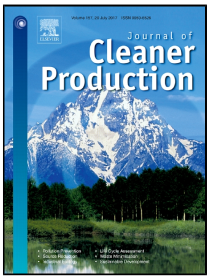

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Wind characterization in Taranto city as a basis for innovative sustainable urban development

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Abstract

The city of Taranto, in the south-east of Italy, is experiencing a transition from one of the most polluted and industrialized area characterized by the presence of the largest integrated steelworks in Europe, to a center of attractions of investments in innovation on sustainability and tourism. Among sustainability projects, urban wind energy is emerging as a technology useful in diffusion of smart grids for energetic sustainable development and also an interesting growing niche market in which there could be new investment opportunities. Numerous projects aimed at developing wind energy production are under constructions and wind characteristics and power potential of various sites have been studied in many Mediterranean countries. The urban wind analysis may represent a new tool to complete local wind atlases including the built environment, to evaluate changes that weathering may cause in the physical and architectural state of buildings, and to analyze the dispersion of pollutants from sources to receptor sites. In this paper, an analysis of wind potential and characteristics in Taranto, Apulia, a north Jonian urban site in Italy, has been performed by using high time resolved (10 min) meteorological data collected over a time span of two years, in the aim to describe the numerical procedures adopted to perform fitting of wind speed data without using special software. This urban site, in the first year of investigation from May 1st, 2009 to April 30th, 2010, was subjected to main wind regimes that come mostly from N with 12.27% and SSW with 9.89% of total hours; the calm occurred with a frequency of 10.94%. In the second year, from May 1st, 2010 to April 30th, 2011, the winds also blown predominantly from N with 12.56% of the total annual hours, and SSW with 9.33%, while the calms reached 11.08%. Dispersion of pollutants emitted from various sources among cement factory, a quarry/landfill, a refinery and the steelworks, poses serious health risks to population mainly resident downwind the prevalent wind directions. Simply computed mean wind speeds had values of 1.84 (sd=0.26 m/s) in the first year and 1.90 m/s (sd=0.30 m/s) in the second year under investigation. Weibull's *k* values, measuring the wind potential of the site, were higher during the spring-summer warmest months and lower during the autumn-winter; the lowest appeared in November 2009 (0.639) the highest in June 2010 (1.665). Mean yearly values of *k* were 1.210 (sd=0.18) in the first year and 1.065 (sd=0.24) in the second year of the study, the correlation between the monthly values of *k* in the years under consideration was R^2=0.59 (p=0.043) indicating that although variations occurred, the wind potential remain partly unaltered from one year to the other examined. LCOE (Levelized Cost of Electricity) for the wind turbines chosen among the 35 ones listed in the "Catalogue of European Urban Wind Turbine Manufactures", excluding those with rated power below 0.1 kW, ranged from 0.12 to 10.6 €/kWh and differs slightly in the two years examined. The values were competitive with some off-shore and on-shore installations, biogas and photovoltaic, but it does not consider pollution costs and subsidies. The proposed solution was economically viable, also by considering the possible integration in a hybrid photovoltaic-wind system, or fossil-based heat generator system supplemented by solar photovoltaic and wind energy.

Keywords: Urban wind turbine, Weibull distribution function, Urban development, Levelized cost of electricity, Sustainability, Taranto

Highlights

- Taranto in southern Italy, needs a sustainable alternative to steelworks
- Projects aimed to develop urban distributed energy production are expected
- Wind potential of an urban area of Taranto, was evaluated
- Costs are competitive with some non-urban power technologies

