Study of complementarity between wind and hydropower schemes for the state of Minas Gerais

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ABSTRACT

The renewable energy sources, especially wind, gaining distinction in Brazil and in the world as a viable alternative stability seasonal energy use through complementarity between natural wind and hydropower schemes, which can result in reasonable rates for service to consumers. This article discusses from existing data, the feasibility of stabilizing seasonal energy supply through the complementarity between these systems, if utilized the abundant natural resources available and the large number of dams deployed in the state of Minas Gerais. This study demonstrates that in spite of Minas Gerais provide a clean matrix-based electricity production of predominantly hydroelectric plants with significant regularization capacity flow, especially those with large reservoirs in many cases were found to decrease production in periods of drought and the same periods there is a possibility of generating electricity through wind power due to the amount of wind in the same period, confirming the viability of the use of complementarity between wind and hydropower systems in the state.

Keywords: wind power, hydropower, complementarity.

1 Introduction

Factors such as the crisis in Europe and the United States have created conditions for alternative energy sources and earned important space within the brazilian energy matrix. Still in its infancy, but with immense potential, the electric power generation that harnesses solar radiation (photovoltaic), the strength of the winds (wind) and biomass (thermal) in Brazil have the ideal setting to develop and enable expansion of the electric.

Wind energy is an alternative source, clean and renewable energy to produce electricity. It is attractive environmentally, by its non-polluting and also from economic point of view, to characterize as an inexhaustible source. Although there is still disagreement among experts and institutions in the estimated wind energy potential of Brazil, several studies indicate values extremely considerable. The capacity of wind power generation in Brazil has increased significantly year on year. In 2010 already had a production capacity of 1,000 MW annually diversified, with increasing industrial investments in progress in order to substantially increase the sector's ability to produce and install between 2.0 GW and 2.5 GW of energy per year [1].

Brazil is a privileged country in terms of availability of natural resources for renewable energy use. Among them, we highlight the resources, whose use enables the provision of more than 90% of electricity generation in the country. These characteristics mean that Brazil has a clean energy matrix in comparison with other countries. To get an idea, while the share of these sources in world primary energy production is 13.5% (including hydropower), in Brazil, corresponding to 47.8%. In electricity generation, the share of renewables is even higher, 87%, 82.8% and hydroelectricity. Worldwide, renewables account for 18.2% of electricity production, with 16.3% hydro [2].

With the predominance of hydroelectric generation in Brazil, stabilization seasonal energy supply has been a historic challenge to the planning of the operation of the interconnected systems, because the hydrological regimes have stochastic character with seasonal fluctuations of significant amplitude. The vast majority of power plants in Brazil depends on the hydrologic regime of the Southeast, which is characterized by seasonal fluctuations of significant amplitude. The risk of deficit of storage capacity in dry seasons criticism has been growing in recent years as a result of the postponement of investments in new generation plants because of the restructuring of the electricity sector and the privatization of power utilities [3].

Minas Gerais is located in southeastern Brazil, has 853 municipalities, a population of 19,597,330 inhabitants and a surface area of 586,852.35 km^2. It borders the states of Goiás, São Paulo, Rio de Janeiro, Espírito Santo, Mato Grosso do Sul and Bahia. The climate is tropical with regional subdivisions, mainly due to the altitude, and variations between: highland tropical, humid tropical etc., in addition to semi-arid climate that occurs in the far north of the state, due to low rainfall. The vegetation of Minas Gerais can be summarized into four types (biomes) main: Cerrado, which appears in 50% of the state especially in the basins of the São Francisco and Jequitinhonha; Atlantic, with high rainfall; Altitude Fields or Rupestres, found in the highest points of the mountains of Mantiqueira, Espinhaço and Canasta; and dry forest that appears in the north of the state, in São Francisco river valley. Several factors, including the climate, topography and watersheds, are predominant in the constitution of regional vegetation varied [4].

In the state, the production of electricity is predominantly derived from hydropower. In 2010, the production was 62,849 GWh (5.405 million tEP), which represents a fall of 0.7% compared to 2009 [5].

The Wind Atlas of Minas Gerais, completed in May of 2010 by the Energy Company of Minas Gerais (Cemig), estimated the seasonal wind potential in the state in three different dimensions, and the results indicate a potential of 10.6 GW, 24.7 GW and 39.0 GW, the height of 50 m, 75 m and 100 m, respectively [6].

This paper seeks a preliminary analysis from existing data, the complementarity between the natural hydro wind regimes in the State of Minas Gerais and opens the discussion on their possible effects on the stabilization of seasonality of supply of energy in the interconnected power system, taking advantage the abundant natural resources available in the state.

For both are analyzed and compared the data generating electricity from hydropower plants of the National Integrated System (SIN), as well as data generated by the study of Cemig, presented at the Wind Atlas of Minas Gerais.

In recent decades, the global wind hydro showed growth in the order of gigawatts needed a very effective contribution to the electrical systems. The discussion of the issue becomes even more relevant given the need to keep your Brazilian energy matrix with reduced carbon intensity, so that their emissions of greenhouse gases not reach unsustainable levels [7].

2 Hydraulic Potential

The state of Minas Gerais has a large hydro potential in its 58.6 million of hectares. The main basins that make up the river system of the state are the rivers Doce, Grand, Jequitinhonha, Mucuri, Paraíba do Sul, Paranaíba, Pardo and San Francisco.

