Assessing the Wind Energy for Rural Areas of Vietnam

Van-Tan Tran*‡, Tsai-Hsiang Chen*

* Department of Electrical Engineering, National Taiwan University of Science and Technology

(D9807802@mail.ntust.edu.tw, thchen@mail.ntust.edu.tw)

‡ Corresponding Author; Van-Tan Tran, # 43, Keelung Road, Section 4, Taipei, Taiwan (10607), R.O.C, +886-975206485, D9807802@mail.ntust.edu.tw

Received: 23.04.2013 Accepted: 09.06.2013

Abstract- This study assesses the wind energy potential of a Bac-Lieu wind farm. The daily wind speed data using in this study was collected over a period of five years between 2006 and 2010. The designed wind farm capacity was 99 MW with 60 individual units of 1.65 MW Vestas wind turbines. The wind energy potential and wind farm economic analysis were carried out by WAsP 10.0 and RETScreen International software, respectively. The results showed that at 80 m height and 0.03 m roughness length, the mean wind speed and wind density were 7.2 m/s and 379 W/m^2, respectively. The most wind energy came from East, Northeast, and North-Northeast directions. The wind farm produces 332.100 GWh/year, and prevents 232,470 tons/year of CO_2 equivalent greenhouse gas (GHG) from entering the local atmosphere. In the economic analysis, the wind farm has total initial cost of $198,100,000 USD. Total annual savings and profit is about $39,558,901 USD. The simple payback and equity payback of the wind farm are around 5.2 years and 2.1 years, respectively. The wind farm being assessed is located at Vinh-Trach-Dong, Bac-Lieu, Vietnam.

Keywords- Wind farm; wind energy; economic analysis; greenhouse gas.

1. Introduction

Renewable energy plays an important role in modern society. Renewable energy is a rich resource, which will substitute for fossil fuel in the near future. There are many types of renewable energy, included: solar energy, wind energy, ocean energy, hydro energy, geothermal energy, and so on. Among them, wind energy is the most important one. Figure 1 showed that, in 2012, the global cumulative installed capacity was 282,430 MW [1]. In Figure 2, Asia was the largest annual installer of wind generation capacity by region in 2012, at 15,750 MW following by North America and Europe at 14,860 MW and 12,416 MW, respectively. The three countries, which had the most installed cumulative capacity, were China with 26.8%, USA with 21.2% and Germany with 11.1%.

Recently, many researchers have focused on wind energy. In Algeria, Y. Himri et al. carried out wind energy potential tests at four selected sites. The study showed that Tindouf had the highest annual average wind speed of 5.8 m/s at height of 17 m above ground level [2]. The development of a wind farm with 30 MW installed capacity in Tindouf could result in avoidance of 23,252 tones of CO_2 per year [3]. In Taiwan, wind energy potential was analyzed at 12 stations [4]. The research pointed out that the average wind speed was between 1.7 m/s and 4.3 m/s. The strongest winds came from Northeast. The average winds speed was 3.41 m/s in Hengchun, Taiwan, and 32% of wind came from the North-Northeast [5]. In the other hand, many researchers analyzed wind farm impact on the power system. Wind farm wake effects was examined by photographs taken [6]. Suitability of energy systems base on superconducting magnetic energy storage was analyzed and compared the topology of power converter [7]. The impact of wind turbines on power quality was determined by wind turbine 0.65 MWA [8]. Finally, the economic impact was estimated in California economy by using input-output models [9].

In Vietnam, wind energy potential at eight stations spread through the county was analyzed by using the Weibull distribution function [10]. The study showed that wind speed highest in Nha-Trang at 11.15 m/s at 100 m height above ground level. At present, Vietnam has many projects to

develop wind farms. Among them, the biggest project is Bac-Lieu wind farm with 99 MW installed capacity. This study simulated the practical wind farm project with 99 MW installed capacity by using Wind Atlas Analysis and Application Program (WAsP). The study used Vestas wind turbine 1.65 MW rate capacity.

