# Wind Resource Assessment of the Metropolitan Area of Barcelona

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**Abstract.** Large cities are engaged in reducing CO2 emissions with the help of renewable energy. The aim of this study is to assess wind energy production over the 640 km² of the Metropolitan Area of Barcelona (AMB in Catalan) in order to set up small wind turbines to be connected to the smart grid. Buildings will create wind acceleration, recirculation areas, blocking effects. CFD software Urbawind models the wind inside this complex urban canopy. The work has been commissioned by the Sustainability Plan and the Environmental Services of the Metropolitan Area of Barcelona.

**Keywords:** Numerical simulations, Wind Resource Assessment, Renewable energy, Urban, Small wind turbines

## 1 Introduction

The Metropolitan Area of Barcelona (AMB in Catalan) has developed a Sustainability Plan for 2014-2020.

In order to develop installation of wind turbines in urban areas, five potential barriers has been identified [1]: Safety (fatigue resistance, braking redundancy…), Wind Resource, Turbine technology (noise, vibration…), Building interactions (resonance frequencies between building and turbine, mechanical and electrical integration), Non-technical obstacles (safety hazards during installation, operations and maintenance…).

In the present paper, we will focus on wind resource assessment in order to guide the deployment of wind turbines in urban environments.

Most of the small wind turbines are designed for rural areas where low turbulence intensity and high mean speed occur. Whereas built environment is characterized by high turbulence intensity and low mean wind speed. Inadequate sitting of small wind turbines could lead to turbine failure and potential liabilities. Thus it is important to provide a good estimation of the wind resource at different heights for developers. In order to bring out characteristics of wind flow in an urban environment, a specific wind model dedicated to urban areas is used. Unlike other meso-scale models, each

building of the urban fabric was modeled and exists as a proper 3D geometry in the computation.
The final goal was, therefore, to detect areas (this is to say roofs or open fields or agricultural lands) to install a small wind turbine suitable for a particular wind potential and to assess the wind energy available for each building owner or to the electrical grid.

## 2 Wind Resource Assessment Methodology

The methodology [2] consists in:

1. Transferring wind data from a weather station to 200 meters high area over the AMB thanks the CFD software Topowind [3] taking into account the effect of topography (elevation and terrain roughness of the site)

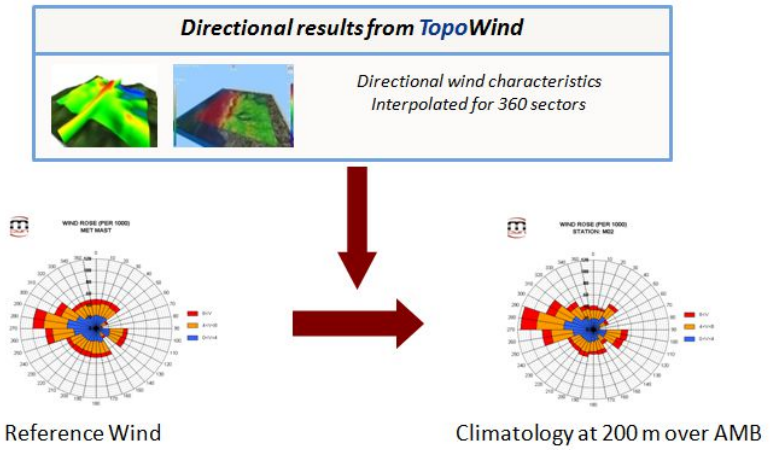


**Fig. 1.** Transfer of wind rose from the weather station (Reference Wind) to the local area at 200 m high

2. Computing the wind flow inside the urban area taking into account the effect of the elevation and the buildings in 3D thanks to UrbaWind [4]

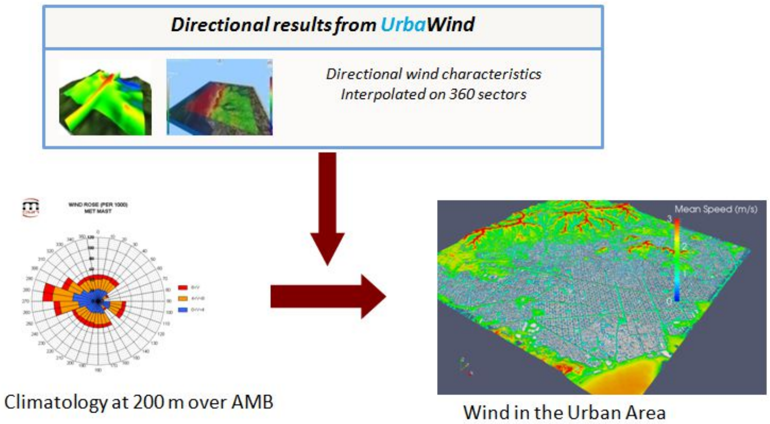


**Fig. 2.** Transfer of wind rose from climatology at 200 m high over AMB to the urban area

## 2.1 Transfer of the reference climatology above the Metropolitan Area of Barcelona

The selected wind reference is from a weather mast located near the shore at Sirena (41°20'28.29"N, 2° 9'57.99"E, H = 10, Port of Barcelona). The wind speed histogram and wind rose observed at the station are included hereunder.

