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Economic feasibility of small wind turbines for domestic consumers in Egypt based on the new Feed-in Tariff

Suzan Abdelhady[a,b*], Domenico Borello[c], Simone Santori[c]

[a]Dipartimento di Ingegneria Astronautica, Elettrica ed Energetica, Sapienza Università di Roma, Via Eudossiana 18, 00184 Rome, Italy

[b]Department of Electrical Engineering, Fayoum University, 63514 Fayoum, Egypt

[c]Dipartimento di Ingegneria Meccanica e Aerospaziale, Sapienza Università di Roma, Via Eudossiana 18, 00184 Rome, Italy

Abstract

This paper provides an overview of the wind power potential at different regions in Egypt, along the Mediterranean and Red Sea, and the Western desert. A further technical and economic assessment is conducted for the electricity generation with 8 different small wind turbines at 17 locations. The annual electricity generation from selected wind turbines is evaluated. The obtained data are presented and discussed investigating the net present value and the payback period analyzing the profitability of selected wind turbines. The dependence of the turbine profitability from the feed-in tariff is specifically addressed.

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Keywords: Wind energy; Economic feasibility, Feed-in tariff; Mediterranean and Red Sea; Western Desert; Egypt.

1. Introduction

Global warming and depletion of fossil fuels is strongly pushing the world towards the use of renewable energies. Several countries around the world already have shares of renewable energy in electricity production above 20%. Total renewable power capacity worldwide in 2012 increased by 8.5% compared to 2011. The top countries for renewable power capacity at the end of 2012 were China, the United States, Brazil, Canada, and Germany [1]. Wind power accounted for about 39% of renewable power capacity added in 2012, followed by hydropower and solar PV, each accounting for approximately 26%. The wind power production is growing annually by 20%, with global installed capacity of 318 GW at the end of 2013 [2], and the growth is relevant in Europe, Asia, and the United States. Europe accounted for 38% of the global installed wind power capacity at the end of 2013, Asia for 36% and North America (including USA, Canada, and Mexico) for 22% [2]. USA accounted for 86% of the total installed wind power capacity in North America [2].

1.1. Current potential of wind energy in Egypt

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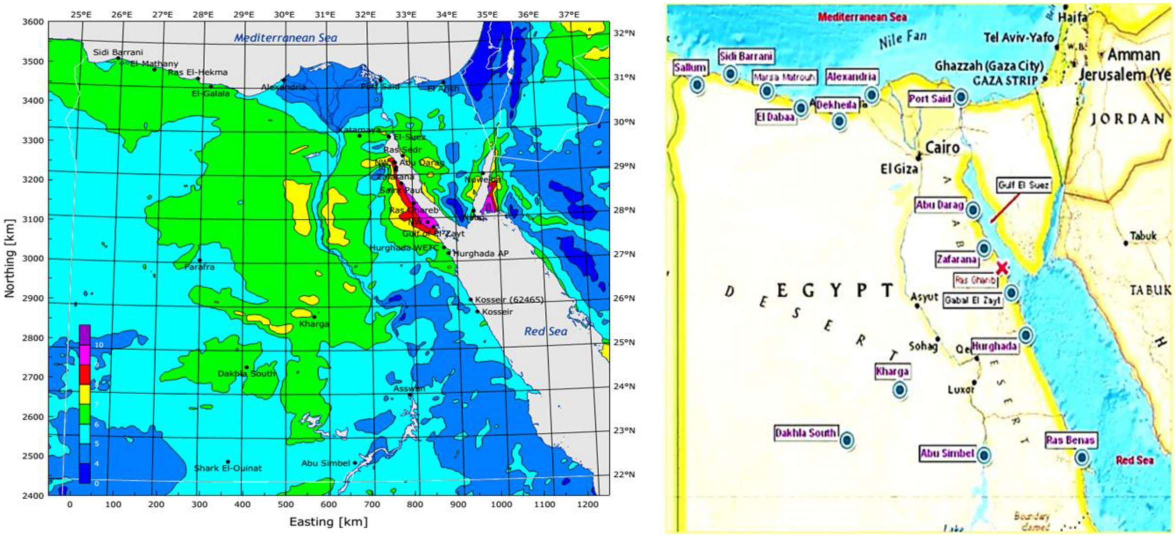
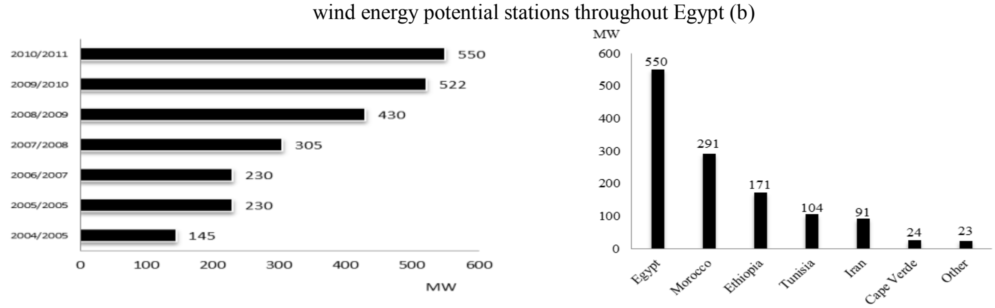
Egypt is endowed with natural resources and enormous potentials of renewable energy, especially solar [3], biomass [4] and wind, which encourages implementing renewable energy projects in the country. In terms of wind energy, Egypt has an excellent wind regime in almost all regions, due to the favorable topography (it has an important role in accelerating and deflecting the wind) [5]. The Egyptian wind atlas (Fig.1a), issued in 2005, indicates that there are many promising areas with high wind speeds such as the Gulf of Suez, some areas located on both sides of the Nile River, some areas in Sinai, in the western desert, and along the coasts of the Mediterranean and Red sea .

