Funded by the European Union

HORIZON EUROPE PROGRAMME – TOPIC HORIZON-CL5-2021-D3-03-05

Wind energy in the natural and social environment

Research and Innovation action (RIA)

WIMBY

Wind in My Backyard: Using holistic modelling tools to advance social awareness and engagement on large wind power installations in the EU

Grant Agreement No. 101083460

Starting date: 1st January 2023 – Duration: 36 months

Deliverable D1.2
Wind Resources API

DOCUMENT INFORMATION

Deliverable number	D1.2
Deliverable title	Wind Resource API
Work Package	WP1
Deliverable type	R
Dissemination level	PU
Due date	15.11.2024 (Month 23)
Pages	25
Document version	4.0
Lead author(s)	Andrea N. Hahmann and Neil N. Davis, DTU
Contributors	Nicolas G. Alonso De Linaje, DTU Rogier Floors (DTU)

The WIMBY project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

DOCUMENT CHANGE HISTORY

Version	Date	Author	Description
DRAFT			
0.1	20.09.2024	Andrea N. Hahmann, DTU	Creation
0.2	25.09.2024	Andrea N. Hahmann, DTU	Consolidation of new input from contributors
FIRST PEER REVIEW			
1.0	06.11.2024	Luis Ramirez Camargo (UU) and Christian Mikovits (BOKU)	Proofreading and peer review
1.1	07.11.2023	Andrea N. Hahmann and Neil Davis (DTU)	Consolidation of input from reviewers
SECOND PEER REVIEW			
2.0	12.11.2024	Luis Ramirez Camargo (UU) and Christian Mikovits (BOKU)	Second peer review
2.1	14.11.2024	Andrea N. Hahmann and Neil Davis (DTU)	Consolidation of input from reviewers
COORDINATOR APPROVAL			
3.0	14.11.2024	Shary Heuninckx (VUB)	Coordinator review and approval
FINAL VERSION			
4.0	15.11.2024	Shary Heuninckx (VUB)	Format review, version ready for submission

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains

SHORT ABSTRACT FOR DISSEMINATION PURPOSES

Abstract

This report describes the WIMBY deliverable D1.2 – Wind resources API (b). It provides a description of the data relevant for estimating long-term wind resources and siting parameters and time series of wind speed, direction and other meteorological parameters for any European site. This data is used in the WIMBY Wind Power tool, WIMBY interactive map and by other partners in their model development and calculations.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains

HORIZON EUROPE PROGRAMME – TOPIC HORIZON-CL5-2021-D3-03-05
Wind energy in the natural and social environment
Research and Innovation action (RIA)

WIMBY

Wind in My Backyard: Using holistic modelling tools to advance social awareness and engagement on large wind power installations in the EU

Grant Agreement No. 101083460
Starting date: 1st January 2023 – Duration: 36 months

Deliverable D1.2
Wind Resources API

ABSTRACT

This report describes the WIMBY deliverable D1.2 – Wind resources API (b). It provides a description of the data relevant for estimating long-term wind resources and siting parameters and time series of wind speed, direction and other meteorological parameters for any European site. This data is used in the WIMBY Wind Power tool, WIMBY interactive map and by other partners in their model development and calculations.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

TABLE OF CONTENTS

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

LIST OF FIGURES

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

LIST OF TABLES

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

ABBREVIATIONS

Acronym	Description
AEP	Annual Energy Production
AGL	Above Ground Level
API	Application Programming Interface
ECMWF	European Centre for Medium-Range Weather Forecasting
ERA5	ECMWF reanalysis Version 5
GASP	Global Atlas for Siting Parameters
GWA	Global Wind Atlas
IEC	International Electrotechnical Commission
NEWA	New European Wind Atlas
netCDF	Network Common Data Form
WRF	Weather, Research and Forecasting
WAsP	Wind Atlas Analysis and Application Program

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

EXECUTIVE SUMMARY

This report describes the meteorological and wind energy data required for the WIMBY Wind Power tool and other partners' model development and calculations for the WIMBY project. Most of the data comes from previous projects but has been enhanced and expanded specifically for use in WIMBY.

The main datasets shared are:

1. Wind resource climatologies, provided by the New European Wind Atlas (NEWA) and Global Wind Atlas projects;
2. A new microscale downscaling of the NEWA climatology that improves the evaluation against tall masts measurements;
3. Wind resource time-series from the NEWA project, extended to 2023;
4. A new dataset characterising the temporal variation of wind speed created using data from the ERA5 reanalysis dataset;
5. Turbine classification data based on siting data (e.g., turbulence and extreme winds) from the Global Atlas of Siting Parameters; and
6. A database of harmonised wind turbine locations created as part of a project funded in collaboration with the Danish Meteorological Institute.

The updated microscale dataset (Dataset 2) and extended mesoscale dataset (Dataset 3) above have been completed and are new with respect to what was reported in Deliverable 1.1.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

1 INTRODUCTION

Wind resource data encompasses diverse information crucial for assessing the potential for harnessing wind energy. Meteorological data, such as wind speed and direction, provides insights into the prevailing atmospheric conditions. Wind resource data is used in many of the WIMBY applications. Due to their varying requirements and source model errors, each application's data selection varies.

This report describes the relevant meteorological and wind energy data needed for use in the WIMBY Wind Power tool and by other partners in their model development and calculations as part of the WIMBY project. Much of the data comes from existing projects but has been improved and expanded for use in WIMBY. The key data described here are:

- Wind resource climatologies, provided by the New European Wind Atlas (NEWA) [1] and Global Wind Atlas projects [2],
- Wind resource time-series from the NEWA project, extended to 2023,
- A new dataset characterising the temporal variation of wind speed created using data from the ERA5 reanalysis dataset [3],
- Turbine classification data based on siting data (e.g., turbulence and extreme winds) from the Global Atlas of Siting Parameters [4], and
- A database of wind turbine locations (and later technical specifications) created as part of a project funded by NCKF, the National Climate Center at the Danish Meteorological Institute.

The remainder of the report is organised as follows: Chapter 2 details the methods used to update the datasets for WIMBY, including additional simulation and changes to the data structures and distribution. Chapter 3 describes the datasets, where they can be accessed, and who can access them. Chapter 4 presents the evaluation of the new microscale downscaling against tall mast data in Europe. Chapter 5 includes a summary of the completed tasks.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

2 METHODS

2.1 Extension of the NEWA time series data

As part of the WIMBY project, the NEWA mesoscale (time series) data was extended from the original period of 1989–2018 to include 2019–2023. The original simulations were carried out in the Barcelona Supercomputer Center cluster (MareNostrum 4) under the funding of a PRACE[1] access allocation. Since the allocation is finished, the new WRF [5] model simulations were done using the Sophia cluster at DTU.

The new simulations used the same model version and configuration as those for the earlier period. But, because of differences in the compilation of the WRF model executable, the runs at MareNostrum4 and Sophia are not bit by bit identical. However, the wind climatologies are consistent.