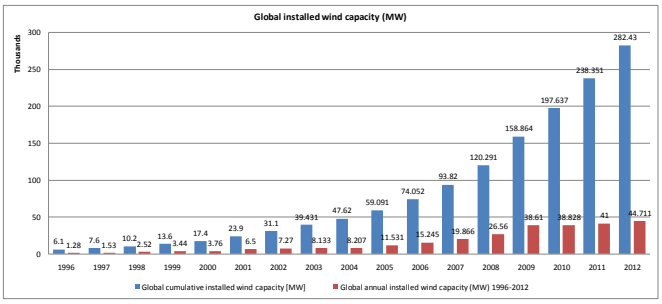


Fig. 1. Global installed capacity (MW) during 1996-2012.

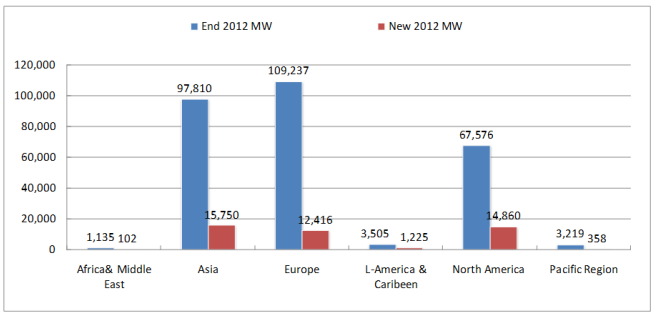
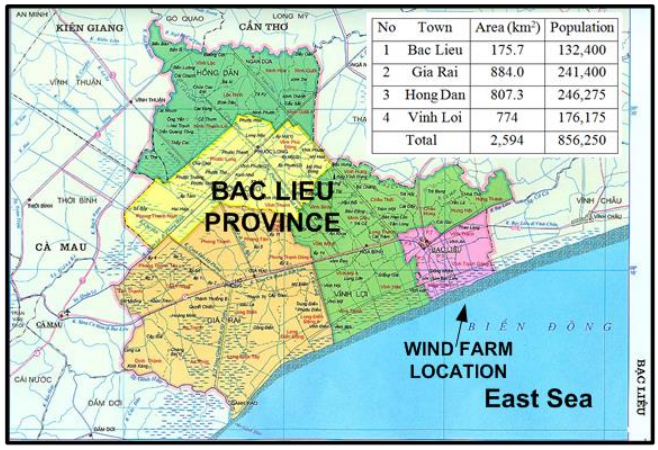


Fig. 2. Global installed capacity (MW) by region during 1996-2012.



No	Town	Area (km²)	Population
1	Bac Lieu	175.7	132,400
2	Gia Rai	884.0	241,400
3	Hong Dan	807.3	246,275
4	Vinh Loi	774	176,175
	Total	2,594	856,250

Fig. 3. Location of Bac-Lieu wind farm.

2. Site and Data Description

Bac-Lieu is a city located in the south west of Vietnam. Bac-Lieu's border with the East Sea in the East is shown in Figure 3. The longitude and the latitude are 105.43º, and 9.17º, respectively. The area of Bac-Lieu is 2,594 km^2. The population was 960,630 people on Dec. 30/2012. Bac-Lieu city is a flat area, with no mountains, and has many rivers [11]. In general, the height of Bac-Lieu is about 3 m above sea level (AGL). The most important feature is that Bac-Lieu has a 54 km border with the sea so that it is an ideal location to develop an offshore wind farm. In the Power Planning VII of Vietnam Power Company, the Government decided to plant an offshore wind farm in Vinh-Trach-Dong commune, Bac-Lieu, Vietnam. The wind farm in Bac-Lieu city is designed for 99 MW rated capacities, using 60 individual units of 1.65 MW Vestas wind turbines (V82). At present, the wind farm has constructed 10 wind turbines and is connected to the grid to supply power. The daily wind data of this station was collected over a period of five years from 2006 to 2010 at the height 10 m AGL from local weather conditions in Bac-Lieu city.

3. Wind Resource

3.1. Wind Speed Analysis

The annual mean wind speed at 80 m height AGL is shown in Figure 4. It was observed that the mean wind speed is usually higher than 5 m/s. There were a few days slower than 5 m/s at the height 80 m height AGL. The wind turbine V82 has a cut-in wind speed at 3.5 m/s, so that the wind farm could produce energy during the whole year. The wind speeds get higher in spring and winter than in the other seasons. Vietnam is a tropical region, so that there are two main seasons: sunny and rainy seasons. Furthermore, most energy in Vietnam comes from hydropower plants. This means that in sunny season, there was a lack of electricity energy. The wind farm could help to solve this problem because the wind farm generated much power in the sunny season.