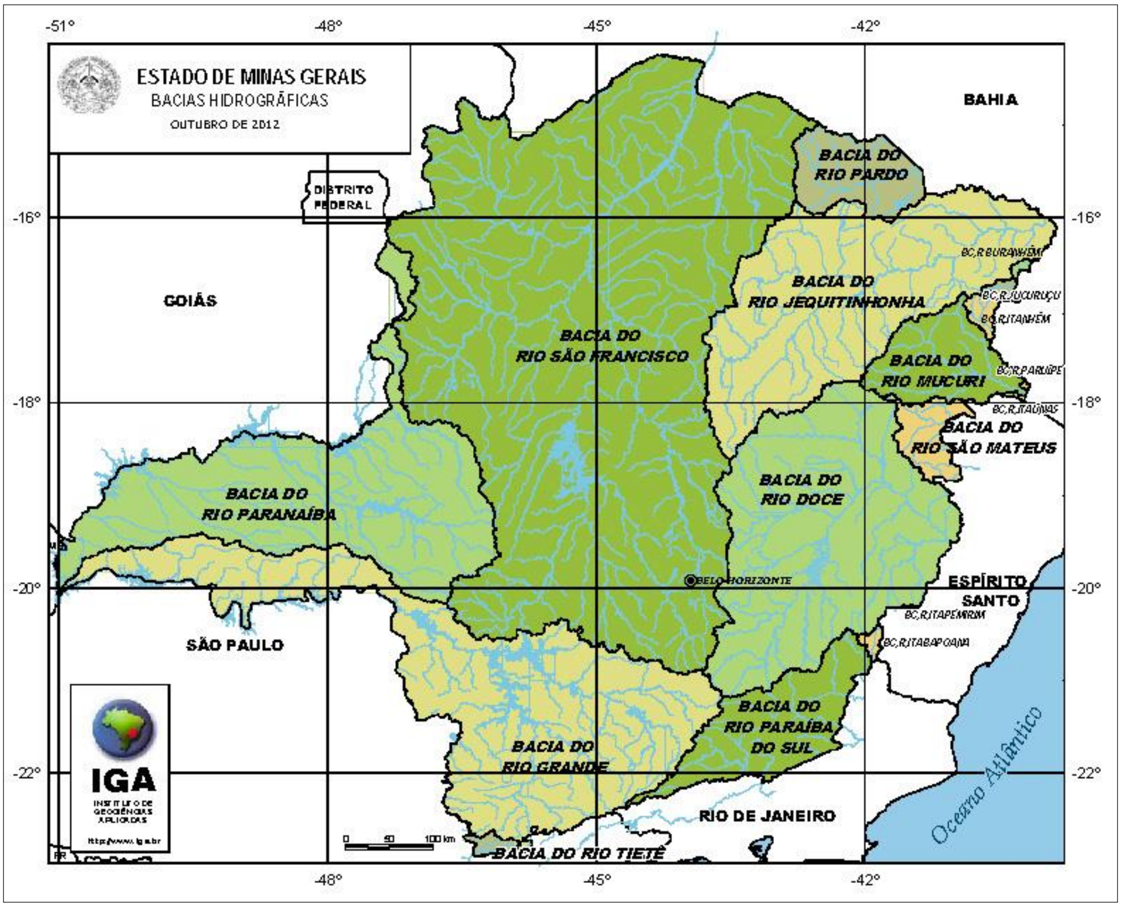


Figure 1: Watersheds of Minas Gerais [8].

The Doce river watershed is located southeast of Minas Gerais comprising an area of 71,500 km^2. The basin of the Grande river belongs to the basin of the Brazilian Paraná river and has a total area in Minas of 86,300 km^2, and the Grande river rises in the foothills of Mantiqueira, in Minas Gerais travels 1,360 km, going in its mouth, to form together with the Parnaíba river and Paraná river. The basin Jequitinhonha river covers much of northeastern state and a small part of southern of state Bahia and Minas, totaling an area of 6,0000 km^2. The basins of the Mucuri river is formed by the junction of the rivers Mucuri South and North Mucuri, having a scope in Minas of 14,900 km^2. The basin of the Paraíba do Sul river reaches 28,000 km^2, this river has its sources in the Serra da Mantiqueira. Already Paranaíba river watershed, one of the trainers of the Paraná River, rises in the hills of the Mata da Corda, and has approximately 1,070 km course to the junction to the Grande river, where they both begin to form the Paraná river, which marks the meeting point between the states of São Paulo, Minas Gerais and Mato Grosso do Sul. In this basin located some of the largest hydroelectric power plants in Brazil. The basin Pardo river was born in Pardo de Minas river. And the basin of the São Francisco river which is the third basin of Brazil, covering 240,000 km^2 in the state, with the head of the river is in the Serra da Canastra in Minas, and the mouth in the Atlantic Ocean between the states of Sergipe and Alagoas.

Watershed	Hydroeletric Power	Type	Water flow entering (m3/s)	Water flow out (m3/s)	level amount (m)	capacity useful (%)
ARAGUARI RIVER	Nova Ponte	Dam	91	154	797,29	40,8
	Miranda	Dam	178	155	694,8	58,96
	Amador Aguiar 1	Run-of-river	170	172		
	Amador Aguiar 2	Run-of-river	178	188		
GRANDE RIVER	Camargos	Dam	79	111	912,11	91,03
	Itutinga	Run-of-river	126	126		
	funil	Run-of-river	199	207		
	Furnas	Dam	515	651	763,77	67,64
	M. Moraes	Dam	666	694	665,34	92,45
	L. C. Barreto	Run-of-river	653	775	619,38	21,63
	Jaguara	Run-of-river	798	760		
	Igarapava	Run-of-river	874	849		
	V. Grande	Run-of-river	901	1225	494,45	69,03
	P. Colômbia	Run-of-river	1167	726	466,17	38,39
	Marimbondo	Dam	1140	1456	443,42	77,45
	A. Vermelha	Dam	1616	1687	381,96	83,67

Figure 2: Hydropower in the rivers Grande and Araguari [9]

In Minas Gerais were built large reservoirs capable of storing water in the wet season, which is converted into electrical energy during the dry period, maintaining regularization in the effluent flow. In recent years, due to major environmental impacts generated by the installation of power plants with reservoirs, added to physical restrictions and the imposition of strict environmental legislation from the 1988 Constitution, was given as a result, investment in the construction of power plants wire water in the state. This type of power plant has characteristics not always regularization flow, taking as a strategy, to be built downstream of large reservoirs. Thus, an immediate corollary of these limitations is the reduced ability to regularize generation.

The construction of Small Hydropower Plants (PCH), due to lower environmental impact in terms of the flooded area, and restricting physical space constitutes an important tool in the exploitation of water resources for self-producers of electricity, however, in terms of the system electrical as a whole, the small scale generation of PCH validates the need for additional wind hydro [7]. The increasing restriction to meet the load in the dry places on the Brazilian electric system the challenge is to complement the water park with plants that have the vocation to operate on the basis of the system during the dry period. Currently this complementation occurs through thermal fossil fuel, in most cases with a high unit variable cost (CVU) [7].

