An assessment of Wind energy potential for electricity generation in southwest of Damascus, Syria

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Abstract

This study aims at investigating the wind characteristics using actual wind data for Al-Hijana Site located on the south east of Damascus. Statistical analysis model was introduced to evaluate the wind energy potential. According to the power calculations done for the site, the annual mean wind density is 288.7 kW/m^2 at a height of 80 m above ground level. This station has a huge wind energy potential for electricity generation, especially during summer season, comparing with some regional countries. Al-Hijana Site was selected to install 50.5 MW using 35 commercial wind turbines "GE 1.5 sle". This site has annual wind speed more than 8.01 m/s at 80 m height and enough area to locate these turbines. The estimated energy production using was 143 GWh/year. Furthermore, the production costs was found 5.1 € cent/kWh, which is a competition price at the wind energy world market.

Keywords: Wind Power, Wind speed, Weibull parameter's, Wind turbine efficiency parameter, Electricity generation costs

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تقييم إمكانات طاقة الرياح لتوليد الكهرباء في جنوب غرب دمشق ، سورية

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الملخص

تهدف هذه الدراسة إلى دراسة خصائص الرياح باستخدام بيانات الرياح الفعلية لموقع الهيجانة الواقع جنوب شرق دمشق. تم تقديم نموذج تحليلي إحصائي لتقييم إمكانات طاقة الرياح. وفقاً لحسابات الطاقة التي أجريت للموقع، فإن متوسط كثافة الرياح السنوية هو 288.7 kW/m^2 على ارتفاع 80 m فوق مستوى سطح الأرض. يتمتع هذه الموقع بإمكانات هائلة من طاقة الرياح لتوليد الكهرباء، بخاصة خلال موسم الصيف ، مقارنةً ببعض الدول الإقليمية. تم اختيار موقع الهيجانة لإنتاج 50.5 MW من 35 عنفة رياحية تجارية الصنع- طراز GE 1.5 sle. تبلغ سرعة الرياح السنوية لهذا الموقع أكثر من 8.01 m/s على ارتفاع 80 m ومساحة كافية لتحديد موقع هذه العنفات. كان إنتاج الطاقة المقدر باستخدام برنامج WASP لمزرعة الرياح هذه هو 143 GWh/year. علاوة على ذلك، وجد أن تكاليف الإنتاج € 5.1 cent/kWh ، وهو سعر منافس في السوق العالمية لطاقة الرياح.

كلمات مفتاحية: الطاقة الريحية، سرعة الرياح، عامل ويبول، عامل كفائة العنفة الريحية، تكاليف إنتاج الطاقة الكهربائية

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1. INTRODUCTION

During the last few decades, wind energy has become the leading contender among the renewable sources of energy. The horizontal-axis wind turbines have been installed in large wind farms around the world [1, 2]. Along with the advancement of technology, the using of renewable energy has increased and the power quality of these sources improved. After the technological improvements and growth rate of energy demand, the interest of wind energy has increased for all countries. Syria is one of the Mediterranean country, which have a good potential for wind energy. Studies on the wind potential in Syria [3, 4] have been conducted for several years and showed that there is a very high wind potential in the country, As indicated in the Wind Atlas [5] developed for the country in 1989 by RISØ (Danish National Research laboratories) and by the serious measurements conducted at fifteen sites during the period 2004-2009. National Energy Research Center has continued wind measurements at seventeen sites up to date and records the data in electronic excel data sheets. Effective use of wind energy for the generation of electricity necessitates detailed information of the wind characteristics and the distribution of wind speeds of the region. Many factors, such as the wind speed, the wind power, the generator type, and a feasibility study, have to be taken into account to install wind energy transformation system in the studied site. Many studies of the wind characteristics and wind power potential have been conducted in many Mediterranean countries. An analyze of the wind speed characteristics and wind energy potential are carried out by Gaydaa Al Zohbi and al. in five sites in Lebanon [6], by Ahmed Shata on the coast of Red Sea in Egypt [7], Electrical energy in Syria is mainly produced by fossil fuels (oil and natural gas) and hydro-power [8]. Since the start of the crisis 2011, Syria’s energy sector has encountered a number of challenges. Damage to energy infrastructure and the effects of sanctions have combined to hinder the development of the country’s energy resources. Demand always exceeds supply and outages are frequent in peak periods. Therefore, the need of a new clean source of energy that increases electricity production from renewable source is crucial. To date, there is no record of wind power plants in Syria [9]. Prior to the current conflict, the Syrian government hoped to emphasize the importance of renewable energy and laid out plans to develop renewable energy sources in the country. The 11th Five-Year Plan for 2011 − 2015 made that goal clear, but progress will be slow until the situation in the country stabilizes. Al-Hijana Site was one of the most promising sites of wind power in Syria. Mean speeds were 5.0 m/s at 10 m height and 6.70 m/s at 40 m height. This paper investigates the wind energy characteristics and wind turbine characteristics needed for the installation of wind turbines at Al-Hijana Site, which is located some 12 km southwest of the Tishreen power station southeast of Damascus. Moreover, the applications of wind turbines for electricity generation, in addition to a cost analysis of the utilized wind turbines are also investigated.