During the past few years, Egypt emerged as a regional leader in the Middle East and Africa in the field of exploiting wind energy for electricity generation. The first wind turbine in Egypt was built in Ras Gharib (see Fig.1b) on the Red Sea coast in 1993, with a capacity of 400 kW, and currently, the total installed capacity of wind power is 550 MW. Figure 2a shows the evolution of wind power installed capacity in Egypt [6]. Figure 2b shows that the majority of installed wind energy capacity in Africa and Middle East Region is present in Egypt with a total installed capacity of 550 MW according to the data of Global Wind Energy Council (GWEC) [2].



(a) (b)

Fig.1 Wind resource map of Egypt: mean wind speed at 50 m a.g.l. determined by mesoscale modeling [7] (a), Distribution of wind energy potential stations throughout Egypt (b)



(a) (b)

Fig.2 Evolution of wind power installed capacity in Egypt [6] (a), Wind power installed capacity– Africa and Middle East at the end of 2013 [2] (b)

1.2. Wind strategy including feed-in tariff

Egypt efforts are directed to achieve a contribution of renewable energies by 20% of the total electricity generation with wind power share of 12% by the year 2020. According to Egyptian Electric Utility and Consumer Protection Regulatory Agency (EEUCPRA) [8], in October 2014 Egypt has set new feed-in tariff for electricity generated by new and renewable energy sources for households and private sector investments. The goal is to reach 2000 MW through effects of medium and small developers. Tariffs will be generated for 20 years taking into consideration the wind speed and capacity. Table 1a shows the feed-in tariff categories. The feed-in tariff will be restricted for the small capacities (less than 50 MW installations) as the international experience has shown that the feed-in tariff is more attractive for smaller investors like farmers, cooperatives, and private investors. Egypt has an excellent wind regime which can satisfy this goal but further assessment studies are needed for the potential sites in the country, considering the new feed-in tariff. This paper provides a technical and economic assessment for the electricity generation with 8 different small wind turbines (Table 1b) at 17 locations including Cairo (Fig.1b).