1. Introduction

The city of Taranto, in the South-East of Italy, is experiencing a decline of the steel production in the largest integrated steelworks in Europe, due to environmental concerns and a transition to a center of attraction for environmental researches, innovation and tourism, by means of projects aimed to foster development of remediation technologies, renewable energies, technological and touristic poles, industrial symbiosis (Notarnicola et al., 2016). The most exciting and difficult challenge was converting the workforce to the green economy, exploiting the known positive effects on employment deriving from environmental policies (Pociovalisteanu et al., 2015). The driving force behind this growing interest in sustainability change was the education system, in particular universities engaged in promoting sustainability to the future stakeholders, scientists and engineers. Following similar experiences in other countries, Italian government is implementing new bachelor's degree in environmental and engineering science following similar initiatives of sustainable development in higher education made in other countries as Mexico (Lozano and Lozano, 2014) and 70 higher education institutions worldwide (Lozano et al., 2015). Moreover the interest of public policies to promote the diffusion of smart grids for energetic sustainable development is directed to balance different interests coming from society, the economy and the environment (Pociovălişteanu, D.M., Popeangă, J.F., Filho, 2014). Such an approach could be useful in the development of Sustainable Energy Action Plans (SEAPs) of the Municipalities to get access to financial tools to reduce green-house gas (GHG) emissions by 20% within 2020, the so-called “Covenant of Majors” initiative, successfully applied in some Apulian cities (Lombardi et al., 2014). In cities experiencing the same transition issues, massive demolition of housing and stimulation of urban center renewal generated a shrinking of population and an increase in social asymmetry, a result that can be even worse in the case of Taranto due to chronically badly managed heavy pollution levels (Sevilla-Buitrago, 2013). Among renewables, wind power technology seems the most suitable to be integrated in smart grids although land based and coastal installations are characterized by lower energy payback time (the amount of time taken to offset the energy consumption during construction) with respect to the off-shore ones. Calculations on energy return intensity (the net energy output per installed unit capacity across the whole lifetime of a wind farm) of off-shore installations revealed a positive return after about 9 years of operations (Zhang et al., 2016). These figures were worst in the case of small scale horizontal axis wind turbines in which LCA studies estimated about 160 years to return the energy used in the production and disposal phases of a 600W rated power turbine and about 100 years to reach the payback balance of GHG’s emissions (Wang and Teah, 2016). A temporal analysis of Chinese wind power installations revealed a characteristic timeline steps: the “early experiments” in which there was a fragmented uncoordinated policy sustained by governmental authorities with weak legitimation, followed by an “ambitious fostering policy” with a rapid and unbalanced growth. In most cases the starting event was represented by the separation of transmission from generation systems, the integration of the energy policies at a political level and the innovation coming from research. These changes reduced taxation for wind power and introduced a concession program where developers were encouraged to invest with a power purchase agreement which guarantees a certain future income per kWh of electricity produced (Karltorp et al., 2016). Similarly in Italy national authorities have introduced economic incentives to make the use of urban wind energy more profitable and efficacies of the internalization of costs of carbon dioxide emissions generated from the introduction of the feed-in tariffs has been widely demonstrated (the feed-in-tariffs are cost-based compensation to renewable energy producers which consists of assuring price certainty in long term contract to make investments more attractive) (Wesseh and Lin, 2016). In Taranto, the development of diffuse micro-grid power generations could foster the transition from energy intensive steelmaking industry to innovative small and medium enterprises specialized in micro-wind generation synergistically connected with the academic institutions, involved in basic research. Unexplored scientific issues in which university research can be useful are numerous, some non-exhaustive examples are the replacement of permanent magnets based on rare earths (actually marketed monopolistically by few suppliers in the world) with surrogates (Lacal-Arántegui, 2015), the studies on the profitability of roof-based wind installation under a life cycle perspective, by using thermoplastics, fiberglass composites and recycled materials in manufacturing and during maintenance, instead of aluminum (Uddin and Kumar, 2014), the development of advanced optimization modelling to balance reduction of emissions of GHGs with the exponential increases of micro-grid system's costs (Rezvani et al., 2015), the smart energy system design as a carbon reduction strategy in cities (Lund et al., 2015). X. Yuan, J. Zuo and D. Huisingh, showed that despite significant environmental benefits of wind power, its social acceptance is a major obstacle (Yuan et al., 2015), an issue that can be overlooked by using well studied guidelines promoting sustainable development independently of which kind of energy facility is being installed (Gonzalez et al., 2017). Micro-generation technologies as micro-wind turbines, can significantly reduce both primary energy demand in buildings sector (Hameed et al., 2016) and the need to expand the high voltage electricity network as energy sources are close to the electrical load (Ishugah et al., 2014) provided that the local authorities adopt energy planning of urban areas considered as sustainable communities making use of micro-generation (Brandoni et al., 2014), micro combined heat and power generators (Conroy et al., 2014), photovoltaics applied in social-housings (Bahaj and James, 2007), micro-combined heat and power unit (Gonçalves et al., 2013). It has been demonstrated that legal constraints may influence domestic microgeneration profitability (Fidalgo and Fontes, 2012) and the implementation of sustainable urban development requires the use of appropriate indicators (Sofeska, 2016). Low speed wind farms are growing and site selection is a critical choice which involves not only economic considerations but also ideas of management and stakeholders (Wu et al., 2017). Site selection is a key step also for locating fossil fuel power plants in the way towards decarbonization of the electricity sector (Shiraki et al., 2016). During the transition the two systems will coexist as the best economic scheme for a distribution company, seems to be in the use of the clean and unclean technologies together (Sadeghi and Kalantar, 2015). Wind characteristics and power potential of various locations have been studied in many countries worldwide, in order to fully describe the mathematical procedures useful to perform analysis in sites with the potential for wind farm installation (Simons and Cheung, 2016). Wind-selective analysis in urban areas is growing as a tool to evaluate the dispersion of pollutants (Di Gilio et al., 2017) and to investigate on the changes that weathering may cause in the physical and architectural state of buildings (Dolske, 1995). Knowledges of the influence of local wind conditions and building orientation on the convective heat transfer at building surfaces (Defraeye and Carmeliet, 2010) is of interest for several urban engineering projects as solar collectors (Sharples and Charlesworth, 1998) and eco-design framework in developing wind turbines (Bonou et al., 2015). One of the main research priority for renewable energy technology in EU, as defined by the Association of European Renewable Energy Research Centers (EUREC), is to study the built environment by downscaling wind atlases for use in the urban environment, by using Computational Fluid Dynamics (CFD) to understand wind flow and turbulence around buildings built with integrated wind turbines (EUREC, 2009). Recently it has been estimated that the likelihood of a proliferation of grid-connected roof-top wind turbines (Mithraratne, 2009) or building integrated Sistan type windmill (Müller et al., 2009) in the urban environment is low, but at coastal sites like that studied in this paper, the technology has a promising future (Zhang et al., 2016). Battery storage coupled with wind power generator, proved to be an environmentally friendly scenario in life cycle assessment with respect to gas-fired power plant (Hacatoglu et al., 2015). Wind energy in small power turbines can be operated in hybrid power system, that combine renewable energy technologies such as wind turbines, photovoltaic generators, micro hydro-power (Izadyar et al., 2016) or biogas electricity from biomasses (Vaisanen et al., 2016), with a conventional heat or power generator: both the solar and wind energy serves the charging of the battery storage, the conventional generator only runs when the renewable energy generated and stored is insufficient, in order to minimize the operation time of the conventional generator and optimize the utilization of renewables as hybrid photovoltaic/wind/diesel/battery system (Diab et al., 2016) using Power Pinch Analysis (Mohammad Rozali et al., 2016) or in stand-alone off-grid hybrid system in remote regions as solar-wind power plant with electricity storage and hydrogen generation (Petrakopoulou et al., 2016) and wind-photovoltaic-diesel-battery hybrid energy systems (Shezan et al., 2015). Analysis of wind speed in urban areas have been used to describe the numerical procedures adopted to perform fitting of wind speed data, with more suitable probability distributions functions and to compute wind shear coefficients without using special software (Lo Brano et al., 2011). In fact no robust method exists to estimate urban wind speed so there is a serious issue concerning the ability to reliably estimate the energy yields of a micro wind turbine (Peacock et al., 2008). In most cases the parameters of the Weibull density distribution function were assumed as the best approximation both in cities and open sea areas although, when comparing the seasonally results of a city area with two other geographically different sites, a wider range of the Weibull's two-parameter values were observed (Lun and Lam, 2000). It has been also demonstrated the possibility to predict the wind energy harvested by a topographical feedforward neural network (Lawan et al., 2016). Chandel et al. (Chandel et al., 2014) has highlighted a critical issue in the analysis of low regime wind speed locations: best results were achieved with high time resolved data (1-10 min interval under a two-year time span) as hourly or daily averaged wind speed data may underestimate the wind resource potential. To the best of our knowledge the nearest urban coastal location ever studied was Brindisi in the Apulia region, facing the Adriatic Sea by using a 1-h measured wind data over a six-year time span and at the same elevation (Gualtieri and Secci, 2011). Recently specific approaches of source apportionment have been used to localize and identify sources of pollutants and to impute its contributions to the total pollution of outdoor ambient air. Source apportionment is based on the assumption that each pollutant's source provides a characteristic fingerprint. Pollutant's concentrations data integrated with the information's of wind direction and speed have been analyzed recently by means of statistical tools as bivariate polar-plots, in order to characterize and localize the pollution sources (Di Gilio et al., 2017). To conduct these studies a high time resolved coverage of wind data and concentration of pollutants at receptor sites located in the urban environment is requested. The need of wind speed and direction data in the urban contest as possible close to the receptor sites is essential to the best apportion of pollution sources in terms of reliability of results and the studies proposed in this paper are suitable for improving the knowledge of pollutant's dispersion and identifying the emission sources. For all these reasons the analysis of wind potential of a coastal site as Taranto, has been performed by using high time resolved (10 min) meteorological data collected from a weather station located on the roof of a building used by the University of Bari "Aldo Moro" over a time span of two years (Laiola E., 2012). The analysis of wind speed in the urban area under investigation have been conducted in the aim to describe the numerical procedures adopted to perform fitting of wind speed data without using special software, to build up a database of wind data useful to perform apportionment studies and to verify the economic viability of building-integrated wind power as a cost-effective solution in the studied area.

2. Materials and Methods

2.1 Data acquisition

Wind data were collected from a weather station located on the roof of a building located in Taranto (Latitude deg N: 40° 27' 03.74', Longitude deg E: 17°16' 08.94', elevation 15 m above sea level, ASL) in the Apulia Region Italy (Figure 1), from May 1st, 2009 to April 30th, 2011.

Figure 1 here

The weather station is composed of a combined sensor for wind-direction and speed DNA022, World Meteorological Organization compliant (LSI-LASTEM, Settala Premenugo, Milan) consisting of a cup and a vane anemometer and temperature, pressure and relative humidity sensors with operating range and accuracy reported in table 1. The measurements were performed every 10 minutes from two E-305 data loggers ELO-105 (LSI-LASTEM, Settala Premenugo, Milan), in cascade connections, sending the acquired data to a computer data station, connected by RS232, with a serial enhancer. Wind data were retrieved by using the applications CommNet EG®, InfoGap®, InfoPanel® (LSI-LASTEM, Settala Premenugo, Milan). In table 2 are reported relevant statistics of the meteorological parameters in the period under investigation.

Table 1 here

Table 2 here

The studied area is located under the Jonian coast of the Apulia region, characterized by a plain surrounded by the Murgia plateau from the north-west to the east. The meteorological station is located in the urban area near the sea in front of the gulf of Taranto, a city with a population of about 200,000 inhabitants on 209.64 km^2. Taranto has a Mediterranean climate characterized by mild wet winters and hot, dry summers (with spikes of 43°C) and mean relative humidity under the examined period of 68.5%. In winter the average temperature rarely drops to 0° C and snowfalls are rare events. The industrial area has quite the same land occupation of the urbanized one, mostly covered by the steelworks, with open air mineral parks, utilized in an integrated process cycle, which starts from raw materials, capable of generating 12 Mt/y of steel, now reduced to about 5 Mt/y. In front of the gulf there are an industrial and civil harbor, a cement factory (with the furnace switched off) and a refinery actually working crude oil of an on-shore oil field in the Basilicata region.