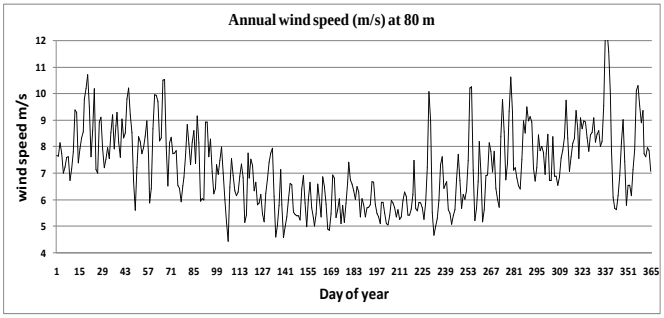


Fig. 4. Mean annual wind speed (m/s) distribution in Bac-Lieu wind farm.

3.2. Wind Direction and Frequency Distribution

The second important factor about wind data is the wind direction. The wind speed data of this station was divided into twelve direction's sectors: North, North-Northeast (NNE), Northeast (NE), East (E), Southeast (SE), South-Southeast (SSE), South (S), South-Southwest (SSW), Southwest (SW), West (W), Northwest (NW), and North-Northwest (NNW), as shown in Figure 5. The wind direction is needed information to conduct wind energy research and displays the impact of geographical features on the wind. According to this figure, the wind mostly comes from NNE, NE, and E 18%, 22%, and 23% of the time, respectively. The frequency distribution of the wind data shows that wind speeds are over 3.5 m/s about 85% of the time. At 10 m height and roughness length of 0.03 m, the mean wind speed

and wind power density were 4.68 m/s and 127 W/m^2, respectively. The shade and scale parameter were 5.27 m/s, and 1.88, respectively.

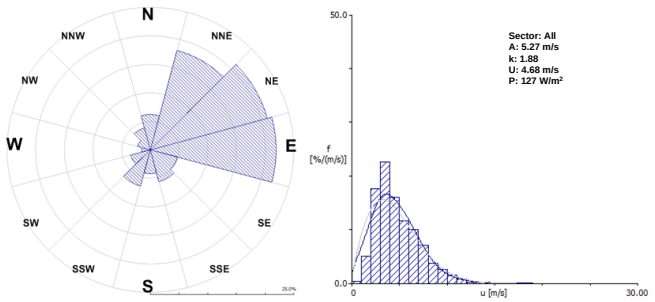


Fig. 5. Wind rose and frequency distribution of mean wind speed at 10 m height

3.3. Wind Energy Estimation

The wind data were measured at Bac-lieu station at a height of 10 m AGL. Because the station is located offshore, the roughness length α (α is from 0 m to 1.5 m) was chosen 0.03 m (for flat area). The WAsP used five reference roughness lengths of 0.00 m, 0.03 m, 0.10 m, 0.40 m, 1.50 m and five reference heights of 10 m, 25 m, 50 m, 100 m, 200 m AGL, as shown in Table 1.

Table 1. Regional wind climate summary

Height	Parameter	0.00 m	0.03 m	0.10 m	0.40 m	1.50 m
10 m	Weibull A [m/s]	7.69	5.27	4.58	3.57	2.39
	Weibull k	2.13	1.88	1.90	1.90	1.95
	Mean speed U	6.81	4.68	4.07	3.17	2.12
	Power density E	348	127	83	39	11
25m	Weibull A [m/s]	8.32	6.29	5.65	4.70	3.61
	Weibull k	2.15	1.99	2.00	1.99	2.03
	Mean speed U	7.37	5.57	5.01	4.17	3.20
	Power density E	437	203	147	85	38
50 m	Weibull A [m/s]	8.79	7.24	6.60	5.67	4.63
	Weibull k	2.17	2.17	2.16	2.13	2.16
	Mean speed U	7.79	6.41	5.85	5.02	4.10
	Power density E	511	286	217	140	75
100 m	Weibull A [m/s]	9.24	8.52	7.82	6.84	5.79
	Weibull k	2.08	2.33	2.37	2.36	2.39
	Mean speed U	8.18	7.55	6.93	6.06	5.13
	Power density E	617	439	336	225	135
200 m	Weibull A [m/s]	9.63	10.46	9.59	8.44	7.28
	Weibull k	1.92	2.30	2.33	2.32	2.38
	Mean speed U	8.54	9.27	8.50	7.48	6.45
	Power density E	759	821	627	428	269