2. CARACTERIZATION OF THE SITE

In this study, wind speed data measured as hourly time-series in meteorological station at Al-Hijana Site, were statistically analyzed. The whole area is dry semi-desert area but with several spots of irrigated land for agriculture. In addition, the mast is place at such irrigated land where some ecological demonstration projects are established. Directly adjacent to this land, unused state land extends until the power plant area. The site is generally flat. Its size is approximately 2 km by 5 km, the site operating capacity is estimated at 50−100 MW, and the site may be expanded to include the all-surrounding area. This expansion would allow a total estimated operating capacity of 200 − 250 MW. Site ground conditions are firm and rocky and there are no buildings or trees on the site that might obstruct wind. Grid connection to the (66kV- 230kV-400kV) system will be possible; there are 400 kV -230kV-66kV overhead lines across the site. More details about the project are included in annex (2). Fig. 1 shows the location of chosen site in (33º22.637N; 36º41.939E) by geographic system with 605 m altitude above sea level. These wind data at 10 m above ground level related to the selected site were taken from the Syrian Meteorological Authority [10], for a period of more than 2 years. The measurements of monthly wind speed are presented in Table 1. At Al-Hijana Site, the wind blows from southwest (SSW & WSW) (wind direction).

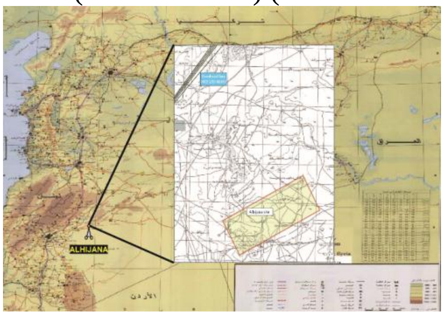

Figure (1) Location of Al-Hijana Site in Syria

Other directions are observed only very rarely. Since there is no major obstacle or topographic characteristic, which would avoid other directions, the shown distribution is representing the general climate condition in the region. The measured percentage frequency of winds blowing from all directions and the calm winds are shown in Fig. 2.

Table 1: Monthly wind speed recorded at Al-Hijana Site for 2005 − 2006 [10]

Month	Data Recovery	Average at 10m	Average at 40m
September	50%	5.23	7.23
October	100%	3.53	5.05
November	100%	2.93	4.22
December	100%	3.26	4.62
January	100%	3.92	5.53
February	100%	4.20	5.78
March	100%	5.33	7.10
April	100%	5.98	7.84
May	100%	4.67	6.26
June	100%	6.28	8.34
July	100%	7.52	9.66
August	100%	6.56	8.69
September	75%	5.21	7.20
Annual mean		5.0	6.7

This figure indicates that:

1. The mean wind speed during September 6.4 m/s has the highest frequency occurrence during the year (51.8%), followed by (44.3%) for mean wind speed 7.1 m/s at June, followed by (40.6%) at 6.3 m/s during May.
2. So, during these months peaks of mean wind speed occur at different days with an average value of 6.3 − 7.1 m/s which is above the cut-in values required for the operation of any wind turbine in Syria.
3. Since the minimum required wind speed for a wind park (at 20 m height) is about 3 m/s which is equivalent to 2.54 m/s at 10 m height, atypical turbine will operate about 75 − 80% of all the time throughout the year [7].