There is a tendency that the capacity of settling tanks becomes increasingly restricted as the load will increase, but the volume of the tanks measured by the energy stored, no. The Figure 3 presents data on this downward trend.

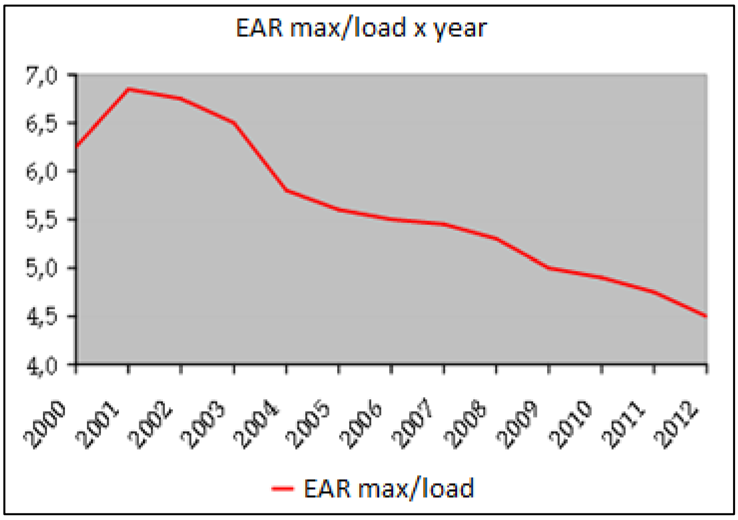


Figure 3: Evolution of regulating capacity of the reservoirs on Brazil EAR Maximum load SIN [7].

The potential energy of the water in the reservoirs is called Energy Stored and allows the adjustment of hydroelectric generation throughout the year. This seasonal behavior is illustrated in Figure 4 where it is found that in February the Natural Energy Affluent (ENA) exceeds 89,000 MWmed in contrast to the ENA around 30,000 MWmed in September. Another significant finding is the comparison between the ENA and the load average. While the ENA in the dry period of the rainy season between May and November is around 38,000 averages MW, the load of the National Interconnected System in 2008 was around 51,000 MWmed [7].

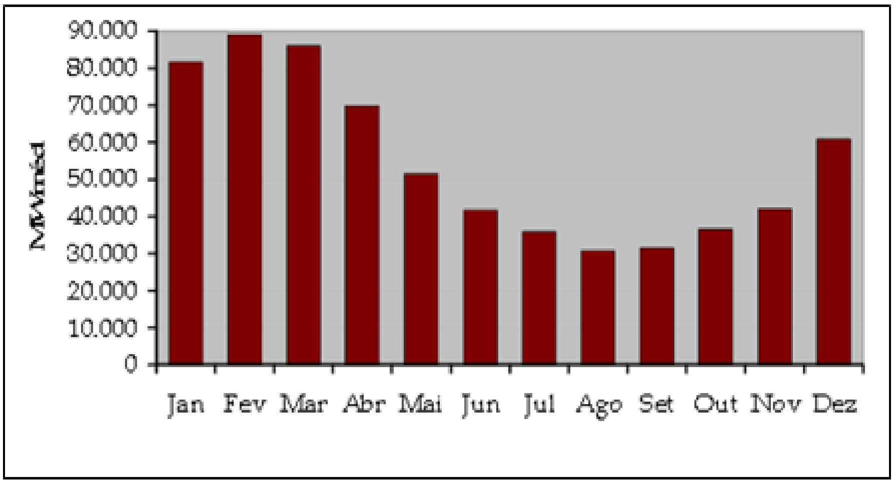


Figure 4: Energy Natural affluent - historical average includes all subsystems SIN [7].

The Brazilian electric system and included in it is of Minas Gerais, is rapidly evolving from a base hydroelectric, thermal generating facilities with operating as a reserve as backup for a hydrothermal system, where the thermal park will have to ship the base during the dry period. Thus, plants with low variable costs, which can operate inflexible during the dry period, have more economic value. This is because besides hold lower costs, save when dispatching the reservoirs, Stored Energy, precisely the period in which the reservoirs are impaired [7].

3 Potential Wind

Brazil is one of the countries that produce renewable energy, due to its climate and its surface has huge potential for wind and solar energy, but does not explore sufficiently capacity in these areas.

According to the "Atlas of Brazilian Wind Potential" [10], the wind potential in Brazil reaches 143,000 MW, this calculation does not include the potential offshore. Must stress that this study was prepared according to the technology of electric generation dominant then which was limited to low-power turbines installable up to 50 m above the ground. Serves exhaustive manner, the significant increase of the wind potential of the state of Rio Grande do Sul, which increased from 15,800 MW to 115,200 MW to 50 m for height 100 m [10]. Brazilian wind Atlas also shows that the wind potential, with the exception of the Amazon region, has a predominant manifestation in the months from June to December, which are precisely the months of lowest rainfall. Considering the Brazilian hydroelectric potential shown more prevalent during inverse of wind potential, it can be inferred that such potential will be complementary, as the demand for electricity in the country.

A decisive factor for the development of wind power in Brazil and the world is technology, since the turbine capacity has grown in recent years, from 50 kW up to a value of 9 MW, it came to allow wind farms constituted blunt an alternative for different levels of demand. In Brazil, the areas with the highest wind potential are in the Northeast, South and Southeast.

Minas Gerais already has one of the cleanest parks generators in the world, as more than 80% of the electricity that supplies the system is waterborne, one of the cleanest and cheapest sources there. A priori, it might seem difficult for a growing share of clean energy in the energy of the state by reducing the levels even lower emissions of greenhouse gases and other pollutants related to power generation, however, this movement is gaining breadth and the each year. Public policies, legal framework and the economic growth of the market related to the subject, demonstrating the support of the authorities, regulators and entrepreneurs, to increase the competitiveness of these sources also justified by the need to maintain security of supply of the Brazilian electric system a scenario of significant growth of the economy. Given this need the State Government launched in august of 2013 the Renewable Energy Program that proposes a series of measures with the aim of encouraging the production and use of energy from renewable sources in Minas Gerais.