2.2 Data Analysis

The analytical expression of Weibull distribution is given by the equation (1):

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

where v is the wind speed and k and C are the Weibull distribution parameters. The density of accumulative probability may be obtained from the total probability distribution function by the equation (2):

$$F(v \le v_0) = 1 - \exp^{\left(-\left(\frac{v_0}{c}\right)^{k}\right)} \tag{2}$$

and represents the probability for the speed v to be lower than v_0. Eq. (2) can be also written as follows:

$$\ln(-\ln(1 - F(v \le v_0))) = k \ln\left(\frac{v_0}{C}\right) = k \ln v_0 - k \ln C \tag{3}$$

In which k and C, can be calculated by using the least squares fitting of the data from eq. (6):

$$Y = \ln(-\ln(1 - F(v \le v_0))) \tag{4}$$

$$X = \ln v_0 \tag{5}$$

$$Y = A + BX \tag{6}$$

The measured values of wind speed (v_i), frequency (n_i) and probability frequency f_i were computed through the relationship $f_i = n_i/n$ where n is the total number of wind speed data obtained in the period under investigation and n_i is the number of data with this particular wind speed value (Vogiatzis et al., 2004). Two mean wind speed values were evaluated: the simply computed mean wind speed (7) and standard deviation of computed wind speed (8), theoretical mean wind speed (9) and standard deviation of theoretical wind speed (10):

$$\bar{v} = \frac{\sum_{1}^{n} v_i}{n} \tag{7}$$

$$\sigma = \sqrt{\frac{\sum_{i}^{n} \left(v_i - \bar{v}\right)^2}{n}} \tag{8}$$

$$\bar{v} = C\Gamma\left(1 + \frac{1}{k}\right) \tag{9}$$

$$\sigma = C\left[\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right)\right]^{\frac{1}{2}} \tag{10}$$

where v_i is the wind speed for the i^{-th} measurement, Γ the *Gamma* function. The mean wind energy density has been obtained by integration of the Weibull probability distribution function:

$$\left\langle \frac{P_a}{A} \right\rangle = \frac{1}{2}\rho\bar{v}^3 = \frac{1}{2}\rho\int_0^v v^3 \rho(v)dv \tag{11}$$

Obtaining:

$$\left\langle \frac{P_a}{A} \right\rangle = \frac{1}{2}\rho C^3 \Gamma\left(1 + \frac{3}{k}\right) \tag{12}$$

where A=area under examination, ρ= mean air density ρ [kg/m^3]. Wind speed of maximum energy carrier is calculated from (13):

$$v_{mec} = C\left(1 + \frac{2}{k}\right)^{\frac{1}{k}} \tag{13}$$

Mean air density ρ [kg/m^3] depends on air temperature T [K] and pressure P [mbar] and was calculated by the formula (14):

$$\rho = \frac{P}{R \times T} \tag{14}$$

where R is the gas constant [287.053 J/kg K]. Wind speed, frequency, direction were plotted in polar diagrams (wind-rose), in which wind direction were measured clockwise in degrees and divided in 16 sectors, each of them covers an arc of 22.5°.

3. Results and discussion

3.1 Wind analysis

The measured values of wind speed (v_i), frequency (n_i) and probability frequency f_i are reported in Table 3 for the period under investigations.

Table 3 here

Figure 2 here

Figure 3 here

Figure 2 represents least square fitting of data by applying the eq. (6), from May 1st, 2009 to April 30th, 2010, figure 3 shows the Weibull distribution for the same period. The same wind data processed from May 1st, 2010 to April 30th, 2011 and least square fitting of the Weibull distribution function are shown in figure 4 and figure 5.

Figure 4 here

Figure 5 here

Table 4 contains *k* and C values for each month separately, from May 1st, 2009 to April 30th, 2011 and the annual mean values. From the analysis, emerges that the local wind potential has the typical characteristics of a coastal site, mean values of C were 1.522 m/s and 1.407 m/s, for the first and the second year of observation with small variations except for November 2009 in which the lowest value was registered (0.685 m/s) a behavior reported also on the urban *Pizia* station in Palermo (Lo Brano et al., 2011). *K* values, which were a measure of the wind potential of the analyzed site, were higher during the spring-summer warmest months, and lower during the autumn-winter coldest months, the lowest value appeared in November 2009 (0.639), the highest in June 2010 (1.665). Mean yearly values of *k* were 1.210 (sd=0.18) in the first year and 1.065 (sd=0.24) in the second year under investigation, with some variations; the correlation between the monthly values of *k* in the years under consideration was R^2=0.59 (under the null hypothesis of no correlation p=0.043) indicating that although variations occurred, the wind potential remain partly unaltered from one year to the other examined. The mean annual values of *k* were slightly less than the Italian wind atlas values ~~(~~comprised between 1.40 and 1.50 at 25m ASL but it should be mentioned that it were determined at higher sea levels) (Botta and Ratto, 2002).

Table 4 here

Table 5 here

Table 6 here

Simply computed mean wind speeds (table 5) had values of 1.84 (sd=0.26 m/s) in the first year and 1.90 m/s (sd=0.30 m/s) in the second year under investigation, theoretical computed mean wind speeds had values of 1.43 (sd=1.18 m/s) in the first year and 1.37 m/s (sd=1.12 m/s) in the second year under investigation; from the Italian wind atlas the measured mean wind speed in the site under investigation is between 3 and 4 m/s, but was determined in open land areas and not in built environment and at higher ASL (Botta and Ratto, 2002). From the analysis of the simply computed monthly mean wind speed values the highest occurred in March 2011 with 2.64 m/s, the lowest in January 2011 with 1.39 m/s and November 2009 with 1.41 m/s. The correlation between monthly simply computed and theoretical wind speed in the first year was $R^2=0.994$ ($p <0.0001$) in the second year was $R^2=0.990$ ($p <0.0001$). This means that the Weibull distribution satisfactorily describe the wind characteristics of the site under investigations with the exception for the periods of stillness (calm), as is also visible in figures 3 and 5 in which the Weibull distribution has zero probability, while the measured frequency was not although at low wind speed regimes, the energy provided by the micro-wind turbines is negligible so this behavior does not affect the productivity of the system. The correlation of monthly simply computed wind speed between the two years under investigations was low $R^2=0.04$ ($p=0.90$) except for the month from June to October in which was higher $R^2=0.84$ ($p=0.07$) indicating that the wind potential of the site under investigation remained almost stable during some parts of the year but not for all. Wind speed of maximum energy carrier was comprised between 3.40 and 3.83 m/s in the first and second year of observation (table 6). Monthly variation of mean air density in the period under examination (table 7), shown higher of mean air density values during the period from October to April confirming the dependence of the density from the temperature and in agreement with similar results on coastal sites in Italy (Gualtieri and Secci, 2011). Figures 6, 7 show the wind-roses in the site, for the period under investigation.

Table 7 here

Figure 6 here

Figure 7 here

This urban site, in the first year of investigation, was subjected to main wind regimes that come mostly from two sectors of wind-rose: N with 12.27% and SSW with 9.89% of total hours; the calm (winds with speed less than 0.5 m/s) occurred with a frequency of 10.94%. In the 85% of annual hours occurred speeds values lower than 4 m/s and for less than 1%, winds with speeds in excess of 6 m/s. In the second year, the winds also blown predominantly from N with 12.56% of frequency, and SSW with 9.33% of frequency, while the calms reached 11.08% of the hours. Finally, it can be noted, as in the first year of observations, that winds blowing from SSW had higher speeds than those blowing from the North, although the latter were more frequent. Considering also that the wind speed of maximum energy carrier was comprised between 3.40 in the first year and 3.83 m/s in the second year of observation, it may be concluded that the wind blowing from SSW was the most productive one in terms of energy produced. Some interesting consideration about the environmental pollution can be made by considering the location of heavily polluting industrial activities around the urbanized area: as can be seen from figure 1, the steelworks, cement factory, refinery and quarry/landfill were located in the NW sector with respect to the urbanized area, exposing population to pollutants at low wind regimes and for longer times during the year, the worst possible condition. For this reason the cement factory due to pressure of environmentalists has stitched off the furnace, the steelworks reduced the production capacity of about a half of its potential and the landfill is improving the management of air quality by means of research projects aimed to control odor emissions (Giungato et al., 2016).

