Empresa de Pesquisa Energética

GENERATION PLANNING

Wind and Photovoltaic Generation

Input data for power and energy models: methodologies and assumptions

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DOCUMENT AND REVIEW IDENTIFICATION

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Reviews	*Issue date*	*Summary description*
r0	02/2021	Original issue
r1	12/2021	Updates: - Accounting for the bifacial gain for centralized photovoltaic plants - Improved methodology for floating solar photovoltaic plants - Inclusion of the year 2020 in the analysis of onshore wind power plants - Use of a 12 MW turbine in the analysis of offshore wind power plants
R2	22/11/2022	Updates: - Onshore wind farms capacity factors - Offshore wind farms: methodology for estimating the energy contribution

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1. INTRODUCTION

This Technical Note aims to present the methodology and assumptions for obtaining representative data of wind (onshore and offshore) and photovoltaic (centralized and floating) plants for the generation and transmission planning studies carried out by EPE. Distributed photovoltaic plants will not be addressed in this Technical Note.

In generation planning studies, these sources are represented by evaluating their monthly and hourly generation expectations. Furthermore, there is a differentiation between the representation of existing plants and future plants. In this Technical Note, only the assumptions for the representation of future plants, which are used in the models as candidates to enter the power system, will be addressed.

As they are variable and non-controllable generation sources, it is important to establish a methodology that is coherent to their energy contributions according to the profile in the places where the projects are being installed in Brazil. Furthermore, the time extension and granularity of the data are fundamental factors to guarantee the representativeness of the studies in relation to future operations.

During 2022, the methodology used in the estimates was modified in the following aspects:

- Updating of wind farm capacity factors, considering the technical characteristics of more recent projects.
- Improvement of the methodology for estimating the contribution of offshore wind farms, considering different areas (based on projects submitted to IBAMA) and sites/points with wind data.

To describe the used procedure, this Technical Note was broken down into 3 chapters, in addition to the introduction and final remarks.

Chapter 2 describes all the databases used in the studies and Chapter 3 shows the methodologies used to estimate energy generation from these databases.

Due to the number of wind and photovoltaic plants installed in Brazil, it is convenient to break down the country into regions. In Chapter 4, the characteristics used for this breakdown are discussed and the data used in EPE generation and transmission studies are shown.

The generation series estimated using the methodologies presented in this study are available on EPE website.

2. DATABASES

It is known that Brazil has a vast wind and solar potential. However, the resources are not equally distributed across the country, with some regions being more favorable to each type of resource. In the case of wind power, the regions with more resources are the Northeast and the South. In the case of solar, the resource is more homogeneous, although a little higher in the Northeast region and in the central part of the country. Even with the number of power plants already installed in these locations, there is still enormous potential in these regions. This allows that the knowledge already acquired about the behavior of resources can be used for future estimates.

The information presented in this study comes from several databases used in the wind and solar sector and described below:

1. **AMA** – meteorological data measured by the owners of wind farms and sent to EPE under energy contracts.

2. **AEGE** – data received by EPE with information on all power generation projects that participate in energy auctions.

3. **BRASIL-SR** – irradiation data provided by the Laboratory for Modeling and Studies on Renewable Energy Resources (LABREN) of the National Institute for Space Research (INPE).

4. **MERRA 2** - Reanalysis data provided by NASA.

5. **ERA 5** – reanalysis data provided by the European Center for Medium-Range Weather Forecasts (ECMWF).

2.1 AMA

The AMA System (Anemometric Measurement Monitoring System) database was conceived based on the identification of the lack of information on the energy characteristics of the wind source, required for planning the expansion of the Brazilian power system. With the consent of the MME (Ministry of Mines and Energy), the Regulated Market (ACR) tender documents have a clause requiring the submission of anemometric and climatological measurements, at the site of the plants that won the auction, throughout the period term of the contract. These data are recorded every 10 minutes and sent every two weeks to EPE in order to gather information with the frequency, quantity and quality necessary to support power and energy studies. Measurements of pressure, temperature, relative humidity, wind speed and direction are recorded.

Since 2012, EPE has been using this base to improve its studies, as it can be consulted at: https://www.epe.gov.br/pt/acesso-restrito/sistema-ama

Currently, data from more than 600 met masts installed in the Northeast and the South are sent to the AMA system, as shown in Figure 1.

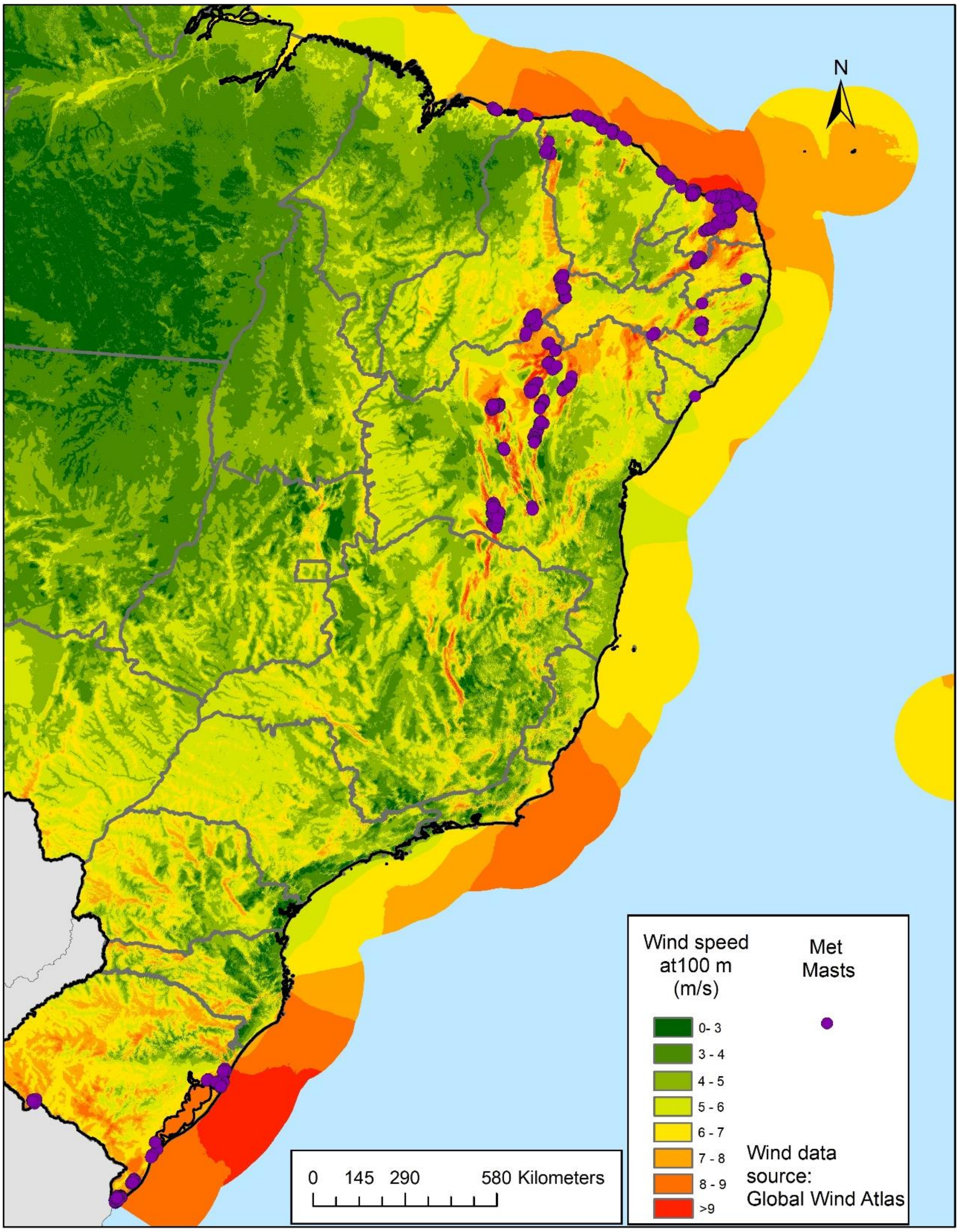


Figure 1- AMA System Stations

In this study, only stations with measurements between 01/01/2017 and 12/31/2019 were used, which reduced the sample to 462 anemometric towers, as shown in Table 1.

Table 1– Station breakdown per State

State	Stations	Power (MW)	Percentage
MA	8	221	2%
PI	52	1412	12%
CE	60	1420	12%
RN	106	2926	26%
PB	3	95	1%
PE	29	757	7%
SE	1	35	0%
BA	126	2960	26%
RS	77	1630	14%
TOTAL	**462**	**11454**	**100%**

It is important to emphasize that the AMA database does not have data from wind farms contracted via PROINFA[1] or the Brazilian free energy market (ACL). Even so, due to the number of met masts and their locations, this sample used is representative of real data for the entire wind generation in the country.

2.2 AEGE

The AEGE (Monitoring of Energy Generating Projects) System database is the main information base on EPE's power generation projects. This database contains information about all projects submitted to the ACR energy auctions, considering electrical, environmental, energy and economic aspects. Several documents released by EPE have the AEGE as their primary database.

In this study, the following information is used:

- Capacity Factor (FC) of wind and photovoltaic plants qualified for the auctions.

- Model of wind turbine in each wind farm.

- Inverter sizing factor, structure type and typical losses for photovoltaic plants.

[1] PROINFA: Incentive Program for Alternative Sources of Power, responsible for installing 1,283 MW in wind farms [1].

2.3 BRASIL-SR

The BRASIL-SR radiative transfer model database was provided by LABREN - INPE and contains hourly data of global horizontal irradiation in the period between 2006 and 2017, considering 42 locations (Figure 2), selected based on information from plants contracted in auctions between 2014 to 2019 and prospective studies. In some cases, nearby sites have been aggregated into a single municipality for simplification purposes.

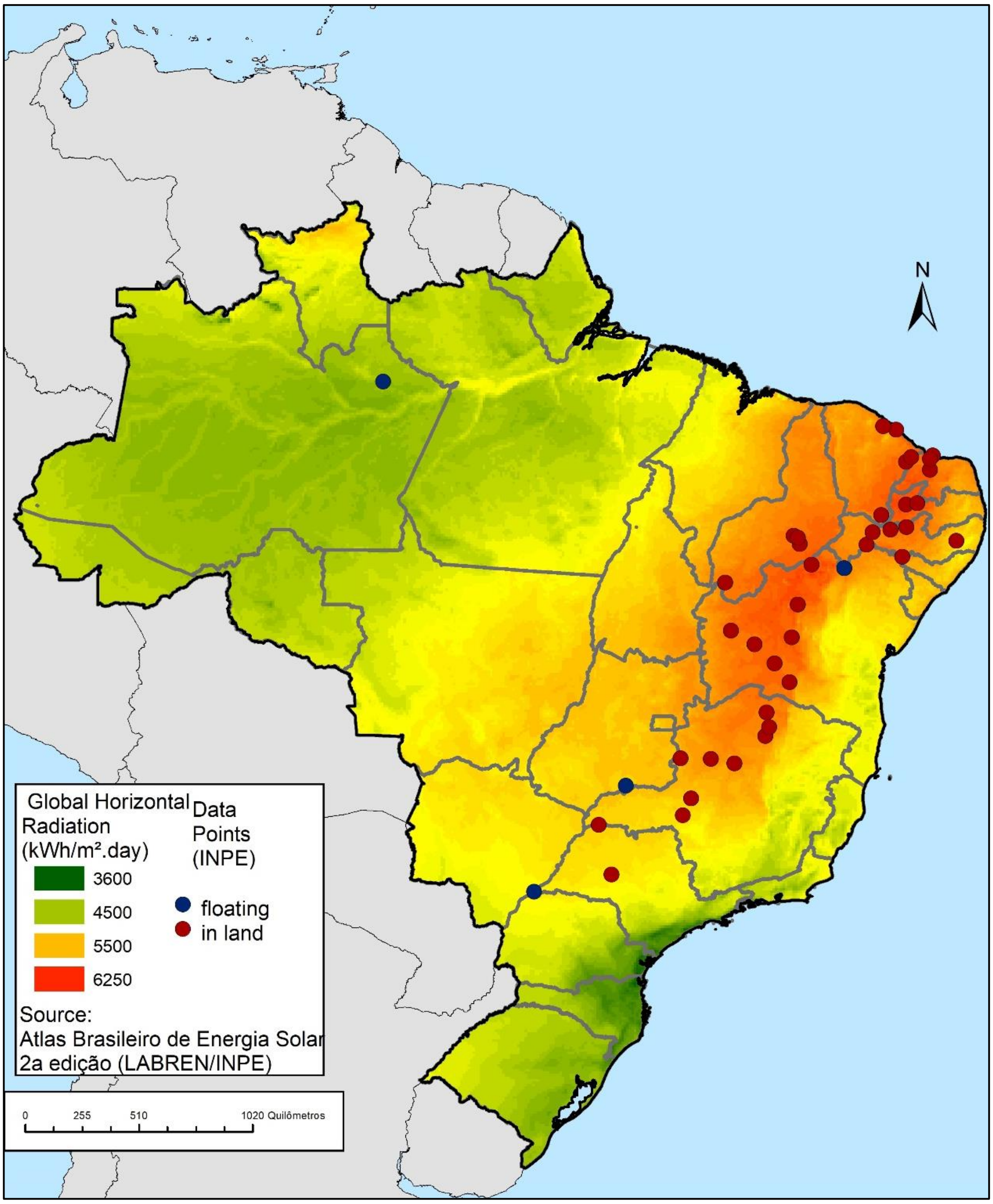


Figure 2 – Brasil-SR database: points used

This database is the same as the one presented in the "Atlas Brasileiro de Energia Solar" (Brazilian Solar Energy Atlas) – 2nd Edition, and the modeling details can be consulted in Pereira et al. [2].