The wind usually blows at varying speeds as a result of a change in the isobaric values of atmospheric pressure. It is clear from Fig. 3 that:

1. The spring and summer seasons in Al-Hijana Site is characterized by a marked increase in the mean wind speeds as a result of a decrease in the isobaric values of atmospheric pressure.
2. However, the noticed decrease in the mean wind speeds at winter and autumn seasons correlated to the increasing of pressure values observed.
3. The highest average monthly wind speed was recorded at July 7.52 m/s at 10m height and 9.66 m/s at 40m height (summer season) and the lowest was during November 2.93 m/s at 10m height and 4.22 m/s at 40m height(winter season).
4. The wind speeds which lie between 4.7 m/s (in winter period) and 7.1 m/s (in summer period) corresponding to an atmospheric pressure between 101.51 and 100.5 kPa.
5. The graph also shown that the peaks of wind speeds are correlated to the reduced values of pressure at different seasons or months throughout the year.

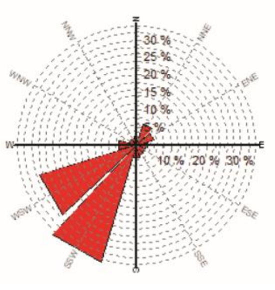

Figure (2) Percentage frequency distributions at 40 m above ground level at Al-Hijana site [10]

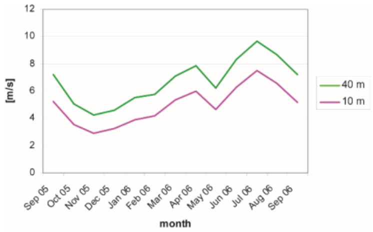

Figure (3) Monthly variation of the wind speed at 10m & 40m height in Al-Hijana Site [10]

3. ANALYSIS PROCEDURE

In order to evaluate the wind energy potential of any site, it is important to drive the expected probability distribution of the site's wind speed. Regarding this aspect, much attention has been given to the Weibull function, which gives a good match with experimental data [11]. The Weibull distribution is characterized by two parameters: the dimensionless shape parameter, k; and the scale parameter c, which has units similar to the speed (m/s). For evaluating the variation of the wind speed with elevation for this site, the mean speeds values were calculated using the power law [12] as:

$$V_2 = V_1 \left(\frac{Z_2}{Z_1}\right)^{\alpha} \quad (1)$$

Where V2, in m/s, is the calculated wind speed at height z2, V1 is the observed wind speed at height z1 and α is the wind speed power law exponent (typically 0.14). Both monthly and annually for the heights of 70 and 100 m in the wind observation station. Obtained results are presented in Table 2. Annual mean wind speed at the 100 m height is determined as 7.65 m/s while the maximum mean wind speed was 10.98 m/s at July. The probability density function for density for the wind velocity V is calculated by [13, 14]:

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

Where c and k are given by [15, 16] as follows:

$$k = 0.83V^{0.5} \quad (3)$$

$$c = \frac{V}{\Gamma(1-k^{-1})} \quad (4)$$

where V is the mean wind velocity and Γ is the gamma function. The Standard formula of the Gamma function of (z) is:

$$\Gamma(z) = \int_0^{\infty} x^{z-1} e^{-x}\, dx \quad (5)$$

However, the available power of the wind per unit area is estimated by [17, 18] :

$$P_{wind} = \frac{1}{2}\rho V_m^3 \quad (6)$$

In case of an ideal turbine, power output is influenced due to change in temperature and pressure. So, the corrected monthly air density $\bar{\rho}$(kg/m3) is expressed as [19]:

$$\bar{\rho} = \frac{\bar{P}}{R_d \bar{T}} \quad (7)$$

Then the corrected power available in wind at the standard height 10 m, can be calculated as follows:

$$P_{10} = \frac{1}{2}\bar{\rho} V_m^3 \quad (8)$$

In addition, for calculating the mean power density over a long time T for 1 month. If we take 30 days per month, we end up with the following equation, where the available mean power for a height less than 100 m, above the ground level per month can be expressed as [20]:

$$P_r(mo) = \frac{720}{1000}\frac{1}{2}\bar{\rho} V_m^3 \left(\frac{h}{10}\right)^{3\alpha} \quad (9)$$

