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Evaluating the Performances of Small Wind Turbines: A Case Study in the South of Italy

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Abstract

Among renewable energy resources, wind energy became more attractive in the last decade. Wind farms installations dramatically increased in areas where climatic conditions, topography and environment have allowed their development. The installation of wind turbines, usually carried out in remote areas, recently began to cover areas identified by a complex terrain such as urban and suburban zones. Although these new sites' choices are characterized by lower productivity there is increasing interest in wind energy production in both urban and suburban area. In this work the authors have carried out an energy analysis developed from a sample of small wind turbines available on the market. This study shows how variable can be the energy production of a small wind turbine according to many design and context parameter: wind profiles, installation height, land use, characteristics of the turbine.

Keywords: Renewable energy; wind energy; small wind turbines; wind profiles; installation height.

1. Introduction

In the last years, due to the boom of renewable energy, the attention of researchers toward wind power has had a rapid increase. Otherwise, the increment of the world energy demand, mainly fulfilled by fossil fuels has brought to an increment in greenhouse gas emissions. A reduction in the greenhouse gas emissions can be achieved by implementation of several actions: increasing energy plants efficiency, energy saving and recovery in the industrial field, renewable energy systems growing [1-4].

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Nomenclature

HAVT	Horizontal Axis Wind Turbine
VAWT	Vertical Axis Wind turbine
DIA	Simple declaration of the opening activity
GC	Green certificate
α	Wind shear exponent
c	Scale factor (m/s)
h_0	Surface roughness
n	Wind speed bins
k	shape factor (dimensionless)
$H(U_i)$	Number of hours in wind speed bin U_i
$P(U_i)$	Power output at that wind speed
s	Calm wind frequency (in percentage)
$t(v)$	Weibull distribution
v	Wind speed (m/s)

The anemological characterization of a site is crucial for exploiting wind energy. Many studies, reported in the literature, have focussed on the estimation of the potential of wind power in different parts of the world and concerning the calculation of wind speeds frequency distribution [5-8].

In the literature are also present other studies focussed on extrapolation of the vertical profile of wind speeds [9, 10]. However, these articles have focussed on large-scale turbines and few are the examples on the potential of wind energy production in urban and suburban areas [11]. As is well known wind energy can be used not only in large systems but also in small installations. Thanks to advances in this technology and to the recent introduction of specific economic incentives [12, 13]. These power generation systems are showing a real growth opportunity. However, the efficacy of an energy policy based on the use of these systems is not possible without a preliminary analysis of the sites aimed at addressing the use of financial resources instead of sites characterized by good energy potential. The choice and location of a small turbine in a site where air velocity may be strongly influenced by the presence of natural or artificial obstacles is not an easy task. Reliable evaluation of the energy production requires good information about wind and site characteristics. The aim of this study is to present an energy analysis developed on a set of small-scale turbines available on the market to be installed in a suburban area of Sicily.

2. Italian regulatory framework

The first norms suitable for regulatory authorization procedures for the encouragement of systems to produce electricity from small wind turbines (power systems less than or equal to 200 kW), are introduced in Italy with the Financial Law 2008 and the Ministerial Decree dated 18/12/2008 on “Incentives of electricity generation from renewable sources”.

By the establishment of the regional energy master plan and documents of territorial planning, the Financial Law 2008 forwards to the regional wind power Regulation the opportunity to decide the sites in which it is possible to build wind farms and regulate the size of the system above which an environmental impact assessment is required.

The Italian legislation provides that the systems in size up to 60 kW, installed in areas in which there is no Special Protection Area or Sites of Community Importance is authorized by a simple declaration of activity's opening (DIA) by the municipality in whose territory the installation site is located.

For systems over 60 kW, or if the installation is in proximity of protected areas, the regions and provinces established the need to perform an environmental impact assessment process in order to obtain the necessary qualifying title: DIA/Unique Authorization.