Table 1 Feed-in tariff categories in Egypt (a) [8], Investment cost C_I and technical data of the selected wind turbines (b) [9]

(a)

Number of operation hours at the rated capacity	First five years (€/kWh)	15 years (€/kWh)
2500	0.09	0.09
2600		0.08
2700		0.08
2800		0.07
2900		0.06
3000		0.06
3100	0.08	0.07
3200		0.06
3300		0.06
3400		0.06
3500		0.05
3600		0.05
3700		0.05
3800		0.04
3900		0.04
4000		0.04

(b)

	C_I (€/kW)	Rated power (kW)	Hub height (m)	Cut in speed (m/s)	Rated speed (m/s)	cut off speed (m/s)
Are110	7700	2.5	13	2.5	11	15.5
Ampair	4200	6	15	3.5	15	17
Fortize	6600	10	30	4	12	15
Jacobs	4300	20	36	3.5	11.6	17.8
Hz30	2400	30	18	3	12	20
Ridreven	3000	50	36	2	11	18
WES18	2500	80	30	2.7	12.5	25
WES30	1700	200	40	2.7	12.5	25

2. Wind turbine capacity factor and output energy

When evaluating the performance of a wind turbine at specified site, it is important to estimate the capacity factor [10-11]. The capacity factor of a wind turbine is the ratio of the average output power of the turbine over a period of time to its potential output if it had operated at rated capacity the entire time (see Eq. (1)) [12-13]:

$$C_f = \frac{P_{ave}}{P_{rated}} \quad (1)$$

$$P_{ave} = \int_{vcutin}^{vcutout} p(v) f(v) dv \tag{2}$$

P_{rated} is the turbine rated power. The average output power of a wind turbine (P_{ave}) can be estimated as Eq. (2) where the probability density function $f(v)$ represents the fraction of duration of wind speed *v*. The most commonly used model to express the wind speed probability distribution *f(v)* is the Weibull distribution [14-16]. $p(v)$ is wind turbine output power curve [9]. Average long-term wind speed data at 10 m hub height are obtained from Ref [7], and [14-18]. The wind speed at turbine hub height can be estimated by Eq. (3) [19-21]. where α denotes wind shear coefficient and it depends on the time of the day, the wind speed level, the wind stability and the surface roughness, and is computed from Eq. (4) [22]. According to the power curve of the selected wind turbines [9] the capacity factor of the selected wind turbines for all the stations are calculated at the turbine hub height. Then the calculation of the average energy production of a turbine can be calculated for one year once C_f is known as Eq. (5). Figure 3 shows the average energy production of selected wind turbines at selected sites.

$$V_h = V_{10}\left(\frac{h}{10}\right)^{\alpha} \tag{3}$$

$$\alpha = 0.37 - 0.0881 \ln V_{10} \tag{4}$$

$$E_{out} = 8760\, C_f P_{rated} \tag{5}$$

3. Feed-in tariff assessment

The results of the annual electricity generation from selected wind turbines at the selected sites were used to investigate the FiT rates. The FiT must take into account length of the contract, interest rate, and number of operation hours at the rated capacity of wind turbine. The net present value (NPV) will essentially include the income from the sale of electricity generated. The capital investment plus the accumulated value of annual operation and maintenance costs constitute the payments. The net present value is represented as follow [23]:

$$NPV = FiT * E_{out}\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] - C_I\left[1 + O_c\left(\frac{(1+i)^n - 1}{i(1+i)^n}\right)\right] \tag{6}$$

- FiT= the electricity price based on the Egyptian feed-in tariff categories (Table1a)
- E_{out} = the annual energy generated by the wind turbine (Fig.4);
- C_I = Initial investment cost; which includes the following costs: the wind turbine cost, and other initial cost including, land cost, power block system, labour cost, connection transmission line, and substation, and the transportation cost. The initial investment cost of the selected wind turbines is shown in Table 1b.
- O_c = the operation and maintenance cost of wind turbine in the first year. 2% of the total investment costs ;
- i = the interest rate. 4% for the wind turbine capacity up to 200kW and 8% for wind turbine capacity from 200kW to 500kW;
- n = the useful life time of turbine in years (20 years).