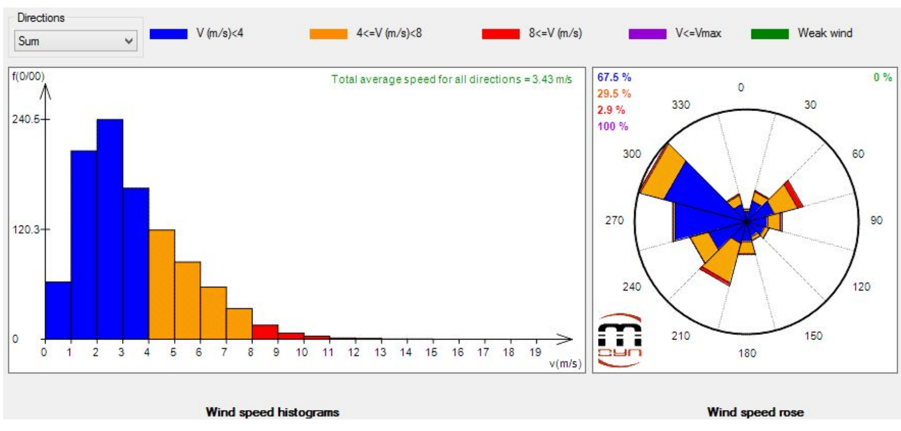


**Fig. 3.** Wind Rose and histogram of the wind reference at Sirena (Barcelona). Data source: Port of Barcelona

Orography data is extracted from the NASA database (SRTM). Roughness is computed from Corine Land Cover database (2006).

TopoWind, commercial software [5], performs the transfer of the wind characteristics from the wind reference to the 200 meters high area above the AMB.

With a horizontal resolution of 25 m, the mesh size is about 20 Million cells for a computational time of 5 hours per direction. The directional resolution is 20 degrees, leading to 18 directions. As an example of these computations, a mapping of the resulting wind speed coefficients for one synoptic wind direction is shown in figure 4. The wind speed coefficient is defined as the horizontal mean speed divided by a wind at 10 m height. The obtained wind characteristics over the AMB were used as the input in the subsequent micro-scale downscaling carried out to include the urban local effects.

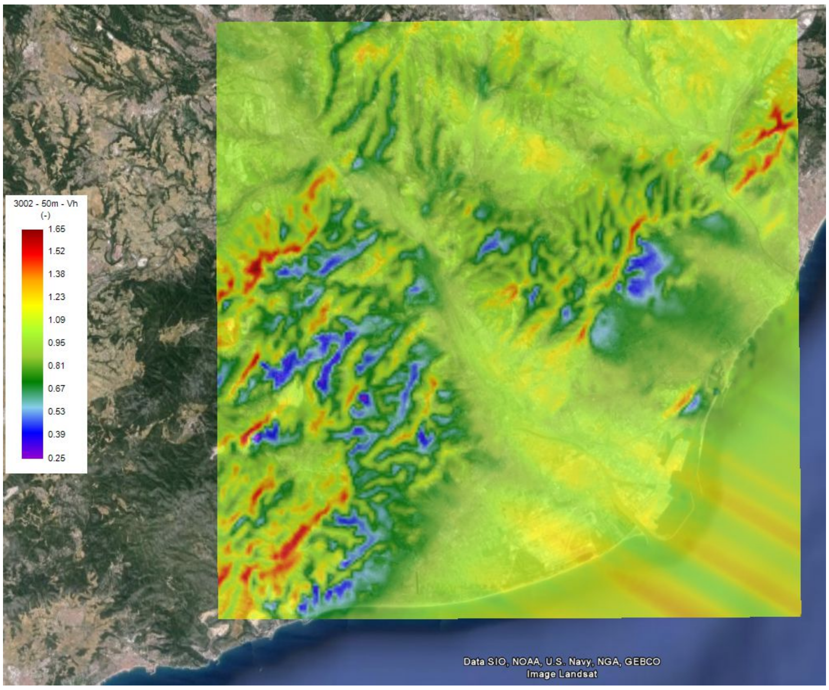


**Fig. 4.** Wind Speed Coefficient mapping for direction 300 deg

### 2.2 Computation of the wind characteristics in urban area

Barcelona Regional, an urban development agency provides the entire numerical model of the 640 km² AMB's urban area. The whole area has been split in small parts with overlapping pats in order to suit the wind model requirements. It includes CAD of the building and orography. For the buildings, Barcelona Regional developed some scripts for GIS and RHINO-Grasshopper in order to get 3D building geometry joining 0.5 meters resolution LiDAR data with Cadastre data. For the terrain it has been used an original 2 meters orography data resolution.

