Development of a Wind Index Concept for Brazil

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Contents

1. Motivation

Brazil obtains much of its electricity from hydro power. Due to increasing energy demand, socio-environmental issues and an unavailability of suitable places for dams for multiannual hydro reservoirs, the Brazilian power grid depends more and more on the nature behaviour and thermoelectricity (mainly from fossil fuels).

At the same time, the share of wind power in the electricity mix increases at fast rate. Such growing share in the mix poses a challenge due to the uncertainty in relation to the resource and the energy availability. In order to minimize the problems and increase the system´s reliability, the knowledge of the joint behaviour of water inflow and wind becomes important.

Therefore, the idea that drives the establishment of regional wind indices is to identify long-term correlations among wind supply and water level in the river basins that could improve the security of energy supply and bring other benefits.

The subject of this research is the establishment of criteria to identify **regions** of "homogeneous" wind behaviour, and to find the **most suitable wind indexes** to be further correlated with water inflow.

2. Introductions

Within the last years the usage of Wind Indices for verification of energy yield production of wind farms has been increased. The most prevalent kind of Wind index is the energy yield production Index.

A Wind index is the most common source of information for estimating the long-term energy yield of wind turbines. The indices enable wind turbine owners to establish whether variations in energy productivity are due to deficiencies in wind turbine performance or due to wind below expected levels. The monthly energy yields are given as relative values compared to the long-term reference.

The wind indices are operating for example in Denmark and Germany. The first index was started by the wind power pioneers in Denmark as recently as 1979 and was the model later copied by Germany, Sweden and the Netherlands. Later Wind indices for other countries and regions like Britain and Northern France followed.

The reasons for the evolution of wind indices in northern and west Europe and nowhere else seem to be mainly historical. Without information of short and long-term wind conditions owners and operators were unable to claim their machine was working according to the expectations.

Furthermore, often local wind measurements were not available for widely dispersed areas in which single wind turbines were being installed. The use of a production data of existing wind farms in combination with a Wind index supplements or replaces site specific wind measurements.

Other countries do not have sufficient production data for creating a wind index base on operational data. Here wind indices are established base on wind data by correlating site wind speed measurements taken over periods of one year up to several years with long term wind speed data from the nearest meteorological station with reliable records.

3. Classification of Wind Indices

3.1. Wind Energy Production Index

The first energy yield production related Wind index has been established in Denmark in 1979. Later on the North Sea neighbouring states Germany and Netherland followed. Meanwhile those indices are considering many years of operation. Since 2010 the Netherland Wind index [35] is not in use anymore. In comparison to most other wind indices the German IWET Index and Danish Wind Index are characterized by different wind index regions. During the operation the Wind Indices have been evaluated and verified. The volatile data set led within the operation time to increased deviation (caused by the developments in hub height, capacity, rotor diameter and regulation) in respect to the defined long-term average (100 % value). Due to the increasing data base additional smaller regions have been defined and the level of the 100 % value has been adjusted again.

The German IWET index is probably the most well-known wind index. The wind index started in 1988 with collection of operational data. Since 1991 9 index regions wind index regions have been defined but data have been published for 4 regions only. Later the index regions have been redefined to 25 Regions. Since the beginning data sets of 22000 different wind turbines have been considered in the data base. Currently, the IWET takes approximately 4500 monthly production data sets into account. Within the accumulated years changes of properties of the wind farms (local distribution, hub height, capacity,) led to changes regarding the representativeness of all wind data. This and partly erroneous long-term correction in the past led to several adjustments (Revisions in 1999, 2003, 2006, 2011) of the representative period for the wind index. The delivery of production data is optional and without data regimentation. Provided operational data are incomplete regarding properties or consistency and sometimes incorrect as well. But the published data base of all turbines allows also consistency checks and verification of production data with the monthly value of relative energy. Finally the several weak points of the index can be compensated by corrections and site specific adjustments. Hence, it is often the preferred tool due to its simplicity and comparable high reliability.

Beside the commonly used IWET Index other production based indices like IWR Index [23] are available for Germany. This wind index is characterised by a rolling average of 10 years and a division of the country in only two regions (Federal states with and without share of shore). The index shows often high deviations to the IWET and ISET index and is not accepted by the majority of wind energy community.

Due to partly high discrepancies regarding of those indices regarding averaging period and index region an alternative wind index (ISET)[45] have been developed additionally.

3.2. Wind Speed Index

An alternative to the consideration of operational data is the usage of meteorological input data. A wind speed index considers only the wind conditions without an application of energetic aspects. The resulting index value represents the relative wind speed value in comparison to long-term. Therefore a wind speed index does not reflect the stronger variations of wind energy at the site, but such an index can be used to compare and show wind conditions variation within the considered region.

The vertical wind speed profile depends on state of the atmospheres and interactions of the wind with the terrain. In order to have comparable information for the evaluation of useable wind conditions is always related to the same height above ground. The remaining changes of the wind conditions between the disperse measurements are calculated by wind model or by interpolation

In analogy to the applying meteorological data from 10 m weather stations or advanced wind measurements as well Reanalysis data (for example MERRA data) can be used. However, there are significant differences in terms of quality.

Meteorological weather stations with a measuring height of 10 m above ground are less useful due to their low representativeness for typical hub heights. Their advantage is the long duration of these measurements.

Significant better reliability can be expected from MERRA or other Reanalysis data. On the one hand they have a long history and can be used without external data for long-term correction and on the other hand they are available in a better spatial resolution.

Since high-resolution data provide a detailed picture, therefore high-resolution data sources are also preferred. That means, on basis of data resolution the MERRA data are preferred due to the increases horizontal, vertical and temporal resolution.

Often a wind speed index is published together with a more important Wind Energy Index. Examples are the weather stations based EuroWind-Index (section 2.1.2) and the reanalysis data based wind index of ANEMOS[33].

3.3. Wind Power Density Index

Wind speed values, frequency and A and k Parameter of the Weibull distribution show important figures of the wind properties. Nevertheless these values show only the wind speed related characteristics. Therefore the consideration of energy in wind or the wind power density supply at the first sight seems be one alternative parameter for a wind index. The following equation describes the relationship of wind power and wind speed:

$$P = \frac{1}{2} A \rho v^3 \qquad (1)$$

And wind power density P/A

$$\frac{P}{A} = \frac{1}{2} \rho v^3 \qquad (2)$$

where A is the swept area ρ the density of the air and v the wind speed.

The application of a wind power density index has to be done with care. It’s true that the power output of a wind turbine follows a cubic function for low wind speeds. The characteristic of a power curve can be determined in two main parts. The left part shows low wind speed values and energy output in a cubic function. The second part and remaining starts after an inflection point where the limitations due to the turbine specifications are more relevant. This leads to nominal power out and cut-out where increases wind speeds do not increase the energy anymore.

A Wind Power Density Index expresses the energy only in free wind. Due to big difference between free wind potential and technical usable potential by the wind turbines, the application of a Wind Power density Index leads to distinctly increased variations in comparison with harvestable energy. Therefore it is not recommended here.

An application for this index might be a local risk management regarding storm losses of the surrounding.

3.4. Wind Energy Production Index from Wind Data

As described in the previous section technical wind potential is not only a cubic function of the wind speed but it's also limited by the power curve with nominal power and cut-out limit. This is considered when a wind index is calculated from wind data by the application of a power curve. The power curve can be a standard or a project specific power curve. Hence the energy yields are simulated by the application of a power curve for a predefined height (section 3.2).

Examples of a application of power curves to the wind conditions are ISET-Index (Germany)[45], EuroWind [32], GL-GH Index UK [36] and Anemos[33]. Those data come from weather stations, NCAR data or site related wind measurements [37].

The ISET Wind Index is based on 60 measured wind data sets at 50 m height compared to the long-term average. The related area is divided into 3800 squares of each 10 km times 10 km. The mean monthly value for the whole of Germany is calculated in relation to the long-term average. The connection between power production and wind speed was determined empirically, by the usage of the annual power production of 1,500 wind turbines in the WMEP[37].

The EuroWind-Index takes exclusively wind measured data of the international weather services into account. The resolution of the energy index map is given by a resolution of 20x20 km. The areas in between have been determined under consideration fluid dynamics simulations.

The GL-GH Wind Index of the United Kingdom considers 50 stations of the mainland. Those stations belong to the UK Met Office. The meteorological stations measure the wind conditions in 10 m above ground level. A separation into regions has not been determined.[42]

Anemos offers as well and monthly Wind Energy Index without operational data, but in comparison to others, Anemos uses Reanalysis data for the wind index. The resolution of the index varies between 5x5 km and 20x20 km resolution according to the country of application.

3.5. Site specific Wind Index

Wind Indices can be created for a site specific use only. Site specific Wind Indices are often in use for the verification of operational wind turbines nearby wind measurements. Here monthly operational data and monthly wind speed data are in use for the calculation of the site-specific sensitivity. The monthly values of energy yield (absolute and relative) can be created on basis of the site-specific sensitivity and available long-term data.

Alternatively, a site specific index can be bases on the appliance of site related wind data and power curve as well.

In addition to the wind indices in general there are also stand-alone production data sets which can be used for verification. Due to the large database, it is also possible to create a wind index thereof. One example for this is the Swedish database vindstat.nu. [25]

4. Comparisons of Wind Indices

The following Table 1 shows the main properties of the different Wind Indices considered in the sections before.

Kind of Wind Index	**Wind Speed Index**	**Power Density Wind Index**	**Wind Energy Production Index based on Wind data**	**Wind Energy Production Index based on Production Data**
Input (monthly)	Average wind speed at certain points, wind flow simulation	Weibull parameters at certain points, wind flow simulation	Energy yield per turbine	
Output (monthly)	Relative wind speed map	Relative power density	Relative value of average Energy Yield output	
Spatial validity	Maps with certain resolution for a defined reference height above ground.		Wind Index Regions	
Reference Height	**Homogeneous** (defined height above ground)		**Inhomogeneous** (input data from different hub heights	
Monthly Variation	Lower than real production	Higher than real production	similar to real conditions	
Advantages	Wind condition can be calculated to other heights easily, Index is less fragile due to fixed values of certain parameters.		Best application to real monthly variation of Energy Yield	
	Easy application, same behaviour as input data	Small differences in wind potential can be better distinguished	Detailed wind information at measurement positions are known	Easy application of operational data. Good representativness of the Index Region. Easy outlier detection Input format (energy) is equal to output format
Disadvantages	The monthly variations do not reflect the variation of energy by the wind turbines		Fragile to site related properties (turbine type, operational modes, ...) Map of energy yield cannot created – one value is repress. for the whole region	
	Monthly variation of relative energy yield is lower than real production	Monthly variation of relative energy yield is higher than real production	Uncertainties regarding application of representative power curve (operation modes)	Real Wind conditions are not known. Inconsistent number of data sets.
Application	Definition of wind index regions		Determination of representative index value regarding energy yield	
Examples	Anemos WSI	Yearly WPdI - applied in German Wind energy report [43]	**Standard or site related power curve**: ISET Index, GL-GH Britain WEI Anemos WEI	IWET, IWR, Danish WEI, Swedish WEI Netherland WEI

Table 1: Comparison of Wind Indices

The Table 1 distinguish between 4 kinds of wind indices. The site specific Index can be assessed depending on the input of data and the aim like every other wind index.

Two main categories can be determined. First the wind or wind power density wind indices and second the Wind energy production indices.

The wind or wind power density wind indices are related to wind conditions only. Both indices are related to certain height and can be used for monthly mapping the wind resources. It should be kept in mind that for a detailed mapping a flow simulation is required. In comparison to the wind atlas the seasonal fluctuations of wind potential can be determined as well. This could be helpful in order to determine wind index regions (section 5.7).

The wind production indices with consideration of individual properties are inhomogeneous due to big variety of site related turbine specifications, like hub height, turbine type or operation modes. They are useful for the determination of a representative monthly value of relative energy. The variation monthly simulated or real operational production data correspond best to the variations in the electrical grid, which is requested finally. On the other hand due to the big variety of wind farm configurations a map creation on basis of the site related production data is not possible.

The second suggested wind index by DEWI considers a wind speed index in combination with an application of a representative power curve (section 5.4).

5. Wind Index Methodology Suggestion

Brazil is one of the countries with impressive wind conditions at several selected locations. The installed production capacities and produced energy accelerated within the last years. It can be expected that the share of wind power will still increase within the next years. As consequence of the fluctuating wind the supply of required energy becomes a raised challenge**. The wind index should provide information regarding monthly and yearly variation of energy in order to secure the energy supply in general. An ideal is the existing hydro power index**.

The technical usable energy potential always belongs to the operating power plants. The technically usable energy potential is often distinctly lower than the free potential. This is particularly true for wind energy with high wind speeds. So DEWI recommends to use an wind energy production index for the application of fluctuating energy. That means the wind data of the AMA measurements can be used to simulate the monthly energy yield for all wind farms. The application of a power curve leads to variations, which are comparable to a production based wind Indices.

5.1. Wind Farm referenced and Spatially referenced Wind Energy Index

The application of the power curve on measurement data has main advantages to show comparable energy fluctuations as operational data. But it has also the disadvantage of the strong dependence of the site related properties like turbine types, hub heights and wind conditions of selected regions. Hence, the development of the wind farms due to technical progress and with this the changing of the properties of the wind farms is always the weakest point of the wind energy production index (called **wind farm referenced wind energy index**). The installed Brazilian wind energy capacity has been increase within 2012 from approximate 1430 MW to 2500 MW (+75%)[39].

Therefore DEWI recommends to create a wind speed based index additionally. As basis AMA wind data with a common pre-defined height can be used. For the comparison to energy yield values a representative power curve should be applied. The **homogeneous wind index** is much more stable regarding installed capacity and also very useful to determine wind index regions. This index is called as **spatially referenced Wind energy Index** in the following.

DEWI assumes that monthly fluctuation within a year can better reproduced by the simulation of the production (Wind Farm referenced Wind Energy Index). On the other hand the yearly fluctuations might be better reproduced by the spatially referenced Wind Energy Index due to less changes of parameter within the operations time of all related the wind farms.

5.2. Organigram for the development of a Wind Index.

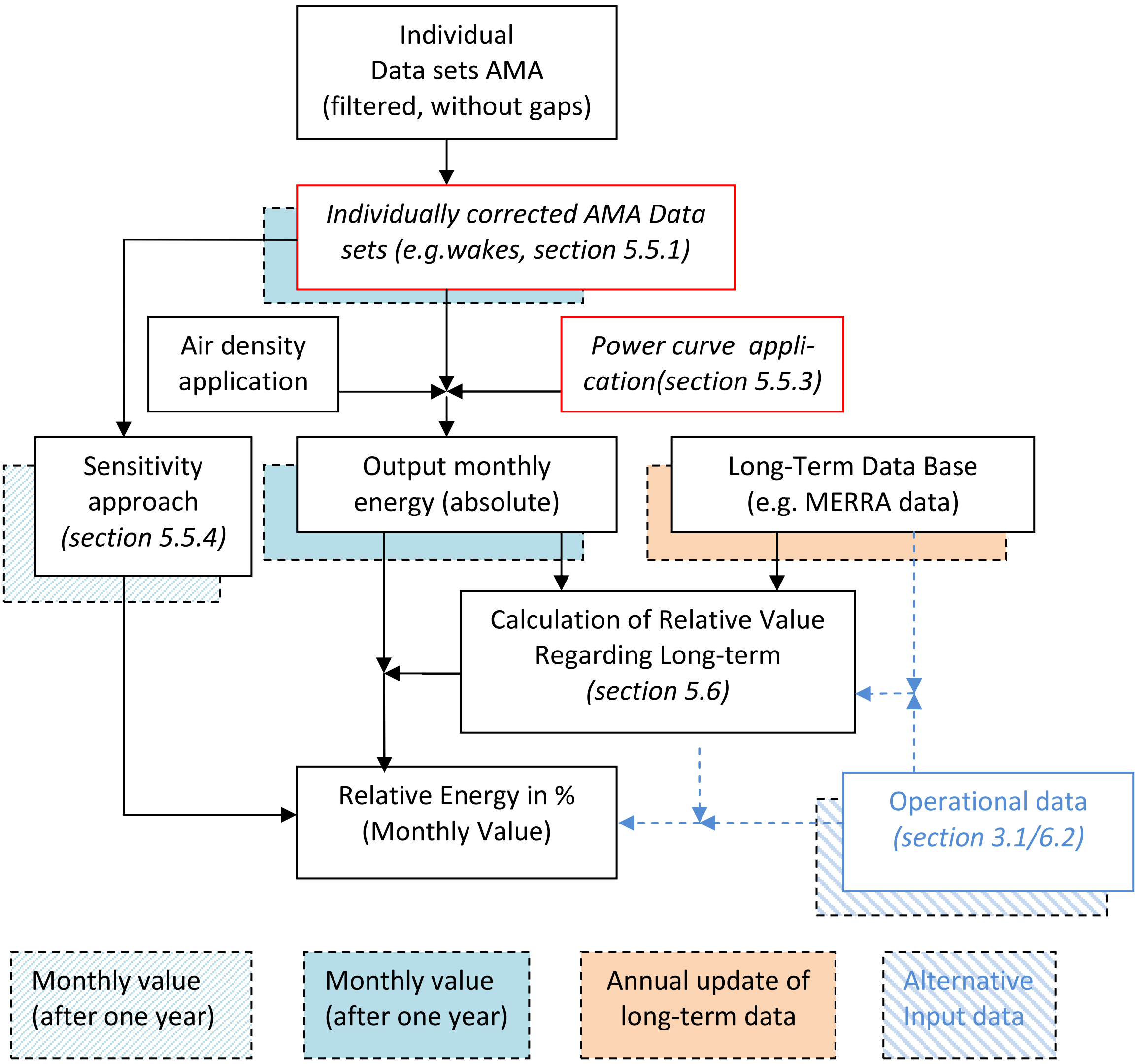
The following organigram considers the procedure of calculating monthly wind index values. The procedures distinguish between always applicable procedures (time series and power curve) and future related possible procedures. The sensitivity approach can be considered to lead to similar result by a reduced work effort.

