Solar and Wind Energy Resource Assessment in BRAZIL

Enio Bueno Pereira
Jorge Henrique Greco Lima

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National Institute for Space Research - INPE
São José dos Campos
1st Edition - May, 2008.

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P414s Solar and wind energy resource assessment in Brazil.

Enio Bueno Pereira ; Jorge Henrique Greco Lima (orgs.).
São José dos Campos, SP, Brasil: MCT/INPE, 2008.
100p. ; (papel).

ISBN: 978-85-17-00038-6

1.Energy. 2.Renewable energy. 3.Solar energy. 4. Energy assessment.
I.Pereira, E. B.; Lima, J.H.G.; Martins, F.R.; Abreu, S.L.; Chan, C.S.; Rüther, R.;
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CDU: 620.91

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São José dos Campos, SP, Brasil: MCT/INPE, 2008.
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ISBN: 978-85-17-00039-3

1.Energy. 2.Renewable energy. 3.Solar energy. 4. Energy assessment.
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FOREWORD

Until very recently climate protection and energy security have been viewed as largely contradictory or separate matters. This scenario has changed in response to the ever-increasing energy demand in developing economies such as Brazil, China and India. In order to ensure a stable climate in a global sustainable development, while providing means for the improvement in our standards of life, we must make responsible decisions about our energy sources while searching for solutions to reduce the dependence on the fossil fuels in our energy matrix.

Industrialized countries are responsible for the greenhouse gases, such as carbon dioxide (CO_2), that have built up in the atmosphere since the beginning of the industrial era. Nonetheless, a worldwide effort is now necessary to reverse or, at least, reduce their effects on climate and prevent future damage to the environment. Although no single solution can meet our society's future energy needs and, at the same time, reduce the buildup of CO_2 and other greenhouse gases in the atmosphere, some practical measures are possible. For example, the gradual but permanent substitution of fossil energy by renewable energy sources for electricity generation, such as wind, solar, geothermal, and bioenergy. To achieve this goal we must increase confidence on renewable energy by reducing barriers to the adoption of renewable technologies, encouraging investors, venture capital firms, independent power producers, and government purchasers of energy.

This report represents a long-term Brazilian cooperative effort between the Electric Power Research Center (CEPEL), the National Institute for Space Research (INPE), and University of Santa Catarina (UFSC) to demonstrate the long-term potential for the large scale use of solar and wind energies in Brazil. It is one of the outputs of Project SWERA (Solar and Wind Energy Resource Assessment) for Brazil, which started in 2001 as a pilot project managed by the United Nations Environment Program (UNEP), co-financed by the Global Environment Facility (GEF), and has expanded in 2006 into a full program. Its mission is to provide high quality information in suitable formats on renewable energy resources for countries and regions around the world, along with the tools needed to apply these data in ways that facilitate renewable energy policies and investments.

EXECUTIVE SUMMARY

The SWERA (Solar and Wind Energy Resource Assessment) program core mission is to provide online high quality renewable energy resource information at no cost to the user for countries and regions around the world. Renewable energy maps, atlases, and assessments can be downloaded in the project's website http://swera.unep.net. Likewise, GIS and time series data along with the energy optimization tools needed to apply these data area also available to facilitate renewable energy policy and investment.

The SWERA project was sponsored by the United Nations Environment Program (UNEP) and by the Global Environment Facility (GEF). It was coordinated in Brazil by the Center for Weather Forecast and Climate Studies of the Brazilian Institute for Space Research (CPTEC/INPE) in association with the Electric Power Research Center (CEPEL) and with the Laboratory of Solar Energy of the Federal University of Santa Catarina (LABSOLAR/UFSC).

This report describes the main outcomes of the project in Brazil and discusses some scenarios for solar and wind energy applications. It opens with a short description of the recent evolution of the energy matrix in Brazil compared to the energy information available for OECD members and other developing countries in the world. The 4.6% increase in the total consumption of electricity was one of the key aspects concerning the performance in 2005 of Brazilian energy sector. The total domestic energy supply in Brazil reached 218.6 Mtoe in 2005. From this total, 97.7 Mtoe (44.7%) are related to renewable energy supply. This share is among the highest in the world, which significantly contrasts with the global average of 13.3%, and with the 6% average observed in OECD countries.

During 2005, there was a 4% increase in energy supply from renewable energies in the Brazilian Domestic Energy Supply (DES). Various factors contribute for this increase, like the reduction in demand for coal, Uranium and their by-products, as well as the stability in demand of petroleum derivatives. Among non-renewable sources, only natural gas presented a significant increase in domestic supply.

The hydro energy share in DES increase between 2004 and 2005 and it is still responsible for the largest part of the energy supply, around 33.5% of the domestic supply of renewable energy. There was also an increase in the share of sugar cane by-products due to a 7.7% increase in ethanol production in 2005. Meanwhile, the energy from firewood and charcoal presented a slight reduction moving from 30.1% to 29.2% at the same period. The contribution of solar and wind energy to the Brazilian DES is minor yet, even though the large national potential as a result of Brazil's location in tropical region of Southern Hemisphere.

The Brazilian DES structure, with an important participation of hydraulic and biomass energy, provides CO_2 emission indicators that are below the average of developed countries. In Brazil, the emission is of 1.57tCO_2/toe of DES, while in OECD countries the emission is of 2.37tCO_2/toe, and in the world it is 2.36tCO_2/toe, and therefore, 50% greater than that of Brazil.

This report also presents the Brazilian policy and initiatives for renewable energy projects. Many NGO and government institutions support a range of initiatives designed to promote rural electrification, such as the *Luz para Todos* Program (LpT).

The Brazilian Government created the Alternative Energy Sources Incentive Program (PROINFA) in 2002 and in its first stage 3300 MW of renewable energy from wind, biomass and small hydroelectric sources will be installed before the end of 2008 through a system of subsidies and incentives. The PROINFA program is expected to generate 150 thousand jobs and to leverage private investments of around US$ 2.6 billions.

Other government incentive programs were created to promote large-scale use of solar water heating systems. The major one is the National Electricity Conservation Program (PROCEL), which was created to promote a more efficient production and consumption of electricity, to reduce costs and support investments in this sector. The use of solar energy for residential water heating is one of the modalities embraced by PROCEL since it was shown that the maximum solar heating is closely related to the peak hours demand and to the total energy consumption.

The wind energy assessment focused the Brazilian Northeast and South Regions, which had been indicated by previous evaluations as the regions offering highest wind energy resources in country. To accomplish this task the mesoscale climate model Eta was configured at a 10km resolution and with 38 layers along the vertical and run in a NEC SX-6 supercomputer at CPTEC. The ground data for validation was collected from airports, from automatic weather stations (AWS), and from wind measurement stations from the SONDA network. In addition to the results of this wind assessment work, the full data set of the CEPEL wind Energy Atlas *[6]* was also made available through this project.

Site-specific wind data analysis suggests there are several locations with valuable wind energy potential. The diurnal cycle was analyzed in these sites and demonstrated that the Northeast region present a more remarkable diurnal cycle, mainly along the seashore due to the sea breeze effects. The most intense winds occur during the daytime as a result of surface heating during the day and the high atmospheric stability that evolves along the night. The winds simulated by the Eta model are close to the values measured at the wind measurement stations located in the Brazilian Northeast Region. The simulated wind average at 50m height for the Northeast Region revealed several areas located at East of the 43°W meridian presenting yearly average wind speed greater than 7m/s which is excellent condition to produce electricity. With regards to seasonal variability, there are two distinct patterns: one ranging from the State of Rio Grande do Norte up to the State of Maranhão, which presents the highest wind speeds in springtime (September to November), and the other in the center of the Northeast Region, where the highest speeds are observed in wintertime (form June to August). It is noticed that the k-form parameter of the Weibull distribution presented values above 3.5 during 6 months of the year in most of the Northeast Region.

The Eta model outcome shows that the Brazilian South Region presents small and isolated areas with worthy wind potential (speeds above 7m/s): the coastal area of the State of Rio Grande do Sul and the border between the State of Santa Catarina and the State of Paraná. The Weibull k-form parameter varies little along the year and presents values ranging from 1.5 and 3.5 in most of the South Region.

The solar energy resource assessment in SWERA project was prepared by using BRASIL-SR radiative transfer model developed jointly by CPTEC/INPE and LABSOLAR/UFSC. The model BRASIL-SR was supplied with satellite data from 1995 to 2005, together with climate data. It has produced maps for annual and monthly solar irradiation average in a 10 km x 10 km ground resolution. In spite of the different climate characteristics along the Brazilian territory, the solar irradiation is uniform. The maximum daily solar irradiation value – 6.5 kWh/m^2.day – occurs in the Northern part of the State of Bahia, close to the border with the State of Piauí. This area exhibits a semi-arid climate with low rainfall throughout the year (roughly 300mm/year) and the lowest annual average cloud amount. The influence of the Tropical High Pressure associated with the South Atlantic Tropical Anticyclone provides a stable condition of low nebulosity and high incidence of solar irradiation for this semi-arid region throughout the year. The lowest daily global horizontal solar irradiation – 4.25 kWh/m^2.day – occurs on the North coastal zone of the State of Santa Catarina where precipitation is well distributed all over the year. The annual average of daily global horizontal solar irradiation in any region of the Brazil are much larger than in most of the European Union countries where projects to harness solar resources are greatly disseminated, some of which, with massive government incentives.

The Amazon Region experiences lower daily solar irradiation during the Summer (December to February) than the Brazilian South Region in spite of being closer to the Equator. This is due to climate characteristics in Amazon, which features a larger cloud coverage and rainfall during the summer as a consequence of strong influence of the Inter-Tropical Convergence Zone (ITCZ). The seasonal variability of solar irradiation is smaller in the North Region than in the South Region. The temperate climate characteristics of the Southern Region and the influence of the frontal systems associated with the Antarctic Polar Anticyclone contribute to enhance in this region the nebulosity mainly during the winter.

In the Central Region of Brazil, the larger incidence of solar radiation occurs during the local dry season, from July to September, when precipitation is low and the number of days with clear sky is greater.

Concluding the report, scenarios for solar and wind energy are presented. A well-matched wind-hydro seasonal complementarily has been demonstrated for a huge area of the Brazilian territory, especially at Northeast Region. In order to comply with increasing energy consumption and country economic development, it is expected that 40GW of new generation capacity should be added to the existing 93GW, in the long term. These facts make wind energy an effective alternative for increasing the offer of energy supply in Brazil, and it was a key argument to establish the incentive program PROINFA mentioned earlier. The wind energy expansion scenario established by the PROINFA Phase II predicts an annual installation of 300MW/year. The whole energy market is expecting the directives for PROINFA Phase II to be established by the Brazilian Government in 2007-2008.

Today, solar energy for water heating is by far the most widespread application of solar energy in Brazil. Nevertheless, this practice is still small when compared to the use of electricity, firewood and fossil fuels, which have a much greater energy density. The reasons that hinder the large-scale widespread national use of solar energy are mainly its high variability, uncertainty, and discontinuity during the night, although skepticism and lack of awareness from the potential users may also play an important role here. Currently, a fairly well developed market already exists for solar water heating systems in Brazil, which has more than 2.2 million m^2 of heating solar collectors installed. However, this figure is small when compared to countries, such as Germany (above 5.7 million m^2), or Turkey (more than 7.2 million m^2), both with solar resources below to what can be available in Brazil. Several industries produce solar water heating systems in Brazil, which concentrate their production in flat plate solar collectors with a glazing. Over the last years, some industries started producing plastic collectors without glazing, used preferentially for heating swimming pools. Collectors with evacuated heat pipes are not manufactured in Brazil. The percentage of energy saved by a typical family (4 persons), which consumes around 300 liters/day of hot water, was simulated by using the F-Chart *[8]* method together with the SWERA database. For this simulation, the typical performance characteristics of a flat plate solar collector with a glazing, produced in Brazil, were used. The simulated system had $4m^2$ of area and a hot water storage tank volume of 300 liters. Despite of the energy savings being higher at locations with warmer weather, the produced energy is not so different for the several Brazilian regions. Bearing in mind the economical point of view, the payback time for this solar heating system is lower in Southern Region where the energy savings would be greater due to the larger demand for water heating.

A preliminary case study for economic feasibility of a large-sized facility was shaped considering a system with $140m^2$ of solar collectors to provide $10m^3$/day of hot water. The results shows a similar pattern, but a larger area in the Southern Region (including the States of São Paulo, Minas Gerais, Rio de Janeiro and part of Mato Grosso do Sul) shows higher achievability and lower payback time.

Economic analysis of photovoltaic (PV) generation systems using life cycle cost analysis over periods of 20 to 30 years gain from accurate and high resolution information on the solar resource. In this context, the SWERA project represents a valuable asset for energy planners and investors. It were identified two major applications for PV in Brazil, where there is a potential for large volumes, and for which the accurate knowledge of the solar resource distribution is critical: hybrid Diesel / PV systems in mini-grids in the Amazon Region and grid-connected PV systems in urban areas.

Brazil is particularly well suited for the application of grid-connected PV due to both considerable solar resource availability, and to the high value that can be attributed to PV in commercial areas of urban centers. Commercial urban regions with high midday air-conditioning loads have normally a demand curve in a good match with the solar irradiance curve. Another important factor in this analysis is the comparison between the peak load values in Summer and Winter. The greater the demand in summertime in comparison with the demand in wintertime, the more closely the load is likely to match the actual solar resource. This is the typical picture of most state capital cities in Brazil.

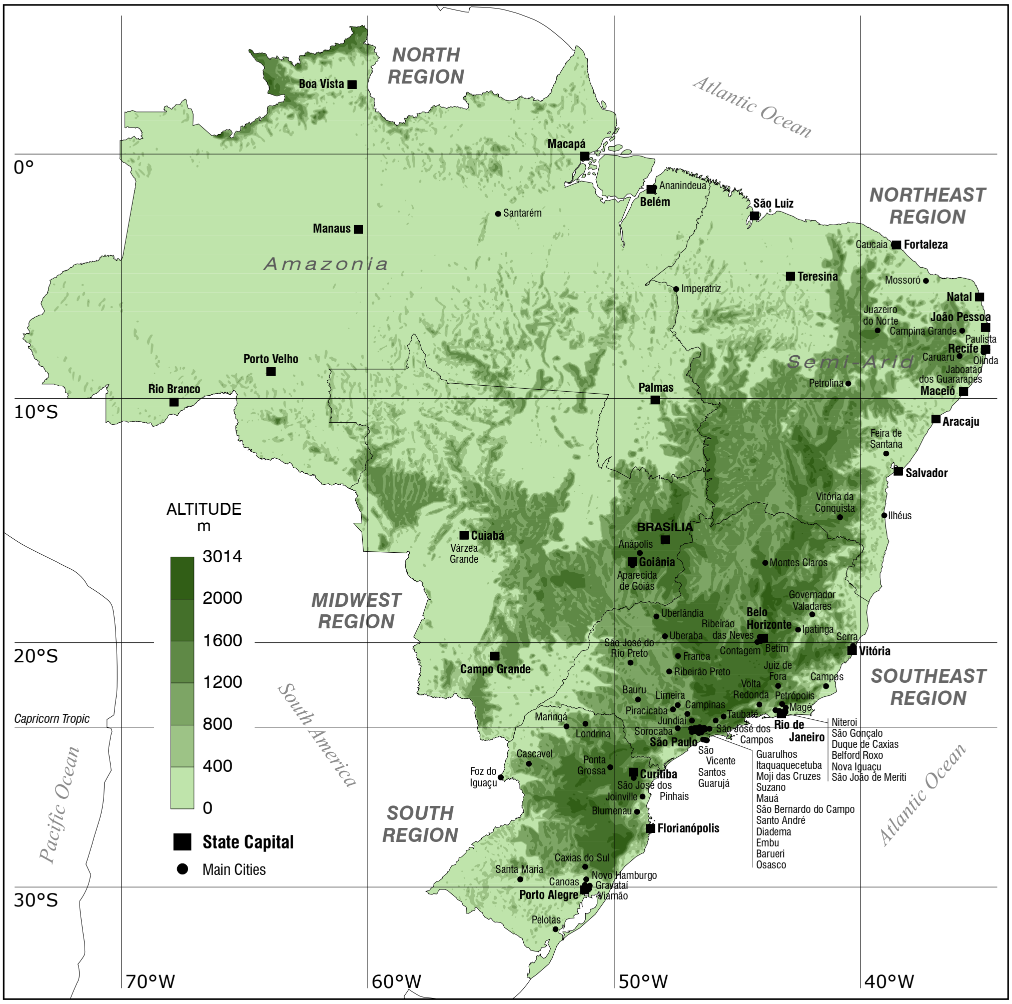
There are currently hundreds of mini-grids operated by independent power producers (IPPs) or local state utilities in the Brazilian Amazon, that cover the main share of this demand, which is however only a small proportion of the country's total energy consumption. Most of the sites where they operate are not easily accessible, increasing cost and decreasing reliability of supply. Many of the operators of these systems, however, make use of a subsidy that covers 100% of the cost of Diesel fuel, as long as they operate at or below the 0.34 l/kWh specific consumption limit. IPPs willing to invest in renewable generation that displaces Diesel oil can claim the cost of the fuel consumption avoided, but so far this has not been attractive enough to encourage them switching to renewables, because of the lack of mandatory targets and a typically short-term management strategy. The potential for using PV, however, is huge, and can be estimated in tens to hundreds of MWp in the Amazon Region alone, even if only a fraction of the 286 existing Diesel oil power plants with a total installed capacity of over 620MVA would adopt some PV to an optimum Diesel / PV mix. Solar PV is one of the most viable renewable energy technologies currently available for the dispersed and relatively small energy density demands in the region.

The SWERA project is now completed. All the products and the solar and wind energy database are available at http://swera.unep.net/ for free access and download. The CD-ROM accompanying this publication contains the "Brazilian Atlas of Solar Energy" *[21]* and the "SWERA Wind Energy Assessment Data" in digital format. Both publications were produced in the SWERA scope with ground data collected at SONDA network. The ground database is available at www.cptec.inpe.br/sonda/. All data for energy sector were provided by the Ministry of Mines and Energy.

BRAZILIAN PRIMARY DATA

The following figure and table present the fundamental information about Brazil as a background.

Figure 1.1.
Map of Brazil.
The largest country in South America, Brazil has a 8,500 km coastline in the Atlantic Ocean.



Surface Area(1)	8,514,877 km²
Population(1)	186.8 million
Language	Portuguese
Gross National Product(2)	796 billion US$
Domestic Energy Supply(3)	229.7 million toe
Domestic Electric Energy Supply(3)	461.3 TWh

Table 1.1.
Basic information about Brazil.

(1) Instituto Brasileiro de Geografia e Estatística - IBGE, 2007
(2) Confederação Nacional da Indústria – CNI, 2005.
(3) http://www.epe.gov.br/PressReleases/20070329_1.pdf, 2007.

ENERGY PROFILE OF THE COUNTRY

BASED ON THE BRAZILIAN NATIONAL ENERGY BALANCE 2006 *[1]*

2.1. DOMESTIC ENERGY SUPPLY

A concise chart which reflects the performance of the Domestic Energy Supply (DES) in Brazil during 2005 was put together based on the energy production, supply and consumption data provided by various agents of the energy sector. The DES reached the 218.6 Mtoe in 2005, which represented a growth of 2.47% regarding the previous year.

The most important aspects concerning the performance in 2005 of Brazilian energy sector were summarized bellow:

- growth of 10.3% in petroleum production;
- growth of 0.5% in the market of petroleum by-products;
- growth of 4.3% in production and 11.3% in imports of natural gas;
- growth of 7.7% in ethanol production;
- growth of 4.6% in the total consumption of electricity by free and captive consumers in the country.

The 2006 Brazilian Energy Matrix (base year 2005) was obtained from the analyses of a set of macro indicators used to assess the behavior of the most important economic sectors from an energy consumption point of view, together with the monthly follow-up of energy and economic statistics. Figure 2.1 shows the percentage breakdown of the DES structure in Brazil and Table 2.1 presents the absolute values, in toe, of the energy supply for the primary energy sources being used in Brazil. Table 2.2 shows the participation of each of the energy sources in the DES. Figures 2.2 and 2.3 show, respectively, the growth of energy production for each source and their variation in the DES sharing during the 2004/2005 period.

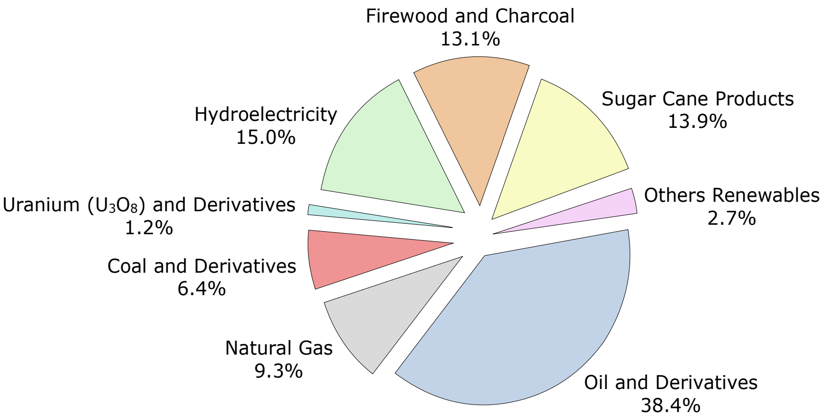


Figure 2.1.
Structure of the Domestic Energy Supply (DES) in Brazil in 2005.

Table 2.1.
Structure of the Domestic Energy Supply in Brazil in millions of toe.

SOURCES	2004	2005	Δ 05/04 (%)
Non Renewable	**119.768**	**120.953**	**1.0**
Oil and Derivatives	83.391	84.020	0.8
Natural Gas	18.982	20.393	7.4
Coal and Derivatives	14.225	13.940	-2.0
Uranium (U_3O_8) and Derivatives	3.170	2.600	-18.0
Renewable	**93.613**	**97.695**	**4.4**
Hydroelectricity	30.804	32.691	6.1
Firewood and Charcoal	28.193	28.560	1.3
Sugar Cane Products	28.756	30.441	5.9
Other Renewables	5.860	6.002	2.4
Total Supply	**213.381**	**218.648**	**2.5**

Table 2.2.
Structure of the Domestic Energy Supply in Brazil in percentile values.

SOURCES	**2004**	**2005**	**Δ 05/04 (%)**
Non Renewable	**56.1**	**55.3**	**-0.8**
Oil and Derivatives	39.1	38.4	-0.7
Natural Gas	8.9	9.3	0.4
Coal and Derivatives	6.7	6.4	-0.3
Uranium (U_3O_8) and Derivatives	1.5	1.2	-0.3
Renewable	**43.9**	**44.7**	**0.8**
Hydroelectricity	14.5	15.0	0.5
Firewood and Charcoal	13.2	13.1	-0.1
Sugar Cane Products	13.5	13.9	0.4
Other Renewables	2.7	2.7	0.0

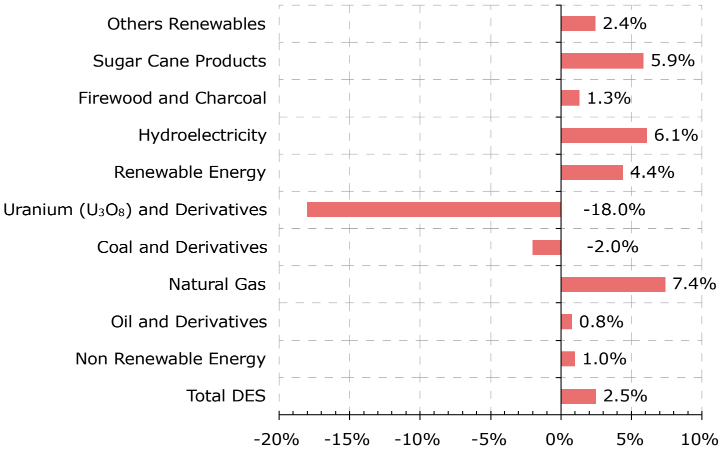


Figure 2.2.
Growth in energy supply for each type of fuel for the 2005/2004 period.

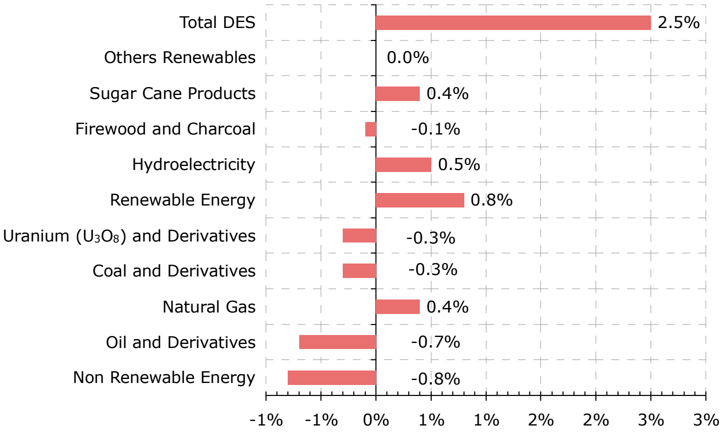


Figure 2.3.
DES variation for the 2004/2005 period for each type of fuel.

The total domestic energy supply in Brazil, in 2005, reached 218.6 Mtoe, where 97.7 Mtoe, or 44.7%, correspond to the domestic supply of renewable energy. This share is among the highest in the world, which significantly contrasts with the global average of 13.3%; and with the 6% average of countries comprising the Organization for Economic Co-operation and Development (OECD). During 2005, there was a 0.8% increase in the participation of renewable energies in the Brazilian DES (Figure 2.4). The reduction in demand for coal, uranium and their by-products, as well as the stability in demand of petroleum derivatives contributed for this increment. Among non-renewable sources, only natural gas presented a significant increase in domestic supply, 7.4% greater than in 2004.

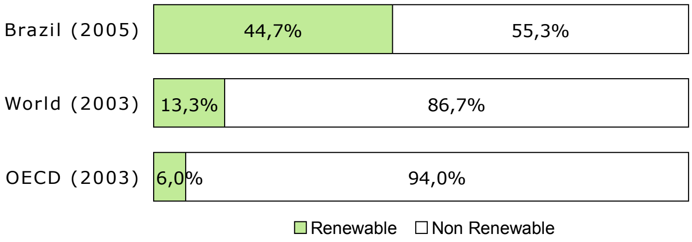


Figure 2.4.
Shares of renewable and non-renewable energy sources to the Domestic Energy Supply in 2005.

In 2005, the net external dependency on petroleum and its by-products dropped 4.2%. The considerable growth in petroleum production (10.3%) associated with a quasi-stable total consumption of its derivatives (growth of only 0.5%) is the factors that justify this reduction of foreign dependency.

Tables 2.3 and 2.4 present the breakdown of the Domestic Electric Energy Supply (DEES) for the 2004/2005 period in TWh. There was a 4% growth in the total supply, where hydraulic generation presented the highest growth during the period, at 6.1%. There was a significant drop in electricity generated using nuclear energy (18%) and in thermoelectric generation supplied by natural gas (5.3%). In 2005, hydraulic energy was responsible for 77.1% of the electricity supply in the country. Despite a reduction in imported electric energy, this source still represents about 8% of the DEES (Figure 2.5). Table 2.5 briefly presents the socio-economic information, regarding the energy sector, for 2005.

