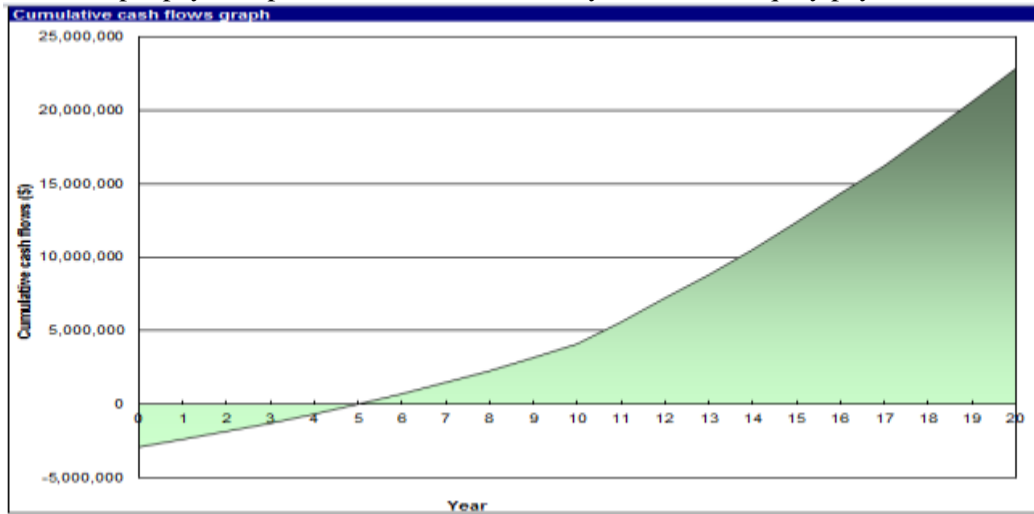


Figure 3- Cumulative cash flow of EWT DW54 wind turbines graph.

### 13. Risk Analysis Results

Risk analysis was performed to show how far the profitability of the project can be affected by errors in the values of input parameters. The risk analysis was performed using a Monte Carlo simulation by RETScreen software, that includes 500 to 5,000 possible combinations of input variables resulting in 500 to 5,000 values of pre and after-tax IRR - equity, pre and after-tax IRR - assets, equity payback, Net Present Value (NPV) or Energy production cost. The risk analysis allows the user to assess if the variability of the financial indicator is acceptable, or not, by looking at the distribution of the possible outcomes. An unacceptable variability will be an indication of a need to put more effort into reducing the uncertainty associated with the input parameters that were identified as having the greatest impact on the financial indicator.

It was found that:

- From Monte Carlo frequency distribution of the financial indicators, shown in the Fig. 4, the minimum within level of confidence was 20.7%, while the maximum within level was 29.6%. A 90% confidence interval indicated that 90% of the 500 financial indicator values will fall within above range. The specified level of risk was 10% of the values, which falls outside the confidence interval (e.g. a 90% confidence interval has a 10% level of risk). [18].

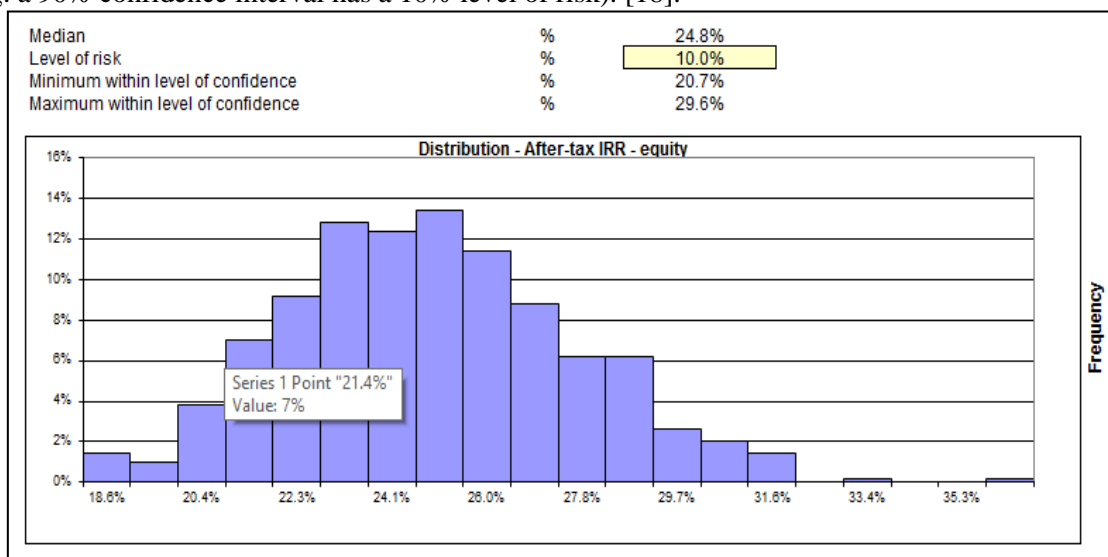


Figure 4- Graph of Monte Carlo frequency distribution the financial indicators.