Where α is the roughness factor, usually in the range$0.05 \le \alpha \le\ 0.5$ In this analysis, α = 0.25, is the standard value for the Syrian terrain and wind conditions [21]. On the other hand, the turbine efficiency η can be defined as the ratio between recoverable energy on the aerogenerator, E_R (kWh/m2/year), and available energy at Betz limit, E_A (kWh/m2/year). Last expression outlined in Refs. [22]. A simple estimating procedure can be introduced to estimate the monthly wind turbine efficiency by the following formula:

$$\eta_{monthly} = \frac{720}{S_a}\frac{P_r}{P_r(mo)} \quad (10)$$

where P_r is the rated power of the used wind turbine (kW), S_a is the rotor swept area (m2). While, we calculate the capacity factor C_f, that is the ratio between the actual yearly energy output, E_{out}, and the rated yearly energy, E_r = $8760P_r$ (a reference quantity that often is used as a rating–datum of the machine). The capacity factor of a wind turbine can be expressed [23]:

$$C_f = \frac{E_{out}}{E_r} \quad (11)$$

Lastly, the present value of money method is used for estimating the cost of a kWh produced by the chosen wind energy conversion systems (WECS).

Table (2) Estimated monthly and annual mean wind speed (m/s) at 65 and 80m heights above the ground level Al-Hijana Site

Month	Wind velocity at 65 m	Wind velocity at 80 m
September	7.8192	8.2196
October	5.4616	5.7412
November	4.5639	4.7976
December	4.9965	5.2523
January	5.9807	6.2869
February	6.2511	6.5711
March	7.6786	8.0718
April	8.4789	8.9131
May	6.7702	7.1168
June	9.0197	9.4815
July	10.4473	10.9822
August	9.3982	9.8794
September	7.7868	8.1855
Annual mean	7.2810	7.6538

To calculate the present value of costs (PVC) of electricity produced per year, the following expression (Eq. 12), which is in agreement with other works [24], is applied as well:

$$PVC = I + C_{omr}\left[\frac{1+i}{r-i}\right] \times \left[1 - \left(\frac{1+i}{1+r}\right)^t\right] - S\left(\frac{1+i}{1+r}\right)^t \qquad (12)$$

where I = the investment includes the turbine price plus its 20% for the civil work and other connections; C_{omr} = operation costs that include operation, repair cost, and maintenance are taken as 25% of the annual cost of the turbine (machine price/life time); S = scrap value taken as 10% of the original investment; i = inflation rate (12%); r = discount rate (15%); t = lifetime of the wind machine (20 years).

4. RESULTS AND DISCUSSION

4.1. Monthly and seasonal Weibull parameters

In order to obtain the monthly and seasonally values of Weibull parameters k and c with the height of 10 m above the ground level for Al-Hijana Site, Eqs. 3 and 4 were applied (see Table 3) When using these values for hub height, k may be assumed to be unaffected by height, and the scale parameter c may be estimated from the usual power law which generally holds up to a height of 100 − 150 m [25].

From Tables 3 we can derive the following:

1. The range of k is between 1.42 and 2.27, where the shape parameters tend to be higher from June to August during the year.
2. The highest c value is 8.49 m/s in July and the lowest is found 3.22 m/s in November.
3. The long-term seasonal k and c values are highlighted in Table 3. In general, values of the scale parameter are low throughout both (winter-autumn) seasons and high during the spring and summer periods.

Table(3) Monthly long-term shape parameter, k, and scale parameter, c, at 10 m hub height.

Month	k	C (m/s)
September	1.8981	5.8937
October	1.5594	3.9274
November	1.4207	3.2220
December	1.4986	3.6108
January	1.6433	4.3823
February	1.7010	4.7074
March	1.9162	6.0081
April	2.0297	6.7493
May	1.7936	5.2505
June	2.0800	7.0900
July	2.2761	8.4893
August	2.1258	7.4071
Annual mean	1.8336	5.5853

4. For large values of k at summer season, the majority of the wind speed data tend to fall around the mean wind speed and then the mean wind speed at this season are high. Hence, the wind is sufficient during the half of the year at Al-Hijana Site for high power generation.