The Wind Atlas of Minas Gerais, completed in May of 2010 for Cemig, estimated the seasonal wind potential in the state in three different dimensions. The Figure 5 shows the potential 100 m in height.

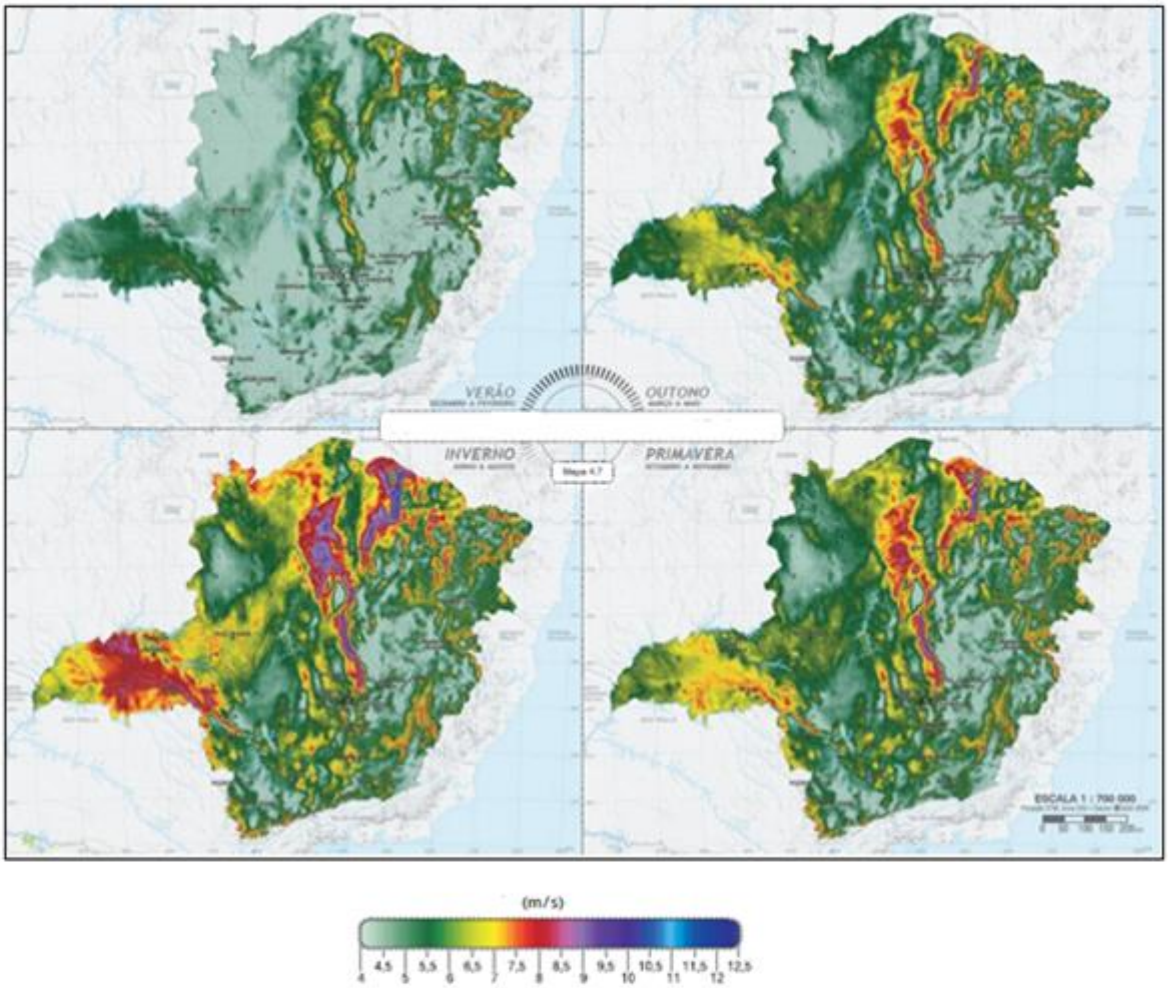
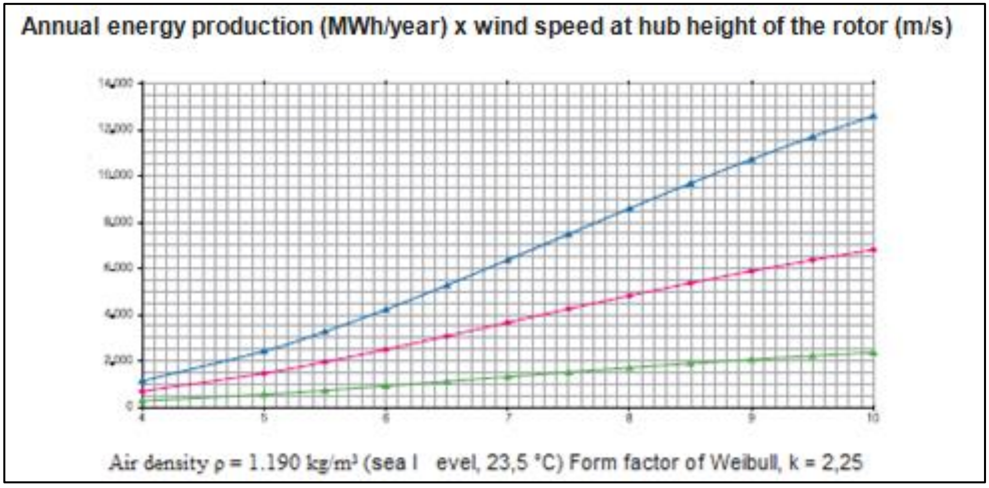


Figure 5: Potential seasonal wind at 100 m height [6].

The wind power potential of Minas Gerais was calculated from the integration of the velocity maps annual averages, making use of geoprocessing resources and performance calculations and energy production of the wind farm in the state of the art world. This process were adopted wind speeds extracted from towers in three heights (50, 75 and 100 m), with mean performance curves of commercial wind turbines of 500 kW class, 1,.5 MW and 3.0 MW, with a rotor diameter of 40 m, 80 m and 100 m.

