FH University of Applied Sciences TECHNIKUM WIEN

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Simplified Site Assessment

WP6.3: Validation of a simplified site assessment methodology for small wind turbines

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Nummer 1/ 2020

www.technikum-wien.at

Impressum

energy scripts – Eine Schriftenreihe des Kompetenzfelds Renewable Energy Systems der FH Technikum Wien

Nummer 1/2020: SmallWind4Cities – Task 2.2 Methodenentwicklung (Standortbewertungsmethode)

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Schürz & Lavicka

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1 Introduction

A detailed evaluation of the wind potential of a site for small wind turbines (SWT), requires a wind measurement device at the planned hub height for at least one year. Such a wind measurement is usually not profitable for small wind turbines and should only be carried out if good wind conditions are already expected. In order to make a first assessment of the potential, a method for site evaluation is needed. On the basis of this it should be decided whether a site can be considered for the installation of a SWT.

A good wind site is characterized by a high average wind speed and a high number of full load hours. The following table shows the respective guideline values for the evaluation of a wind site:

Table 1 Factors for site evaluation (Reiterer, 2014)

	Full load hours per year	Average wind speed	Energy in wind per year
Excellent site	>1200	>5 m/s	>1280 kWh/m²a
Good site	800 – 1200	4 – 5 m/s	≤1280 kWh/m²a
Average site	500 – 800	2.5 – 4 m/s	≤655 kWh/m²a
Poor site	<500	<2.5 m/s	<160 kWh/m²a

However, the wind potential of a site is not only dependent on its prevailing mean annual wind speed. The local orographic conditions and obstacles can have a positive as well as a negative impact on the wind potential. It is therefore important to choose an installation site that is not negatively affected by the local environment and has an airflow as low turbulent as possible in the main wind direction.

1.1 Aim of the deliverable

This deliverable addresses the development of a site assessment method for small wind turbines. In order to identify wind hotspots in selected cities systematically and with low effort, methods are developed and applied in the selected cities. The aim of this work package is development of a simplified site assessment method. This method addresses the following stakeholders and problems:

- Applicable method for retailers, planners and manufacturers of small wind turbines.
- Avoiding the installation on low wind sites.
- Enhancing the consulting service in the field of small wind.

2 Method development for site assessment

The annual mean wind speed is a significant factor for evaluating a potential SWT site. It is defined as the average of all measured wind speed values over a year. Conventional SWTs have a starting wind speed of 2 to 3 m/s and begin their power output at 3 to 4 m/s. The power output of a SWT increases to the third power with increasing wind speed. Therefore it is crucial to choose a site with a high annual mean wind speed for the installation of a SWT (Reiterer, 2014). Based on empirical values at urban and rural locations, from an energetic point of view, an installation of a SWT only makes sense at 3.5 m/s annual mean wind speed.

The GlobalWindAtlas can be used to provide a first assessment for a potential SWT site. In order to have a low cost and easy to use solution, the open access wind potential map, appeared to be the most convenient solution for Austria. The GlobalWindAtlas was developed by the University of Denmark (DTU Wind Energy) in collaboration with the World Bank Group and uses modelling to indicate the wind potential worldwide on land and near the coast (DTU Wind Energy, 2023). The wind potentials were modelled using 10 year series of measured data. Thus, an accurate network of data with the mean annual wind speed, for the heights 10 m, 50 m, 100 m, 150 m and 200 m above ground could be created.

It offers a direct display of the average windspeed of a site on the website, but also provides GIS (geographic information system) files which can be used in specific software (e.g. QGIS) to get a more detailed site assessment.

In the following work the focus will be on the following two methods and their accuracy of assessing a site:

- Method 1 – Rayleigh distribution with Map data
- Method 2 – Weibull distribution with Map data

2.1 Method 1 – Rayleigh distribution with map data

2.1.1 Rayleigh distribution

If only the annual mean speed is known, Rayleigh distribution function can be used as an approximation. Comparisons showed that the Rayleigh distribution is a relatively good approximation of the wind distributions for locations in Central Europe (Hau, 2014). An exemplary plot can be seen in Figure 1, the shape of the curve always remains the same and no varying frequencies can be represented.

The Rayleigh distribution can be calculated with the following equation.

$$f_{Rayleigh}(v) = \frac{\pi}{2} * \frac{v_i}{v_m^2} * \exp\left(-\frac{\pi}{4} * \frac{v_i^2}{v_m^2}\right) \qquad 2\text{-}1$$

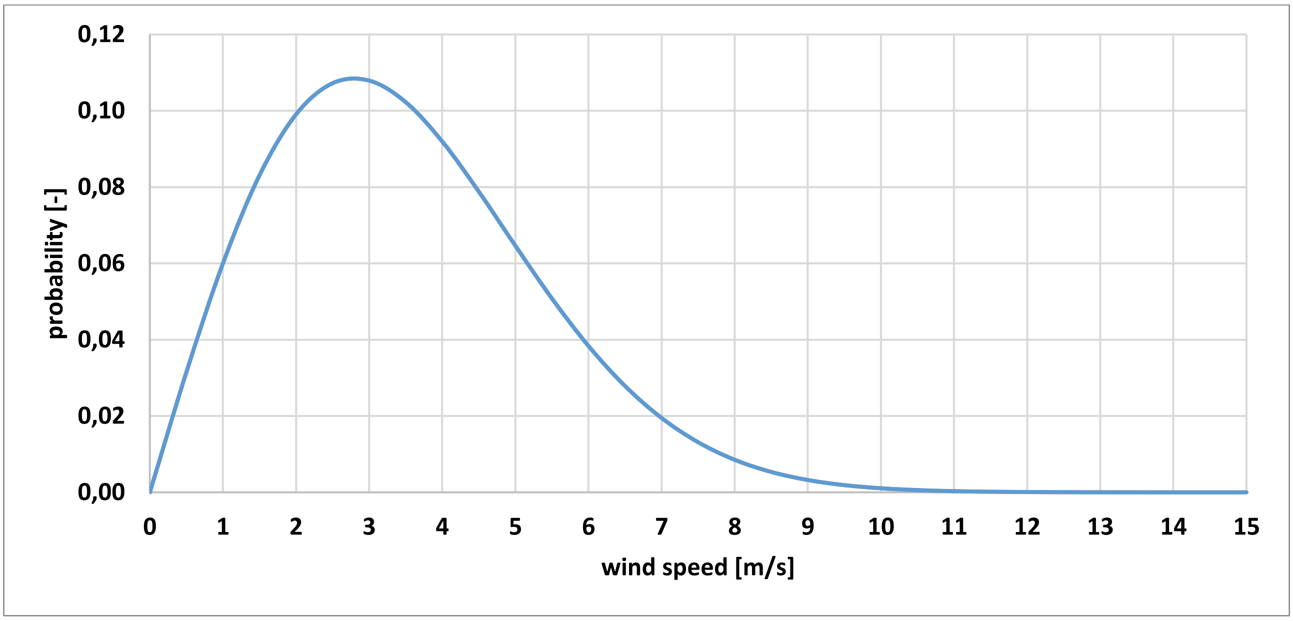

Figure 1 Rayleigh distribution with an average windspeed of 4m/s

2.1.2 Map data

The wind data from Global Wind Atlas can be used to calculate the Rayleigh distribution. The GlobalWindAtlas provides the wind speed at the heights of 10m, 50m, 100m, 150m and 200m. These are extracted from the map in the used browser (see Figure 2). For this purpose, the coordinates of the respective location are entered and marked on the map. The annual mean wind speed of the marked area is displayed by means of a colour scale and can be used for further calculations.