2.4 MERRA 2

The MERRA 2 (Modern Era Retrospective Analysis for Research and Applications) database is a public database made available by NASA and widely used in the wind sector [3]. MERRA-2 has a grid with 576 points in the longitudinal direction and 361 points in the latitudinal one, corresponding to a resolution of 0.625° × 0.5°, covering the entire planet. Each point contains weather data on an hourly basis starting in 1981. In this study, only the anemometric data corresponding to the Northeast and South Regions were used, as shown in Figure 3. As for temperature, data from the Southeast Region were also used.

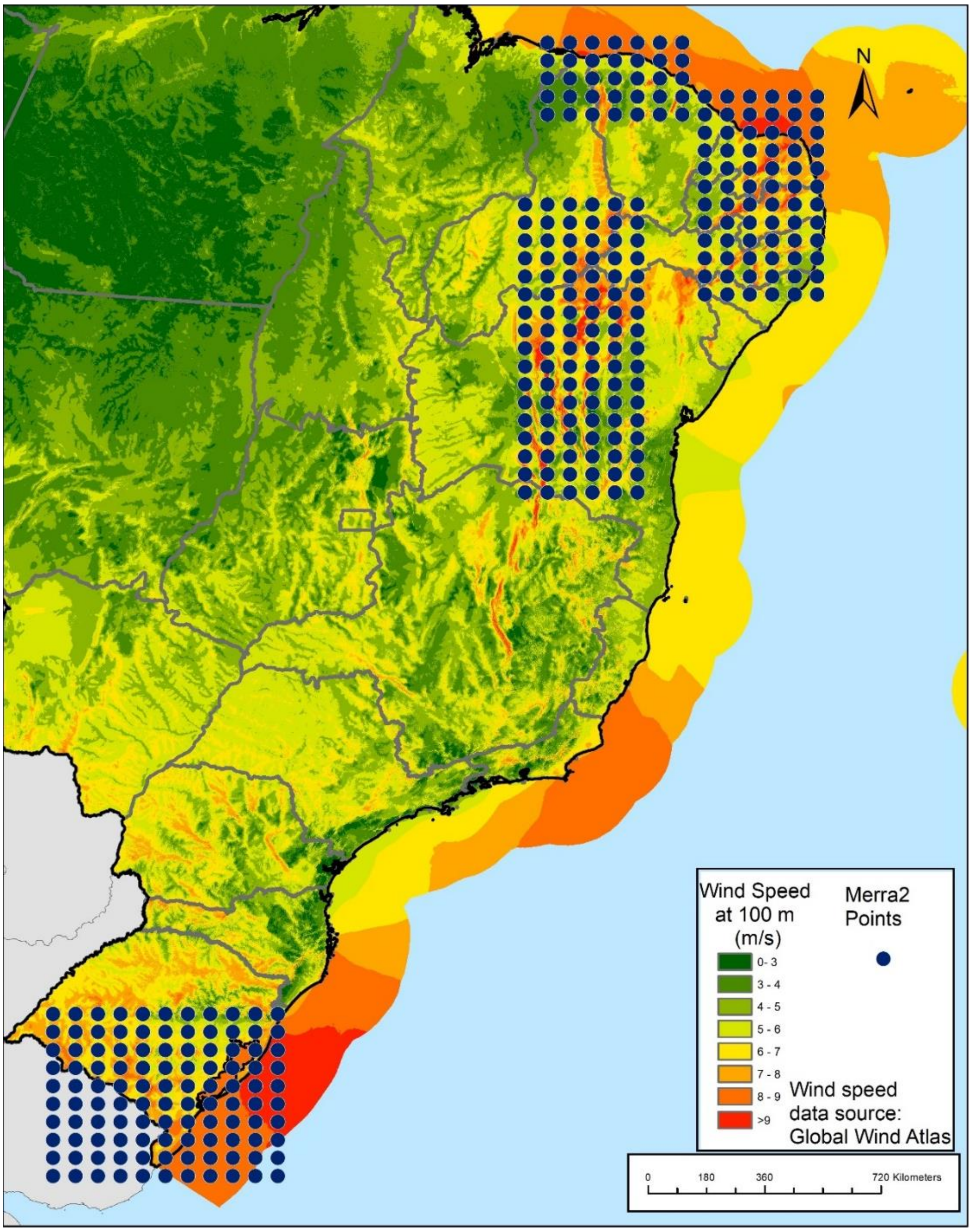


Figure 3 – MERRA 2 Database: points used

2.5 ERA 5

The ERA 5 database is a public database provided by the ECMWF that has a global horizontal resolution of 31 km. The data include hourly frequency, wind speed at 100 meters and period starting in 1979[2].

In this study, the ERA 5 base was used only in the offshore wind analysis.

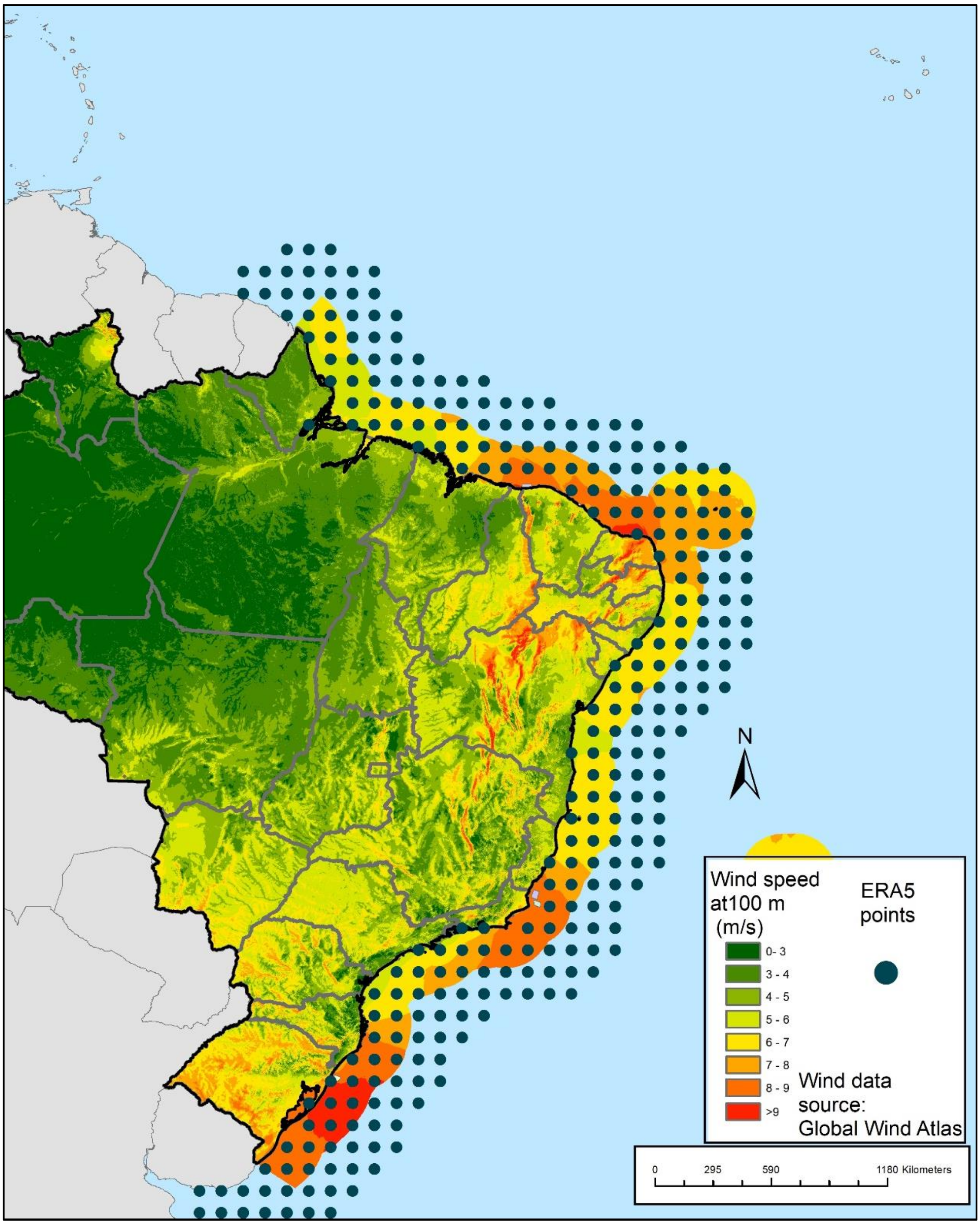


Figure 4- ERA 5 database: points used

[2] According to the ECMWF website, the series from 1950 onwards are already available.

2.6 Summary Table

Table 2 consolidates the databases used and their main characteristics.

Table 2 – Summary of the data used

Database	Variables used	Height	Period used	Number of points	Time resolution
AMA	Wind speed Pressure Temperature Humidity	Varies according to the wind farm	2017 to 2019	462 stations	10 minutes
AEGE	Capacity factor Project data	Not applicable	Long-term average	935 solar plants and 362 wind plants	Monthly
BRASIL-SR	Irradiation	Not applicable	2006 to 2017	42 locations	Hourly
MERRA 2	Wind speed Temperature	50 m	1981 to 2020	50 km resolution	Hourly
ERA 5	Wind speed Pressure Temperature Humidity	100 m	2000 to 2017	31 km resolution	Hourly

3. METHODOLOGY FOR ENERGY ESTIMATION

Simulations were made for energy estimates using the data on energy resources, whether wind speed or irradiation. The methodologies for simulating photovoltaic energy and onshore and offshore wind energy will be detailed below.

3.1 Centralized Solar Photovoltaic

The hourly data of global horizontal irradiation (BRASIL-SR) and temperature (MERRA 2) were simulated for photovoltaic generation, using the System Advisor Model (SAM) software package, version 2020.11.29, developed by NREL [4].

Since SAM is a model that has annual data entry, it is necessary to perform the 12-year calculations for each location separately. After breaking down the data into annual files, treating the failures and calculating the diffuse irradiation, the hourly production for each year in each location was simulated. For leap years, February 29 was excluded, as the SAM does not allow the insertion of years with 366 days. From the specification of a standard plant, based on sizing practices and current technology, the result is a 12-year time series for each location. The equipment and configurations considered in the simulations are presented in Table 3. The results are normalized for later aggregation of subsystems according to the weights established in each study.

Table 3 – Equipment and arrangements considered at the standard plant

Modules	
Cell type:	Bifacial monocrystalline silicon
Maximum rated power	375 W
Bifaciality	0.85
Inverters	
CA power:	3,109 kW
Array	
Modules in series:	24
Parallel series:	444
Total CC power	3,997 kW
Inverter sizing factor	0.78
Structure	1 axis tracking

Some loss factors are calculated by the software from the hourly production simulation, such as loss due to module temperature, incident angle and efficiency of the inverter, and the bifacial gain. Others are entered manually and were defined from typical values found in current projects, so that the annual and monthly capacity factors resulting from the simulations were similar to those found in the AEGE database. The list of simulated locations is presented in Table 4.