4. Results and discussion

Figure 4 and 5 represents the payback period and NPV respectively of selected wind turbines at selected sites. The NPV and Payback period (PBP) have been assessed based on the annual energy production by the selected wind turbines and the number of hours corresponding to the wind rated power. Payback period (PBP) for each turbine was calculated and shows length of time which could recover initial investment for the wind turbines. Figure 4 shows that PBP of WS30 is smaller than useful life of the selected turbines at all selected sites which mean that it is acceptable to be considered. Are110 is not acceptable for the all selected sites because its PBP is greater than 20 year. WSE18, Ridreven 55kw and Jacobs 31-20 are acceptable at all sites except Cairo. Ampair 6000x5.5 is acceptable only at four sites (Gabal El Zayt, Ras Gharib, Zafarana, Abu Darag, and Hurghada). Fortize Alize is acceptable only at Gabal El Zayt, and Ras Gharib. Hz 30kw is acceptable at all selected sites except Cairo Alexandria Dekheila, Sallum, and Abu Simbel. According to NPV (Fig.5) only three models (WES18, WES30, and Hz 30 kW) of wind turbines can be economic feasible. WSE30 is economically feasible to be installed 11 locations. WSE18 is economical feasible at four sites (Gabal El Zayt**,** Ras Gharib, Zafarana, Abu Darag). Hz 30 kW is economic feasible at only Ras Gharib. The results show that variability and low price of Feed-in Tariff in Egypt is a major factor for this case.

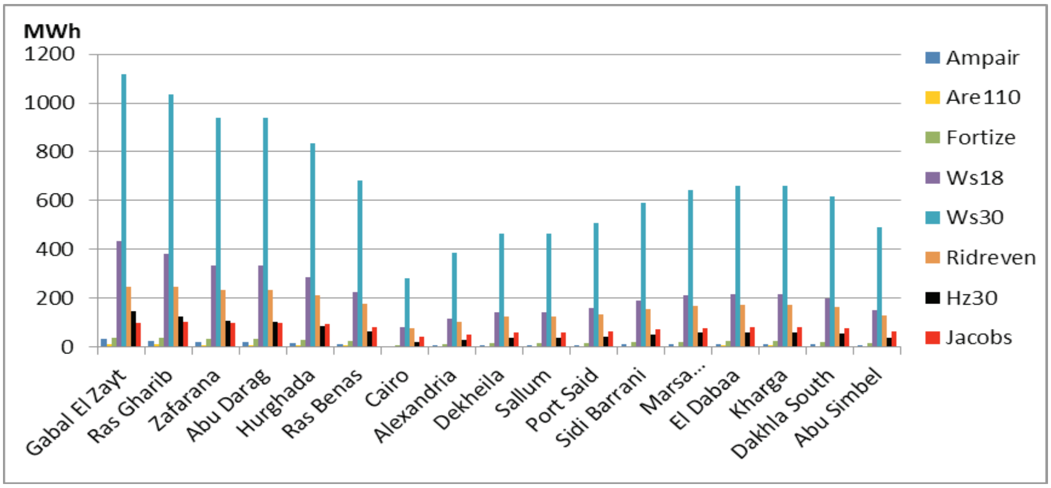


Fig.3 Annual energy production of selected wind turbines at all selected sites

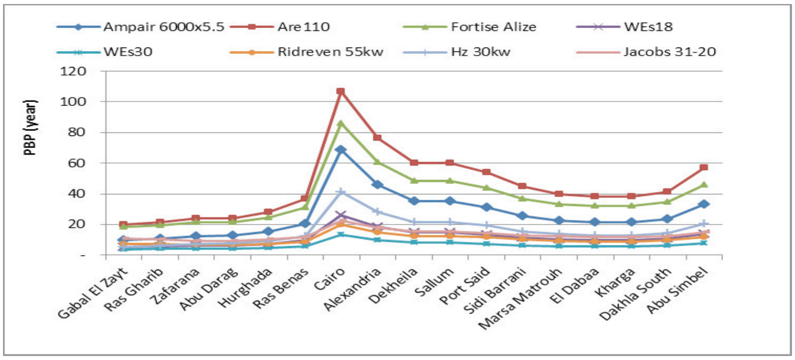


Fig.4 Payback period of selected wind turbines at all selected sites

5. Conclusion

Average long-term wind speed data of the selected sites has been used to investigate the economic value of small wind turbines. The most important results of the present study can be summarized as follows:

- Adoption of wind turbines with rated power more than 200kW is recommended.
- WS18 and WS30 are the most economic feasible wind turbines.
- Despite the high wind regime of the selected sites, the small wind turbines are not economic feasible.
- The obtained results show that, in the considered locations, the reduced value of the Feed-in tariff is a detrimental factor affecting the small wind turbines profitability. If FiT will increase in the future, it will be possible to reconsider the economic convenience of the small wind turbine.
- Further research needs to extend such feasibility analysis by using wind turbine with rated power higher than 200 kW to investigate applicability of the present Feed-in tariff.

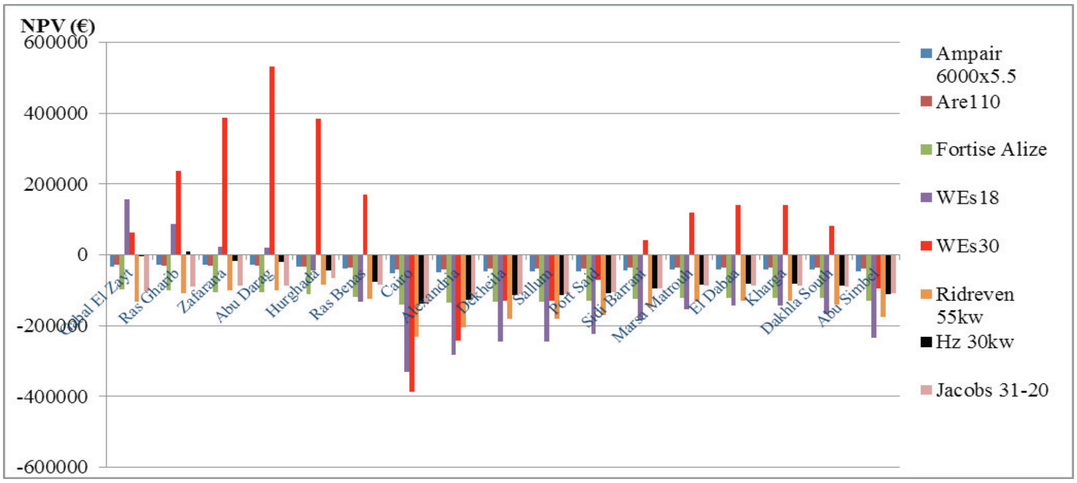


Fig.5 NPV of selected wind turbines

References

[1] REN21, "Renewables 2013: Global Feature Report," IRENA, 2013. [Online]. Available: http://www.ren21.net/portals/0/documents/resources/gsr/2013/gsr2013_lowres.pdf. [Accessed: 28-Jun-2014].
[2] GWEC, "GLOBAL WIND STATISTICS: 2013," GWEC, 2014. [Online]. Available: http://www.gwec.net/wp-content/uploads/2014/02/GWEC-PRstats-2013_EN.pdf. [Accessed: 30-Jun-2014].
[3] S. Abdelhady, D. Borello, and E. Tortora, "Design of a small scale stand-alone solar thermal co-generation plant for an isolated region in Egypt," Energy Convers. Manag., vol. 88, pp. 872–882, Dec. 2014. Doi:10.1016/j.enconman.2014.08.066
[4] S. Abdelhady, D. Borello, A. Shaban, and F. Rispoli, "Viability Study of Biomass Power Plant Fired with Rice Straw in Egypt," Energy Procedia, 2014, vol. 61, pp. 211-215. Doi:10.1016/j.egypro.2014.11.1072
[5] M. Rizk, "Wind characteristics and the available wind energy in egypt," Sol. Wind Technol., vol. 4, no. 4, pp. 491–499, Jan. 1987.
[6] NREA, "New & Renewable Energy Authority (NREA). Annual Report 2011-2012," NREA, 2012. [Online]. Available: http://www.nrea.gov.eg/annual report/ANNUAL_EN_2011_2012.pdf. [Accessed: 28-Jun-2014].
[7] N. Mortensen, U. Said, and J. Badger, Wind Atlas of Egypt. 2006.
[8] ECUCPRA, "Egyptian Electric Utility And Consumer Protection Regulatory Agency," 2014. [Online]. Available: http://egyptera.org/en/. [Accessed: 27-Oct-2014].
[9] M. Bortolini, M. Gamberi, A. Graziani, R. Manzini, and F. Pilati, "Performance and viability analysis of small wind turbines in the European Union," Renew. Energy, vol. 62, pp. 629–639, Feb. 2014.
[10] M. H. Albadi and E. F. El-Saadany, "Wind Turbines Capacity Factor Modeling—A Novel Approach," IEEE Trans. Power Syst., vol. 24, no. 3, pp. 1637–1638, Aug. 2009.
[11] S. H. Jangamshetti and V. G. Ran, "Optimum siting of wind turbine generators," IEEE Trans. Energy Convers., vol. 16, no. 1, pp. 8–13, Mar. 2001.

