Wind Resource of Uruguay

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Summary

The wind energy sector is booming worldwide and Latin American countries are not an exception. The initial prospection of interesting wind energy sites is challenging, especially when few or none historical reliable local data exists. The use of Mesoscale numerical models is a useful tool to perform this initial approach, identifying interesting areas to develop wind energy projects.

MEGAJOULE has used the Weather Research and Forecasting model system (WFR) to simulate the regional wind climate in Uruguay and input climate data from the NCEP/NCAR reanalysis project.

The estimated average annual wind speed is presented at 60m a.g.l. and is a result of hourly averaged wind speed values simulated with a spatial resolution of 9 km.

Mapping the wind resource of a whole country, like Uruguay, has many expeditious applications. Namely, it is possible to support political decisions planning potential global and regional wind energy contribution in the country energy grid, also supporting the initially site prospection and greenfield development, in the private investment domain.

The main limitations of mesoscale models are linked with the fact that they cannot represent microscale features since they are limited by the grid resolution.

These results provide information that guides the placement of measurement masts and further microscale studies.

1. Introduction

Demand for energy is increasing globally, especially at developing countries. In the other hand, this development depends on energy supply at a constant basis and at competitive prices. Wind energy, like other renewable sources, can contribute significantly to fill part of this demand, at competitive prices and with environmental benefits. Previously, the world's biggest wind energy market players were European countries. In 2004 Europe represented 75% of worldwide wind energy market, but in 2007 this value had already decreased to 45%, with the United States and China accomplishing 26% and 17% of the 2007 newly installed capacity, respectively.

Globalization trends presented by the wind energy market tend to seek for new projects at non studied regions/countries. The identification of promising sites is a first and valuable step to evaluate at early stages the feasibility of a project and investment strategy.

Combining the market evolution with key strategies of promoting the diversification of national energy matrixes and energy independency, several Latin American countries are changing their energy policies benefiting renewable sources. Recent governmental policies taken in Uruguay promotes considerable expansion of its renewable energy matrix, including wind energy as a basis for future developments and a nationwide characterization of wind patterns from local data, produced in cooperation with *Universidad de la Republica*.

Consequently, the main goal of this paper is to present the results of an initial evaluation of the countrywide wind resource potential. MEGAJOULE has composed a Wind Map by employing a numerical simulation Mesoscale model, the Weather Research and Forecasting System (WRF), thus supporting an initial approach of wind energy potential characterization.

2. Current energy market and wind energy scenario

The electricity consumption at Uruguay is currently of 9 TWh per year. According to a *Dirección Nacional de Energia y Tecnologia Nuclear* publication, during 2003 and 2007 the Uruguayan electricity production matrix was composed 68% by hydro power and 32% from small thermal power plants and mobile diesel generators that, generally, are turned on mostly during peak hours. This hydro dependency presents considerable supply risks due to the seasonal and infra-annual rainfall patterns variation. Indeed, Uruguay has bought electricity from his neighbor countries, Brazil and Argentina, several times during the past decade, especially during dry years.

Nowadays, the Uruguayan government is promoting, among other renewable sources, the wind energy sector development. The advantages of this decision are motivated and mostly related to:

- Using a clean and renewable energy source.
- Following the increasing consumption needs, reducing the energy dependency from its neighboring countries.
- Recognizing and making use of the already observed complementarities between hydro and wind energy sources.
- Selling energy to neighbor countries, in case of production surplus. Recent efforts have been made strengthening the existent electricity network, especially the connections with Brazil and Argentina.
- Be a part of the Carbon trading market, selling Emission Reduction Units to industrialized countries. Uruguay has low greenhouse gas emissions and does not have to fulfill any kind of emission targets regarding the Kyoto Protocol.

The wind energy at Uruguay is still at an infancy stage. During 1988 and 1993 it was developed the *Mapa Eólico del Uruguay*, that states the elevate wind energy potential of some areas, namely *la Sierra de los Caracoles* and *la Sierra de las Ánimas*. Also the coastal area should be of interest.