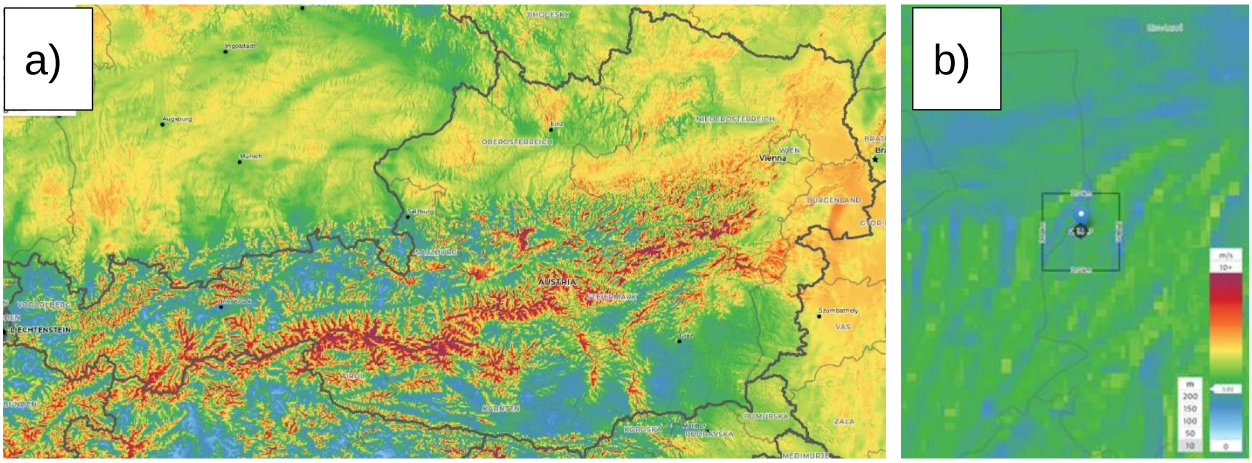

Figure 2 Annual wind speed Austria a) at 50 m, b) 10 m of a specific site from Global Wind Atlas

If the planned site is in a height between 10 m and 50 m the windspeed has to be approximated to the specific height. This is done with the roughness length of the site, the logarithmic wind profile and the wind speed data from Global Wind Atlas.

2.1.3 Roughness length and log wind profile

At a certain height, between 0 and 100 m above ground (Prandtl layer), the wind speed increases exponentially with height, depending on the ground roughness. The ground roughness is described by the roughness length z_0, which is defined depending on the orography. This parameter indicates the height at which the wind reaches 0 m/s on average (Hau, 2014). Table 2 shows roughness lengths and the corresponding terrain surfaces.

Table 2 Roughness length as a function of orography (Hau, 2014)

z0 [m]	Orography
1.00	Cities
0.50	Suburbs, settlements
0.30	Built up area
0.20	Many trees and/or bushes
0.10	Agricultural terrain with closed appearance
0.05	Agricultural terrain with open appearance

Using the annual mean wind speeds from 10 m and 50 m above ground, the ground roughness can be calculated by inserting the wind speed and heights into the following equation:

$$z_0 = e^{\left(\frac{v_1 * \ln(h_2) - v_2 * \ln(h_1)}{v_1 - v_2}\right)} \qquad \text{2-2}$$

v_1 Wind speed [m/s]

v_2 Wind speed [m/s]

h_1 Height [m]

h_2 Height [m]

z_0 Roughness length [m]

The relationship between two average wind speeds at different heights and the roughness length is shown in the following equation:

$$\frac{v_2}{v_1} = \frac{\ln\left(\frac{h_2}{z_0}\right)}{\ln\left(\frac{h_1}{z_0}\right)} \qquad \text{2-3}$$

v_1 Wind speed [m/s]

v_2 Wind speed [m/s]

h_1 Height [m]

h_2 Height [m]

z_0 Roughness length [m]

Figure 3 shows a possible progression of wind speed with increasing altitude.

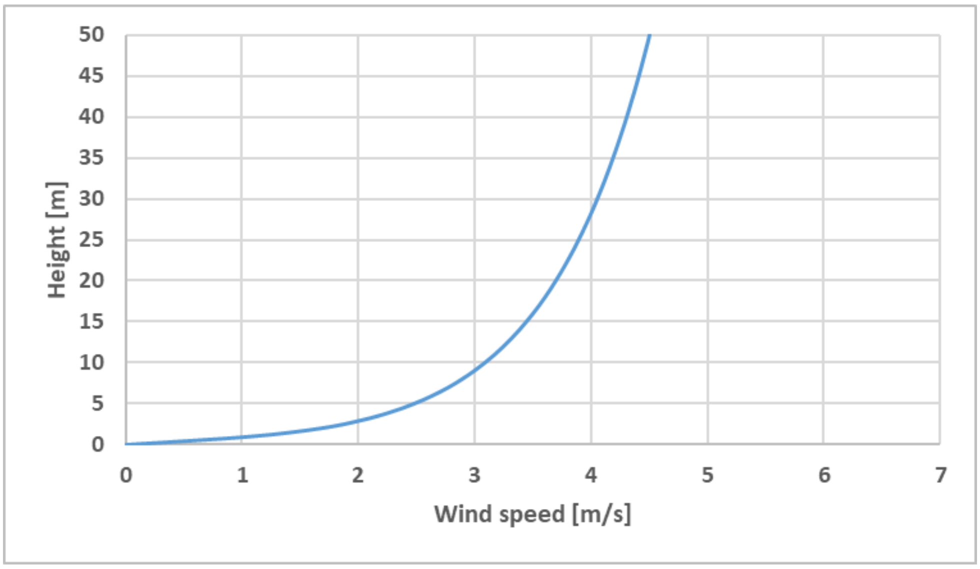

Figure 3 Increase in wind speed with increasing altitude

By calculating the ground roughness and determining two average wind speeds, the annual mean wind speed at a given height can be determined. If only the wind speed at one height is available, the ground roughness can be estimated using Table 2

The Rayleigh distribution can be calculated according to the formula in chapter 2.1.1 using the annual mean wind speed for the desired height.

2.2 Method 2 – Weibull distribution with map data

2.2.1 Weibull distribution

The Weibull distribution is a two-parameter probability distribution which is used to model the wind speed distribution. To calculate the Weibull distribution, a sufficient amount of wind measurement data is needed to calculate the shape factor k and scale parameter A and to obtain the most accurate approximation of the wind speed distribution (see Figure 4). This is done with the following equations:

$$f_{weibull}(v) = \frac{k}{A} * \left(\frac{v_i}{A}\right)^{k-1} * e^{\left(-\left(\frac{v_i}{A}\right)^k\right)} \quad 2\text{-}4$$

$$k = \frac{v_m}{\sigma} \quad 2\text{-}5$$

$$A = \frac{v_m}{\left(0{,}586 + \frac{0{,}434}{k}\right)^{\frac{1}{k}}} \quad 2\text{-}6$$

v_m Mean wind speed [m/s]

σ Standard deviation wind speed (measured values)[m/s]

k	Shape factor [-]
A	Scaling factor [m/s]
v_i	Wind speed (x-axis – Weibull distribution) [m/s]