Source	2005	2004	Δ 05/04 (%)
Total Supply	**441.6**	**424.8**	**4.0%**
Hydroelectricity	340.5	320.8	6.1%
Nuclear	9.5	11.6	-18.0%
Natural Gas	18.2	19.3	-5.3%
Coal and Derivatives	7.2	7.0	2.4%
Oil and Derivatives	12.4	12.1	1.9%
Biomass	17.4	16.7	4.7%
Importation	36.5	37.4	-2.5%

Table 2.3.
Domestic Electric Energy Supply in TWh.*

**Included electric energy auto-production.*

Source	2005	2004
Hydroelectricity	77.1	75.5
Nuclear	2.2	2.7
Natural Gas	4.1	4.5
Coal and Derivatives	1.6	1.6
Oil and Derivatives	2.8	2.9
Biomass	3.9	3.9
Importation	8.3	8.8

Table 2.4.
Percentile participation of each energy source in the supply structure of electricity.*

**Included electric energy auto-production.*

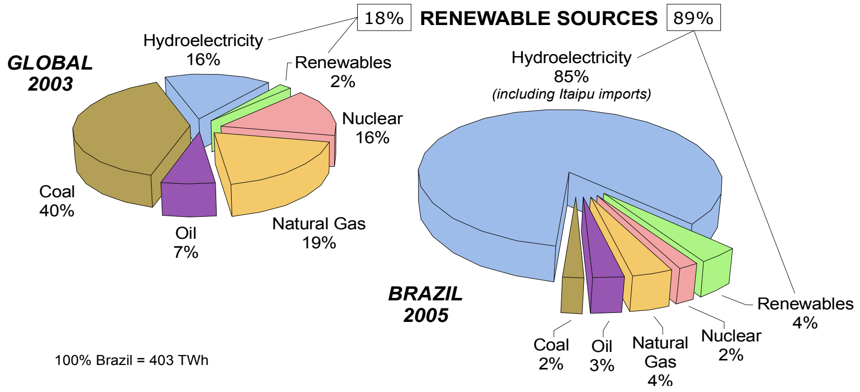


Figure 2.5.
Electric Energy Supply Structure according IEA, 2003, and MME, 2006.

Table 2.5.
Summary of the main results in the energy sector in 2005.

(1) Preliminary;
(2) bbl = barrel, included liquids of natural gas;
(3) Included autoproduction;
(4) Estimation;
(5) Estimate of the IBGE (R$ 1.937,6 x 109) converted for US$ by the medium exchange rate of 2005 (Central Bank: R$ 1.00 = US$ 2.435).

Main parameters	Unity	2005 (1)	2004	Δ%
Oil Production (2)	10^3 bbl/day	1699.5	1540.8	10.3
Natural Gas Production	10^6 m^3/day	48.5	46.5	4.3
Electric Energy Generation	TWh	405.2	387.5	4.5
Consumption of Oil Derivatives	10^3 bbl/day	1619.3	1611.2	0.5
Consumption of Electric Energy	TWh	376.1	359.1	4.6
Domestic Energy Supply	10^6 toe	218.6	213.4	2.5
Domestic Electric Energy Supply (3)	TWh	441.6	424.8	4.0
Population (4)	10^6 inhab	184.2	181.6	1.4
GDP (2005) (5)	10^9 US$	795.9	778.0	2.3
Main indicative				
GDP per capita	US$/inhab	4321	4284	0.9
DES per capita	toe/inhab	1.187	1.175	1.0
DES by GDP (2005)	toe/10^3 US$	0.2747	0.2743	0.13
DEES per capita	KWh/inhab	2397	2339	2.5
DEES by GDP (2005)	KWh/10^3 US$	555	546	1.6

2.2. RENEWABLE ENERGY

The domestic supply of renewable energy in Brazil grew about 4% in 2005 and several factors contribute to this increase. Among such, the following are highlighted:

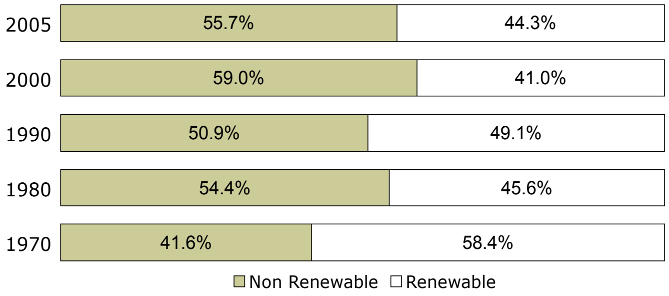
- hydraulic energy continued to be responsible for the largest part of the energy supply, at around 33.5% of total renewable energy supply, i. e. about 15% of the total DES;
- the hydraulic share grew 6.1% in the DES between 2004 and 2005, thereby increasing its participation in generation;
- there was an increase in the share of sugar cane by-products in the domestic energy supply, 13.9% of the total DES, due to a 7.7% increase in ethanol production last year;
- firewood and charcoal presented a slight reduction in DES participation, moving from 30.1% to 29.2% during the 2004/2005 period, but practically maintained their participation constant at around 13.1%;
- the beginning of the commercial production of biodiesel, a fuel obtained from raw materials such as castorbeans, soybeans and oilpalm – the initial authorization is for 2% of biodiesel to be blended with regular diesel oil. The National Energy Policy Council (CNPE) will supervise a gradual increase in this percentage over the next years.

2.3. NON-RENEWABLE ENERGY

The participation of non-renewable sources of energy in the DES suffered a decrease of 0.6% during the 2004/2005 period (Figure 2.6), and reached 55.3% of the Brazilian DES. The main aspects related to this reduction are:

- with the increase in petroleum production (10.3%), imports suffered a significant drop of 17.8% and exports presented an 18.9% growth;
- there was an increase in refining with the purpose of better adjusting to the profile of domestic needs for petroleum-derived products, which resulted in a reduction of imports (8.5%) and of exports (1.7%) of such by-products;
- the participation of coal and its by-products in the domestic energy supply presented a 2.0% drop, which was a reflex of reduction in its use in industrial activity, despite the increase on its application in electricity generation;
- the participation of Uranium (U_3O_8) and its derived products in the DES dropped 18%, and went from 1.5% in 2004 to 1.2% in 2005, thereby repeating the same performance in the 2003/2004 period;
- the drop in the nuclear energy share in the DES reflects the reduction from 11.6 TWh to 9.5 TWh in electricity generation using uranium during the 2004/2005 period;
- natural gas is the fuel that presents the highest growth rates on the energy matrix and moved from 3.7% (1998) to 9.3% (2005);
- the production of natural gas increased by 4.3% and imports rose 11.3% in 2005, as a consequence of the substitution of fuel gas and the liquid petroleum gas (LPG) in the industry, and substitution of gasoline in transportation, besides other smaller-scale substitutions;
- the DES resulting from thermoelectric plants dropped 2.9% during the 2004/2005 period as a result of reductions in the use of natural gas as a primary source (5.3%) and nuclear generation;
- the use of coal, of petroleum derivatives and of biomass as a primary source of thermoelectric generation presented an increase in 2005.

Figure 2.6.
Evolution in the participation of renewable and non-renewable energy sources in the Brazilian DES.



2.4. EVOLUTION OF THE ENERGY MATRIX IN BRAZIL AND IN THE WORLD

The development process of the nations leads to a natural reduction in the use of firewood as a source of energy. In the farming sector, the rudimentary uses of firewood as in flour-making operations, in drying of grains and leaves, in brick kilns, in lime kilns and in the production of homemade sweets, are gradually losing importance due to urbanization and industrialization. In the countryside residential sector, firewood is being replaced by LPG in cooking. In the industry, especially in the food and ceramics sectors, the modernization of processes leads to the use of more efficient sources of energy. In Brazil, the 70s were a period in which petroleum-derived products rapidly substituted firewood, which significantly reduced the share of the latter in the energy matrix.

Table 2.6 presents the evolution of the domestic energy supply over the 30-year period comprised between 1973 and 2003, for OECD countries and for the whole world. The data for Brazil refer to the 1973/2005 period. The sum of the last two lines in Table 2.6 can be construed as being the evolution in the supply of energy provided by renewable sources.

Despite a reduction in the use of firewood, within 1973 to 2005 period, the share of renewable energy in the Brazilian DES has kept itself high, dropping from approximately 58% to 44.7%. The reduction in the participation of firewood, from 38.8% to 13.1%, was offset by a strong increase in the participation of hydraulic energy, from 6.1% to 15.0%, and of sugar cane products, from 5.7% to 13.9%.

Table 2.6.
Evolution of the Energy Supply Structure.

** Biomass included firewood, charcoal, sugar cane products, solar energy, wind energy, geothermal energy, etc.*

SOURCE	**BRAZIL**		**OECD**		**WORLD**	
	1973	**2005**	**1973**	**2003**	**1973**	**2003**
Oil and Derivatives	46.0%	38.4%	53.0%	40.7%	46.0%	35.3%
Natural Gás	0.4%	9.3%	18.8%	22.0%	15.9%	20.9%
Coal and Derivatives	3.1%	6.4%	22.4%	20.5%	24.3%	24.1%
Uranium (U_3O_8) and Derivatives	0.0%	1.2%	1.3%	10.7%	0.9%	6.4%
Hydroelectricity	6.1%	15.0%	2.1%	2.0%	1.8%	2.1%
Biomass*	44.8%	29.7%	2.5%	4.0%	11.0%	11.2%

In the world, the participation of renewable sources (hydraulic, biomass, solar, wind and geothermal) in DES presented an increase of only 3.9% over the last three decades, moving from 12.8% in 1973 to 13.3% in 2003.

In OECD countries, the participation of renewable sources in the DES is even smaller. However, it presented an important growth over the last three decades moving from a little over 4.6% in 1973 to almost 6.0% in 2003. The participation of the hydraulic source dropped from 2.1% to 2%, which contrasts with other renewable sources of energy, which almost doubled their participation in the energy matrix, going from 2.5% in 1973 to 4% in 2003. One of the main factors associated with this growth is the concern in reducing the emissions of atmospheric pollutants *[24]*.

Between 1973 and 2003, the participation of petroleum and its derivatives in the worldwide DES presented a decrease from 46% to 35.3%. In OECD countries, this reduction was from 53% to 40.7%, during the same period. These results reflect the effort to substitute these products, mainly as a result of the petroleum price crisis that took place in 1973 (from US$ 3 per barrel to US$ 12) and in 1979 (from US$ 12 to US$ 40). Besides this, the concern with the environmental consequences regarding the accumulation of greenhouse gases emitted from the burning of fossil fuels has also contributed towards this reduction over the last decade.

In Brazil, the maximum participation of petroleum and its derivatives in the domestic energy supply occurred in 1979, when it reached 50.4%. The drop of this share, from 46% in 1973 to 38.4% in 2005, shows that the country has invested significant efforts to substitute these sources of energy. The increase of hydroelectricity and sugar cane derivates were the main energy sources adopted for such replacement.

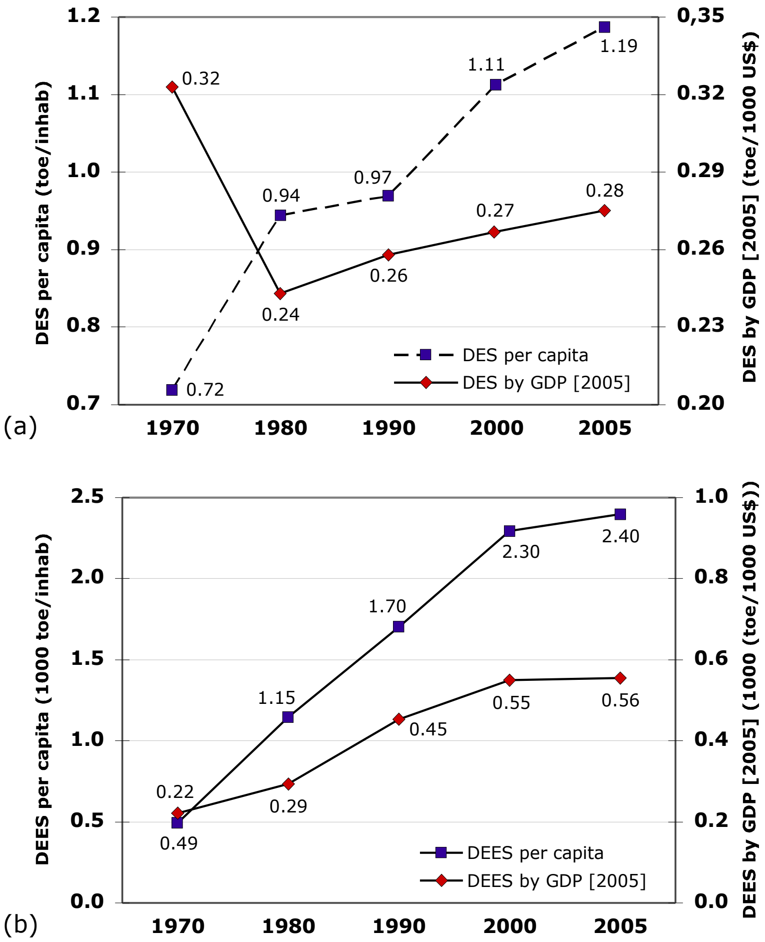
Figure 2.7 shows the evolution over time of the energy intensity and of the Electric energy intensity in Brazil over the last 35 years. It can be noted that the DES/GDP ratio presented a sharp drop (of around 25%) during the 70s, when the Brazilian GDP grew 8.6% per year, on average. From this period on, the DES/GDP ratio has presented a growth of around 4.5%. The ratio between DEES and GDP presented a steep growth up to the year 2000, of about 150%. The DEES/GDP ratio has kept stable at the approximate level of 560 toe/10^3US$ since 2000. Table 2.7 complements this information with the historical evolution of the main economic indicators for the same period.

Main parameters	**Unity**	**1970**	**1980**	**1990**	**2000**	**2005** (1)
Domestic Energy Supply	10^6 toe	66.9	114.8	142.0	190.6	218.6
Domestic Electricity Supply (2)	TWh	45.7	139.2	249.4	393.2	441.6
Population	10^6 inhab	93.1	121.6	146.6	171.3	184.2
GDP (3)	10^6 US$	206.9	473.3	550.1	714.3	795.9
Main indicators						
GDP per capita	US$/inhab	2220	3890	3750	4170	4321
DES per capita	toe/inhab	0.719	0.944	0.969	1.113	1.187
DES by GDP	toe/10^3 US$	0.323	0.243	0.258	0.267	0.2747
DEES per capita	KWh/inhab	490.9	1144.7	1701.2	2295.4	2397.4
DEES by GDP	KWh/10^3 US$	220.9	294.1	453.4	550.5	554.8

Table 2.7.
Evolution of the Main Parameters and Indicators.

(1) Preliminary;
(2) Included auto production;
(3) Prices of 2005.

Figure 2.7.
Evolution of the Energy Intensity (a) and of the Electricity Intensity (b) from 1970 to 2005.



2.5. CO_2 EMISSIONS

The Brazilian Domestic Energy Supply structure, with an important participation of hydraulic and biomass energy, provides CO_2 emission indicators that are below the average of developed countries. In Brazil, the emission is of 1.57 tCO_2 per toe of DES (Figure 2.8), while in OECD countries the emission is of 2.37 tCO_2/toe. The CO_2 emissions in the world achieve 2.36 tCO_2, and therefore, it is 50% greater than Brazilian emissions.

Table 2.8 allows comparing the results obtained for the main CO_2 emission indicators in Brazil and in the highly industrialized countries (USA and Japan) with the average values presented by the world and other countries in Latin America.

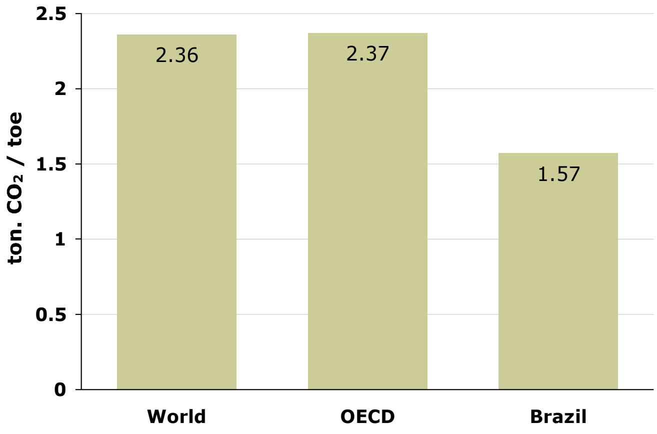


Figure 2.8.
Energy-related CO_2 emissions per toe, data for 2003.

Indicator	Brazil	USA	Japan	Latin América	World
tCO_2/inhab	1.77	19.6	9.47	1.98	3.89
tCO_2/toe DES	1.62	2.47	2.33	1,9	2.32
$tCO_2/10^3$ US$ by GDP*	0.27	0.6	0.4	0.3	0.6
tCO_2/km^2 of surface	36.3	614.9	3197.8	46.0	119.3

Table 2.8.
Values for the main CO_2 emission indicators obtained in Brazil and in specific countries and regions of the globe. Data for 2002.

* US$ in current values of 1995.

Brazil was the first country to sign the Convention on Climate Change, as a result of the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992. According to the Kyoto Protocol, Brazil, as a developing country, is classified as non-Annex I Country, and has no targets for CO_2 emissions reduction.

In Brazil, 75% of the total CO_2 emissions are due to deforestation (change of land use and forestry), being the burn of fossil fuels responsible for only 23%. Figure 2.9 presents the sources of emissions in more detail *[24]*.

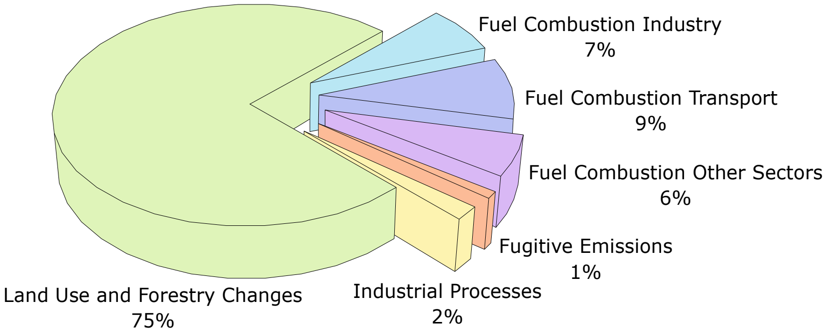


Figure 2.9.
CO_2 emissions per sector, data for 1994 [24].

RENEWABLE ENERGY RELATED PROGRAMS

3.1. ASSESSMENT OF EXISTING RURAL ELECTRIFICATION PROGRAMS

The Brazilian government and a variety of financial institutions support a range of initiatives designed to promote rural electrification. Some pilot experiences with PV technology for rural electrification were carried out together with international institutions i.e. NREL – National Renewable Energy Laboratory (USA), and GTZ – Gesellshaft für Technische Zusammenarbeit (Germany).

The first initiative of The Brazilian Federal Government was the establishment of the Program for Energy Development of States and Municipalities (PRODEEM – Programa de Desenvolvimento Energético de Estados e Municípios) through a Presidential Decree of December 1994. The objective of the PRODEEM was to promote the supply of energy to poor rural communities that are far away from conventional electric systems. In such cases, the cost of transmission/distribution lines extension is high, due to several factors: large distances, vegetation, rivers, etc., and normally is considered not economically viable, since the expected energy consumption is very low.

The PRODEEM was coordinated by the National Energy Development Department (DNDE), of the Brazilian Ministry of Mines and Energy (MME). The CEPEL - Electric Power Research Centre (Centro de Pesquisas de Energia Elétrica), which is a Federal Company located in Rio de Janeiro, was responsible for the technical guidelines for projects, comprising equipment specification for the bidding, project evaluation, technical personnel training, installation standards, installation verification, performance and failure analysis.

The PRODEEM was mainly based on PV systems and three types of stand-alone systems have been considered in PRODEEM: PV electric energy generation systems, PV water pumping systems and PV public lighting systems. The systems were intended solely for community applications, what means that they must improve the communities' quality of life and are not intended to private use. The amount of PV power already involved in the several phases of PRODEEM comprises about 5.2MWp, with over 8,700 PV systems. The systems were installed scattered throughout all the 26 Brazilian Federal States, but specially in the Northeast (semiarid) and North (Amazon) regions of the country.

Nowadays, the federal government supports *Luz para Todos* program that focuses on rural grid extensions and, in some cases, on solar photovoltaic technology for remote community applications. *Luz para Todos* has incorporated PRODEEM and other rural electrification programs.

In addition, there are rural electrification activities under several non-sectorial and decentralized initiatives such as those of the Ministry of Agriculture, the Northeast Development Bank (Banco do Nordeste), and the World Bank Poverty Alleviation Program. Some states have access to bilateral funds to finance their rural electrification programs as, for example, the State of Tocantins, which has support from the Japanese Bank for International Cooperation (JBIC). Other new programs are under preparation (for example, KfW's solar home system project) *[2]*.

3.2. *LUZ PARA TODOS* PROGRAM

Luz para Todos Program enclosed the former existing programs in the area of rural electrification:

- *Luz no Campo* Program: it was specifically designed to supply energy to remote rural communities. Although focused in grid extensions, some specific projects include the utilization of PV panels to generate energy. The 9,000 solar home systems are being installed is an example of this program results;
- Program for the Energy Development of States and Municipalities (PRODEEM): it was designed primarily to electrify small rural social loads such as Schools, Health Clinics, Water Wells, etc.; by using decentralized and local renewable sources of energy. At the first moment, the program's priority was solar energy and more than 8,700 PV systems, comprising more than 5.2MWp of PV modules, were installed in several regions of the country *[25]*.

Official electricity coverage numbers from the Brazilian Institute of Geography and Statistics (IBGE), presented in Table 3.1, are based on the 2001 Census. These data show that 94.5% of the Brazilian population has access to electricity. Furthermore, there are important inequities concerning income levels. The 2001 Census shows that 17% of the families with monthly income of up to one minimum wage (US$100) have no electricity service, weigh against to only 0.15% for those with income 20 times above the minimum wage. Besides that, 78.2% of non-supplied households have monthly incomes under two times the minimum wage.

The Ministry of Mines and Energy (MME) has provided more recent data presented in Table 3.2 and it shows that only 73% of the people in rural areas have access to electricity compared to 98.8% in urban areas. This means that more than 10 million Brazilians have no access to electricity today. In addition, there is substantial disparity among Brazilian geographical regions: 98.3% of the southeastern population has access to electricity meanwhile only 83.9% of the population in the northern region has it.

Table 3.1.
Access to electricity in Brazil in accordance with data acquired by Brazilian Institute of Statistics and Geography in 2001 Census.

UNIT OF MEASURE	TOTAL
Number of Households	44,776,740
Electric Lighting	42,331,817
Rate of Electrification	94.5%

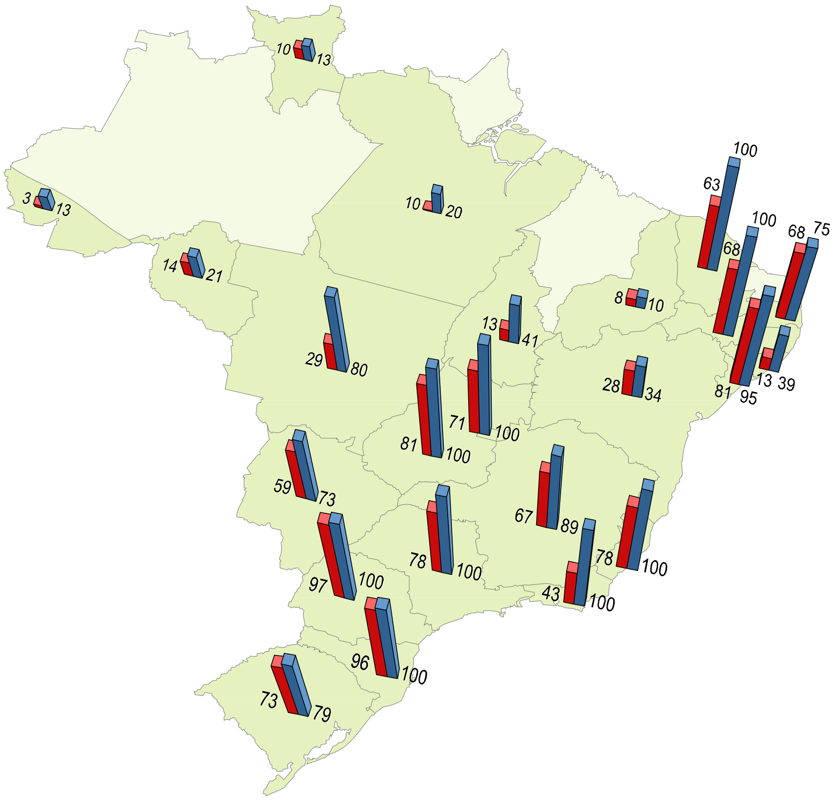
Table 3.2.
Rate of non-electrification by region. The data was acquired in 2001 Census covering all Brazilian territory.

Source: MME–PNU (data from Census 2000, projection for December 2002, including the achievements of "Luz para Todos" Program.

REGIONS	PERMANENT PRIVATE HOUSEHOLDS WITHOUT ELECTRICITY (Dec. 2002)					
	URBAN	%	RURAL	%	TOTAL	%
Brazil	505,023	1.2%	1,979,249	27.0%	2,484,271	5.2%
North	56,195	2.4%	447,124	59.7%	503,319	16.1%
Northeast	201,642	2.2%	1,110,339	34.4%	1,311,981	10.7%
Southeast	166,565	0.8%	206,214	11.9%	372,779	1.7%
South	49,011	0.8%	125,235	10.3%	174,246	2.3%
Midwest	31,610	1.0%	90,336	21.5%	121,946	3.5%

Figure 3.1.
Status of rural electrification in 1998 (lighter column), and targets established for "Luz para Todos" Program (darker column) [1].

Numbers in percentage.



According to the 1996 Agriculture Census, which focuses only on agro-business, roughly 3 million Brazilian farms had no access to electricity at that time. ELETROBRÁS has consolidated data from the National Research by Household Sample (PNAD 98) and from the Agriculture Census and revealed huge disparities in the rural electrification rates among Brazilian states, which varied from 96% in the State of Santa Catarina (South Region) to 0.8% in the State of Pará (North Region). From this analysis, ELETROBRÁS established the targets of the *Luz para Todos* Program for each state presented above in Figure 3.1 (darker columns) together with the status of rural electrification at the time the program was launched in 1998 (lighter columns).

3.3. ALTERNATIVE ENERGY SOURCES INCENTIVE PROGRAM – PROINFA

The Brazilian Parliament approved Law 10438 in April 2002 for the creation of the PROINFA (Program of Incentives for Alternative Electricity Sources) *[3]*.

In the first phase, 3,300 MW of renewable energy from wind (1,422.92MW), biomass (685.24MW) and small hydroelectric sources (1,191.24MW) will be deployed by the end of 2008 through a system of incentives, and specific rules. Under the PROINFA rules, the program is managed by ELETROBRÁS, which buy energy at pre-set preferential prices ("economic values" for each of the three sources) and market "renewable" electricity. PPA – Power Purchase Agreement Contracts were signed between ELETROBRÁS and the "renewable" energy producers and are valid for 20 years. These contracts are applicable for plants that start production before the end of 2008.

The Brazilian National Social Development Bank (BNDES) is responsible for financing programs available for renewable energy projects that signed contract within the PROINFA Program. BNDES can finance up to 80% of capital costs (excluding land acquisition and imported goods and services) in 12 years period.. ELETROBRÁS provides all the warranties in the long-term by purchasing a minimum income of 70% of the contracted energy during the financing period, as well as a full coverage to exposure risks to the short-term market.

PROINFA is expected to generate 150 thousand jobs and to leverage private investments of around US$ 2.6 billions. It is required a minimum nationalization of 60% in total construction costs. The Table 3.3 shows the present stage of PROINFA for each adopted technology.

TECHNOLOGY	PLANNED	CONTRACTED
Biomass	1,100 MW	685.24 MW
Wind	1,100 MW	1,422.92 MW
Small Hydro	1,100 MW	1,191.24 MW

Table 3.3.
Present status (2005) of PROINFA for each renewable technology [1].

According to Law 10438, once the 3,300 MW capacity has been met, PROINFA will aims at increasing the share of electricity produced by the three renewable sources to 10% of annual consumption within 20 years. In second phase, PROINFA renewable producers will be required, before January 30th of each year, to issue a number of Renewable Energy Certificates proportional to the amount of clean energy produced by the plant.