The average occupancy rate of the land taken was 1.5 MW/km2. On maps with a resolution of 200m x 200m, were integrated areas with annual average speeds of 6.0 m/s in ranges of 0.5 m/s. Load factors were corrected for the density of the air, ranging from 0.975 to 1.15 kg/m3, as the region of the state. The Weibull shape factor was calculated yearly to 75 m high, also the mesoscale model Mesomap and has varied between 2-3 k [6].

Figure 6: Annual energy production by wind speed [6].



The calculation of the generation and performance of the plant was considered an availability factor of 98%, an efficiency factor of 97% and a loss factor of 25%. The results indicate a potential of 10.6 GW, 24.7 GW and 39.0 GW, the heights of 50 m, 75 m and 100 m, respectively [6]. The data are listed in Figure 7.

POTENTIAL FOR WIND GENERATION									
Integration by speed ranges						Integrating cumulative			
Height (m)	Wind (m/s)	Area (Km2)	Potential installable (MW)	Capacity factor	Annual energy (GWh)	Wind (m/s)	Area (Km2)	Potential installable (MW)	Annual energy (GWh)
100	6.0 - 6.5	58,096	87,144	0,172	131,46	≥ 6.0	121,51	182,266	326,36
100	6.5 - 7.0	37,386	56,08	0,21	102,82	≥ 6.5	63,415	95,123	194,899
100	7.0 - 7.5	15,384	23,076	0,246	49,789	≥ 7.0	**26,029**	**39,043**	**92,076**
100	7.5 - 8.0	6,887	10,331	0,284	25,673	≥ 7.5	10,645	15,967	42,287
100	8.0 - 8.5	2,403	3,604	0,318	10,04	≥ 8.0	3,757	5,636	16,615
100	≥ 8.5	1,355	2,032	0,369	6,575	≥ 8.5	1,355	2,032	6,575
75	6.0 - 6.5	50,647	75,971	0,172	114,88	≥ 6.0	93,685	140,528	245,317
75	6.5 - 7.0	26,543	39,814	0,209	72,63	≥ 6.5	43,038	64,557	130,441
75	7.0 - 7.5	10,329	15,493	0,247	33,461	≥ 7.0	16,495	24,742	57,812
75	7.5 - 8.0	4,11	6,165	0,282	15,25	≥ 7.5	6,166	9,249	24,351
75	8.0 - 8.5	1,255	1,883	0,318	5,242	≥ 8.0	2,056	3,084	9,101
75	≥ 8.5	0,801	1,201	0,367	3,589	≥ 8.5	0,801	1,201	3,859
50	6.0 - 6.5	35,344	53,016	0,186	86,295	≥ 6.0	55,228	82,841	149,798
50	6.5 - 7.0	12,837	19,256	0,223	37,722	≥ 6.5	19,884	29,825	63,503
50	7.0 - 7.5	4,812	7,218	0,261	16,501	≥ 7.0	7,046	10,57	25,781
50	7.5 - 8.0	1,411	2,117	0,298	5,522	≥ 7.5	2,235	3,352	9,28
50	8.0 - 8.5	0,544	0,816	0,333	2,378	≥ 8.0	0,823	1,235	3,757
50	≥ 8.5	0,279	0,419	0,376	1,379	≥ 8.5	0,279	0,419	1,379

Figure 7: Potential Wind Generation in Minas Gerais [6].

5 Results and Discussion

As proposed methodology will be analyzed and compared the data generating electricity from hydropower plants [12] the National Integrated System (NIS), as well as data generated by the study of Cemig, presented at the Wind Atlas of Minas Gerais [6].For purposes of this study, we analyzed the production of electricity in Araguari river and Grande river, which integrate the basin of Paranaíba River and the Paraná river, respectively.

The data [12] refer to the year 2012 and were drawn from the historical generation Integrated System (SIN). The UHEs Amador Aguiar I and II, old UHEs Capim Branco I and II, the UHEs Miranda and Nova ponte are installed in Araguari river and presented an overview of regularization flow, not wavering in the dry season, as Figure 8.

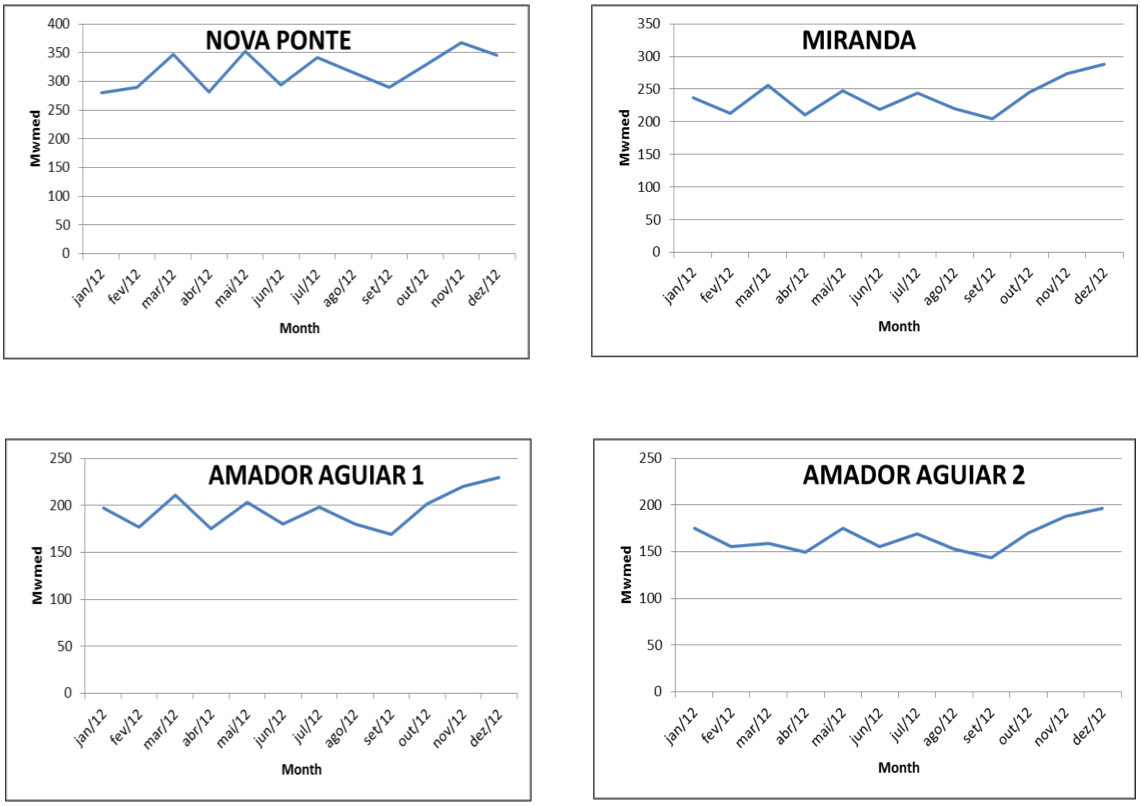
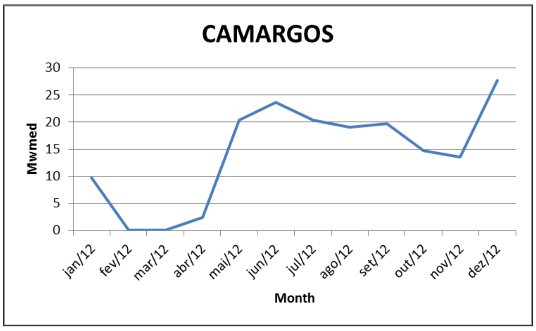
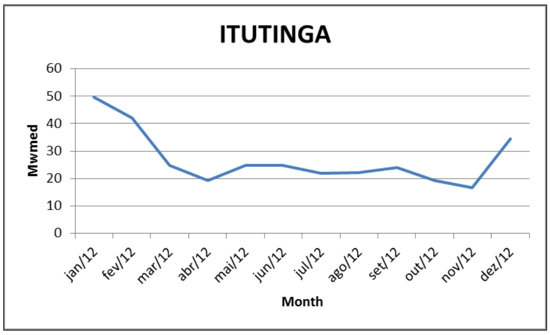