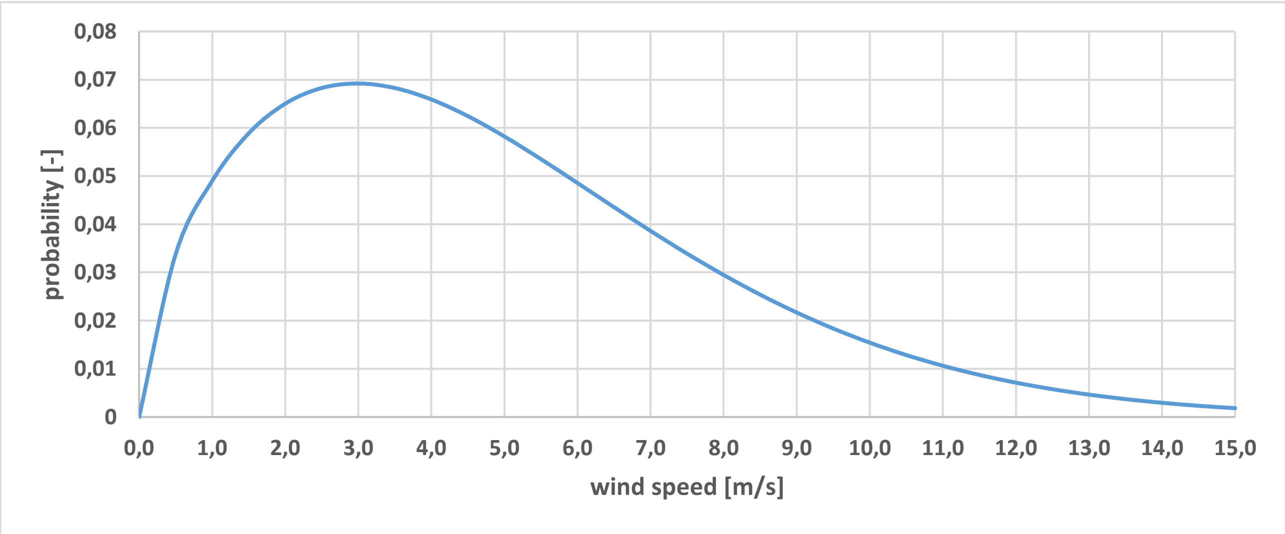

Figure 4 Weibull distribution with shape factor k = 1.6 and scaling factor A = 5.5

2.2.2 Map data

The Global Wind Atlas doesn’t provide the A and k in the browser version. However, they can be accessed via the download of the respective GIS file and API access (see Figure 5).

Figure 5 GIS File Download Area

The following data layers were downloaded and used for the exemplary evaluation:

Table 3 Exported GIS Files from Global Wind Atlas

Country	Layer	Height [m]
Austria	Weibull A factor	10
		50
		100
	Weibull k factor	10
		50
		100
	Wind speed	10
		50
		100

2.2.3 QGIS and GIS files

To evaluate the exported GIS files a specific software is needed. In this work the software QGIS was used. QGIS is a free and open-source geographic information system application were geodata can be viewed, edited, and analysed.

Additionally, to the Global Wind Atlas GIS files need to be imported. A GIS file contains the geographical data of the desired country. For Austria this is provided under the “Open Government Data Österreich Lizenz CC-BY 4.0” and is free to download and use. In Figure 6 shows QGIS with all the imported GIS Layers sorted by their height.

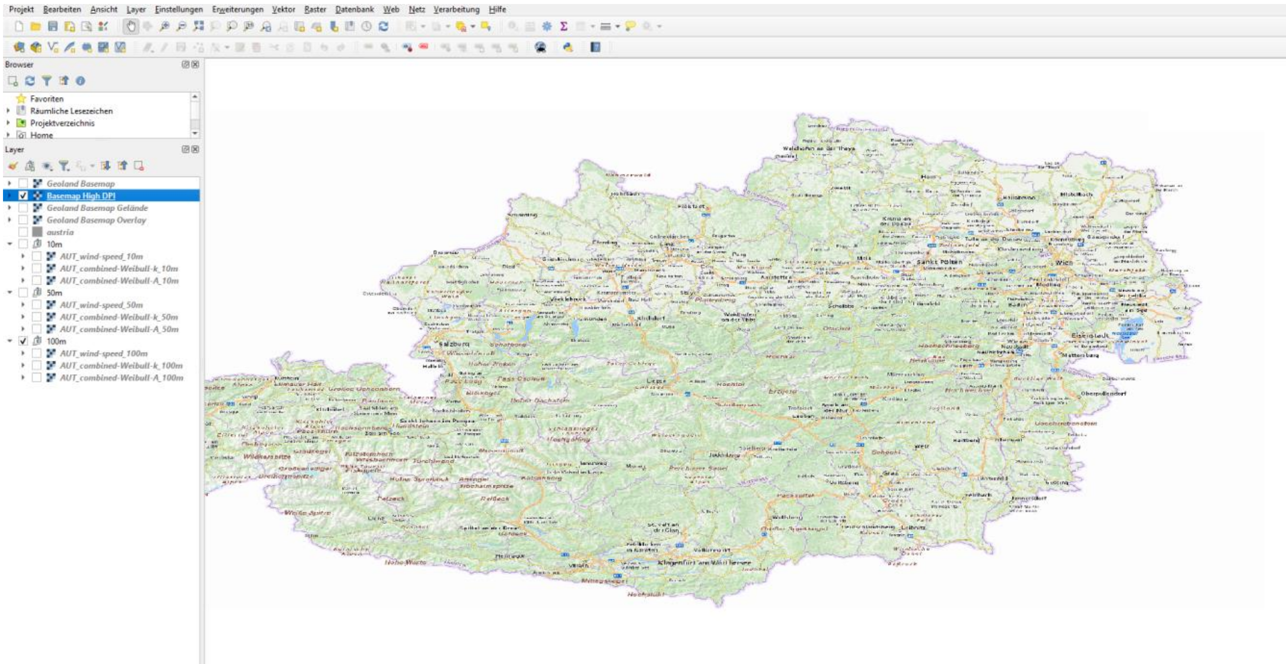

Figure 6 Screenshot QGIS with Austria and imported GIS Files

For each layer it is possible to select different interpolation modes, the amount of classes as well as the colour for all layers to provide the desired overview (see Figure 7).

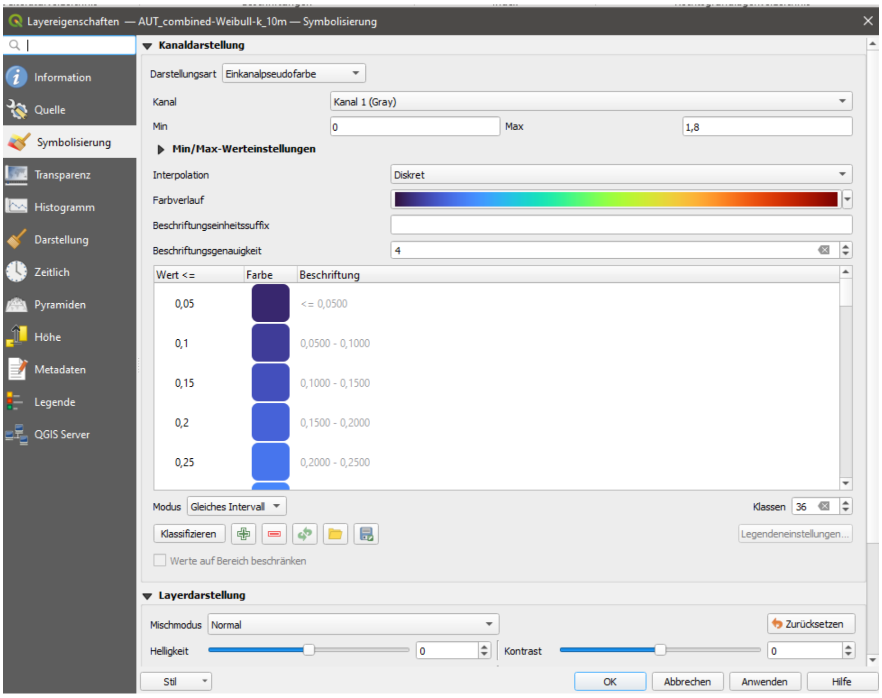

Figure 7 QGIS Layer options

After all adjustments are done, it is possible to select the layer and take a closer look at the data provided and the data of a specific site (see Figure 8). It is also possible to change the colour for more contrast and easier evaluation (see Figure 9).