3.4. OTHER PROGRAMS OF INCENTIVES

Some incentive programs were created to promote the large-scale use of solar water heating systems. Some of them came about as a consequence of governmental initiatives with the purpose of strategically supporting this area and others by mobilizing the groups of companies of the energy sector. The main incentive program is the National Electricity Conservation Program (PROCEL), along with some tax exemption programs.

The objective of PROCEL is to promote the rationalized production and consumption of electricity, to eliminate inefficient uses and reduce costs and investments of related sectors. The use of solar energy for residential water heating is one of the modalities enclosed by this program, since in the particular case of Brazil, it is closely related to the demand in electricity consumption at peak hours and to the total energy consumption. The Brazilian Electric Energy Agency (ANEEL) sets forth that the utilities of electric energy distribution (public services) shall invest, at least, 0.5% of their annual turnover in programs that increment the energy efficiency in the final usage of electricity. By using part of such resources, it is possible for the electricity sector companies to donate, subsidize or offer favorable financing to acquire solar heating systems, as long as the energy optimization goals of the company have been met.

Another form of incentive offered for the acquisition of solar heating systems is tax exemption. Manufacturers of solar heating equipment are entitled to tax exemption for industrialized products (IPI) and the commercialization of such equipment is not taxed regarding sales tax (ICMS).

The Federal Savings Bank (CEF), as the governmental agency that sponsors housing investments, offers specific credit lines for solar heating, which may be acquired with the same advantages offered for any other material intended to be used in residential construction.

SOLAR AND WIND ENERGY RESOURCE ASSESSMENT

This chapter describes the solar and wind energy mapping task activities in Brazil within SWERA. The Center for Weather Forecast and Climate Studies of the Brazilian Institute for Space Research (CPTEC-INPE) and Solar Energy Laboratory of University of Santa Catarina (LABSOLAR/UFSC) have worked as a team for the solar energy assessment that resulted in the publication of the Brazilian Atlas of Solar Energy *[21]*, included in the CD-ROM annex at the end of this book. The wind energy assessment was conducted by CPTEC/INPE using the Eta mesoscale model, and performed WAsP analysis for several selected sites in Brazil. A more detailed description of this work and the complete database are also available in the CD-ROM accompanying this document. Furthermore, a comparison between the Eta-generated data and the data from the Brazilian Atlas of Wind Potential, a national reference for wind energy information, produced by the CEPEL - Electric Power Research Center is also performed for completeness *[6]*.

4.1. WIND ENERGY ASSESSMENT

The specific purpose of this topic is to present the wind potential in different Brazilian regions based on numerical model. Most part of Brazil is located in the tropical region where persistent and moderately intense winds, the so-called trade winds, are predominant. Besides that, the topography with plateau regions favors the occurrence of moderate winds near the surface. In order to assess the degree of uncertainty of the wind resource mapping, the analyses of the wind regimes were conducted using existing databases:

- *Ground data:* this database was collected in airports, in automatic weather stations (AWS), and in wind measurement stations operating as part of the SONDA project www.cptec.inpe.br/sonda/. The ground database is at the high frequency required to adequately characterize the wind regime along the day, however, the observations present low spatial density. The SONDA wind towers have wind sensors installed at 25m and 50m heights. Although the standard height for wind sensors is established at 10m, some of the airport and AWS sites have wind sensors located at 2m or 3m height, normally above the rooftop.

- *NCEP/NCAR reanalysis data:* this database contains a good spatial coverage, but low temporal and spatial resolution. This database was used to provide the initial condition and boundary data to the Eta model.

The results presented here are focused on Brazilian Northeast and South Regions, which had been indicated by previous assessments as the regions offering highest wind energy resources. The Eta model was configured at 10km resolution and with 38 layers in the vertical in two domains: one covering the South and the other the Northeast of Brazil. The Eta model was adapted to read the topography and vegetation data from a 1-km resolution grid. The model used the NCEP reanalysis data as its initial conditions. The NCEP reanalysis database were used at the side edges of the model and updated every 6 hours.

Wind analysis, based on ground data, used here as a first approach to the national wind distribution, suggests there are several locations with valuable wind energy potential in Brazil. The diurnal cycle was analyzed and demonstrated that the sites in the Northeast Region exhibit a more remarkable diurnal cycle, mainly at the sites located along the coast due to the sea breeze effects. The most intense winds occur at the daytime due to surface heating, whereas weaker winds (but yet good for generation) occur during high atmospheric stability at the night-time. Figure 4.1 shows: (a) the wind speed mapping obtained from ground data acquired from 2003 till 2005, and (b) the map for Weibull distribution k-form parameter obtained from statistical analysis of ground data. Both maps were produced by using the WAsP code. One can note that Figure 4.1(a) confirms the high-speed wind availability in several areas of the Northeast Region. However, in the Brazilian South Region, the favorable areas are concentrated in the Eastern part of the State of Santa Catarina. The mapping is hindered by the scarcity of available ground data and is only a crude reference for the wind. The wind assessment requires other tools in order to resolve the scarcity of ground data and the enormous national territory. This was achieved by using the Eta meteorological model.

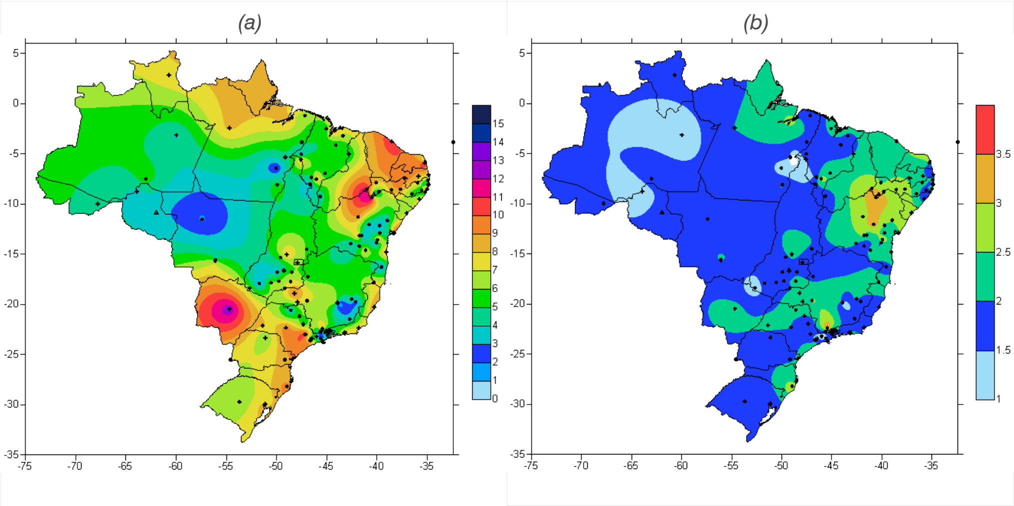
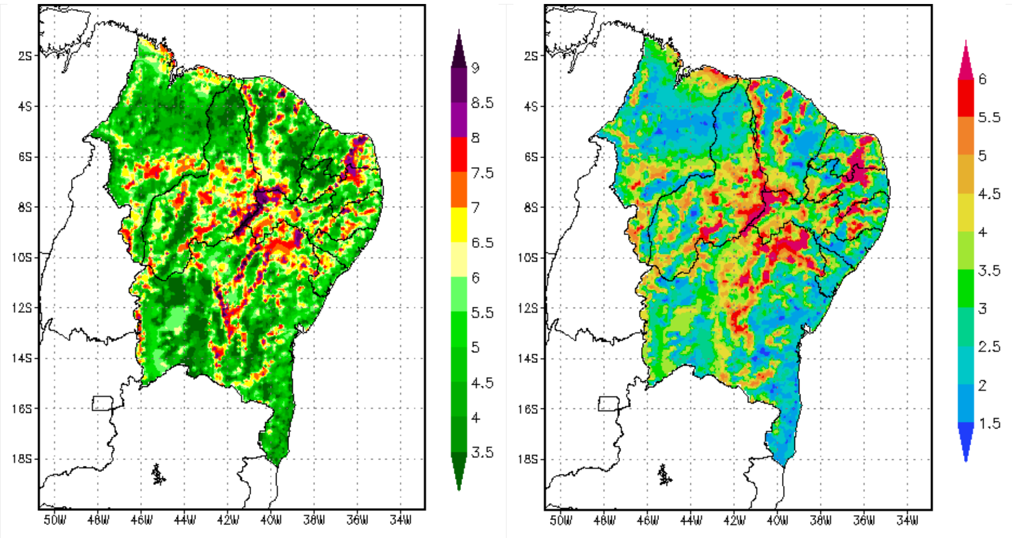


Figure 4.1.
(a) Average wind (m/s) and (b) k-form parameter, provided by WAsP code using data acquired at airports (identified by + in the map), at AWS (•) and at wind towers (Δ).

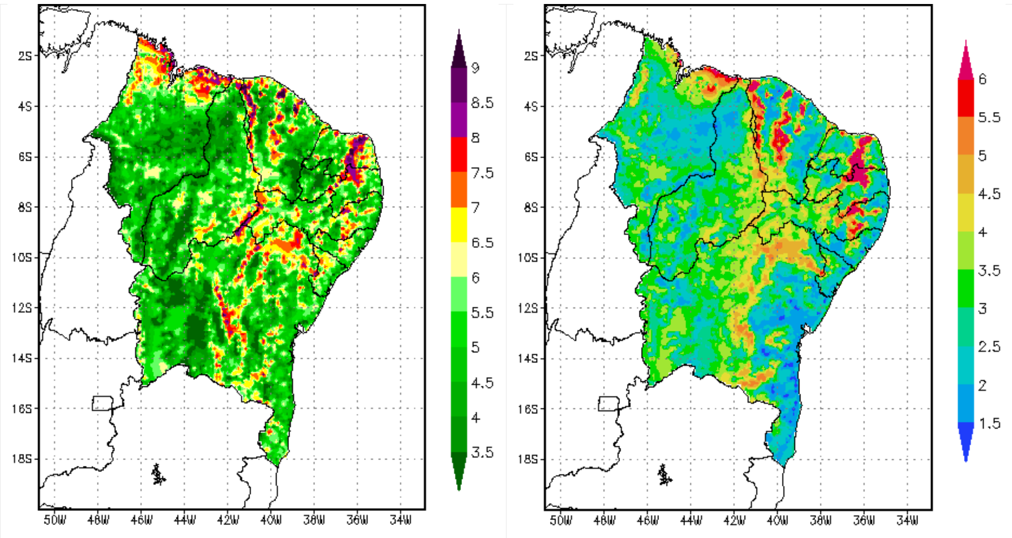
The winds obtained with the Eta model are fairly close to the values of the wind measurements from stations located in the Brazilian Northeast Region, except for the intense winds in the neighborhood of Triunfo (city of the State of Pernambuco near the border with the State of Paraíba) that were not captured by the model (probably due to the complex terrain characteristics of the place). The estimates for Weibull k parameter are usually larger than the measured values at the wind towers.

The wind average at 50m height, simulated by Eta model for the Northeast Region shows that several areas located at East of the 43°W meridian present areas with yearly average wind speed greater than 7m/s and therefore are viable for electricity generation from wind energy. With regards to seasonal variability, there are two distinct patterns: one ranging from the State of Rio Grande do Norte up to the State of Maranhão, which presents the highest springtime (from September to November) wind speeds, and the other in the center of the Brazilian Northeast Region and part of the State of Rio Grande do Norte, where the highest speeds are observed during wintertime (from June to August). It is observed that the k-form parameter of the Weibull distribution presented values above 3.5 during 6 months of the year in most of the Northeast Region. Figures 4.2 till 4.5 presents the seasonal maps for average wind speed and k parameter in Brazilian Northeast Region.



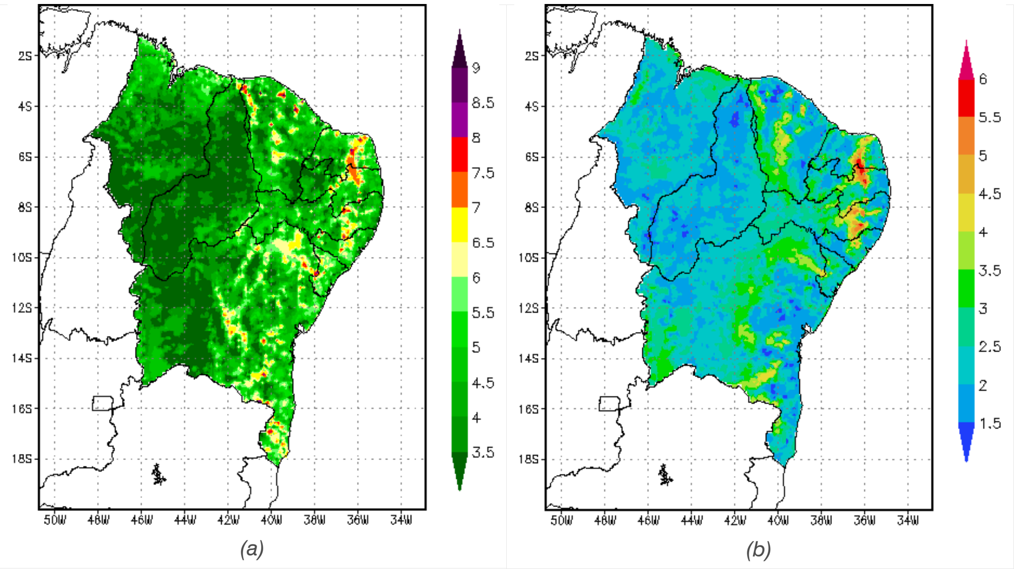
(a) (b)

Figure 4.2. (a) Average wind (m/s) and(b) k-form parameter at 50 m height simulated by Eta model during Winter in Northeast Region.



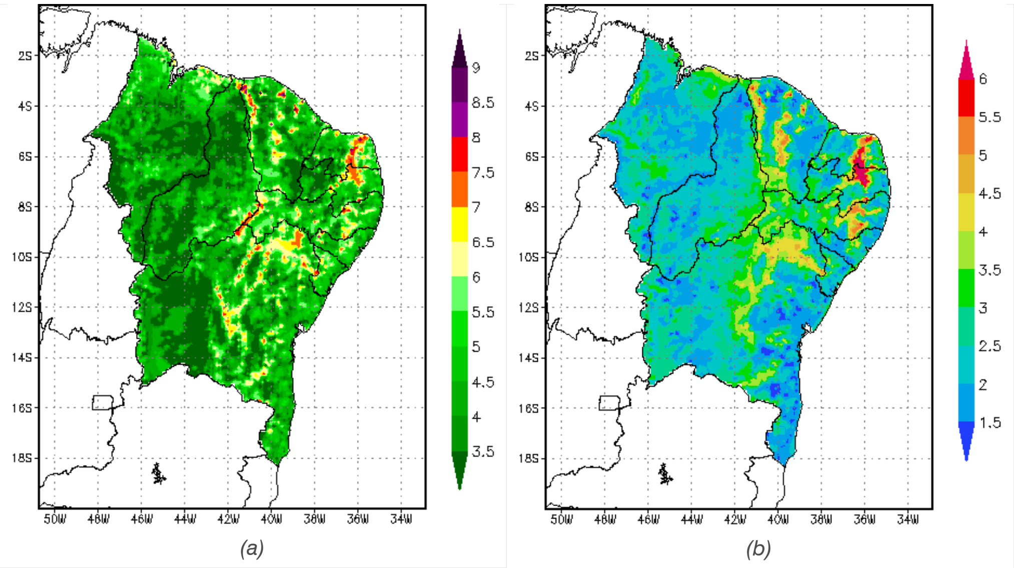
(a) (b)

Figure 4.3. (a) Average wind (m/s) and(b) k-form parameter at 50 m height simulated by Eta model during Spring in Northeast Region.



(a) (b)

Figure 4.4.
(a) Average wind (m/s) and(b) k-form parameter at 50 m height simulated by Eta model during Summer in Northeast Region.

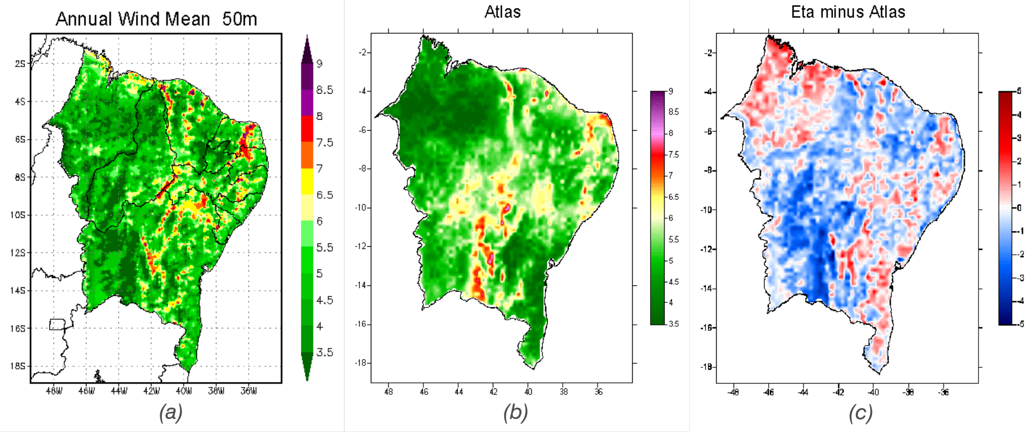


(a) (b)

Figure 4.5.
(a) Average wind (m/s) and(b) k-form parameter at 50 m height simulated by Eta model during Autumn in Northeast Region.

When comparing Figures 4.6 (a) with 4.6 (b), a good matching between the areas with more intense winds can be observed in the maps provided by Eta model and by the Brazilian Wind Atlas *[6]* for annual average wind speeds at 50m height. Two major regions are highlighted due to remarkable differences. The first one along a wide corridor composed by the Diamantina highlands located in the central part of the State of Bahia and the other one in most of the State of Maranhão, mainly along the coast. The Eta mapping does not indicated very intense annual winds in the State of Bahia and intensifies the winds in most of the State of Maranhão.

Figure 4.6. Annual average wind mapping at 50 m for the Brazilian Northeast Region provided by (a) the 10km-Eta Model, (b) Brazilian Wind Atlas [6]. The difference between them is shown in (c). Unit in m/s.

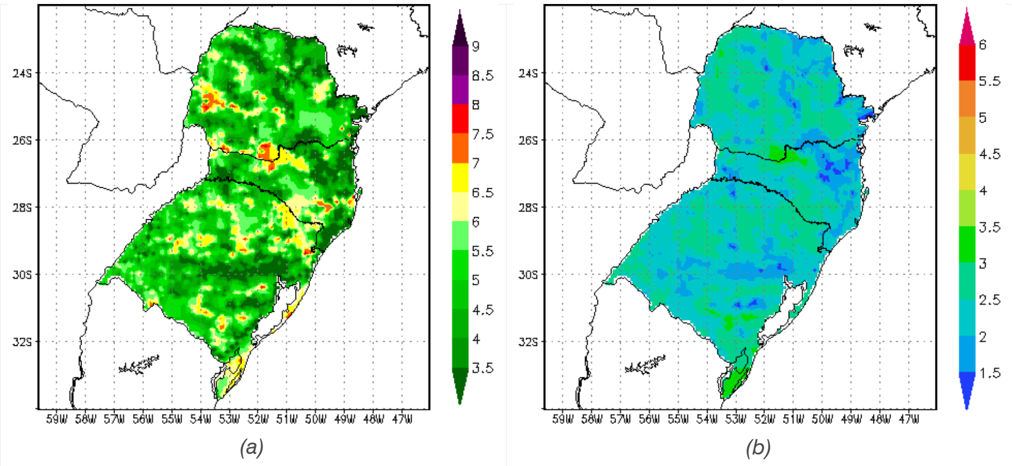


(a) (b) (c)

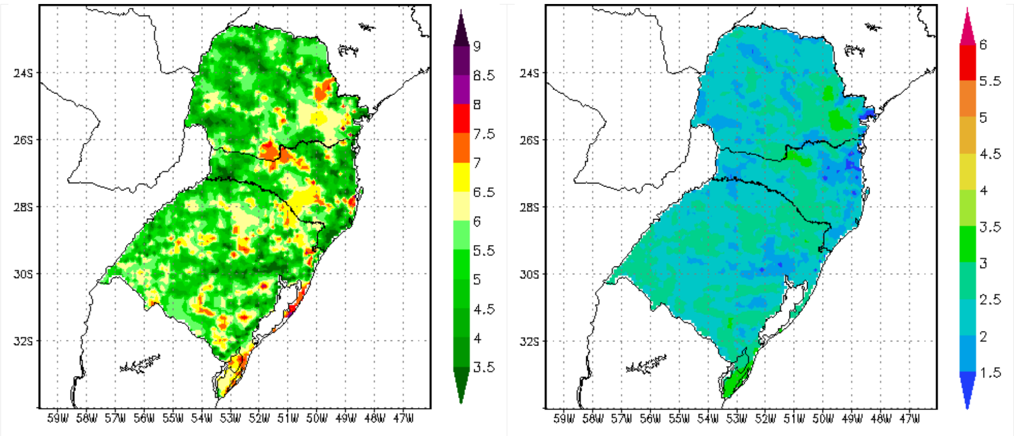
Regarding seasonal variation, the mapping simulated by the Eta model agrees with the Brazilian Wind Atlas during the Summer time (from December to February). During Autumn (from March to May), the Eta model calculate more intense winds in the Borborema highlands and at the border between the States of Piauí and Pernambuco, both areas were not indicated in the Brazilian Wind Atlas. During the Winter (from June to August) and Spring (from September to November), the areas with more intense winds are smaller in maps provided by the Eta model when compared to the Brazilian Wind Atlas. The Weibull k parameter values provided by the Eta model are generally larger indicating greater persistency of winds.

The average wind simulated at 50m height for the Brazilian South Region exhibits small and isolated areas with worthy wind potential (above 7m/s) in the coastal area of the State of Rio Grande do Sul and the border between the States of Santa Catarina and Paraná. The Weibull k-form parameter varies little along the year and exhibits values ranging from 1.5 and 3.5 in most of the South Region. The highest k values are observed in areas with higher wind speeds. Figures 4.7 to 4.10 show the seasonal maps for average wind speed and Weibull k parameter in Brazilian Southern Region.

Figure 4.7. (a) Average wind (m/s) and(b) k parameter at 50m height simulated by Eta model for Winter in South region.



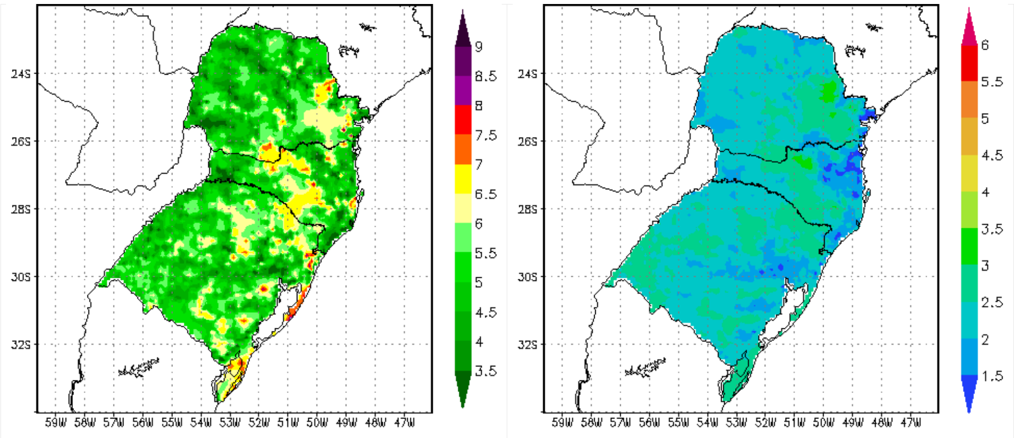
(a) (b)



(a)

(b)

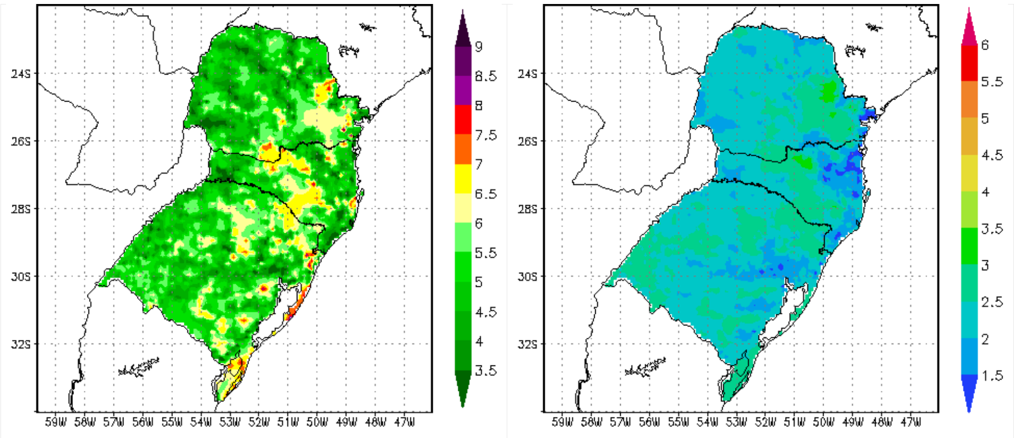
Figure 4.8.
(a) Average wind (m/s) and (b) k parameterat 50m height simulated by Eta model for Spring in South region.



(a)

(b)

Figure 4.9.
(a) Average wind (m/s) and(b) k parameter at 50m height simulated by Eta model for Summer in the Brazilian South Region.

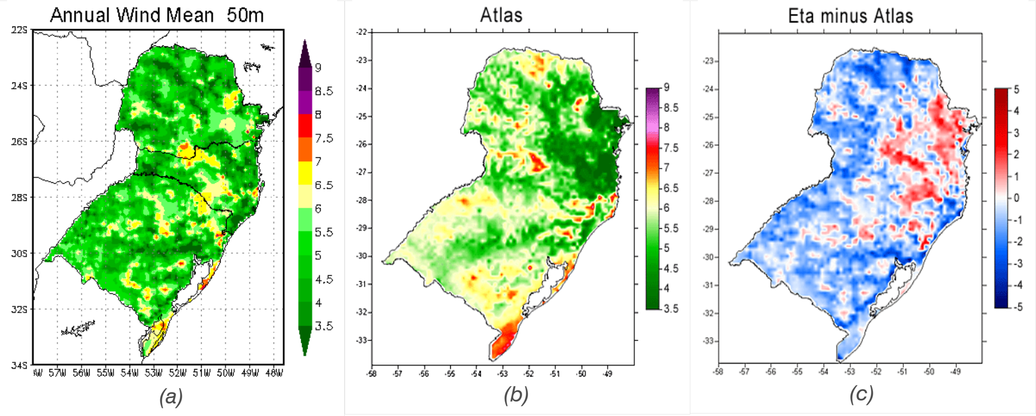


(a)

(b)

Figure 4.10.
(a) Average wind (m/s) and (b) k parameter at 50m height simulated by Eta model for Autumn in the Brazilian South Region.

Figure 4.11 allows comparing the annual average wind speed in the Southern Region provided by Eta model with results presented in the Brazilian Wind Atlas. In general, it can be observed that the locations indicated as favorable by the Brazilian Wind Atlas are generally indicated by the Eta model map, but such areas are fairly reduced in the latter one. The mapping generated by the Eta model showed more intense winds in the Eastern part of the region where mountain ranges are present. However, there is a decrease in wind speeds in the Western part, which would not be attractive for electricity generation, if confirmed, in the Northern part of the State of Paraná and in the Western part of the State of Rio Grande do Sul. None of the two maps matchs to the pattern observed in the map produced from the few surface data that are available for the South Region (Figure 4.1).