The application of **operational data** can be used as verification or as substitution of simulated energy production. A combination of simulated and real gained energy yield is not recommended. Therefore the part operational data is shown with another colour.

Furthermore additional connections (extension by operational data and long-term comparisons) are shown as well.

The organigram is valid for both, wind farm referenced and spatially referenced wind index. Differences between both occur in the individually corrected data sets and power curve application. These steps are shown in the organigram with red frames. For the Wind Farm referenced Wind energy index each single wind turbine has to be considered with the individual heights and calculated losses. Concerning the alternative spatially referenced wind energy index, the AMA wind measurements have to be corrected to reference height (section 5.5.2).

Each step of the wind index development is detailed in this report.



5.3. Wind Farm referenced Wind Energy Index

The wind index reflects a relative value. Nevertheless, its purpose is to determine an absolute value of the available wind energy with the help of the AMA measurements finally. In order to determine a most accurate value, the energy values of all individual turbines should be considered for Wind Energy Index.

The following equation show the required inputs for the energy yield of one single turbine for one month.

$$E_{WT} = \sum_{i}^{n} P_{pc,i} \frac{\rho_{WT}}{\rho_{pc}} t_i \tag{3}$$

Symbols:		**Indices**	
E	energy	WT	Wind turbine related value
P	power	pc	power curve
ρ	air density	i	individual value for each time step
t	period of individual time step	n	number of time steps

The monthly value of energy yield derived by the following equation:

$$E_{month} = \sum_{i}^{n} E_{WT,i} \tag{4}$$

Symbols:		**Indices**	
E	energy	month	monthly value
		j	individual value for each wind turbine
		n	number of wind turbines
		WT	wind turbine

The final value or relative energy yield is determined by the ratio of the individual month and the long-term average.

$$WEI = \frac{E_{month}}{E_{lt}} \tag{5}$$

Symbols:		**Indices**	
WEI	Wind energy yield Index	month	monthly value
E	energy	lt	Long-term

In order to have really a representative energy output the individual output of each turbine should be determined. These values can be calculated or verified with energy yield assessments. A rough assessment would consider a weighting of AMA measurements according the installed capacity. Anyhow a losses assessment, notably farm efficiency losses, might be difficult, but is recommended, in particular when the AMA measurement is running and wind farm is not built yet.

5.4. Spatially referenced Wind Energy Index

The alternative wind energy resource index is independent from the amount of turbines and defined for a selected height above ground. Therefore the related wind speed has to be recalculated to the defined height. The AMA measurements comprise wind speed measurements in several heights above ground. Beside top and backup measurements the reference measurements are usually also included. The reference measurement is usually located approximately 20 m lower than the top measurement.

Finally the AMA measurements can be used for the determination of the site specific wind profile and a recalculation of wind speeds for other heights.

The wind profile follows the power law according Hellman:

$$\frac{v_z}{v_r} = \left(\frac{z}{z_r}\right)^{\propto} \qquad (6)$$

Symbols:		**Indices**	
v	wind speed	r	reference
z	height	z	related height
∝	Hellman wind shear exponent		

After transposing:

$$v_z = v_r \left(\frac{z}{z_r}\right)^{\propto} \qquad (7)$$

The remaining unknown parameter is the Hellman exponent alpha. On basis of known wind speed values in two or more heights above ground those values can be calculated.

$$\propto = \frac{\ln(v_z) - \ln(v_{z_r})}{\ln(z) - \ln(z_r)} \qquad (8)$$

It should be considered to check the sheltering effects [15] as well. Often the Back-up and Reference anemometer are mounted with the same orientation. In this case the effect is counterbalanced by both heights. Hence the correction is not needed. In combination with a minimum distance of both heights, DEWI recommends to consider Backup and Reference anemometer for the determination of Hellman exponent alpha.

The final step the appliance of the power curve is the same as section 5.3. A weighting or accumulation of energy yields is not needed. That means one measurement mast represents the monthly energy yield for one turbine in the recalculated height. The calculations of the relative values follow the same procedure as in section 5.3.

The gained monthly wind data related to one **reference** height is also the basis for the determination of wind index regions. In dependence on a representative height of AMA measurements and further possible applications of external data sets, like Vortex Wind atlas [44] 80 m are recommended as reference height. For the medium or long term the reference height should be meet the prospective hub heights as well. Here reference height should be determined to approximately 120 m above ground.

5.5. Transformation to Representative Energy Value

Since a Wind Energy Index is related to the energy of the wind farms, wind speed measured at the level of energy production must be converted.

For the calculation of the energy yield according the following parameters should be considered. For the two different Index approaches (section 5.1) the required in parameters have to be adjusted differently.

Wind farm reference Wind Energy Index

- Corrected time series for each individual turbine position
- Local air density
- Turbine specific power curve (measured preferred)
- Farm efficiency
- Additional losses (operation modes, curtailments, grid maintenance, ...)

Spatially reference Wind Energy Index (alternative index)

- Corrected time series for each AMA measurement to **reference height**
- Local air density
- **Representative** power curve (measured preferred)

Parameters with minimal impact or small differences in comparison (rotor blade degeneration) can also be neglected, because the uncertainty in the wind speed and the power curve is several times higher.

The AMA measurements are high quality measurements, but time series are not always without errors. To ensure data plausibility, the measurements are checked by the operator and by EPE. Generally it should be checked whether site conditions (section 5.6) or only measurements values are changing or erroneous (section 5.5.1). More details regarding adjustment to reference height for the spatially reference Wind Energy Index can be found in section 5.5.2.

5.5.1. Correction of Input Data

The operating performance of an anemometer can change during any period promptly or slightly by wearing or malfunction. In order to determine changes in the behaviour of the anemometer the IEC 61400-12-1 [6] recommends a post-calibration of the installed anemometers or at least a so called "in-situ" test. The requirement of an existing back-up anemometer (up to 2.5 m below top measurement) is usually fulfilled for the AMA Measurements. The In-situ test is recommended as periodic check in particular for location with maritime climate. Here the probability of accelerated ageing und abrasion is increased.

Due to the strong sensitivity of the energy output in respect of the wind speed, a precise determination of the exact wind speed is essential. In addition to the correction of erroneous data and the filling of data gaps, the correction of wind speed data is very important.

Wake effects correction

Figure 5 shows the wake losses for selected wind speeds over the wind directions for an example. Although the different wind speeds show different results, the losses from 2 to 12 m/s are fairly similar. For higher wind speeds the wake losses are getting smaller as higher the wind speed is.

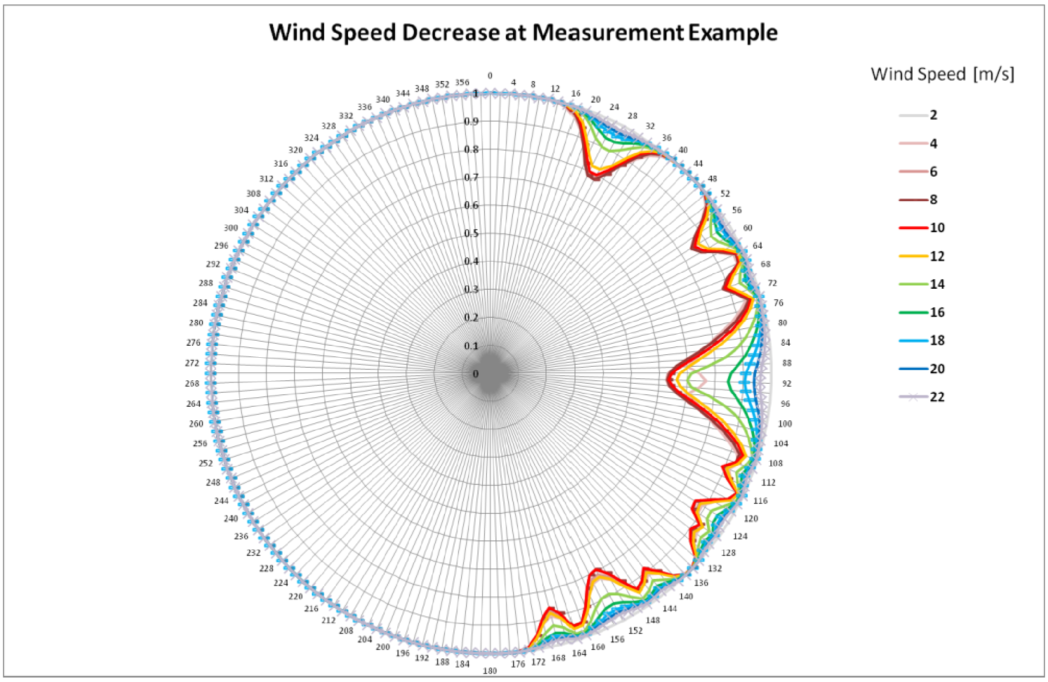


Figure 1: Wake-induced wind speed decrease for selected wind speeds and wind direction. (example).

The calculation of wind speed decreases due to the wake losses can be easily realized with the common wind software like WASP, WindFarmer [11] Flap or a CFD Wake model. DEWI recommends to assess the correction matrix in the beginning and the configuration of neighbouring wind turbines changes later.

DEWI knows that this would lead to a strong increased work effort, but at least for the critical measurements (wakes in a main wind direction) this should be performed as verification.

Tower shading correction

Sheltering effects of the mast or boom can lead to significant errors in the energy yield assessment [15]. The data of the anemometers and wind vanes should be checked according shading patterns. Reason for such pattern can derive from wrong mounting or changes of the configuration due to abrasion, storm losses or vandalism. The sheltering effect can be detected be the comparison of two wind sensors. For a good verification of those effects a similar height of e.g. top and backup sensor is required. DEWI recommends to follow the guideline of wind measurements IEC 61400-12-1 [6].

Anemometer correction

Outdoor examinations have shown that different anemometer types give different results outside even if their results are the same in the wind channel where they were calibrated (refer to[15]). It should be checked that the used anemometers should subjected a strict quality check. Changes of anemometer type should be avoided.

5.5.2. Adjustment to reference height

The determination of wind index regions and the creation of a spatial referenced Wind energy index require wind data on basis on one comparable representative height above ground.

The **representative height** can be defined as one value for the whole country or one value by the Index Region. That means due to the many differences in the wind conditions within Brazil (near-shore / complex terrain) a diversification regarding the region could lead to a higher accordance for a regional map. On the other hand if Index regions would be re-organised this could lead to an increased correction effort.

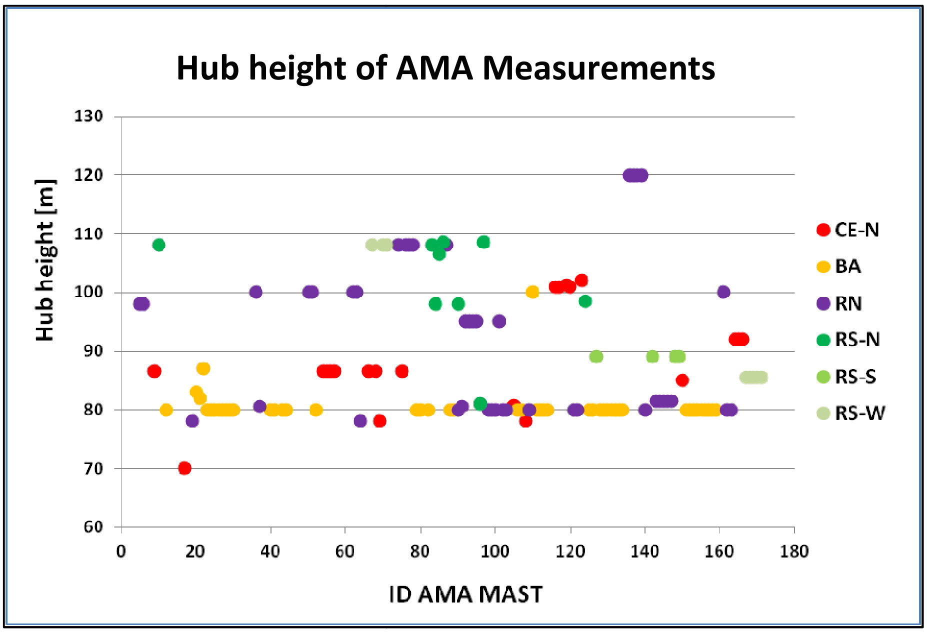


Figure 2: Measurement heights of AMA Met masts

In dependence on a representative height of AMA measurements and further possible applications of external data sets, like Vortex Wind atlas [44] 80 m are recommended as reference height. If the wind index should take future conditions into account, DEWI recommends to consider higher heights like 120 m as reference. It can be expected that the growth of wind turbine dimensions is not at the end yet.

The AMA system [40] contains the information of the measured wind shear for each mast as well. On basis of this parameter the wind potential condition can be recalculated to a reference height (section 5.4). Data quality depends on the quality of measuring and mounting of sensors. Therefore the height correction should be taken also shading effects of anemometer into account [15].

For a separation or merging of Wind Index Regions the similarity of the wind conditions should be considered.

5.5.3. Energy Yield on basis of Power Curve and Time Series

The calculation of the energy yield should be performed on basis of the time series and not on basis of A and k parameter. Although the A and k parameters have been used for the determination of regional clusters and index regional there are always an approximation, especially for such a short period like a month.

Figure 3 shows the wind speed distribution and Weibull approximation for the site Aratua 1. Like Aratura 1 many AMA measurements show also strong deviations between Weibull parameters and measured wind speed distributions, the more reliable measured time series should be preferred for the energy yield calculation.

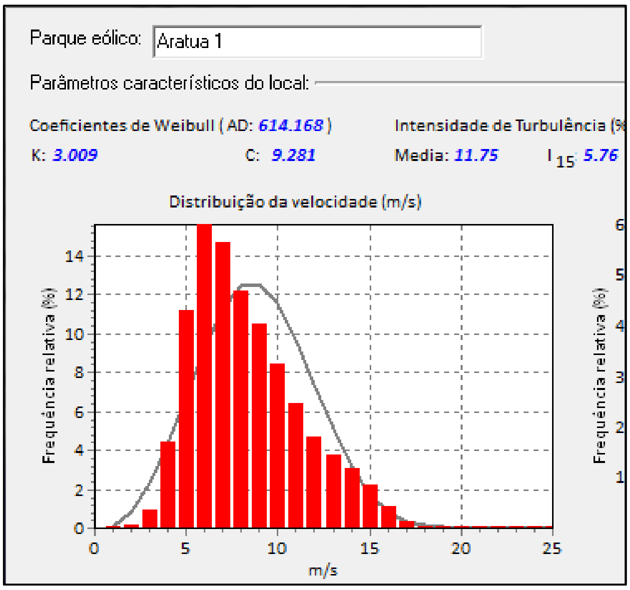


Figure 3: Wind speed distribution and Weibull approximation for the site Aratua 1

Finally the weighting of the wind indices with the amount of energy production has to be considered as well. Thus every single turbine should be considered for the energy yield calculation and its wake losses. The farm efficiency calculation might be difficult for the application within the AMA system. On the one hand the calculations considers additional information (distances and trust curve values), on the other hand neighbouring wind farms might affect the farm efficiency as well.