Table 4 – List of simulated locations

Subsystem	STATE	Municipality	Latitude (º)	Longitude (º)
Northeast	BA	Barreiras	-12.04	-45.07
		Bom Jesus da Lapa	-13.37	-43.3
		Casa Nova	-9.38	-41.81
		Guanambi	-14.13	-42.7
		Itaguaçu da Bahia	-10.99	-42.36
		Juazeiro	-9.53	-40.49
		Oliveira dos Brejinhos	-12.32	-42.61
		Tabocas do Brejo Velho	-12.6	-44.11
	CE	Abaiara	-7.38	-39
		Aquiraz	-3.94	-38.39
		Caucaia	-3.79	-38.92
		Limoeiro do Norte	-5.24	-38
		Quixeré	-5.04	-37.79
	PB	Coremas	-6.96	-37.99
		Malta	-6.91	-37.55
	PE	Agrestina	-8.42	-35.96
		Flores	-7.87	-37.98
		Orocó	-8.57	-39.59
		São José do Belmonte	-7.97	-38.63
		Tacaratu	-9.07	-38.15
		Terra Nova	-8.08	-39.34
	PI	João Costa	-8.55	-42.29
		Ribeira do Piauí	-8.21	-42.53
		São Gonçalo do Gurguéia	-10.11	-45.3
		São João do Piauí	-8.29	-42.37
	RN	Açu	-5.55	-37.03
		Areia Branca	-4.98	-36.91
		Serra do Mel	-5.12	-37.03
Southeast/Midwest	MG	Araxá	-19.5	-47
		Francisco Sá	-16.3	-43.67
		Guimarânia	-18.82	-46.67
		Jaíba	-15.35	-43.63
		Janaúba	-15.94	-43.52
		João Pinheiro	-17.23	-45.87
		Paracatu	-17.2	-47.09
		Pirapora	-17.41	-44.92
	SP	Guaimbê	-21.89	-49.88
		Ouroeste	-19.89	50.4

It is important to emphasize that each location has different amounts of installed or contracted solar plants. Therefore, depending on the study being carried out, each location will have different weights. For example, in generation studies, the total number of plants installed or contracted up to the moment of their preparation is used as a reference for photovoltaic generation in the main grid. In transmission studies, on the other hand, different weights can be used, which represent the expectation or potential for installing photovoltaic plants in a given region. Thus, the simulated time series for this set of locations have flexibility to carry out various studies, simply by adapting the installed power per location to the desired purpose.

3.2 Floating Solar Photovoltaic

In this planning cycle, the production estimate of floating photovoltaic plants was improved. Similar to the centralized ones, production in selected locations was simulated. The main differences were:

(i) use of fixed structures, with modules facing north at 10 degrees tilt angle;

(ii) monofacial modules; and

(iii) Reduced temperature loss due to evaporative cooling effect.

Four locations were considered to represent existing floating plant projects: Balbina (data from Presidente Figueiredo - AM), Itumbiara (GO), Sobradinho (data from Juazeiro - BA) and Porto Primavera (Rosana - SP). The geographic coordinates taken into account are shown in Table 5.

Table 5 - Location of floating photovoltaic plants

Municipality	STATE	Latitude (º)	Longitude (º)
Itumbiara	GO	-18.30	-49.30
Juazeiro	BA	-9.53	-40.49
Presidente Figueiredo	AM	-2.00	-59.10
Rosana	SP	-22.58	-53.00

3.3 Onshore Wind

For onshore wind farms, generation data, in MWh, were obtained by simulating the generation of wind farms from AMA data. By applying the 10-minute averages of wind speed and other climatic parameters in the power curves of wind turbine models, the output of a single generator positioned at the measurement site is estimated. It is assumed that this calculated output can be scaled by the number of machines installed in the plant and is representative of the generation of the entire wind farm. The simulation methodology is extremely simple, but it leads to results that are sufficiently accurate to guide planning studies.

The wind turbine models used in the simulations and shown in Table 6 come from the AEGE project database, considering only the models that should be installed in upcoming years, according to market trends. It should be noted that there are numerous other models on the market and only those that have been used are listed.

Table 6 – Wind turbines considered in the analysis

Manufacturer	Model	Rotor diameter (m)	Capacity (MW)
GE	GE158	158	5.5
Siemens Gamesa	SG145	145	4.8
Siemens Gamesa	SG170	170	6.2
Vestas	V126	126	3.3
Vestas	V150	150	4.2
WEG	AGW147	147	4.0

From AMA data and turbines power curves, the energy of each plant was calculated every 10 minutes. These values were consolidated by hour and subsystem of interest: North, Northeast and South.

Thus, 3 series with hourly generation data were estimated between 2017 and 2019. However, this period is too short for safe decision-making. There is a risk of having 3 years that were much above the average or much below it. Aiming at a safe prospective analysis, it is necessary to obtain a long-term series that accurately represents future wind farms. For this, the time series were extrapolated for a longer period using the MERRA 2 database, according to the procedure described below.

From the points where the plants are located, a model based on multilinear regression was created that uses the MERRA 2 wind speeds as explanatory variables for the generation of the 3 subsystems. The models follow a format of "$Y = \beta 0 + \beta 1X1 + \beta 2X2 + ... + \beta nXn + \varepsilon$", where Y the generation, X1..n the wind speed data of each point of the MERRA-2 used, β0..n the coefficients that validate the relation between wind and generation and ε the error ($\mu = 0, \sigma 2$).

Different models were created for each subsystem and the coefficients of determination – R2 of each model are listed in Table 7. The regressors found for each model were applied in the 40 years of the MERRA-2 data (1981 to 2020).

Table 7 – Determination Coefficient – R2 for each regression

Subsystem	R2
South	0.7752
Northeast	0.8825
North	0.6119

The maps below show the 20 MERRA-2 data points used in the models for the contracted plants for the South and Northeast and the 2 most representative points of the regressions calculated for the North subsystem.

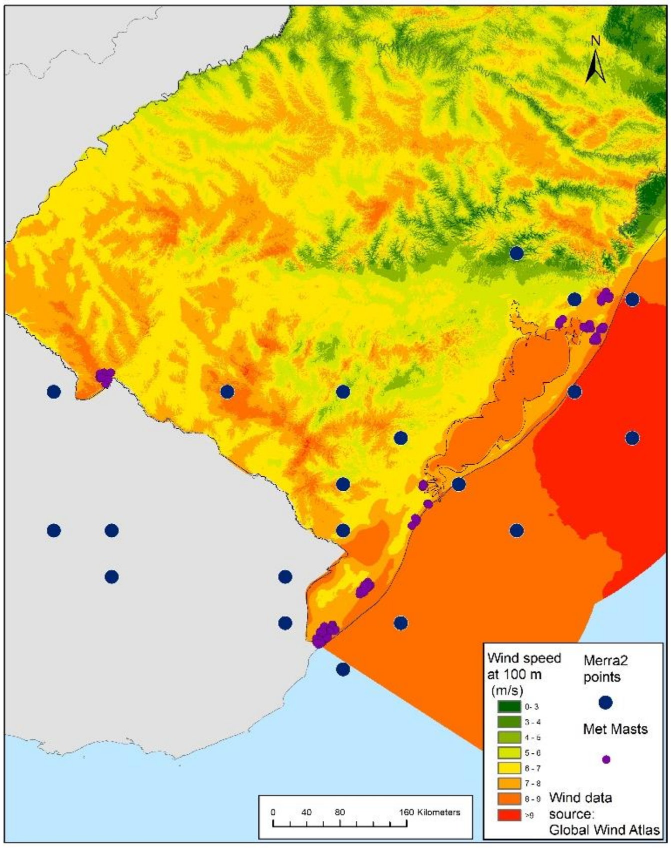


Figure 5 – South Subsystem - Flagship points

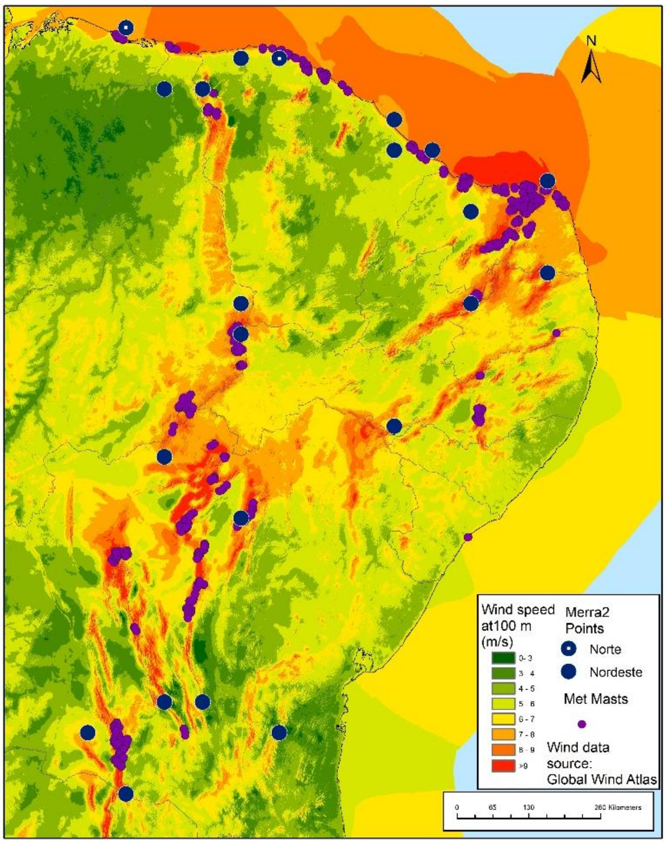


Figure 6 – Northeast and North Subsystems - Flagship points

The flowchart shown in Figure 7 summarizes the methodology used to estimate the time series between 1981 and 2020. It is important to emphasize that this methodology still has many points of improvement, to be addressed in future versions of this document.

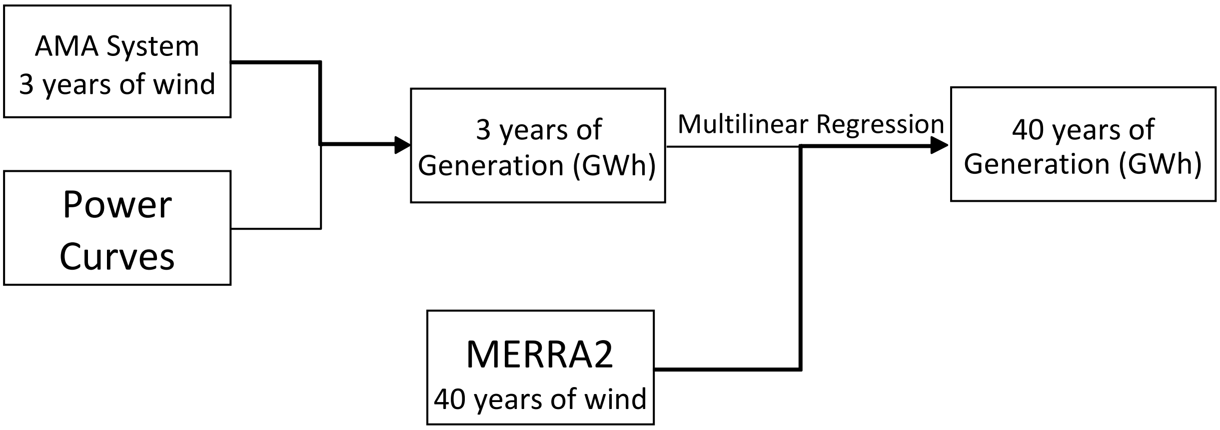


Figure 7 – Onshore wind – Flowchart

3.4 Offshore Wind

EPE currently does not have offshore wind measurement data. Therefore, only reanalysis data was used. The ERA 5 database was chosen because it already contains data series at a height of 100 meters, which gives more precision to the estimates. The methodology used was the same adopted in the potential estimate presented in the Roadmap Brazil Offshore Wind [5][6].

Energy production was estimated from wind speed data (from ERA 5 database, for the points listed below) and the power curve of a 12 MW turbine, representative of wind farms currently being built in the world. The turbine power curve used in the estimates, provided by NREL [13], is presented in Figure 8.

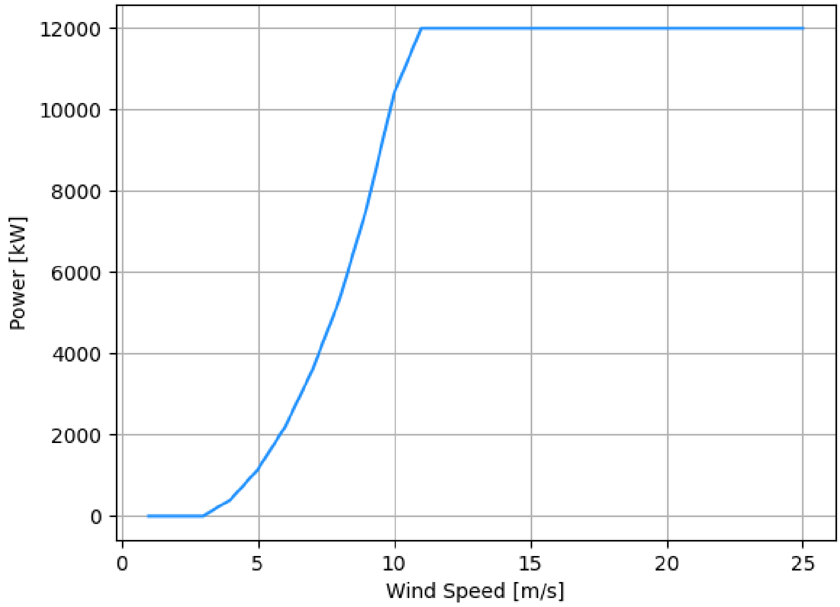


Figure 8 – Offshore turbine: power curve. [13]

Based on this, the list of projects submitted to IBAMA for the environmental licensing process (June 2022 version)[3] was considered. Generation was simulated for the selected areas, resulting in the points listed in Tables 8, 9 and 10, in which the geographic coordinates correspond to the points of the ERA 5 model in the region of each park from which the wind data were obtained. Figures 9, 10 and 11 illustrate the location of these wind farms and of ERA 5 points (markers in red) in the region.