At the same height of 10 m AGL, wind speed decreased when the roughness length increased from 0 m to 1.5 m. The wind powers density had the same trend with wind speed. However, the wind speed and wind power density is proportional with the hub height. At the same roughness length of 0.03 m, the wind speed and wind power density are 4.68 m/s, and 127 W/m^2 at 10 m hub height, while at 200 m height the wind speed and wind power density are 9.27 m/s, and 821 W/m^2, respectively. In addition, the Weibull scale parameter A increased from 7.69 m/s to 9.63 m/s when the height increased from 10 m to 200 m. However, it decreased from 7.69 m/s to 2.39 m/s when the roughness length increased from 0 m to 1.5 m. The Weibull shade parameter k varies around value 2. The peak value is 2.39 at 100 m height, and roughness length 1.5 m. The slowest value is 1.88 at 10 m height, and 0.03 m roughness length.

Table 2. Parameters of wind turbine used in the study:

Item	Value
Model	V82
Rate power (MW)	1.65
Rotor diameter (m)	82
Hub height (m)	80
Swept area of rotor (m²)	5,281
Cut-in-wind speed (m/s)	3.5
Rate wind speed (m/s)	13
Cut-out-wind speed (m/s)	20
Rotor speed (rpm)	14.4
Stator voltage (50 Hz. Operation)	690 V

The wind farm was simulated by WAsP 10 software. The detailed parameters of the wind turbine is shown in Table 2 [12]. The wind turbine used in this study is the Vestas 1.65 MW wind turbine. The rated power is 1.65 MW, with rotor diameter of 82 m. The hub height is 80 m. The wind turbine has cut-in wind speed at 3.5 m/s, rated wind speed of 13 m/s, and cut-out wind speed at 20 m/s. At wind speed more than 20 m/s, the wind turbine will stop generating power, as shown in Figure 6.

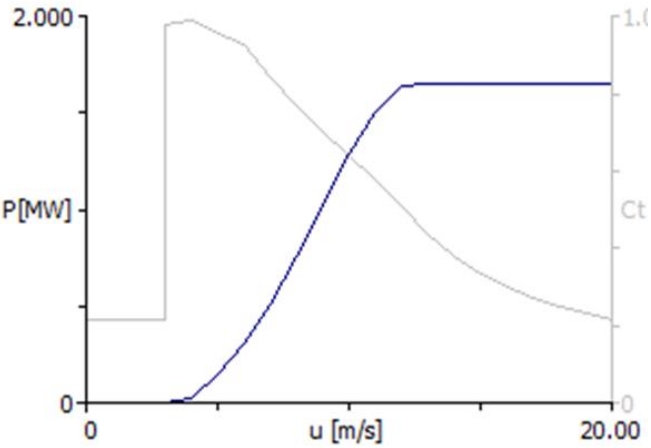


Fig. 6. Wind power curve of 1.65 MW Vestas wind turbines (V82).

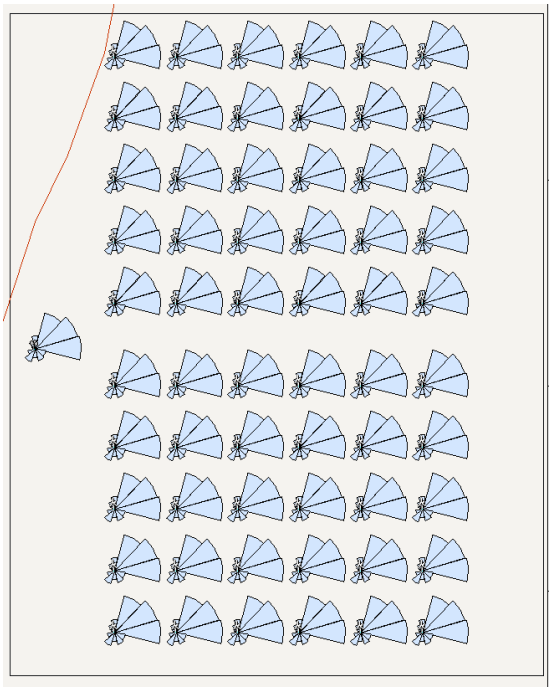


Fig. 7. Prediction of wind frequency in the Bac-Lieu wind farm.