As first approach also provided values of farm efficiency could be taken into account as well. Since the park efficiency is dependent on wind speed, the wind direction and the number of wind turbines, the long-term representative farm efficiency is only a rough approximation in terms of single monthly or certain years related farm efficiency.

5.5.4. Energy Yield under consideration of Sensitivity

If several months (e.g. 1 year) are available it can be checked whether the relationship of wind speed and energy yield of each wind farm can be described simplified on base of sensitivity. The sensitivity approach is shown in the following. The procedure refers to the site creation of a site specific wind index as described in section 3.5 .

On basis of the sensitivity value (c) the wind speed data can be transformed into an energy value (E) easily.

$$E \sim v^c \qquad (9)$$

Instead of using E ~ v³ the sensitivity c is used as exponent. c is a calculated sensitivity of the energy yield in regards to the wind speed (dE/dv). The sensitivity is site-specific and depends on the applied power curve and the wind conditions at the site. That means simultaneous values of wind speed and energy yield are need. It does not matter whether the energy values are based on the real operation or an accurate prediction.

Definition of DEWI sensitivity and derivation of the above formula:

$$c \sim \frac{v}{E}\left(\frac{dE}{dv}\right) \qquad (10)$$

This can be reformed and finally integrated:

$$c\int \frac{1}{v}\,dv \sim \int \frac{1}{E}\,dE \qquad (11)$$

This can be logarithmised and finally leads to the above relationship for transforming wind speed into energy.

$$c\ \ln v \sim \ln E \qquad (12)$$

5.6. Definition of representative Long-Term Period

The selection of a representative long time period is the most important part to a balance of short-time-related data. Due to the fact that the real long-term average years are not yet available within operation period, difficulties arises in the calculation. The review of the past is therefore an approach for the future.

Important aspects of a representative long-term period are:

- Selection of a reliable data sets (consistency check)
- Distance to the site is within a reliable range
- Check of plausibility of temporal fluctuation with other data sets (daily, monthly, yearly)
- Definition of the length of a representative long-term period (dimensioning, balancing of elder and latest data)

To create a reference base it is very important to use trustworthy data. The long term data set should have similar properties and should show a similar behaviour regarding short-term characteristics. That means, the data set should be free of errors, gaps or trends and should include representative pattern (e.g. diurnal pattern, seasonal changes). This applies to both data sets, the short-term and long-term data. Moreover, the data sets should be verified with additional plausible data sources. Useful tools for choosing the right long-term source are variance and correlation coefficient R^2 (Pearson).

Kind of long term periods:

- Fixed defined period
- Rolling period (monthly or yearly shift of period)
- Extending period (annual update)

A definition of a **fixed 100% long-term-value** for the wind index reflects always the conditions of the past. Due to changes in the surrounding (erection of new turbines, buildings, deforestation or climate change) the bases of average wind potential related to the wind farm might change as well. That means that a defined 100 % reference value has to be adjusted to the real conditions in the future probably. This long-term reference has been applied for the Danish and German Wind IWET Wind index.

An alternative might be the **rolling average**. The rolling averages consider always the same length of historical data, but within a periodic update. That means the related period for long-term is not fixed. On the one hand it leads to softer adjustments, but on the other hand it is very hard to compare wind index values of different years if the data show a trend. The rolling average could be determined by a monthly update or a yearly update.

DEWI recommends to consider an **extending average** by a yearly update. All consecutive and independent data which are reliable form the beginning in the past should be considered. That means with every new year all reliable data sets should be considered.

Wind measurements are always related to a location. Hence, also data long-term data have a geographic reference. In relatively small countries such as Denmark and Germany, the definition long-term mean differs hardly within the land area.

DEWI recommends to perform long-term verification for each Index Region separately. As much as reliable data is available as much as possible (full years) should be considered. If the data set is based on AMA measurements only, different “long-term” periods will be defined automatically.

At the moment the AMA measurements comprise only a few months up to 3 years. This is distinctly too short to use the measurement data set as long term data source. Hence, additional independent long-term data are required. DEWI has downloaded, converted, and evaluated 20 years of MERRA data for the investigation of monthly wind speed values of 20 selected AMA site locations.

In case of doubt other periods should be investigated. As a comparison periods of at least 10 years (such as Wind Index Denmark) to a maximum of 30 years (climatologic observation period) should be used.

Correlation Coefficient

Main criteria to chose a trustful and reliability data set is the correlation coefficient R^2 (Pearson) for the closest and most appropriate long-term data sets in the surrounding. A long-term correction has to be performed in order to decrease the influences of year-to-year wind variations on the short-term wind statistics.

$$\mathrm{r} = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}} \tag{13}$$

For the first rough investigation DEWI has checked the MERRA data sets of 7 AMA sites (section 8.6). Table 2 shows the correlations coefficient MERRA data (50 m) according the surrounded grid points. The additional interpolated grid points are usually not better than the best grid point values.

DEWI recommends for detailed long-term assessments to evaluate several data sets and to compare reliability, correlation coefficient and distance to the site.

N°	SW50	SE50	NW50	NW50	IP50	choice	Site name	Region
1	85.3%	87.4%	**91.6%**	90.3%	88.1%	**91.6%**	*Park1	RS-W
3	76.6%	**81.5%**	74.1%	81.4%	79.7%	**81.5%**	*Park3	RS-N
5	95.4%	93.6%	**97.1%**	93.6%	96.8%	**97.1%**	*Park5	BA
7	96.2%	91.2%	**97.2%**	94.6%	96.3%	**97.2%**	*Park7	BA
12	81.4%	87.3%	83.1%	**88.6%**	83.2%	**88.6%**	*Park12	RN-W
14	90.8%	**90.8%**	85.3%	79.2%	89.7%	**90.8%**	*Park14	RN-W
15	**94.2%**	85.0%	85.4%	76.2%	90.5%	**94.2%**	*Park15	CE

Table 2: Correlation coefficient for 7 selected AMA sites with MERRA data (based on 50 m values, different orientation from site)

At the seven selected Brazilian AMA sites the correlation coefficients varies between 76.2% and 97.2%. The best site related R^2 values varies between 81.5 % and 97.2 %. If the distances of the long-term data sets are within an accepted range and the time series are reliable the long-term correction should be performed on basis of the data set with the highest correlation coefficient.

Verification of long-term behaviour

Figure 2 shows the relative wind speed of MERRA data related to the grid points nearby the 7 selected AMA sites. The average has been defined by the period of more than 10 years with the lowest variation.

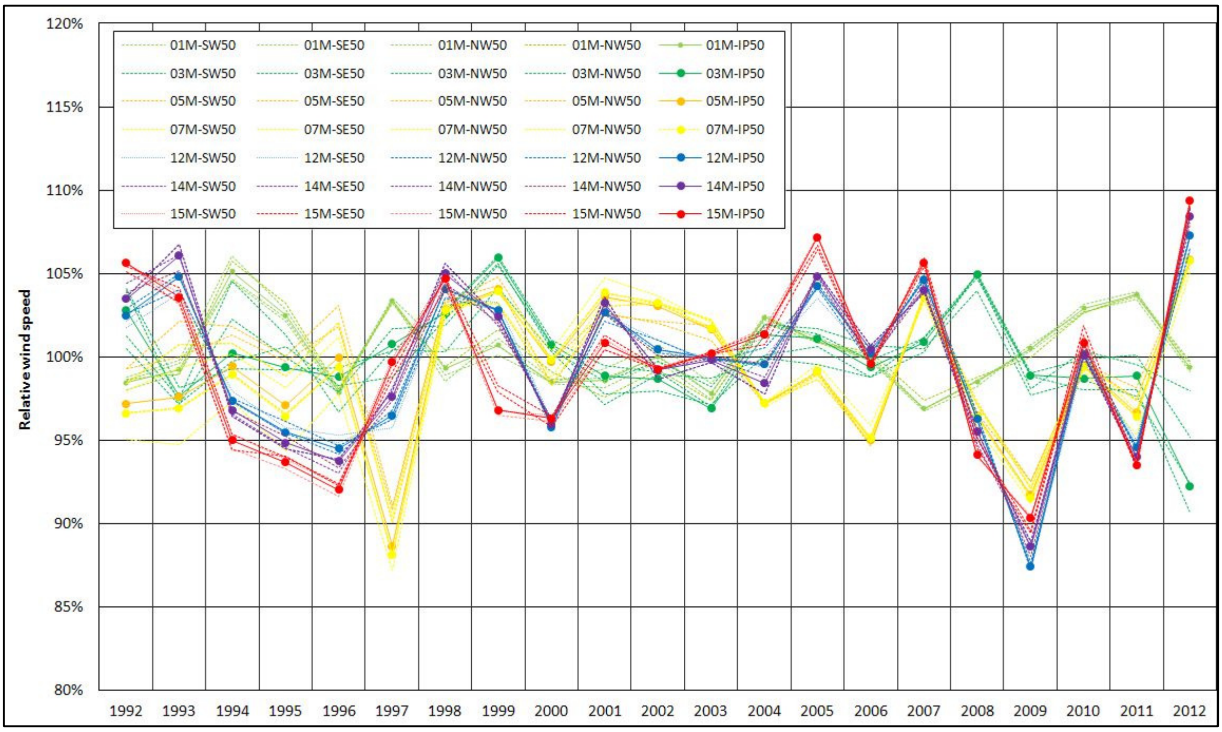


Figure 4: Proportional variation of the yearly means of wind speed calculated for different long-term data (100%: average of period 2001-01-01 – 2012-12-31).

Beside the correlation coefficient it's important to check the long-term data regarding trends. The reliability of data can be determined by the comparison of independent data sets. If there is no general agreement of the long-term behavior data sets have to be excluded for the long term correction.

Long-term correction Scaling Factors

Table 3 shows relative wide range of scaling factors for the long-term correction of one year of measurement. If more years of AMA measurements are available and considered the long-term corrections will get smoother year by year.

N°	SW50	SE50	NW50	NW50	IP50	choice	Site name	Region
1	100.8%	100.3%	**100.6%**	100.3%	100.6%	**100.6%**	*Park1	RS-W
3	104.3%	**107.9%**	102.0%	107.0%	106.8%	**107.9%**	*Park3	RS-N
5	94.3%	94.1%	**94.4%**	93.9%	94.3%	**94.4%**	*Park5	BA
7	94.6%	94.2%	**95.5%**	94.4%	94.6%	**95.5%**	*Park7	BA
12	95.2%	95.4%	94.9%	**95.4%**	95.1%	**95.4%**	*Park12	RN-W
14	95.1%	**95.1%**	95.0%	95.7%	95.3%	**95.1%**	*Park14	RN-W
15	**92.5%**	92.5%	93.0%	93.8%	92.7%	**92.5%**	*Park15	CE

Table 3: AMA data scaling values according for long-term correction with MERRA data (based on 50 m values, different orientation from site) related to the long-term period 2001-01-01 – 2012-12-31.

Within accumulated years of measured wind data of the impact of long-term correction drops down. It should be checked whether the application of MERRA data makes still sense or which other data source can be applied additionally. A comparison of yearly MERRA data shows that the deviations of wind speed between the neighboring grid points at each side are distinctly higher for the period in the 90's than for the last 10 years. This behavior should be scrutinized for the consideration of the long-term period as well.

5.7. Creation of Index Regions

The annual wind conditions composed from all AMA measurements differing from location to location. With this the available wind energy at every individual location develops more or less differently. Only one code for whole Brazil is therefore not sufficient to describe the “wind year” or wind month. Moreover, the evaluation of annual available wind energy must be carried out separately for the smallest areas possible and reliable. So the accuracy of an Index can be increased by the splitting up of the wind regions into smaller divisions. Here the wind index should be determined for geographical contiguous regions.

A fine spatial resolution has the advantage of a detailed picture of local conditions. The number of wind index regions is connected with quality and quantity of local records. With an increased number of local data sets (high density of wind farms), the geographical area can be reduced and their local representativeness can be increased. Usually those data sets are spread heterogeneously with different distances to the neighboring measurements. In some cases this could lead to significant discrepancies in regional data density and representativeness. In contrast are the reanalysis data sets available, which are distributed spatial relative homogeneously (refer to section 3).

Due to the required homogeneous properties wind conditions will be used as considered for the input of the spatially referenced Wind Energy Index. The determined index regions will be valid for the Wind farm referenced Wind Energy Production Index as well.

For the creation of wind index Regions the regional **representativeness** must be taken into account. Each region should represent a regional behaviour with deviation within a certain (small) range. If the accepted deviation is high a large region can be defined. If the limit of variation is relative low the region will be small as well. That means the definition of the region is mainly determined by the accepted variation within the data set. Anyhow a minimum number of data sets should be defined.

Usually, neighbouring locations have similar characteristics. If this is the case, and the deviations of neighbouring sites regarding wind potential are small, the individual representative measurements can be increased or merged to one cluster or region.

Main subjects for the creation of a Wind Index Region are:

- Definition of fixed wind Parameter (height)
- Definition of the maximum variance within data set / minimum data sets of independence
- Influence of topography regarding representative area
- Distance of the extended representative area / representative region
- Weighting of data (redundancy of independent data sets)

Wind Index Regions are determined by different wind conditions within the related country. That means nearby measurements have a higher probability to belong to the same wind index region than far away measurements. Because of the distribution of measurements across the vast country a separation in at least 3 regions seems to be obvious.

In order to have comparable values for the determination of wind index regions, data set comparisons should be performed of standardised parameter. Here, the corrected wind conditions to a standard hub height should be taken into account.

Figure 2 shows a topographical map with the operating AMA measurements together with existing or planned wind farms of Brazil. The colours of the used marks of the AMA locations correspond to split regions, described in the sections 1.6.1 to 1.6.4. Detailed maps are shown in the appendix in section 8.1 also.

In addition to the three main regions with measurements Rio Grande do Norte/Ceará (RN/CE), Bahia (BA) and Rio Grande do Sul (RS), wind farms with AMA system will be erected outside of these narrow regions in the future as well. The expected additional construction of wind turbines will lead most likely to spatial extensions of wind index regions. This should be taken into account where possible. The Index would be also more accurate, if the energy yield production of wind farms without AMA Systems should be taken into account as well.

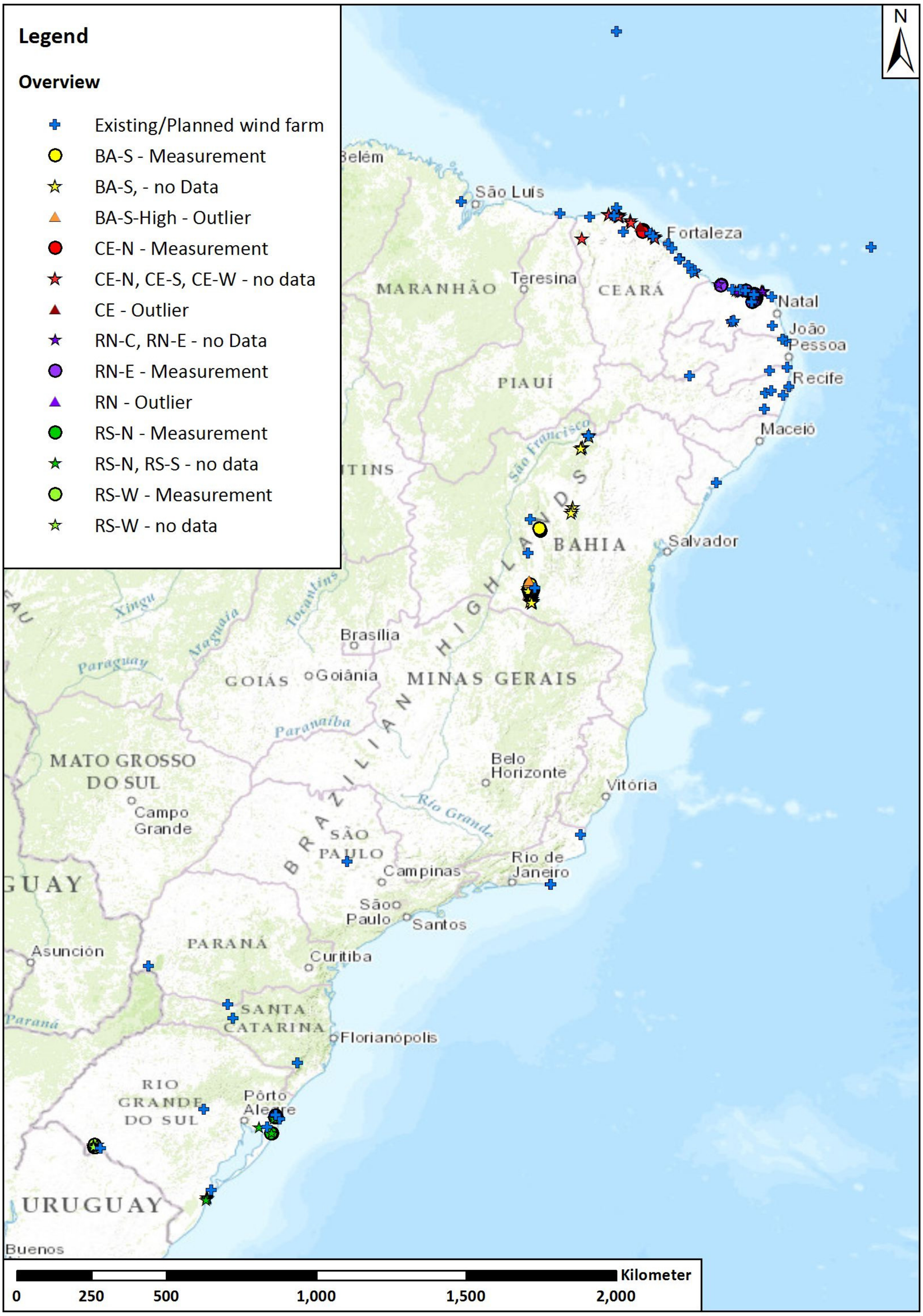


Figure 5: Topographical Map of East Brazil including AMA Measurements in Brazil (circle/star) and operating/planned Wind Farms (blue cross).