Nowadays there are two wind farms in operation, a privately owned development at Sierra de Rochas area and a second one at Sierra de los Caracoles, having both an installed capacity of 10 MW. Apart from this two wind farm projects, there are already 6 MW registered at *Administración Nacional de Usinas y Trasmisiones Eléctricas* (UTE), corresponding to another two small wind farm projects.

The *Política Energética 2005-2030* document goals states that, by 2015, Uruguay must have 15% of country energy needs provided by wind, solar and biomass sources. In other words, this should imply a wind energy installed capacity of 200 to 300 MW, around 6 % of the national energy needs by that year. It is also under approval, and should be published by the end of July 2009, a decree setting out tax exemption for clean energy generation projects, which should be a stimulus to the market development.

Therefore, the goals are set and indicate that there should be available around 180 to 280 MW to be installed by 2015. It is imperative to identify the most interesting areas to implement wind farm projects.

3. Relevance and application

The main goal of the Uruguay wind atlas is to provide an overall indication of the geographical distribution and magnitude of the wind resource. The wind map here presented intends to be a contribution for a more detailed wind atlas.

Mesoscale modeling can help private and public decision makers to plan their strategic investment actions. It is a useful tool that provides initial knowledge about the wind resource distribution at country or regional levels. Possible applications are the initial site selection for wind farm development, strategic developments of utility networks and balance of production capacity to better integrate renewable energy sources. This methodology is particularly useful to reduce risk in Greenfield development.

The production of a Wind Atlas at a country or region scale, using Mesoscale modeling, can help selecting the most suitable places for development. Moreover, detailing the information within an area of study can provide high-quality tools to define, for instance, the placement of measurement masts.

Concurrently, Mesoscale modeling results can be coupled with Microscale flow models (like WAsP or CFD), using synthesized virtual wind data series, to support preliminary micro-sitting and the energy yield estimates, before reliable data from local measurement campaigns are made available. Numerical simulation data can also assist the evaluation of annual variability of wind resource.

4. Methodology

a. Motivation

An extensive comprehension of wind patterns is crucial to the successful deployment of new wind farms. In order to obtain the necessary data several studies are carried out including mainly on-site measurements, micro-scale simulations and large time-scale climate analysis. However, the traditional large-scale studies often neglect the local effects, since they are based on broad analysis that do not consider the effect of regional features, such as mountains and hills, therefore creating a considerable gap between climate patterns and local measurements.

The ideal approach to fulfill this gap is to have several on-site measurements for long periods. However, this approach is seldom available to promoters on initial studies and green-field procurement. Consequently, the usage of Mesoscale computational modeling of wind climate can provide key information to initial studies.

b. Mesoscale modeling

Regional climate simulations require an extensive quantity of data, covering at least 30 years, and a computational system capable of describing in great detail the effects of local features. In order to obtain a comprehensive large-scale climate data the NCEP/NCAR Reanalysis database is used. This project, conceived by the National Oceanic and Atmospheric Administration (NOAA) and National Center for Environmental Prediction, consists of a database of global observations from various sources (standard meteorological observations, buoys, satellites, and several others) reconstructed using advanced quality control and modeling techniques. This data seamlessly describes the atmosphere in several vertical levels, with a spatial resolution of 2.5 degrees, therefore being used in large-scale studies and to initialize smaller scale simulations. This data is routinely used for Mesoscale modeling of wind resources and in leading climate research projects.

A comprehensive description of the mean atmospheric conditions requires at least 30 years of data, but conducting high-resolution numerical simulations with such data demands an immense computational infrastructure, therefore an initial large-scale analysis is conducted to determine the year (or range of years) that best describes the average conditions in several locations across the desired area for which long term climate data is available.