For lines in the 6 MW the partner for the practice of connecting is the local power distributor. After doing an inspection it must agree for connection according the electrical standards of the wind turbine. It must also provide the detail of expenditure to be incurred the authorization process and for any works to be carried out in order to adjust the network connection.

The Finance Law, indicates the incentive recognized to system between 1 kW and 200 kW in the form of the Energy Account is 300 €/MWh for energy produced and fed into the network (in low or medium voltage).

This incentive, comprehensive of quota sale replaces the green certificate (GC), which is not always advantageous. The GC should be treated as a title on the appropriate market and it is often realized at a figure less than the nominal value.

The opportunities offered by the new Italian regulatory framework allow to address greater attention to a potential market of larger size compared to what was done until today and promised a significant spread of wind turbines of small and medium size, until now neglected.

It is assumed that this will lead to reduced costs of industrial development, distribution and greater competitiveness of the technology.

3. Small wind turbines available on the market

Wind turbines convert wind kinetic energy into mechanical power. It consists of a certain number of blades (usually three) fixed to a crankshaft. There are two kinds of wind turbines: the vertical axis design (VAWT – Vertical Axis Wind turbine) and the horizontal axis design (HAVT – Horizontal Axis Wind Turbine). The small turbines with horizontal axis have benefited from the advancement made by machines of big size.

Generally, the smaller turbine have fixed blades and are regulated for tilt or yaw while the slightly larger size are often equipped with control systems for pitch control.

The VAWT, helped by their low environmental impact are better adapted to be installed nearby the residential and urban areas because they have lower start-up speed and low noise level. These are also appropriate to be installed in areas with strong winds; the VAWT are indifferent to wind direction.

In this paper a set of wind turbines subdivided into six size classes (class 0.5 ÷ 1.8 kW, class 2 ÷ 3.5 kW, class 5 ÷ 6 kW, class 10 ÷ 12.5 kW, class 15 ÷ 17.5 kW and class 20 ÷25 kW) will be analyzed. For each class the authors have considered small turbines with horizontal axis and vertical axis.

The power classes and the codes are shown in Table 1. As an example, Table 2 shows respectively the technical data for turbine with code HAWT1.

Table 1. Set of wind turbines subdivided into power class

Power classes	Code
Class 0.5 – 1.8 kW	HAWT1
	VAWT1
Class 2 – 3.5 kW	HAWT2
	VAWT2
Class 5 - 6 kW	HAWT3
	VAWT3
Class 10 – 12.5 kW	HAWT4
	VAWT4
Class 15 – 17.5 kW	HAWT5
	HAWT5a
Class 20 - 25 kW	HAWT6
	VAWT6

Table 2. Technical data for turbine HAWT1

Wind turbine	Technical Data	
HAWT1	Nominal Power	1 kW
	Rotor diameter	2.7 m
	Cut-in wind speed	3.5 m/s
	Cut-off wind speed	50 m/s
	Rated wind speed	10 m/s
	Security wind speed	50 m/s
	Weight nacelle	50 Kg
	Weight tower	45 Kg
	Price per kW	1,980 €/kW

4. Energy analysis

The study of wind geographical distribution is often carried out through the creation of wind maps. With these maps, however, one loses the ability to keep into account the local phenomena related, for example, to the orography of the area.

Consequently, the knowledge of the territory combined with analysis of wind data detected are essential for the correct choice of the site, of the turbine to be installed, for the electricity production and therefore for the validity of the project. This work was carried out using wind data recorded by an anemometric station located in Mazzara Del Vallo (see Fig. 1). The wind speed sensor is installed at height 10 m. The available data span over a period of six years. The statistical distribution of wind speeds was considered for 2 different land types: “rural area” and “suburban area”. In the evaluation of energy capability of a system two key aspects are considered: the characteristics of the wind in the sites under consideration and the features of the turbine to be installed.

Fig. 1. Localization of anemometric stations

In order to calculate the power from a wind turbine over a range of wind speeds, a generalised expression is needed for the probability density distribution. An expression which gives a good fit to wind data is known as the Weibull distribution:

$$t(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{1}$$

where v is the wind speed (m/s), c is the scale factor (m/s) and k is the shape factor (dimensionless).