5.7.1. Clustering of Wind Farm Sites

Wind index regions can be classified by the wind conditions of the wind farms and the related spatial resolution.

In addition to the three pre-selected main regions with measurements Rio Grande do Norte/Ceará (RN/CE), Bahia (BA) and Rio Grande do Sul (RS) more wind farm locations can be expected. With the higher distance to the site the probability increased to show an individual variance of energy yield production data in comparison of the considered data set in the surrounding. That means the question arises whether the characteristic of the measurement still belongs to the considered wind index Region.

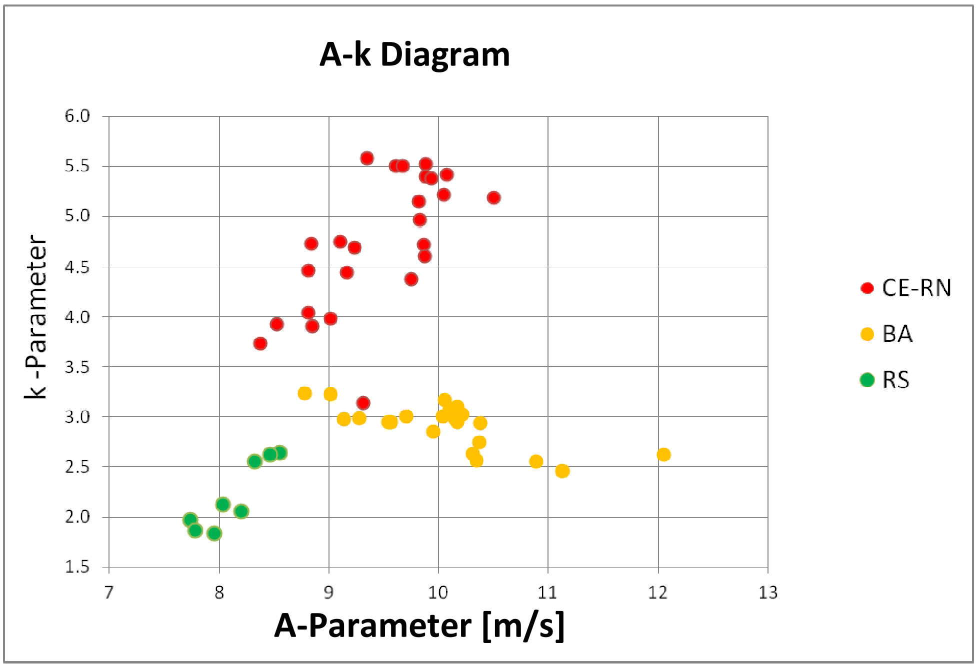


Figure 6: Scatter of Weibull Parameter form the AMA system for whole Brazil. Additional separations have been considered

The Figure 6 shows the characteristic parameters A and k in a diagram. As expected the Weibull parameter A and k scatter to in their geographical regions significantly.

At the first sight clustering of the AMA measurements seems to be very easy due to the spatial differences between the three main regions. Anyhow, the separation in at least 3 main regions might change in the future when a clear geographic separation disappears. For the sub sections or future development detailed cluster analysis is recommended [41].

Figure 6 does not consider further geographic criteria which shall be considered for the definition of the Index regions.

This cluster analysis can consider variations according:

- Shape parameter k (including coastal behaviour)
- Scale parameter A
- Wind speed
- Wind power density
- Wind direction
- Correlation coefficient between neighboured wind indices
- Geographic local properties (terrain type)
- Political / commercial boundaries

Depending on the parameter or the combination and weighting of parameter the result for clustering will vary as well. The above shown parameters are sorted according their significance.

In the following the clustering of according Weibull parameter and geographic reference is shown. Here DEWI checked the distribution of the average A and k Parameter and the standard deviation of monthly wind speed values regarding the shape Parameter A.

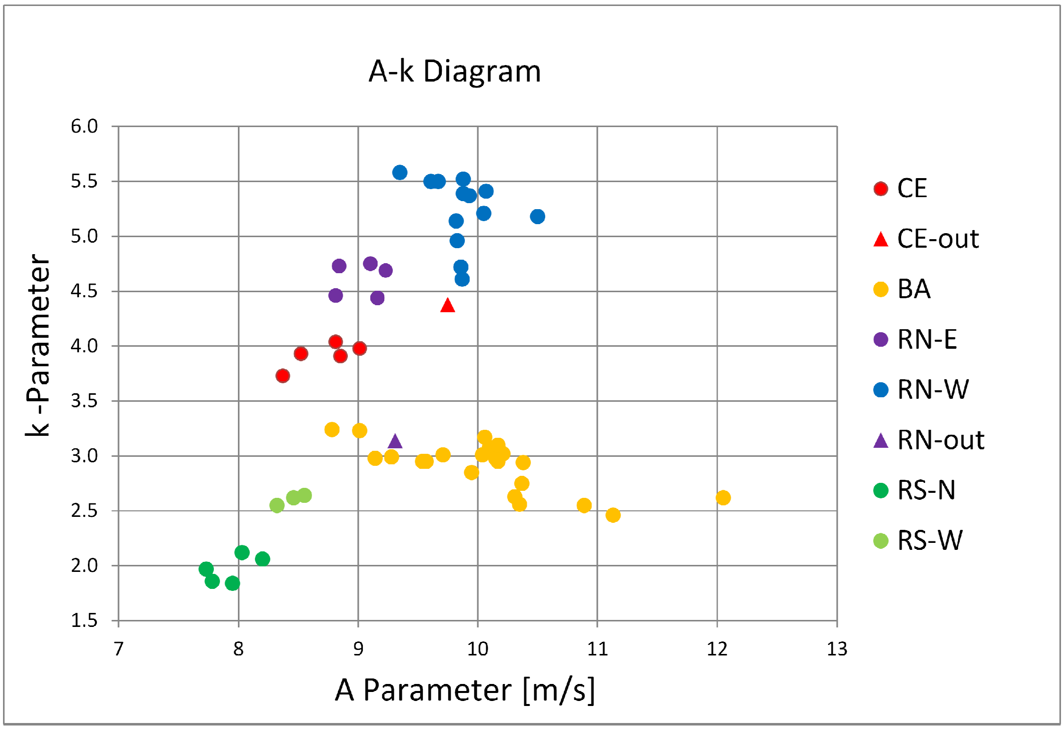


Figure 7: Scatter Wind conditions regarding Weibull Parameter. The measurements are clustered according Weibull parameter A and C and coloured according geographic location (federal state and geographic direction)

Figure 7 shows the same data as Figure 6 but with 6 instead of 3 clusters (+ 2 outliers). Two outliers have been determined and marked with triangles instead of circles in the following. They show a significant deviation regarding A and k from the representative cluster average. Here derives the questions whether the outliers are also outliers regarding the temporal fluctuation.

As the wind index should reflect seasonal fluctuations, it also makes sense to look at the variation of monthly wind speed. DEWI has calculated the monthly standard deviation of wind speed and compared this to the average k Parameter of the site. Figure 8 shows the strong regional differences in this respect. Therefore, a wind index region should also be tested regarding this behaviour. This could lead to further separations, but also to merging of separated clusters if the monthly variation is indicating this.

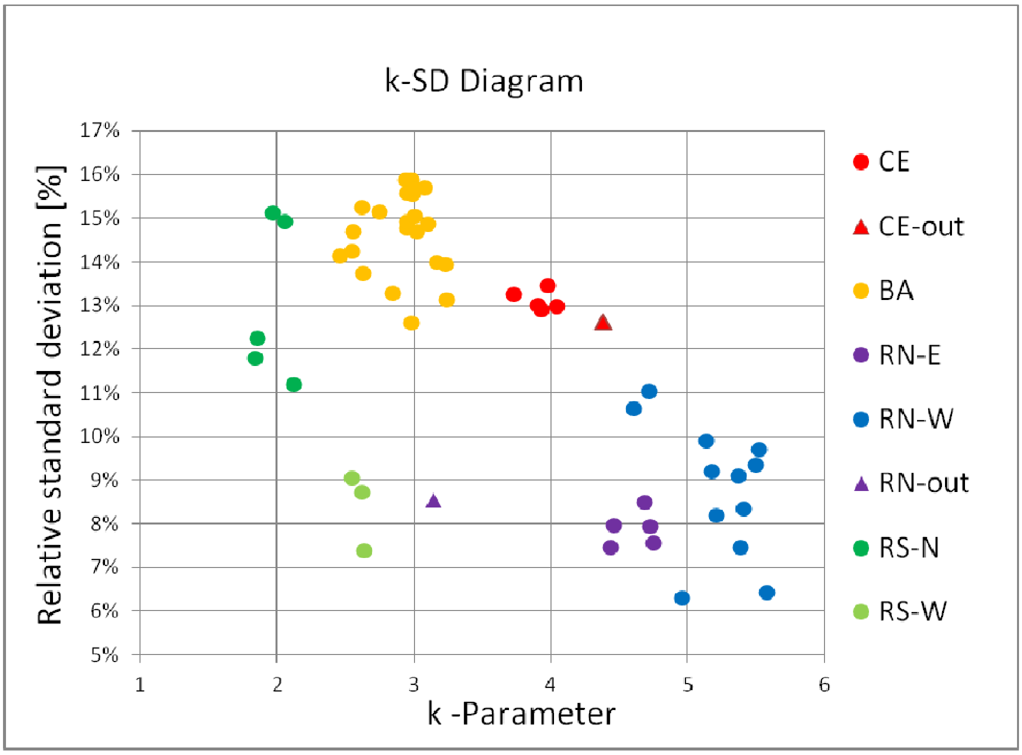


Figure 8: Diagram of relative standard deviation of the monthly wind speed at the AMA sites according the k Parameter within one year of measurement. The dots are coloured according geographic location (federal state and geographic direction)

The clustering can be done manually or better by the support of mathematical models. One simple clustering analysis is the "**k-mean**" clustering. The aim is to find the proper number of clusters which show a compact behaviour. The method leads generally relative reliable results.

EPE performed the clustering according the k-mean method and defined 5 clusters on basis of comparison on Weibull parameters, wind power density and indicator of coastal region [41]. The consistency and compactness can be confirmed. The data sets within the clusters are similar regarding their considered properties. But in order to improve the accuracy, index regions should be as small as possible. Additional separation should be performed for the cluster with the highest variance of data. But finally the minimum number of cluster is related to the kind of application as well. The here considered AMA sites are located in 2 of the 4 hydro power regions (section 8.2) only.

In Brazil the high variance is determined in the south, in Rio Grande do Sul and in the north-east in the countries Ceará and Rio Grande do norte. The south comprises only few measurements and one separation has been performed already. The north-east of the country has the best wind potential and most independent wind farm regions. Therefore DEWI recommends to split the region in more parts than performed by EPE. In the previous diagram (Figure 8) DEWI has separated the region in three parts (red, blue and violet points).

Beside the measurements, properties of long-term data can be considered as well. The comparison of the long-term scaling factors could help to classify the AMA sites as well. The correction factors from data sets of the same region are much closer to each other than correction factors from far away sites. The relationship is confirmed by Table 3 and Figure 2. Although always different MERRA data sets have been used for the long term correction for the seven sites, the long-term correction values of AMA sites Santa Clara VI and Areia Branca are quite similar.

The definition of minimum number of data sets is also important. Each single AMA measurement or each wind turbine can be determined as one index as well and would reflect the highest accuracy as possible, but it would not meet the definition of an area anymore. Furthermore the detection of an outlier would be much more difficult. DEWI recommend to considered wind index regions with at least 3 AMA measurements in order to determine outlier or erroneous data.

Outliers are generally not representative in comparison to the remaining data in the same set. In order to consider comparable data dispersion DEWI considered the standard deviation as selected parameter (refer to section 8.10). Due to the comparable low number data sets the many data sets would excluded by the appliance one standard deviation (+/- 1σ). A wider range of +/- 2σ of the normal distribution considers about 95% of all data. DEWI estimates that outliers are usually not within the range of the 95% normal distribution. Therefore DEWI suggested the +/- 2σ as limit a criteria for the determination of outliers.

Finally, the investigation according Weibull parameter is only a first indication that reflects the parameters A and k both diurnal and seasonal fluctuations. In short, the same A and k parameters can also derive from different temporary fluctuations. An overview of diurnal pattern is shown in the appendix, section 9.4. Furthermore it should be stated as well, that the investigated measurements (available data of more than one year) belongs to only 8 extended wind farm areas. As a comparison, the UK Index if GL-GH considers 50 stations and the ISET Index of Germany 60 stations. Verification with external data, e.g. MERRA data is strongly recommended.

5.7.2. Definition of Representative Area

The determination of a representative geographical area for an Index region is determined by the amount of data, the continuity of the terrain and regional changes in wind potential.

Definition of the extension can be determined/limited by:

- Redundancy of measurement data
- Change of elevation within the terrain
- Change of main topography properties (orography/roughness)
- Measurement height

In general data can be used weighted or non-weighted. The weighting of data is then conformed to turn the question of which parameter and in what amount a weight can be made. DEWI has checked the wind conditions at the sites regarding several parameters roughly. As the measurement heights are between 80 and 120 m, influences of the different hub heights are considered to be negligible for the definition of the areas.

Verification of Index Region

In the previous section 5.7.1, the measured wind conditions were compared in terms of their Weibull parameters. It has been shown that the AMA measurements comprise site-specific Weibull characteristics. A comparison of the measured wind conditions by wind atlas or Reanalysis data set (e.g. MERRA) predicted wind condition could lead to a wide extension of the representative Wind Index Regions.

If no additional data is considered the extension of Index Regions can be determined by:

- Defined fix value of maximum distance
- Regional Classification (Administration / grid net)

A regional classification would close gaps, but it could lead to a high risk of strong adjustment of the representative mean value of the region. Figure 5 shows the locations of the AMA Measurements. For a general separation of the country in different and linked areas a “**Voronoi diagram**” can be applied. This would help to draw border lines between the defined clusters.

5.7.3. Extension of Representative Area

The wind conditions are determined by a plurality of variable parameters. Among them is the type of terrain. Depending on the climate, the nature of the terrain can greatly affect the wind in respect to the wind profile and the potential. A good example is the difference between diurnal variation in coastal and inland locations.

Even within small coastal regions strong deviations in sea-land circulation can occur. Diurnal pattern may change strongly depending on distance to the sea at the coast or by elevation in complex terrain.

On the basis of site related properties different areas of a region or clusters can be determined. Therewith it is not clarified whether and how distant area can be defined as the same or different wind index region.

Since no measurement data from the AMA system for remote regions exist, it should be considered to use external data as well. Anyhow it should be taken into account that those Wind (refer to appendix 8.2 [27]) values are connected with an uncertainty value, which is distinctly higher than the uncertainty of the AMA measurements. Hence, the limits of the areas can be drawn more reliable regarding additional data sets in the future.