Vegetation is not taken into account because, inside the urban canopy, its effect on the small wind turbines is negligible compared to the effect of the buildings.
The CAD of the building includes roof superstructures such as chimneys and shed dormers.
The 10 meters horizontal resolution of topography maps was fine enough to catch slopes over 2.5 % responsible for wind acceleration.

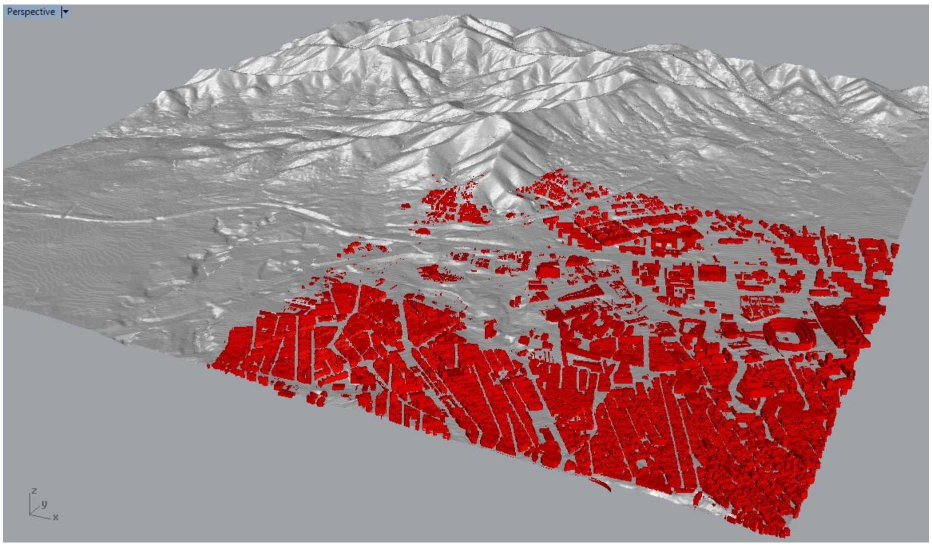


**Fig. 5.** Sample of buildings and topography - Source: Barcelona Regional

One single simulation of the entire area entails 1.7 TB of RAM. In order to be able to run such a simulation on a standard cluster, the area is split in smaller domains. The AMB is divided then into 138 sub-areas of 2.5 km x 2.5 km each.
An overlapping area of 450 m is added to each border to ensure better wind characteristics thanks to the extra roughness on the ground. Thus each computed sub-area has a 3.4 km x 3.4 km total surface.

Once the wind characteristics is computed at 200 meters high area over the AMB, UrbaWind transfers the wind inside the urban area taking into account the effect of the elevation and the buildings.

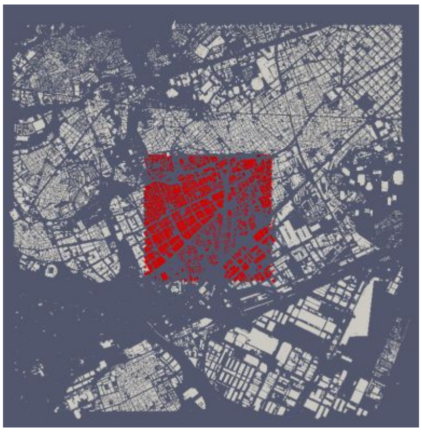

**Fig. 6.** 3.4 km x 3.4 km domain (red area) - Source: Barcelona Regional

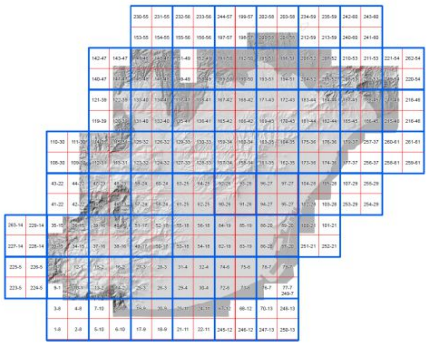

**Fig. 7.** AMB divided into 138 small areas - Source: Barcelona Regional

UrbaWind solves the Navier-Stokes equations with a one-equation turbulence model, where the turbulent length scale $L_T$ varies linearly with the distance to the nearest wall [6].