Wind energy frequency can be observed from Figure 7. The most wind energy comes from North and East. This result matched the wind rose shown in the Figure 5. Unlike wind speed, wind power density is mostly from the Northeast, as shown in Figure 8.

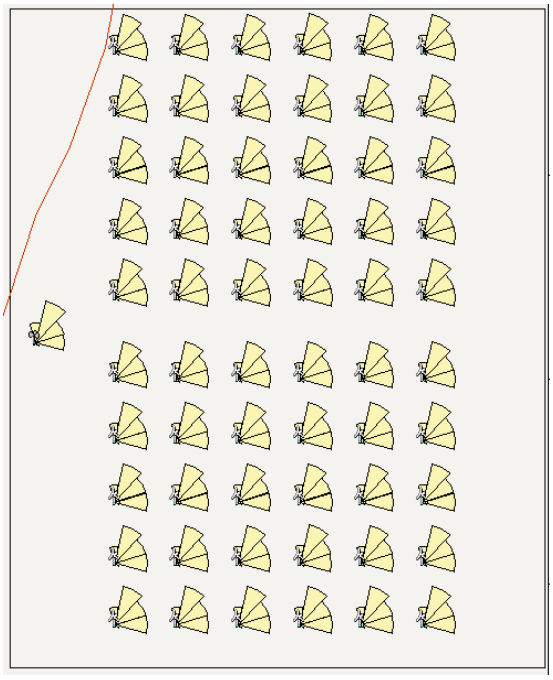


Fig. 8. Assessment of power density of the Bac-Lieu wind farm.

The wind energy production is shown in Table 3. The annual wind energy production was 332.100 [GWh]. The maximum energy production of one turbine was about 5.550 [GWh], and the minimum was 5.242 [GWh]. Wind turbine 18 produced the less energy. The most energy production comes from turbines 51 to 60, as shown in Figure 9. Turbines 41 to 60 produced more energy than wind turbines 1 to 40, due to effects of wake losses. In addition, effects of roughness, obstacles, and orographic were assumed zero in the analysis. According to [13], an offshore wind farm producing one kWh electricity could save about 700 grams of CO_2 GHG. The Bac-Lieu wind farm will produce 332.1 GWh/yr so that will prevent 232,470 tons CO_2 per year. The average lifetime of a wind turbine is assumed 20 years. This means that the wind farm could prevent 4,649,400 tons CO_2 emission into the atmosphere of Bac-Lieu city. In addition, the average electricity consumption of a household in Vietnam is 500 kWh per month. When the wind farm is completes and commercially operational, it will supply electricity for more than 650,000 households in this region.

Table 3. Summary results of wind energy production for the Bac-Lieu wind farm

Parameter	Total	Average	Min	Max
Net AEP [GWh]	325.283	5.421	5.101	5.550
Gross AEP [GWh]	332.100	5.535	5.242	5.568
Wake loss [%]	2.05	2.052	0.310	2.850

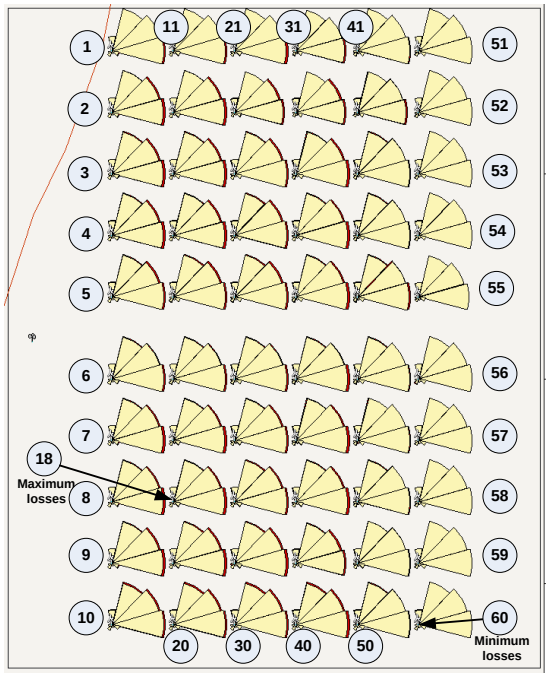


Fig. 9. Annual energy production gross and wake losses of the Bac-Lieu wind farm.