The presented figures and comparisons are based on 52 measurements with at least one year of measurement. The data set is representative for 8 wind farm areas only. This number of representative data sets is not yet sufficient for a final definition of wind index regions. By using all 137 currently working data sets in combination with geographic properties a definition of Index Regions for selected large regions (e.g. Brazilian states) might be possible. A creation of index regions for the whole country is not possible due to the large distances between the wind farms or AMA measurements.

Extension on basis of external data

It can be expected that MERRA data or a Brazilian Wind Atlas would help to extent the wind index regions to areas with similar wind conditions. A Geographic Information System program (GIS) can be used to proof whether these boundary conditions (like A and k Parameter in section 5.7.1) are fulfilled for certain areas. Furthermore verification with MERRA data or a Wind Atlas could help to detect inconsistencies between those two data sources (e.g. section 8.2). Hence, it would help to increase the quality of the representative area.

These extensions might lead also to overlapping of several wind index regions. That means for overlapping areas the criteria can be defined to be tighter. The process can continue in an iteration loop as long as several wind index regions have an overlap.

Criteria of an extension of Wind Index regions:

- K-mean approach using grid points
- Verification of deviation with nearby data
- Detection of outliers
- Usage of wind parameters recalculated to a common and comparable height
- Local distribution of hydropower regions
- Correlation of the wind index values of neighbouring areas

5.8. Alternative Forms of Wind Index

In analogy to the described development of a wind index for the AMA measurements, Reanalysis data, MERRA data or other measuring data (meteorological stations) can be used for the creation of a

spatially referenced Wind Energy Index alternatively. However, there are significant differences in terms of quality.

Meteorological weather stations with a measurement height of 10 m above ground and relative long distances to neighbouring measurements are not useful due to very high uncertainties in vertical and horizontal extrapolation.

Significant better reliability can be expected from MERRA, Reanalysis data. On the one hand they have a long history and can be used without external data for long-term correction and on the other hand they are available in a better spatial resolution.

Since high-resolution data provide a detailed picture, therefore high-resolution data sources are also preferred. That means, on basis of data resolution the MERRA data are preferred due to the increases horizontal, vertical and temporal resolution.

5.8.1. Creating Regions

The creation of regions can be applied as described in the previous section.5.7. Alternatively A and k values of the Wind Atlas data sets could be considered as well, but seasonal variation are not included. That means a separation would considered only the average value of the years, but it's at least the most important value.

MERRA data are available with a higher temporal resolution (1 hour). Therefore MERRA data can be able the provide information about the seasonal fluctuations.

The consideration of spatial distribution of a precise Wind Atlas and seasonal fluctuation of MERRA might be good solution. The long-term values of MERRA data and the Wind atlas can be uses for a verification of those data sets.

Figure 9 and Figure 10 show the Weibull parameter and standard deviation of monthly mean wind speed from MERRA data related to 20 selected AMA sites (refer to appendix 9.5). The circles are coloured according there geographic reference. As outlier of the cluster the location of the AMA site "Pedra do Reino III" has be determined.

Due to coarse or moderate resolution of Reanalysis or MERRA Data could often not follow strong changes of the sea and continental wind conditions. Hence, those predictions of wind conditions along coastlines are connected with higher uncertainty usually.

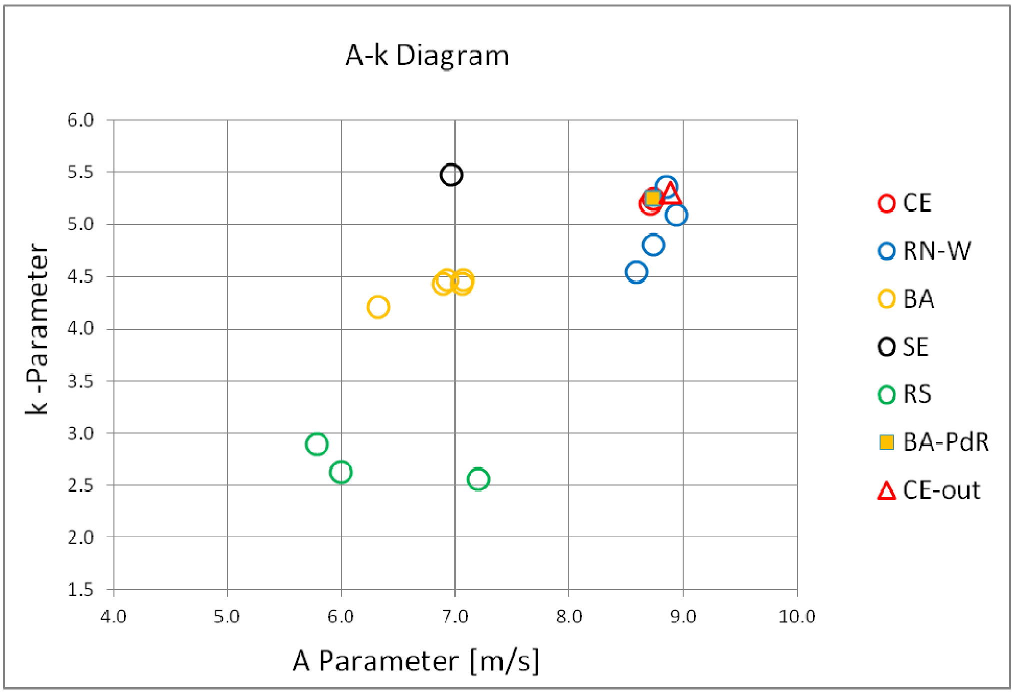


Figure 9: Scatter Wind conditions regarding Weibull Parameter. The measurements are clustered according geographic location and similar wind parameters for two approaches. The dots are coloured according geographic location (Brazilian state and geographic direction)

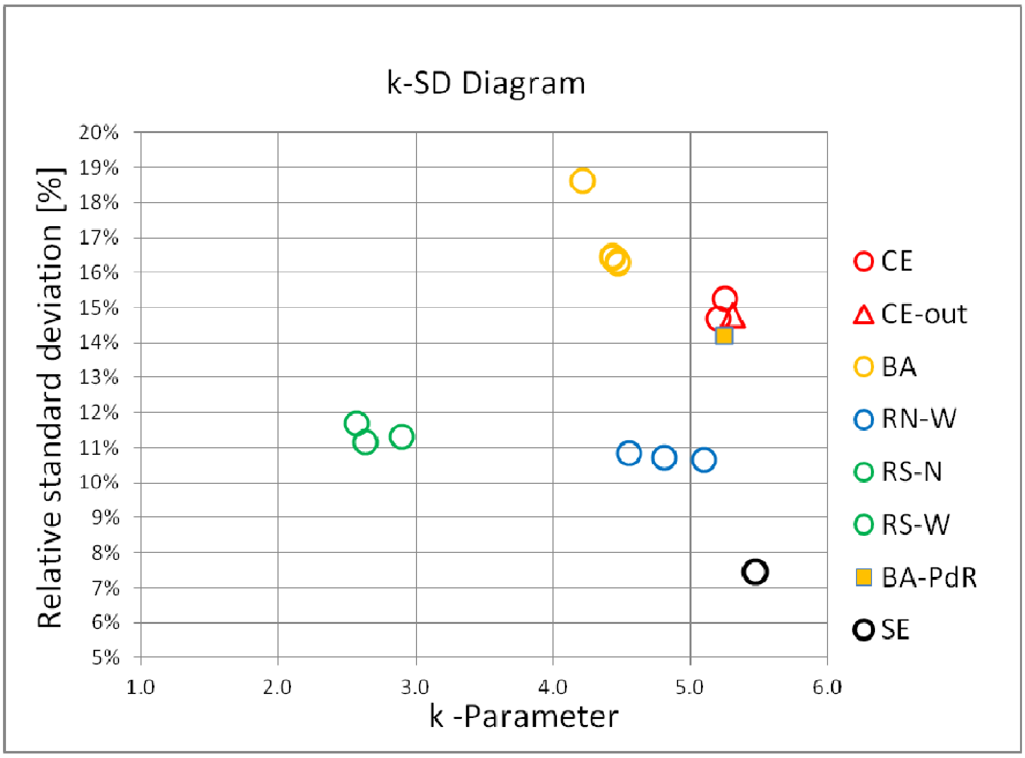


Figure 10: Diagram of relative standard deviation of the monthly wind speed at the sites from MERRA data 50 m according the k Parameter within one year of measurement.

5.8.2. Representative Parameter

Wind conditions at can be described by different parameter.

- Wind speed
- Wind power density
- **Energy yield**

Wind speed and Wind power density are suitable well for the Wind Energy Index, because the variation of the values do not reflects the variation of the energy yield of a representative wind turbine. Wind speed values show a lower variation and wind power density data show a higher variation compared to production data of wind farms. That means only energy yields should be taken into account for comparability. This can be simulated production or real operational data.

Finally, for the creation of energy yield based wind index the properties of the wind farms should be taken into account as well. Hence wind speed distributions must be recalculated to turbine position and hub height and transferred to energy as described in the section 1.7. One big advantage is the undisturbed wind potential. That means no wake losses (section 5.5.1) correction is required.

It's expected that the appliance of alternative input data can show similar behaviour regarding region separation. Trends in time series or site related wind conditions are relative similar. This is confirmed by the comparison of Figure 7 and Figure 8 with Figure 9 and Figure 10**.** But the absolute values of k and A differ much. Therefore reliable wind energy yield values can determined by local verifications only. Without an adjustment those values are not usable for a wind index.

As a first approach scaling factors considering the relationship of MERRA and AMA could be applied. If the variation of the ratio of monthly MERRA and AMA data is low they can be applied approximately as well.

Due to the high significance of the sensitivity DEWI assumes that alternative data sets without verification of energy production are not usable for the creating a Wind farm related Wind Energy Index. But for the extensions of Index regions those data can be used. If sufficient data for verification is available and a transfer function works well the creation of a representative spatially referenced wind index might be possible as well.

Advantages:

- Good spatial resolution
- periods available
- wake correction not necessary

Disadvantages:

- high discrepancy with absolute values
- verification with operational data required

6. Next steps – Methodology update

6.1. Expanding AMA´s data

Due to the legal requirement to install new measurements of wind farm sites, there is huge potential for expansion. Many measurements are already installed a majority doesn't include a fully usable data base of a whole year yet.

DEWI recommends an annual reconsideration of the data, starting from the consideration of new sites, updated long-term correction and inspections and completion of the cluster. From the second year of measurement, the energy output can be simplified taken into account using sensitivity approach.

6.2. Considering the power output of the turbines in operation

The wind index based on AMA data is a model with the claim to reproduce the reality regarding feed in energy of wind farms. Hence there is always the uncertainty of transformation to reality.

Expected deviations due to:

- Differences between real and by AMA predicted wind condition
- Problems while turbine test run in the beginning of operation
- Maintenance losses
- Power curve (real / theoretical)
- Wake losses in particular for large wind farms
- Grid operator intervention

The consideration of production data lead to more parameter which can be checked as well. Beside the energy yield production systematical losses can be determined.

6.3. Technological advance in future

Within the last years hub heights and rotor diameter have been increased worldwide. Still today manufactures announce bigger turbines for the upcoming years. At the moment it not clear, how long the growth of wind turbine dimensions will continue. Any how it can be expected that the development goes on.

With the rise of hub heights in the future the wind flow and the connected energy yield production will be more homogeneous and the influence of the terrain will be decreased. That means variation of monthly energy yield is getting to be decreased as well.

7. Summary/Conclusion

The definition of a Wind Energy Index allows two kinds of wind index. First is the spatial referenced Wind Energy Index related with a common definition of height above ground and secondly there is the wind farm referenced Wind Energy Index based on considered wind turbines.

In the previous sections DEWI suggested the **Wind Farm referenced** and the **Spatial referenced Wind Energy Index**. The main investigation followed the aim to create a representative energy yield value.

The approach of usage wind farm related referenced wind index leads to the most accurate determination of energy yield value, which is desired for a national energy strategy. In order to be more independent of local properties of considered wind turbines and related adjustments in the future a creation of a spatial referenced wind energy Index has been suggested as well. The bases for this index are wind conditions recalculated to a reference height. The monthly value of Weibull parameters have been suggested to determine clusters or in combination with additional data wind index regions. The number of clusters is related to the application and the dispersion of measurements within the country.

The investigation has shown that the Weibull A-k parameter are a good indicator for determine clusters of representative AMA measurements. In combination with the relative standard deviation of wind speed the variations of monthly values has been considered as well. A third criterion is the geographic relationship between the measurements which should be considered as well.

Due to the small number of representative wind farm areas the data base is not sufficient for the determination of accurate wind index regions. The application of external data (e.g. MERRA) could help to verify and extend the areas to wind index regions. In order to have a low uncertainty, the measurements should be checked and corrected continuously. DEWI recommends to check calibration values and to correct the shading effects of related anemometers due to mounting and wake effects due to neighbouring turbines as well.

The representative wind index value in combination with the related period should be updated every year. With the increased amount of data also the representative period will extend. This should be considered for each defined wind index region individually.

The AMA measurements are in use since about 2 years. Older wind farms are not considered at the moments. For the national energy strategy of a countrywide representative wind index is should be considered to take these additional available production data into account.

8. Appendix

8.1. Topographical Map including AMA Measurements

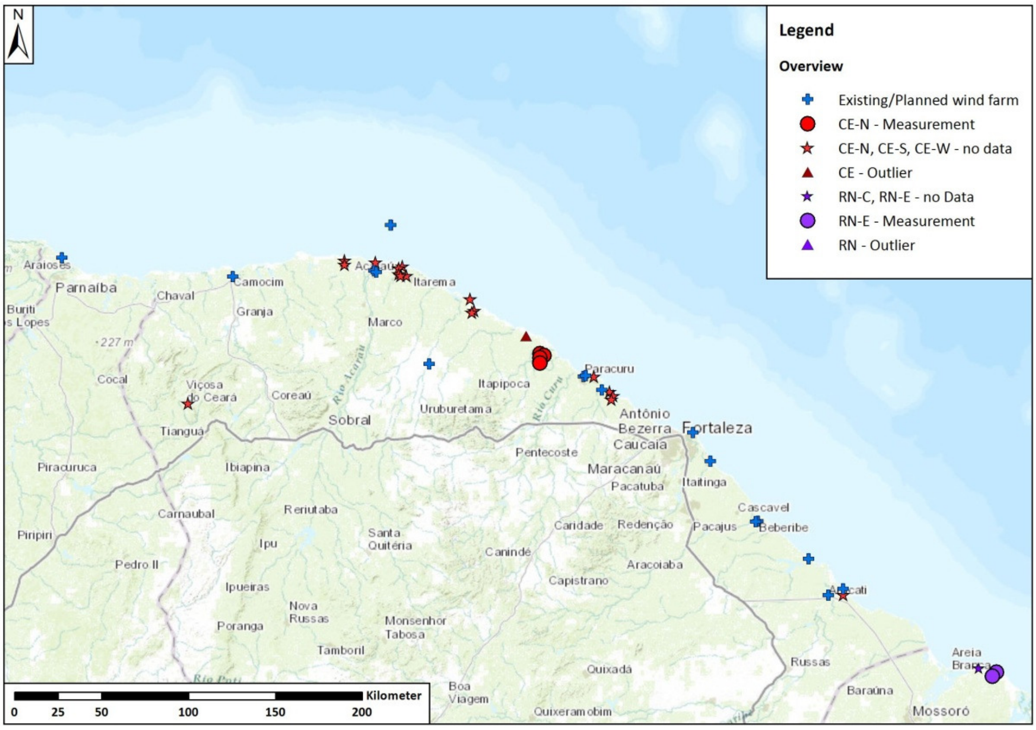


Figure 11: Topographical Map of North Ceará including AMA Measurements in Brazil (circle/star) and operating/planned Wind Farms (blue cross).