3.2 Economic analysis

There are several factors affecting the unit cost of electricity produced by a wind turbine and these costs vary from country to country, while the economic benefits of a wind turbine heavily depend on local conditions (Mostafaeipour et al., 2011). Series-produced commercial wind turbines were available for less than 1000 US$ per kW rated power (Saeidi et al., 2013). Following Mathew (Mathew, 2007) that analyzed economics details of wind energy resources and included insurance and taxes as other expenses occurred annually, it is possible to assign 1.5–2% of the turbine's cost to total annual cost for repair, maintenance, and salaries of workers. In the initial year, annual costs of wind turbine during its life span of n years can be estimated as:

$$C_{OM} = m\, C_I \tag{15}$$

where C_I is the initial cost of investment and C_{OM} is the operations and maintenances costs for n^{-th} year and m = 0.02 (2% of the turbine's cost to total annual cost), present worth (PW) that can be calculated by (16):

$$PW(C_{OM})_{1-n} = mC_I\left[\frac{(1+I)^n - 1}{I(1+I)^n}\right] \tag{16}$$

where I is the annual interest rate, in Italy in 2015 equal to 0.17% based on annual data of European Commission (Eurostat, 2015). Including the initial investment C_I, the accumulated net present worth (NPW) of all costs is as following:

$$NPW(C_A)_{1-n} = C_I\left\langle 1 + m\left[\frac{(1+I)^n - 1}{I(1+I)^n}\right]\right\rangle \tag{17}$$

The yearly actualized cost of operation, maintenance and initial investment for the turbine is:

$$NPW(C_A) = \frac{NPW(C_A)_{1-n}}{n} = \frac{C_I}{n}\left\langle 1 + m\left[\frac{(1+I)^n - 1}{I(1+I)^n}\right]\right\rangle \tag{18}$$

The energy generated (E_I) by the turbine in a year is:

$$(E_I) = 8760 \times P_R \times CF \tag{19}$$

where P_R = rated power and CF = capacity factor that can be defined as the ratio of the actual power generated to the rated power output (Lu et al., 2002). The Levelized Cost of Electricity (LCOE) of the wind-generator is given by:

$$LCOE = \frac{NPW(C_A)}{E_I} = \frac{C_I}{8760n}\left(\frac{1}{P_R CF}\right)\left\langle 1 + m\left[\frac{(1+I)^n - 1}{I(1+I)^n}\right]\right\rangle \tag{20}$$

To find the best choice of a small wind turbine in this urban context, the technical specifications listed in *Catalogue of European Urban Wind Turbine Manufactures* were used including the producers having joined the *Intelligent Energy Europe Program* (Intelligent Energy - Europe, 2005). For every turbine, except those with rated power below 0.1 kW, among the different 35 turbines in the catalog, the CF was computed and the economic analysis was reported in table 8 taking into account an estimated cost of the turbine of 1000€/kW of rated power (Kost et al., 2013) while other initial costs including installation, transportation, custom fee and grid integration were assumed to be 40% of the turbine cost, considering 25 years' useful life, an overoptimistic choice supported by a recent survey on structural changes of global power generation capacity towards sustainability which estimates a mean of 35 years (Farfan and Breyer, 2017), annual operation and maintenance costs plus the land rent as 2% of the turbine cost. The LCOE ranged from 0.12 to 10.6 €/kWh and differ slightly in the two years examined. In table 9 it is reported the cost of electricity of different energy sources with the present urban wind system (IRENA, 1997; Kost et al., 2013) to make some comparisons. In this case, the lowest LCOE was competitive with the off-shore installations, some on-shore ones, biogas and photovoltaic, but considering pollution costs and subsidies, which are not included in LCOE estimations, the option studied in this work may be cheaper and economically viable with respect to the other alternatives. Moreover, by considering the integration in hybrid diesel systems supplemented by solar PV and wind energy, the profitability of this innovative sustainable urban development could be improved by means of Power Pinch analysis (Mohammad Rozali et al., 2015) or with HOMER software (Ngan and Tan, 2012).

Table 8 here

Table 9 here

4. Conclusions

The city of Taranto, in the South-East of Italy, is experiencing the preliminary stages of the transition from a highly industrialized and polluted area to a center of attractions of investments in innovation on sustainability and tourism. Among sustainability projects, urban wind energy is emerging both as a technology useful in diffusion of smart grids for energetic sustainable development and as an interesting growing niche market in which there could be new investment opportunities. In this paper some distinct aspects of innovative sustainable urban development have been investigated: the creation of a knowledge base of wind data suitable for sustainable power generation over a period of two years by using a higher time resolved coverage device and conducted in the aim to describe the numerical procedures adopted to perform fitting of wind speed data, without using special software; the analysis of local wind regimes to provide to environmental scientists a useful database useful to perform apportionment studies and dispersion of pollutants emitted from some of the heavy industries located in the area; the economic viability of a building-integrated wind turbine as a cost-effective solution. The urban site investigated is characterized by low mean annual wind speed typical of urban areas, blowing prevalently from North, but with interesting wind bursts from SSW sector. This urban site, in the first year of investigation, was subjected to main wind regimes that come mostly from N with 12.27% and SSW with 9.89% of total hours; the calm (in this case considered as winds with speeds less than 0.5 m/s) occurred with a frequency of 10.94%. In the 85% of annual hours occurred speeds values lower than 4 m/s and for less than 1% of annual hours, winds with speeds in excess of 6 m/s. In the second year, the winds also blown predominantly from N with 12.56% of frequency, and SSW with 9.33% of frequency, while the calms reaches 11.08% of frequency. Winds blowing from SSW had higher speeds than those blowing from the North, although the latter were more frequent. Simply computed mean wind speeds had values of 1.84 (sd=0.26 m/s) in the first year and 1.90 m/s (sd=0.30 m/s) in the second year under investigation, theoretical computed mean wind speeds had values of 1.43 (sd=1.18 m/s) in the first year and 1.37 m/s (sd=1.12 m/s) in the second year under investigation. Weibull's k values, which measures the wind potential of the site, were higher during the spring-summer warmest months and lower during the autumn-winter; the lowest appears in November 2009 (0.639) the highest in June 2010 (1.665). Mean yearly values of k were 1.210 (sd=0.18) in the first year and 1.065 (sd=0.24) in the second year, the correlation between the monthly values of k in the years under consideration was $R^2=0.59$ ($p=0.043$) indicating that the wind potential remains essentially unaltered from one year to the other examined. Wind speed of maximum energy carrier was comprised between 3.40 in the first year and 3.83 m/s in the second year of observation. Dispersion of pollutants emitted from various sources among cement factory, a quarry/landfill, a refinery and the steelworks, poses serious health risks to population mainly resident downwind the prevalent wind directions. LCOE computed for the wind turbines chosen among the 35 ones listed in the "Catalogue of European Urban Wind Turbine Manufactures", but excluding those with rated power below 0.1 kW, ranged from 0.12 to 10.6 €/kWh and differ slightly in the two years examined. The lower value was competitive with the off-shore installations and some on-shore ones, biogas and photovoltaic, but it should be taken into account that do not consider pollution costs and subsidies, usually not included in LCOE estimations. For these reasons the proposed solution could be economically viable also by considering the subsidies and the integration of the micro wind turbine in a hybrid photovoltaic-wind system, or fossil-based heat generator system supplemented by solar photovoltaic and wind energy, that may constitute the future development of the present work. The aspects analyzed in this work and their outcomes could be integrated and unified from a sustainability angle taking into account the results of a recent review by Bayulken and Huising in which the key elements in achieving the eco-towns' goals were highlighted: the political commitment, timing, financial aspects, physical qualities, stakeholder involvement and environmental planning (Bayulken and Huisingh, 2015). These conditions may be achieved in the studied context as the existing feed-in tariffs could provide financial models and regulatory conditions required by eco-towns projects for the development of distributed micro-wind generations. It is fundamental to acquire consensus among all political, public, financial and other actors who are involved or affected by the processes, improving social acceptance of the environmental benefits of micro-wind power generation, by using well studied guidelines promoting sustainable development of energy facilities being installed. Stakeholder involvement from the early stages of the planning, could raise participants' awareness of their impacts on the outcome and may lead to successful implementations of sustainable urban development.