[3] Available at: http://www.ibama.gov.br/laf/consultas/mapas-de-projetos-em-licenciamento-complexos-eolicos-offshore

Table 8 – Offshore Wind – Representative points in the Northeast

Parque	Longitude (°)	Latitude (°)	Average wind speed (m/s)
CE-03	-39,25	-3	8,64
	-39,25	-2,75	
CE-05	-40,25	-2,5	8,92
	-40	-2,5	
CE-06	-38	-4	8,45
	-37,75	-4	
	-38	-3,75	
CE-10	-38,75	-3,25	8,66
	-38,5	-3,25	
CE-12	-37	-4,75	8,87
	-37	-4,5	
	-37,25	-4,5	
PI-03	-41,5	-2,75	8,19
	-41,25	-2,75	
RN-02	-36	-5	8,90
	-36	-4,75	
	-36,25	-4,75	
	-36,25	-5	
RN-03	-35,5	-5	8,77
	-35,75	-5	
RN-08	-36,75	-4,75	9,04
	-36,5	-4,75	

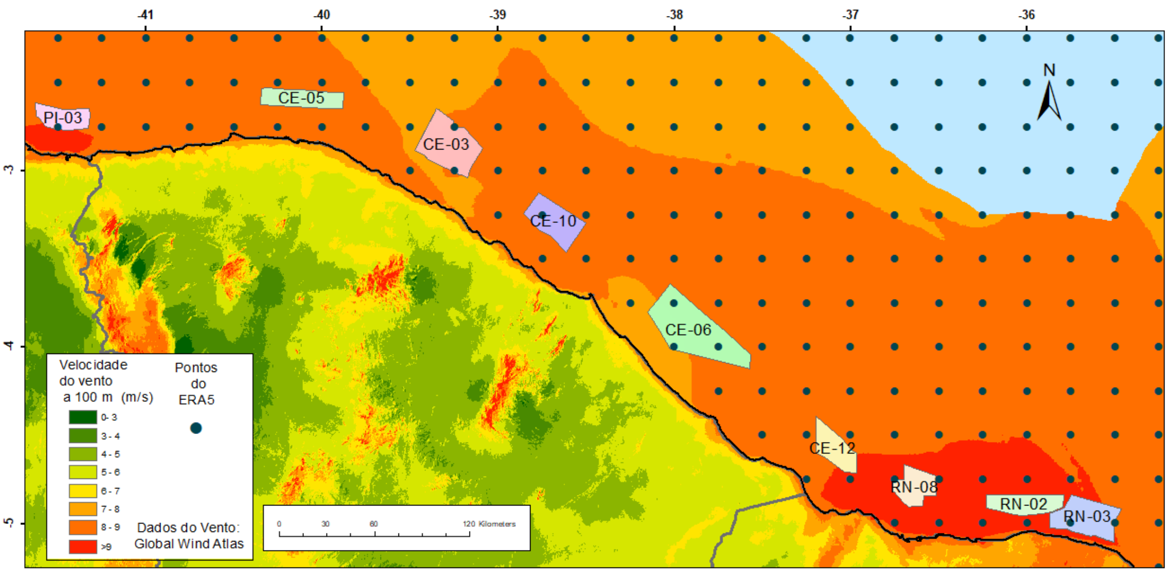


Figure 9 – Offshore Wind – Representative sites in the Northeast

Table 9 – Offshore Wind – Representative points in the Southeast

Wind Farm	Longitude (º)	Latitude (º)	Avarage Wind Speed (m/s)
ES-04	-40,25	-20,75	7,33
	-40,25	-21	
	-40,5	-21	
RJ-01	-40,5	-22	8,08
	-40,5	-21,75	
RJ-02	-40,5	-21,25	7,56
	-40,5	-21,5	
	-40,75	-21,25	
	-40,75	-21,5	
RJ-03	-41	-22,25	8,02
	-41	-22,5	
	-40,75	-22,25	
	-40,75	-22,5	
RJ-04	-41,25	-22,5	7,73
	-41,25	-22,75	
	-41,5	-22,5	
	-41,5	-22,75	
RJ-06	-40,25	-21,5	8,04
	-40,25	-21,75	
	-40,5	-21,5	
	-40,5	-21,75	

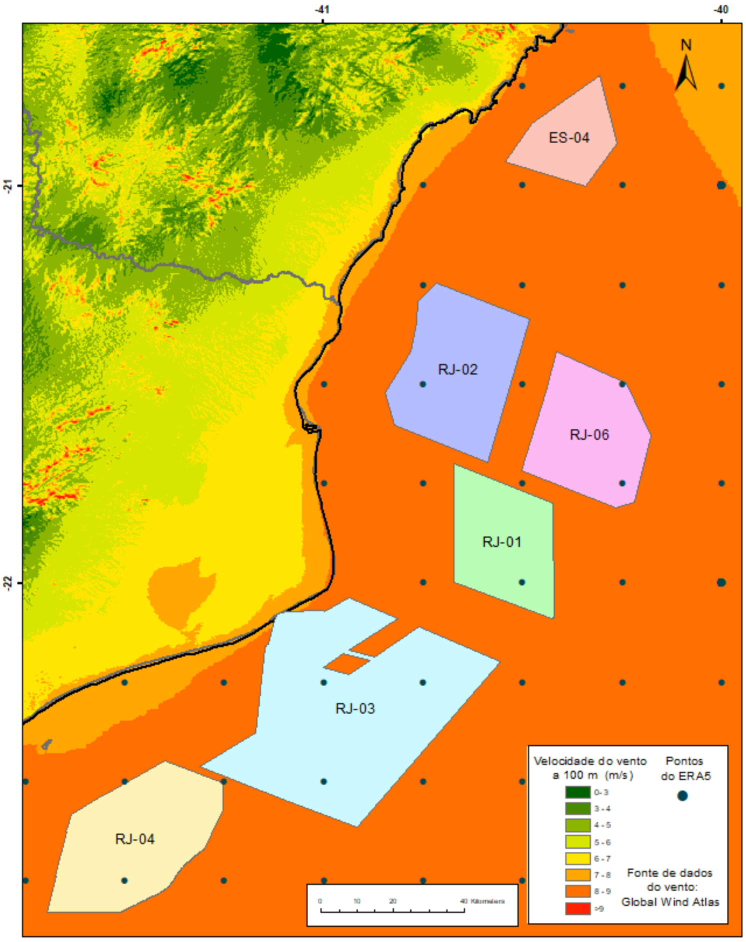


Figure 10 – Offshore Wind – Representative sites in the Southeast

Table 10 – Offshore Wind – Representative points in the South

Wind Farm	Longitude (º)	Latitude (º)	Avarage Wind Speed (m/s)
RS-02	-50	-30,25	8,41
	-50	-30,5	
	-49,75	-30,25	
	-50,25	-30,5	
	-50,25	-30,75	
RS-09	-53	-33,75	8,21
	-52,75	-33,5	
	-52,75	-33,75	
RS-11	-52	-32,5	7,95
	-52,25	-32,5	
RS-12	-51,5	-32	8,26
	-51,75	-32,25	
RS-17	-52,5	-33,25	8,27
	-52,5	-33,5	
SC-01	-49	-29	8,13
	-48,5	-28,75	
	-48,75	-29	

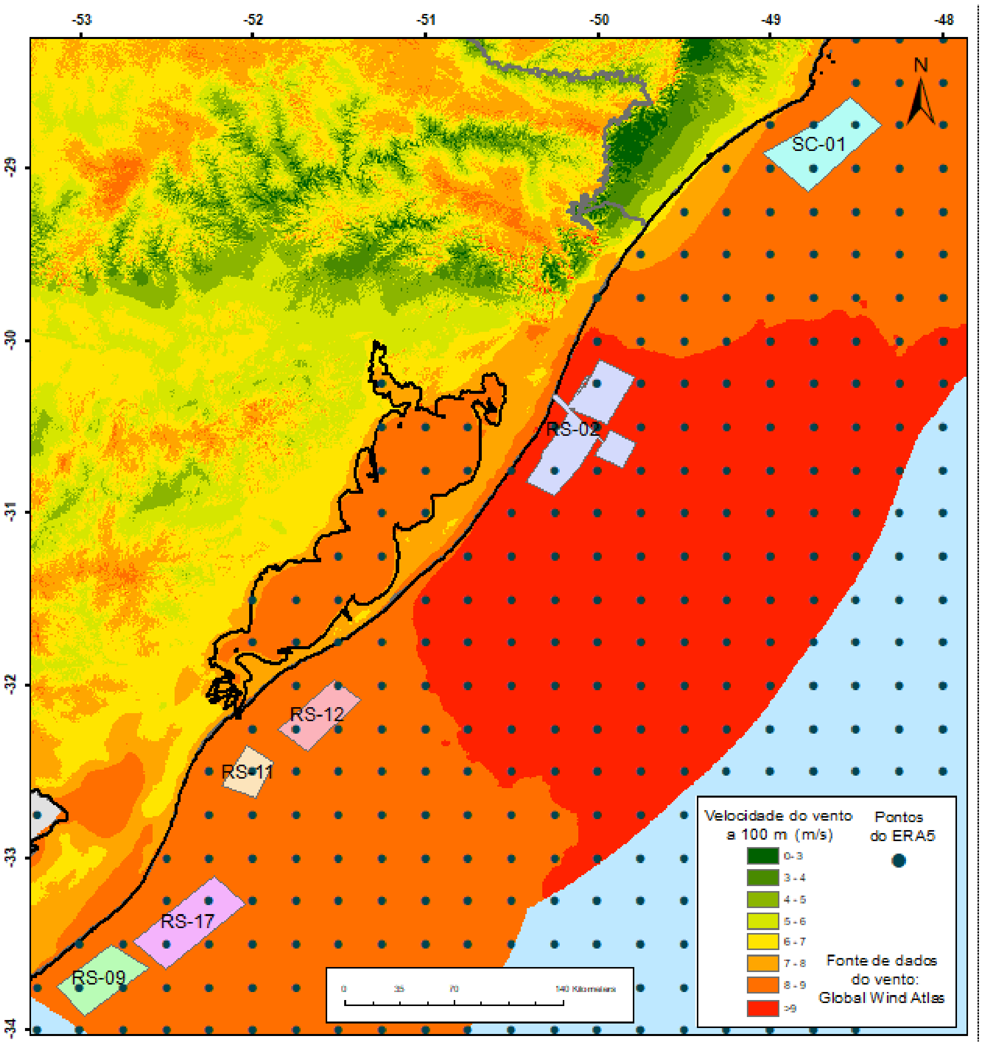


Figure 11 – Offshore Wind – Representative sites in the South

4. RESULTS AND APPLICATION IN MODELS

From the procedures and data shown above, hourly energy series (in MWh) that represent the installed wind and solar plants were estimated. As the future installed capacity is unknown, all energy estimates calculated in this study are in PU (Per Unit), allowing them to be used, regardless of the future number of projects. In addition to this data normalization, it is important to make an aggregation of plants into groups with similar characteristics. This is necessary because, as the number of wind and solar farms is very large, the computational cost of individual analysis is very high.

In this chapter, the attributes used to breakdown plants into regions and sub-regions will be shown. Then, it shows the data used in EPE's generation and transmission studies.

4.1 Breakdown into Regions

The breakdown of wind and solar power plants into regions is an important step for the insertion of these sources in the models used by EPE. For each study, there is an ideal breakdown, which will depend on the characteristics of the models used.

In the generation planning studies, covered in item 4.2, the breakdown is done by subsystem, that is: North, Northeast, Southeast/Midwest and South. As for the transmission studies, the breakdown is done by substations of the main grid, as will be shown in item 4.3.

In other analyzes and studies by EPE, it is important to know the breakdown of plants according to their energy characteristics, a topic that is detailed below.

4.1.1. Solar Photovoltaic

Spatial variability of solar photovoltaic generation is relatively small compared to other sources. Plants located tens of kilometers away tend to have relatively similar profiles, except in regions with rugged terrain, which are little used for this source. For this reason, each set of nearby plants is represented in the studies as just one point, using the solarimetric data of that municipality. Considering, therefore, that the number of representative points is relatively small (38 are currently used), the trend in EPE generation and transmission studies is to use the complete set of simulated hourly data presented in Chapter 3, adjusting the weights of each location according to the study in question.

However, when analyzing the monthly profiles of each location, it is clear that there are differences between the regions. Four regions were identified with different monthly profiles, shown on the map in Figure 12 –12.