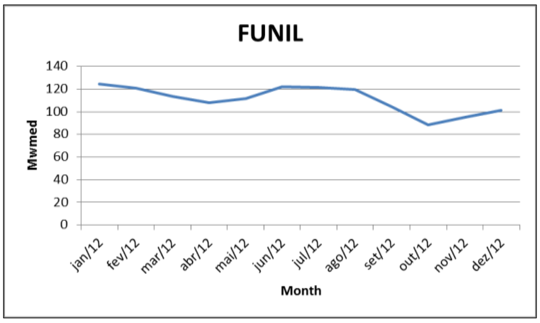
Figure 8: Energy Production in Araguari (2012).

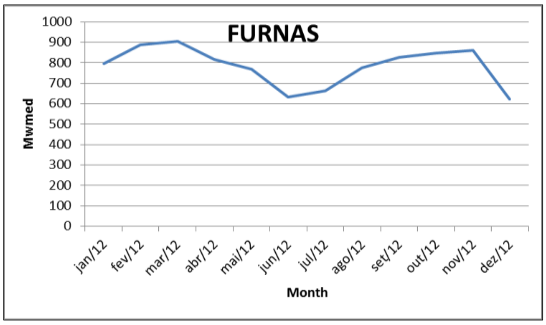
We also analyzed the UHEs of the Grande river, which had different characteristics. UHEs of the Agua vermelha e Marimbondo showed a drop in production that may be linked to a temporal cycle, UHE Mascarenhas de Moraes is seen a regularization flow, but the UHEs

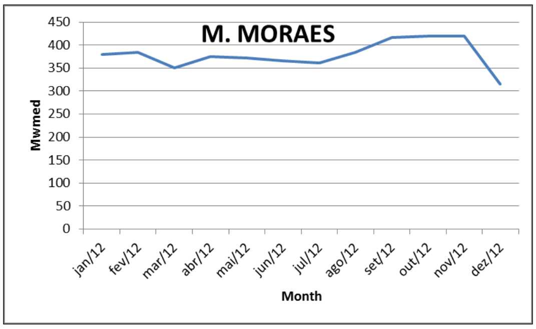
Furnas, Puerto Colombia, Itutinga, Igarapava and Camargos demonstrated declining production in drier periods, which favors complementarity hydro wind.