[12] T. Ayodele, A. Jimoh, J. Munda, and J. Agee, “Wind distribution and capacity factor estimation for wind turbines in the coastal region of South Africa,” Energy Convers. …, 2012.
[13] S. Hu and J. Cheng, “Performance evaluation of pairing between sites and wind turbines,” Renew. Energy, vol. 32, no. 11, pp. 1934–1947, Sep. 2007.
[14] Y. A. Hamouda, “Wind energy in Egypt: Economic feasibility for Cairo,” Renew. Sustain. Energy Rev., vol. 16, no. 5, pp. 3312–3319, Jun. 2012.
[15] A. S. Ahmed Shata and R. Hanitsch, “The potential of electricity generation on the east coast of Red Sea in Egypt,” Renew. Energy, vol. 31, no. 10, pp. 1597–1615, Aug. 2006.
[16] A. S. Ahmed Shata and R. Hanitsch, “Evaluation of wind energy potential and electricity generation on the coast of Mediterranean Sea in Egypt,” Renew. Energy, vol. 31, no. 8, pp. 1183–1202, Jul. 2006.
[17] A. S. Ahmed, “Analysis of electrical power form the wind farm sitting on the Nile River of Aswan, Egypt,” Renew. Sustain. Energy Rev., vol. 15, no. 3, pp. 1637–1645, Apr. 2011.
[18] I. Helal, A. M. Atallah, and M. A. Samy, “Electrical power analysis of Zayt Gulf onshore wind farm,” in 2012 IEEE Power and Energy Society General Meeting, 2012, pp. 1–8.
[19] G. Gualtieri and S. Secci, “Methods to extrapolate wind resource to the turbine hub height based on power law: A 1-h wind speed vs. Weibull distribution extrapolation comparison,” Renew. Energy, 2012.
[20] A. N. Celik, “A Techno-Economic Analysis of Wind Energy in Southern Turkey,” Int. J. Green Energy, vol. 4, no. 3, pp. 233–247, May 2007.
[21] E. K. Akpinar and S. Akpinar, “An Analysis of the Wind Energy Potential of Elazig, Turkey,” Int. J. Green Energy, vol. 1, no. 2, pp. 193–207, Dec. 2004.
[22] C. Justus and A. Mikhail, “Height variation of wind speed and wind distributions statistics,” Geophys. Res. Lett., 1976.
[23] S. Mathew, Wind Energy. Berlin, Heidelberg: Springer Berlin Heidelberg, 2006.

Biography

Suzan Abdelhady is a Research and Teaching Assistant in Electrical Engineering Department, Fayoum University, Fayoum, Egypt. Currently, she is conducting her PhD research in renewable energy technologies at the University of Rome ‘La Sapienza’, Rome, Italy. Her research interests are in assessment of renewable energy potentials in Egypt.