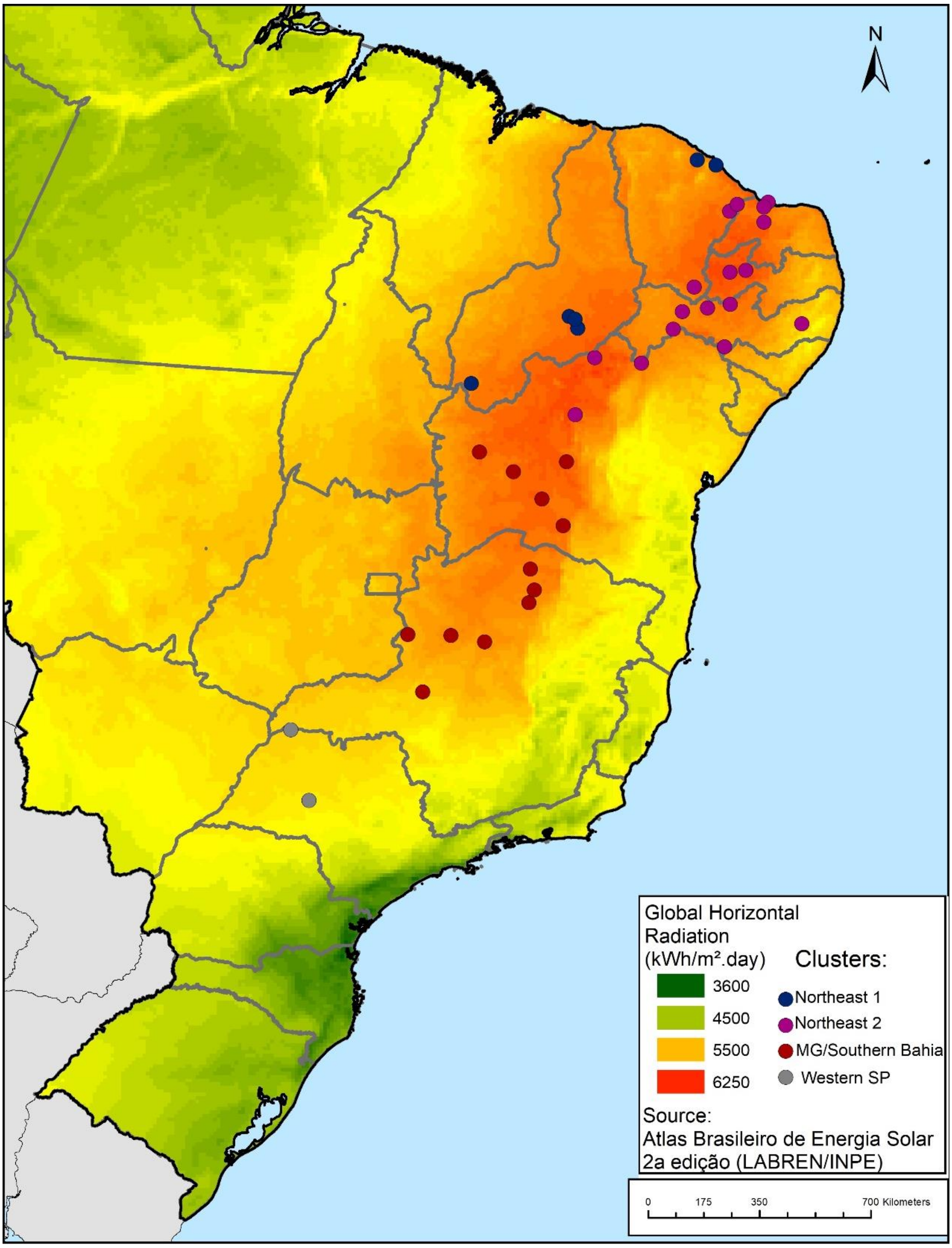


Figure 12 – Breakdown by clusters of points simulated for solar photovoltaic

Figure 13 exemplifies the monthly profiles for each region, taking a representative location for each of them. It should be noted that source seasonal variations are relatively small for all places, being a little larger for the west of São Paulo. Furthermore, the differences between each region, although they exist, are not very significant, and depending on the study, this breakdown is not considered.

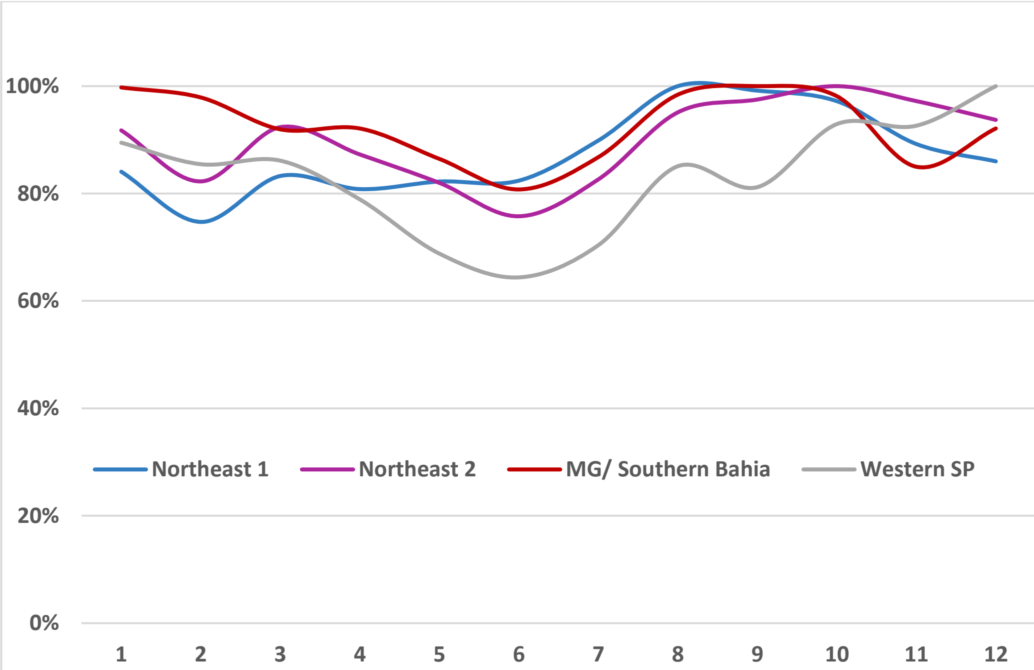


Figure 13 – Example of monthly profile by region

It is noteworthy that this breakdown has not been used in EPE studies and each location is represented individually. However, in future works, this breakdown could be adopted, depending on the need for simplification.

4.1.2. Onshore Wind

The breakdown of the wind farms into regions was carried out in two stages. In the first stage, the seasonality of the plants was evaluated, that is, their monthly characteristics. This analysis was used to break down plants into regions. In the second stage, each of the regions was broken down into sub-regions, according to their hourly characteristics. These procedures were carried out for the Northeast and South regions.

In order to assess the similarity between the plants, the correlations between the 462 measurement stations of the AMA System were calculated. Below are the results and monthly and hourly characteristics for each region.

In the first stage, the Northeast Region was broken down into 3 regions. The region with green spots, called Coastline, comprises plants from Maranhão to Paraíba States. The region in blue corresponds to the plants in the Interior and includes Bahia, southern Piauí and western Pernambuco. The region in red, in its turn, corresponds to some plants in Pernambuco in the region of Garanhuns that have a very different behavior from the other 2 regions, as can be seen in Figure 15. All charts shown are normalized by maximum generation.

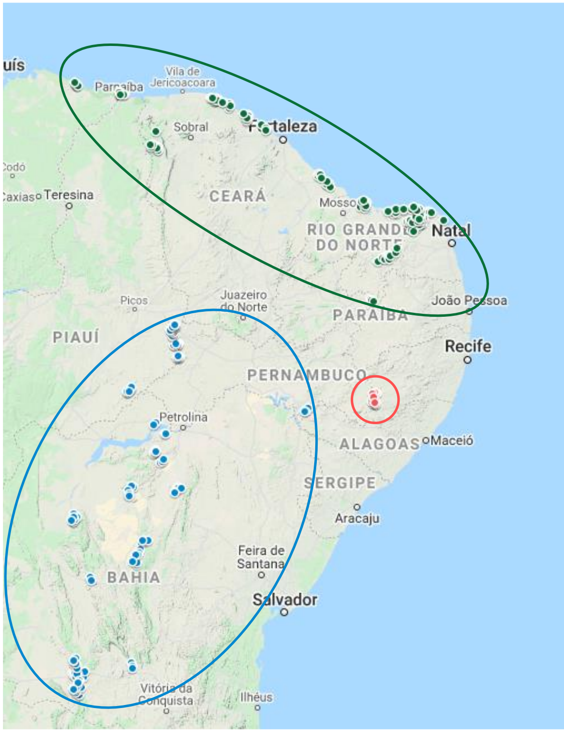


Figure 14 – **Breakdown of the Northeast into Regions**

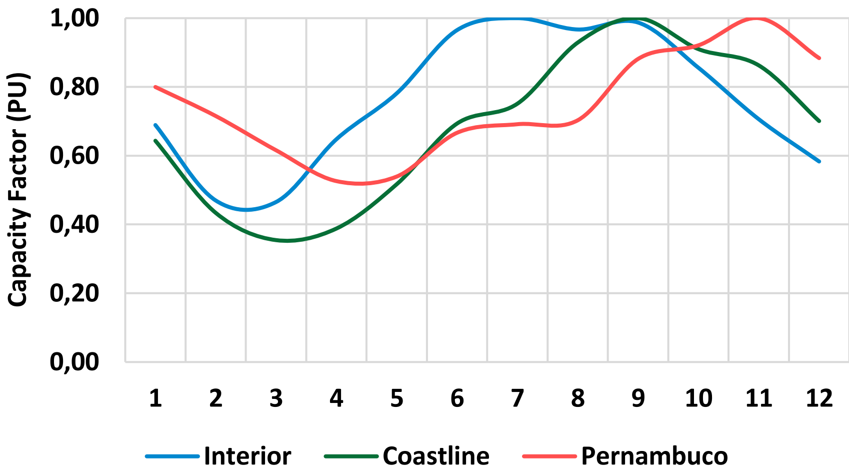


Figure 15 – **Northeast Regions: Monthly profile**

Despite similar monthly behaviors, when observing the hourly profile, it is clear that there are differences between plants in the same region. Therefore, regions, where necessary, were broken down into sub-regions, as shown below. The Interior of the Northeast was broken down into 5 sub-regions:

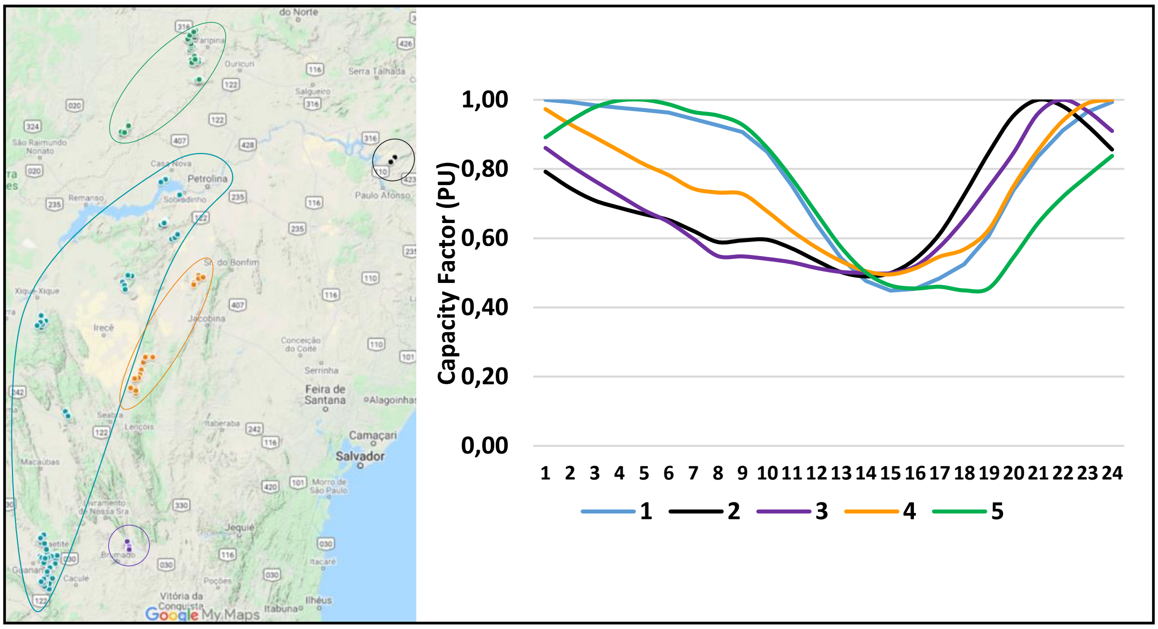


Figure 16 – Subregions of the Northeast Interior

The Northeast Coast was broken down into 4 sub-regions. Note that, in this case, the plants in the same sub-region are not always close together. Sub-region 2 (green), for example, is formed by plants on the coast of Maranhão, Ceará and Rio Grande do Norte.