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Abbreviations and symbols

Γ = *Gamma* function

v = mean wind speed

A = area under examination

ASL = Above Sea Level

CF = Capacity Factor

CFD = Computational Fluid Dynamics

$\mathbf{C_I}$ = Initial Cost of Investment

$\mathbf{C_{OM}}$ = Operations and Maintenance Costs

$\mathbf{E_I}$ = Yearly energy generated by a wind turbine

f_i = probability frequency

GHG = Green-House Gas

I = annual interest rate

***k*, C** = Weibull distribution parameters

LCA = Life Cycle Assessment

LCOE = Levelized Cost of Electricity

n_i = frequency

NPW = accumulated Net Present Worth of costs

P = air pressure [mbar]

$\mathbf{P_a/A}$ = Mean wind energy density

$\mathbf{P_R}$ = rated power of a wind turbine

PW = accumulated Present Worth of costs

Sd = standard deviation

SEAP = Sustainable Energy Action Plan

T = air temperature [K]

v_i = wind speed

v_{mec} = wind speed of maximum energy carrier

ρ = mean air density [kg/m^3]

σ = standard deviation

N = North

NNE = North North East

NE = North East

ENE = East North East

E = East

ESE = East South East

SE = South East

SSE = South South East

S = South

SSW = South South West

SW = South West

WSW = West South West

W = West

WNW = West North West

NW = North West

NWW = North West West

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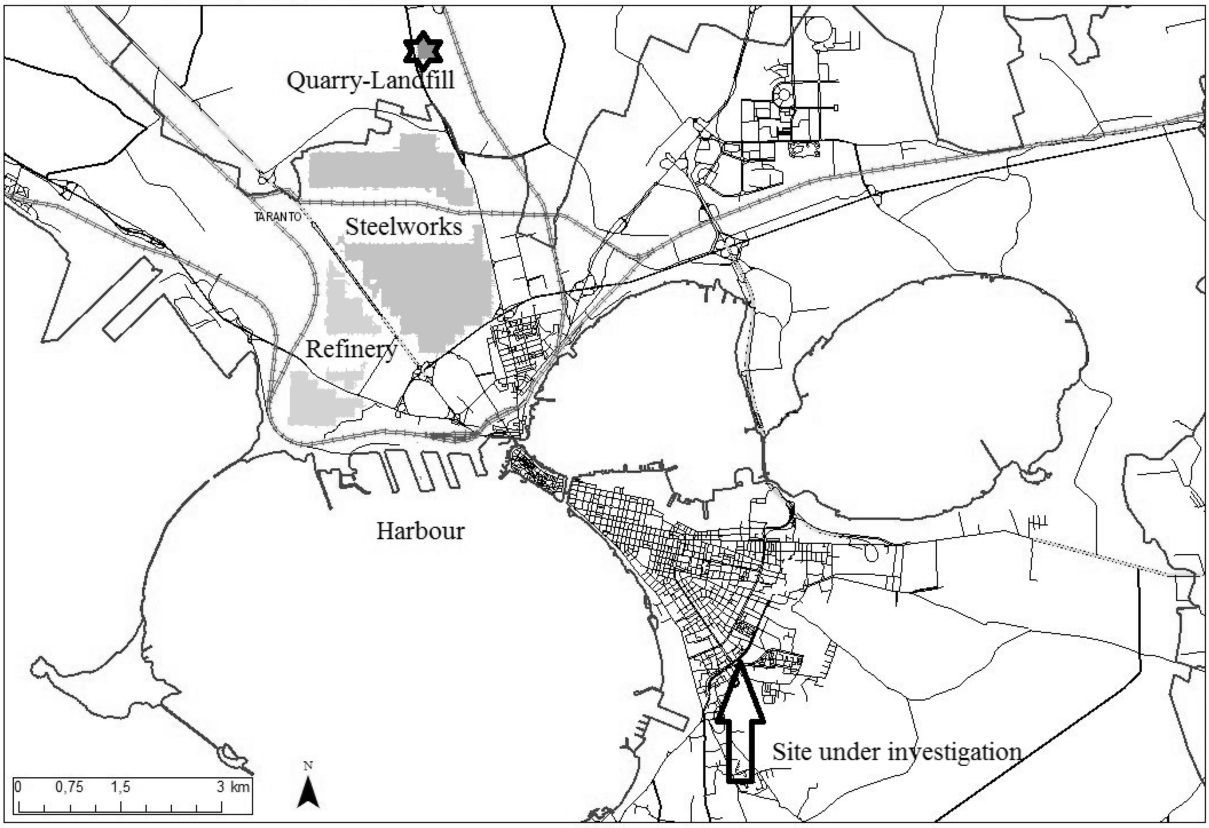
Zhang, J., Zhang, J., Cai, L., Ma, L., 2016. Energy performance of wind power in China : A comparison among inland , coastal and offshore wind farms 143, 1–7. doi:10.1016/j.jclepro.2016.12.040

Figure 1



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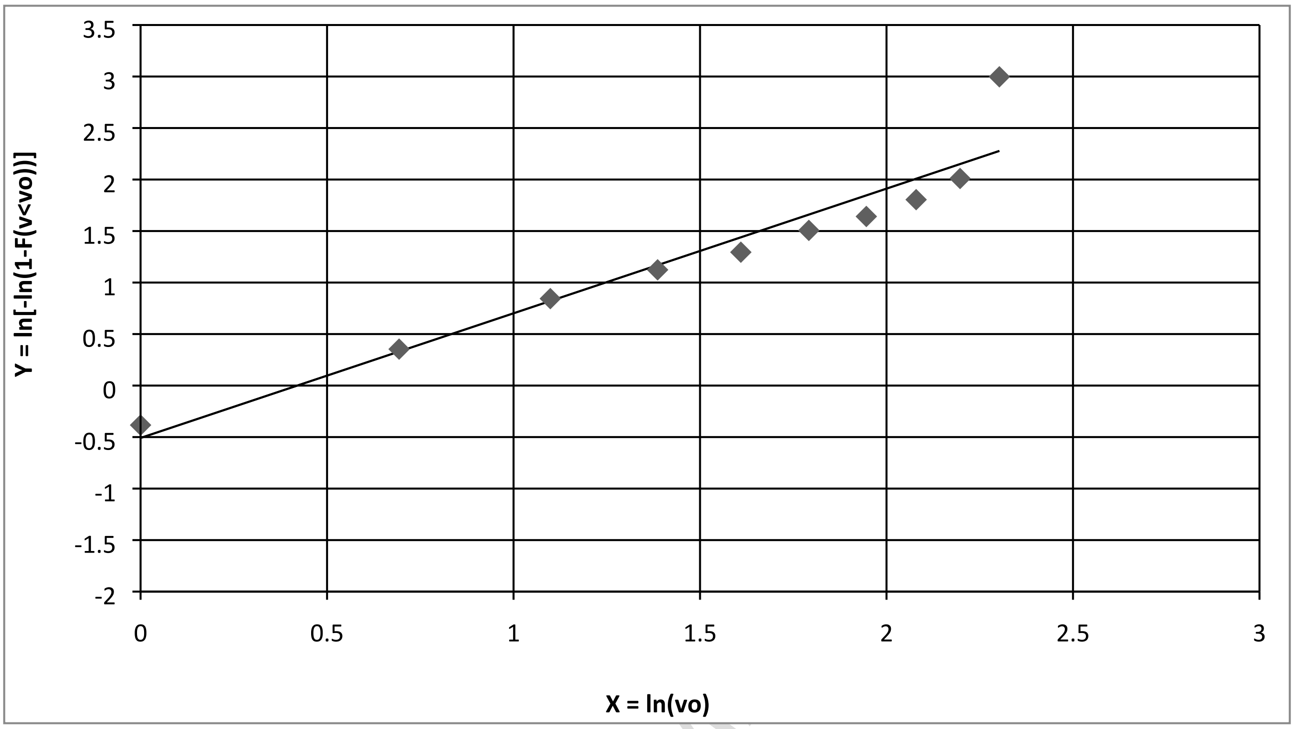