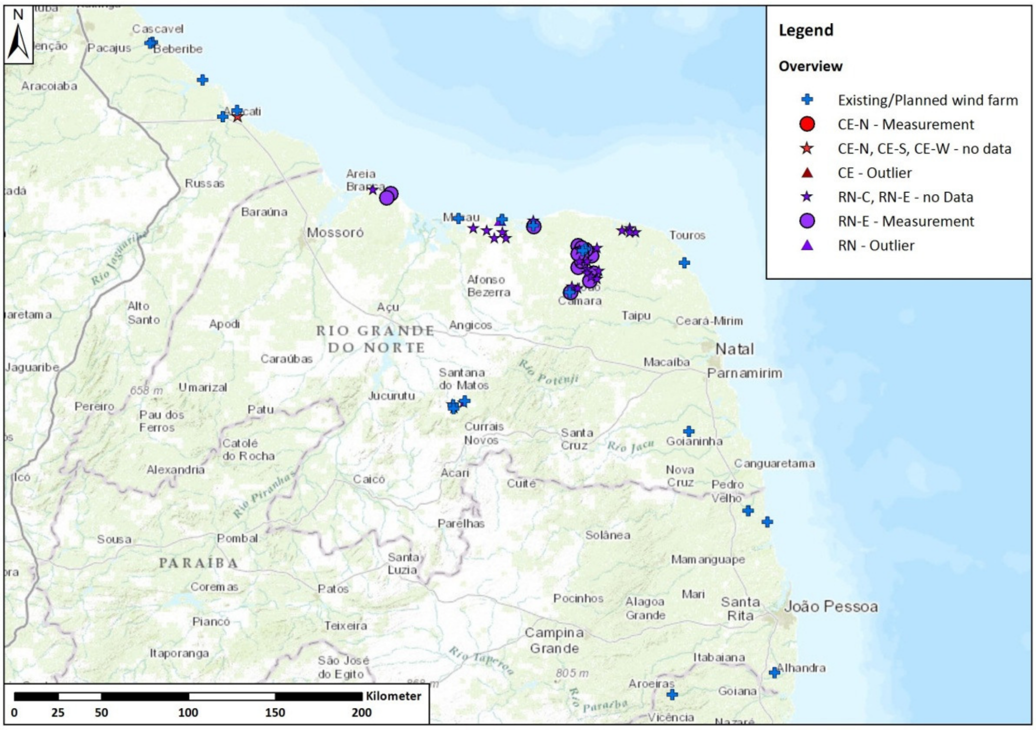


Figure 12: Topographical Map of Rio Grande do Norte including AMA Measurements in Brazil (circle/star) and operating/planned Wind Farms (blue cross).

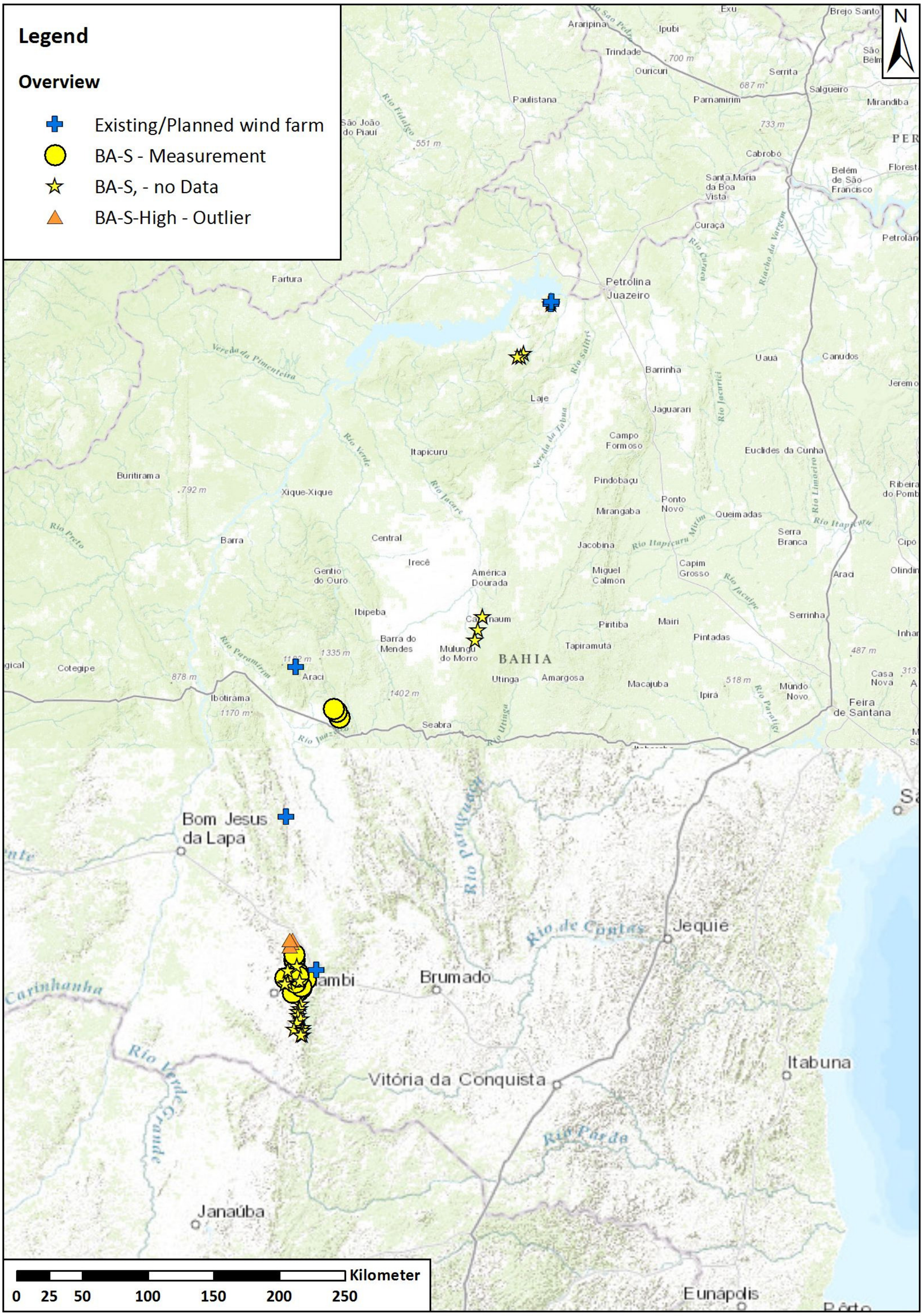


Figure 13: Topographical Map of Bahia including AMA Measurements in Brazil (circle/star) and operating/planned Wind Farms (blue cross).

Figure 14: Topographical Map of Rio Grande do Sul including AMA Measurements in Brazil (circle/star) and operating/planned Wind Farms (blue cross).

8.2. Hydro Power Grid

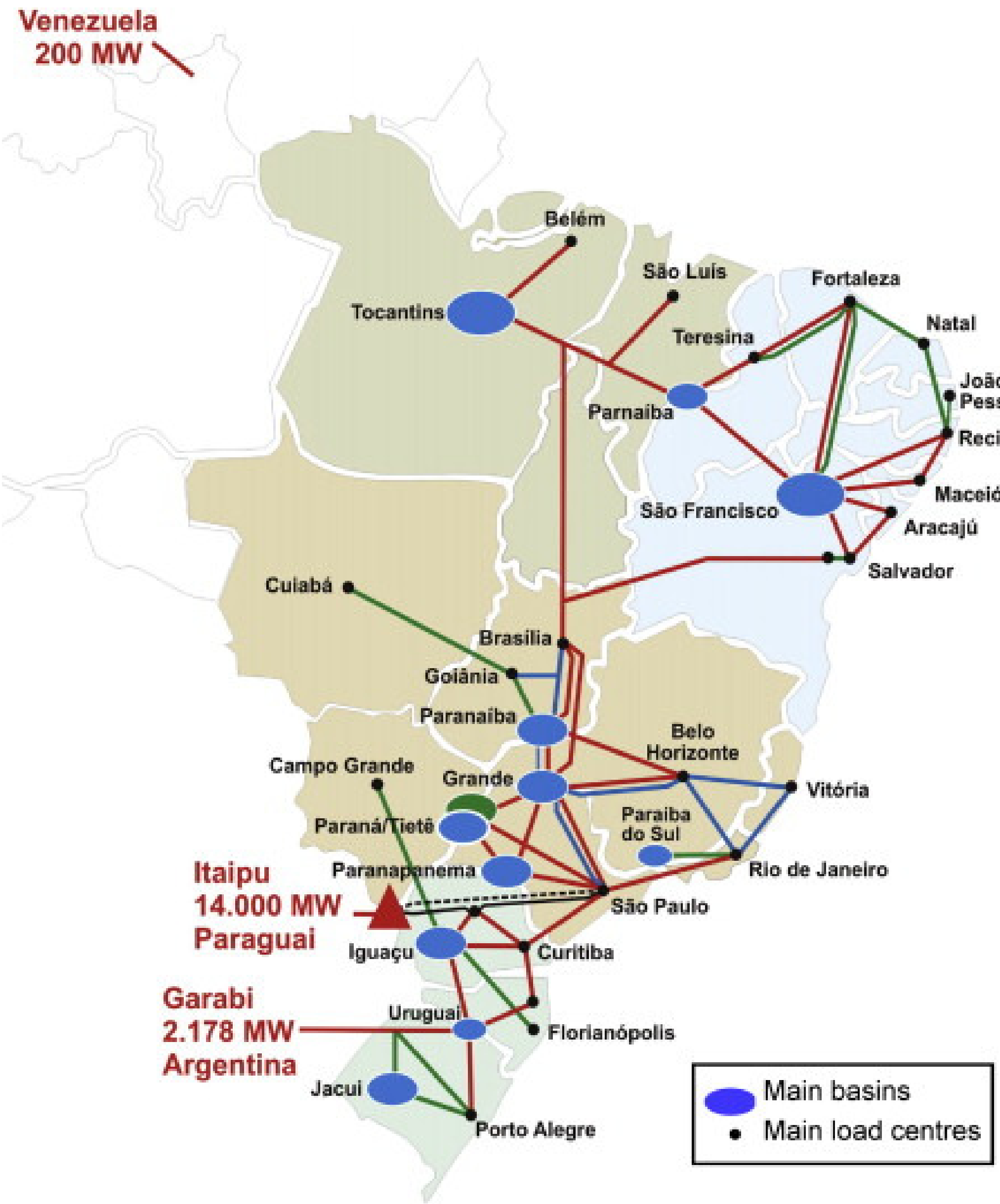
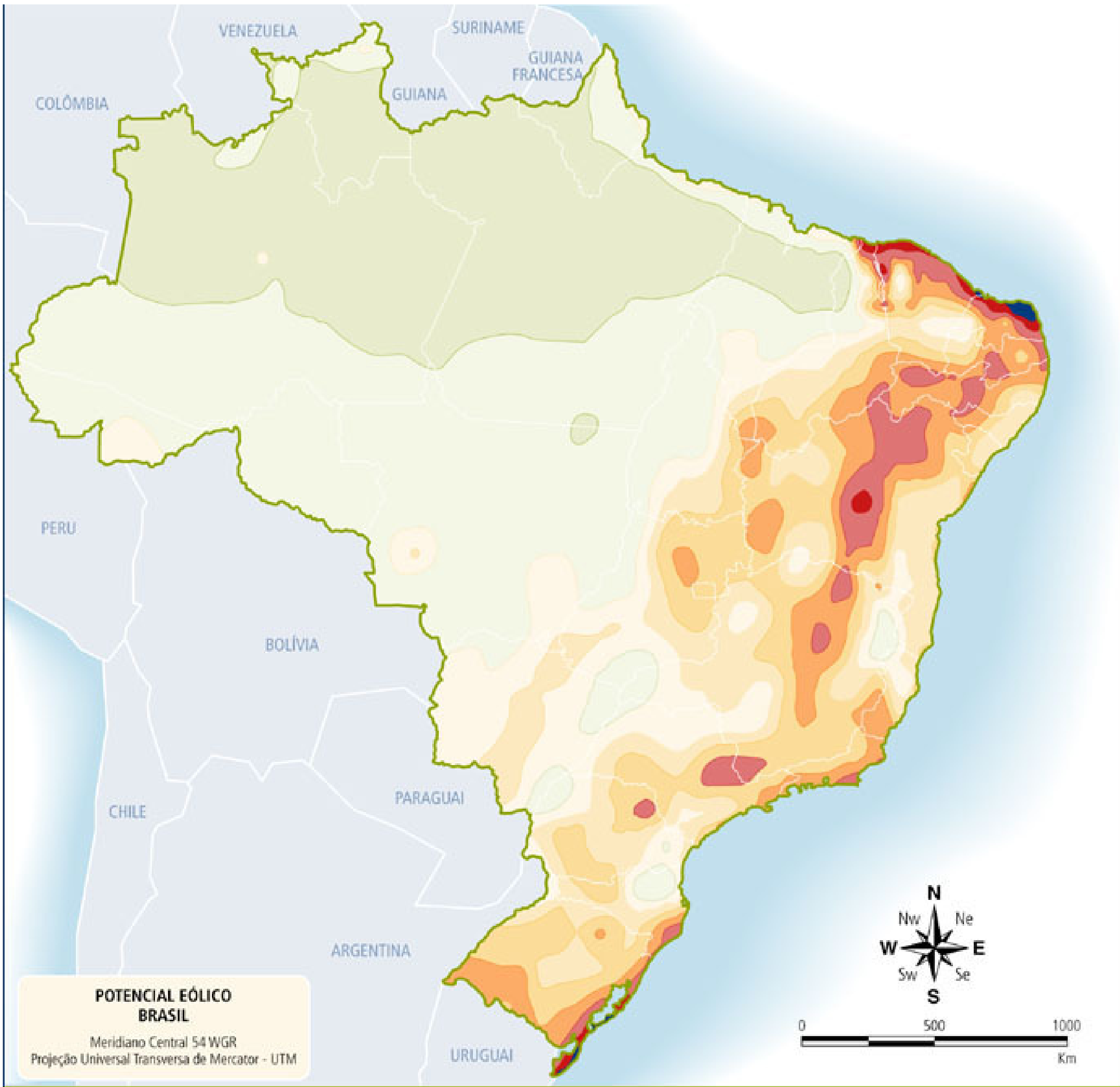


Figure 15: Brazilian wind index regions with main basins and main load centres

8.3. Wind Speed Map Brazil



Velocidade média do vento (m/s)
50 m acima do nível da superfície

Classes de energia	Mata	Campo Aberto	Zona Costeira	Morro	Montanha
4	> 6,0	> 7,0	> 8,0	> 9,0	> 11,0
3	4,5 - 6,0	6,0 - 7,0	6,0 - 7,0	7,5 - 9,0	8,5 - 11,0
2	3,0 - 4,5	4,5 - 6,0	4,5 - 6,0	6,0 - 7,5	7,0 - 8,5
1	< 3,0	< 4,5	< 4,5	< 6,0	< 7,0

NOTAS:
Mata indica áreas de vegetação nativa, com arbustos e árvores altas.

Campo aberto refere-se a áreas planas de pastagens, plantações e/ ou vegetação baixa, sem muitas árvores altas.

Zonas costeiras são áreas de praia, normalmente com larga faixa de areia, onde o vento incide predominantemente no sentido mar-terra.

Morros são áreas de relevo levemente ondulado, relativamente complexo e de pouca vegetação ou pasto.

Montanhas representam áreas de relevo complexo com altas montanhas. O potencial eólico é dado para locais nos topos das montanhas em condições favoráveis para o fluxo de vento.