The raw output from the WRF model was post-processed using the same Python scripts as used in the NEWA project, with one exception. The original scripts had a bug in handling the solar data; this bug was fixed as part of the updated simulations. Correct solar data will now be part of the NEWA and WIMBY project. The post-processing extracts and precomputes variables of interest for the Wind Energy community and interpolates variables to seven desired heights AGL (see Table 2.1). This reduces the size of the dataset while making it easy to use in wind energy projects.

2.2 Updating NEWA time series data storage

The workflow of the reformatting of the data is presented in Fig. 2.1. The post-processed NEWA time series data is approximately 150 terabytes in size. This makes storing and accessing it a challenge. The data was initially stored as daily netCDF [6] files for all of Europe. While netCDF is a traditional format for scientific data and is favoured for its rich data model, it is less efficient with large datasets, has challenges with multiple processes trying to access the same file at the same time, and requires files to be kept relatively small, on the order of a few gigabytes. In recent years, the Zarr [7] format has been developed to help address some of these shortcomings. Zarr can use the same rich data model as netCDF but is designed for cloud and large-scale applications, which makes it better at handling large datasets, such as NEWA. A Zarr archive

[1] PRACE: Partnership for Advanced Computing in Europe, https://prace-ri.eu/

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

Table 2.1: Details of the NEWA mesoscale wind atlas datasets.

Mesoscale wind atlas	
Property	**Description**
Horizontal grid spacing	3 km × 3 km
Vertical levels	50, 75, 100, 150, 200, 250, 500 m AGL
Temporal resolution	30 minutes
Period covered	1989–2018 (updated to 2023)
Static fields	Surface elevation Land mask (1 land; 0 ocean) Dominant land use category
Single-level fields	Time series of: Boundary layer height Wind speed at 10 m Air temperature at 2 m Air temperature at 100 m Turbulent kinetic energy at 50 m Surface air density Surface pressure
Multi-level fields	Time series of: Wind speed and direction Wind power density Air temperature Water vapour specific humidity

consists of many files stored in a specific binary format with a specific naming convention and several JSON files to handle the metadata. The small binary files store "chunks" of the larger dataset; a chunk is a multi-dimensional slice of the larger dataset.

As part of the WIMBY project, we converted the netCDF data to Zarr using the following chunk sizes (time=17,520 (365 days); west_east=50; and south_north=50; height=1). This storage approach focused on making the data more accessible to extract as time series data for a few points. The previous daily-based storage made it easier to extract the entire domain for a single time period. The focus on long-term period extraction was something that had been identified as a preferred access pattern after the NEWA project finished.

During the data conversion, it was discovered that the interpolation function from the WRF-python package [8], which was used in the post-processing step to interpolate the model levels to heights, added a few random NaN values across the whole dataset. This was corrected af-

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

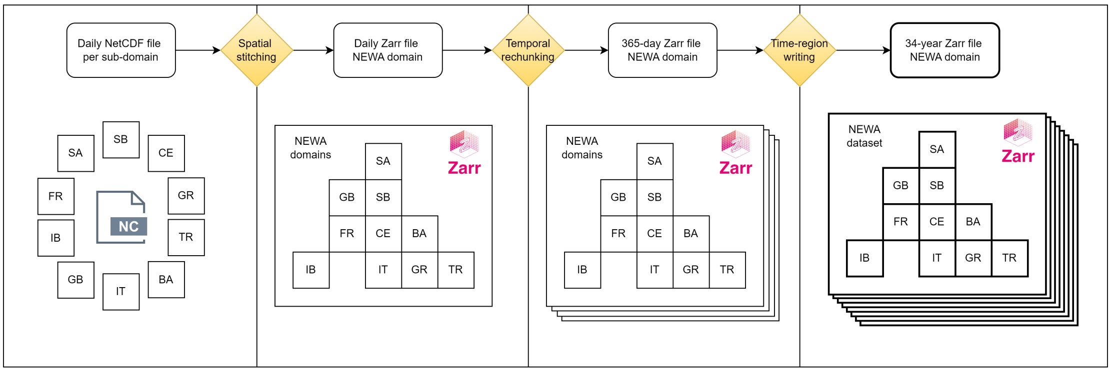

Figure 2.1: Workflow used to reformat the original NEWA daily files to a Zarr time series.

ter completing the data conversion, which added additional time to the data conversion process. Additionally, due to the large amount of data and the age of the NEWA server system, the re-processing of the original (1989–2018) NEWA time series added considerably more time than anticipated.

2.3 New microscale calculations for NEWA V2

The microscale modelling described in [1] (hereafter NEWA V1) provided a high-resolution wind speed map over Europe. However, it was later assessed that the dataset contained systematic errors, especially over complex terrain [1, 9].

Since then, several new features have been integrated into the microscale Wind Atlas Analysis and Application Program (WAsP) [10]. In addition, new high-resolution datasets have been made available that allow using better boundary conditions for running the microscale model. Below, we describe the changes to the model chain for WIMBY, which will hereafter be referred to as NEWA V2.

Floors et al. [11] introduced a displacement height model, allowing for a better representation of forested areas using a zero-plane displacement height. Thus, a new polygon-based dataset of landcover classes was created based on the CORINE data [12]. For each polygon of a forested class (i.e. with landcover identifier >310 and <320), a mean tree height was calculated from the ETH tree height data introduced in Lang et al. [13]. The tree height was rounded to the nearest integer number because a maximum of 100 landcover classes can be used in WAsP. An additional 41 classes were thus generated describing forests with tree heights from 1 m to 41 m, in addition to the 44 classes already present in

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

the CORINE data.

Elevation data has a significant impact on flow modelling results. In NEWA V1, the SRTM data at approximately 90 m horizontal grid spacing was one of the best data sources available. In the meantime, [14] showed that the Copernicus DEM30 shows improved skill compared to Lidar scans to represent the earth's surface elevation. This dataset was, therefore, downloaded and processed to a constant horizontal grid spacing of 0.000 27° (30 m) throughout the European domain [15].

Atmospheric stability significantly impacts the modelling of vertical profiles, and Floors et al. [16] introduced a model to use output from mesoscale or global models to give an improved description of Weibull A and k modelling in WAsP. This method was applied by computing the temperature and planetary boundary layer height scale for 12 wind direction sectors from the WRF model data and using it for the generalisation and downscaling procedure.

Finally, the air density model in NEWA V1 was based on coarse scale reanalysis data from CFSRv2 [17]. In NEWA V2, the temperature and specific humidity at 2 m and pressure at the surface, which are the required inputs for the air density model, were extracted from the NEWA WRF model output for the newest 10 years (2014–2023) and averaged. The lapse rate (i.e. the change in temperature with height) was computed using the ERA5 dataset, and not from the NEWA WRF model output as the vertical resolution was not fine enough. This does not degrade the results because the sensitivity to the lapse rate in the air density calculation is low [17].

