TECHNICAL REPORT

Validation of the Wind Resource Maps Across Europe

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UL Solutions

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Executive summary

UL Solutions has performed a new validation of its existing 200-meter resolution wind map with 315 meteorological masts spread across Europe. This complements the validation performed in 2012 with a different set of 433 stations. Together, the two exercises include more than 750 measurement points distributed in 20 countries, resulting in two main outcomes:

- **Almost no mean bias**
  The mean bias of the wind speed map is very close to zero (-0.04 m/s found in 2012 vs 0.22 m/s in 2023).

- **Outperforms public sources**
  The UL Solutions model outperforms public sources, such as the New European Wind Atlas and the Global Wind Atlas, with a lower bias, uncertainty and root mean square error.

The 200-meter resolution wind maps and associated data can be downloaded in GIS-compatible format or as a Wind Resource Grid (WRG) through the Windnavigator[1] platform and Renewable Resource Assessment Platform (RRAP).

Introduction

The high-resolution maps of estimated mean annual wind speed included in the digital platforms by UL Solutions are designed for preliminary wind resource assessments and created with the Mesomap system. In 2012, UL Solutions published a report (Information Services, 2012) describing the methods and models behind the maps and the validation of subsequent. This new document presents an updated validation of Europe's wind speed map, performed with data from more than 300 meteorological masts, different from the ones used in the 2012 validation. A comparison against two of the most used public sources of wind resource data, the Global Wind Atlas (GWA) and the New European Wind Atlas (NEWA), is also included.

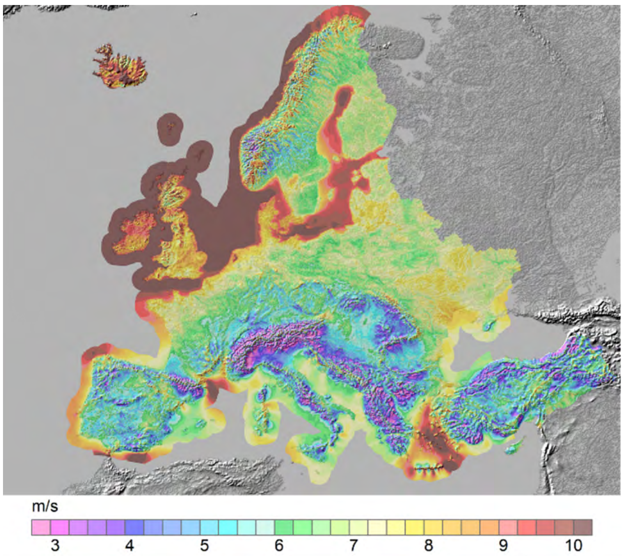

Figure 1. Mean Annual Wind Speed at 140 m

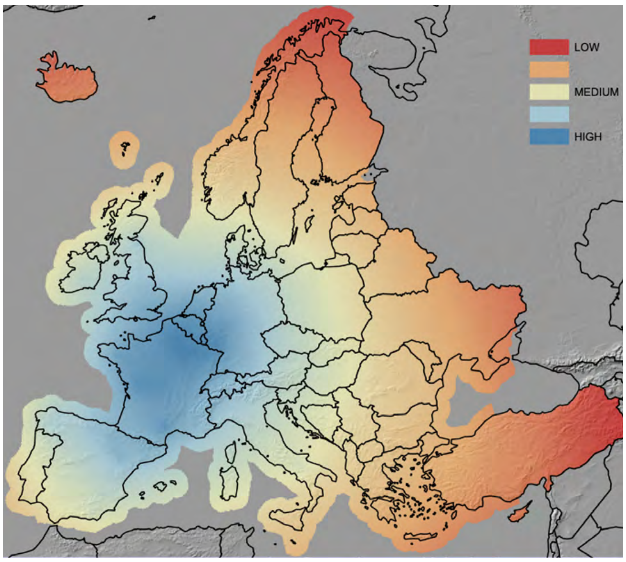

Figure 2. Density of stations used in the 2012 and 2023 validations

1. https://windnavigator.ul-renewables.com/wsa

Validation of the wind resource maps

The data used in the validation was first filtered and long-term adjusted at the top measurement height. However, before proceeding to map adjustment and validation, met stations were carefully selected according to the following guidelines:

- Masts with less than one year of measurements are removed from the sample to avoid seasonal biases. When more than one mast are found within the same wind development project or area, as is often the case for a wind project in the pre-construction phase, a single met mast will be chosen as the most representative of the site. Typically, we select the met mast with the longest period of records and tallest measurement heights, assuming everything else is equal. The rationale behind this filtering is to even out as much as possible the weighting given to all the areas of the map with met masts when performing the map adjustment. Otherwise, our map adjustment procedure intended to reduce the overall bias of the map would give too much weight to areas with a high density of met masts. Also, if there are met masts in different terrain conditions (e.g., hilltop vs. valley) or land use conditions (e.g., cultivation vs. forest) within the same wind development project or area, it is more appropriate to select the most representative mast than take the average of all the masts.