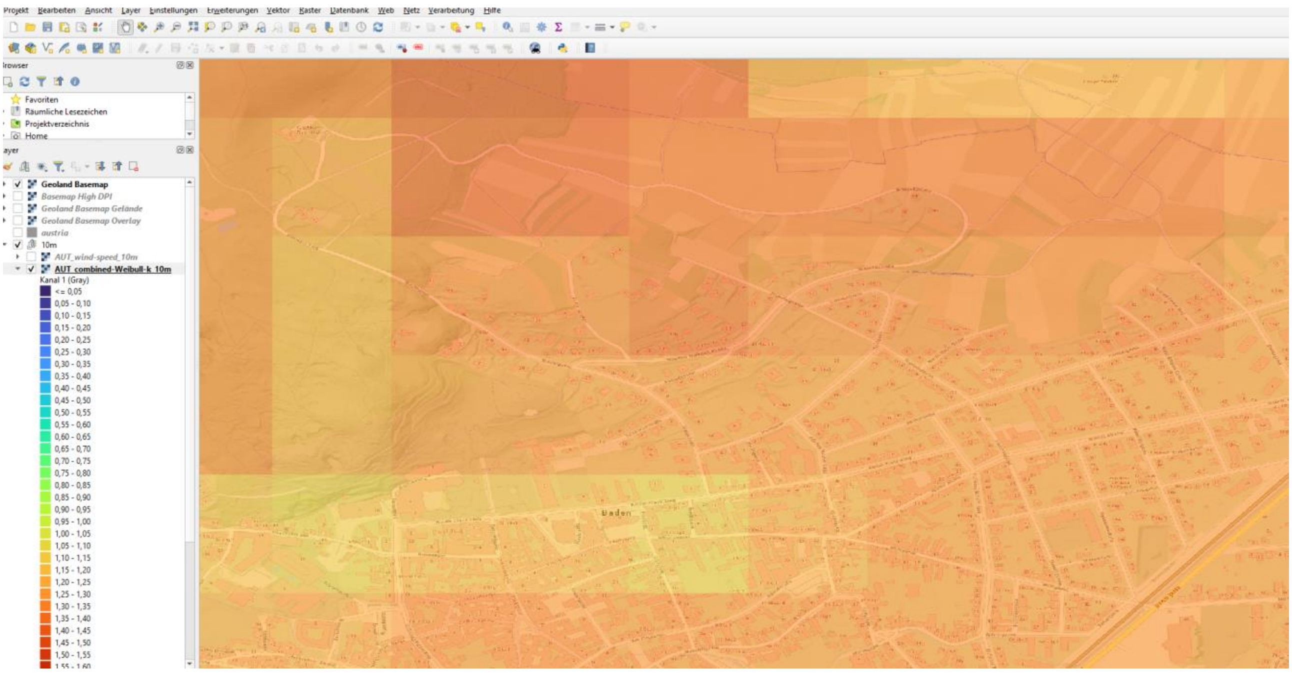

Figure 8 QGIS with active Layer (k factors between 1.20 and 1.40)

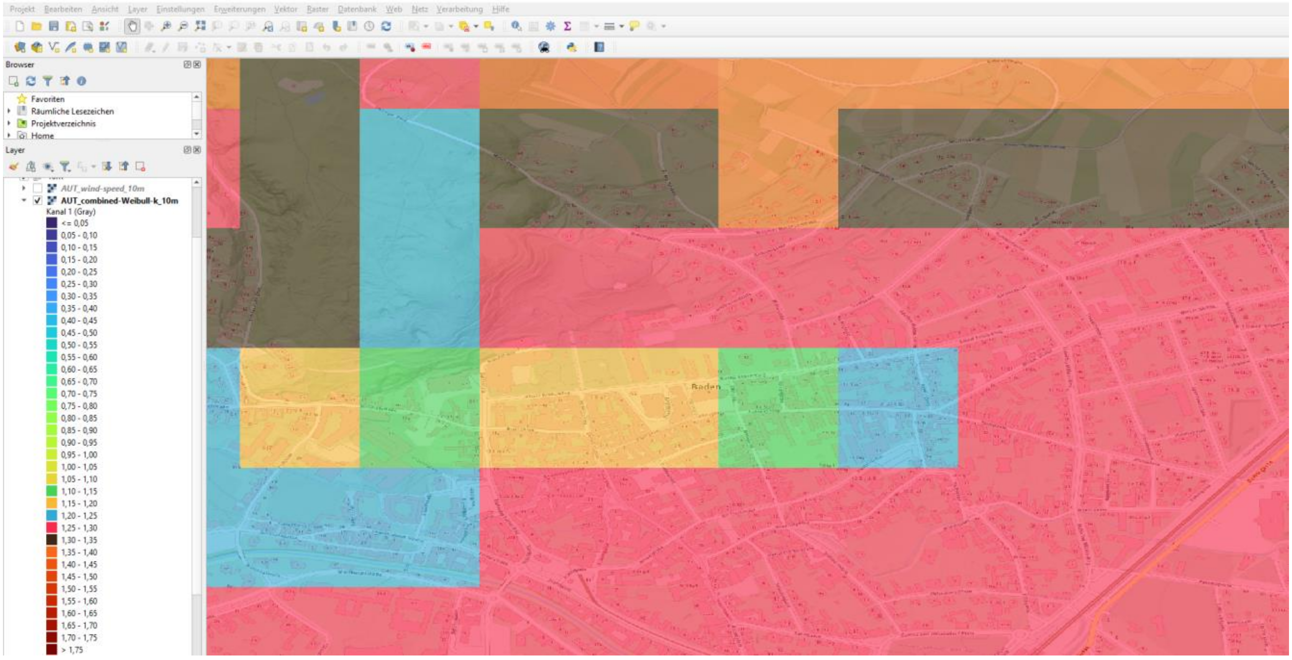

Figure 9 QGIS with active Layer and changed colours (k factors between 1.20 and 1.40)

For each site the A and k values, as well as the average windspeed are determined via QGIS. If a site is on a different height than the data, the data has to be approximated accordingly. The wind speed can be approximated with the roughness length and log wind profile described in 2.1.3 and for the A and k – factors functions have to be developed for each specific site.

2.2.4 Approximation of A and k factors

For the approximation of the A and k factors linear or quadratic function were used depending on the site. For this the A and k factors of the available heights of 10, 50, and 100 m were used. Depending on the increase either a linear or a quadratic function was created via MS Excel (see Figure 10). The A and k factors for the desired height were then calculated with the corresponding function.

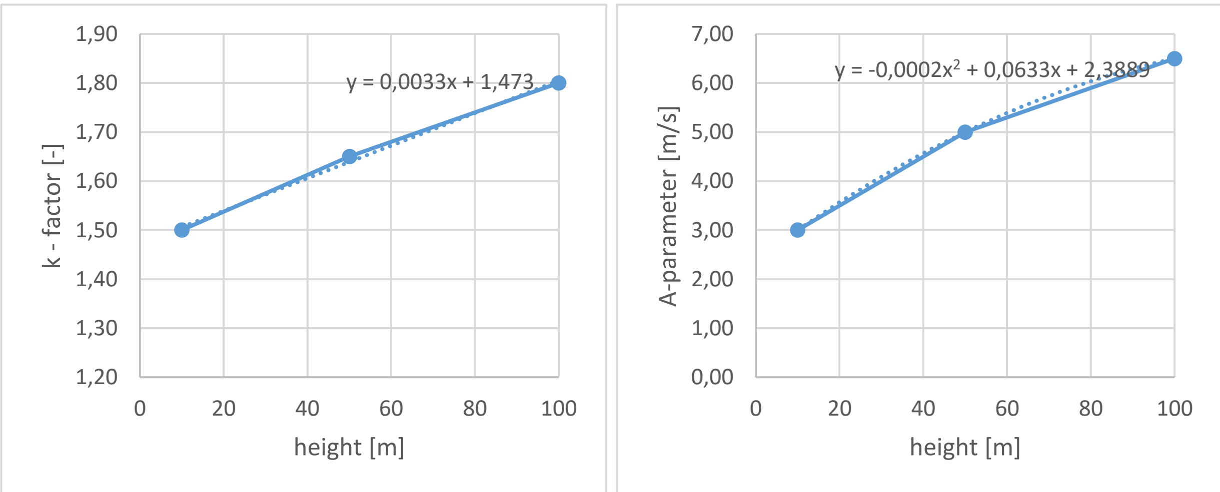

Figure 10 Approximation of the k – factor and A-parameter of a SWT site

2.3 Power curve of SWT

The SWT which is used for the exemplary yield assessment is the Schachner SW5. The properties can be seen in Table 4 and a picture of the turbine as well as the power curve in Figure 11.