The microscale high-resolution outputs were generated at the DTU HPC cluster Sophia. The same projection and map were used as in NEWA V1, i.e. the ETRS89-extended / LAEA Europe projection described by EPSG code 3035. The domain was split into 1183 tiles with 2000 $\times$ 2000 grid points in a 100 by 100 km area (i.e. a horizontal grid spacing of 50 m). This results in a calculation of about 4.7 billion points. A Python package, PyWAsP-swarm, was used to pre-process the required input data for each tile and distribute these points to PyWAsP, the Python interface to the WAsP Fortran core routines. Running a single tile required about 47 CPU hours. Therefore, running the simulations on a single-core desktop machine would take approximately 6.5 years. Luckily, each compute node on Sophia has 32 cores, and by deploying about 30 nodes in parallel, all computations could be finished in about a week (excluding pre-processing of input data).

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

2.4 Creation of time variation dataset

Certain WIMBY models require a description of the time variations of wind speed over time. The complete time series is large, making them slow to obtain and challenging to work with. As an alternative for these models, we developed a so-called 12 (months) $\times$ 24 (hours) table of wind speed averages from the ERA5 wind speed for the 10 years of 2013–2022. An example of this evolution is given in Fig. 2.2 for a grid point located at 40°N and 10°E. This dataset covers all Europe from 15°W–35°E and from 35°N–72°N.

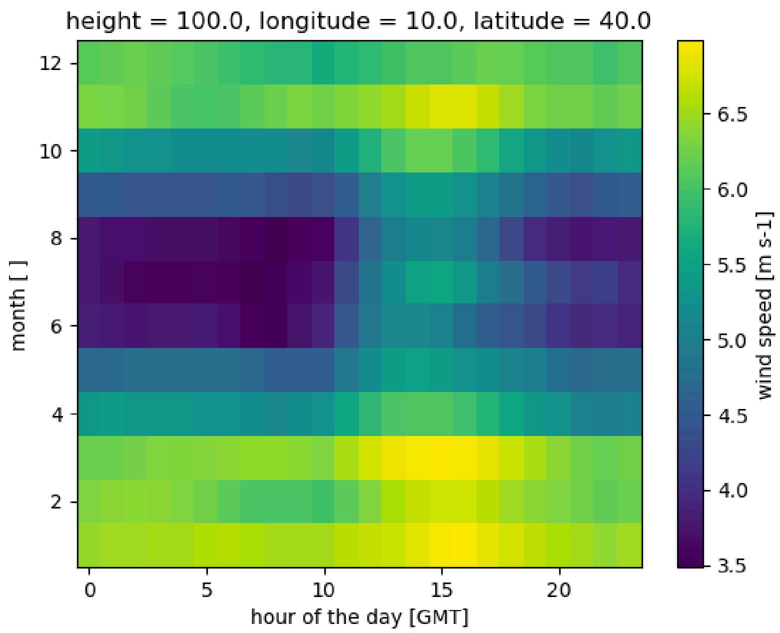

Figure 2.2: ERA5-derived wind speed at 100 m averaged over the month of the year and the time of the day for a grid point located at 40°N and 10°E.

Because of the known biases in wind speed of the ERA5 over complex terrain [1], we suggest that the 12 x 24 mean wind speed is bias corrected before use. The procedure should be as follows. The mean wind speed, $\overline{U}$, is corrected as

$$\overline{U}(x, y, \text{month}, \text{hour}) = \overline{U}_E(x_E, y_E, \text{month}, \text{hour}) \times w(x, y) \tag{2.1}$$

where (x, y) is the turbine location, (x_E, y_E) is the ERA5 grid point closest to the turbine site, and $w(x, y)$ is the GWA-derived bias correction ratio (defined as GWA2 divided by ERA5) at the turbine site. A map of these weights at 100 m is shown in Fig. 2.3. This method has been successfully used in [18, 19], and verified against wind and power observations.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

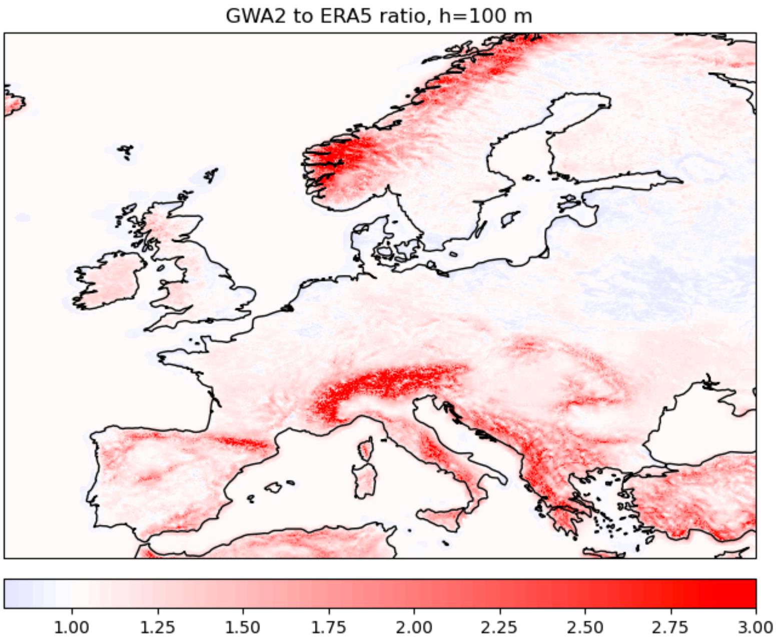

Figure 2.3: Ratio [-] between the mean wind speed from GWA2 and that from ERA5 over Europe at 100 m AGL.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

3 DATASET DESCRIPTIONS

This section describes the different datasets and where they can be obtained. An overview is provided in Table 3.1, and a detailed description is made in each sub-section.

3.1 Wind resource data

Wind resource data can be represented in different forms depending on the application. High-resolution datasets provide climatological statistics about the wind, including the wind speed and direction distributions over a long period of time. To better understand how wind speed and direction vary over time, temporal averages are provided via a 24 x 12 table, which provides the mean wind speed for each hour of each month based on coarser resolution data. Finally, for the best temporal resolution, 30-minute time-series data is provided for the period 1998–2023. The data volume for the time-series data is significantly larger than the other data and, therefore, only used when necessary.

3.1.1 ERA5 data

The ERA5 dataset [3] is derived from the Copernicus collection of ECMWF reanalysis data [20] — an atmospheric reanalysis of the global climate covering the period from January 1940 to the present. The ERA5 combines vast historical observations into global estimates using advanced modelling and data assimilation systems. Because of data assimilation, ERA5 is a good choice for applications requiring accurate time variations. However, the provided wind data might contain systematic errors, especially over complex terrain [1].

In the WIMBY project, the ERA5 data was used to create the "12 x 24 mean wind speed", described in Section 2.4.

3.1.2 Global wind atlas (GWA2/GWA3) data

The Global Wind Atlas (GWA) is a free, web-based application developed to help policymakers, planners, and investors identify high-wind areas for wind power generation virtually anywhere globally and perform preliminary wind resource calculations [21, 2].

The microscale wind speed data is used to bias correct the ERA5 climatologies and time series. The scaling factor is computed between the long-term mean wind speed from the reanalysis and the mean wind speed from the GWA2. We recommend using the data from the older GWA2 dataset released in November 2017 instead of the newer GWA3

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

Table 3.1: Main wind-related datasets available in the WIMBY project.