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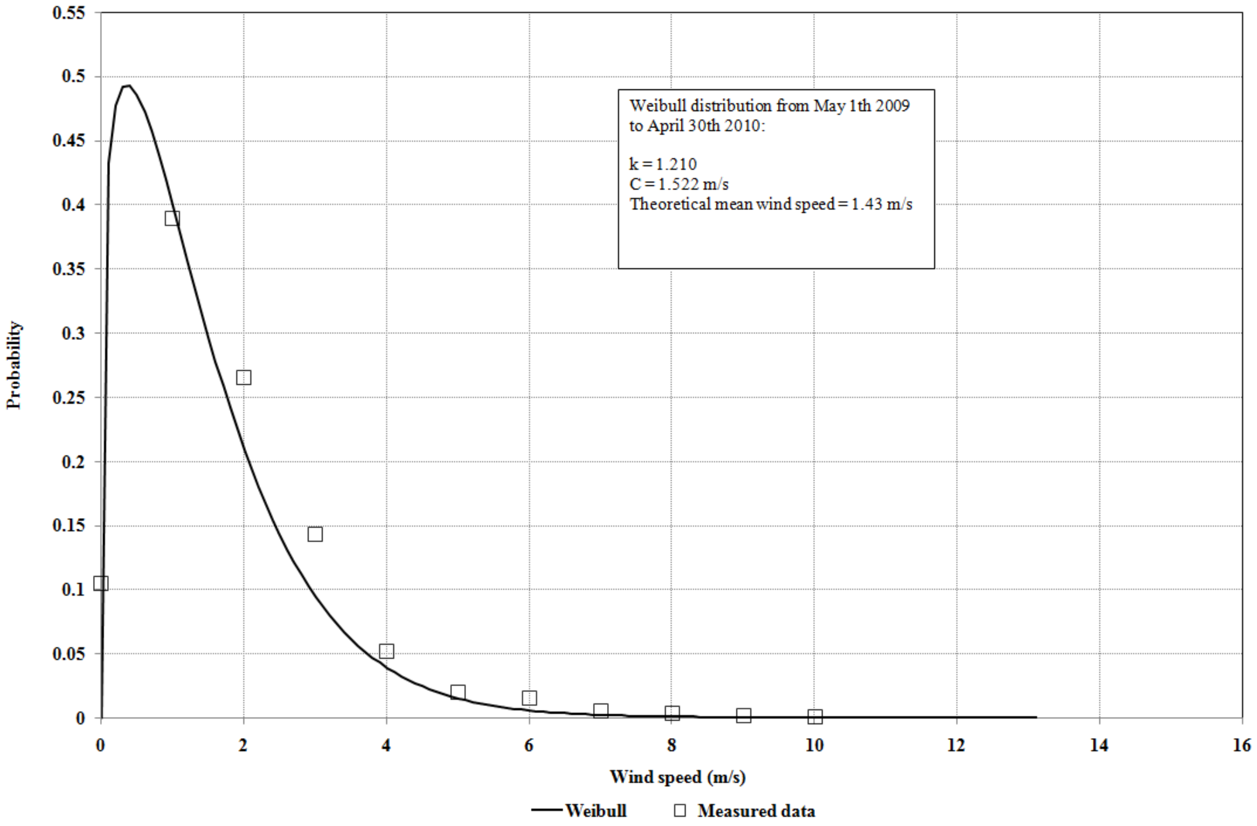

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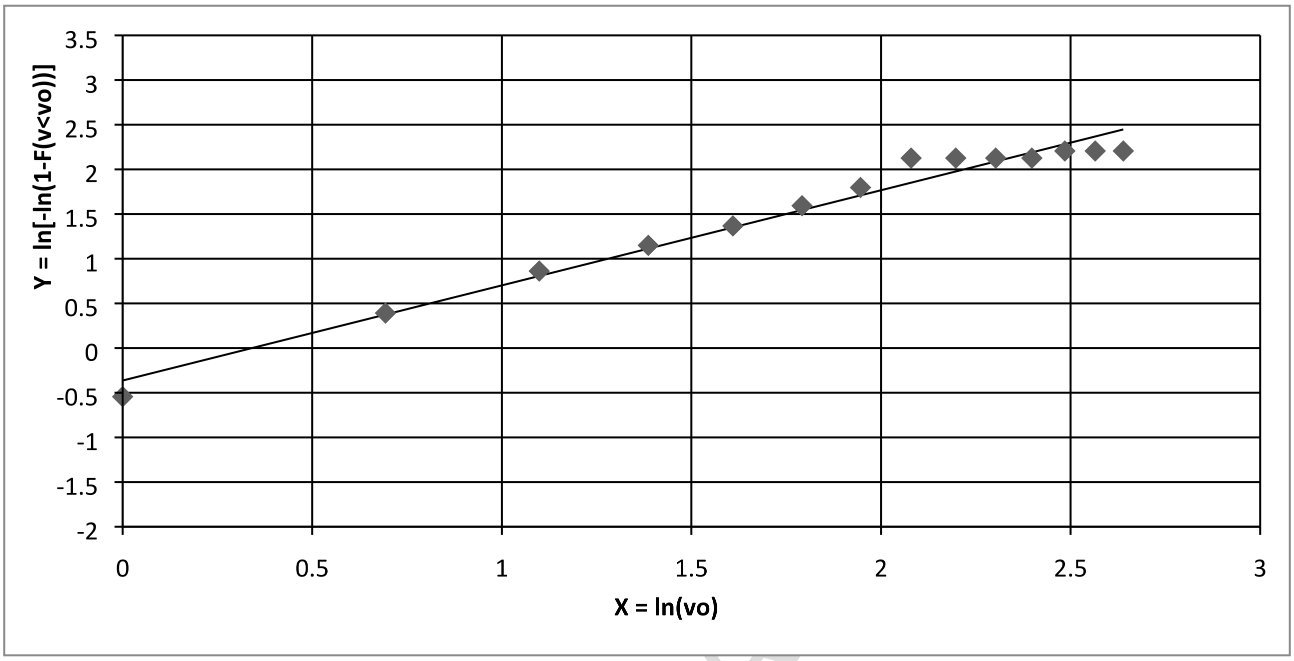

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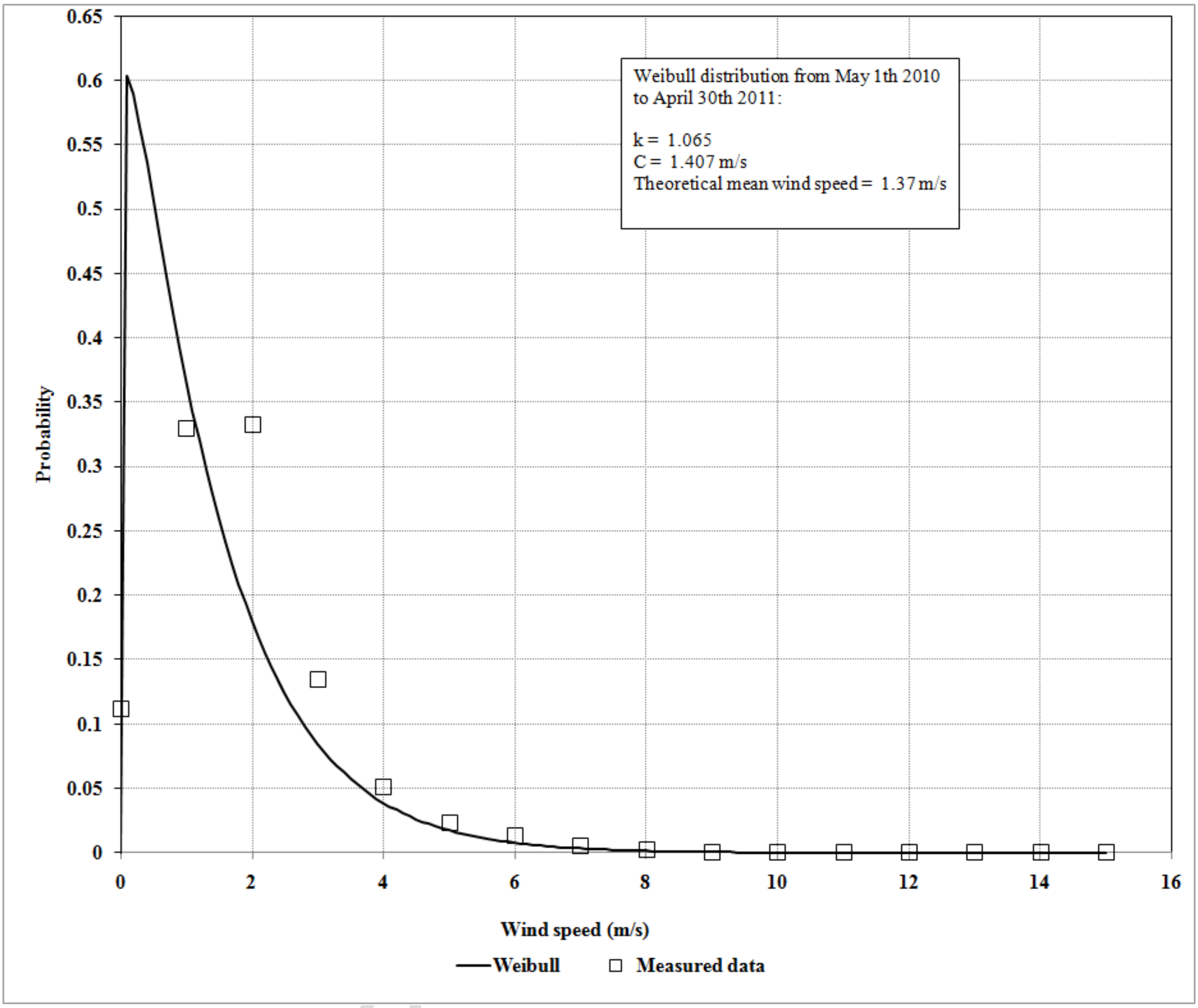