Table 4 Schachner SW5 characteristics

Company	Schachner Kleinwindkraft	
Turbine name	SW5	
Rotation axis	Horizontal - Lee	
Nominal power	4.8	kW
Rotational speed at nominal power	240	RPM
Rotaional diameter	5.6	m
Rotor blades	3	-

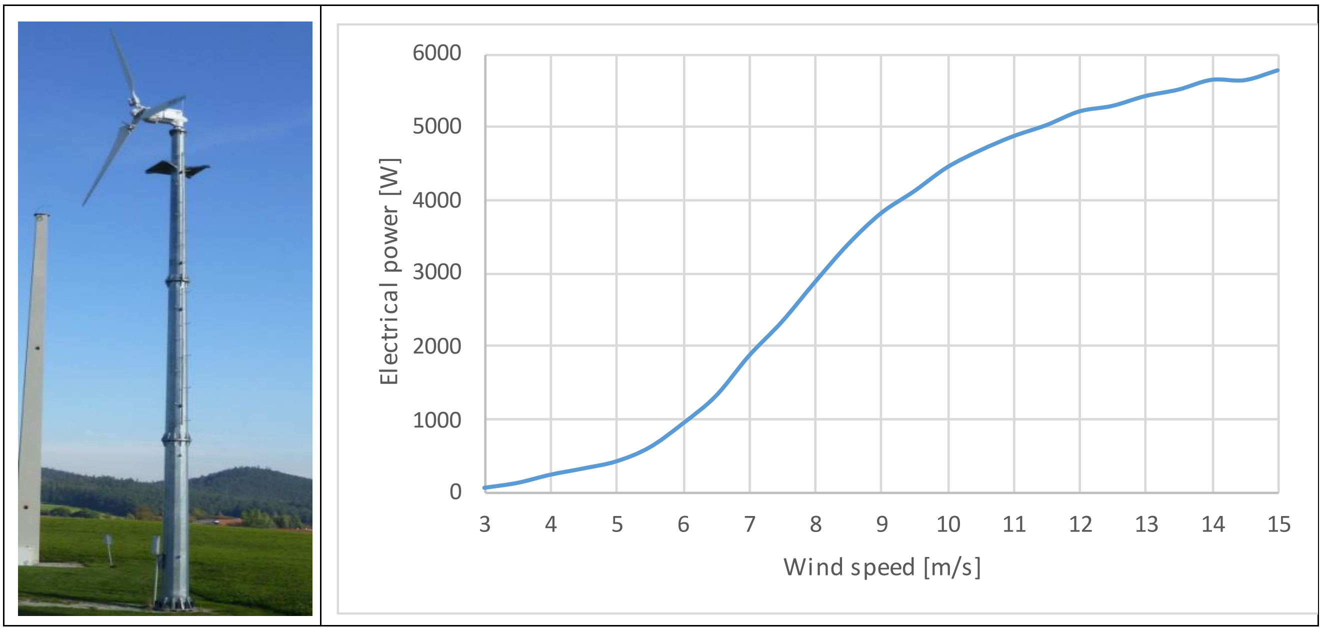

Figure 11 Schachner SW5 and power curve (measured)

2.4 Yield calculation (AEP)

The annual yield (AEP - annual energy production) of a plant is calculated using the power curve of the planned SWT and the previously calculated Rayleigh distribution or Weibull distribution. With the power and probability per wind speed, the yield in kWh/a can be calculated per wind speed BIN.

$$AEP_M = \sum f_{Rayleigh}(v_i) * P(v_i) * t \qquad \text{2-7}$$

AEP_M Monthly yield [Wh]

v_i Wind speed [m/s]

$f_{Rayleigh}$ Probability [-]

P Power according to manufacuturer’s curve [W]

t Hours per month (e.g.: January 24h*31d) [h]

For the accuracy of the annual yield it is important that the power curve meets the requirements of the standard EN61400-12.

2.5 Windrose

Wind roses are created to display probability of the wind speeds for each wind direction. Figure 12 shows an example of a wind rose, which displays the frequency of wind speed in each wind direction in addition to the main wind directions (south, north-west). The width of the coloured bars describes the frequency of the corresponding wind class. Wind roses are mainly used to evaluate the main wind direction and any obstacles that may be present.

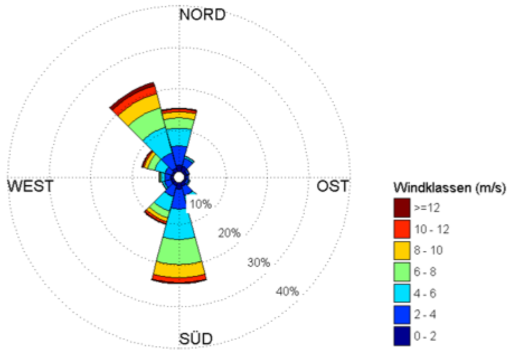

Figure 12 Wind rose with wind classes

Global Wind Atlas offers an evaluation of the wind direction in form of a windrose for the surrounding area (3km * 3km) of a site.

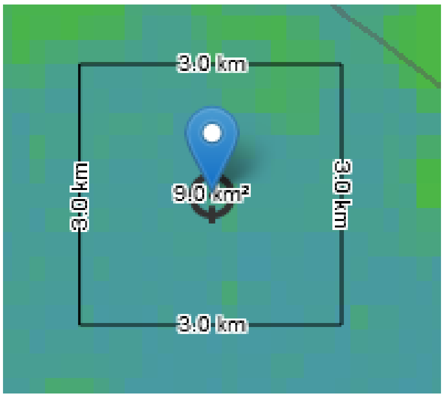

Figure 13 Evaluated area Global Wind Atlas

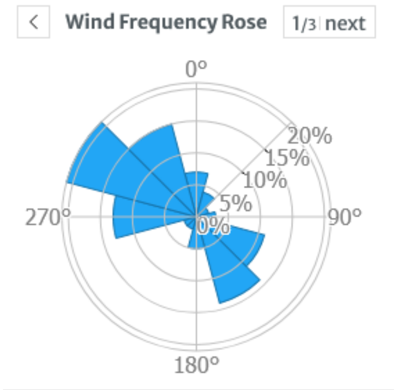

Figure 14 Wind rose Global Wind Atlas

2.6 Influence of obstacles

The wind conditions of a site are largely determined by the orography (surface). Individual obstacles cause strong turbulence. The installation of a SWT must be done outside turbulent areas. Furthermore, a SWT should be placed at the highest point of gentle hills or buildings to avoid stalls and turbulence. If it is not possible for the SWT to be free of obstacles, at least a free flow field in the main wind direction should be ensured. Obstacles cause turbulence at a height which can be twice the height of the obstacle. Furthermore, turbulence can still occur far behind the obstacle. These can occur at a distance behind the obstacle, which can be 20 times the height of the obstacle (Reiterer, 2014).