Name	Description	Location
ws_mean_era5_12_by_24	ERA5 12 (months) x 24 (hours) mean wind speed (see Section 3.1.1)	DOI:10.24416/UU01-EN1BWR
bias_correction_era5_ratios	Spatial ratio between the GWA2 wind speed and that of the ERA5 (see Section 3.1.1)	DOI:10.24416/UU01-TNSZBJ
NEWA Microscale Data V2	Mean wind speed distributions from NEWA (see Section 3.1.3)	DOI:10.11583/DTU.27724032
NEWA Mesoscale time series	30-min resolution time series data from NEWA	DOI: 10.11583/DTU.14414096
GASP wind sitting data	Global data for wind turbine siting (see Section 3.2)	DOI:10.11583/DTU.14753349
wind_turbine_database	Dataset of harmonised turbine locations over Europe (see Section 3.3)	YODA (Consortium)

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

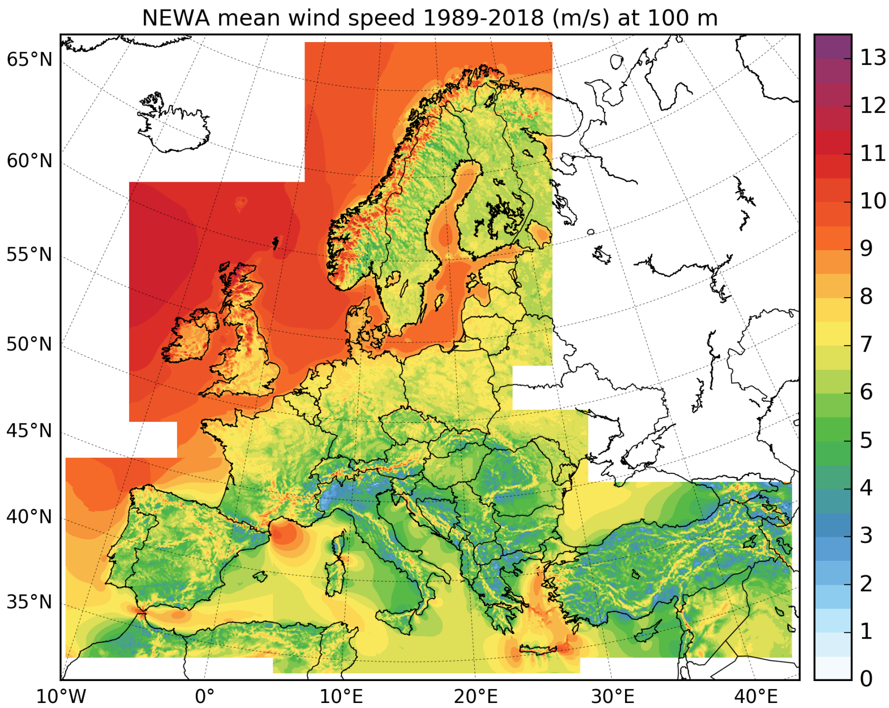

Figure 3.1: Long-term mean wind speed (in m s^{-1} for 1989–2018) at 100 m from the NEWA project.

(released November 2018) because of known biases in the microscale downscaling [9, 18]. These biases are also present in the NEWA microscale data, especially over complex terrain. Within the WIMBY project, we have re-calculated the NEWA microscale wind atlas using updated surface roughness lengths and generalisation procedures, which are believed to cause part of the biases (see Chapter 4).

3.1.3 NEWA data

The NEWA data is taken from the mesoscale simulations of the New European Wind Atlas [22, 1], a previous project funded by the European Commission (topic FP7-ENERGY.2013.10.1.2) . These simulations were created using the Weather, Research and Forecasting Model, WRF [5]. We also used the microscale layers of the NEWA wind atlas that were created using the WAsP model [23]. Dörenkämper et al. [1] describes the methods and provides validation of the NEWA wind speeds at turbine height against many tall masts in Europe. Further validation was carried out in [9, 19], and the wind speed fields at the sea surface are compared to satellite data in [24].

The WRF model simulations were run using the ERA5 [3] reanalysis. Land

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

surface properties were modified from the standard WRF model simulations in the NEWA project using WRF version 3.8.1 to match European land characteristics [1]. Further details on the NEWA mesoscale database are given in Table 2.1.

The NEWA simulations were done over ten different domains that share an outer grid and cover all European Union member states, Norway, Turkey, Switzerland, and the Balkans, as well as offshore areas 100 km off each coast and the complete North and Baltic seas (See the NEWA paper [1] Figure 1). The data from these ten domains were combined by selecting a given domain for each country and including data from that domain for all of that country's economic exclusion zone to form a continuous dataset at 3 km × 3 km spatial grid spacing. Figure 3.1 includes the long-term (1989–2018) mean wind speed; an outline of the original NEWA domains is still identifiable. These identifiable differences in wind speed in the overlap of the computational domains are less than 0.1 m s^{-1}. The simulations also overlap during the spin-up period of 24 h, which is discarded, as described in [25]. Time series are extracted directly from these simulations.

Table 3.2: Details of the NEWA microscale wind atlas dataset.

Microscale wind atlas	
Property	**description**
horizontal resolution	50 m × 50 m
vertical levels	50, 100, 200 m AGL
temporal resolution	long-term climatology
period covered	1989–2018 (NEWA V1) 2014–2023 (NEWA V2)
available raw fields	mean air density, frequency and Weibull parameters for 12 wind direction sectors (0° to 360°) of 60° each.
derived fields	long-term mean of wind speed and wind power density

For distribution in the WIMBY project, the data has been reorganised in many ways. The processes used for the reorganisation are described in Section 2.1.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

3.2 Wind siting data

Wind turbines are designed for specific conditions. During the construction and design phase, assumptions are made about the wind climate to which the wind turbines will be exposed.

The Global Atlas for Siting Parameters (GASP) project created a global atlas of siting parameters, including the 50-year wind, turbulence, and turbine class recommendations based on relevant generic turbines, at a spatial resolution of 275 m. More details are given in [4]. Using the correct turbine type helps to lower the risk of over-designing by reducing the critical mismatch between the turbine and the site.

Wind classes determine which turbine is suitable for the average wind conditions of a particular site. The average wind speed, extreme 50-year gusts, and turbulence determine turbine classes. Modern wind turbines are typically designed according to the requirements for class certification defined by the IEC 61400-1 design standard, as outlined in Table 3.3. There are three main classes of turbines based on the 50-year wind at a temporal resolution of 10 min at the hub height and the annual average wind speed, each with sub-classes based on turbulence. Extreme winds and turbulence statistics are needed to determine what types of turbines can withstand the site-specific wind loads.

Table 3.3: Wind turbine design classes in IEC 61400-1 ed 4. Adapted from [4].