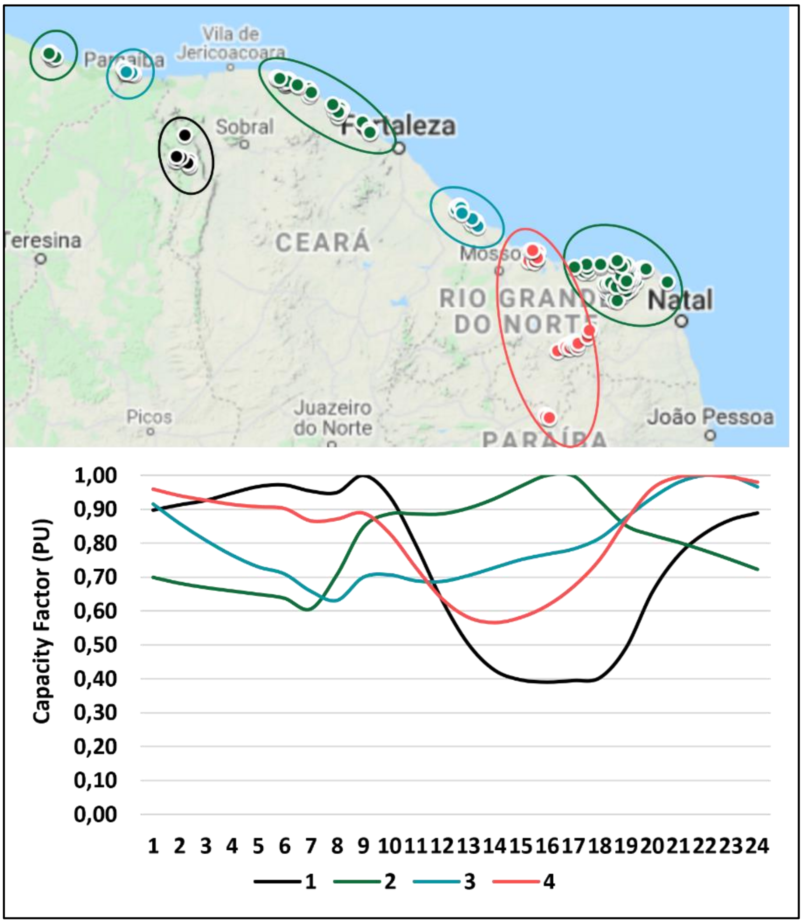


Figure 17 – Subregions of the Northeast Coastline

In the Garanhuns region there is no difference in the time profile of the plants, shown in Figure 18.

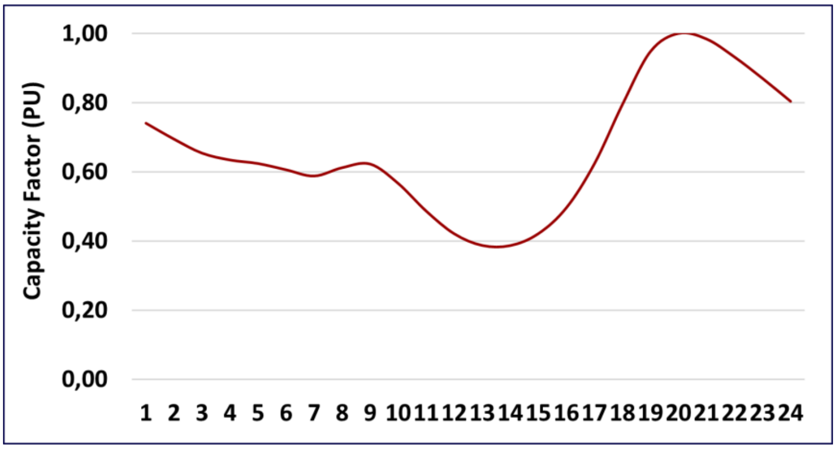


Figure 18 – Garanhuns/PE: Hourly profile

In the South Region, the wind farms were broken down into three regions, as shown below.

The Region in red corresponds to the interior parks of Rio Grande do Sul state. The coastline was broken down into two different regions.

In the South Region, the wind does not behave the same way during different days. In other words, in one day, the maximum generation can be at 1 PM. The next day can be at 2 PM. Thus, there is no typical hourly profile as it happens with the Northeast winds. Therefore, there is no need to divide regions into sub-regions.

Figure 19 – Breakdown of the South into Regions

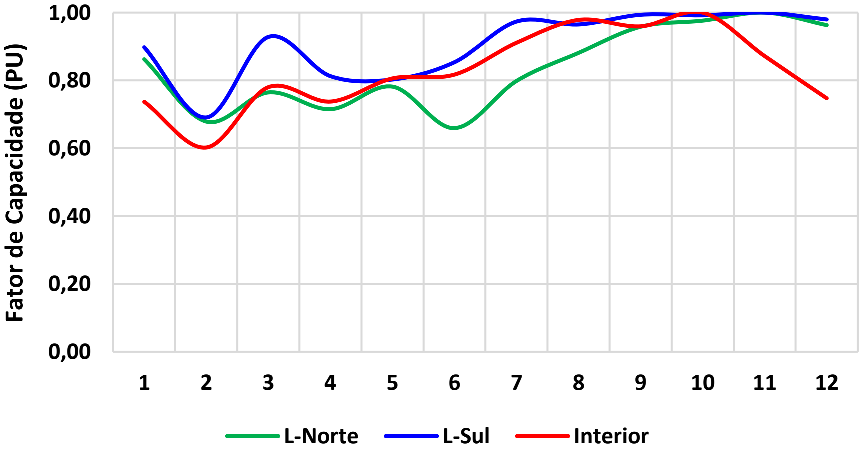


Figure 20 – South Regions: Monthly profile

4.1.3. Offshore Wind

Offshore wind studies at EPE doesn’t include yet the same detail level as onshore wind, and it consider the generation estimation for the areas shown in section 3.4.

For comparison, and following the results presentation for the other sources, the data were aggregated by region, as show in Figure 21, although this aggregated is not used in EPE’S studies until now. However, it can be used in future studies, depending on the need for simplifying.

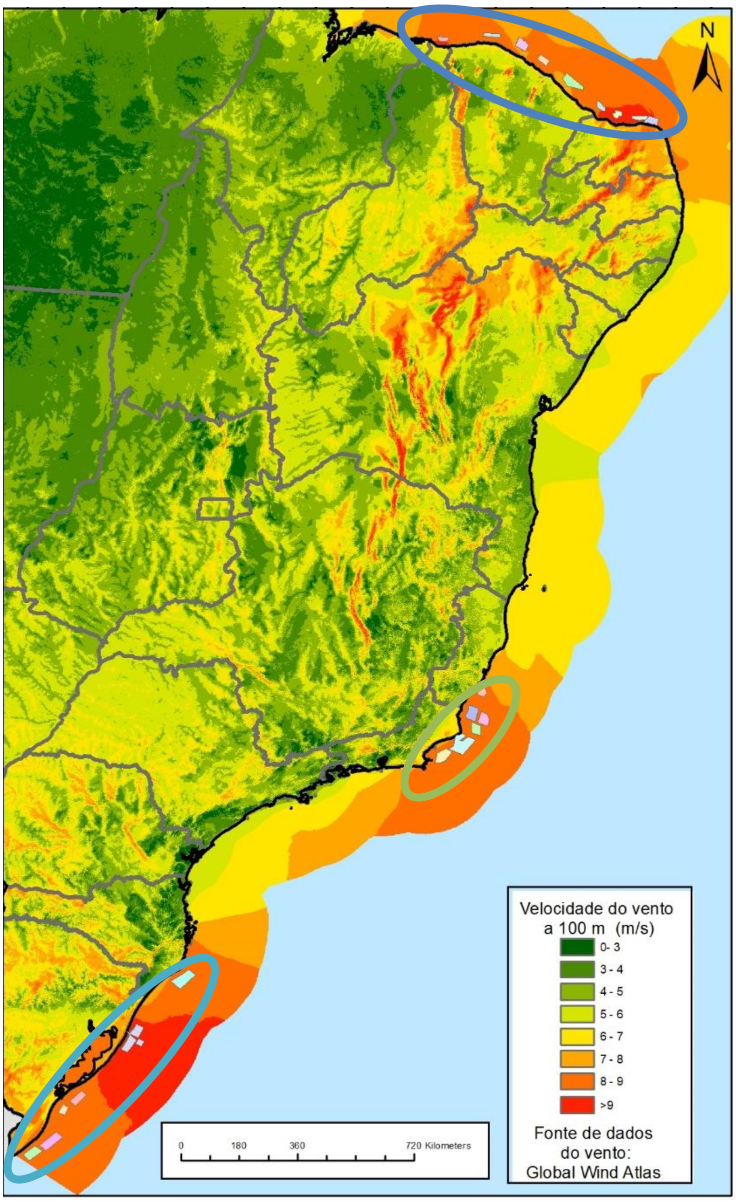


Figure 21 – Offshore wind: Breakdwon into regions

The Figure 22 brings examples of montlhy profiles for each region, considering the the average of the wind farms in each one. The re are significant variations, with a more intese seasonality in the Northeast region. The second semester has a higer genaration in the three cases.

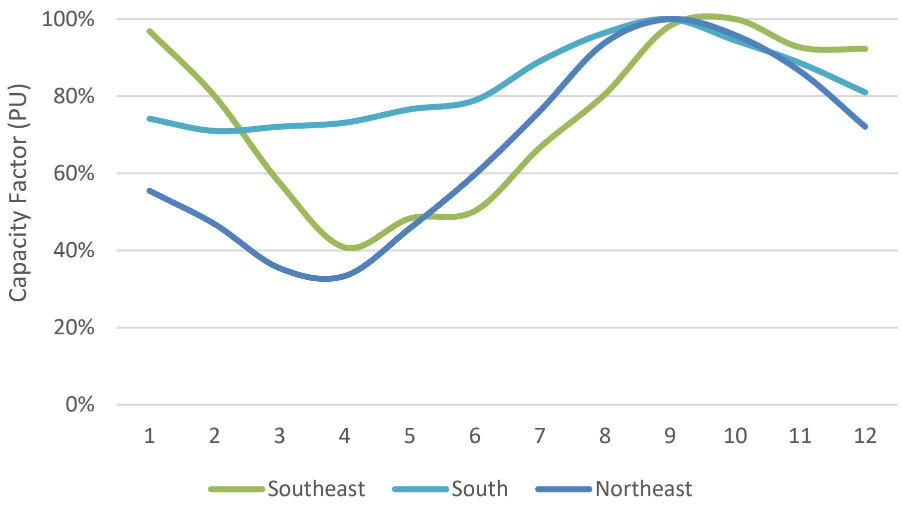


Figure 22 – Offshore *wind*: monthly profile - regional averages

It is import to take care when reading this graph, especially in the comparison between regions, as data are in PU and have been normalized considering the highest monthly values in each region. The graphs in section 4.2.3 allows a capacity factor comparison.

4.2. Energy Studies

In the energy studies carried out by EPE, mainly in the Ten-Year Energy Expansion Plan (henceforth, PDE as in the Portuguese acronym), 3 main models are used (NEWAVE, MDI and Power Balance), where the conditions of the power system are assessed in relation to the criteria for the supply of energy and power [7]. These models have several data entries relating to all energy sources that are used in the country. In this item, only data entries related to the energy contribution of wind and solar photovoltaic sources will be addressed.

For the NEWAVE and MDI models, monthly expected generation data (capacity factor) must be provided, apart from the energy contribution by load blocks to emulate a load duration curve (light, medium, heavy and peak load blocks).

The contributions by load block (light, medium and heavy) are calculated considering the representative value as the average expected generation for the typical hours of each block. Then, the rated representative values, for each month, are divided by the monthly generation to have the representative value in PU. For example, considering the typical hours of heavy load in July at 7, 8 and 9 P.M., we calculate the average of the hourly generation scenarios of the source for these hours, to have the representative value. Then, the result is divided by the average of all expected generation scenarios, for all hours of the month. This procedure considers the typical hours of each load block for each month of the year, set as reference for the load forecast. This can be applied both for the gross or the net load, changing the typical hours of each block.

For the peak block, also used in the PDE methodology, the representative value is calculated based on the hourly generation forecast with 95% probability (P95) of occurrence, based in all the hourly expected scenarios distribution, for each month. into obtain the PU factor, the representative value is also divided by the monthly average generation. Unlike the representative values considered in other load blocks, the peak value consideration is independent of typical load hours. This can be explained by two main reasons: the greater uncertainty on the peak or maximum instantaneous load hours; and greater risk aversion for the hourly variability of wind and solar irradiation.

Table 11 summarizes the necessary inputs to the energy models used in the PDE.

Table 11 – PDE – Data input

Data	NEWAVE / MDI	Power Balance
Solar Photovoltaic	- Monthly capacity factor (AEGE system) - Breakdown into load blocks from hourly generation data (section 3.1)	Hourly estimated generation with the methodology described in section 3.1.
Onshore wind	- Monthly capacity factor (AEGE system) - Breakdown into load blocks from hourly generation data (section 3.2)	Hourly estimated generation with the methodology described in section 3.2
Offshore wind	- Monthly capacity factor and breakdown into levels from ERA 5 data (section 3.3)	Hourly estimated generation with the methodology described in section 3.4

Since in the previous chapters the issues related to the estimatives of the hourly generation series have already been stated, in this item the procedures used to assess the monthly capacity factors based on data from the AEGE System will be detailed. It is important to highlight that, in the PDE studies there is a differentiation between the representation of existing and future plants. In this item, only issues related to future plants will be addressed.