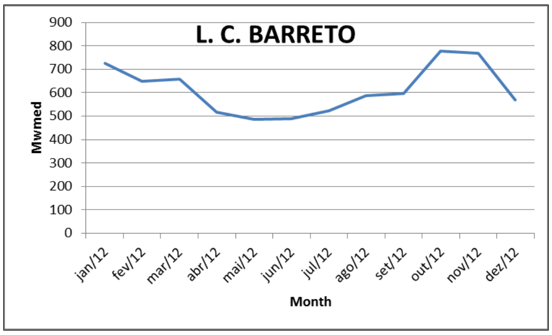


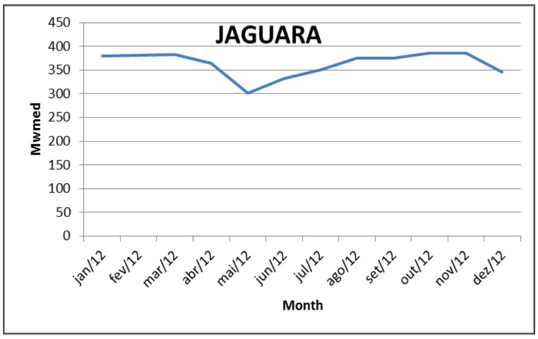


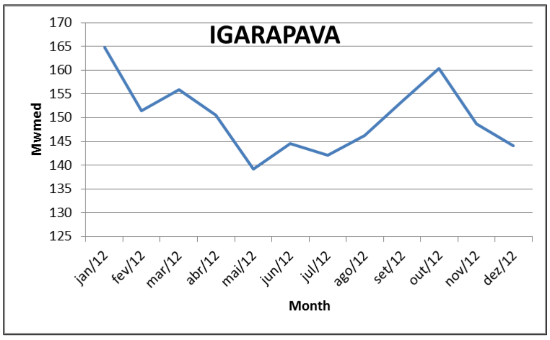












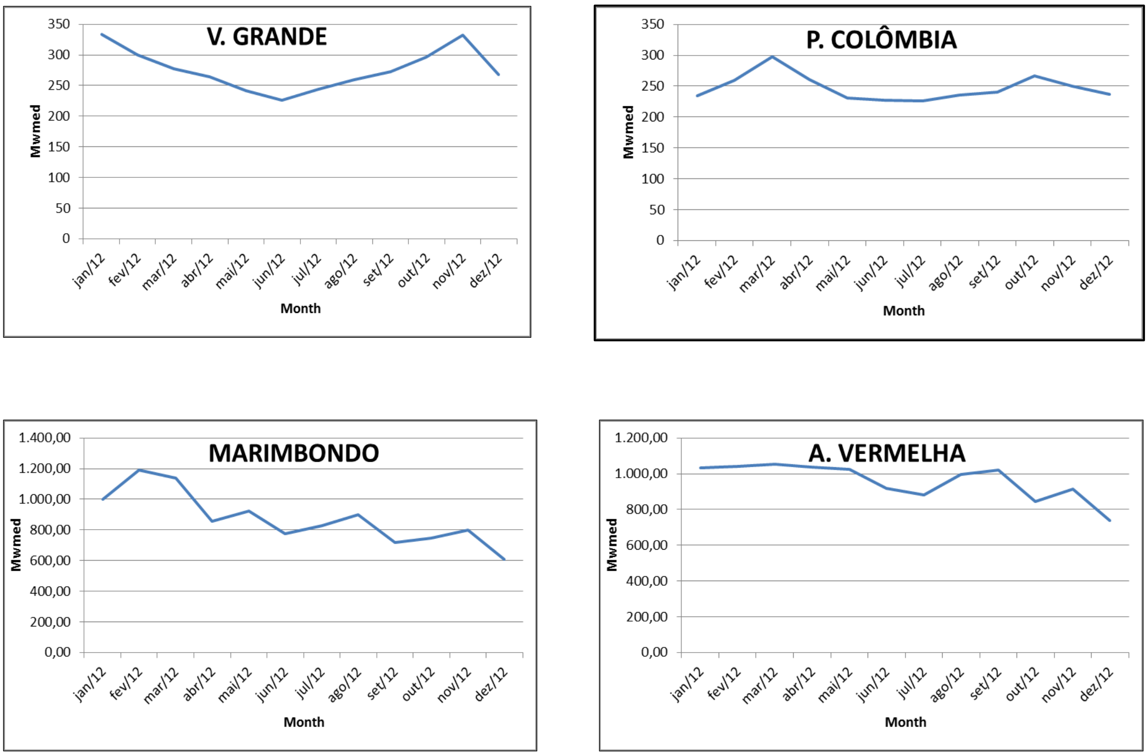


Figure 9: energy produced by months of the year in Grande river (2012).

Measurements taken by Cemig over the last decades, around the Minas Gerais territory, show that the predominant wind regime is one in which the average speed during the day is higher than average night. However, some measurements at sites of plateau, and in places where the average speed is the order most relevant to the interest of wind farms, showed an inverse predominant regime. The figure 10 includes schemes daytime average recorded by the ancient gas measurement Cemig anemographs (1968-1983).

The clouds lines diurnal average schemes suggest that as we increase the influence of the mesoscale as well as the annual average speed regimes tend to have higher speeds overnight. This trend is repeated in the most recent measurements (1997-2009), performed with the anemometers Meteorological Telemetry System (STH) of the Cemig, which were considered in the mapping process presented in the Atlas. Seasonally, most of the state territory stronger winds predominate in winter and spring [6].