(a)

(b)

(c)

Figure 4.11. Wind mapping at 50m height for the Brazilian South Region provided by (a) the 10km-Eta Model, (b) Brazilian Wind Atlas [6]. The difference between them is shown in (c). Unit in m/s.

The Brazilian Wind Atlas and the Eta model results presented a good matching in the Weibull k-form parameter in the Southern Region. Both methodologies have identified areas presenting low values. However, the Eta model exhibited slightly greater values.

It is necessary to acquire more ground measurements in the Western area of the Brazilian Southern Region, in order to better analyze the discrepancies found. This area is receiving large investments for implementation of wind farms; however, the data from the models and the few stations in the region do not corroborate the wind potential presented in the Brazilian Wind Atlas. Nevertheless, PROINFA staff informed that the sites deployed in this region confirm a tendency of good winds. Unfortunately, ground data acquired in several sites at this region are not of public domain.

The Southern part of the State of Bahia in Brazilian Northeast also calls for systematic ground measurement due to the mismatch between the mapping derived from the Eta model and from the Brazilian Wind Atlas.

More details on wind energy assessment can be obtained in the Brazilian Report for Wind Energy Assessment available in CD-ROM and in http://swera.unep.net/. This report presents wind maps for wind speed and Weibull k-form parameter at 50m and 100m heights provided by Eta model as well as statistical analysis of ground data acquired in several airports, AWS sites and all SONDA wind measuring stations.

4.2. SOLAR ENERGY ASSESSMENT

The solar irradiation assessment in Brazil has been made by several authors using both interpolations between ground data *[26]* and satellite models *[28]*. In the SWERA project the assessment was accomplished jointly by CPTEC/INPE and LABSOLAR/UFSC by using BRASIL-SR radiative transfer model and satellite database acquired from July 1995 to December 2005 – a full decade dataset *[21]*. The data and maps in this report are average values for the daily total estimates of solar irradiation in 10km x 10km spatial resolution.

The map shown in Figure 4.12 exhibits the daily annual average of the global horizontal solar irradiation. Despite of the different climate characteristics along the Brazilian territory, one can observe that global irradiation is fairly uniform. The maximum value – 6.5kWh/m^2 - occurs in the Northern part of the State of Bahia close to the border with the State of Piauí. This area exhibits a semi-arid climate with low rainfall throughout the year (approximately 300mm/year) and the lowest annual average cloud coverage of Brazil. The lowest value – 4.25kWh/m^2 - occurs along the North shore of the State of Santa Catarina where precipitation is well distributed throughout the year. The annual average of daily global horizontal solar irradiation in any region of the Brazil (1,500 to 2,500kWh/m^2) is larger than those for the majority of the European countries such as Germany (900 to 1,250kWh/m^2), France (900 to 1,650kWh/m^2), and Spain (1,200 to 1,850kWh/m^2) where projects to harness solar resources are greatly disseminated, some of which, with big government incentives *[4]*.

Figure 4.13 shows the maps for seasonal averages of daily global horizontal irradiation. The North Region receives lower solar irradiation during the Summer (December to February) than the South Region in spite of its closer location to the Equator. The opposite occurs during the Winter (June to August), when the Amazon Region receives greater solar irradiation. This is due to climate characteristics of the Amazon Region which features a larger cloud coverage and rainfall during the Summer because of strong influence of the Inter-Tropical Convergence Zone (ITCZ). The variation of the solar irradiation between Winter and Summer is smaller in the North region than in the South and Southeast. The inherent decrease of solar irradiation at the top of the atmosphere in the Winter due to latitude is counterbalanced in the Amazon Region by a smaller cloudiness associated to the ITCZ displacement towards the Northern hemisphere.

The ITCZ displacement combined with the incursion of the trade winds coming from the Atlantic Ocean are responsible for larger precipitation (about 1100mm) at the Northwestern portion of the Amazon Region even during the dry season between July and September. In reason of that, the West area of the State of Amazon exhibits the smallest average yearly solar irradiation of the North Region of Brazil.

The trade winds incursion also explains the smaller solar irradiation on the coastal region of the Brazilian Northeast. The maximum solar irradiation values are observed in Western area of the Northeast region including the Northern area of the State of Minas Gerais, the Northeast area of the State of Goiás and the South area of the State of Tocantins. During the whole year, the influence of the Tropical High Pressure associated to the South Atlantic Tropical Anticyclone provides a stable condition of low nebulosity and high incidence of solar irradiation for this region.

The daily global horizontal solar irradiation exhibits greater inter-seasonal variation in the Southern Region. In addition, the Southern Region shows the smallest values of global horizontal solar irradiation in Brazil, notably on the Northern coast of the State of Santa Catarina, and the shorelines of the States of Paraná and São Paulo. The subtropical climate characteristics of this region and the influence of the frontal systems associated with the Antarctic Polar Anticyclone contribute to enhance the nebulosity, mainly in the Winter months.

As in the Northern Region, the Central Region of Brazil is subjected to a larger incidence of solar radiation during the dry seasons (Autumn and Winter), mainly between the months of July and September, when the precipitation is low and the number of clear sky days is larger.

Figures 4.14 and 4.15 exhibit the maps of annual and seasonal averages of daily solar radiation that reaches a flat-plate collector oriented toward the equator and tilted at an angle equal to the latitude of that site. Disregarding the local topography and cloudiness, as well as the albedo, this configuration theoretically allows capturing the maximum yearly solar energy. The solar irradiation on a tilted plane exhibits a strong influence of the surface albedo. The greatest levels of irradiation on the tilted plane occur in the range that goes from the Northeast to the Southwest during the Spring (from September to November) and the smallest values in all Brazilian regions occur during the Winter (from June to August).

Figures 4.16 and 4.17 exhibit respectively the maps of annual and seasonal averages of the diffuse component of the daily total of solar irradiation. On the annual average, one can observe that the Northern Region receives greater diffuse irradiation mainly in the estuary of the Amazon River. This is due to the greater nebulosity in the region because of the ITCZ influence. Seasonally the greatest diffuse irradiation occurs during the Summer (from December to February) throughout the Amazon Region and the smallest values happen during the Winter in the Southeast and South Regions.

A deeper discussion on the solar energy assessment and its seasonal and inter-annual variability is presented in Brazilian Solar Energy Atlas *[21]* available on CD-ROM and free access in http://swera.unep.net/. The Brazilian Atlas also presents a short description of the BRASIL-SR radiative transfer model, the reliability analysis of the solar energy maps, and the temporal trend showed in the 10-year period, by solar irradiation in all Brazilian geographic regions.

Figure 4.12.
Map showing the annual average of the daily total global horizontal solar irradiation.

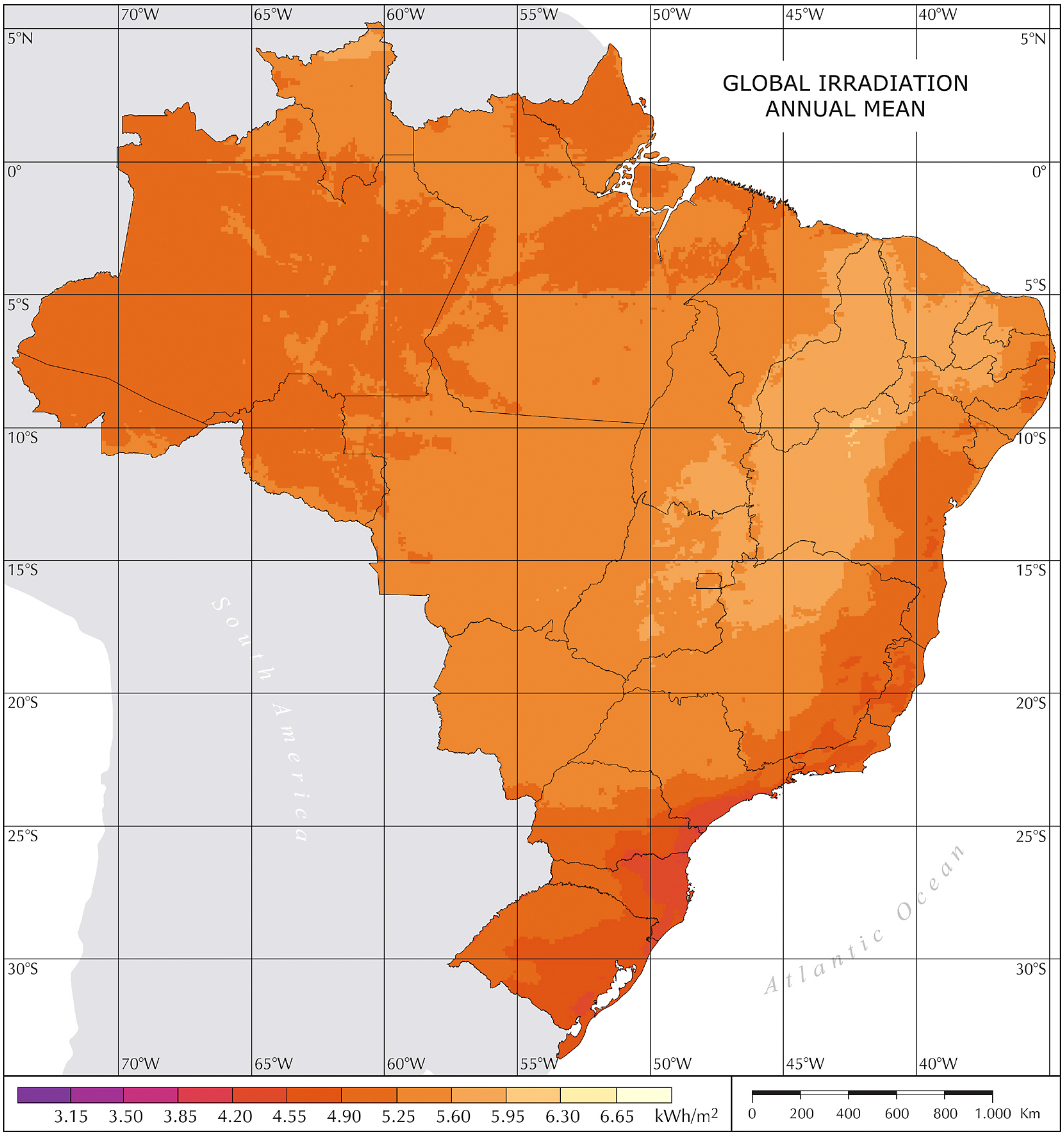


Figure 4.13.
Maps of the seasonal average of the daily total of global horizontal solar irradiation.

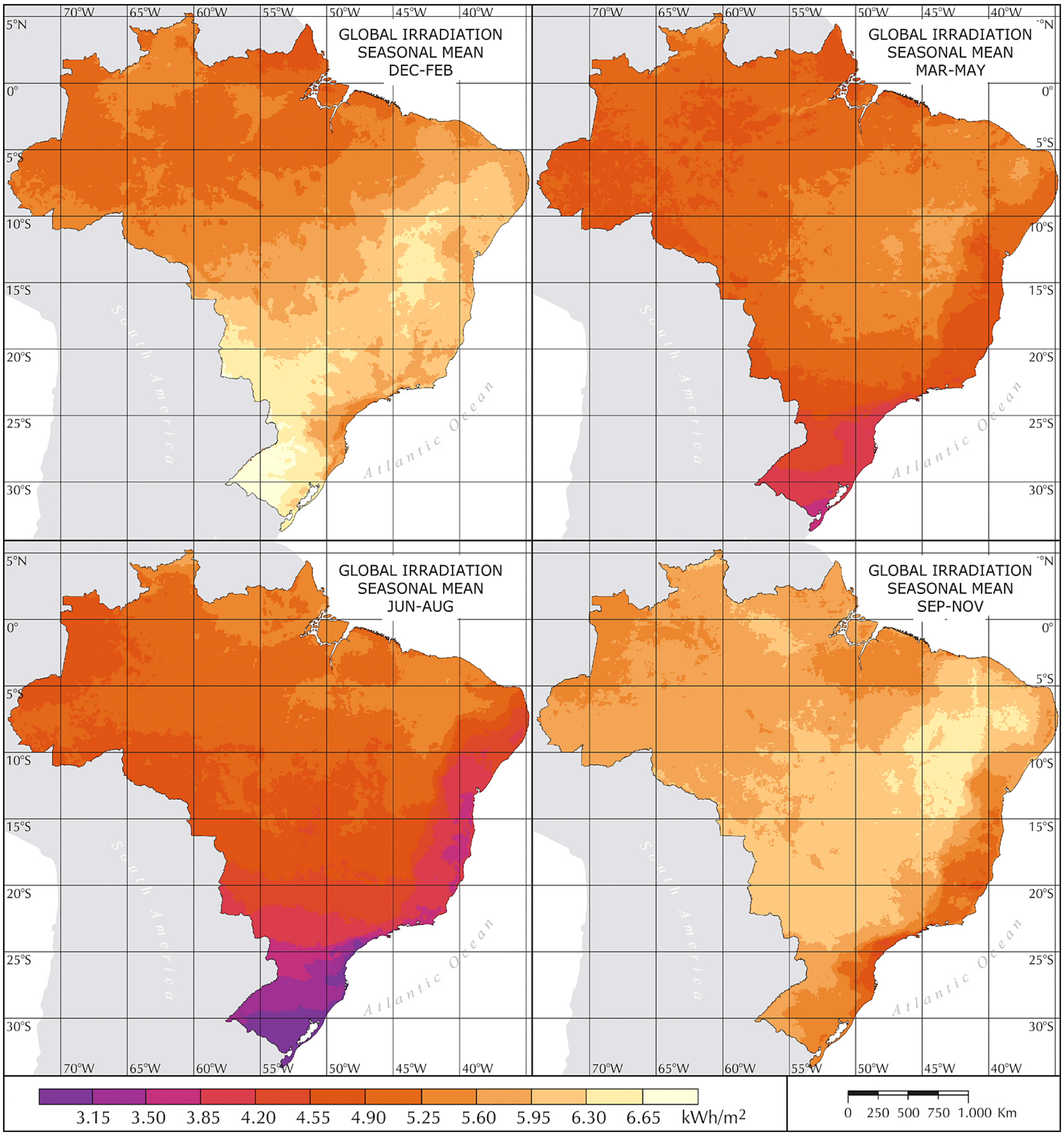


Figure 4.14.
Map of the annual average of the daily of solar radiation that reaches a flat-plate collector oriented toward the equator and tilted at an angle equal to the latitude of that site.

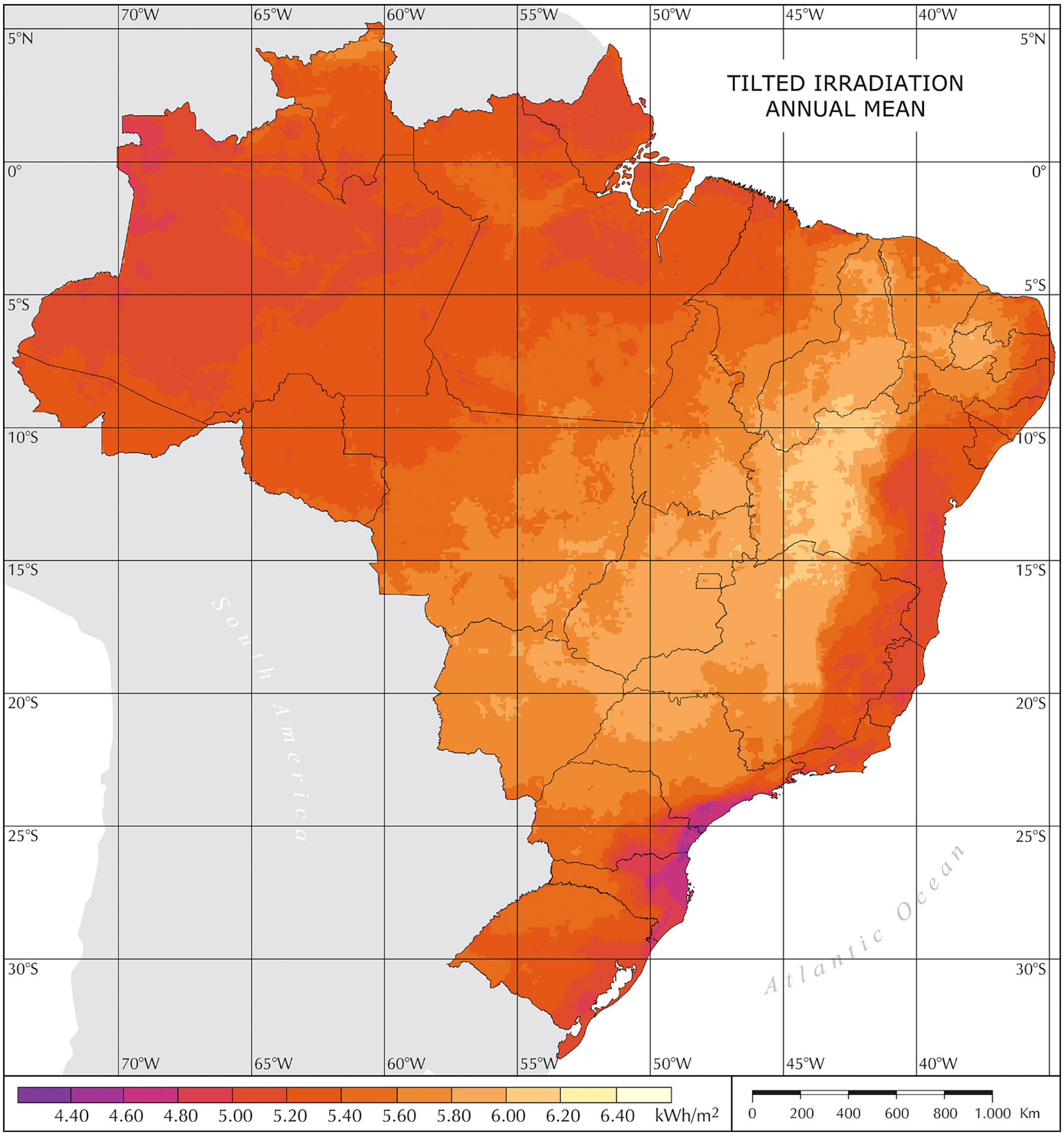


Figure 4.15.
Map of the seasonal averages of the daily solar radiation that reaches a flat-plate collector oriented toward the equator and tilted at an angle equal to the latitude of that site.

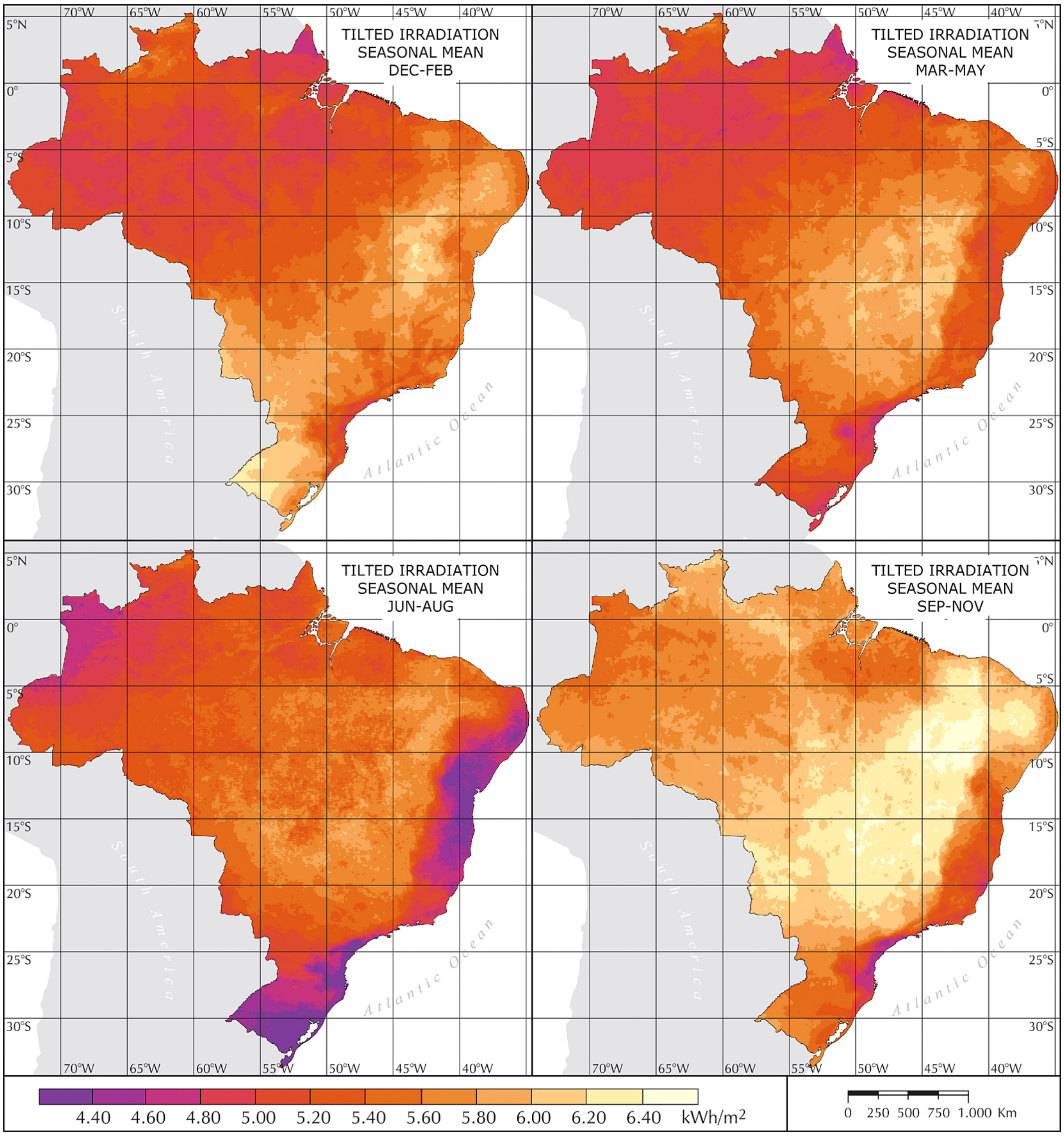


Figure 4.16.
Map of the annual average of the diffuse component of the daily total of solar irradiation

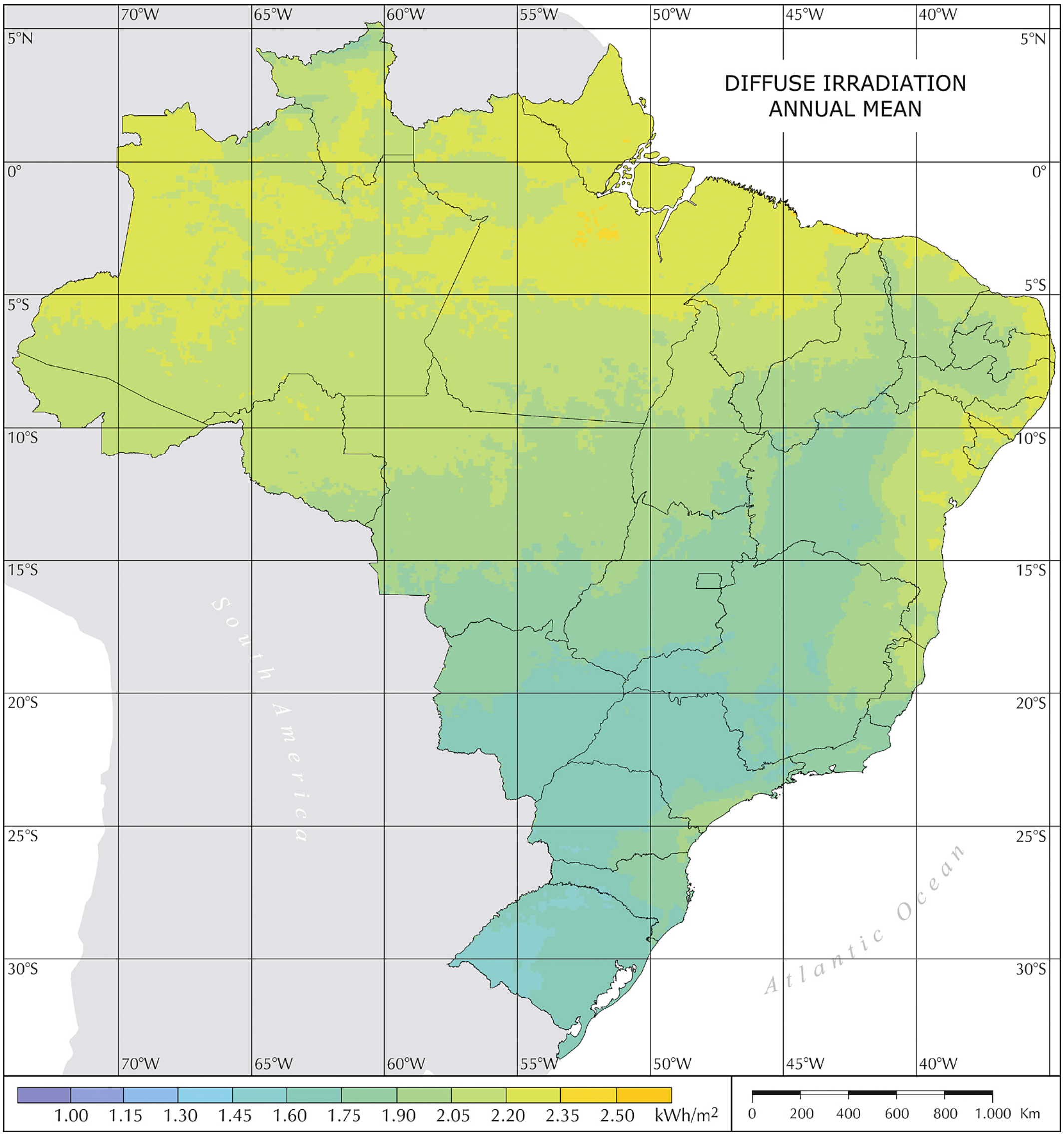
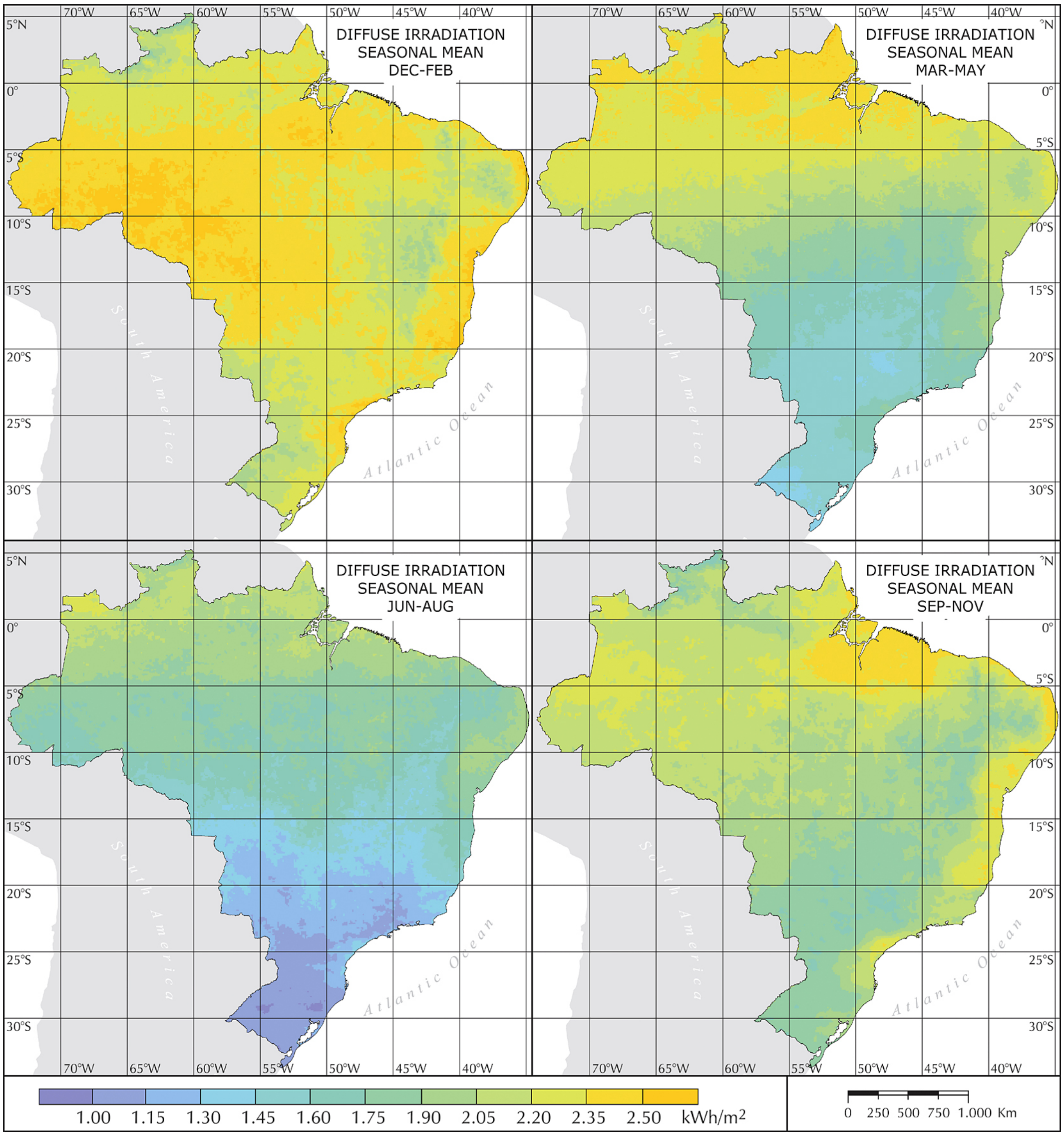


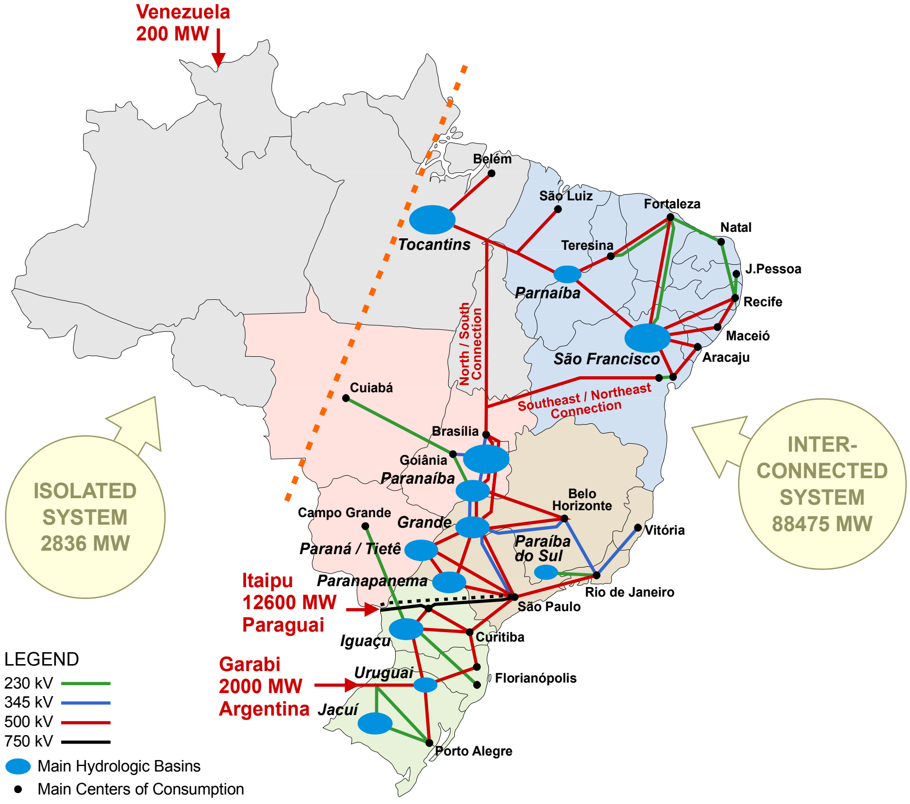
Figure 4.17.
Map of the seasonal average of the diffuse component of the daily total of solar irradiation.