Figure-4 shows, as an example, that at 7% of the time of project life, IRR is  $21.4 \pm 7\%$ . Confidence was 29.6% for a risk of 10% and, out of these two limits, the project would be under risk.

#### 14. Conclusion

The studied site lies in the 3rd class of IEC classification which means the suitability of AL Shihabi site for wind energy project construction.

The feasible model was 10 units of 500kW wind turbines (EWT DW54). The proposed wind farm with an overall wind plant capacity factor of 38.34% can export an electrical power to the grid with a value of 13,703MWh per year at a selling price of 100\$/MWh. The unit cost of electricity was found to be 0.028 and 0.0399 \$/kWh resulted from LCOE and NPV methods, respectively. The variations of the unit cost of electricity which were obtained by using LCOE and NPV methods could be attributed to the methodology and procedure followed in each of them. Finally, the project is acceptable and feasible.

#### References

1. Firas Hadi A., Samah Shyaa Oudah, Al-Baldawi Rafa A. **2019**. "Pre-feasibility Study of Hypothetical Wind Energy Project Using Simulated and Measured Data", *IEEE Xplore*: 30 May DOI: 10.1109 /ICETS.  
"Mistaya Engineering Inc. Windographer", [www.windographer.com](http://www.windographer.com).
2. The vip kr k. **2000**. "International Electro technical Commission" (IEC), Website [www.iec.ch](http://www.iec.ch).
3. Elliott D. L. **1987**. Wind energy resource atlas of the United States. NASA STI/Recon Technical Report N 87.
4. Stehly T., Moné C., Maples B. and Settle E. **2014**. *Cost of Wind Energy Review*, Science Direct, NREL.
5. RETScreen International, **2016**. *Clean energy project analysis RETScreen engineering & cases textbook*, 3d edition.
6. Moné C., Smith A., Maples B. and Hand M. **2013**. *Cost of Wind Energy Review*, Science Direct, NREL.
7. Gilbert, M. **2004**. *Renewable and Efficient Electric Power System*, John Wiley & Sons, Inc. ISBN 0-471-28060-7.
8. [Ragheb, M.](#) **2017**, *Wind Energy Engineering: A Handbook for Onshore and Offshore Wind Turbines*. [Elsevier Inc.](#).
9. Short W., Packey D. and Holt T. **2013**. A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies, *National Renewable Energy Laboratory*.
10. Blair N., Cory K., Hand M., Parkhill L., Speer B., Stehly T., Feldman D., Lantz E., Augustine C., Turchi C., and O'Connor P. **2015**. Annual Technology, *National Renewable Energy Laboratory*, Report No. NREL/PR-6A20-64077, July.
11. Ali K., Abdulrazzaq Firas H., and Nmr J. S. **2015**. Suitable Wind Turbine Identification Using Capacity Factor and Economic Feasibility, *International Journal of Science and Technology*, **4**(8): August.
12. Monarque Leng G. A., Graham S., Higgins S., and Cleghorn H. **2004**. RETScreen International, Results and Impacts, 1996-2012, Minister of National Resources, Canada.
13. Baris O., Serra O., and Mahir T. **2006**. Feasibility study of wind farms: A case study for Izmir, Turkey, *Journal of Wind Engineering and Industrial Aerodynamics*, **94**: 725–743, April.
14. National Investment Commission Republic of Iraq, [investpromo.gov.iq](http://investpromo.gov.iq).
15. Gokçek M., Erdem H., and Bayülken H. **2007**. A techno-economical evaluation for installation of suitable wind energy plants in Western Marmara Turkey, *Energ. Explor. Exploit.* **25**: 407–428 .
16. The Wind Power, Manufacturers and turbines, [www.thewindpower.net](http://www.thewindpower.net)
17. Gokçek M., Genç S., **2009**. Evaluation of electricity generation and energy cost of wind energy conversion systems (WECS) in central Turkey, *ApplEnerg*, **86**: 2731–2739.