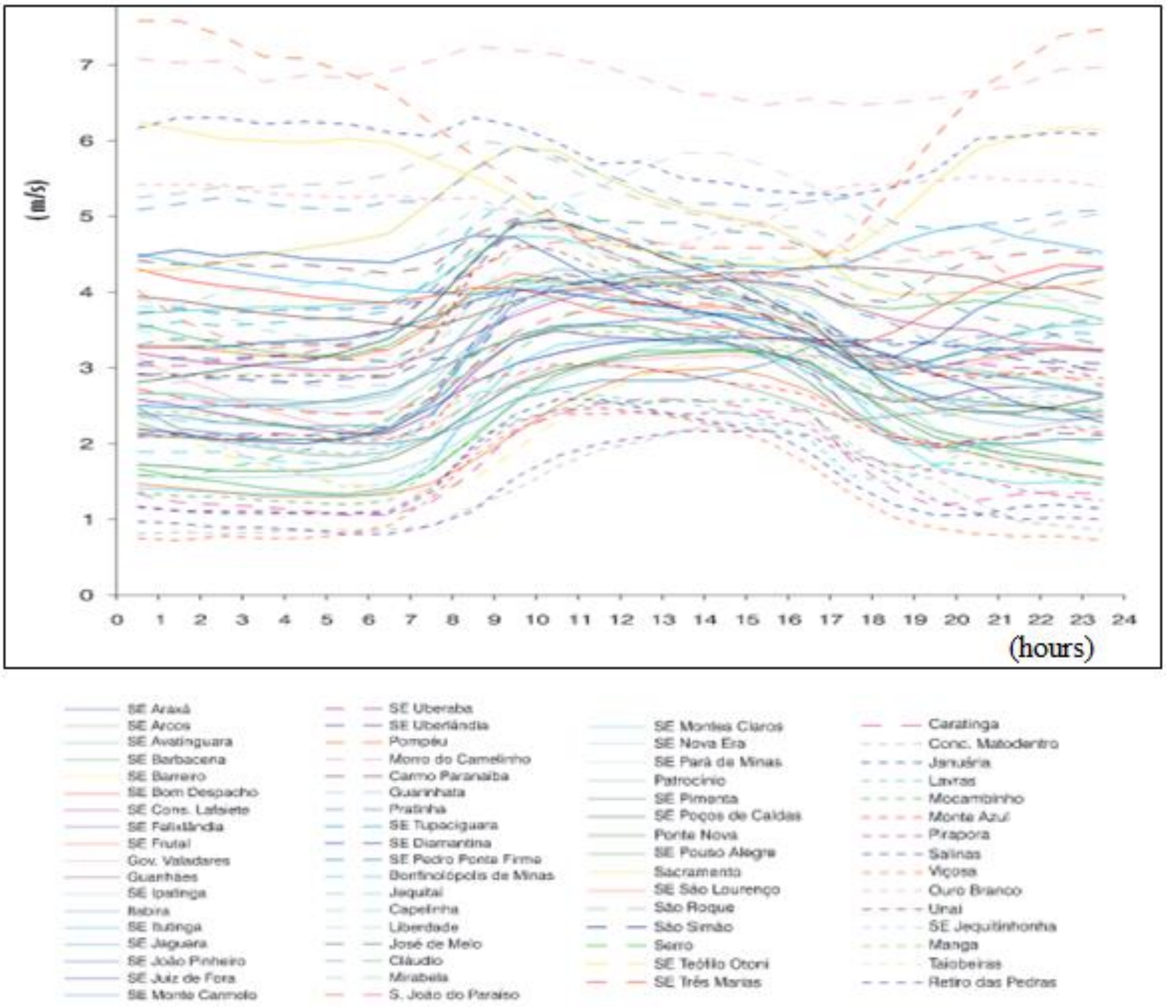


Figure 10: Scheme of wind in Minas Gerais [6].

From the data presented, and comparing studies of complementarity in northeastern Brazil [14,15], and also those performed to the northeast, south and southeast of the country [2], is then ratified the evidence of the possibility of complementary seasonal hydro wind for the state of Minas Gerais, as shown in Figure 11. The study also suggests that the deployment of wind power plants make up in areas of hydropower due to local wind speed, and also in the areas identified by the wind potential map of Minas Gerais [6], and the Triangulo Mineiro and mountains of Serra do Espinhaço are the best regions of wind potential. The Serra do Espinhaço, due to its large size, can be subdivided into three microregions. The first corresponds to the area of Janaúba and Grão Mogol, which also includes the cities of Espinosa, Gameleiras, Monte Azul, Mato Verde, Porteirinha, Serranópolis de Minas, the Riacho dos Machados e Francisco Sá. The second area of Montes Claros, still covering the municipalities of the Coração de Jesus, São João da Lagoa e Brasília de Minas. And the third area corresponding to Curvelo, Diamantina and Sete Lagoas.

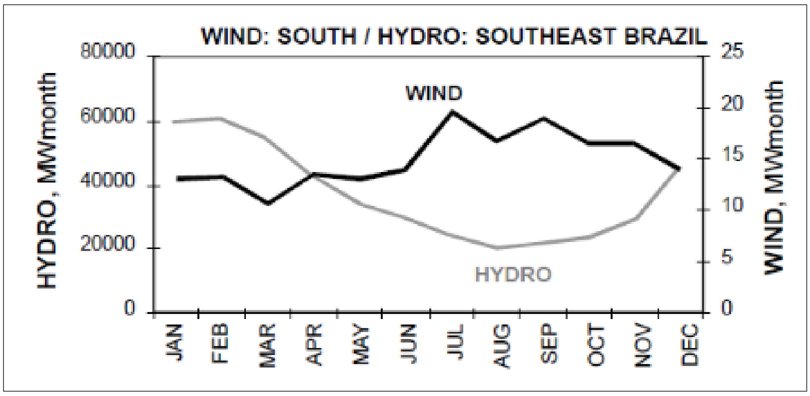


Figure 11: Complementarity hydro wind in southeastern Brazil [2]

Wind energy has an emission factor impacting on greenhouse gases in the same order of magnitude of hydroelectric plants. Thus, exploring this alternative energy source is consistent with the need to mitigate global emissions of greenhouse gases in impactful. Thus, for Minas Gerais environmental aspect in the development of wind energy would maintain the quality standard of your odd electrical grid [15].

The positive externality that wind power holds, and which justifies its inclusion in the higher energy matrix, is related to complementarity with the water park: the wind regime is strongest precisely in the dry period. It is worth to note that wind power plants, as well as the PCH, have reduced construction time and less environmental impact, minimizing the risk of delay in the projects so common in large projects, especially hydroelectric projects. In contrast, the intermittency of wind constitutes a negative aspect of this energy source. Unlike hydroelectricity, which has historically been regularized through the construction of large reservoirs, wind energy is not likely to be stored. However, in our case this does not constitute intermittency problem of major importance because the integration of wind energy must occur precisely at the base of the system in addition to the water park with decreasing ability to regulate the generation [15].

Besides the seasonal variability will be manifested also natural climate variability daily and yearly, as well as regional and global climate change. It should be noted, however, that climate change is a long-term change, while climate variability is a natural event and that tends to occur cyclically. The records of the annual variability in time series show the temporal behavior of certain features that serve to examine past climate, describing the present and predict the future movements and extremes. The proper use of knowledge of climate variability monthly, seasonal and other time scales can improve management hydro energy in the current conditions, collaborating with the adaptation of systems to changing conditions.

Complementarity hydro wind can replace the use of the thermal energy matrix [16]. In future research, alternative energy sources such as small hydro, offshore wind, photovoltaics and biomass cogeneration and natural gas should be evaluated in addition to wind power, in order to increase production capacity and maintain clean energy matrix.

6 Conclusions

This study demonstrates that in spite of Minas Gerais provide a clean matrix-based electricity production of predominantly hydroelectric plants with significant regularization capacity flow, especially those with large reservoirs in many cases were found to decrease production in periods of drought and the same periods there is a possibility of generating electricity through wind power due to the amount of wind in the same period, confirming the viability of the use of complementarity between wind and hydropower systems in the state.

The inability to build new large reservoirs due to major environmental impacts and the charges brought by the Federal Constitution of 1988, have gradually reducing the ability of regularization of hydroelectric generation. Thus, the Brazilian electric system and the Minas Gerais system require increasingly complementary generation in the dry season. The most appropriate way to accomplish this is to supplement the insert in the electric generation sources with seasonal vocation operating base, such as wind power. This energy has proven to be extremely competitive with conventional sources of electricity generation, as shown in recent energy auctions, since the benefit that they provide to the electrical system is properly sized and valued. In short, the electric matrix stete mining is undergoing a process of inserting new technologies derived from renewable sources, which helps to keep the energy matrix predominantly clean. Accordingly, this study sought to provide a new basis for rethinking the expansion of the generating, by permeating environmental concepts for the planning of the electric future of the State of Minas Gerais.

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