ELECTRICITY EXPANSION PLAN

The growth in the economy of Brazil during the year of 2005 has caused direct influence on the internal consumption of electricity surpassing 370TWh, with a growth rate of about 4.2% regarding the previous year. The interconnected electric system (Figure 5.1) also evolved accordingly, reaching over 93GW, in country, of installed capacity (not considering imports and 50% of Itaipu Hydro Power Plant). The transmission grid increased about 3% per year reaching an extension of 82,000km with 815 links above 230kV, and a total capacity of 178,000MVA in 321 substations.

Figure 5.1.
Electricity Distribution System in Brazil.



5.1. TEN-YEAR EXPANSION PLAN (2006-2015) *[5]*

The assumed trend in the Brazilian economy development during the 10-year expansion plan for electricity market combines elements from scenarios of sustained and moderate economic growth rates and it is summarized by the GDP growth rates shown in the Table 5.1. The demographic scenario, based on the 2004 census indicates higher growth than was previously forecasted and the scenario is shown in the Table 5.2.

Period	GDP Growth Rate %
2007/2011	**4.0**
2012/2015	**4.5**
2005/2015	**4.2**

Table 5.1.
GDP scenarios for 2005/2015 period in Brazil.

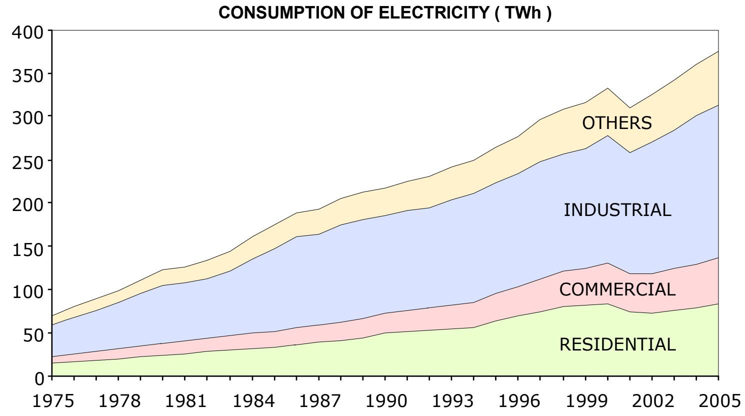
Demography Scenario *(x 1000)*	Population	Households	Inhab./Household
2005	182,507	52,223	3.5
2010	193,027	59,586	3.2
2015	202,418	67,827	3.0
Growth Rates (% p.a.)			
2005-2010	1.13	2.67	
2010-2015	0.93	2.62	
2005-2015	1.04	2.65	

Table 5.2.
Demographic scenario for the 2005/2015 period in Brazil.

5.2. FORECAST FOR ENERGY CONSUMPTION

As a result of the electric energy crisis, the consumption in 2001, for the first time in 50-year period, registered a negative growth rate. Utilities sold 283.8 TWh, down 7.7% on 2000. Taking into account self-generation, the total consumption in Brazil in 2001 reached 309.9TWh, 6.5% less than 2000, as shown in Figure 5.2.

Figure 5.2.
Consumption of electricity in Brazil from 1975 to 2005 [1].



The 2006-2015 ten-year expansion plan studies indicate that energy consumption as supplied by utilities will rise to 567TWh in 2015. As a result, the average growth rate of energy consumption during the 10-year expansion plan is 5%, indicating an income-elasticity during this period of approximately 1.2. The Table 5.3 and 5.4 provides a summary of the scenarios projected for the utilities markets, itemized by consumer class and energy system.

Table 5.3.
Scenarios for electricity consumption in the 2006/2015 period.

Consumption of Electricity *(utilities) TWh*	**2005**	**2010**	**Δ%**	**2015**	**Δ%**
Consumer Class					
Residential	82.3	109.2	5.8	142.5	5.5
Commercial	52.9	73.4	6.7	101.9	6.8
Industrial	161.1	198.4	4.3	244.7	4.3
Others	49.8	62.6	4.7	77.8	4.4
Energy Systems					
North (Isolated System)	7.2	10.9	8.7	16.0	8.0
North (Interconnected System)	23.5	30.7	5.5	45.5	8.1
Northeast	47.5	61.2	5.2	78.1	5.0
Southeast/Midwest	209.1	266.8	5.0	335.1	4.7
South	58.8	73.9	4.7	92.2	4.5
Brazil	**346.1**	**443.5**	**5.1**	**566.8**	**5.0**

Table 5.4.
Scenarios for electricity consumption in the 2006/2015 period.

The Economy and Energy Consumption	**2005/2010**	**2010/2015**	**2005/2015**
Economic Growth (% p.a.)	4.0	4.5	4.2
Growth in Consumption (% p.a.)	5.1	5.0	5.0
Income Elasticity	1.28	1.1	1.2

5.3. LOAD ESTIMATES (SYSTEM REQUIREMENTS)

Reflecting the behavior of consumption, the electric load dropped in 2001 as a direct result of the energy saving program throughout most of the interconnected system. According to the forecast, the electric load requirement of the systems totalizes 47.6GW average in 2005, and 76.2GW average in 2015, with an annual average growth during the 10-year plan of 4.8%. The Table 5.5 and 5.6 provide a summary of the forecasted electric loads and losses figures.

Load estimates **Energy load** *(MW average)*	**2000**	**2001**	**Δ%**	**2005**	**Δ%**	**2015**	**Δ%**
Isolated System	884	930	5.5	1,242	1.3	2,226	6.0
North Interconnected System	2,487	2,331	-6.3	3,150	1,4	6,039	6.7
Northeast Interconnected System	5,897	5,295	-9.9	6,725	1.3	10,712	4.8
SE / Midwest Interconnected System	26,206	23,521	-10.2	28,812	1.2	45,346	4.6
South Interconnected System	6,431	6,604	2.7	7,654	1.2	11,901	4.5
Brazil	**41,887**	**38,681**	**-7.7**	**47,583**	**1.2**	**76,224**	**4.8**

Table 5.5. Scenarios for electric load in the 2006/2015 period.

Total losses estimates **Energy load** *(MW average)*	**2000**	**2005**	**2010**	**2015**
Isolated System	30.5	34.0	26.0	18.0
North Interconnected System	13.5	14.7	14.4	14.1
Northeast interconnected system	20.0	19.3	18.0	16.8
SE / Midwest Interconnected System	16.5	17.1	16.4	15.6
South Interconnected System	12.4	12.4	12.0	11.6
Brazil	**16.5**	**16.5**	**15.8**	**15.0**

Table 5.6. Scenarios for total losses estimates in the 2006/2015 period.

RENEWABLE ENERGY SCENARIOS

6.1. WIND ENERGY SCENARIOS

6.1.1. THE WIND RESOURCE

ANALYSIS AND FORECAST FOR WIND ENERGY IN BRAZIL

The huge wind energy resource in Brazil is favored by 8,500km of coastline and extensive inland elevated plateaus. In its 8.5 million km^2 territory, the regional influences of trade winds, sea breezes, the Atlantic Subtropical High Pressure Area, the Low Pressure Area at East of the Andes and the recurrent transit of cold fronts, as well as local mesoscale effects, distribute across the country a useful and clean energy source in the form of kinetic energy of the moving atmospheric air masses.

More than 71 thousand km^2 of the Brazilian territory are estimated to have annual average wind speeds above 7m/s at 50m height above ground level. Assuming conservative figures of 50m height and 2 MW/km^{2,} and integrating areas, the estimated onshore wind energy potential is 143GW or 272TWh/year *[6]* - quite significant if compared to Brazil's electricity production capacity and consumption in year 2005: 93GW and 370TWh/year *[1]*. Moreover, almost all the windy areas are relatively close to the Interconnected National Grid and closer to populated centers than existing and future hydro power plants.

6.1.2. THE IMPORTANCE OF WIND ENERGY IN BRAZIL

Independent studies (Figure 6.1, 6.2 and 6.3), conducted at utilities in Northeast and South Brazil *[7]*, have shown that hydroelectric power plants located in Southeast and Northeast Brazil have almost similar hydrological seasonal regimes: higher natural water flow during Summer-Autumn (Dec-Apr), while critical reservoir levels are sometimes reached during Winter-Spring (Jul-Oct). This fact has posed an important historical challenge to the operation and planning of the Brazilian Interconnected Electric System, and it is also reflected in tariffs for large industrial consumers in the whole country. Moreover, existing measurements show that both South and Northeast Brazilian wind regimes are complementary to the seasonal hydro regime. The higher wind power penetration in the Brazilian system, the higher water savings in the hydro power plant reservoirs during the critical dry season. That potential benefit from wind-hydro seasonal complementarity's is even more important in the Northeast Brazil, especially for the management of hydro power plant reservoirs in the basin of the São Francisco River.

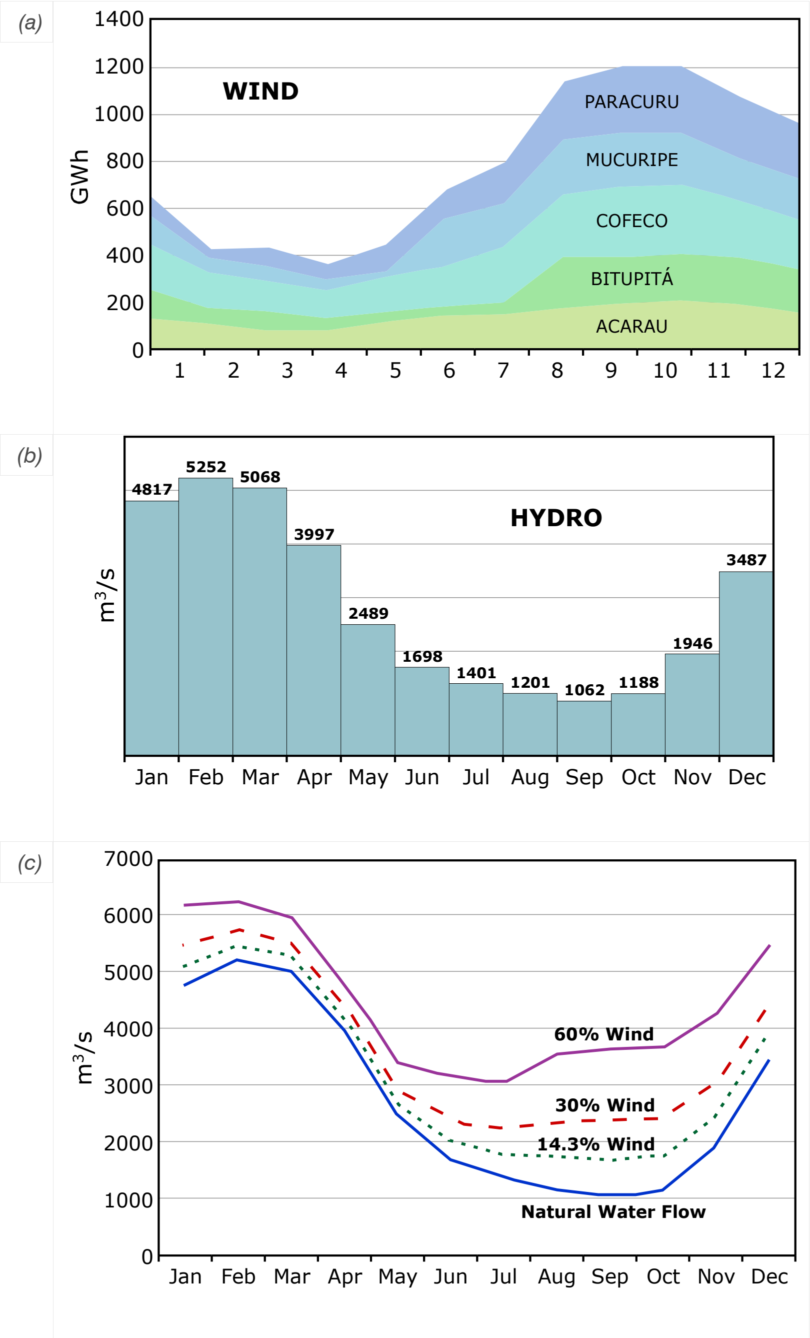


Figure 6.1.
(a) Simulated production of hypothetical 3GW wind farms in Northeast Brazil; (b) Natural water inflow at the CHESF Sobradinho power plant reservoir in River São Francisco (1931-1992); (c) Equivalent water inflow at Sobradinho with increasing wind energy penetration [7].

Figure 6.2.
Integration of a hypothetical Palmas 50 MW wind farm into the Southern Brazilian Electric sub-system [7].

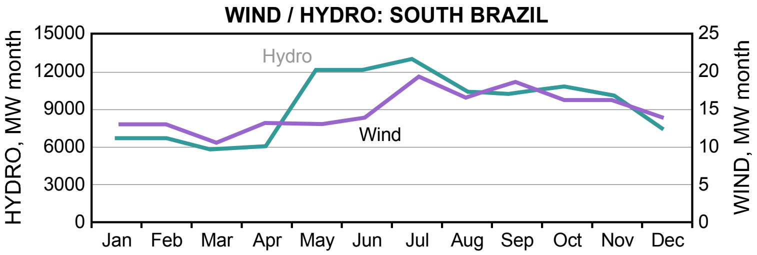
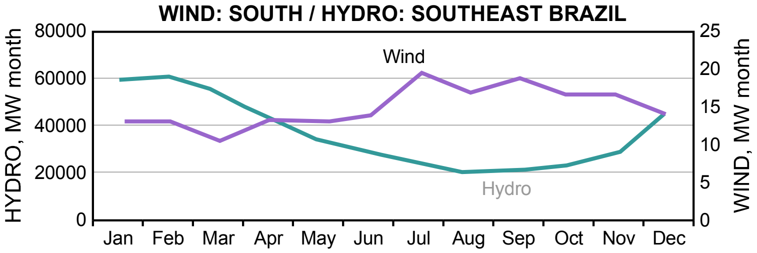


Figure 6.3.
Integration of a hypothetical Palmas 50 MW wind farm into the South-eastern Brazilian Electric sub-system [7].



In 2005, hydropower provided 85% of the Brazilian electric energy consumption, including Itaipu imports *[1]*. This hydro-dominant electricity generation is subject to seasonal rainfall cycles of significant amplitude - reflected in higher energy prices during the dry season. In 2001, Brazil suffered a severe electricity supply crisis, with most of the Southeast and Northeast hydro power plant reservoirs reaching an almost critical depletion.

However, a well-matched wind-hydro seasonal complementarity has been evidenced for the relevant part of the Brazilian electricity market *[7]*. This fact makes wind energy an effective alternative for increasing security of energy supply in Brazil, and it was a key argument for the federal government to establish the Alternative Energy Sources Incentive Program – PROINFA – described earlier. In April 2002, the Brazilian Government established the incentive program for renewable energy sources - PROINFA - with the main aim of increasing the security of energy supply by using efficiently the available renewable energy sources.

6.1.3. PROINFA – THE EXISTING INCENTIVE FOR WIND ENERGY IN BRAZIL

PROINFA was established by the Brazilian Congress as a two-phase, long-term program. In the first phase, 1,422.92 MW of wind farm projects have been already selected and awarded the 20-year Power Purchase Agreement through ELETROBRÁS. The selection bidding process required some of the main pre-requisites for financing the projects: environmental licenses, qualified wind measurements, land clearance through lease or property ownership, etc. The 20 year power purchase contracts with ELETROBRÁS have energy prices ranging from R$212 to R$241/MWh in March 2007, (equivalent to €77 to €87/MWh) depending on the capacity factor of the project.

In PROINFA's first phase, as of December 2006, 208.3MW of wind energy projects are commissioned (159 MW in South, 49.3MW in Northeast Brazil). Deadline for commissioning the remaining PROINFA I projects is December 2008 (Figure 6.4).

Although PROINFA Phase I has already managed to add 208.3MW to the formerly existing 29MW of Brazilian installed wind capacity, there have been several obstacles to a higher degree of success in the established goal of 1,422MW wind. Some of the main reasons have been:

1. PROINFA I coincided with a world shortage of wind turbines and higher prices due to a boom in installation of wind farms, especially in the North American market;
2. corporate finance rules offered by Brazilian development bank BNDES did not match the capability of most of the PROINFA wind farm developers; only in 2006 BNDES started offering project finance rules, which are expected to make many projects feasible;
3. although the Congress' PROINFA 10438 Law established a long-term policy, the Government has failed to establish clear, long-term rules, needed to ease the wind energy market development – manufacturers, equipment prices, investors. Essential part of the PROINFA Law, the long-term Phase II has not yet presented a final regulation.

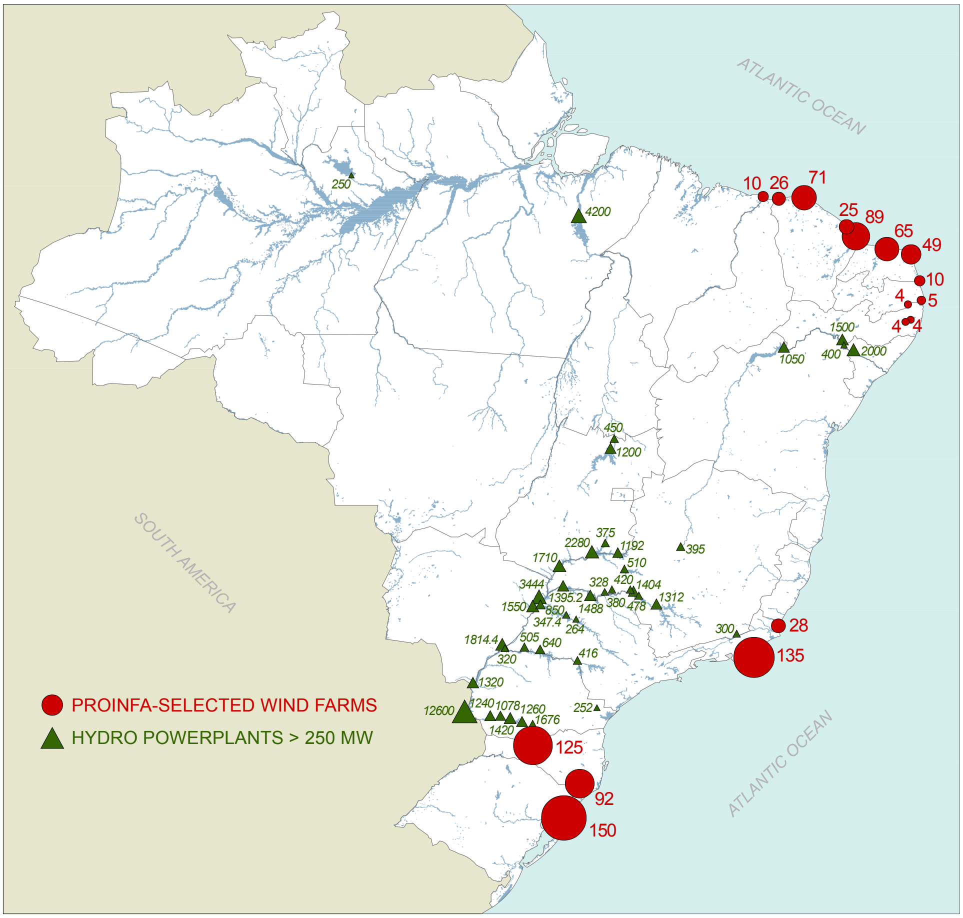


Figure 6.4.
PROINFA I wind farms capacities in MW:
NE 805MW
SE 163 MW
S 454 MW

6.1.4. THE BRAZILIAN WIND INDUSTRY

The PROINFA incentives require a local content of 60% in the total value of each installed project in the first phase, increasing to 90% in the second phase - a state policy with the aim of stimulating the wind turbine industry in generating jobs. Up to the moment, only a subsidiary of the leading German wind turbine manufacturer established in Brazil long before PROINFA (1998) – has supplied the equipment to all the installed wind farms in Brazil, before PROINFA.

However, the Brazilian industry has been exporting components of wind turbines to the world wind energy market in a significant scale: composite rotor blades, rotor hubs, nacelle bedplates, electric generators, special bearings and other minor components. Noteworthy is the export of large composite rotor blades, manufactured by a Brazilian company that emerged from the aerospace industrial area of São José dos Campos, SP (Figure 6.5). More than 10% of the world market of wind rotor blades in 2006 was supplied by Brazilian companies. The huge potential of wind energy in Brazil is certainly favored by the technology and production capacity of the local industry.

Figure 6.5.
The Brazilian wind turbine industry.

6.1.5. FORECAST – WIND ENERGY IN BRAZIL, 2006-2015

As the licensing, financing and construction of large hydro power plants require long maturation cycles, planning the expansion of the Brazilian electric energy supply is done with horizons typically of 10 and 30 years. The 10-Year Expansion Plan 2006–2015 *[5]*, produced by EPE – the Brazilian Government's "Company of Energy Research", has been recently released. It contains detailed analyses and forecasts of the expansion of the market, on the consumption side, based on macroeconomic and demographic projections. Since the PROINFA Law 10438 establishes:

1. a minimum of 15% of the annual increase in electric energy consumption shall be supplied by new wind, small hydro and biomass plants, in equal amounts of installed capacity;
2. these renewable sources shall supply 10% of the annual electric energy consumption in Brazil within 20 years.

Considering the projected annual increase in electric energy consumption from *[5]*, as shown in Figure 6.6, and the long-term policy of Brazilian Law 10438, the expansion of wind energy capacity in Brazil should be as seen in Table 6.1.

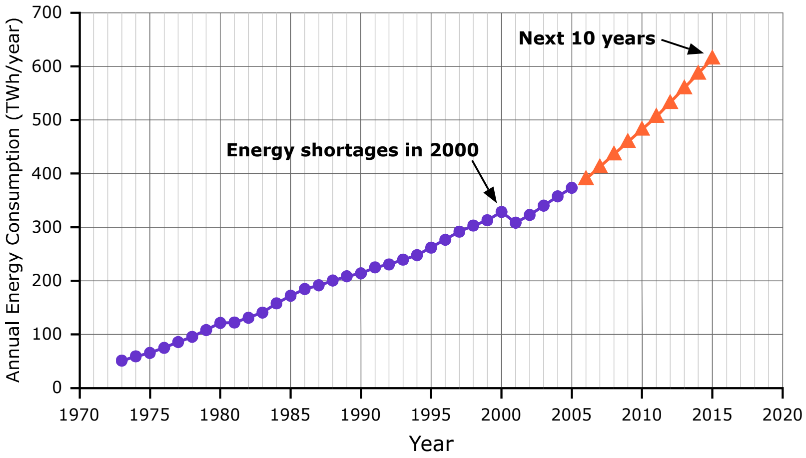


Figure 6.6.
Brazilian Decennial Plan 2006-2015 – reference scenario for energy consumption.

Table 6.1.
Brazilian Decennial Plan 2006-2015 - reference scenario for energy consumption.

Year		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Projected Electricity Consumption *[1]*	TWh/year	373.5	393.6	414.6	436.6	459.6	483.5	508.4	534.3	561.1	588.9	617.7
Consumption Increase	TWh/year		20.1	21.0	22.0	23.0	23.9	24.9	25.9	26.8	27.8	28.8
15% of Annual Increase (PROINFA)	TWh/year	-	-	-	-	3.45	3.59	3.74	3.88	4.03	4.17	4.32
WIND Annual Installation	TWh/year	-	1378			262	273	284	295	306	317	328
Cumulative Wind Installed	MW	30	239	-	1378	1640	1913	2198	2493	2799	3117	3445

The wind energy expansion scenario established by the PROINFA Phase II predicts an annual installation of about 300 MW/year after the Phase I is completed. The whole market is expecting the regulation of the Phase II from the Brazilian Government, since it will detail the rules and procedures to comply with the established policy from Law 10.438. This regulation should be presented in years 2007-2008.