The scale parameter is related in a univocal way to the average speed, is directly proportional to it and its value does not differ very much from it. The shape factor is a dimensionless term characterizing the amplitude of wind speed dispersion around the mean. This parameter, such as the scale parameter, is typical of the site under investigation and should be given by a measurement campaign. When this is not possible, one should use a guide value based on the climatic conditions of the area under study or similarity to other sites in the same climatic area. The shape factor is therefore an irregularity index of the wind regime. Mountain areas and urban areas characterized by very irregular winds have values of k between 1 and 1.5, ocean areas with very regular winds have a value between 2.5 and 4, the coastal areas in temperate areas have a value of k around 2. The Weibull expressed by equation (1) falls into defect when the wind speed is null. In order to take this into account the calm wind frequency (in percentage) must be considered. Globally, calm frequency does not exceed 9.98%. Because each turbine can be installed on towers at different heights, it is necessary to calculate the wind speed v according to quota h (vertical velocity profile). This speed is usually expressed by the following relationship:

$$v = v_0\left(\frac{h}{h_0}\right)^{\alpha} \tag{2}$$

where v is the wind speed at the height to be extrapolated, v0 is the wind speed recorded by meteorological station from the ground level h0 (10 m) and the power law exponent α is the wind shear exponent. This parameter is generally between 0.1 and 0.4 and depends on the surface roughness, atmospheric stability and height range. In particularly α is 0.2 for rural area and 0.4 for suburban area.

From the knowledge of the Weibull's parameters and of the wind speed profile at different height, different wind speed density distributions have been built for the two types of terrain the curves t(vi), where the index i is related to the height for which the curve was plotted (see Fig. 2). The heights considered (10, 15, 20 and 25 meters) are those set out by producers themselves to the towers of the turbines considered.

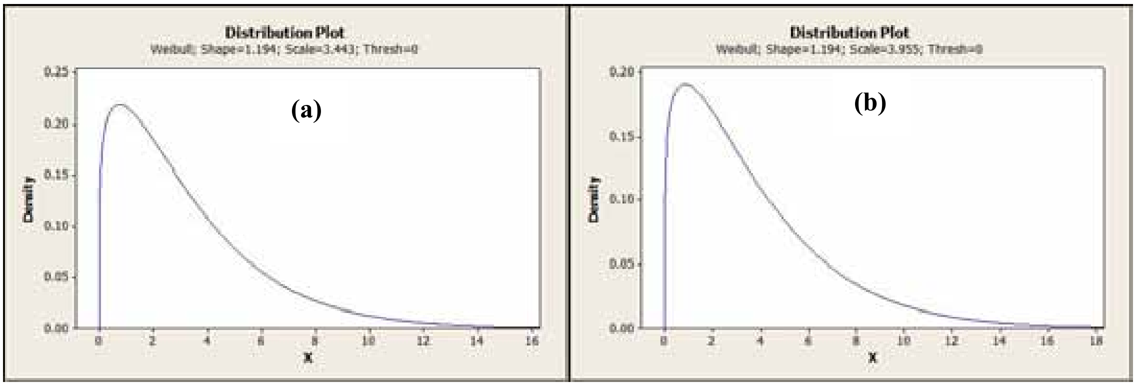

Fig. 2. Wind speed distribution for rural (a) and suburban (b) area at 20 m.

Once built the curves *t(v)* for each site, it was calculated the electrical producibility of each turbine, considering for each of them the different heights of the tower as suggested by the producers. If measured site wind speed data is available then the energy yield of a wind turbine can be estimated by combining the binned wind speed distribution with the power curve:

$$Energy = \sum_{i=1}^{i=n} H(U_i)P(U_i) \tag{3}$$

where $H(U_i)$ is the number of hours in wind speed bin U_i, $P(U_i)$ is the power output at that wind speed and there are n wind speed bins. To obtain an additional comparative assessment of different turbines performance, the capacity factor will be evaluated.