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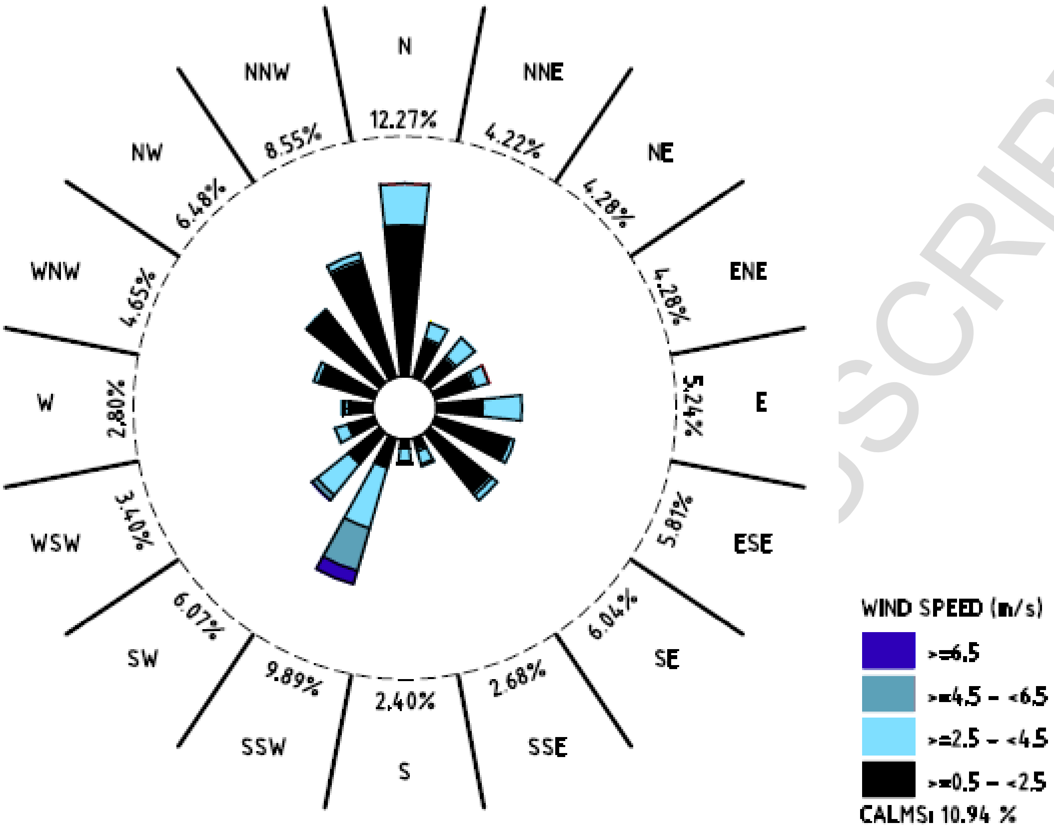

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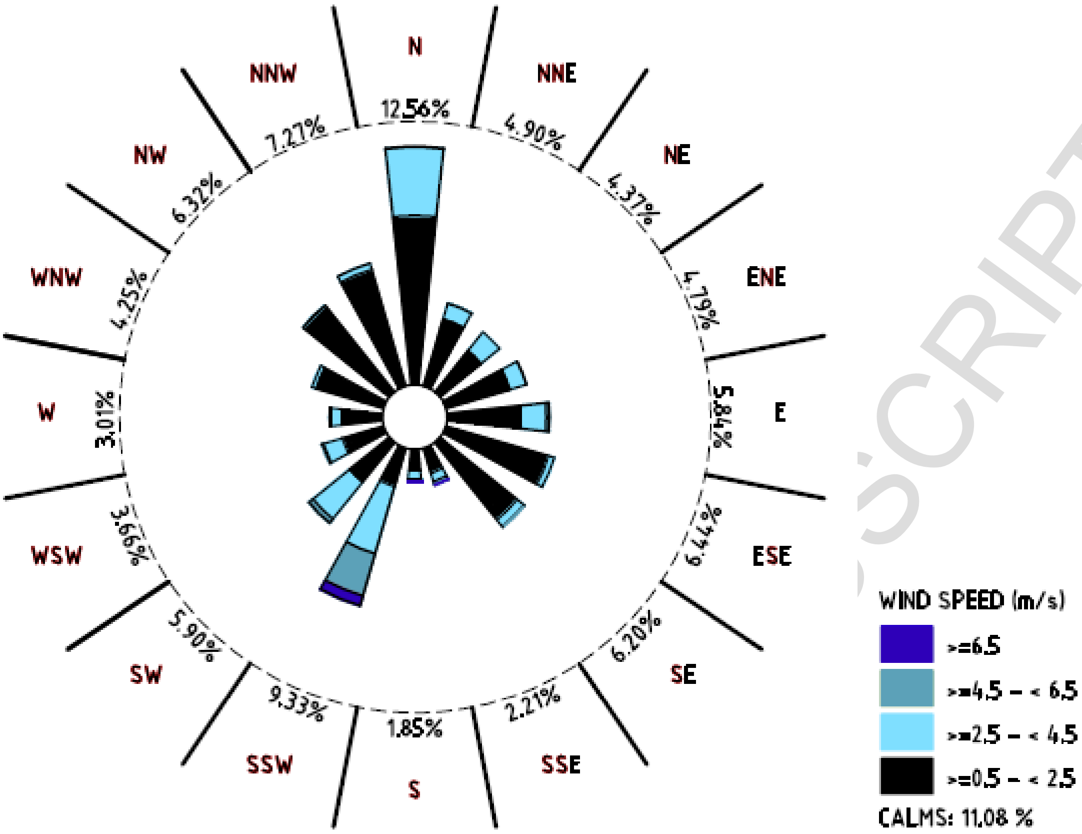

Figure 7. Wind-rose for data collected from May 1st, 2010 to April 30th, 2011 (wind flow is from the directions shown).

Table 1

Table 1. Type, operating range and accuracy used for data collection.

Parameter	**Sensor type**	**Operating range**	**Accuracy**
Wind speed	LSI LASTEM DNA022	0-60 m/s	0.1 m/s (readout)
Wind direction	LSI LASTEM DNA022	0-360°	1% full scale
Temperature	LSI LASTEM DMA572.1	-30 to 70°C	± 0.3%
Pressure	LSI LASTEM DQA240.1	800-1100 mbar	1 mbar
Relative humidity	LSI LASTEM DMA572.1	0-100%	± 3%

Table 2

Table 2. Relevant statistics of the meteorological parameters in the period under investigation (May 1st, 2009 to April 30th, 2011).