A closer analysis of the Government's 10-Year Expansion Plan 2006-2015 reveals great challenges to the expansion of the energy supply in Brazil for the next decade. To comply with increasing energy consumption and country economic development, about 40GW of new generation capacity should be added to the existing 93GW. The uncertainties in the 2015 Plan:

1. 45% of the planned 40GW expansion is based on new large hydro capacity to be added is in the North or in the Midwest Brazil, very far from the consumption centers in Southeast, South and Northeast;
2. 25% of the new 40GW expansion is planned using thermoelectric plants, mostly based on natural gas, and one nuclear plant. There is a shortage of natural gas for power generation in 2006, and some uncertainties exist about that much availability in the next 10 years;
3. Distant large hydroelectric plants, long transmission lines and associated electric losses, as well as thermoelectric power generation, point to steeper increases in energy prices. Delays in the construction of some planned plants may pose critical dependency on rainfall regimes. A close attention the Brazilian electric energy market in the next years will be very interesting for the wind energy players (developers, investors, manufacturers, etc.). There is a good probability that wind energy will be required to play a role much more important than the figures established in PROINFA Law and existing renewables policy.

6.2. THERMAL SOLAR ENERGY SCENARIOS

One of the main goals of SWERA was to provide reliable information regarding the solar resource (as well as wind), to be used by designers, financial analysts and legislators, due to the lack of reliable data. This lack of good quality data made in many cases the uncertainties too high regarding the performance of systems, and consequently regarding the economic viability analysis of projects. As a consequence, the amount of investments in solar energy is reduced, once the risks would be, in many cases, at undesirable levels.

The market for products using solar energy has been growing over the years. The economic feasibility of certain applications combined with the greater ecological awareness, along with a growing concern about the long-term impact of using conventional sources of energy, were the key factors for the growth of the market for equipment using solar energy.

One of the most important application of solar energy in Brazil is the one in which the solar energy is directly transformed into heat. Despite the high initial investment, the payback time is low, as will be further discussed in details. Thermal solar energy applications in other areas, such as the agro-industry, request for greater investments due to the low value added to production. For this reason, the technologies in use are generally not very sophisticated. Another use of thermal solar energy is cooling. Such application, however, requires further technological development in order to become a market alternative.

6.2.1. THERMAL SOLAR ENERGY FOR WATER HEATING

Thermal solar energy is one of the oldest applications of this energy source, where solar radiation is directly used to produce heat. The reasons that hinder the large-scale use of solar energy are the high variability, uncertainty, and discontinuity during the night and low energy density. In reason of that, the thermal use of solar energy is still small when compared to the combustion of firewood and fossil fuels, which have a much greater energy density.

Brazil has a particular characteristic that sets it apart from other countries regarding water heating for residential use. During the 1960s and 1970s, huge investments were made in the hydroelectric energy generation sector. Since economic growth did not go together with the growth in production during certain periods, the consumption of the exceeding electricity was encouraged, so electric showerheads became widely used in the country. Figure 6.7 shows the total and per sector demand of electricity in Brazil during the day. By observing the curve that represents total demand, a pronounced peak can be seen during the early nighttime hours. This peak is reproduced in the residential consumption curve, which leads to the conclusion that this is the major responsible of the existence of the "peak demand time" in electricity consumption. It is exactly during this peak demand time that the electric shower is most widely used, and therefore, its substitution may be considered as an efficient measure and rational use of electric energy in Brazil. Electric showerheads are high power equipment – above 4kW, reaching up to 7kW – with a low load factor, since they are used only a few minutes a day.

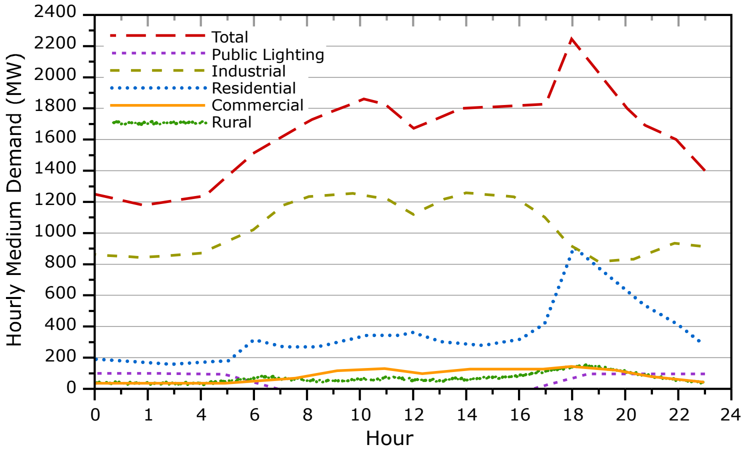
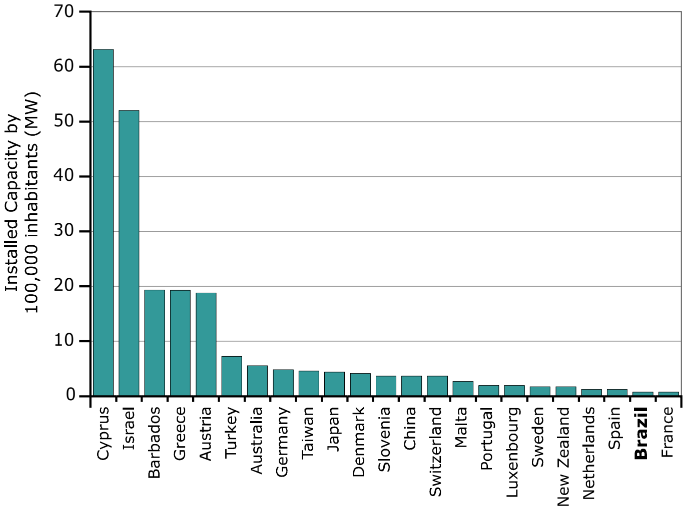


Figure 6.7.
Average hourly demand of electric energy per sector in Brazil.

Water heating is the most promising application of solar energy in Brazil. Currently, a fairly well developed market already exists for solar heating systems in Brazil, which has more than 2.2 million m^2 of thermal solar collectors for water heating installed. However, this area is small when compared to that of countries where the solar energy resource and the population are smaller, such as Germany (above 5.7 million m^2), or Turkey (more than 7.2 million m^2). The graph of Figure 6.8 shows the installed capacity in thermal Megawatts per group of 100,000 inhabitants in several countries. It can be observed that Brazil has a very low ratio, which indicates that a large market is still available in the country *[9]*.

Figure 6.8.
Installed capacity of solar collectors for water heating per group of 100,000 inhabitants in 2004.



There are several industries for solar heating systems in Brazil, which concentrate their production in flat plate solar collectors with glazing. Over the last years, some industries started producing plastic collectors without cover, used preferentially for heating swimming pools. Collectors with evacuated heat pipes are not yet manufactured in Brazil.

The low-cost home water solar heating system commonly used in Brazil consists of a flat plate collector and a storage tank. It operates by direct heating (no heat exchanger) and water circulation though a thermo-siphon. Generally, It does not consume electric energy, if some distance/heights are observed, otherwise a water circulation pump is necessary, and some energy is consumed.

The flat plate solar collectors consist of a black Copper absorber, a thermally insulated box and a front glazing. The hot water is stored in cylindrical insulated water tanks.

A labeling program, which started in 1998, headed by PROCEL and INMETRO, tests several characteristics of the collectors and tanks, and grants quality and efficiency labels. In 2007, the best labeled collectors have an efficiency of 77%.

The solar energy data generated during the SWERA project have a spatial resolution of 10km x 10km of the monthly averages for daily totals. This type of data is widely used for economic scenario studies. Although, this spatial resolution is not enough for detailed execution projects, it makes possible to perform quick simulations with adequate accuracy for energy planning and pre-design facilities. If more detailed simulations are necessary, the SWERA project has also made available the typical meteorological years (TMY – available in the annexed CD-ROM) for the 20 Brazilian cities listed in Table 6.2. The choice of such cities prioritized the distribution throughout all Brazilian regions, as can be seen in Figure 6.9.

ID	City	State
1	Campo Grande	Mato Grosso do Sul
2	Curitiba	Paraná
3	Florianópolis	Santa Catarina
4	Fortaleza	Ceará
5	Recife	Pernanbuco
6	Cuiabá	Mato Grosso
7	Petrolina	Pernambuco
8	Belo Horizonte	Minas Gerais
9	Porto Nacional	Tocantins
10	Boa Vista	Roraima
11	São Paulo	São Paulo
12	Brasília	Distrito Federal
13	Rio de Janeiro	Rio de Janeiro
14	Belém	Pará
15	Porto Velho	Roraima
16	Jacareacanga	Pará
17	Salvador	Bahia
18	Bom Jesus da Lapa	Bahia
19	Manaus	Amazonas
20	Santa Maria	Rio Grande do Sul

Table 6.2.
Cities for which the "Typical Meteorological Year" (TMY) was generated.

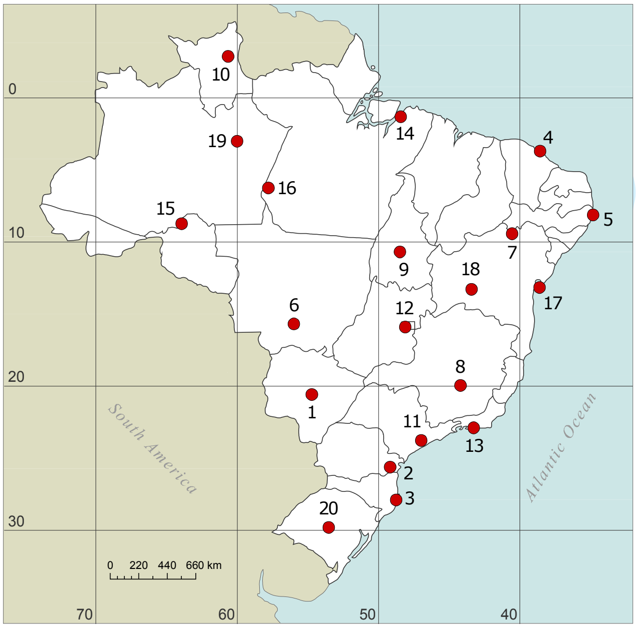


Figure 6.9.
Location of the cities for which the Typical Meteorological Year (TMY) was generated during the SWERA project (numbered as per Table 6.2).

The most widely used scheme to simulate the performance of solar heating systems based on monthly solar radiation averages is the F-chart method *[10]*. By using the F-chart method together with SWERA data, it is possible to map the fraction of saved electricity. Based on this map, the detailed economic analysis and specific cases of practical interest were done.

6.2.1.1. RESIDENTIAL SOLAR WATER HEATING IN BRAZIL

The most remarkable characteristic of the solar energy market in Brazil is that the main users thereof are higher income families. The reason for this is the high initial cost of a solar heating system when compared to the electric showerhead alternative. However, the solar water heating system is normally not considered in the design phase, but adapted to existing houses. As a result, normally the collectors are not installed at optimum orientation and tilt, so the area of collectors must be increased, and the systems become more expensive. On the other hand, in high-income residences, a conventional electric or gas water heating system is normally already considered during the design phase. Therefore, hot water distribution plumbing is already existent, which consequently reduces the additional price of the solar heating system when it is adapted, in relation to the additional installation cost of the collection panels.

Additionally, in some important urban areas of Brazil, like Rio de Janeiro and São Paulo, the use of gas (Natural Gas or LPG) water heating systems is widespread. Since the cost of operation of these systems are very low (much lower than the electric water heating systems), there is little interest in installing solar heating systems.

For lower income residences, the most common option ends up being the electric showerhead, where no cost is required for hot water distribution, since the heating is done directly at the consumption point and, therefore, the costs of a solar heating system becomes even more unfavorable. In order to partially solve this problem, some manufacturers produce compact systems, for smaller hot-water demands and with external hot water distribution.

The map of Figure 6.10 shows the percentage of electric energy saved per one family, which needs around 300 liters of hot water per day. For this simulation, the performance characteristics of a flat-plate solar collector with a single glass cover of 60% efficiency, were adopted. Currently this is the standard configuration available in the Brazilian market. In order to calculate the heating needs, the required energy is assumed as a function of the monthly average temperature for each point on the map. The simulated system had 4m^2 of area and a water tank volume of to 300 liters.

The map of Figure 6.11 shows the energy produced per year considering the described system. It can be observed that despite the relative energy savings being higher at locations with warmer weather, the produced energy is not so different for the several Brazilian regions. Bearing in mind the economical point of view, the payback time of this solar heating system is lower in regions with more favorable climate, but the quantity of saved energy may be greater in regions where the demand for water heating is larger once the system is correctly sized.

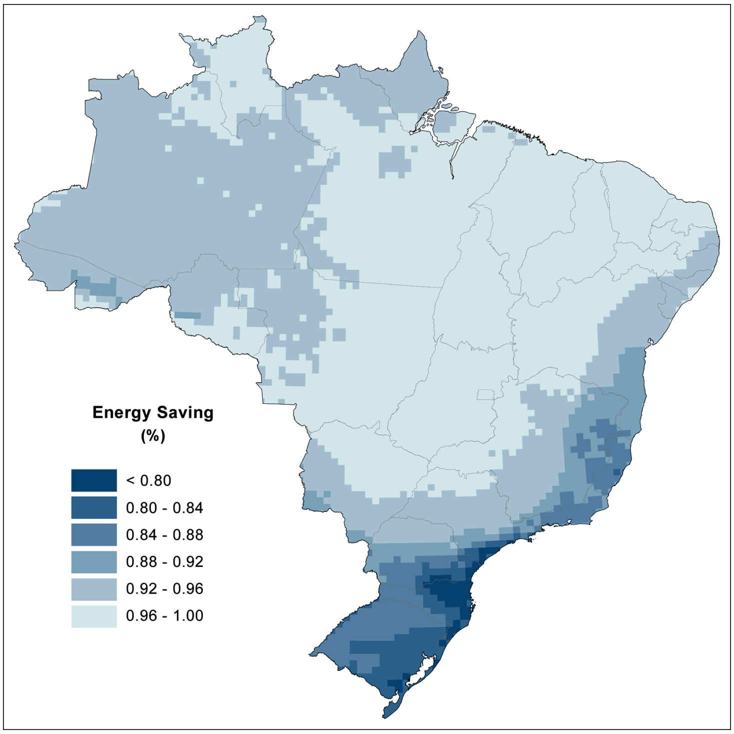


Figure 6.10.
Percentile electric energy savings of a typical residential heating system in Brazil.

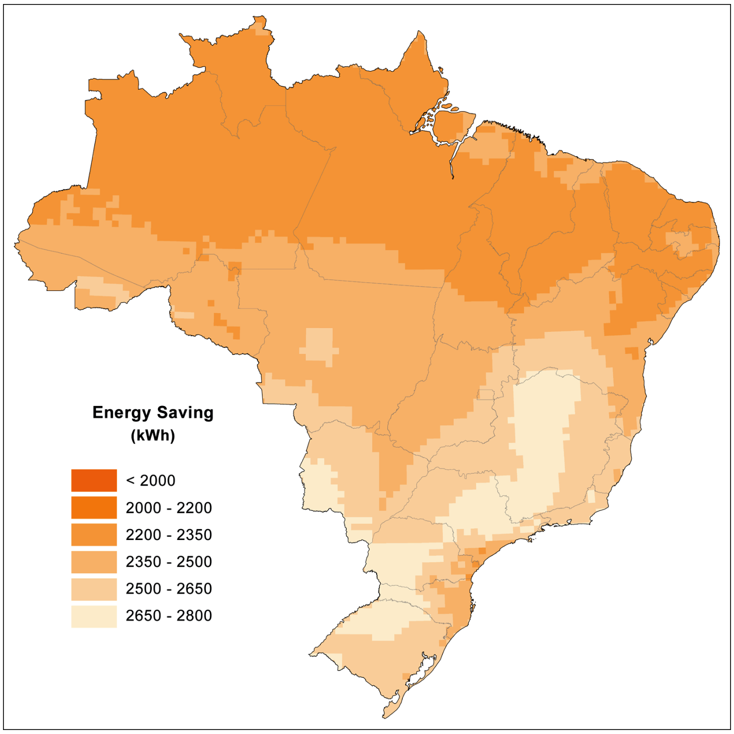


Figure 6.11.
Yearly electric energy savings of a typical residential heating system in Brazil.

6.2.1.2. LARGE-SCALE SOLAR WATER HEATING IN BRAZIL.

The objective of large-scale solar heating systems may not just be the heating for domestic applications, but also any application in which water heated to a temperature that is compatible with that supplied by solar heating systems (up to ~60°C) may be used. The multi-family residential sector like multi-home complexes or vertical buildings, where solar heating can act in combination with a large central heating system, is one of the main application examples of such systems. The payback time in such cases, in general, is faster than that of single home systems, since the ratio between the cost of the produced thermal energy and the system size decreases for larger system size.

This type of equipment presents a better return on investment than smaller systems, but, besides the initial installation costs, it is common to not have the required area to install the equipment on building tops.

Other factor that contributes for hindering solar systems employment is related to the lack of knowledge regarding the benefits of solar energy, which leads building dealers to not choose this option, since it implies higher construction costs. This mentality is gradually changing and currently there are some building companies that use solar heating as an additional selling advantage. For hotels and motels, the choice in favor of solar heating is more widespread since the operational cost reduction shall be easily observed as an additional profit of the enterprise. For hotel complexes and tourist locations, mainly in the South and Southeast Regions, besides the well-known advantages of large-sized systems, there is also the complementary aspect between the increase in demand during the high season and the larger availability of solar energy during the Summer.

It is difficult to precisely establish what the savings will be in present value, as well as the return on investment during the life cycle, in generic terms, since the economic analysis always depends on a series of factors that vary for each case. The cost of auxiliary energy, discount and inflation rates, cost of equipment, depreciation, and taxes, are some of the economic parameters that should be taken into consideration during the economic analysis, and therefore, it is recommended that it be done for each specific case. Duffie and Beckmann *[8]* present a fairly complete analysis of the solar heating system economic analysis.

In order to allow for a preliminary economic feasibility estimate of a large-sized facility it was considered a system having 140m^2 of solar panel to provide 10m^3/day of hot water. A preliminary estimate was obtained for the annual return and the total investment ratio or payback time of the system. The technical characteristics of the system used in this simulation were the same as those used in the example of item 6.2.1.1. Figure 6.12 shows the results obtained.

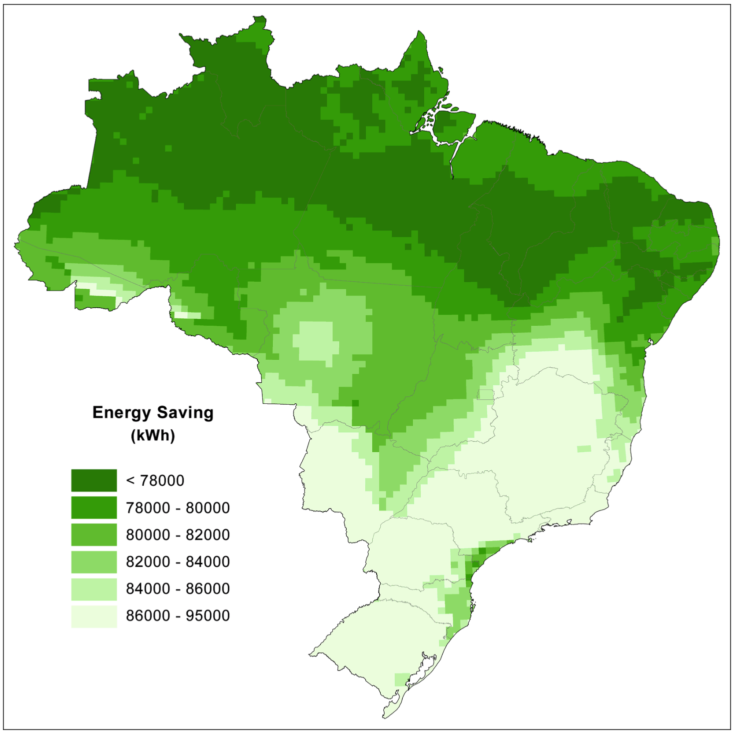


Figure 6.12.
Yearly energy savings per square meter of collection panels for large-sized systems.

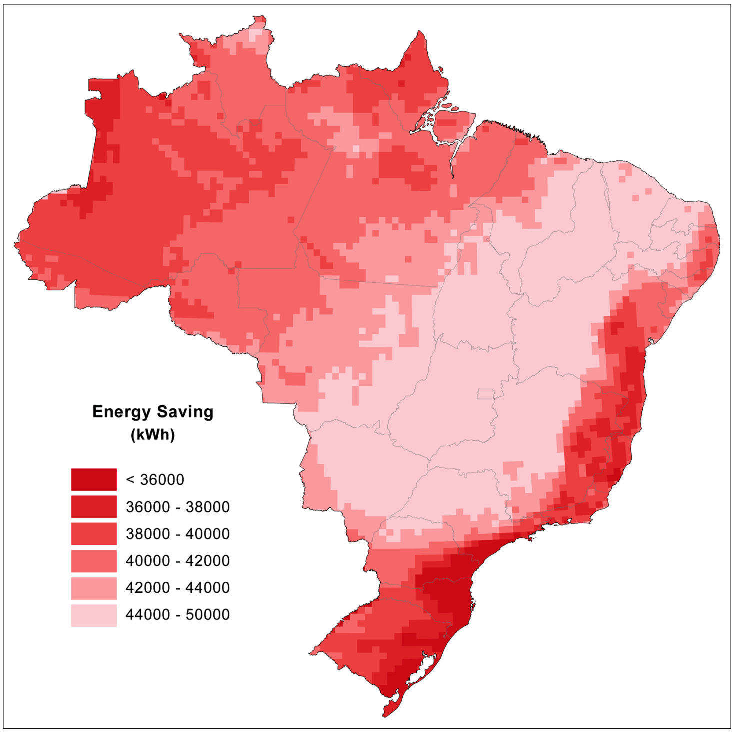
6.2.1.3. SOLAR HEATING FOR SWIMMING POOLS IN BRAZIL

In Brazil, solar heating for swimming pools compete mainly with electric heat pumps. The use of firewood to produce heat for pools is also deployed because of its low cost. In the latter case, the replacement by solar heating has the advantage of minimizing greenhouse gases emissions that result from the combustion process.

The elevated coefficient of performance (COP) of heat pumps decreases the ratio between saved electric energy and the thermal energy produced by the solar heating system. It must, however, be taken into consideration that the COP drops considerably as the ambient temperature decreases and this effect is generally not taken into consideration when a comparison is made between a heat pump and solar heating. The use of a solar heating system combined with the heat exchangers of a heat pump is an alternative to improve the performance of the entire system, but this solution needs to be more developed to achieve a commercial configuration at a reasonable cost.

Figure 6.13 shows what the annual energy savings would be for a heated pool, maintained at a temperature of 28°C, with an area of $50m^2$, where a solar heating system with the same area was installed. The performance characteristics used in the simulation were those for a plastic solar flat-plate collector without cover and without thermal insulation (considered to be one of the most efficient collectors in the Brazilian market at this category, as labeled by PROCEL/INMETRO).

Figure 6.13.
Energy savings for a 50 m2 swimming pool equipped with a solar heating system of the same area.



6.3. PHOTOVOLTAIC SYSTEMS

In most of the large countries of the developing world, it is widely acknowledged that distributed resources are the only way of providing electricity to more than a billion people, supposedly, that presently do not have access to it. In most cases, it is not cost-effective to deliver electric power in the conventional way. Long distances and relatively small energy demands may make transmission and distribution costs prohibitive.

Mini-grids fed by small to medium Diesel oil generator sets are commonly used to supply electricity to most of remote villages and small towns. While this might be a least-cost alternative to grid extension, considering the initial investment, operation costs are high (sometimes reliability and service quality are low), and the life-cycle equation will often show there are better options. One of such options is the use of hybrid Diesel / Photovoltaic (PV) power plant systems without storage of energy in batteries, where PV systems are added to the existing Diesel oil plants, thus reducing Diesel oil consumption during daylight time hours. These systems in the future might be converted to fuel cell / PV hybrid configurations, where energy generation would rely on PV.

It can be argued that in the short-term hybrid Diesel / PV and in the medium-term hybrid fuel cell / PV plants feeding mini-grids can represent real markets for PV, creating demands that can lead to large-scale PV manufacturing in countries like Brazil, leading to the necessary cost reductions for PV to become a real player in the country. Grid-connected, building-integrated PV systems in the urban environment of developing countries can also have an important role to play, especially in sunny areas, where high annual energy yields make PV generation more competitive.

Government incentives for displacing the use of fossil fuels in thermal generation, by the use of renewables, like solar, wind and biomass, are already in place, but are not attractive enough to justify their adoption by private enterprises.

Grid-connected PV is presently the fastest growing renewable energy technology in the world, increasing the installed power by 55% per year from 2000 – 2005 *[15]*, although this increase is only possible due to incentives and subsidies. Second is wind power, which grew by 28% per year *[14]*. On the other hand, PV conversion of solar energy to electricity is still one of the most expensive energy generation alternatives commercially available. For this reason, maximizing the benefits of this decentralized, modular, silent and clean renewable energy technology has fundamental importance to improve its economic value when compared with more traditional energy technologies.

Detailed knowledge of the solar energy resource availability, with increased space and time resolution, has extreme value in order to reduce the uncertainties associated with PV system performance and energy generation forecasting *[12]*. Economic analysis of PV generation systems using life cycle cost analysis over periods of 20 – 30 years can only be performed with an acceptable confidence level, if accurate and high-resolution information on the solar resource is available. In this context, the SWERA project represents a valuable asset for energy planners and investors.

6.3.1. OVERVIEW OF PHOTOVOLTAIC APPLICATION SEGMENTS

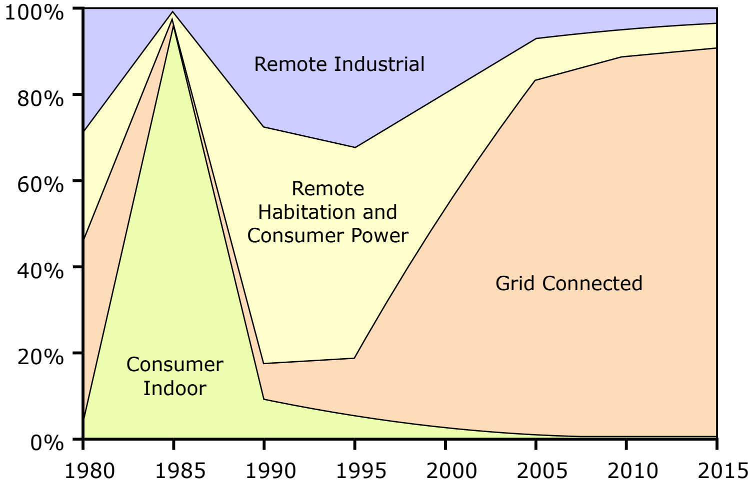
Table 6.3 shows an overview of the traditional PV industry application segments: Remote Industrial; Remote Habitation; Consumer Power and Consumer Indoors; Grid-Connected Residential, Commercial and Utility.

Figure 6.14 shows the evolution of the market share of each segment, and the forecasted breakdown until 2015. Table 6.4 shows the regional PV demand growth, in terms of both installed capacity and percentage of total, and the evolution of the PV market from 2000 to 2005.

Table 6.3.
Major photovoltaic market categories [15].

Market category	Status – Valuation – Reliability	Customer description
Remote Industrial	• Earliest commercial market • High credit for economic value • Reliability required: high urgent	• Most sophisticated customer • Requires detailed specifications but lesser systems support
Remote Habitation	• Second market entered in volume • Medium value and reliability • PV is life-cycle-competitive now	• Least sophisticated customer, in developing countries • Most systems support required
Consumer Power	• Established niche markets • Novelty, portability, and independence from conventional power are key	• More sophisticated customer in industrialized countries • Little customer support required
Grid-connected	• Market penetration continuing, driven by incentive schemes • Low credit for economic value • System reliability required: high • Lifetime required: long	• Industrial country consumer • Education needed to raise perception of value • Ongoing support structure required • Beginning of interest from building industry
Consumer Indoor	• 1980s – market entry and saturation • Economic value: non-issue • Reliability, life required: low	• Broad, global customer base • Little customer support required • Short lifetime expected

Figure 6.14.
Breakdown of photovoltaic application by major market segment [15].