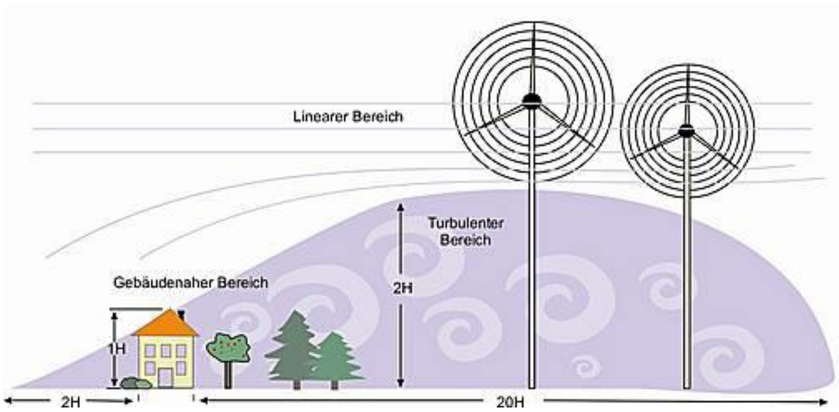

Figure 15 Turbulent area behind obstacles (Reiterer, 2014)

3 Evaluation of the sites

3.1 Energy research park Lichtenegg

Comparing the result from Global Wind Atlas with the measured data it can be seen that the wind speed gets overestimated by more than 1 m/s by the map data. Because of that difference the Rayleigh distribution is not a reliable method of evaluation for this site. The A and k factor for the Weibull distribution get underestimated by the map material. The A factor by 0.52 and the k factor by 0.34.

The energy yield calculated with the probability of the Weibull distribution of measurement data and map data are very close and only show a difference of 255 kWh or 2.68 %.

Table 5 Comparison measurement and map data energy research park Lichtenegg

	Measurement data	Map data
Average wind speed [m/s]	5.05	6.21
A - factor [-]	5.62	5.50
k - factor [-]	1.84	1.50
Energy yield with SW5 [kWh]	9,265.94	9,521.35

By comparing the different distributions in Figure 16 it can be said, that neither the Rayleigh nor the Weibull distribution of the map data is able to accurately describe the wind situation in the research park Lichtenegg accurately. This can be attributed to the site being very complex on the top of a hill surrounded in the near area by agriculture and forests.

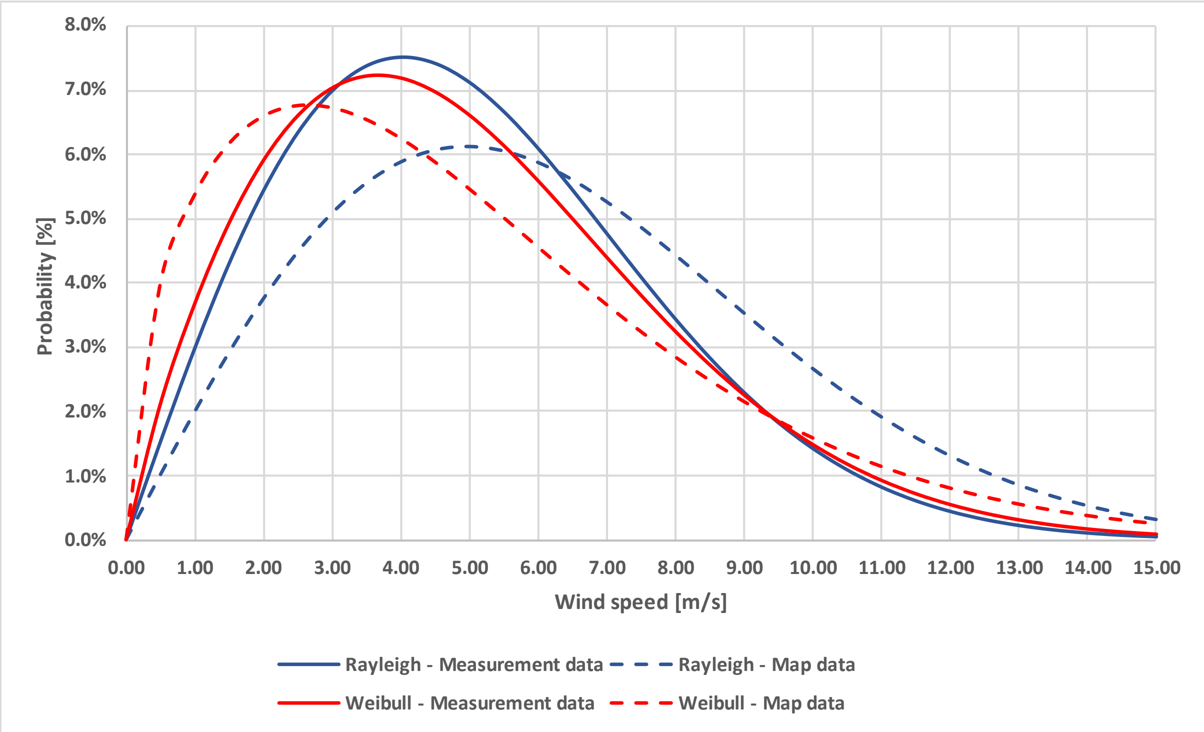

Figure 16 Comparison Rayleigh and Weibull distribution energy research park Lichtenegg

In Figure 17 the wind roses from the map data and the measurement data for the energy research park in Lichtengg are displayed. It shows that the wind rose from the map data predicts the main wind direction between Northwest and Southwest with the main direction around 320°. The measurement data shows that the main wind direction is between northwest and north as well as the southwest. The main directions is 345°.

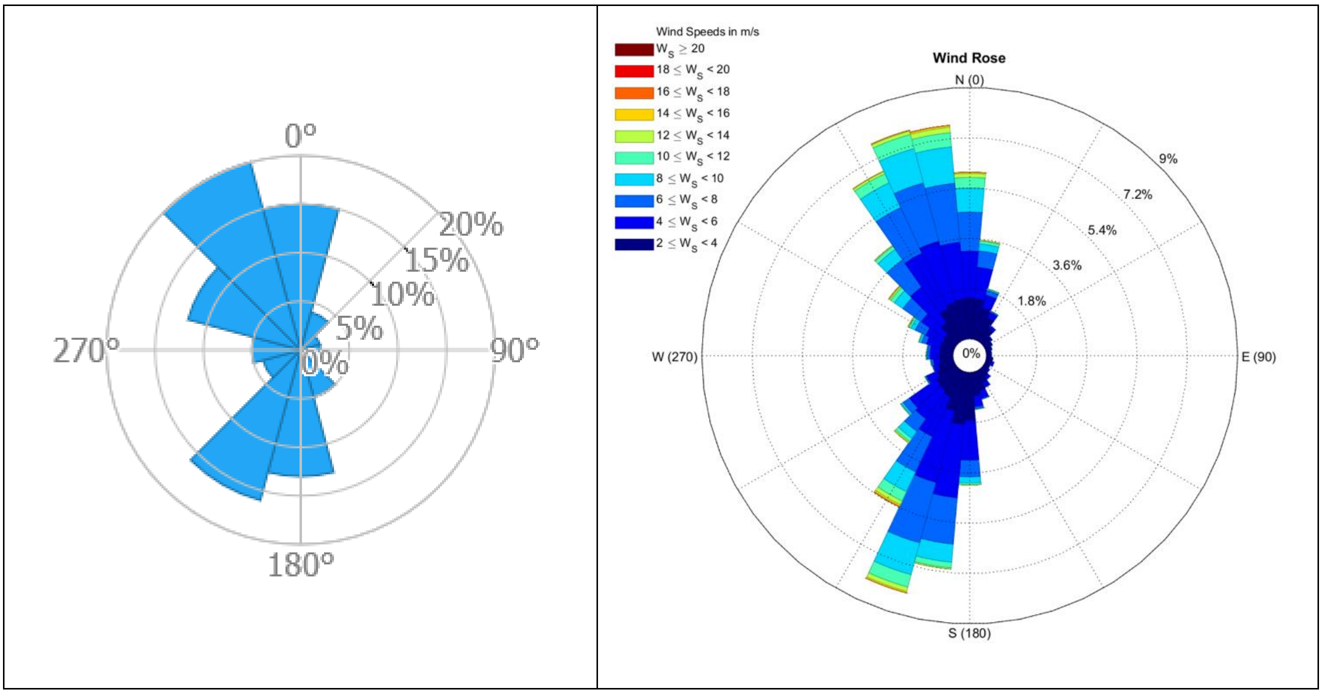

Figure 17 Comparison wind rose map data (left) and measurement data (right) in Lichtenegg