4.2. Potential power resource.

By applying the measured wind data for Al-Hijana Site (monthly average air temperature, mean monthly of air pressure) with Eq. 6 & Eq. 9, the values of corrected monthly air density $\bar{\rho}$, corrected monthly wind power P_{10} at a height of 10 m and the monthly wind power available P_{80} at hub height 80 m during the year were calculated and listed in Table 4. From this table, we found that the absolute maximum highest wind power, P_{80}, was recorded in June 820.72 kW/m2 and the absolute minimum of P_{80}, was found to be 48.55 kW/m2 in November. In addition, the highest of value the mean power density for the summer season is 1844 kW/m2 and then followed by 901.5 kW/m2 in spring for actual data. Since the wind energy available in the wind cannot be completely extracted by any wind turbine, the wind turbine efficiency , defined as the ratio of the recoverable energy on the aerogenerator outlet (rotor + gearbox + generator) is given by the machine power curve and the wind statistical distribution to the available energy by ideal wind turbine (at Betz limit) [22]. It can be seen from Eq. 10 that the wind turbine efficiency is not only a function of wind turbine performance, but also a function of wind speed distribution. The wind turbine efficiency permit to figure out the relationship between energy available in the wind and how much energy a turbine can be transfer. It is important to note that the theoretical optimum for utilizing the power in the wind by reducing its speed was first discovered by Betz [26]. According to Betz, under the assumption that the turbine swirl and transmission losses were neglected, the theoretically maximum power that can be extracted from the wind is 59% of the wind power available in the wind. Therefore, for any wind turbine, the wind turbine efficiency should not exceed 0.59. By using the monthly values of mean wind speed for Al-Hijana Site at a height of 80 m which are listed in Table 4 and then by substituting these values in Eq. 10, we obtain the monthly values of at hub height 80 m for the last considered wind turbine.

4.3. Applications of electricity generation

The main objective of this study to evaluate the performance of 35 wind turbines operating in real conditions within a grid connection wind farm with total capacity of 52.5 MW at Al-Hijana Site. The amount of power generated by a wind turbine depends on both the design characteristics of the turbine and the properties of the wind resource represented by wind speed probability density. Matching the actual wind frequency distribution of the region with a suitable model of wind energy conversion system can maximize the energy output. This means, that in order to attain the maximum possible efficiency from a wind turbine it should be designed for that specific region. However, it is not practical to design a wind turbine for each location, because it is associated with extra funds. Therefore, usually a wind turbine - with parameters (such as cut-in speed, cut out speed, rated speed, and rated power), that best matches the wind characteristics of the region - is chosen from the existing wind turbines in the market [27]. So, the choice of the best suitable wind turbine for Al-Hijana Site is discussed. For this study the commercial wind turbine "General Electric GE 1.5 sle" Fig 4 with a capacity of 1.5MW and 80 m hub height was chosen, which has lower rated speed 14 m/s competitive with another commercial wind turbines of capacity 1500 kW in the market.

Table(4) Monthly available wind power and monthly values of wind turbine efficiency $\eta_{monthly}$ for Al-Hijana Site

Month	P_{10} (W/m^2)	P_{80} $(kW/m^2 month)$	η
September	80.61	276.09	0.84
October	24.77	84.89	2.73
November	14.17	48.55	4.78
December	19.52	66.86	3.47
January	33.94	116.25	1.99
February	41.75	142.98	1.62
March	85.32	292.23	0.79
April	120.50	412.71	0.56
May	57.39	196.56	1.17
June	139.56	477.99	0.48
July	239.63	820.72	0.28
August	159.08	544.82	0.43
Annual mean	84.31	288.74	1.54

Table (5) Annual energy gain and technical characteristics of wind turbine GE 1.5 sle

Turbine model	GE 1.5 sle
E_{out} (kW/h/year)	4, 093, 339
Rated power(P_r)	1500 kW
Hub height	64.5 m
Rotor diameter	77 m
Swept area	4657 m^2
Number of blades	3
Cut-in wind speed(V_{ci})	3.5 m/s
Rated wind speed(V_r)	14 m/s
Cut-off wind speed(V_{co})(10 min avg.)	25 m/s
Price [EUR]	1, 300, 000

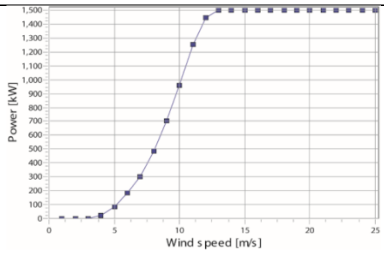

Figure (4) Power curve for 'General Electric GE 1.5 sle 1500 kW selected in this study

In this case, the annual assessment of energy production in one site is an important factor. Given the power curve of a specific wind turbine, we are therefore able to estimate the actual energy production during the year by using WASP program (Wind Atlas Analysis and Application Program) developed by RISø National Laboratories, Roskilde Denmark, as shown in Fig 5.