Figure 15: FEITOSA, E. A. N. et al. Panorama do Potencial Eólico no Brasil. Brasília: Dupligráfica, 2003. (adaptado) [27]

8.4. Map of German Wind Index Region

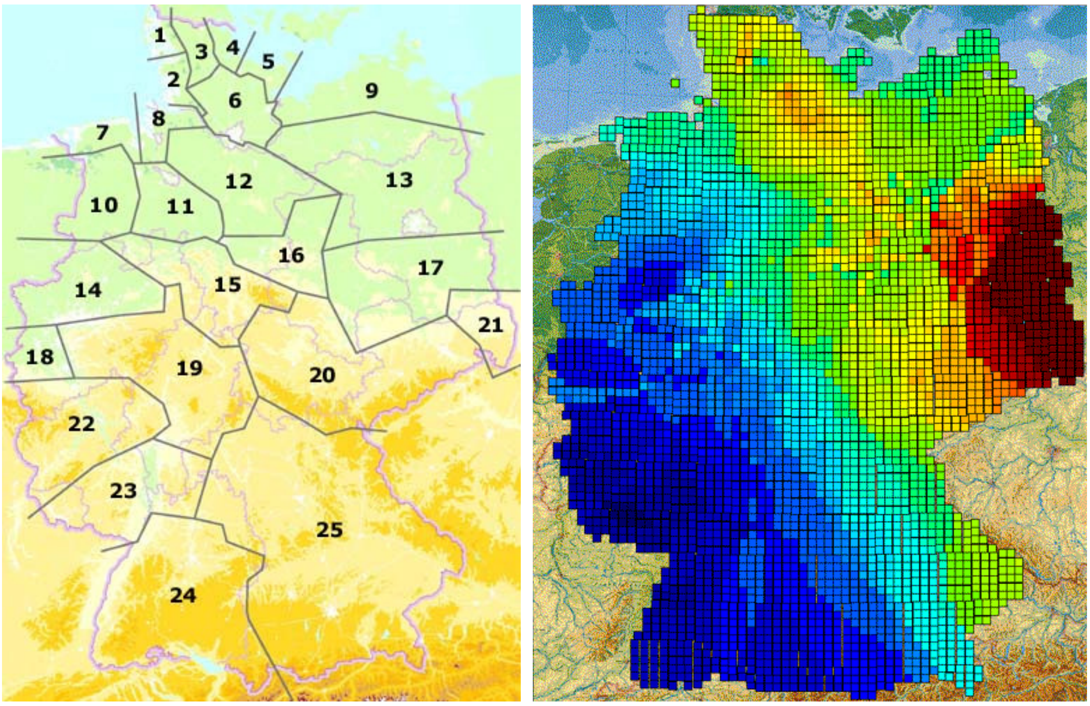


Figure 16: German Wind Index Regions,
left: IWET-Index
right: ISET-Index

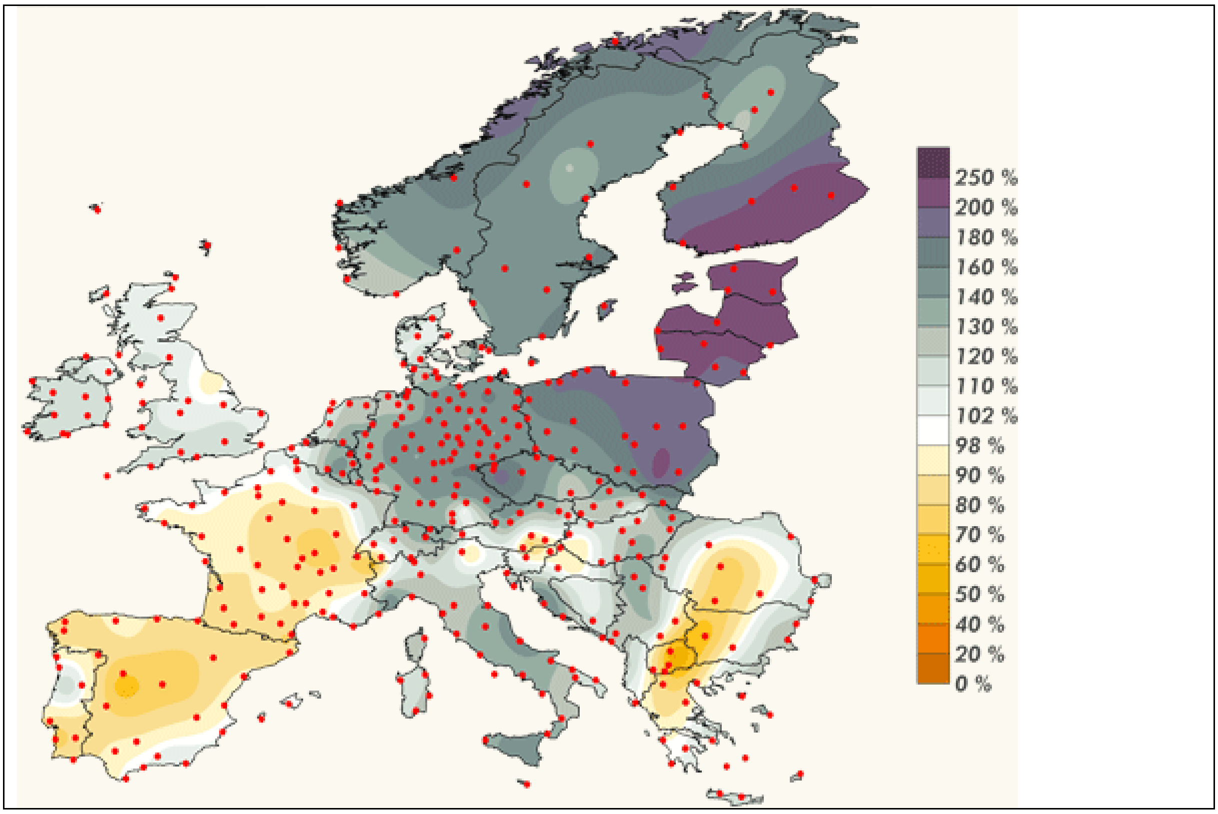


Figure 17: Area distribution of the site related Euro wind index for an example month and in order to calculate the used measuring stations of the European weather service (red dots).

8.5. Diurnal Pattern

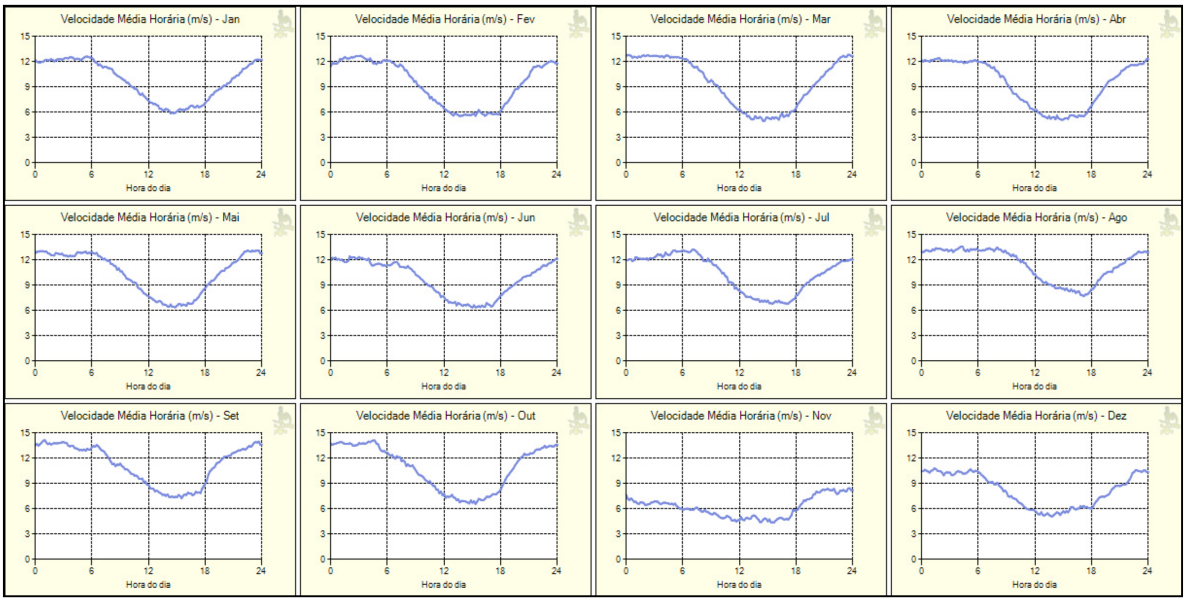


Figure 18: Diurnal pattern of Parque Eólico “X”(2012), Bahia, monthly images

8.6. Provided Data

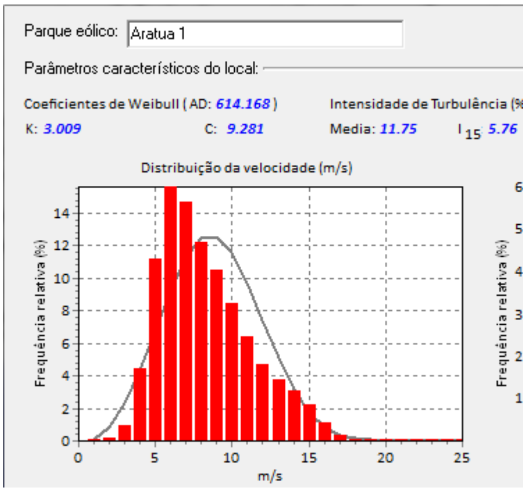
MERRA Data (monthly values of 20 year)

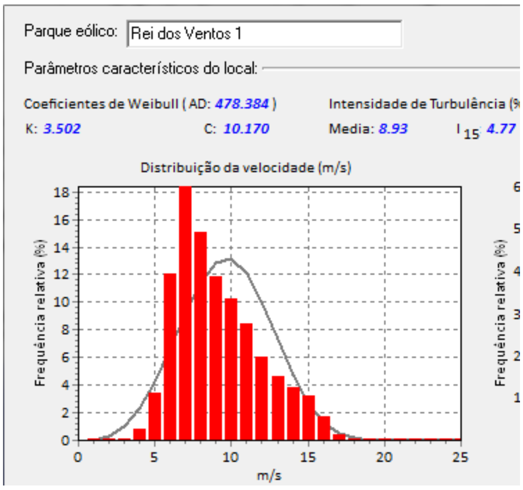
01 Coxilha Negra VII
02 Fazenda Rosario
03 Osorio2
04 Seraima
05 Tanque
06 Pajeu Do Ventodat
07 da Prata
08 Novo Horizonte
09 BARRA DOS COQUEIROS
10 CABECO PRETO IV
11 Eurus III
12 Santa Clara VI
13 Mangue Seco 3
14 Areia Branca
15 Faisa I
16 Embuaca
17 Icarai
18 Pedra do Reino
19 Aratua1
20 Rei dos Ventos1

8.7. Weibull Distribution

Litoral Nordeste

Aratuá e Rei dos Ventos I: F. Correl = 0,843





Aratuá e Porto Seguro: F. Correl = -0,219

Aratuá e Rio Verde: F. Correl = -0,202

Aratuá e Seraima: F. Correl =

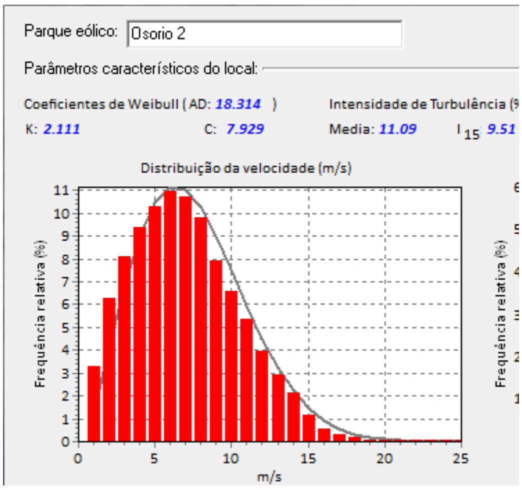
Aratuá e Candiba: F. Correl =

Aratuá e Fedra do Reino: F. Correl =

Rei dos Ventos I e Porto Seguro: F. Correl = -0,622

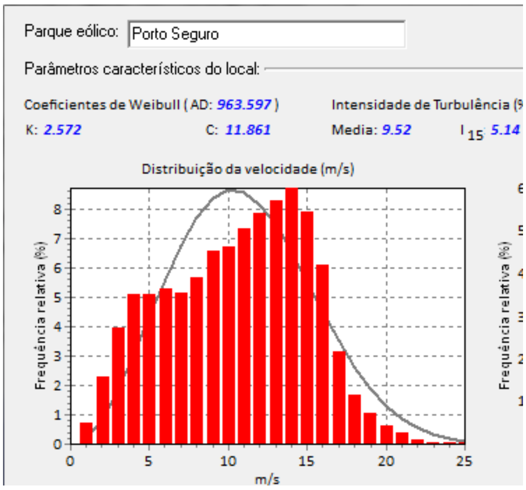
Rei dos Ventos I e Rio Verde: F. Correl = -0,620

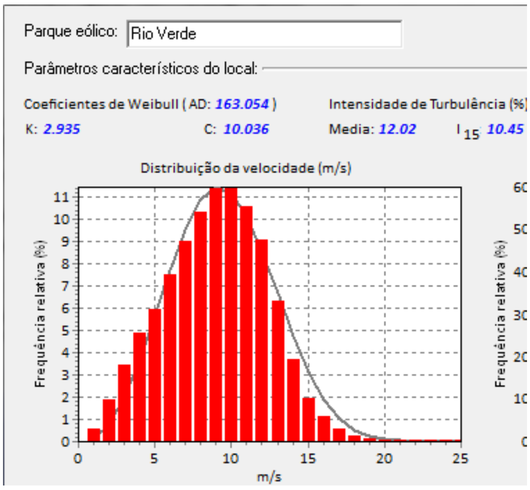
Rio Grande do Sul

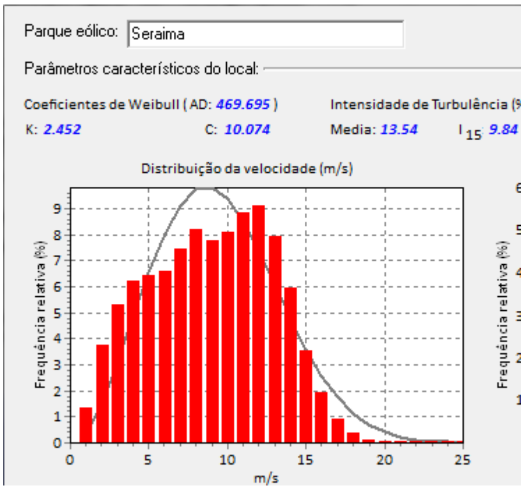


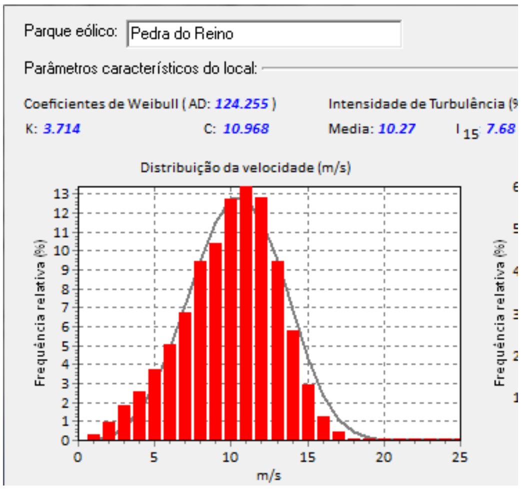
BAHIA

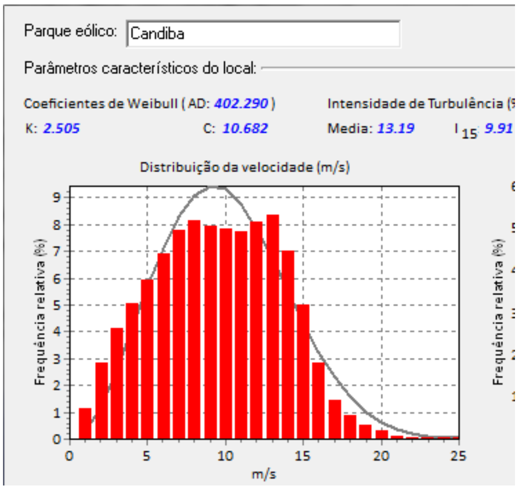
Porto Seguro e Rio Verde: F. Correl = 0,994











8.8. MERRA Reanalysis Data

Data from the GMAO[1] MERRA[2] reanalysis project [10] have been considered for rough long-term evaluation correction of 20 AMA sites (section 8.6). The GMAO MERRA data product is based on the GEOS Data Assimilation System, conducted at the NASA Center for Climate Simulation (NCCS).

Input of the used MERRA data are global observations collected over the so called "satellite era" (from 1979 to the present) and assimilated into a global circulation model (GEOS-5 GCM). Similarly to other reanalysis projects, the analysis is designed to be as consistent as possible over time and it uses a fixed assimilation system. This contrasts with weather-focused analysis where the assimilation system may vary over time as changes to the model and the analysis are implemented to improve weather forecasts.