Parameter	Unit	Mean	Valid data (%)
Wind speed	m/s	1.87	99.83
Temperature	°C	17.26	99.83
Pressure	mbar	1005	99.83
Relative humidity	%	68.5	99.83
Air density	[kg/m^3]	1.205	99.83

Table 3

Table 3. Measured values of wind speed (v_i), frequency (n_i) and probability frequency f_i for the period under investigatons (May 1st 2009 to April 30th 2010 and the period May 1st 2010-April 30th 2011).

Wind speed (m/s)	**May 1st 2009-April 30th 2010**		**May 1st 2010-April 30th 2011**	
	Frequency, n_i	***Probability frequency, f_i***	***Frequency, n_i***	***Probability frequency, f_i***
0	914	0.105	971	0.111
1	3400	0.389	2886	0.329
2	2316	0.265	2908	0.332
3	1248	0.143	1174	0.134
4	450	0.052	448	0.051
5	176	0.020	200	0.023
6	131	0.015	109	0.012
7	46	0.005	43	0.005
8	30	0.003	19	0.002
9	15	0.002	0	0.000
10	5	0.001	0	0.000
11	0	0.000	0	0.000
12	0	0.000	1	0.000
13	0	0.000	0	0.000
14	0	0.000	0	0.000
15	0	0.000	1	0.000

Table 4

Table 4. Comparison of Weibull's parameter *k* and C, from May 1st, 2009 to April 30th, 2011.

	k	***C***		***k***	***C***
May 1st, 2009-April 30th, 2010	1.210	1.522	**May 1st, 2010-April 30th, 2011**	1.065	1.407
May 2009	1.115	1.278	May 2010	1.265	1.696
June 2009	1.134	1.536	June 2010	1.665	1.633
July 2009	1.305	1.303	July 2010	1.519	1.382
August 2009	1.375	1.221	August 2010	1.494	1.362
September 2009	1.189	1.185	September 2010	1.390	1.473
October 2009	1.074	1.500	October 2010	1.269	1.500
November 2009	0.639	0.685	November 2010	1.018	1.668
December 2009	1.142	1.793	December 2010	0.947	1.490
January 2010	1.090	1.820	January 2011	0.965	0.944
February 2010	1.147	1.710	February 2011	1.234	1.420
March 2010	1.017	1.575	March 2011	1.209	2.252
April 2010	1.253	1.573	April 2011	1.615	1.629

Table 5

Table 5. Comparison between theoretical and calculated mean wind speed values for data collected from May 1st 2009 to April 30th 2011.

Period	**May 1st, 2009- April 30th, 2010**		**May 1st, 2010- April 30th, 2011**	
	Mean speed Theor.(m/s)	**Mean speed Simp. comp. (m/s)**	**Mean speed Theor.(m/s)**	**Mean speed Simp. Comp. (m/s)**
May	1.23	1.65	1.58	2.05
June	1.47	1.89	1.46	1.91
July	1.20	1.59	1.25	1.64
August	1.12	1.57	1.23	1.65
September	1.12	1.62	1.34	1.81
October	1.46	1.90	1.39	1.84
November	0.95	1.41	1.66	2.04
December	1.71	2.15	1.53	2.03
January	1.76	2.20	0.96	1.39
February	1.63	2.12	1.33	1.83
March	1.57	2.02	2.11	2.64
April	1.46	1.91	1.46	1.98

Table 6

Table 6. Mean wind energy density (P_a/A), wind speed of maximum energy carrier (v_{mec}), simply computed and theoretical mean wind speed ( ) and standard deviation of simply computed and theoretical wind speed (σ), for data collected from May 1st 2009 to April 30th 2011.

Parameter		May 1st, 2009 April 30th, 2010	May 1st, 2010 April 30th, 2011
$\langle P_a/A\rangle$ (W/m^2)		6.90	6.82
v_{mec} (m/s)		3.40	3.83
$\bar{v}$ (m/s)	Theor.	1.39	1.44
	Simply comp.	1.84	1.90
σ (m/s)	Theor.	0.26	0.28
	Simply comp.	0.26	0.30

Table 7. Monthly variation of mean air density (kg/m^3) from May 1st 2009 to April 30th 2011.

Month	**Mean air density (kg/m^3)**	
	May 1st 2009 April 30th 2010	**May 1st 2010 April 30th 2011**
May	1.190	1.198
June	1.179	1.176
July	1.164	1.163
August	1.164	1.161
September	1.184	1.187
October	1.206	1.206
November	1.226	1.211
December	1.224	1.236
January	1.239	1.248
February	1.229	1.240
March	1.235	1.239
April	1.216	1.213

Table 8

Table 8. Economic and technical analysis of the turbines listed in the Catalogue of European Urban Wind Turbine Manufactures, in the period under investigation.

Wind turbine	**Extractable energy (Wh)**	**Capacity Factor (%)**	**Rated power (kW)**	**Initial investment (€)**	**LCOE May 1st. 2009-April 30th. 2010 (€/kWh)**	**LCOE May 1st. 2010-April 30th. 2011 (€/kWh)**
Gaia-Wind A/S	7,408,000	0.0769	11.00	15,400	0.124	0.118
Travere Industries	674,020	0.0366	2.10	2940	0.260	0.256
Wind Energy Solutions	517,484	0.0236	2.50	3500	0.403	0.396
Tulipower	508,108	0.0232	2.50	3500	0.410	0.407
Aircon	2,028,800	0.0232	10.00	14,000	0.411	0.407
Marlec Engineering	17,894	0.0227	0.09	126	0.419	0.415
Proven Energy Products	105,140	0.0200	0.60	840	0.476	0.470
Marlec Engineering	4262	0.0195	0.03	35	0.489	0.484
Travere Industries	135,960	0.0172	0.90	1260	0.552	0.559
Travere Industries	237,790	0.0170	1.60	2240	0.561	0.568
Travere Industries	813,600	0.0169	5.50	7700	0.564	0.571
Proven Energy Products	2,159,400	0.0164	15.00	21,000	0.579	0.575
Iskra Wind Turbines	705,811	0.0161	5.00	7000	0.591	0.586
Proven Energy Products	829,850	0.0158	6.00	8400	0.603	0.596
Pitchwind Systems AB	3,925,200	0.0149	30.00	42,000	0.637	0.623
Surface Powe	58,680	0.0146	0.46	644	0.654	0.652
Electric Energy	42,565	0.0121	0.40	560	0.784	0.773
Sviab	79,770	0.0121	0.75	1050	0.784	0.775
OY Windside Production Ltd	103,220	0.0118	1.00	1400	0.808	0.783
Travere Industries	297,030	0.0113	3.00	4200	0.842	0.846
Ampair Pacific Hawk	8860	0.0101	0.10	140	0.941	0.942
Fortis Montana	459,490	0.0094	5.60	7840	1.016	1.003
Winddam	158,640	0.0091	2.00	2800	1.051	1.065
Ropatec S.p.a.	225,770	0.0086	3.00	4200	1.108	1.104
Fortis Wind Energy	57,810	0.0082	0.80	1120	1.154	1.172
Jonica Impianti	1,441,300	0.0082	20.00	28,000	1.157	1.180
Ampair Pacific Hawk	20,925	0.0080	0.30	420	1.196	1.189
Ropatec S.p.a.	51,345	0.0078	0.75	1050	1.218	1.207
Fortis Wind Energy	93,442	0.0076	1.40	1960	1.249	1.283
Winddam	248,025	0.0071	4.00	5600	1.345	1.371
Ropatec S.p.a.	255,400	0.0049	6.00	8400	1.959	1.961
OY Windside Production Ltd	309,812	0.0044	8.00	11,200	2.153	2.064
Venturi Wind b.v.	16,612	0.0038	0.50	700	2.510	2.473
Turby B.V.	66,528	0.0030	2.50	3500	3.134	3.562
Fortis Montana	801,700	0.0009	10.00	14,000	10.402	10.568

Table 9. LCOE (€cent/kWh) by power technology.

Technology	Low cost	High cost
Coal (brown)	38	53
Coal (hard)	63	80
Combine Cycle Gas Turbine	75	98
Onshore wind farms (*)	45	107
Offshore wind farms (*)	119	194
Photovoltaic	78	142
Biogas power plant	135	250
Onshore wind farms (**)	60	120
Offshore wind farms (**)	100	121
Best of the case study	118	

* Kost C., 2013; **IRENA, 2015 in US$ cent.