Boundary conditions are automatically generated. The vertical profile of the mean wind speed at the inlet is divided in three layers: logarithmic profile within the surface layer; in the Ekman layer wind speed profile is a logarithmic function of geostrophic wind speed; at the upper limit of the surface layer and above the ABL the wind speed is constant and equal to the geostrophic wind speed.

The geostrophic wind speed is a function of ABL height and the wind speed at 10 meters high in open land.

A 'Blasius'law is modeled by introducing a volume drag force in the cells lying inside the obstacle.

The equations resolution is based on a finite volume method with a rectangular multi-bloc refined mesh. A very efficient coupled multi-grid solver is used [7].

The mesh resolution is about 1.0 m around the buildings and close to the ground leading to a number of cells of about 10 million per direction. The computational time for one direction is about 1 day. Considering 8 directional computations for each of the 138 sub-areas, the total computational time is about 1104 days. Three computers with 8 processors 2.4 GHZ Intel Xeon each helps to reduce the computation time to 3 months (efficiency in parallel of 50%).

Once all sub-areas are completed, the results at the borders can be non-homogeneous and present discontinuities.

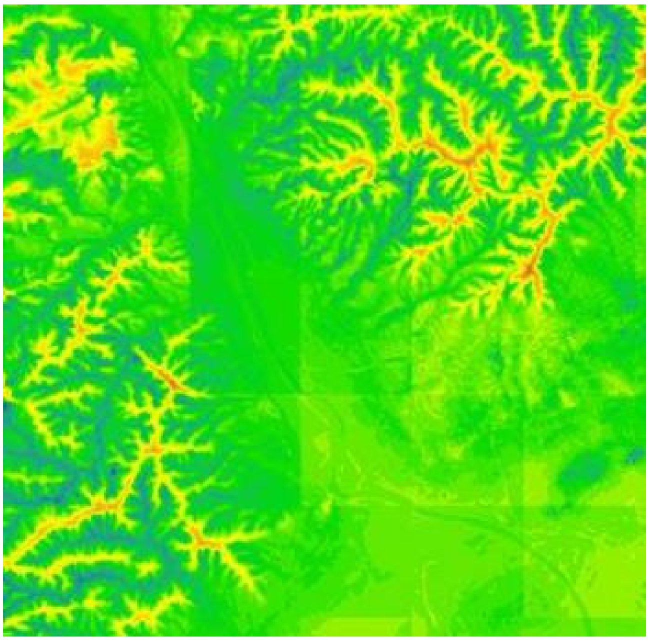

**Fig. 8.** Non-homogeneous result at the border for mean wind speed

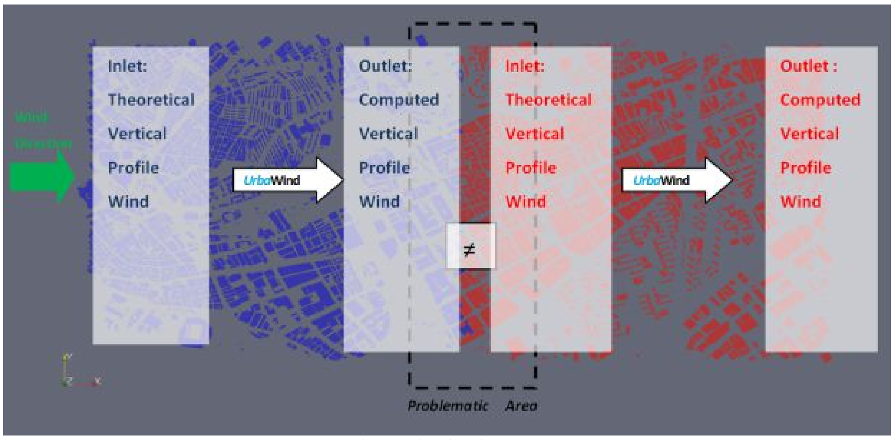


**Fig. 9.** Discontinuity between two areas

Those discontinuities appear when there is a roughness difference between two sub-areas. In fact for an Urbawind directional computation, the roughness inlet is limited to 4 different profiles (Water, Open country, Small density city, and High density city) whereas in reality the value of the roughness could be different. The wind characteristics at the exit of a sub-domain take into account the real roughness of the city. Therefore a wind speed difference between the outlet of a sub-area and the inlet of the adjacent one may come out.