The simulation of the regional wind climate is performed by the Weather Research and Forecasting system (WRF, UCAR). This state of the art Mesoscale model is currently used by numerous institutions around the world, and its versatility guarantees a complete customization to a wide range of studies. This numerical modeling system consists of several modules especially created to ingest observational data and simulate atmospheric conditions, solving several physical equations and describing the dynamics and thermodynamics of the atmospheric flow in limited areas. The WRF is a transient, non-linear model, and as any numerical solver it depends on boundary data to depict the initial conditions of the system and maintain numerical stability during the simulation. In order to describe a complex atmospheric system, it is required to have accurate data to represent the initial state of the atmosphere and its physical boundaries, such as surface roughness, topography and land cover.

Large-scale conditions from the Reanalysis dataset are used in a dynamical downscaling method, in order to provide the necessary transient initialization data. Such method consists of the initialization of a limited area model (LAM), such as WRF, by using mass, momentum and thermodynamic data from a general circulation model (GCM) or another LAM with greater area, and by providing lateral boundaries conditions during the numerical integration of the LAM. This technique offers the advantage of enhancing the simulation of regional features due to the increase in the horizontal resolution (and the consequent refinement of lower boundary discretization) and by allowing the representation (as opposed to parametrization) of certain dynamical features that fall within mesoscale range, such as deep convection for instance.

Physical boundary data is provided by the USGS 30-second Global Elevation Data (United States Geological Survey and University Corporation for Atmospheric Research). This dataset is a Digital Elevation Model (DEM) that provides terrain elevation information in a horizontal grid of 30 arc seconds (approximately 1 km), derived from several raster and vector sources of topographic information. Land cover data is provided by the Global Land Cover Characteristics Data Base (USGS, National Center for Earth Resources Observation and Science – EROS, Joint Research Centre of the European Commission). It consists of a 1 km resolution global land cover characteristics dataset, conceived to be used in a wide range of environment research and modeling applications, and derived from global observations acquired between April 1992 and March 1993 from the Advanced High Resolution Radiometer, located aboard the NOAA series satellites.

5. Results

The following picture represents the resulting wind map of Uruguay with the annual average wind speeds for 60 m a.g.l.

The best wind resources are mainly found throughout the shoreline and *Rio de Plata* bay, where wind speed can rise up to the average 8.0 m/s, mainly in the Atlantic shore.

In the mainland, wind speeds decrease significantly due to surface roughness. The countryside lacks extensive topographic features, as Uruguay is mainly a plain between Argentina's *pampas* and mountainous regions of South Brazil. The most interesting inland areas are the *Cuchila Grande* region, north of *Piriapolis*, and the mountainous area around *Tacuarembo*, where wind speeds can reach 7.0 m/s.

Generally, areas with higher potential are located within a 50km radius from Uruguay's most populated regions, thus having an easier access to potential customers. Furthermore, the districts of Florida, Maldonado, Treinta y Tres and Lavalleja, which concentrates most of the average speeds above 7m/s, have access to the nationwide distribution network, being Minas (60kV line) and Valentines (150kV line) approximately 10km away, and San Carlos (500kV line) approximately 20km away from areas with higher potential.

Given the horizontal resolution of 9x9 km minor scale features, such as hills or valleys, can considerably alter the average wind resource estimated. These are intended to provide a broader scale indication of the regions with better local wind resource availability.