3.2 ENERGYbase Vienna

Comparing the data from the map and the measured data it can be seen that the wind speed gets overestimated by 0.3 m/s by the map data. The data could be used for a Rayleigh distribution, but the result would lead to an overestimated probability distribution of the site. The A factor of the Weibull distribution gets overestimated of the map data by 0.10 and the k factor gets underestimated by 0.09 by the map data. The A and k values overall are quite accurate compared to the measured data. The energy yield with the probability of the Weibull distribution of measurement data and map data show a difference of 679 kW or 14.56 %.

Table 6 Comparison measurement data and map data ENERGYbase Vienna

	Measurement data	Map data
Average wind speed [m/s]	3.63	3.90
A - factor [-]	4.01	4.11
k - factor [-]	1.68	1.57
Energy yield with SW5 [kWh]	3,984.62	4,663.65

By comparing the different distributions in Figure 18 it can be seen, that the Rayleigh and Weibull distribution both lead to similar curves. Still the map data overestimated the measured data which could lead to wrong yield data.

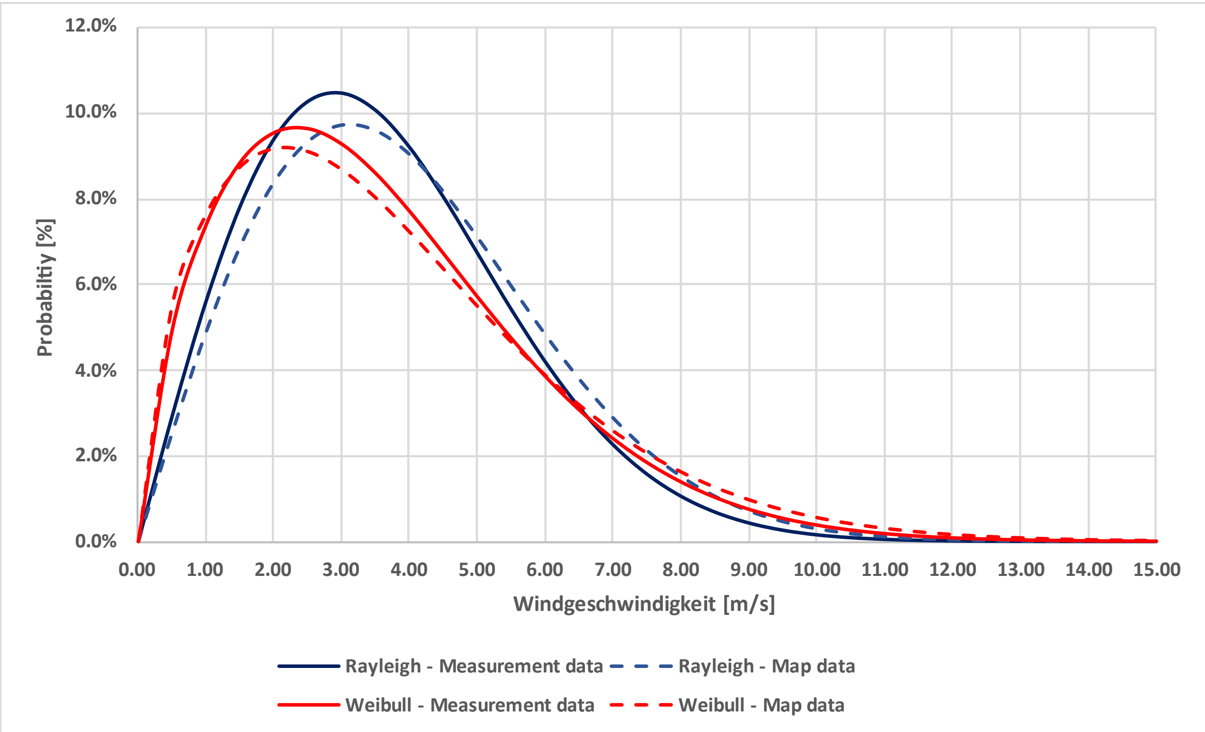

Figure 18 Comparison Rayleigh and Weibull distribution ENERGYbase Vienna

In Figure 19 the wind roses from the map data and the measurement data are displayed. It shows that the wind rose from the map data predicts the main wind direction between north and west as well as southeast with the main direction of 300°. The measurement data shows that the main wind direction is between northwest and north as well as southeast. The main direction is 330°.

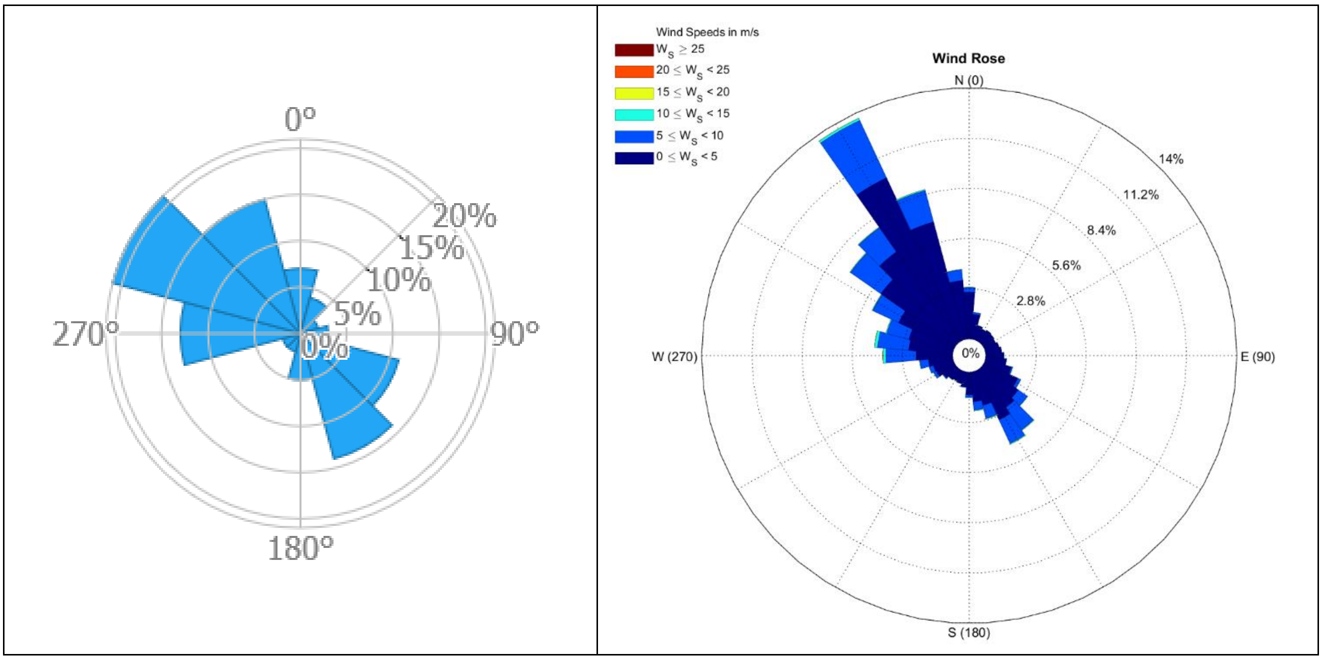

Figure 19 Comparison wind rose map data (left) and measurement data (right) in Vienna

4 Comparison and Interpretation of results

Comparing the Weibull distributions of both sites, it can be seen that the curves at the ENERGYbase are much closer and of similar shape than in Lichtenegg. The calculated energy yield however shows a difference of 679 kW or 14.56 % for the ENERGYbase and a difference of 255 kWh or 2.68 % in Lichtenegg. This can be traced back to the probability of the lower and higher wind speeds at the Energybase and the power curve of the SWT.