Region	2000	2001	2002	2003	2004	2005	CAGR 2000 2005
Europe	74.1	119.9	172.6	232.6	472.4	667.4	55%
Percent Total	29%	34%	34%	34%	45%	48%	
Asia	83.3	117.4	187.1	262.7	341.5	448.0	40%
Percent Total	33%	33%	37%	39%	33%	32%	
North America	36.8	46.2	61.9	77.6	105.0	139.0	30%
Percent Total	15%	13%	12%	11%	10%	10%	
West Asia	15.1	18.4	23.5	28.3	42.0	48.6	28%
Percent Total	6%	5%	5%	4%	4%	3%	
Latin America	11.3	13.2	15.5	18.6	21.0	20.8	13%
Percent Total	4%	4%	3%	3%	2%	1%	
Oceania	9.3	11.7	14.4	19.6	22.1	20.8	18%
Percent Total	4%	3%	3%	3%	2%	1%	
Southeast Asia	6.1	7.2	8.8	11.0	15.8	19.5	26%
Percent Total	2%	2%	2%	2%	2%	1%	
Central & Southern Africa	10.1	12.0	13.3	15.7	18.9	18.1	12%
Percent Total	4%	3%	3%	2%	2%	1%	
Middle East	2.6	3.1	3.4	4.1	4.9	5.6	16%
Percent Total	1%	1%	1%	1%	<1%	<1%	
North Africa	3.3	3.8	4.4	5.1	6.3	1.8	-11%
Percent Total	1%	1%	1%	1%	1%	<1%	
Total	252.0	352.9	504.9	675.3	1049.8	1389.5	41%
Percent Total	100%	100%	100%	100%	100%	100%	

Table 6.4. Regional demand growth of the photovoltaic market [15].

Each of these segments presents peculiarities in the way PV systems are designed and installed, and might differ in who will be the user of the solar radiation data necessary to size the installation or application.

Remote industrial applications: Telecommunications applications made up the bulk of the first commercial PV market, which also included other remote industrial applications, like cathodic protection. During initial market entry, PV products were often sold on a system basis, with the PV manufacturer making a direct, turnkey sale of the communications power supply subsystem. As the technology became more accepted and understood, communications applications have moved toward the commodity sale of PV modules that are integrated by a regional communications dealer or PV distributor and in some cases by the individual end-user customer. This trend is partly the result of this customer being the most professional and experienced in electric and electronic technology of all the end-users of PV applications.

On a comparative basis, other applications such as water pumping, village power or rural lighting, involve end-users who often have no prior electric experience, other than the use of small primary dry cell batteries in a transistor radio or flashlight. Users of solar radiation data in this application segment include engineers and technicians that are skilled enough to handle this information. Data quality is sometimes critical.

Remote residential applications: In industrialized countries, notably North America, Australia and in the emerging market in China, PV has become quite popular for off-grid homes, the so-called solar home systems. Costs of moderate grid extensions are now being directly charged to the homeowner, and with grid-extension costs ranging from US$10,000 to US$20,000 per km of line extension, a growing number of consumers are turning to off-grid PV systems as an equal or even lower first-cost alternative.

In developing nations, remote households represent the largest share of the PV market. Financing, regulation and the presence of a commercial financial infrastructure remain the most critical factors to increase growth rates. Without such financing, a number of new remote village power systems will continue to be installed using Diesel oil generators, primarily because of the low initial cost of the generators. Life-cycle cost analysis is seldom included in the decision-making process. If barriers such as credit mechanisms, administration inadequacies, training and maintenance issues were properly dealt with, growth in this application segment would accelerate. While financing is key to shifting customer evaluations from first-cost to life-cycle cost, the availability of financial mechanisms must, in turn, be shifted from governmental to commercial sources. This is necessary to reduce the complex project assessment and development cycles (five years or more) that slow the implementation cycle and greatly increase the cost. On-the-ground system design and management of quality systems are required to achieve sustained system performance. Users of solar radiation data in this application segment include engineers in private and public companies, utilities and often the end-user, with a varying degree of skill to handle this information.

Small power and indoor applications: The modest consumer power and consumer indoor segment contains a large number of, specialized applications, approximately the half of which require customized PV modules, tailored for the applications power requirements, and in some cases designed specifically to fit in or on the product being powered (battery chargers, calculators, watches etc.). Though a market for these products for consumer applications has certainly opened up in the 80’s, as shown in Figure 6.14 it has not expanded substantially. Users of solar radiation data in this application segment include product designers and engineers, and for most of these applications, knowledge of the precise solar energy resource is not necessary.

Grid-connected applications: While the off-grid market has been the steady commercial base to support the gradual expansion of the PV industry, grid-connected applications have grown to 82% of the terrestrial PV market volume in 2005, with a compound annual growth rate (CAGR) of 55% in the 2000–2005 and 32% in the 1980–2005 periods *[15]*. This application also uses much larger volumes per individual installation than most of the other PV applications, and is expected to continue to expand, as more countries adopt incentives and subsidies. While at present most of this application development is taking place in the developed world, it is expected that with declining costs the benefits of the distributed nature of grid-connected PV will extend a more widespread adoption of this application worldwide. Users of solar radiation data in this application segment include engineers and energy planners in both the public and private sector, and since life-cycle cost analysis is current practice in the establishment of the incentive programs related to this segment, data quality is critical and of great value.

6.3.2. PHOTOVOLTAICS IN THE WORLD

The establishment of national incentive and subsidy programs in many countries worldwide, especially in Japan, Germany, Spain and the USA, has led to the impressive growth rates shown in Figure 6.15, and the installation of some 1.8GWp of PV in 2005. More than 80% of the new installations were grid-connected PV systems *[15]*. Table 6.4 shows the regional PV demand growth, in terms of both installed capacity and percentage of total, and the evolution of the PV market from 2000 to 2005, and Figure 6.16 shows the forecast of this booming market for the next 10 years, on a business as usual (BAU) and accelerated (ACC) scenario.

Despite the huge solar energy resource availability and the potential of using PV in a variety of grid-connected and stand alone applications, Latin America has been responsible for a very small fraction of the worldwide PV market, shrinking from some 4% (11MWp) in 2000 to about 1% (20MWp) in 2005, as shown in Table 6.5. This relative reduction in demand in Latin American countries could mean that PV is less used than other renewables for many reasons, including cost and the lack of knowledge, or that conventional energy sources are preferred. It could also mean that financial resources for off grid PV systems for solar home systems, which are the most common application of PV in the region (68% as shown in Table 6.5), are not available, or that programs are well disseminated.

In the next section, we will show the potential of PV in Brazil in two distinct and considerably different markets, namely hybrid PV-Diesel installations in mini-grids of the isolated Brazilian electricity system in the Amazon Region, and grid-connected PV in urban areas of the interconnected Brazilian electric system.

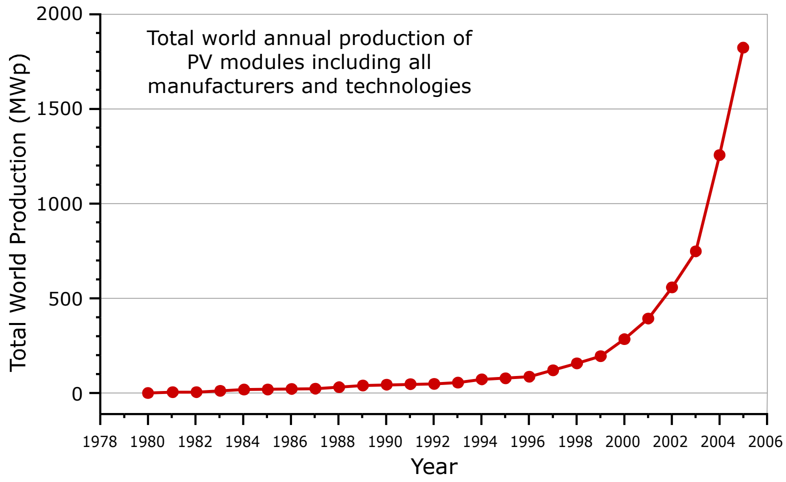


Figure 6.15.
Evolution of the global photovoltaic market including all technologies and manufacturers [18].

Figure 6.16.
Projected photovoltaic industry growth in the business as usual (BAU), and accelerated (ACC) scenarios, with compound annual growth rates (CAGR) [15].

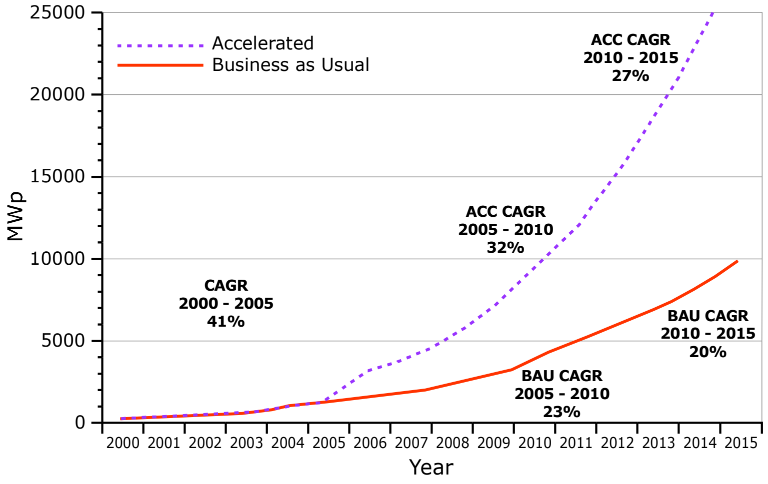


Table 6.5.
Breakdown of the photovoltaic market by region and application segment [15].

Region	2005 Total MWP	Grid Residential	Grid Commercial	Grid Utility	Off Grid Industrial	Off Grid Habitation	Consumer Power	Consumer Indoor
North America	139.0	35%	28%	<1%	16%	15%	4%	0%
Latin America	20.8	0%	<1%	4%	27%	68%	1%	0%
Europe	667.4	54%	43%	<1%	1%	1%	<1%	0%
Middle East	5.6	0%	1%	4%	55%	35%	5%	0%
North Africa	1.8	0%	2%	0%	58%	35%	5%	0%
Central & Southern Africa	18.1	0%	0%	3%	28%	65%	4%	0%
West Asia	48.6	0%	4%	7%	44%	39%	5%	<1%
Asia	448.0	85%	2%	0%	4%	4%	2%	2%
Southeast Asia	19.5	2%	<1%	0%	29%	56%	7%	5%
Oceania	20.8	9%	1%	1%	44%	36%	9%	0%
Global Total	1389.5	57%	25%	1%	7%	8%	2%	1%

6.3.3. PHOTOVOLTAICS SCENARIOS FOR BRAZIL

We have identified two major applications for PV in Brazil, where there is a potential for large volumes, and for which the accurate knowledge of the solar resource distribution is critical. In the following sections, we describe these and show examples of SWERA products that can be directly applied to project design and economic viability assessment.

6.3.3.1. HYBRID DIESEL / PV SYSTEMS FOR MINI-GRIDS IN THE AMAZON REGION

Energy supply to dispersed populations in the Brazilian rainforest assumes a number of configurations; Small PV solar home systems with limited energy supply and service, and mini-grids supplied by Diesel oil generator sets. There are currently hundreds of mini-grids operated by independent power producers (IPPs) or local state utilities in the Amazon, that cover the main share of this demand, which is, however, only a small proportion of the country's total energy consumption. Mini-grids extend over some 45% of the area, but supply energy to only 3% of the population *[19]*. Most of the sites where they operate are not easily accessible, increasing cost and decreasing reliability of supply. The operators of these systems, however, all make use of a subsidy that covers 100% of the fuel cost, as long as they operate at or below the 0.34L/kWh specific consumption limit. This government subsidy's life span has recently been extended for another 20 years. Electric utilities are allowed to include a surcharge to all urban and rural consumers of the national interconnected electric system to collect funds to subsidize consumers of these isolated systems. These surcharge systems, and the funds collected, are directed to the so-called CCC Account (Fuels Consumption Account of the Isolated Systems) which subsidizes Diesel oil for the thermal plants in isolated mini-grids. IPPs willing to invest in renewable generation that displaces Diesel oil can claim the cost of the fuel consumption avoided, but so far this has not been attractive enough to encourage them to switch to renewables, because the lack of mandatory targets and a typically short-term management strategy.

The potential for using PV, however, is huge, and can be estimated in tens to hundreds of MWp in the Amazon Region alone, even if only a fraction of the 286 existing Diesel oil power plants with a total installed capacity of over 620MVA would adopt some PV to an optimized Diesel / PV mix *[11]*. Furthermore, while the solar radiation resource distribution in the region is considerable, and with a small seasonal variation, as demonstrated in former works and now also by the SWERA results shown in Figures 6.17 to 6.19 on an annual and seasonal average, the wind resource distribution in the region is one of the worst in the country, well known before and as also confirmed by the SWERA results shown in Figures 6.20 to 6.22 on an annual and seasonal average.

Together with biomass, Solar PV is among the most viable renewable energy technologies currently available for the dispersed and relatively small energy demands in the region. Figure 6.23 shows, on an annual average, SWERA results for the daily PV generation yields, in kWh/kWp, that can be expected for the amorphous silicon thin-film PV technology deployed at latitude-tilted arrays in the Amazon region, together with the location of villages/towns and Diesel generation units in the region.

Figure 6.24 shows, on an annual average, SWERA results for the direct radiation availability in the region, which is of fundamental importance in assessing the technical and economic viability of using concentrating PV systems. All the solar resource maps shown in Figures 6.17 to 6.24 are also available on a monthly basis, where seasonal trends can be seen in more detail, and are shown in Brazilian Atlas of Solar Energy.

Figure 6.17.
SWERA assessment of the annual average of the latitude-tilted daily solar radiation availability at the Amazon region.

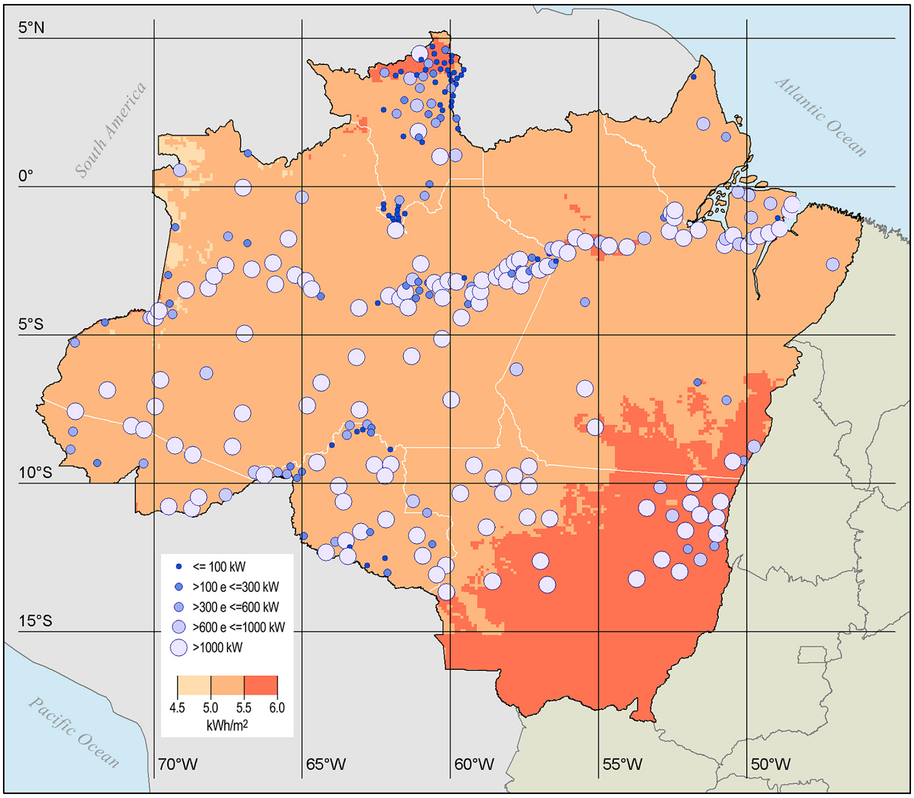
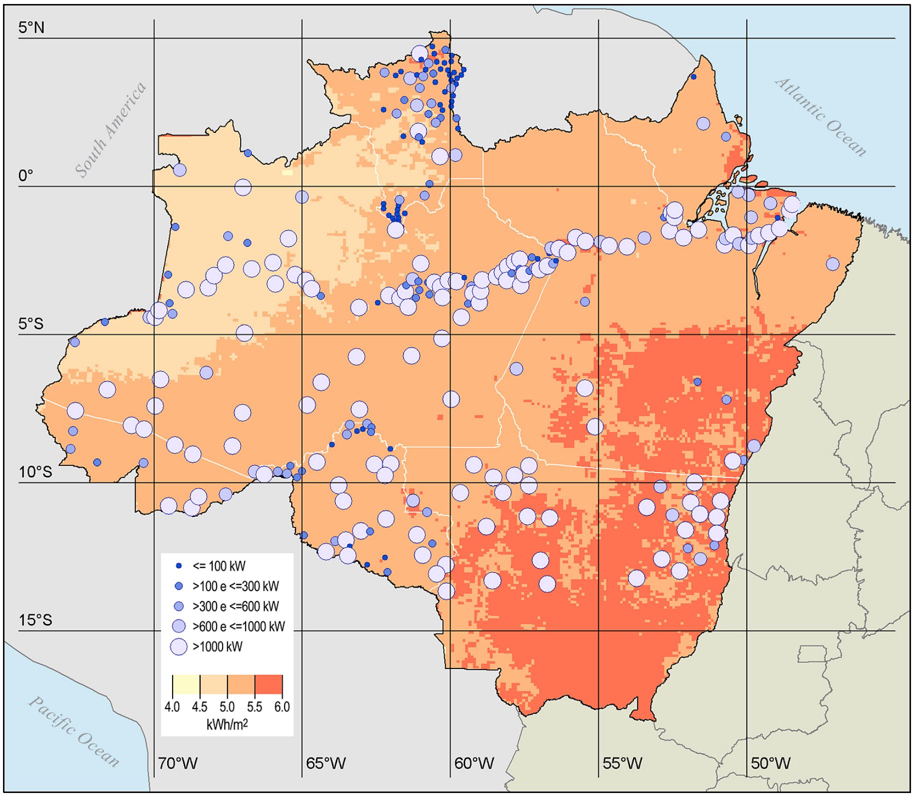


Figure 6.18.
SWERA assessment of the Winter average of the latitude-tilted daily solar radiation availability at the Amazon region.



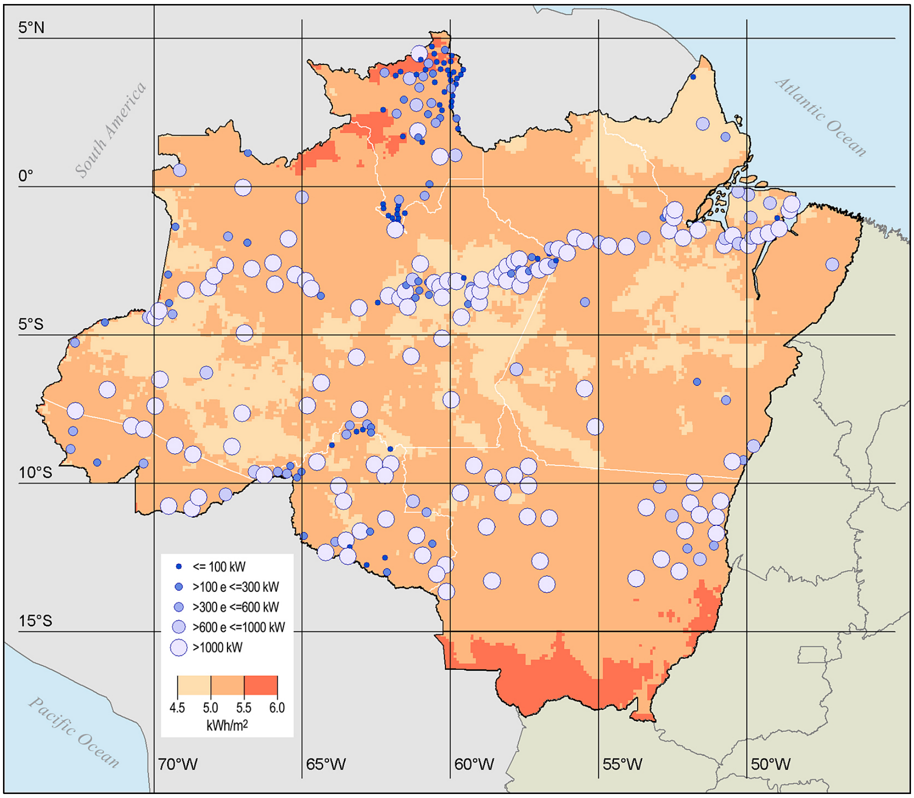


Figure 6.19.
SWERA assessment of the Summer average of the latitude-tilted daily solar radiation availability at the Amazon region.

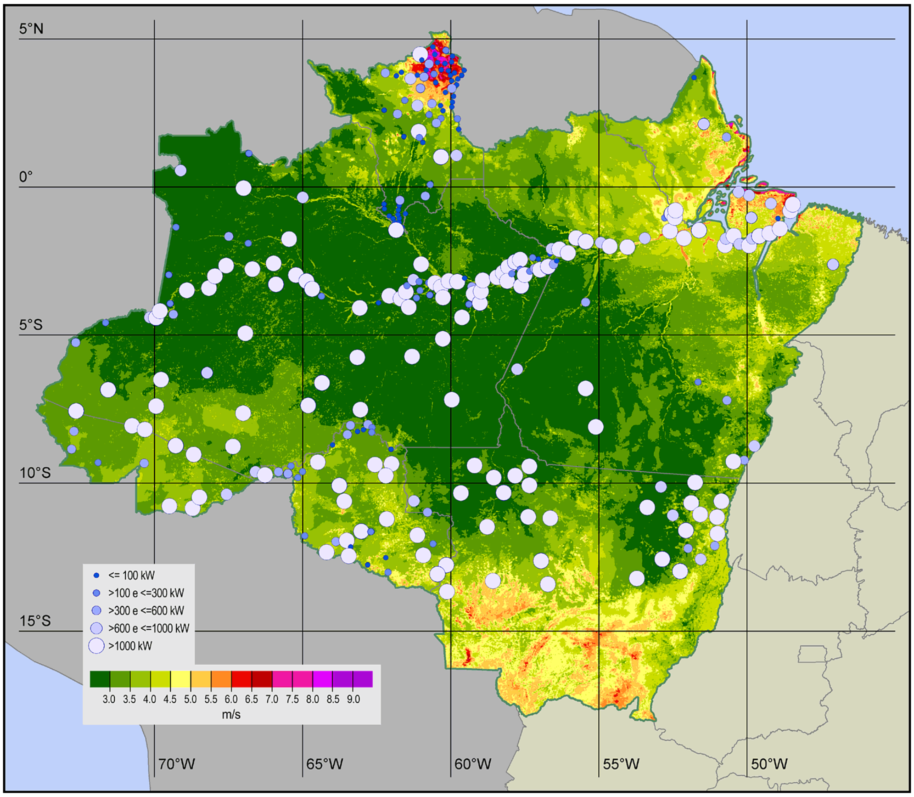


Figure 6.20.
SWERA assessment of the annual average of wind speed availability at the Amazon region.

Figure 6.21.
SWERA assessment of the Winter average of wind speed availability at the Amazon region.

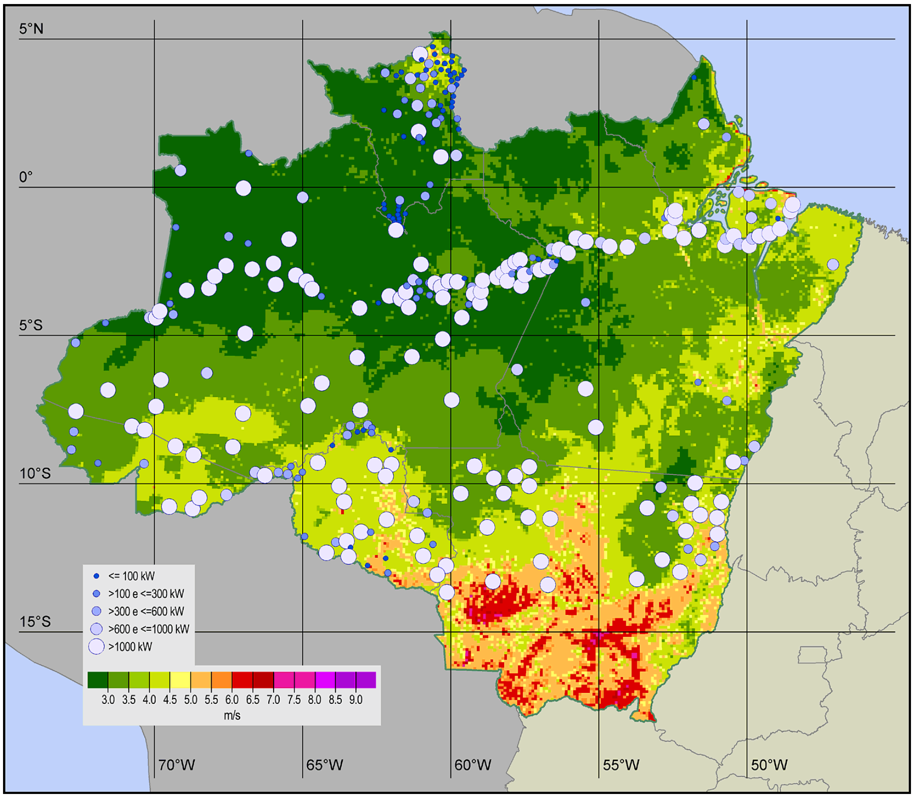
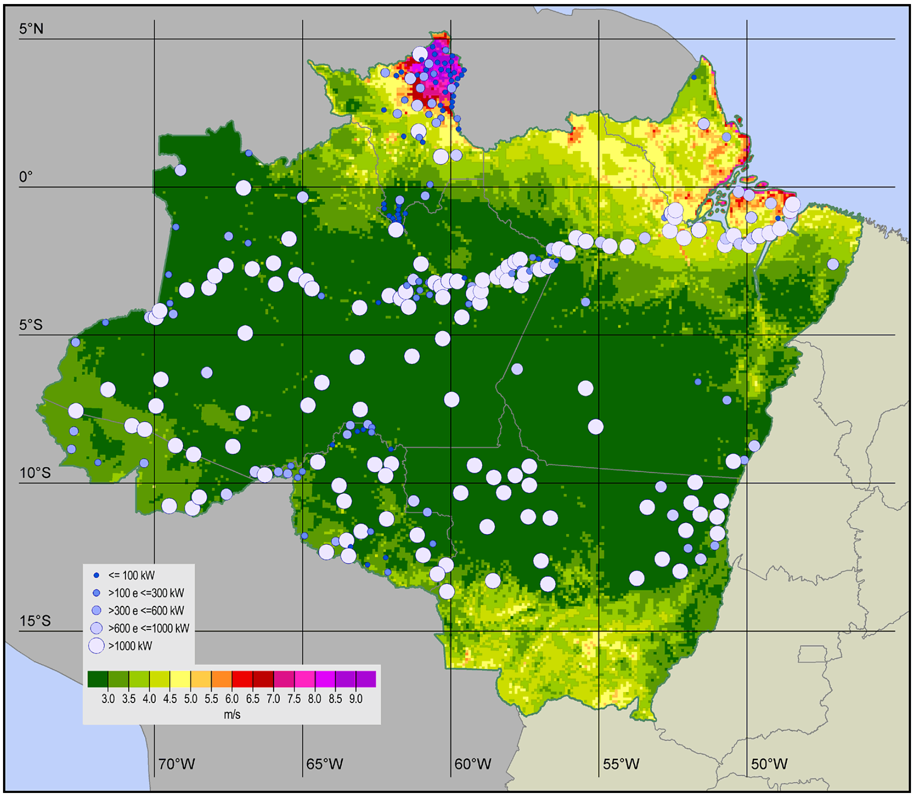


Figure 6.22.
SWERA assessment of the Summer average of wind speed availability at the Amazon region.