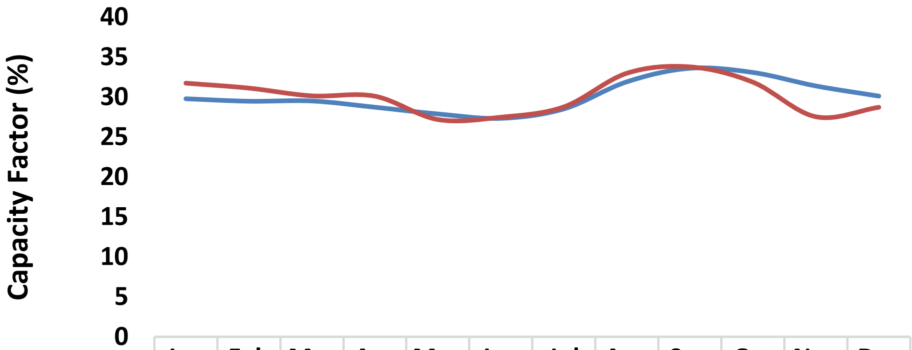
4.2.1. Solar Photovoltaic

The monthly energy contribution of the photovoltaic source can be estimated from the typical capacity factors of this source in the different subsystems, obtained from the data of the projects qualified for the regulated market energy auctions.

From the AEGE System Database, the Monthly Capacity Factors (mean values of the project sample) were defined for the NE and SE/CO subsystems, on a CA basis, considering only the projects qualified in the A-4/2019, A-6/2019 and A-4/2020 energy auctions, with single axis tracking system, as all the winning projects in recent auctions/years considers this configuration. [8]

The capacity factor on an AC basis is used for correct comparison with other sources and consideration of the use of the transmission system. The sample comprises 863 projects in the Northeast and 72 in the Southeast/Midwest.

As a result, the capacity factors presented in Figure 2323 were obtained.

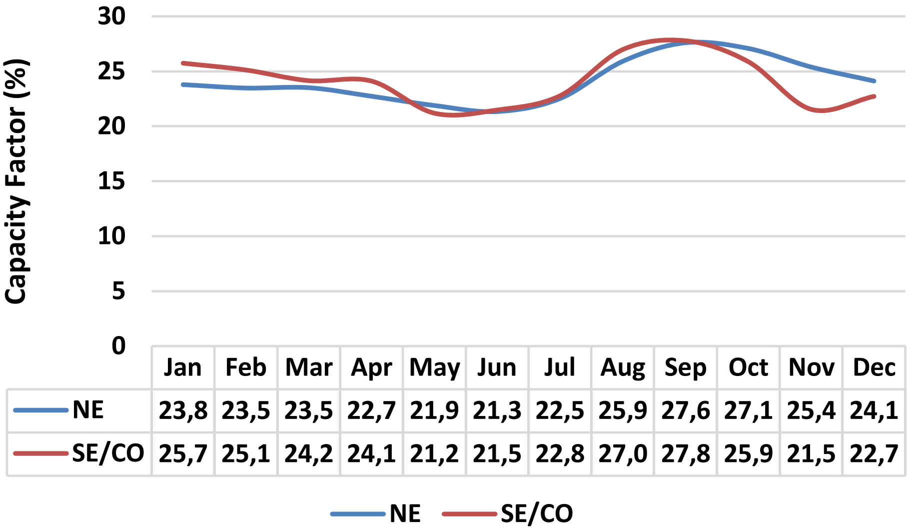


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NE	29,8	29,5	29,5	28,7	27,9	27,3	28,5	31,9	33,6	33,1	31,4	30,1
SE/CO	31,7	31,1	30,2	30,1	27,2	27,5	28,8	33,0	33,8	31,9	27,5	28,7

NE SE/CO

Figure 23 – Photovoltaic: Monthly capacity factor per subsystem

For floating solar photovoltaic plants, considering that they generally use fixed structures, lower capacity factors were considered instead of those from plants with single axis tracking, with a small gain resulting from the lower operating temperature of the modules [9]. Given the absence of plants of this type in the auctions, and consequently, in the AEGE system, a reduction of 6 percentage points was used as an approximation in relation to the values obtained for centralized plants, with single axis tracking system.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NE	23,8	23,5	23,5	22,7	21,9	21,3	22,5	25,9	27,6	27,1	25,4	24,1
SE/CO	25,7	25,1	24,2	24,1	21,2	21,5	22,8	27,0	27,8	25,9	21,5	22,7

Figure 24 – **Floating Photovoltaic: Monthly capacity factor per subsystem**

4.2.2. Onshore Wind

The monthly energy contribution of the onshore wind source can be estimated from the typical capacity factors of this source in the different subsystems, obtained from the data of the projects qualified for the regulated market energy auctions.

Regarding the indicative plants (expansion power plants), based on data from the AEGE system, from projects qualified for the energy auctions, monthly capacity factors (average values of the project sample) were obtained for each subsystem.

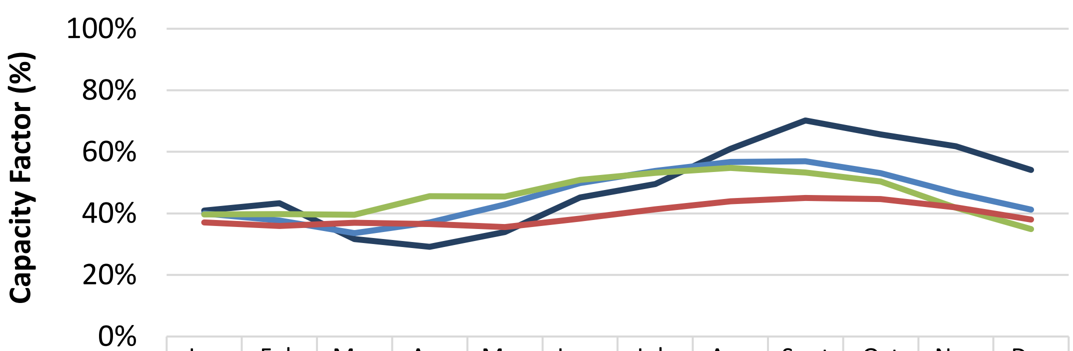
The first step in this process was determining the sample to be used. As the technology used to generate wind energy has developed a lot in recent years, only qualified projects were used, whose wind turbines fit into the group of more recent models, according to Table 12. In fact, the trend observed in recent years is towards the adoption of wind turbine models with higher capacities and larger rotors [10]. The final sample has 664 projects in the Northeast, 100 in the South, 54 in the Southeast/Midwest, and 3 in the North.

Table 12 – Wind turbines adopted

Manufacturer	Model	Rotor diameter (m)	Capacity (MW)
GE	GE158	158	5,5
GE	GE158	158	5,3
GE	GE158	158	4,8
Nordex	N149	149	5,5
Nordex	N163	163	5,5
Nordex	N163	163	5,7
Siemens Gamesa	SG145	145	4,8
Siemens Gamesa	SG170	170	6,0
Siemens Gamesa	SG170	170	6,2
Vestas	V136	136	4,2
Vestas	V150	150	4,2
Vestas	V150	150	4,0
Vestas	V150	150	4,5
WEG	AGW147	147	4,2
WEG	AGW147	147	4,0

After defining the sample, the second stage dealt with the calculation of the monthly Capacity Factor for each project. The AEGE System has annual firm energy certificate values available on a P90 basis and monthly certified productions on a P50 basis. Thus, it is necessary to adjust the P90 according to the monthly P50 values, obtaining monthly P90 values for each project. From this data, monthly capacity factors can be calculated.

Based on the above, the following results were obtained:



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
N	40,9%	43,3%	31,7%	29,1%	34,0%	45,2%	49,5%	61,0%	70,2%	65,6%	61,9%	54,1%
NE	40,0%	37,7%	33,6%	37,0%	42,9%	49,9%	53,8%	56,7%	56,9%	53,1%	46,7%	41,2%
SE/CO	39,7%	39,8%	39,5%	45,6%	45,5%	50,9%	53,2%	54,8%	53,3%	50,4%	41,8%	34,9%
S	37,0%	35,9%	36,9%	36,5%	35,6%	38,3%	41,3%	43,9%	45,0%	44,7%	42,0%	38,0%

Figure 25 – Onshore wind: Monthly capacity factor per subsystem

Note that the results for the SE/CO and N subsystems have a limited sample. Thus, these data are consistent only with the specific locations registered in the AEGE System. The results of the NE and S subsystems are representative of the average profile of these regions.

4.2.3. Offshore Wind

It was not possible to use the AEGE data to estimate the contribution of offshore wind power plants, as there are no projects registered at EPE. Thus, only reanalysis data from the Brazilian coast was used, as has been shown in items 3.2.3 and 4.1.3, for calculating the energy generation in each site, shown on the graphs below.

It is interesting to see the resource differences between these sites. For all areas, the generation is higher during the second semester, which is even more intense in the Northeast, as shows the Figures 26, 27 and 28.

For the neergy models we selected the candidates with the highest capacity factor in each region (RN-08, RJ-01 e RS-02), highlighted with red lines in the graphs. However, the differences are very little in some cases.

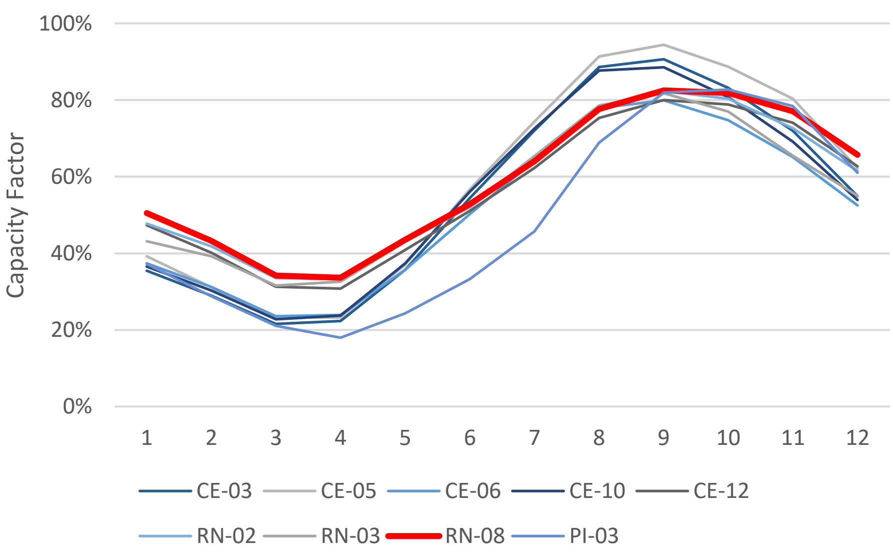


Figure 26 – Offshore wind: Monthly profile - Northeast

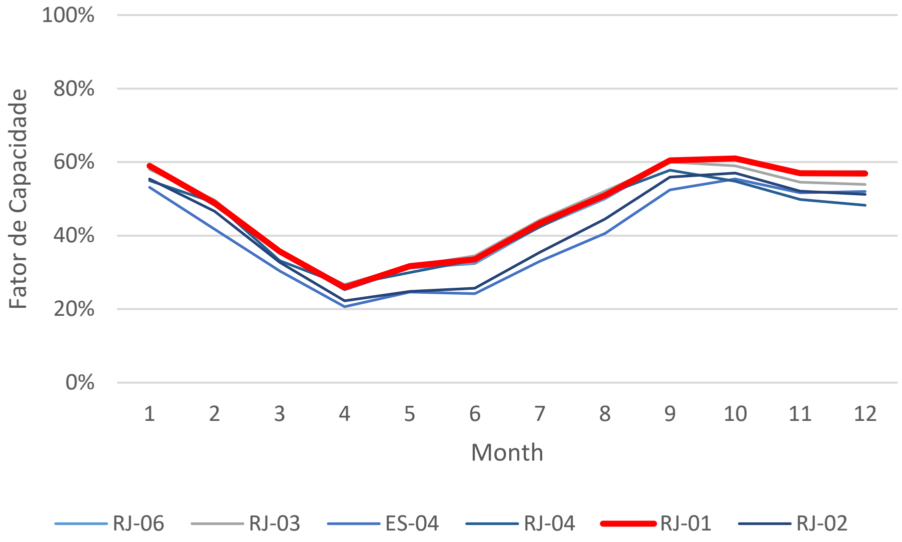


Figure 27 – Offshore wind: Monthly profile - Southeast

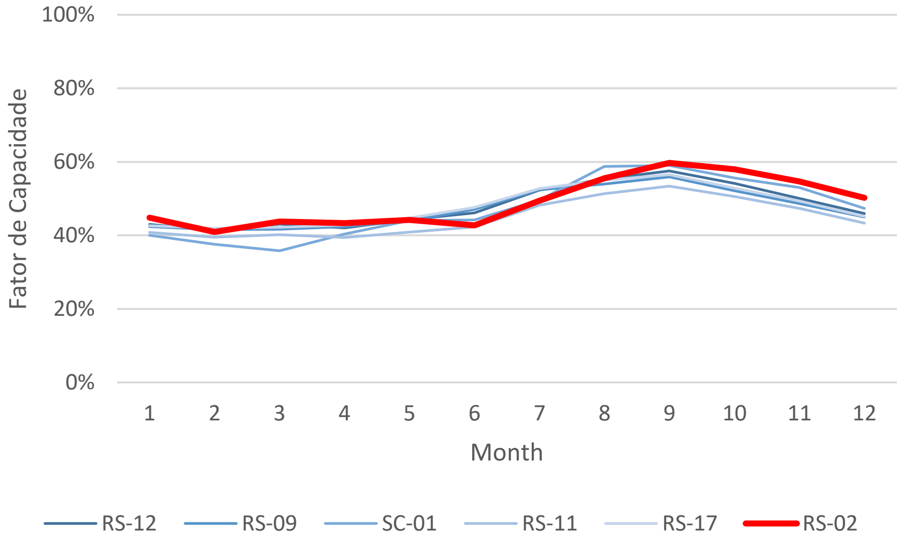


Figure 28 – Offshore wind: Monthly profile - South

Regarding the hourly profile, in the Northeast, there wind is usually stronger during the night in some sites, while in the Southeast and South it seems more flat during the day.