Wind turbine class	**I**	**II**	**III**
Annual average wind speed ($m\,s^{-1}$)	10.0	8.5	7.5
Reference extreme wind speed ($m\,s^{-1}$) over 10 min	50.0	42.5	37.5
A+ category for very high turbulence characteristics		0.18	
A category for higher turbulence characteristics		0.16	
B category for medium turbulence characteristics		0.14	
C category for lower turbulence characteristics		0.12	

Figures 3.2 and 3.3 show two examples from GASP for Europe [source: GWA web site [21]]. The GASP IEC Class for Fatigue loads shows the wind turbine class in terms of mean wind speed (wind turbine class I, II, III, and S) and turbulence parameters (turbulence category A+, A, B, and C) from Table 3.3. The GASP IEC Class for Extreme loads shows the wind turbine class in terms of extreme wind speed and air density at high wind speed (wind turbine class I, II, III, T and S) from Table 3.3.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

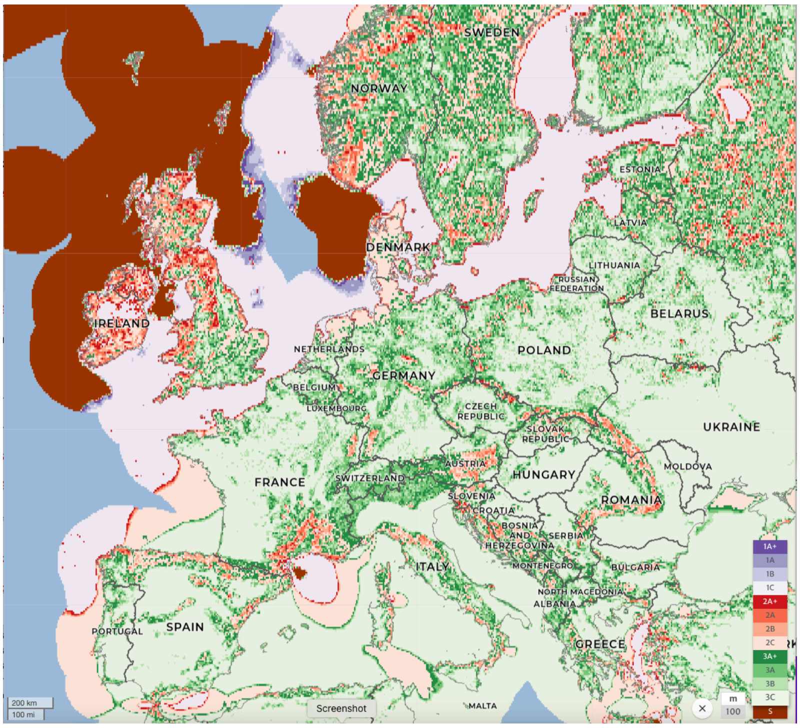

Figure 3.2: GASP IEC Class for Fatigue loads at 100 m.

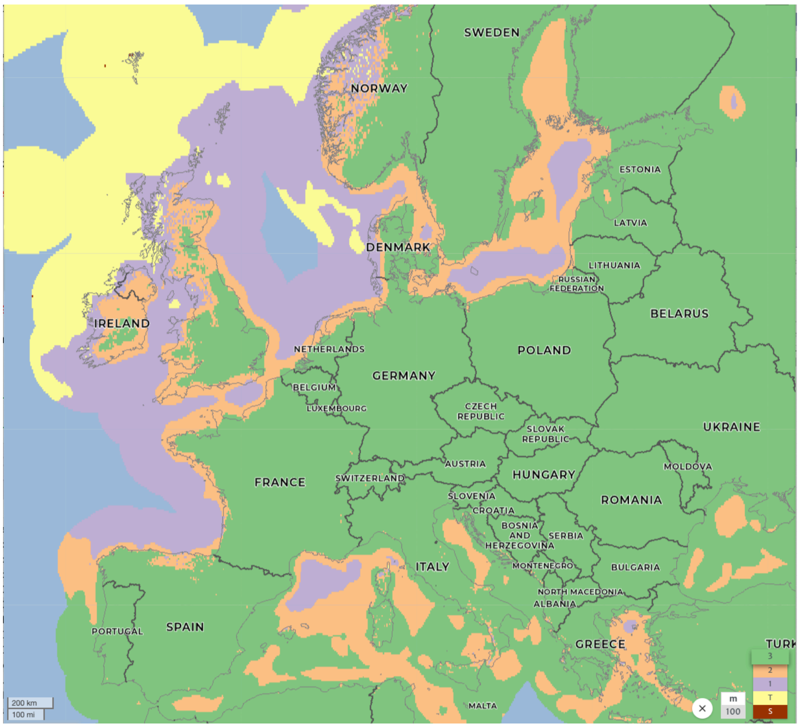

Figure 3.3: GASP IEC Class for Extreme loads at 100 m.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

3.3 Wind turbine database

As part of a project funded by the National Climate Center at the Danish Meteorological Institute (NCKF), a database of wind turbine locations and technical specifications (hub height, rotor diameter, rated power, thrust, and power curves) was created. The database combines information from national datasets [26, 27, 28], a European-wide wind farm database [29], OpenStreetMap [30] and the European Marine Observation and Data Network (EMODnet) [31].

Extensive work was carried out to harmonise and gap-fill the combined dataset, including filling missing data via random-forest-based models and associating wind farm information with individual turbines via a developed wind farm splitting algorithm.

The database contains the location of the wind turbines, the turbine type, hub height and rotor diameter, rated power, cut-in and cut-out wind speed and the turbine power and thrust curve. It also includes the commissioning and decommissioning dates of the wind farms. We updated the wind turbine database to include all of Europe, as shown in Figure 3.4. These data now reside in YODA.

The dataset uploaded to YODA includes all European land wind turbines. Table 3.4 summarises the installed capacity per country divided between on- and off-shore.

This data cannot be publicly shared. Parameters from open data sources (such as location and hub height) will be shared with the consortium and the public. Parameters coming from licensed databases can only be shared under the conditions of the licenses. The most significant contributor to the wind turbine database, WindPower data [29], was contacted. The company consented to make the derived dataset created in WIMBY accessible to all partners, and the positions of the wind turbines can be displayed in the WIMBY interactive map. Data cannot be shared with groups or individuals outside the project.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