Capacity factor is the energy generated during the year divided by the rated power multiplied by the number of hours in the year. To calculate the capacity factor has been considered the share of 15, 20 and 25 meters for the rural area and the sub-urban area (see Fig. 3).

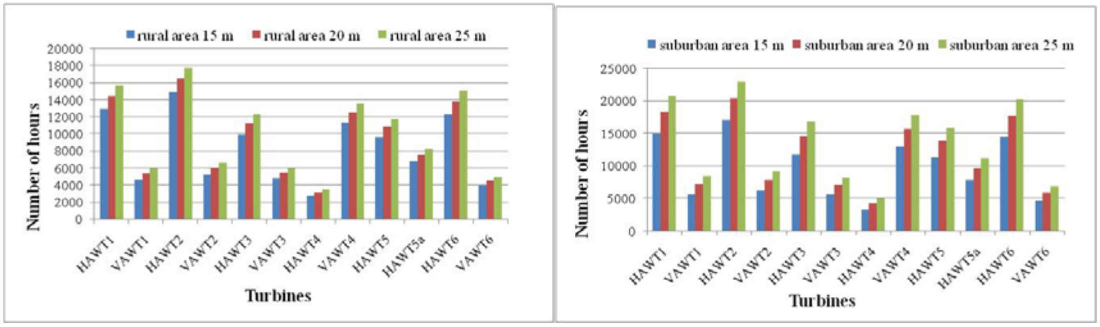

Fig. 3. Mazzara del Vallo capacity factor for rural and suburban area

The graphs show that horizontal axis wind turbines produce more energy than the vertical axis. This difference probably depends from power curves of small turbines showed in Fig. 4.

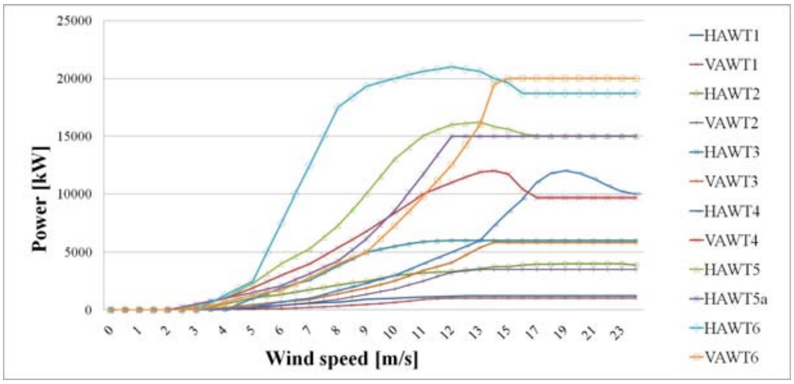

Fig. 4. Power curves for considered small turbines

5. Economic analysis

The following economic analysis has used values derived from a market research on cost of small turbine previously analyzed, obtained by the companies that work in the sector.

In the first phase it was computed the final expenditure commitments for each turbine, given by the sum of cost of various components (generator, inverter, control panel, etc.). However, frequently producers do not provide the cost of the accessories and therefore it is impossible to do a real evaluation of the costs and in particular their comparison. Therefore, in order to make costs of the turbines comparable, the authors have considered the specific costs for every kW installed.

In order to obtain the pay back return, the annual revenues obtainable for every value of productivity have been calculated, such as product of the by the amount of the tariff that is accessed.

In this study an all-inclusive rate was applied, that provides an incentive payment of € 0.30 per kWh transferred to the electricity grid. The relationship between the specific cost and revenues allowed to obtain the payback period. Figure 5 shows the payback period for small turbines with major capacity factor at the height of 25 m for rural and suburban area. Comparing all classes it follows that the turbine with major capacity factor is HAWT2 of 3 kW, the one that presents the lowest capacity is the HAWT4 of 10 kW (either with horizontal axis).