In order to smooth results between two neighboring sub-areas, a box average over three points is performed

## 3 Results

Mean Annual Wind Speed and Mean Annual Energy Production for a TechnoWind 1 kW wind turbine are computed on various mappings at 10 m, 20 m, 30 m, 40 m and 50 m above the ground with a horizontal resolution of 10 m.

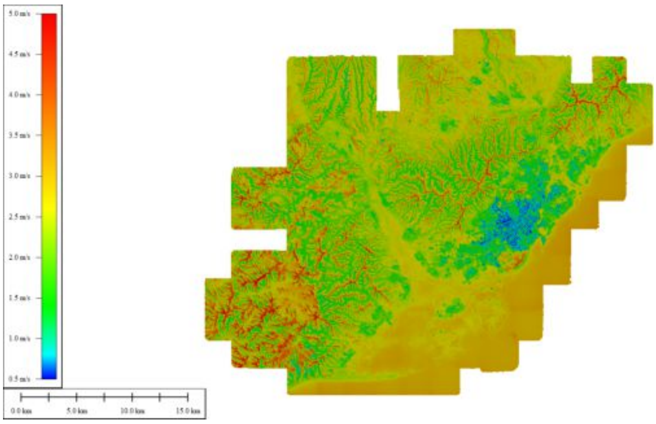

**Fig. 10**. Mean Annual Wind Speed Atlas at 20 m high

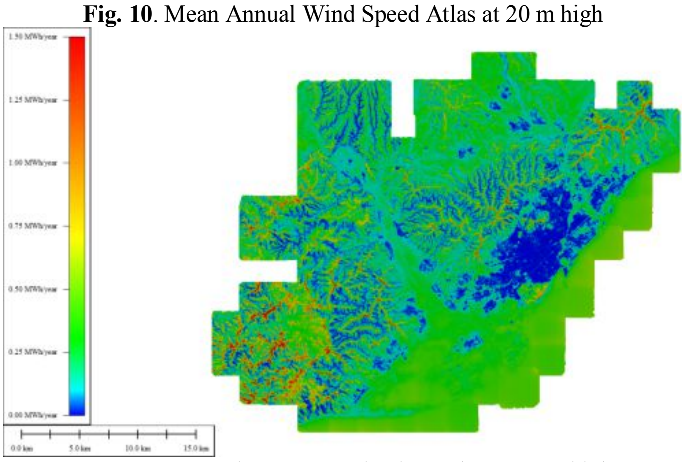

**Fig. 11**. Mean Annual Energy Production Atlas at 20 m high

## 4 Validation and conclusions

A cross-validation of the numerical results is performed thanks to seven weather stations located in the AMB. The period starts from 04/01/2011 until 12/31/2012 with a time step of 30 minutes to 1 hour depending on the station.
The difference between measured and computed wind speeds remains under 0.4 m/s except for the station of Vallirana.
The computed values underestimate the mean speed recorded at the weather station.
For the station of Vallirana, the mast is located near some vegetation.

Higher computed results can be explained because of the non-existence of the vegetation in the simulation, which leads to an over-estimation of wind speed.

**Table 1.** Comparison between Computed Mean Speed and Measured Mean Speed.

| Station | Height | Mean Speed Measured | Mean Speed Computed | Difference |
|---|---|---|---|---|
| El Prat de Llobregat | 10 m | 3.0 m/s | 2.6 m/s | 0.4 m/s |
| Barcelona - Zona Universitaria | 10 m | 2.1 m/s | 2.1 m/s | 0.0 m/s |
| Barcelona - el Raval | 30 m | 2.0 m/s | 1.7 m/s | 0.3 m/s |
| Vallirana | 10 m | 1.9 m/s | 2.5 m/s | -0.6 m/s |
| Castellbisbal | 10 m | 2.4 m/s | 2.2 m/s | 0.2 m/s |
| Badalona - Museu | 33 m | 2.7 m/s | 2.8 m/s | -0.1 m/s |
| Barcelona - Observatori Fabra | 10 m | 4.7 m/s | 4.3 m/s | 0.4 m/s |

The wind resource assessment of the Metropolitan Area of Barcelona is computed thanks to the large scale CAD model done by the Barcelona Regional and CFD software such as TopoWind and UrbaWind.
Because small wind turbines usually require a minimum of 4 m/s annual mean velocity to start working, 20 m height for wind turbine location is a minimum for wind energy production. In fact about 5 % of the Metropolitan Area of Barcelona reaches the minimum mean velocity criteria at 20 m hub height. For higher hub heights, the percentage of exceeding the minimum velocity criteria will increase.

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