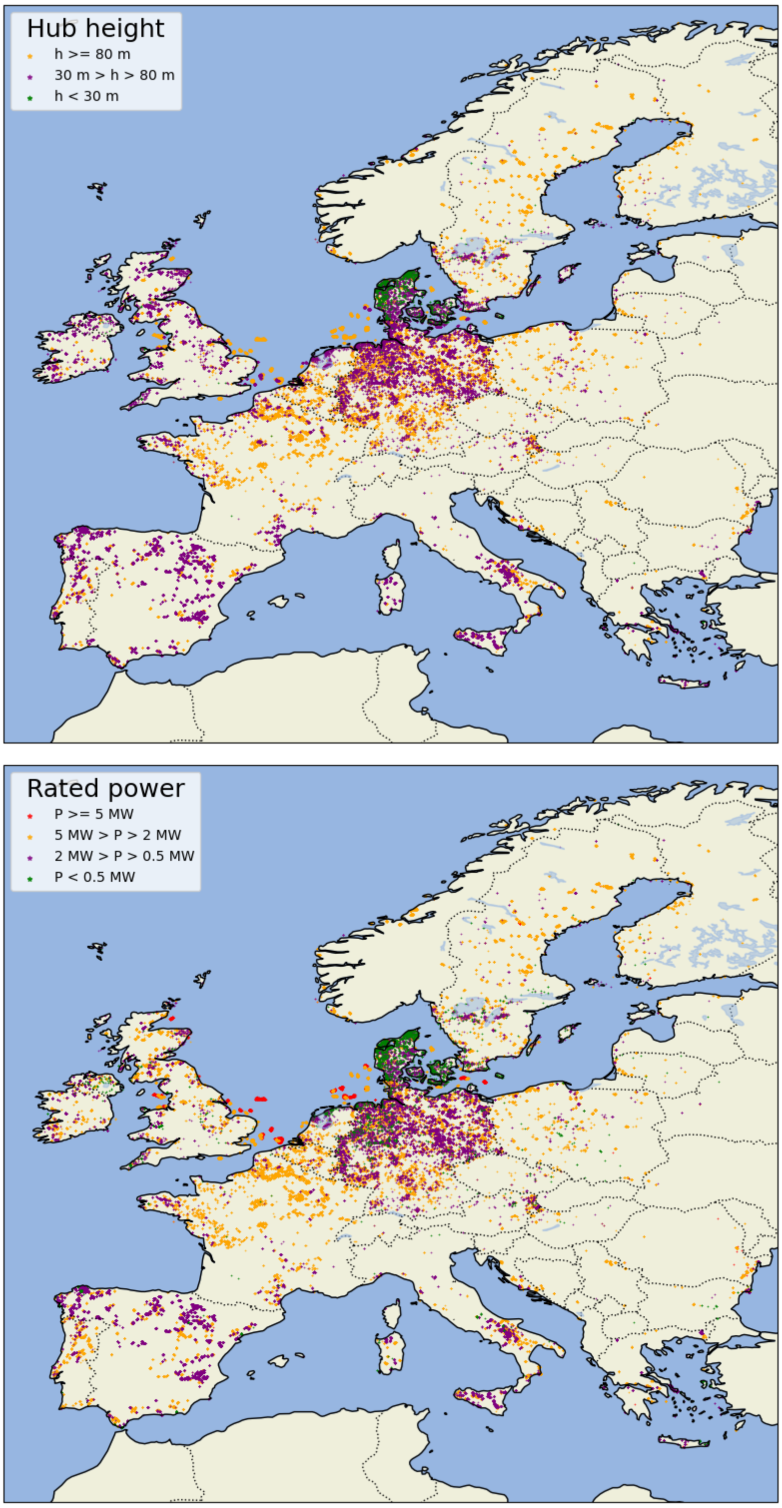

Figure 3.4: Location of individual wind turbines in the database (dots). The dots are coloured by the turbine hub height (top) and the rated power (bottom).

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

Table 3.4: [Wind turbine database statistics. Installed capacity [in GW] of land-based and offshore wind turbines in the wind turbine dataset per country as of November 2021.

Country	Onshore	Offshore	Country	Onshore	Offshore
AT	2.3	0.0	BA	0.1	0.0
BE	1.9	2.3	BG	0.4	0.0
BY	0.0	0.0	CH	0.1	0.0
CY	0.1	0.0	CZ	0.3	0.0
DE	52.7	7.3	DK	4.3	2.3
EE	0.3	0.0	ES	15.9	0.0
FI	1.8	0.1	FO	0.0	0.0
FR	13.6	0.0	GB	10.1	10.2
GR	1.2	0.0	HR	0.8	0.0
HU	0.2	0.0	IE	2.8	0.0
IS	0.0	0.0	IT	7.0	0.0
LT	0.4	0.0	LU	0.1	0.0
LV	0.1	0.0	ME	0.1	0.0
MK	0.0	0.0	NL	2.7	2.6
NO	3.0	0.0	PL	3.8	0.0
PT	3.4	0.0	RO	1.1	0.0
RS	0.5	0.0	SE	11.1	0.2
SI	0.0	0.0	SK	0.0	0.0
UA	0.7	0.0	XK	0.0	0.0

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

4 EVALUATION OF NEWA V2

4.1 Data

Here, we evaluate the new NEWA V2 data against the previous data and against mast data from a set of tall masts over Europe. 48 masts were selected from a variety of sources, such as the NEWA experiments [22], the Marine Data Exchange [32], the Tall tower dataset [33] and masts operated by DTU as part of the national test center infrastructure (Fig. 4.1). Because most of the sites had observations at several levels, there are 204 points available for this validation.

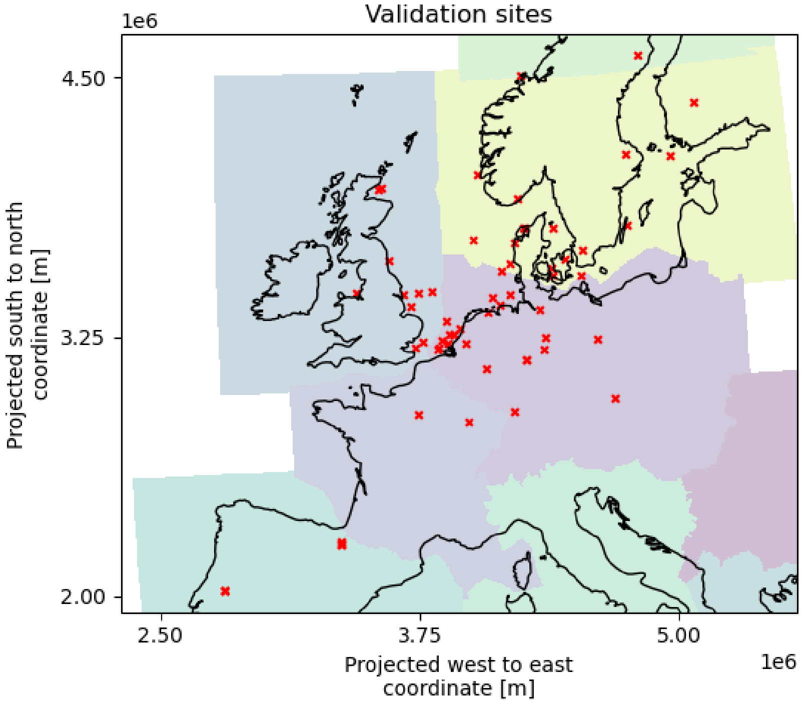

Figure 4.1: Overview of the 48 meteorological masts and wind lidars. The map projection is ETRS89/LCC (EPSG:3035). The colours are those of the NEWA mesoscale domains as in Fig. 3.1.