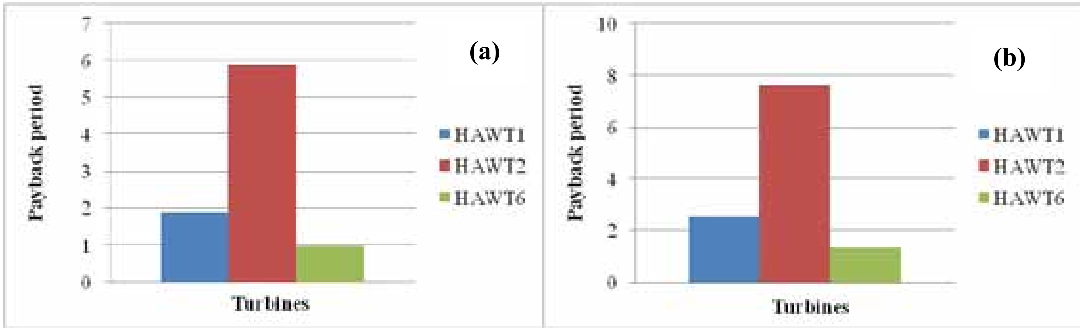

Fig. 5. Payback period for rural (a) and suburban (b) area at 25 m

6. Conclusions

Modern large turbines, used mainly in wind farm to produce electricity represent a mature technology. Small wind turbines, have to date not received the same attention as their large counterparts. This work fits in this framework by developing an energy and economical analysis developed through the exercise of certain micro turbines available on the market. This study showed that the choice of turbine is closely related to the wind conditions and to the type of terrain. Due to the high cost of small systems their diffusion is closely related to financing and government incentives. As with European countries, Italy has recently introduced economic incentives meant to increase the exploitation of wind power. The Italian regulations have introduced subside measures: in particular, the wind farm whit a annual average production ranging from 1 to 200 kW can sell the electricity at a price of 0.30 €/kWh for a maximum period of 15 years. The opportunity offered by the Italian legislative framework allow to pay more attention to a new potential market: the urban areas.

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References

[1] Messineo A, Panno G. LNG cold energy use in agro-food industry: a case study in Sicily. Journal of Natural Gas Science and Engineering 2011; 3: 356-363.

[2] Messineo A, Panno D. Potential applications using LNG cold energy in Sicily. International Journal of Energy Research 2008; 32: 1058–1064.

[3] Messineo A, Marchese F. Performance evaluation of hybrid RO/MEE systems powered by a WTE plant. Desalination 2008; 229: 82-93.

[4] Panno D, Messineo A, Dispenza A. Cogeneration plant in a pasta factory, energy saving and environmental benefit. Energy 2007; 32: 746-754.

[5] Kasbadji N. Wind energy potential of Algeria. Renewable Energy 2000; 21: 553 62.

[6] Bilgili M, Sahin B, Kahraman A. Wind energy potential in Antakya and Iskenderun regions, Turkey. Renewable Energy 2004; 29: 1733–1745.

[7] Sathyajith M, Pandey KP, Anil Kumar V. Analysis of wind regimes for energy estimation. Renewable Energy 2002; 25: 381–399.

[8] Culotta S, Messineo A, Messineo S. The application of different model of multi-layer perceptrons in the estimation of wind speed. Advanced Material Research 2012; 452 – 453: 690-694.

[9] Lange B, Larsen S, Hojstrup J, Barthelmie R. Importance of thermal effects and sea surface roughness for offshore wind resource assessment. Journal of wind engineering and industrial aerodynamics 2004; 92: 959-88.

[10] Rehman S, Al-Abbadi NM. Wind shear coefficients and energy yield for Dhahran, Saudi Arabia. Renewable Energy 2007; 32: 738–49.

[11] Cabello M, Orza JAG. Wind speed analysis in the province of Alicante, Spain. Potential for small-scale wind turbines. Renewable and Sustainable Energy Reviews 2010; 14: 3185-3191.

[12] Financial Law 2008 n. 244 del 21/12/2007.

[13] Ministerial Decree dated 18/12/2008 on “Incentives of electricity generation from renewable sources”.