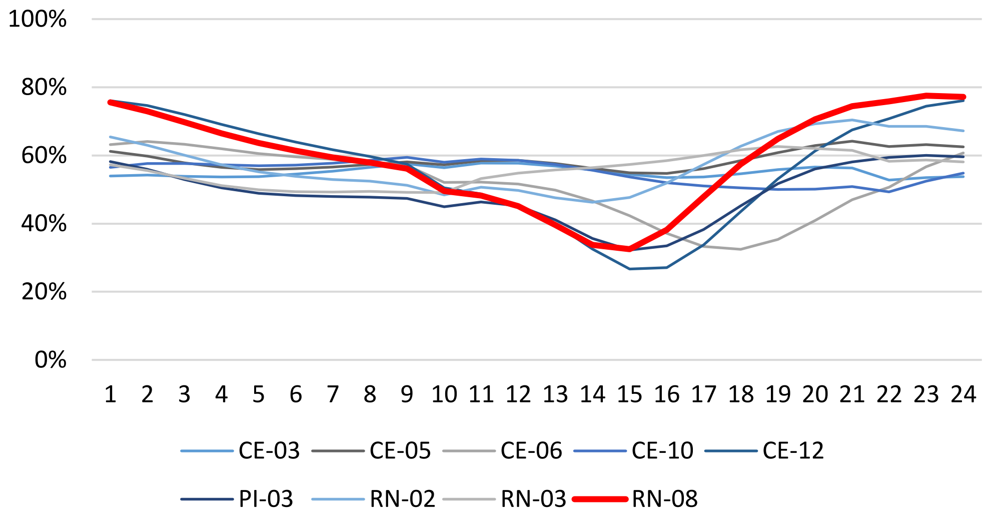


Figure 29 – Offshore wind: Hourly profile - Northeast

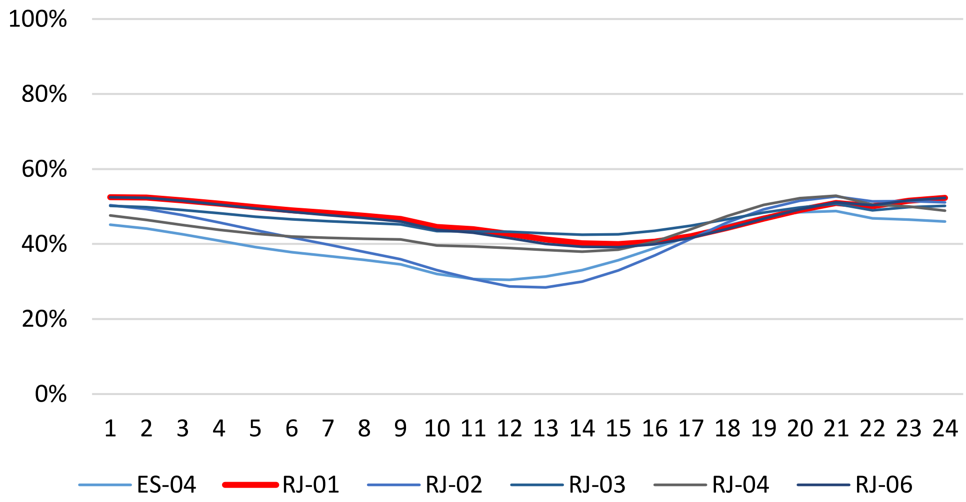


Figure 30 – Offshore wind: Hourly profile - Southeast

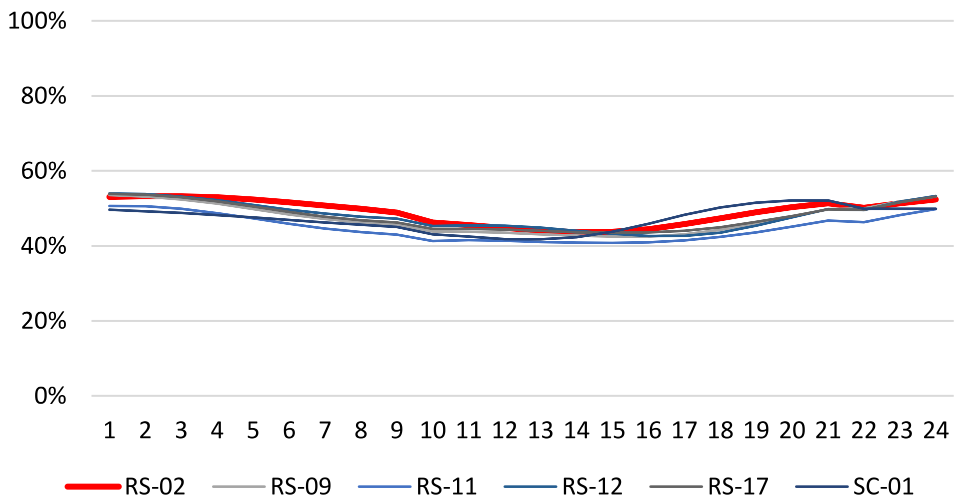


Figure 31 – Offshore wind: Hourly profile – South

The graphs below compares onshore and offshore wind generation in the Northest and South regions, based on average data.

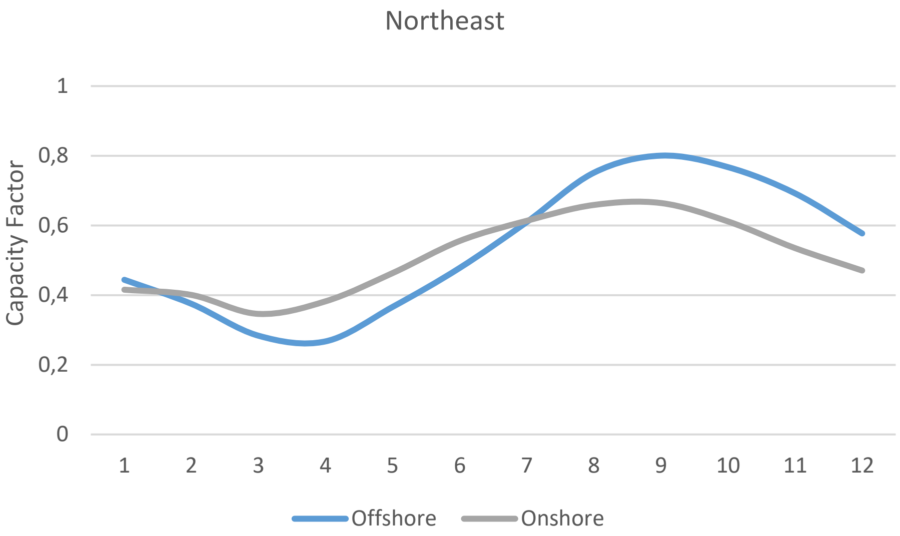


Figure 32 – *Onshore* and *Offshore wind*: Average monthly profile – Northeast

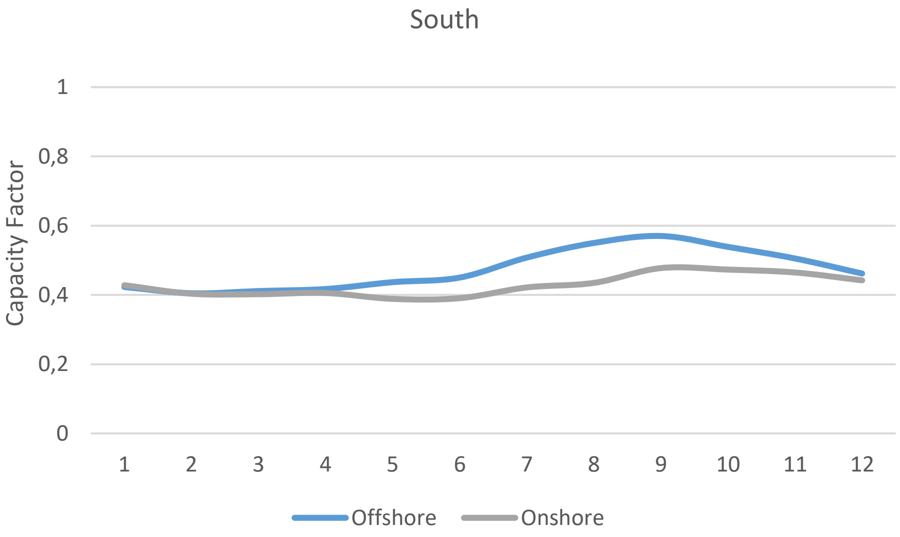


Figure 33 – *Onshore* and *Offshore wind*: Average monthly profile – South

The ofshore wind capacity factor was a little higher than the onshore in the Northeast, but with a more intense seasonality. The South had a greater difference, but with lower capacity factors. As shown in the previous graphs, there are different generation profiles within a region, both for onshore and offshore wind.

These comparions, however, are very simple, as they consider regional average numbers, calculated solely from reanalysis data in the case of the offshore wind. Thus, it is important to have wind measurements to validate and improve such estimations.

4.3. Power Studies

The power studies carried out at EPE use a chain of specific models for power flow, short-circuit, electromechanical transients and other analysis. The initial study of the power grid is carried out by analyzing the performance in steady state at different load levels and generation dispatch scenarios, through power flow simulations using ANAREDE software [11].

These generation dispatch scenarios must be representative of the critical conditions of the assessed system and, in the case of wind and solar generation, the data series must have the greatest possible time-step granularity, due to the high variability of these sources. Therefore, the wind power series have a granularity of 10 minutes and the solar series, a 1 hour one.

An important difference between energy and power studies is the breakdown into regions. In power studies, greater detailing is needed than the breakdown into subsystems used in energy studies. As shown in the previous chapters, wind generation estimates are made by plants and solar generation estimates are made by location. Since the number of wind farms is very large, 18 substations were grouped up. In the case of solar generation, 37 locations were maintained.

The main parameters of the bases used are summarized in Table 13.

Table 13 – Input data for power studies

Source	Spatial breakdown	Time resolution
Solar PV	37 locations	1 hour
Wind	18 substations	10 minutes

It is important that all data from different regions are synchronized, so that simultaneous generation analyzes can be carried out between regions. Thus, it is possible, for example, to estimate the probability of generation in a region, when another region is at 100% of its rated power.

5. FINAL REMARKS

In EPE studies, it is often necessary to estimate the energy contribution of non-controllable sources (wind and photovoltaic solar), both in power and energy studies carried out annually, such as the PDE, and in special studies related to hybrid power plants, offshore wind, the modernization of the power sector or other analysis of commercial and regulatory issues, and others. For this, the use of representative series of the long-term behavior of sources is essential to assess not only the effects of the average contribution of each generation source, but their annual, monthly and hourly variability.

In this regard, it is important that both the methodology used by EPE and the series are made available published, with as much detail as possible, at EPE´s website.

Due to the number of wind farms installed in Brazil, it is convenient to break down the country into regions. Since 2013, EPE has used the regions defined in NT DEA 15/13 [12], which was published when the AMA System had only 84 anemometric stations. From this study (since its first version), we considered data from 462 AMA system stations, and defined new regions and sub-regions, which will be the new reference for EPE studies.

Additionally, given the progress of discussions on offshore wind in Brazil, the current version of this document brought an updated methodology, which aims to represent the sites of greatest interest for the use of this resource.

It is important to highlight that the same primary database is used for energy and power studies, ensuring that, even when carried out independently, they have consistent assumptions.

The considerations presented here depend on the technology used in the generation sources, the available wind and radiation data and the locations in which the sources are developed. Thus, these studies can and should be revisited periodically to include new locations, update the technology used and project locations, or use primary data with greater resolution.

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