4. Wind Farm Economic Analysis

In the last decade, many researchers have used RETScreen International software to analyze the economics of wind farms [3, 14-16]. The wind farm economic analysis in this study was also carried out based on the RETScreen International software. The details of the costs related to the wind farm involved in the analysis were given in reference [17]. On the 19th of September, 2011, the Prime Minister of Vietnam issued Decision No 37/2011/QĐ-TTg about incentives and grants for the development of wind energy in Vietnam [18]. The financial parameters of the wind farm are

shown in Table 4. In which the inflation rate, debt ratio, debt interest rate, and debt term were 5%, 70%, 6%, and 15 years, respectively. Table 5 shows the initial and annual costs and debt payments of the wind farm. The total initial cost is $198,100,000 USD, and the total annual cost is $16,377,846 USD. Table 6 summarizes the annual saving and profit of the wind farm. As seen from the Table 6, the profit from electricity exportation and GHG reduction are $38,505,456 USD, and $1,053,445 USD, respectively. In addition, the simple payback is 5.2 years. The cumulative cash flows are shown in the Figure 10. As given in this figure, after 20 years the cumulative cash flows reached over $1 billion USD.

Table 4. Financial parameters of the Bac-Lieu wind farm

Financial parameters	Unit	Amount
Inflation rate	%	5
Project life	yr	20
Debt ratio	%	70
Debt interest rate	%	6
Debt term	yr	15

Table 5. Initial costs of the Bac-Lieu wind farm

Initial costs	Unit	Amount
Power system	$	188,100,000
Other	$	10,000,000
Total initial costs	$	198,100,000
Incentives and grants	$	5,000,000
Annual costs and debt payments		
O&M (savings) costs	$	2,100,000
Fuel cost - proposed case	$	0
Debt payments - 15 yrs	$	14,277,846
Total annual costs	$	16,377,846

Table 6. Annual saving and profit of the Bac-Lieu wind farm

Annual savings and profit	Unit	Amount
Fuel cost - base case	$	0
Electricity export income	$	38,505,456
GHG reduction income - 21 yrs	$	1,053,445
Total annual savings and profit	$	39,558,901
Financial viability		
Pre-tax IRR - equity	%	53.2
Pre-tax IRR - assets	%	18.4
Simple payback	yr	5.2
Equity payback	yr	2.1

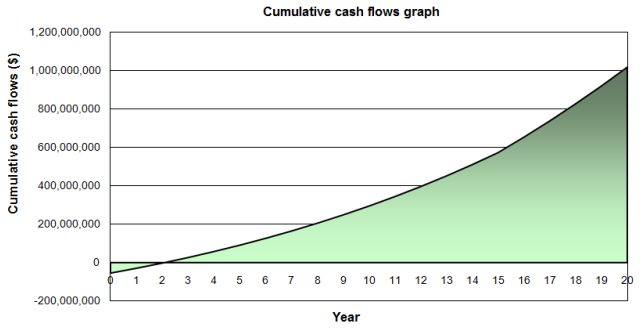


Fig. 10. Cumulative cash flows of the Bac-Lieu wind farm

5. Conclusion

This study carried out wind energy potential evaluation and economic analysis for the practical 99 MW wind farm in Bac-Lieu, Vietnam. The wind farm had 60 Vestas 1.65 MW wind turbines. This study used the long-term annual wind data at 10 m height AGL. The research concludes as follows:

- At the end of 2012, the new annual global wind installed capacity was 44,711 MW. The global cumulative installed capacity was 282,430 MW. Asia has the largest installed capacity with 15,750 MW.
- In Bac-Lieu wind farm, at 80 m AGL and roughness length 0.03 m, the annual mean speed was 7.2 m/s. In addition, the most wind energy comes from the Northeast direction.
- The 99 MW wind farm with 60 units of 1.65 MW Vestas wind turbines could produce about 325 GWh/year for the power system.
- The Bac-Lieu wind farm could cause a reduction of 232,470 ton of CO2 per year compared with fossil fuels. This can contribute to create a clean and healthy atmosphere for Bac-Lieu city and the region as well.
- Most losses were wake losses with 2.05% of the gross average energy production. Wind turbines 1 to 40 will have more losses than wind turbines 41 to 60 due to wake effects.
- In the economic analysis, the total initial cost was $198,100,000 USD and the total annual cost was $16,377,846 USD.
- The total annual saving and profit was about $39,558,901 USD. The equity payback and simple payback of the wind farm were 2.1 years, and 5.2 years, respectively.

References

[1] GWEC, "global wind statistics 2012," ed, 2013.

[2] Y. Himri, S. Himri, and A. Boudghene Stambouli, "Assessing the wind energy potential projects in Algeria," Renewable and Sustainable Energy Reviews, vol. 13, pp. 2187-2191, 2009.

[3] Y. Himri, S. Rehman, A. Agus Setiawan, and S. Himri, "Wind energy for rural areas of Algeria," Renewable and Sustainable Energy Reviews, vol. 16, pp. 2381-2385, 2012.

[4] T. H. Chen, V. T. Tran, N. C. Yang, and T. Y. Hsieh, "Wind Energy Potential in Taiwan," Applied Mechanics and Materials pp. 1062-1066, 2013.

[5] V. T. Tran, T. H. Chen, and T. Y. Hsieh, "Assessment of Renewable Energy Potential at Hengchun in Taiwan," ed: ACTA Press, 2012.

[6] C. Hasager, L. Rasmussen, A. Peña, L. Jensen, and P.-E. Réthoré, "Wind Farm Wake: The Horns Rev Photo Case," Energies, vol. 6, pp. 696-716, 2013.

[7] A. Rodríguez, F. Huerta, E. Bueno, and F. Rodríguez, "Analysis and Performance Comparison of Different Power Conditioning Systems for SMES-Based Energy Systems in Wind Turbines," Energies, vol. 6, pp. 1527-1553, 2013.

[8] N. Golovanov, G. Lazaroiu, M. Roscia, and D. Zaninelli, "Power Quality Assessment in Small Scale Renewable Energy Sources Supplying Distribution Systems," Energies, vol. 6, pp. 634-645, 2013.

[9] T. Considine and E. Manderson, "Balancing Fiscal, Energy, and Environmental Concerns: Analyzing the Policy Options for California's Energy and Economic Future," Energies, vol. 6, pp. 1266-1297, 2013.

[10] V. T. Tran, T. H. Chen, and T. Y. Hsieh, "Wind Energy Potential in Vietnam," ed: ACTA Press, 2012.

[11] Bac Lieu Map. Available: http://www.amitourist.com/

[12] Vestas V82 wind turbine. Available: http://www.vestas.com/files%2ffiler%2fen%2fsustainability%2flca%2flca_v82-1.65_mw_onshore.pdf

[13] M. Pehnt, M. Oeser, and D. J. Swider, "Consequential environmental system analysis of expected offshore wind electricity production in Germany," Energy, vol. 33, pp. 747-759, 2008.

[14] M. Ertürk, "The evaluation of feed-in tariff regulation of Turkey for onshore wind energy based on the economic analysis," Energy Policy, vol. 45, pp. 359-367, 2012.

[15] Y. Himri, S. Rehman, B. Draoui, and S. Himri, "Wind power potential assessment for three locations in Algeria," Renewable and Sustainable Energy Reviews, vol. 12, pp. 2495-2504, 2008.

[16] Y. Himri, A. Boudghene Stambouli, and B. Draoui, "Prospects of wind farm development in Algeria," Desalination, vol. 239, pp. 130-138, 2009.

[17] RETScreen International. Available: http://www.retscreen.net/ang/home.php

[18] N. T. Dung. (2011). Mechanism Supporting Wind Power Development Projects in Vietnam. Available: www.stipc.soctrang.gov.vn/wps/portal