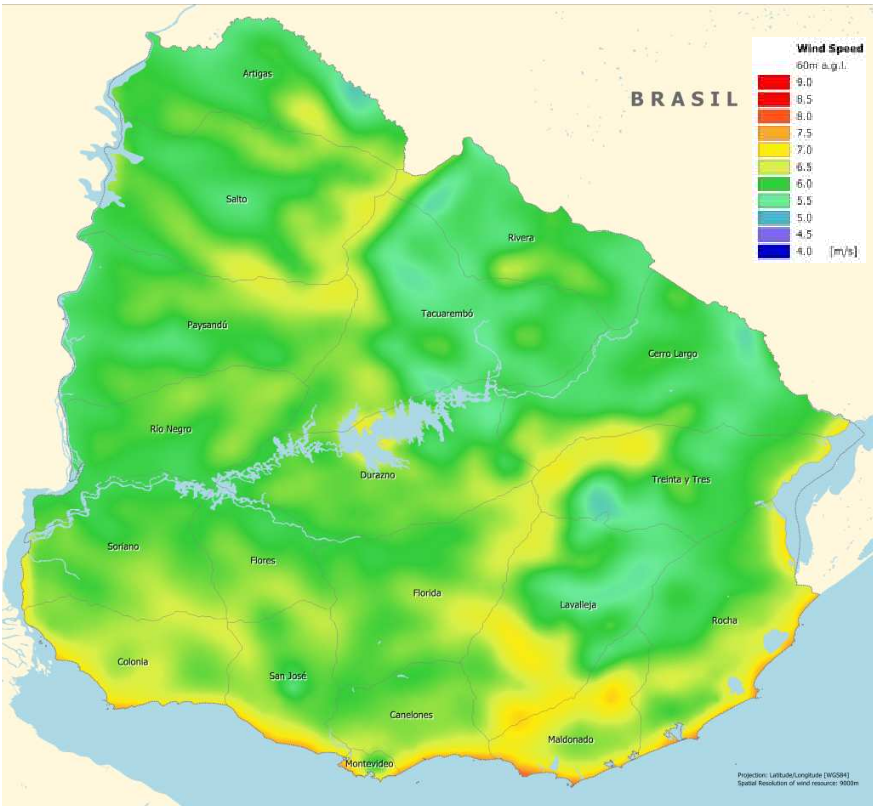

Figure 1: Wind Map of Uruguay, Average Annual Wind Speed at 60 m a.g.l. for 9x9 km resolution

6. Limitations

Deviations in wind direction and magnitude are expected, originated from an intrinsic limitation existing in any grid-based numerical model. Such models operate by performing an adjustment to the lower boundary data in order to adapt it to its horizontal resolution, vertical resolution and projection. Sub-grid features will be smoothed in order to adjust them to the model native grid, leading to a misrepresentation of features which are smaller than the used horizontal resolution, thus leading to different results.

Several validation efforts where conducted, in a broad range of sites, indicating that mesoscale modeling can determine monthly and annually averaged wind speeds with a deviation under 5%. This value can be significantly different on areas where local patterns are defined by topographic features smaller than the resolution used. The complexity of the site is a key factor and should be evaluated in regard to the horizontal resolution used in any numerical simulation.

A mesoscale approach is an important factor in initial studies, but it is not a substitute to locally acquired data. A complete study with higher horizontal resolution and coupling with microscale models can overcome limitations in the lower boundary discretization, better representing sites with complex terrain and thermally-induced atmospheric patterns.

7. Conclusions

The best wind resources in Uruguay are estimated to be located along the Atlantic and *Rio del Plata* shore. Wind speed can go up to 8 m/s on those locations.

Deeper inland, wind resource has a low variability, related with the gentle orography of the country. Only a few mountainous areas exist that accelerate the wind up to typical interesting levels, of at least 7 m/s. From those, the *Cuchila Grande* mountainous region, north of *Piriapolis,* seems to be the most promising one.

The modeling horizontal resolution, of 9x9 km, should be considered when interpreting the results. Regional features, such as hills or valleys, will result on different wind resources than the estimated, which are intended to be a broader scale indication of the most promising regions.

The Uruguay Wind Atlas can support the decision making processes, providing an initial estimate of wind resource in a short time frame, especially where the local resource is not well known. This solution can be of great value for several wind energy promoters, ranging from government institutions to private investors, and could possibly complement future wind resource characterizations due to be released by the government.

The construction of a detailed Wind Atlas is of great interest, as wind energy sector is beginning to make its way into this country. A throughout analysis should include land occupation, environmental classification, local restrictions, electric grid characteristics, numerical simulations fitted in accordance with the local terrain complexity, and locally acquired data at relevant height to wind energy exploitation.

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