Because the local roughness can highly influence measurements close to the ground and these are not relevant for wind energy applications, only heights between 50 m to 200 m were selected. Basic quality control was performed for all of the masts, and where possible, the appropriate boom was used, dependent on the wind direction, to avoid flow distortion from the mast.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

4.2 Method

We use the following approach to compare the new NEWA V2 dataset with the previous version NEWA V1 and the global wind atlas (GWA) [2]. Because the measurements were not concurrent, we computed absolute errors in power density in percent between the microscale output for all the sites, for whatever the period of validity was of the wind atlas. For the GWA, NEWA V2 and NEWA V1, these periods are 2008–2017, 2013–2022 and 1989–2018, respectively. This means there are potential additional errors due to the climatic period needing to represent the shorter period in which the measurements were done. However, it was ensured that most of the 48 masts had longer measuring periods of at least a year.

4.3 Results

The results of the validation are shown in Table 4.1. The GWA has the highest errors in power density compared to the measurements both in power density (ε_P) and wind speed (ε_U). The NEWA V2 dataset has the lowest errors in ε_P and ε_U and substantially improved over the NEWA V1.

Table 4.1: Mean absolute errors in power density (ε_P) and wind speed (ε_U) in percent comparing the Global Wind Atlas v3 (GWA), NEWA V1 and NEWA V2 at the 48 masts in Fig. 4.1.

Model	ε_P (%)	ε_U (%)
GWA V3	52.6	13.1
NEWA V1	48.9	11.9
NEWA V2	27.4	8.6

Because the wind atlases presented here are also used for grid-integration studies, it is helpful also to identify the spatial impact over an area. Therefore, Fig. 4.2 (left) shows the differences between NEWA V2 and NEWA V1, where blue colours indicate that the power density at 100 m AGL is decreased in V2. In some coastal areas, for example, in the Netherlands and Denmark, the power density in NEWA V2 is higher than that of V1, but the power density is mostly lower. This can likely be attributed to the new approach to estimating the roughness length based on the tree heights, which increases the roughness of tall forested areas. In addition, the inclusion of displacement heights will lower the wind resources in forested areas. Offshore, the power density is slightly decreased in NEWA V2, which might be related to implementing the new stability model because the roughness length is unchanged compared to NEWA V1 in offshore areas.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

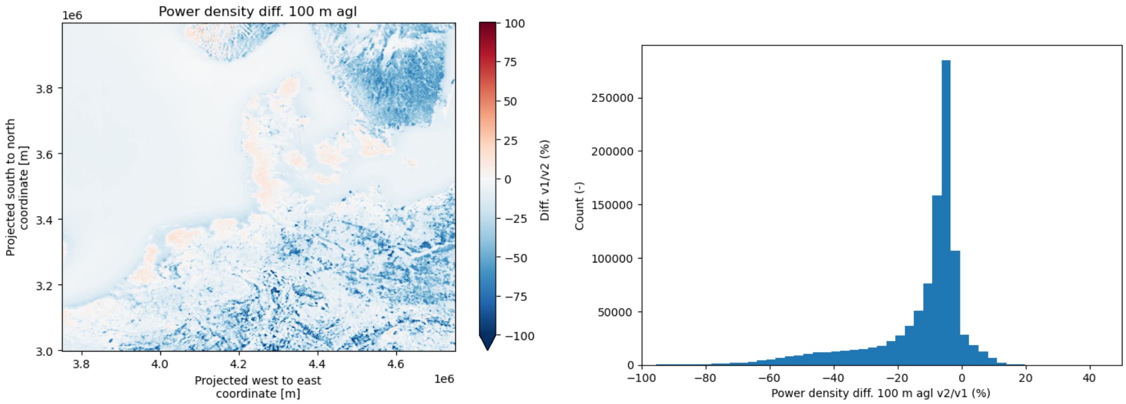

Figure 4.2: (left) Difference in power density at 100 m AGL in percent between the NEWA microscale V2 and V1. (right) Histogram of the difference in power density at 100 m AGL in percent between the NEWA V2 and V1 in the area shown in the left Figure.

The histogram of power density differences for all the grid cells in the same area, as shown in the right panel, is shown in Fig. 4.2 (left). A clear reduction in wind resources is seen over this particular area, with significant areas experiencing up to 50 % lower power density in the new version of the dataset. This is believed to be realistic, as positive biases of the NEWA V1 over Germany and France have been reported.

It is also instructive in investigating biases of the new dataset in different types of terrain. It is well-known that the linearised microscale model overestimates the wind speeds at steep hills that experience flow separation. However, the improvements in NEWA V2 compared to the measurements shown in Table 4.1 can also hold when we split the measurements by terrain ruggedness indicator (RIX). This indicator relates to the steepness of the slopes in a 3 km radius around the site of interest, i.e. a RIX of 0 % indicates that now flow separation is expected to occur and the WAsP results are more trustworthy. NEWA V2 shows lower mean absolute relative power density errors in all terrain complexities.

When looking at the impact at sites that are offshore, onshore or onshore with forests, the improvements are most considerable in the onshore category. The classification is based on the omnidirectional geometric mean of the mesoscale roughness length, where the offshore class has $z_0 <= 0.0003\,m$, onshore has $0.0003 < z_0 <= 0.4\,m$ and onshore (forest) denotes $z_0 > 0.4\,m$. Also offshore, despite NEWA V2 having the same roughness length as NEWA V1, there is still a decrease in errors. This might be related to the introduction of the new stability model.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

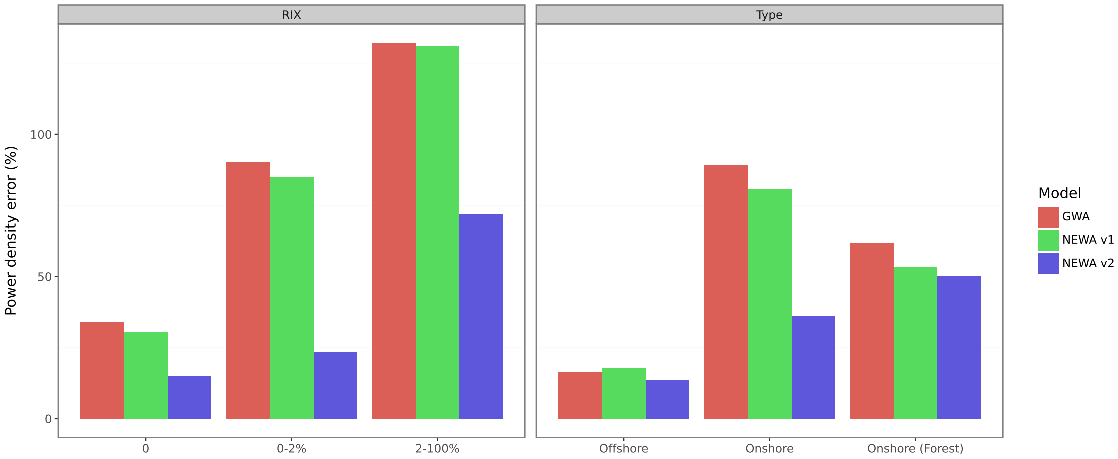

Figure 4.3: Mean absolute error in power density for different types of terrain complexity, as categorised by the RIX indicator being between classes from 0 to 100% (left) and as categorised by omnidirectional mesoscale roughness length (right).