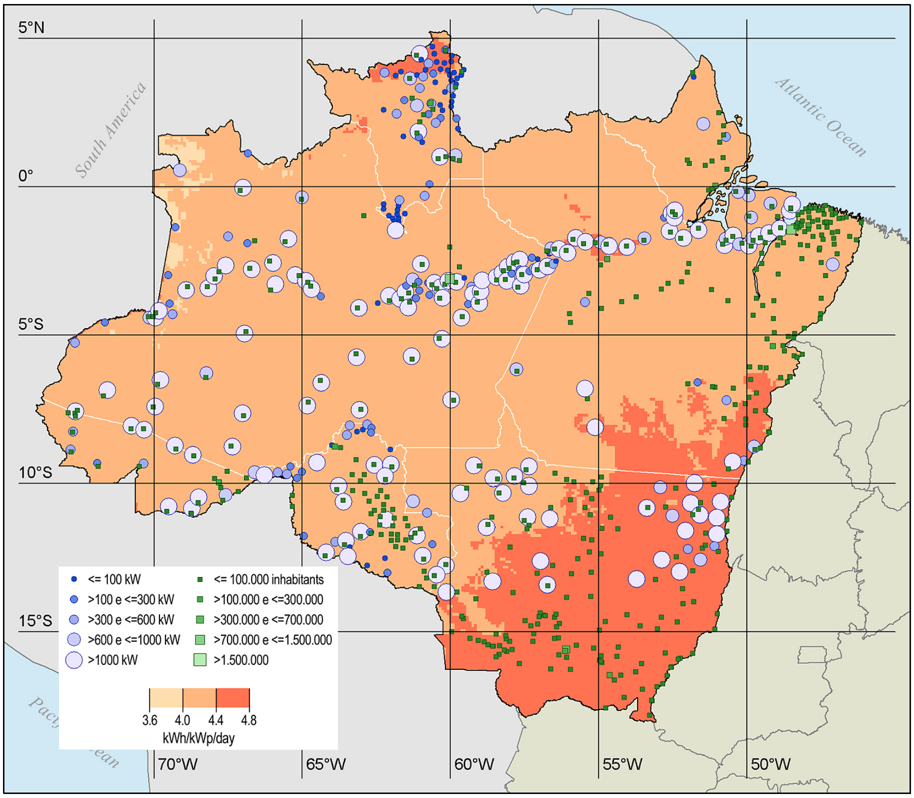


Figure 6.23.
Daily yield, in kWh/kWp, of latitude-tilted amorphous silicon thin-film PV installations, together with the location and size of Diesel oil-powered generation units and villages/towns in the Amazon region.

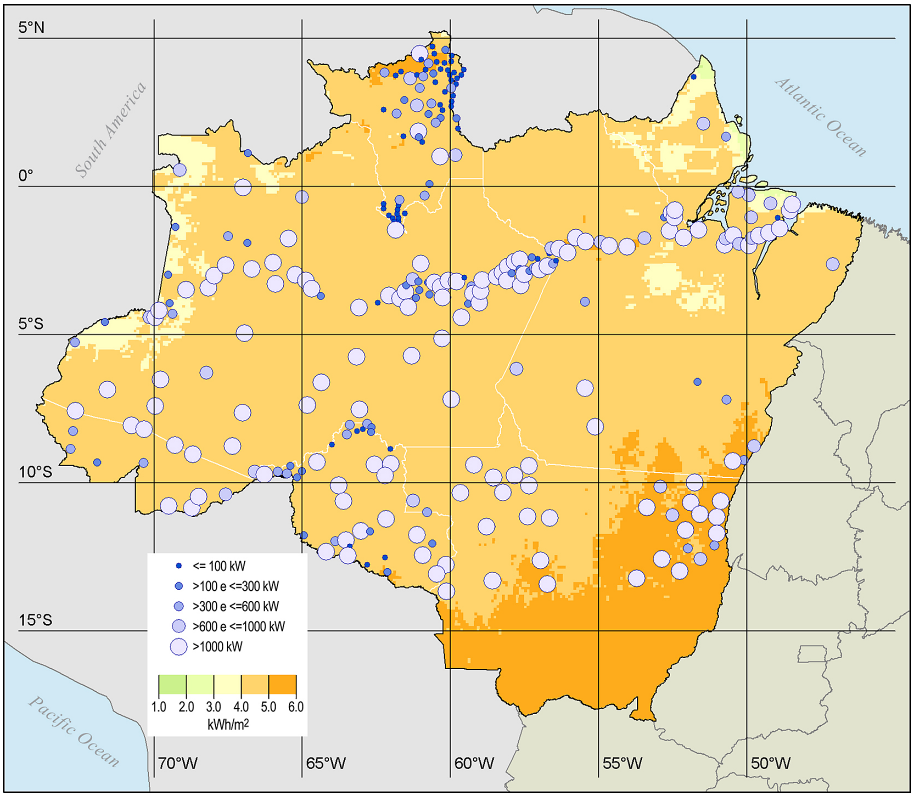


Figure 6.24.
SWERA assessment of the annual average of the direct solar radiation availability at the Amazon region.

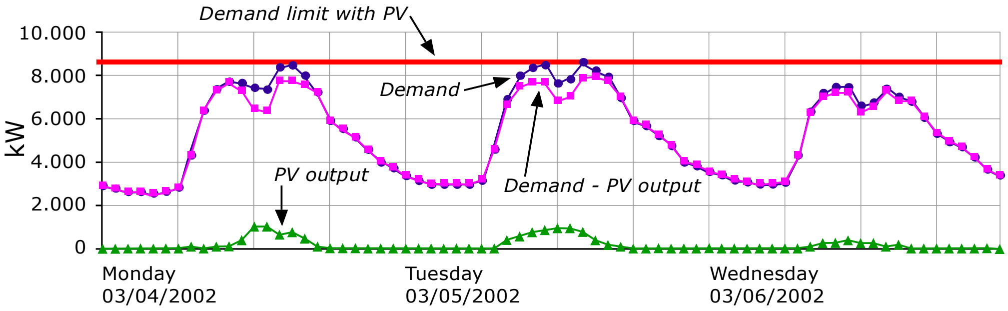
6.3.3.2. GRID-CONNECTED PV SYSTEMS IN URBAN AREAS

While most of the impressive growth in the PV market is related to grid-connected installations in developed countries, there is a huge potential for this application in sunny urban areas all over the world as well. Brazil is particularly well suited for the application of grid-connected PV due to both considerable solar resource availability, and to the high value that can be attributed to PV in commercial areas of urban centers *[20]*. Figure 4.14 shows SWERA results for the annual average of the daily solar radiation availability at the latitude-tilted plane for the Brazilian territory, and Figure 4.15 shows the same information on a seasonal basis, demonstrating both the potential of deploying PV all over the country, and the small seasonal variability throughout the year. In the assessment of the economic viability of PV projects, more detailed information on the seasonal behavior of the solar radiation resource distribution is necessary, and it is available in http://swera.unep.net/.

PV can contribute to a utility's system if the demand peak occurs in the daytime period. Commercial regions with high air-conditioning loads during daylight hours have normally a demand curve in a reasonable time synchronism with the solar irradiance *[13; 17]*. Another important factor in this analysis is the comparison between the peak load values in Summer and Winter. The greater the demand in summertime in comparison with the demand in wintertime, the more closely the load is likely to match the actual solar resource. This is the typical picture of most capital cities in Brazil.

Utility's feeders in urban areas all over the country show distinct regions where commercial and office buildings dominate, and which present daytime peak demand curves, and residential regions where the peak demand values take place in the evening. To add value to the distributed nature of solar generated electricity, it is important to know the PV capacity of the different regions of a city when installing a PV power plant, in order to select the feeder with the greatest capacity credit. In this context, the concept of the Effective Load Carrying Capacity (ELCC) of PV was defined, to quantify the capacity credit of a strategically sited PV installation *[13; 16]*. Figure 6.25 shows, for a typical daytime peaking utility feeder in an urban center, the peak-shaving effect of adding a small amount of PV to assist in reducing the load requirements of the feeder. To determine the capacity benefits of PV as shown in Figure 6.25, knowledge of the solar radiation resource distribution on an hourly basis is necessary, and this information can be retrieved for the whole of the Brazilian territory through SWERA. In the near future, when the use of grid-connected PV becomes more widespread due to both cost reductions and the acknowledgment of the benefits of distributed PV, the assessment of ELCC will be of strategic value for utilities and investors.

Figure 6.25.
Demand behavior of a typical urban utility feeder serving a commercial / office building region in Brazil, showing how the distributed nature of grid-connected PV can assist in peak shaving. The upper curves show the demand curve without PV; the lower curves show the PV generation profile for three consecutive days (partly overcast day, clear day and overcast day respectively); and the intermediate curve shows the effect of adding a small fraction of PV to assist in peak load reduction [13].



6.4. CSPP – CONCENTRATING SOLAR POWER PLANTS

The solar thermal power can be employed in two different ways: low or high temperature applications. The low temperature systems include water and space heating for commercial and residential buildings. Scenarios for low temperature applications in Brazil were discussed earlier.

This topic presents a brief discussion on high temperature application to produce electricity using the steam turbine driven electrical generator. Many studies point out the solar thermal power as one of the key alternatives to help the future electricity demand.

Regarding technical features, the conversion path of solar energy relies on four basic elements: concentrator, receiver, transport-storage and power conversion. Temperatures up to ~600°C are achieved in the receiver which absorbs the concentrated solar radiation transferring its heat to a working fluid. The heat transferred to a working fluid is used to generate steam employed to drive a steam turbine. The other technology is the Stirling Motor that uses a combustion cycle engine directed couple to a conventional electricity generator.

The two most developed technologies to concentrate solar radiation are the "parabolic troughs" and the "solar towers". The main idea of the parabolic through collectors is to concentrate the solar radiation using a parabolic mirror that has a pipe in its focus. Solar towers are composed of a series of mirrors (heliostat field) tracking the Sun path and reflecting solar radiation at a fixed receiver placed at the top of a tower. The main requirements for both technologies are the availability of high direct solar irradiation. In the case of the steam technologies, hydro resources accessibility and proximity to electricity transmission line are also required *[23]*.

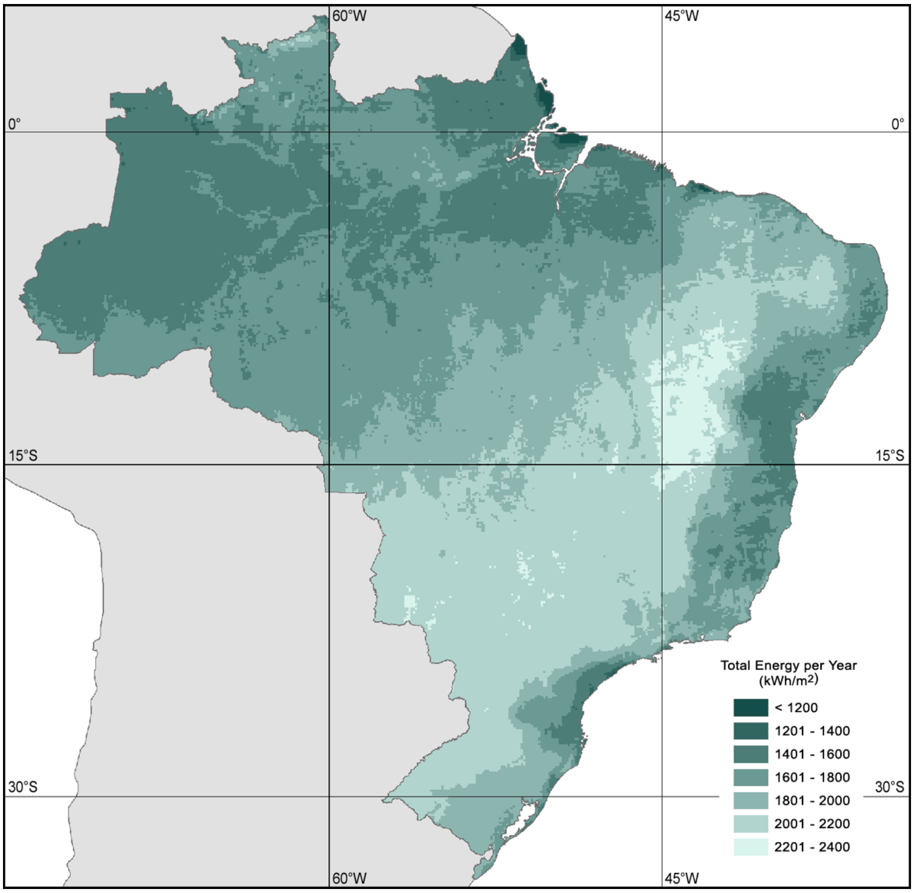
The two major power plants of this kind in operation are in Mojave region (USA) and Sanlucar La Mayor (Spain) where cumulative direct solar energy reaches, respectively, 2.8MWh/m^2 and 2.1MWh/m^2

throughout the year. Mehos and Owens *[22]* have considered 2.4 MWh/m^2 as the minimum annual solar energy in order to evaluate the economic feasibility of CSP plants in USA. In Brazil, earlier survey made by CEPEL on site opportunities for CSP plants have pointed out locations with 2.1 MWh/m^2 in Northeast semi-arid region *[23]*. The authors have employed a solar radiation map interpolated from ground data together with geographically referenced information for site characterization. However, most of the solar data employed were based in data from insolation hours, extracted from the *Atlas Solarimétrico do Brasil [26]*. It used also data from INMET, and validated with a ground station pyrheliometer, resulting in an estimated annual RMS deviation of 3.58%, which is considered satisfactory, and is in the same order of magnitude of satellite measurement.

In this report, direct solar irradiation maps produced in SWERA using the radiative transfer model BRASIL-SR was employed to develop a similar work to identify potential sites to install CSP plants.

The Figure 6.26 presents the cumulative direct beam irradiation (kWh/m^2) in the Brazilian territory. The cumulative solar energy reaches values larger than 2.0MWh/m^2 in the most of the Brazilian territory, including the western area of Southern Region, where are located the states which consume more electric energy (São Paulo, Minas Gerais and Rio de Janeiro). Values larger than 2.2MWh/m^2 were found mainly at the semi-arid region of the Brazilian Northeast, where the low precipitation and large number of insolation hours are the key climate characteristics, as already mentioned.

Figure 6.26.
Map for annual total for solar energy from direct beam irradiation.



In order to take in account for the monthly variability along the year, the map presented in Figure 6.27 shows the areas where the monthly averages of direct solar irradiation are larger than 5.0kWh/m^2.day throughout the year. The map shows that Northeastern Region is the most auspicious area for investment in CSP plants.

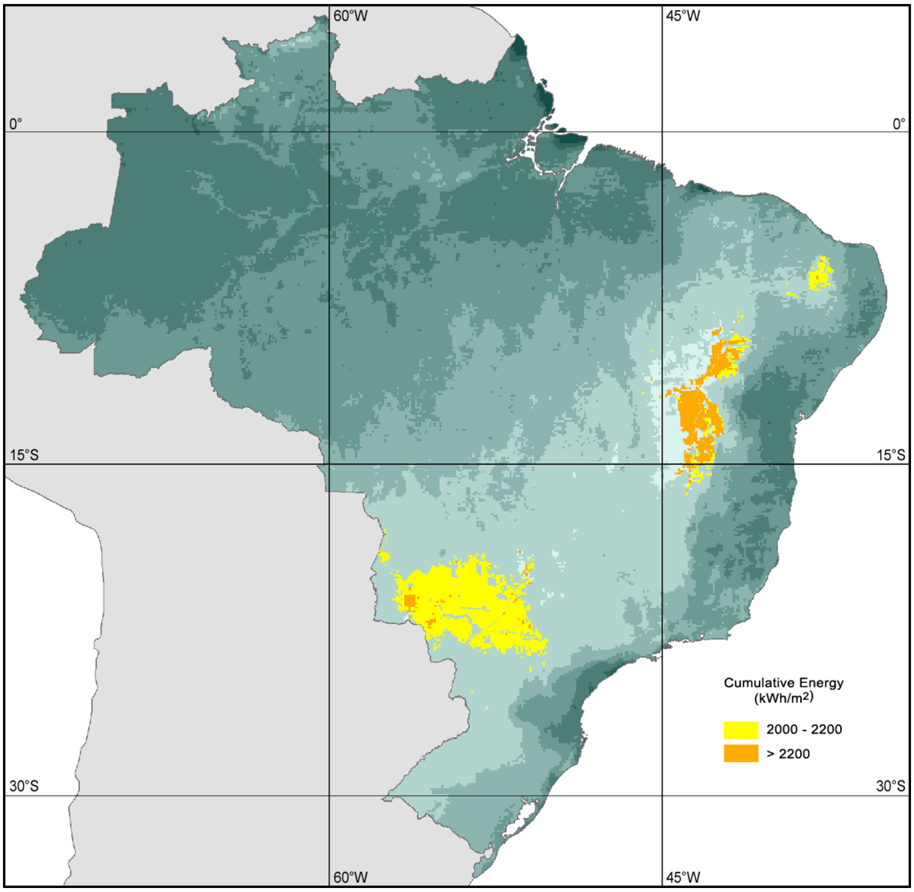
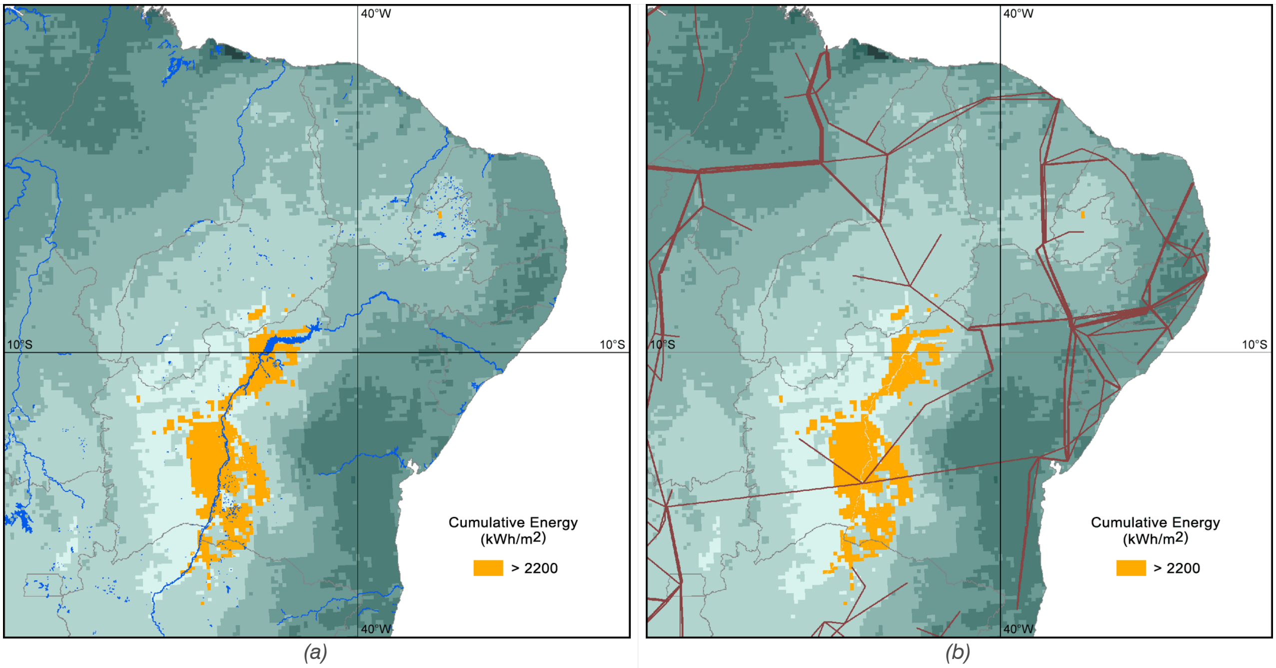


Figure 6.27.
Areas with monthly average direct solar irradiation larger than 5.0kWh/m.day. The area marked in lighter gray represents the region where the cumulative energy is larger than 2.0MWh/m^2 while the darker gray area indicates where the cumulative energy is larger than 2.2MWh/m^2.

Taking into consideration only the Northeast Region, the Figure 6.28 includes the geographical data for rivers and electricity grid together with solar energy information. The São Francisco basin traverses the orange area improving the economic potential for CSP plant at this region. Besides that, this area is near 230kV, 440kV and 550kV transmission lines.

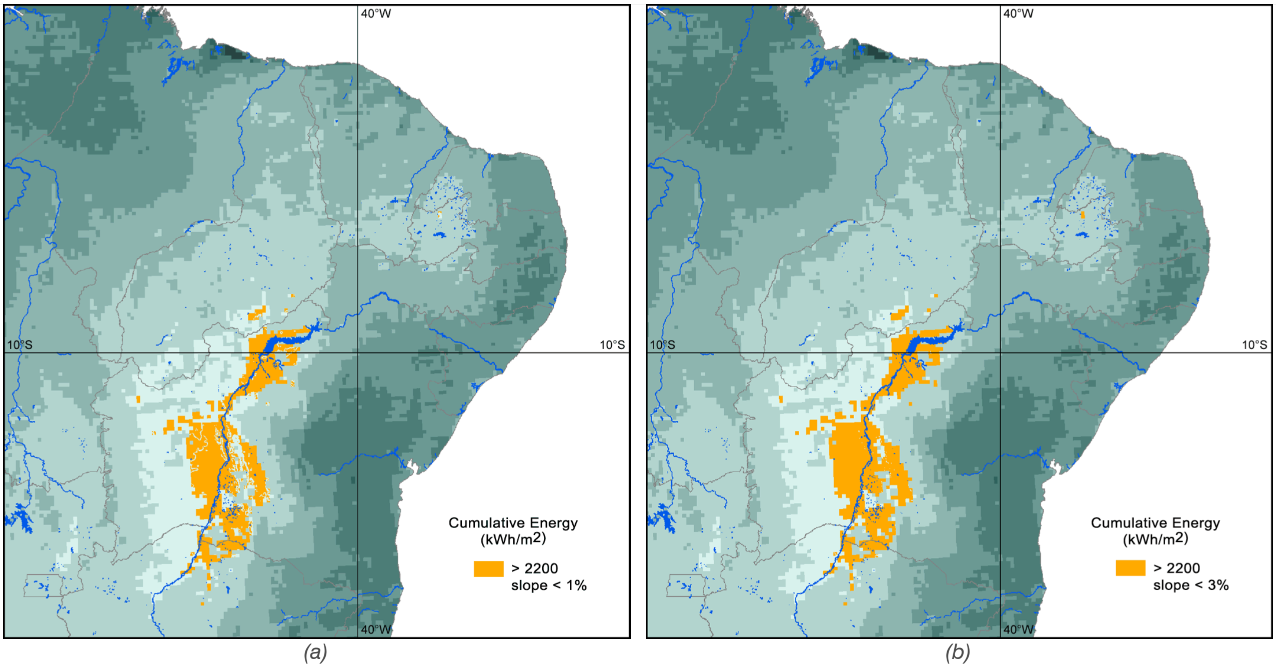
Mehos and Owens *[22]* suggest some other restrictions to select the best places to install CSP plants like land use, ownership with commercial restrictions and terrain slope lower in contiguous areas greater than 10km^2. The map presented in Figure 6.29 shows the same area presented in Figure 6.28 excluding the sites where terrain slope are greater than 1% and 3%. Unfortunately, the land use information is not available for this work, but probably most of the area is currently used to agriculture.

Figure 6.28.
Solar information for Northeastern region put together with (a) flooded areas and main rivers and (b) transmission lines.



(a) *(b)*

Figure 6.29.
Solar information put together with terrain slope lower than 1% (a) and 3% (b).



(a) *(b)*

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ACRONYMS

ACC – Accelerated scenario....72

ANEEL *(Agência Nacional de Energia Elétrica)* – Electric Energy Agency....31

AWS – Automatic Weather Station....10, 33, 39

BAU – Business as Usual....72

BNDES *(Banco Nacional de Desenvolvimento Econômico e Social)* – Brazilian National Social Development Bank....30, 56

CAGR – Compound Annual Growth Rate....71

CCC *(Conta de Consumo de Combustíveis)* – Fuel Consumption Account of the Isolated System....74

CEF *(Caixa Econômica Federal)* – Federal Economic Bank....31

CEPEL *(Centro de Pesquisas de Energia Elétrica)* – Electric Power Research Center....9, 10, 27, 33, 81

CHESF *(Companhia Hidroelétrica do São Francisco)* – Hydroelectric Company of the São Francisco River....60

CNPE *(Conselho Nacional de Política Energética)* – National Energy Policy Council....21

COP – Coefficient of Performance....66

CPTEC *(Centro de Previsão do Tempo e Estudos Climáticos)* – Center for Weather Forecast and Climate Studies....9-11, 33, 40

CSP - Concentrating Solar Power....81, 82

DEES – Domestic Electric Energy Supply....20, 24

DES – Domestic Energy Supply....9, 10, 17, 19, 21-25

DNDE - National Energy Development Department....27

ELCC – Effective Load Carrying Capacity........79

ELETROBRÁS *(Centrais Elétricas Brasileiras S/A)* – Holding Company of the Brazilian Electrical Power System........30, 55

EPE *(Empresa de Pesquisas Energéticas)* – Company of Energy Research

GDP – Gross Domestic Product........24, 50

GEF – Global Environment Facility........9

GIS – Geographic Information System........9

GTZ *(Gesellshaft für Technische Zusammenarbeit)* – Society for Technical Cooperation........27

IBGE *(Instituto Brasileiro de Geografia e Estatística)* – Brazilian Institute of Geography and Statistics........28

ICMS *(Imposto de Circulação de Mercadorias e Serviços)* – Tax on Circulation of Merchandises and Services. 31

INMET *(Instituto Nacional de Meteorologia)* – National Institute for Meteorology........81

INMETRO *(Instituto Nacional e Metrologia e Qualidade Industrial)* – National Institute for Metrology and Industrial Quality........61, 66

INPE *(Instituto Nacional de Pesquisas Espaciais)* – National Institute for Space Research........9, 11, 33, 40

IPI *(Imposto sobre Produtos Industrializados)* – Tax for Industrialized Products........31

IPPs – Independent Power Producers........12, 13, 74

ITCZ – Inter-Tropical Convergence Zone........11, 40, 41

JBIC – Japanese Bank for International Cooperation........28

LABSOLAR *(Laboratório de Energia Solar)* – Solar Energy Laboratory........9, 11, 33, 40

LPG – Liquid Petroleum Gas........20, 23, 63

LpT *(Programa Luz para Todos)* – Luz para Todos Programm........10

MME *(Ministério de Minas e Energia)* – Ministry of Mines and Energy........27, 28

NCAR – National Center for Atmospheric Research........34

NCEP – National Centers for Environment Prediction........34

NGO – Non-Governmental Organization........10

NREL – National Renewable Energy Laboratory........27

OECD – Organization for Economic Cooperation and Development........9, 10, 19, 23-25

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SONDA Wind Database

WAsP Wind Analysis

Wind Climatology Based on NCEP-NCAR Reanalysis

* Two issues of this report: color and gray versions

Images (in GIF format):

The images used in the reports separated into directories

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http://www.cptec.inpe.br/

ISBN
978-85-17-00038-6