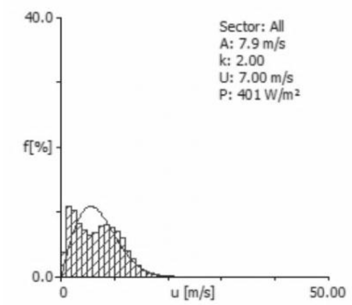

Figure (5) Histogram and WAsP Weibull distribution for the 40 m wind speed measurements [10]

Turbines in the 52.5 MW-wind farm at Al-Hijana Site are considered to be located 150 m distance a part each other to prevent energy production loses of park effect [21]. Southwest was found as prevailing wind direction. Other directions are observed only very rarely. Respecting the prevailing wind direction (southwest), the turbines shall be placed in rows perpendicular to the main wind speed. The minimum distance between the turbines in such a row should be about three times the rotor diameter. For the distance between the rows, typically eight times the rotor diameter is recommended as the minimum. Since the space is not considered a limiting factor in the investigated case, larger distance are recommended to improve the wind park efficiency. The technical data of the wind turbine 'GE 1.5 sle' used are summarized in Table 5. Using this data and the estimated annual mean wind speed at 80 m (hub height of this wind machine) will be 8.01 m/s at Al-Hijana Site together with the WASP program, the annual energy production, Eout, from the wind farm consists of 35 wind turbines with total capacity of 52.5MW was found to be 143266 MWh/year and the obtained capacity factor is high 31.1%, see Table 5.

4.4. Economical evaluation.

The present value of money method is used for estimating the cost of a kilowatt-hour produced by the wind farm with total capacity of 52.5MW considered at Al-Hijana Site. We used Eq. 12 with followed assumptions, and in case of the wind farm, the capital investment, I, is taken as the number of units multiplied by the unit price, from which the PVC value was obtained. Dividing this value by the total energy produced during the life time machines at wind farm, So, the expected cost of a kWh electricity generated is obtained as follows: PVC= 25, 548, 145, 402.

So, the specific cost per kWh can be calculated by :

[(25, 548, 145, 402)/(35 × 143, 126, 865)]= 5.1 € cent. Hence, these results which contain the expected cost per kWh = 5.1 € cent, encourage the construction of several wind farms at Al-Hijana Site. Where the expected specific cost for electricity generation is a competition price at the wind energy world market.

4. CONCLUSIONS

In this research, establishment of wind farm with capacity of 52.5 MW to operate at Al-Hijana Site were studied. The results of this investigation were very promising. Observation of the measured and estimated values leads to the following conclusions:

1. The wind in Al-Hijana Site is predominantly southwesterly throughout the year. So, north seems the only wind direction to consider in wind farm project, which will be developed on the campus area.
2. For the investigated station with Weibull parameters k and c, see Tables 3 and 4, we can drive that the wind is sufficient during

the half of the year (spring and summer periods) for high power generation.

3. The monthly corrected values of air density is lightly smaller than the standard air density = 1.127 kg/m3. Which confirms the stability of the atmosphere at Al-Hijana Site during the year and therefore, it causes an improvement in the efficiency of wind turbines worked at this site.
4. Investigation of available power density at the heights of 10 − 70 m indicates that, there are a huge wind power densities over the year, especially at spring and summer seasons in the range of 1063−1200 kW/m2. This agrees with the information given by our Weibull parameters investigation.
5. We recommend that at Al-Hijana Site, we should use wind turbines with rated power greater than 1000 kW at 80 m hub height.

6. An estimation of cost analysis of installing a wind farm with total capacity of 52.5 MW (35 commercial wind turbines GE 1.5 sle with a grid-connection) at Al-Hijana Site for electricity generation is carried out. The expected yearly energy gain from it was 143 GWh/year. Furthermore, the specific cost of each kWh was found to be 5.1 € cent, which is a competition price at the wind energy world market.

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