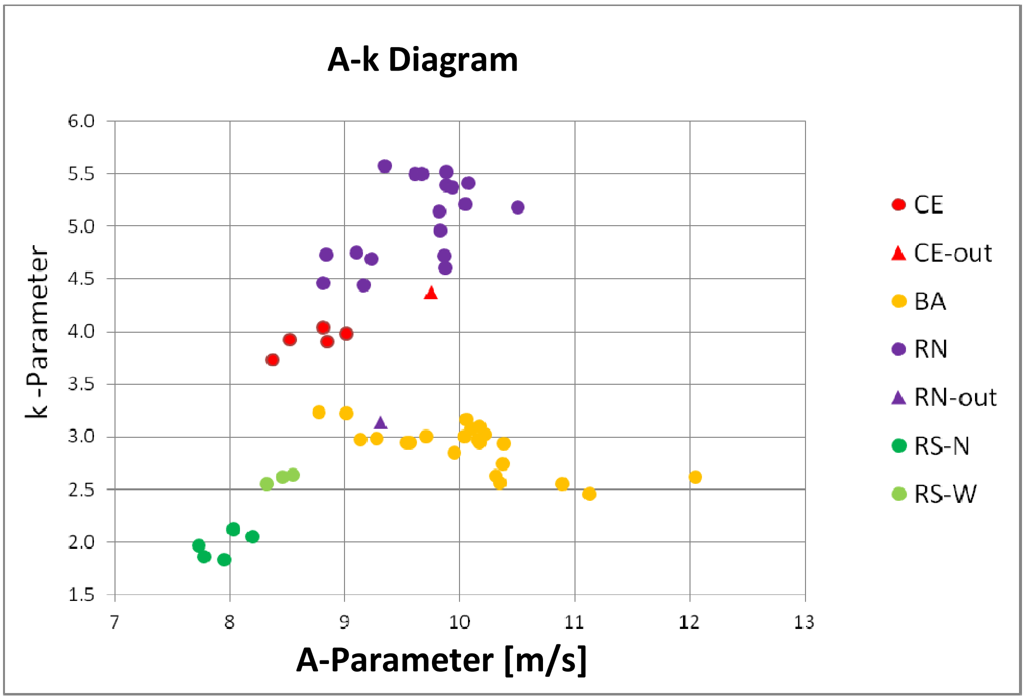
The MERRA reanalysis products include several variables available at different spatial and temporal resolution. The dataset used in the present assessment were hourly time series of wind speed at a resolution equal to ⅔° longitude and ½° latitude for the 50m diagnostic level. The time series have been extracted for all the four grid points surrounding the site. An additional time series have been produced by DEWI by bilinear interpolation to the site position.

Data source	GMAO MERRA Reanalysis
Data period used	1991-12-01 – 2013-02-28
Time resolution	1 h
Grid resolution	⅔° longitude and ½° latitude

Table 4: Overview of the used Reanalysis wind data.

[1] Global Modeling and Assimilation Office of the NASA Center for Climate Simulation
[2] The Modern Era Retrospective-analysis for Research and Applications

8.9. Scatter of suggested Clusters



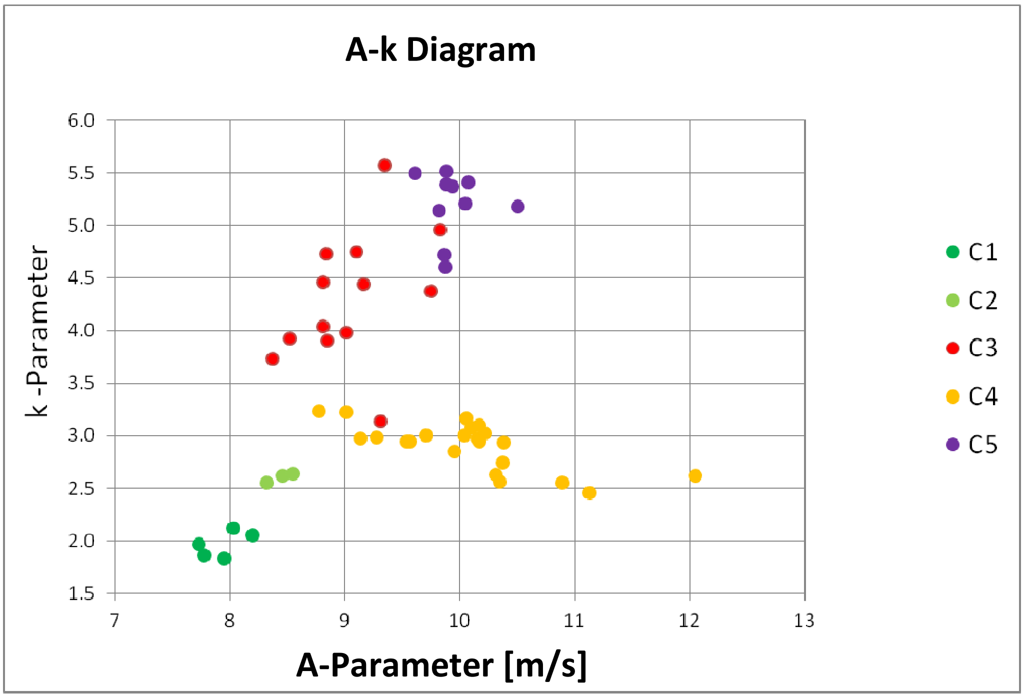
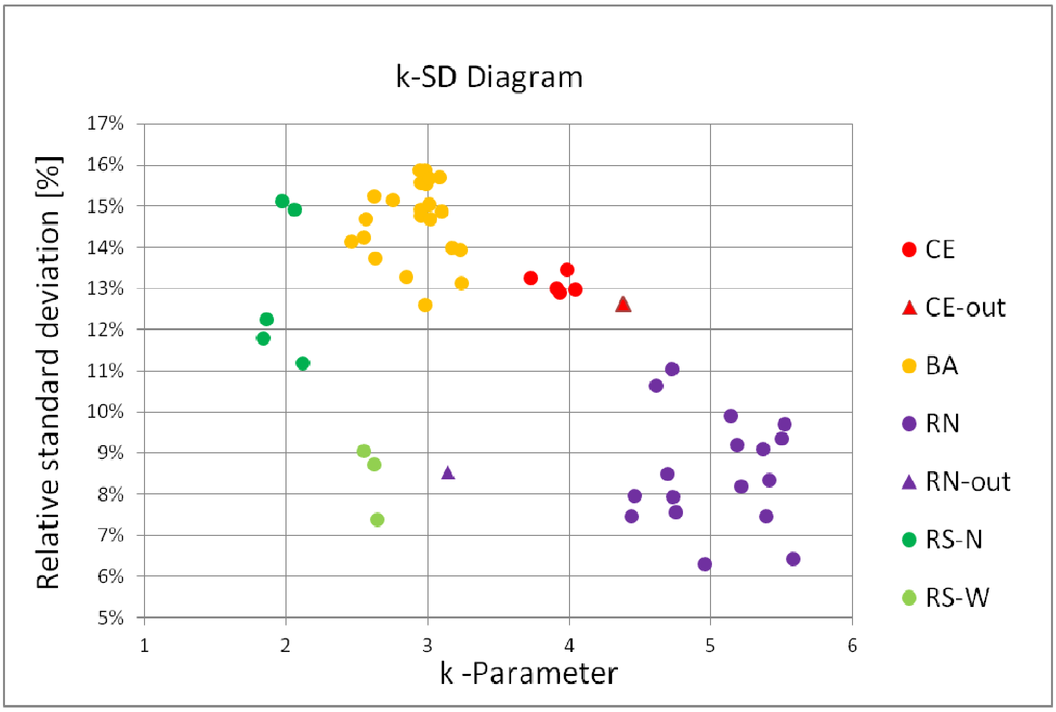


Figure 19: Scatter Wind conditions regarding Weibull Parameter. The measurements are clustered according geographic location and similar wind parameters for two approaches.
Above: DEWI
Below: EPE



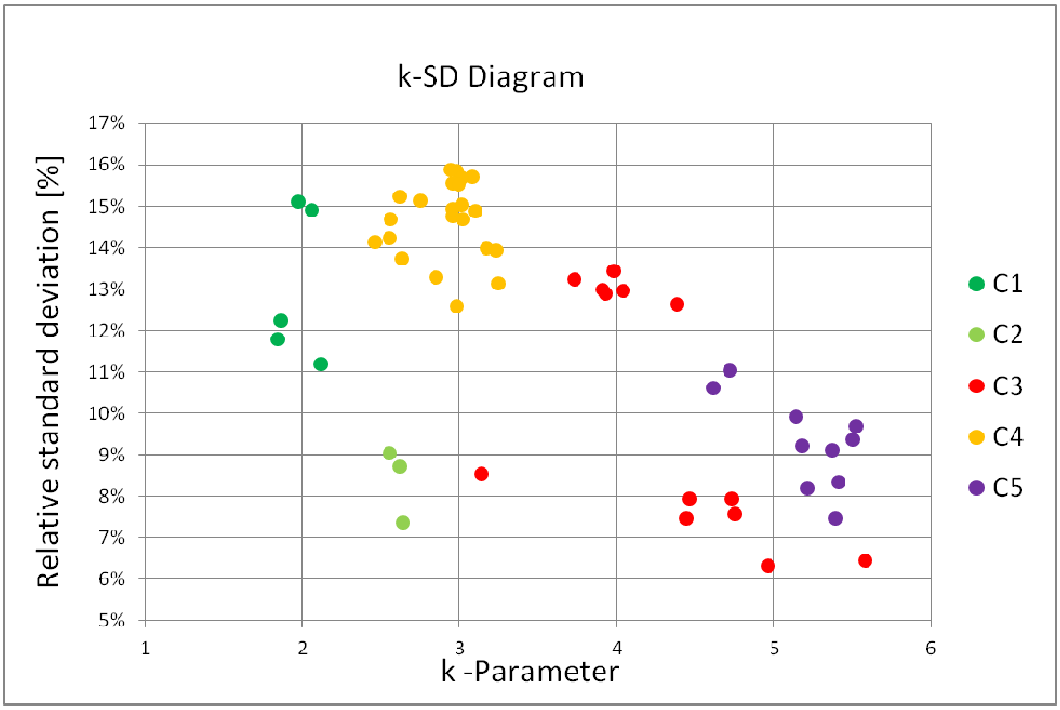
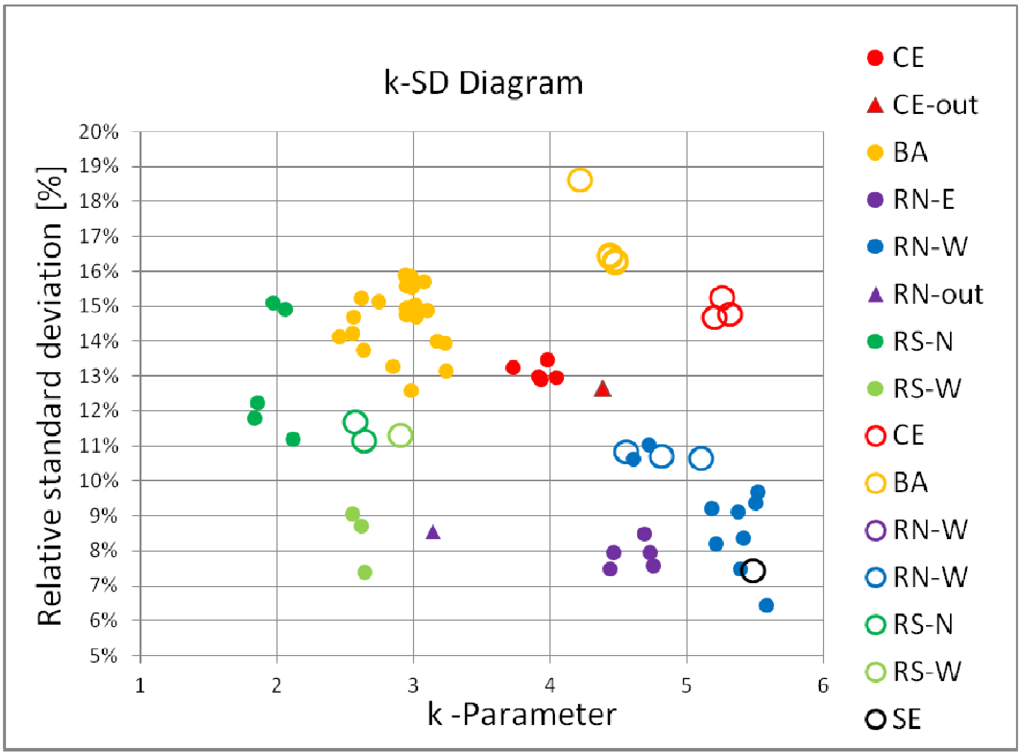


Figure 20: Diagram of relative standard deviation of the monthly wind speed at the sites according the k Parameter within one year of measurement.
Above: DEWI
Below: EPE



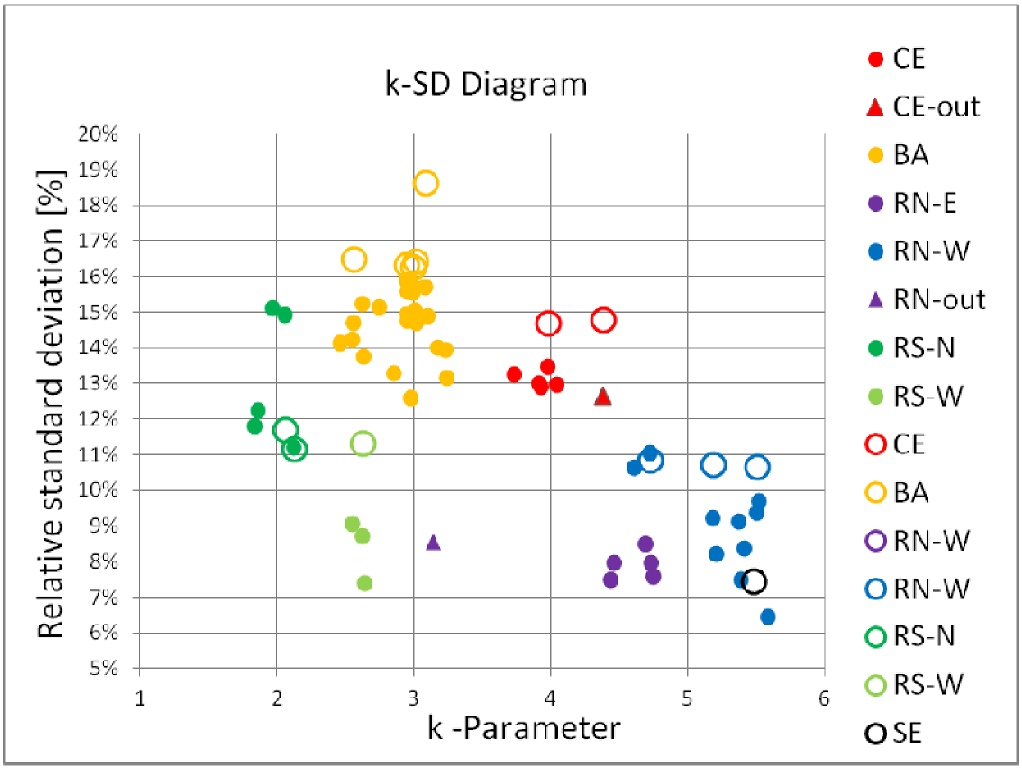


Figure 21: above and below: Diagrams of relative standard deviation of the monthly wind speed at the sites according the k Parameter within one year of measurement. Legend:

dots AMA measurements
circles MERRA data of selected sites
above original data (AMA, MERRA)
below MERRA k parameter replaced by site related AMA-measurements (for comparison of determined standard deviation of AMA and MERRA)

8.10. Normal distribution and standard distribution

In statistics and probability theory, shows standard deviation (represented by the symbol sigma, σ), how much variation or dispersion from the average (arithmetic mean) or the expected value exists. A low standard deviation indicates that the data points tend to be very close to the average, high standard deviation indicates that the data out are spread over a large range of values.

$$s_N = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

The standard deviation considered about 68.4% of all considered value according of a normal distribution. Those data are coloured with dark blue between -1 σ and +1 σ. That means statistically usually 31.8% of data (100% -2x34.1%) are out of the range.

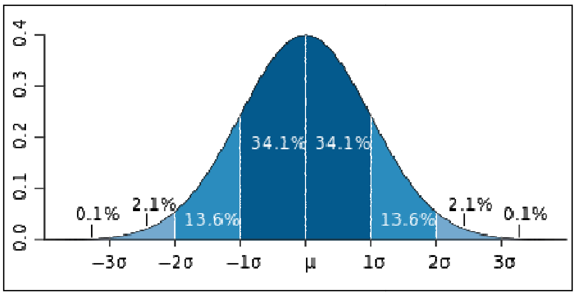


Figure 22: Normal distribution

8.11. Used Software

DEWI used among several tools and programs for evaluation and correlation of the wind data the following software for the investigation in hand:

- Wind Atlas Analysis and Application Program (WA^SP), version 5.01, build 81110, Risø National Laboratory, Roskilde, Denmark.
- Farm Layout Program (FlaP), version 2.7a0, ForWind, Zentrum für Windenergieforschung, Oldenburg, Germany.
- WindPRO, version 2.7 EMD International A/S, Denmark
- Surfer, version 7.05, Golden Software, Inc., Colorado
- Garrad Hassan and Partners Limited; Windfarmer, Bristol, 1997 - 2013.

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A Question of system Optimisation
http://www.dewi.de/dewi/fileadmin/pdf/publications/Magazin_40/04.pdf