In Figure 21 the calculated yield versus the wind speed can be seen. The yield calculation shows that in Lichtenegg between 3 and 9.5 m/s the map data underestimated the yield and after 9.5 m/s it overestimated the yield. Therefore, the overall yield evens out to a difference of only 255 kWh. On the ENERGYbase calculated yield gets overestimated for all windspeeds and therefore results in a difference of 679 kWh.

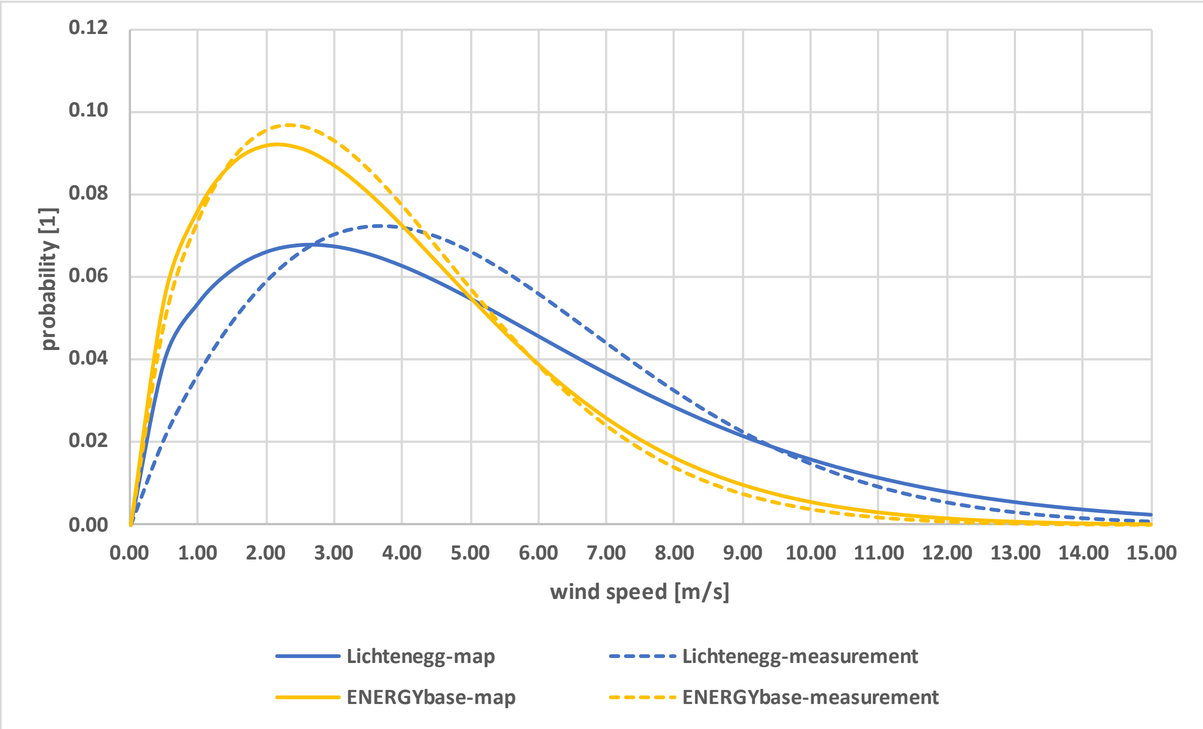

Figure 20 Comparison Weibull distribution energy research park Lichtenegg and ENERGYbase

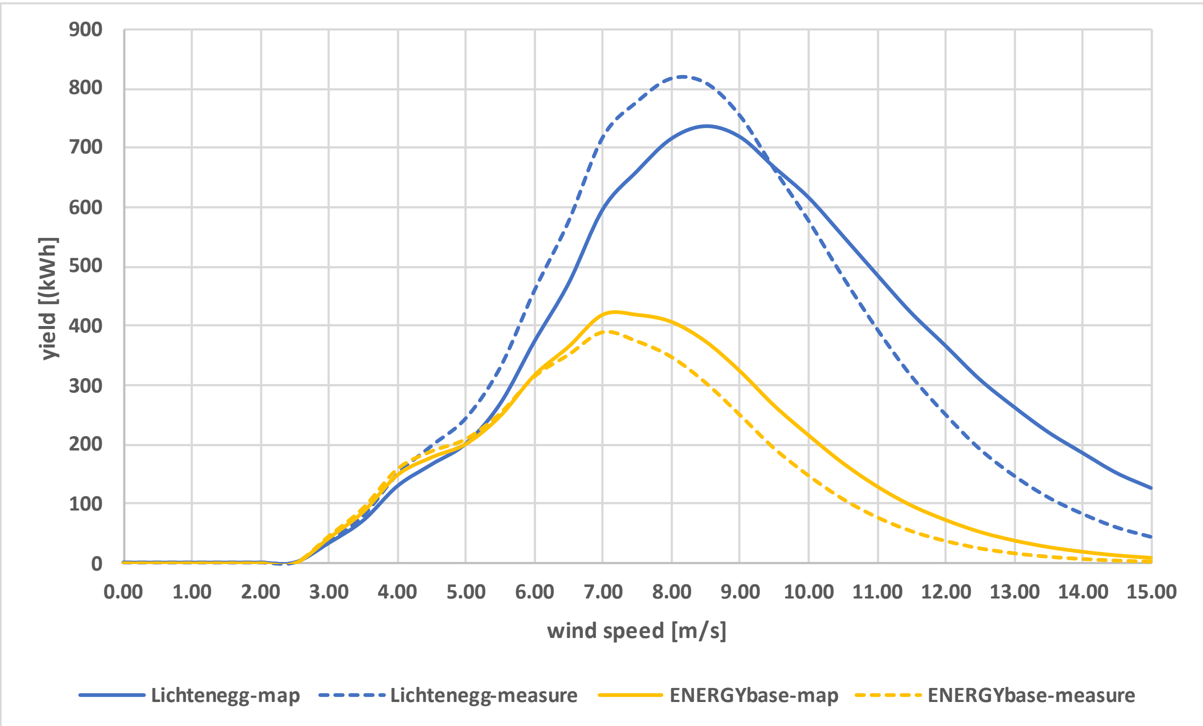

Figure 21 Comparison yield over wind speed energy research park Lichtenegg and ENERGYbase

In conclusion it can be said that the evaluation of the ENERGYbase shows a more realistic site assessment with an error of around 15 % compared to the measured values. The error of only around 3 % in the energy research park Lichenegg was not due to the accuracy of the method but due to the distribution curve and power curve of the SWT.

Neither of the methods offer a near 100 % accurate site assessment for small wind turbines. The error of around 15 % can be attributed to the influence of the nearby obstacles which cannot be assessed via map data alone. The wind direction assessment of the map data shows a similar result. The main wind direction from the map data differs around 30° from the measured data.

Therefore, the results of an evaluation via map data have to be validated by comparison with similar sites and by verifying the surrounding area of the potential site for obstacles which could positively or negatively affect the wind resources. With these steps the error could be reduced further and a more realistic site assessment could be developed.

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