In Table 4.1, we have compared absolute power density errors, which indicate whether the spread between the model and the observations has decreased. In Fig. 4.4, we finally compare the signed errors in power density to see if biases have been improved. Comparing the models, the NEWA V2 stands out as having both the smallest spread and lowest biases compared to the GWA and NEWA V1.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

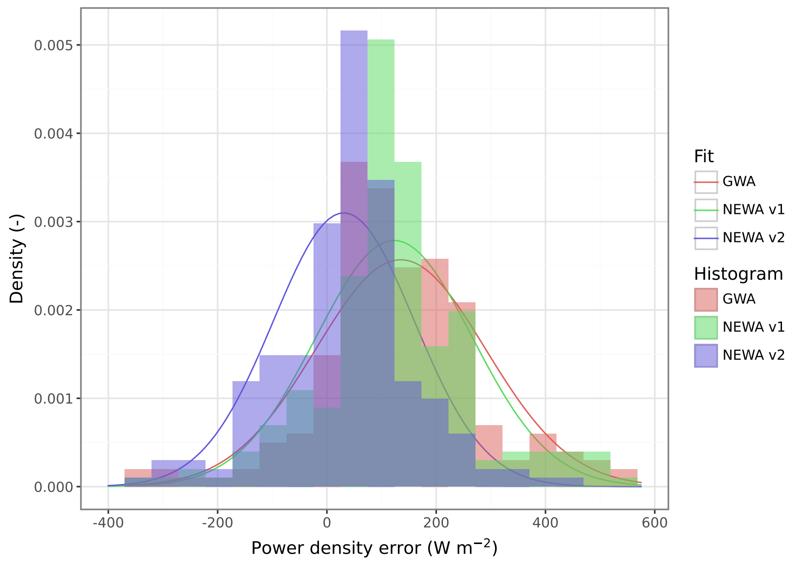

Figure 4.4: Histograms of the distribution of power density errors (%) and the corresponding Gaussian distribution with the mean and standard deviation from the same samples.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

5 CONCLUSIONS

5.1 Conclusions

This report describes the meteorological and wind energy data required for the WIMBY Wind Power tool and other partners' model development and calculations for the WIMBY project. Most of the data comes from previous projects but has been enhanced and expanded specifically for use in WIMBY.

The main datasets described in this report are:

- Five additional years of simulations for the NEWA mesoscale time series data were run.
- The NEWA time series dataset was re-chunked and saved as a Zarr archive to improve access speed when requesting long periods for a small area.
- A new dataset to characterise the temporal variation of the wind was created using the ERA5 reanalysis and a ratio between the mean GWA2 and ERA5 wind speeds at 50 m, 100 m and 200 m AGL.
- The updated NEWA microscale was completed using the latest advances in the WAsP model. The evaluation against tall masts in Europe shows substantial wind speed and power density reductions.
- The filling of NaN values in the NEWA time series data using nearest neighbour interpolation in time is nearly complete. Data processing has been slow due to data server migration.
- The wind turbine database has been updated to cover all of Europe and include additional wind turbine characteristics. All data in this database can now be shared among all the WIMBY partners.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

6 REFERENCES

[1] M. Dörenkämper et al. "The Making of the New European Wind Atlas - Part 2: Production and evaluation". In: *Geosci Model Dev.* 13.10 (2020), pp. 5079–5102. DOI: 10.5194/gmd-13-5079-2020.

[2] N. N. Davis et al. "The Global Wind Atlas: A High-Resolution Dataset of Climatologies and Associated Web-Based Application". In: *Bull of the American Meteorological Society* 104 (2023), pp. 1507–1525. DOI: https://doi.org/10.1175/BAMS-D-21-0075.1.

[3] H. Hersbach et al. "The ERA5 global reanalysis". In: *Quarterly Journal of the Royal Meteorological Society* 146.730 (2020), pp. 1999–2049.

[4] X. G. Lars/'en et al. "The Global Atlas for Siting Parameters project: Extreme wind, turbulence, and turbine classes". In: *Wind Energy* 25.11 (2022), pp. 1841–1859. DOI: https://doi.org/10.1002/we.2771. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/we.2771.

[9] J. P. Murcia et al. "Validation of European-scale simulated wind speed and wind generation time series". In: *Applied Energy* 305 (2022), p. 117794.

[11] R. Floors et al. "Satellite-based estimation of roughness lengths and displacement heights for wind resource modelling". In: *Wind Energy Science* 6 (6 Nov. 2021), pp. 1379–1400. ISSN: 2366-7451. DOI: 10.5194/wes-6-1379-2021. URL: https://wes.copernicus.org/articles/6/1379/2021/.

[13] N. Lang et al. "A high-resolution canopy height model of the Earth". In: *Nature Ecology & Evolution* (2023), pp. 1–12.

[14] P. L. Guth and T. M. Geoffroy. "LiDAR point cloud and ICESat-2 evaluation of 1 second global digital elevation models: Copernicus wins". In: *Transactions in GIS* 25.5 (2021), pp. 2245–2261. DOI: https://doi.org/10.1111/tgis.12825. eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/tgis.12825. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/tgis.12825.

[16] R. Floors, I. Troen, and A. Peña. "Using observed and modelled heat fluxes for improved extrapolation of wind distributions". en. In: *Boundary Layer Meteorol.* 188.1 (July 2023), pp. 75–101.

[17] R. Floors and M. Nielsen. "Estimating Air Density Using Observations and Re-Analysis Outputs for Wind Energy Purposes". In: *Energies* 12.11 (2019). ISSN: 1996-1073. DOI: 10.3390/en12112038. URL: https://www.mdpi.com/1996-1073/12/11/2038.

[18] K. Gruber et al. "Towards global validation of wind power simulations: A multi-country assessment of wind power simulation from

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.

MERRA-2 and ERA-5 reanalyses bias-corrected with the global wind atlas". In: *Energy* 238 (2022), p. 121520. ISSN: 0360-5442. DOI: https://doi.org/10.1016/j.energy.2021.121520. URL: https://www.sciencedirect.com/science/article/pii/S0360544221017680.

[19] G. Luzia, A. N. Hahmann, and M. J. Koivisto. "Evaluating the mesoscale spatio-temporal variability in simulated wind speed time series over northern Europe". In: *Wind Energy Science* 7.6 (2022), pp. 2255–2270.

[24] C. B. Hasager et al. "Europe's offshore winds assessed from SAR, ASCAT and WRF". In: *Wind Energy Sci.* 5 (2020), pp. 375–390.

[25] A. N. Hahmann et al. "Wind climate estimation using WRF model output: Method and model sensitivities over the sea". In: *Int. J. Climatol.* 35.12 (2015), pp. 3422–3439.

This project has received funding from the European Union's research and innovation programme Horizon Europe under the grant agreement No. 101083460. This document reflects only the author's view, and the Commission is not responsible for any use that may be made of the information it contains.