- Met masts that appear to have the wrong coordinates based on ancillary data are discarded.

Once the met mast selection is completed, a bias is then calculated between the raw (unadjusted) wind map and the extrapolated-observed wind speed for each station. The next step consists of adjusting the raw wind map to the extrapolated-observed wind speeds to reduce the regional biases in the map. An in-house software program interprets the biases and applies the bias correction algorithm to adjust the raw wind map. Leave-one-out cross-validation is also carried out by the same software to determine the sensitivity of the wind map adjustment to different tuning parameters. After a few iterations with the tuning parameters to minimize any cross-validation errors, the final settings are selected, and the final wind map is created. This process does not eliminate the bias at every station, as this could produce unreasonable adjustments in some areas. Instead, it is designed to eliminate spatially correlated biases affecting regions of a significant size (roughly the mean spacing between stations, about 50 km-100 km).

To put the error and uncertainty values obtained in the validation process into context, we've compared a 200-meter resolution wind map by UL Solutions with the two most used public sources of wind resource data:

- **Global Wind Atlas (GWA)**
  (Technical University of Denmark (DTU), World Bank Group, and Energy Sector Management Assistance Program (ESMAP), 2015)

- **New European Wind Atlas (NEWA)**
  (Witha, et al., 2019)

Europe validation

The new validation of the existing 200-meter resolution wind map by UL Solutions was conducted with an initial sample of 315 tall met masts spread over 18 European countries. After filtering the station list to account for the minimum measurement period, one (representative) mast per project and the reliability of the coordinates, 176 measurements remained available. The performance of the 200-meter resolution wind map is compared to the GWA and NEWA maps and summarized in Table 1. The original validation by UL Solutions of the same map dating back to 2012 is also included.

	Average bias (m/s)	Uncertainty (m/s)	RMSE (%)
UL Solutions	0.22	0.58	9.9 %
NEWA	0.51	0.62	12.8 %
GWA	0.65	0.61	14.3%
UL Solutions (2012)	-0.04	0.54	8.5%

Table 1. Validation summary for Europe

The new validation yields a low mean bias of 0.22 m/s and an uncertainty, estimated as the standard deviation of the biases, of 0.58 m/s. Errors tend to be larger in more complex terrain and land cover. The comparison with the reference models shows a better performance of the map by UL Solutions in all three statistical indexes: the bias, uncertainty and root mean square error (RMSE) are lower than the GWA and NEWA. It's worth mentioning that the three models show a positive mean bias, so at least for the sample used in this exercise, all models overestimate the average wind speed. Table 2 shows the mean bias and the RMSE obtained in specific countries:

Country	Average bias (m/s)			RMSE (%)		
	UL Solutions	NEWA	GWA	UL Solutions	NEWA	GWA
Belgium	0.09	0.46	0.79	1.4%	7.0%	12.0%
Finland	-0.25	-0.09	-0.14	6.4%	6.6%	4.7%
France	0.24	0.59	0.78	7.7%	11.8%	14.7%
Germany	0.20	1.08	1.03	3.2%	17.3%	16.4%
Ireland	0.36	0.18	1.05	8.5%	8.2%	16.4%
Italy	-0.09	0.51	0.22	8.3%	12.6%	12.7%
Romania	0.45	1.18	0.33	11.7%	15.6%	10.8%
Spain	-0.06	0.21	0.24	10.5%	12.6%	11.0%
Sweden	0.27	0.64	0.22	3.9%	9.3%	4.2%
Turkey	0.94	0.84	0.92	21.8%	23.1%	23.4%

Table 2. Validation by country for Europe

The 2012 validation was performed with a larger sample of 433 wind monitoring stations. However, 45% were surface-based measurements (i.e., 10 m height), while the new validation only includes tall met towers. Moreover, if we only look at the tall towers used in the 2012 and 2024 UL Solutions validations, the ones in this new validation are more recent and thus taller on average. Due to these nuances, the new validation provides more added value than it might seem from the similarity with the previous results and encourages even greater confidence in the reliability of wind speed maps.

Summary and conclusions

In this report, the results of the Mesomap validation have been presented. The following two conclusions can be extracted:

- The UL Solutions model for wind resource prospecting obtains significantly better results than NEWA and GWA in all three statistical parameters, i.e., mean bias, uncertainty and RMSE.
- The results obtained by UL Solutions model are very similar to those obtained 12 years ago with a completely different set of measurements. Considering both data sets, the model has been tested against more than 750 met masts over Europe.

Although this report helps delimit the range of errors in prospecting models, UL Solutions recommends measuring the wind resource on-site before committing funds to a wind energy project of a substantial size.

Attribution

GWA data was obtained from the Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex and funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info

NEWA data was obtained from the New European Wind Atlas, a free, web-based application developed, owned and operated by the NEWA Consortium. For additional information see www.neweuropeanwindatlas.eu.

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