ESTIMATION OF COMPLEMENTARITIES BETWEEN SOLAR WIND AND HYDRO ENERGY SOURCES FOR THE PLANNING REGIONS OF THE STATE OF MINAS GERAIS

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ABSTRACT

The use of resources of energy complementaries has the potential of improving the quality of the energy service provided, since fewer failures are expected. Moreover, when idle areas of land in the vicinity of hydroelectric power plants are used to site other power plants, in general, there is no need of additional investments in new transmission lines. Therefore, this study presents an analysis of the complementarities of solar and wind resources with hydro resource associated to hydroelectric power plants located in the planning regions of the state of Minas

Gerais. The study aims to assess each hydroelectric power plants by region planning of the State of Minas Gerais, Brazil, indicating the feasibility or not of complementarities with solar or wind power generation, considering possible effects of seasonal stabilization of electrical energy supply in Brazilian the interconnected power system. The database used in this study is composed of generating hydroelectric power plants in operation in the state, wind speed and solar radiation of surveys near the plants available from the Companhia Energética de Minas Gerais - Cemig, the utility of the state, Agência Nacional de Energia Elétrica (ANEEL), the Brazilian regulation agency, and other institutions. The results of this study show that for certain hydroelectric power plants there are possibility of complementarities of wind or solar power resources. Moreover, for other hydroelectric power plants the study showed the convenience of power reconditioning.

Keywords: hydro power, complementarity of energy resources, renewable energy, planning.

1 - INTRODUCTION

Energy is a key factor for satisfaction of most of human needs. However, these needs have continuously increased along time but the natural energy resources are limited.

Brazil is a privileged country in terms of availability of renewable resources for energy production. Among them, water resources can be highlighted, their use enable the provision of more than 90% of the electricity in the country. Therefore, Brazil is characterized by a rather clean electricity matrix, in comparison with other countries. For instance, the participation of wind, solar and hydro resources in world primary energy production is 13.5%, in Brazil they represent 47.8% of the primary energy. When only electricity generation is considered, the share of the renewables sources is even higher, 87%. Hydroelectricity alone represents the 82.8% of the total electricity consumption. Worldwide, renewables account only for 18.2% of electricity production, with 16.3% from hydro power stations [1].

With the predominance of hydro power in Brazil, obtaining a steady energy supply along the seasons has been a historic challenge to planning decisions of the operation of the power sector, due to the seasonal fluctuations of significant amplitude of the hydro potential. This seasonality is more important in the Southeastern region, which also has the greatest reservoirs. Moreover, the risk of shortfall of energy has increased in recent years as a result of the postponement of investments in new power plants and due to the fact that new hydroelectric plants are run-of-river.[2]. Notice that Minas Gerais is located in the Southeastern region of Brazil. It has 853 municipalities, a population of 19,597,330 inhabitants and a surface area of 586,852.35 km². It borders the states of Goiás, São Paulo, Rio de Janeiro, Espírito Santo, Mato Grosso do Sul and Bahia. In the state, the production of electricity is predominantly derived from hydro power stations [3].

Recently, reservoirs levels have dropped significantly. As a consequence, thermal power plants have been dispatched more frequently than usual and electricity price has increased significantly. These facts sparked discussions about the direction in which the national energy matrix must evolve. The inability to build new large reservoirs, determined by environmental regulation is gradually reducing the firm hydro power available. In this context, alternative sources can play an important role in the expansion of the electricity matrix. The Brazilian and the Minas Gerais electricity matrices are undergoing a rapid process of transition in which is necessary to carefully select future candidate projects for the expansion of their power systems with emphasis on sustainable development.

Notice that the use of complementary energy sources has the potential of reducing failures in energy supply. Moreover, it is common to find idle areas of land near hydroelectric plants. By installing alternative and complementary sources in these lands, there is no need of additional investments in new transmission lines. Therefore, this research aims to analyze solar and wind potentials in lands near hydroelectric plants in the different planning regions of the state of Minas Gerais. The objective is to assess complementarities among hydro, wind and solar resources that would improve electricity supply along the dry and wet seasons.

The aim is to contribute with the decision-making about public policies for sustainable development in the State of Minas Gerais. To this end, the analysis is carried out considering the planning regions in which the state is divided. In the 1970s, the state government has promoted regional studies to gather municipalities linked by socioeconomic characteristies. Since the 1990s, it is in effect the division established by the old Department of Planning and General Coordination (Secretaria do Planejamento e Coordenação Geral – Seplan), now Department of Planning and Management (Secretaria de Planejamento e Gestão - Seplag), which includes ten regions (Figure 1). Originally envisaged in the bill 1590/93, the criterion became effective with the Multiannual Government Action Plan (Plano Plurianual de Ação Governamental - PPAG) 1996-1999, adopted in December 1995 [4].
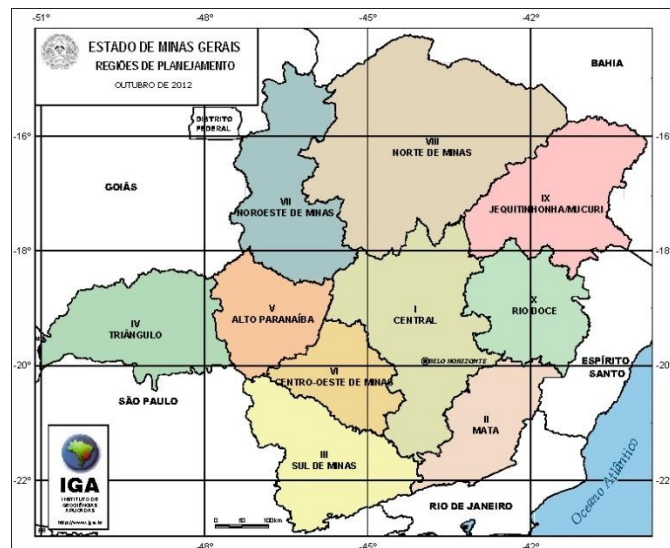

Figure 1 – Map of the Regions Planning of the State of Minas Gerais (MG Government Portal, 2012). [3]

In the definition of the regions, the state adopted the Modified Potential Model, which resulted in the determination of two quantities: socioeconomic mass and distance between elements of regionalization. The variables that compose the first magnitude were calculated using the Principal Components Analysis (PCA) technique, considering the following sources: the Census 1991, data from the Center of Statistics and Information of Fundação João Pinheiro (FJP) and the Multimodal Plan Deplan/Setop/DER-MG 1994. For the second magnitude, the distance between the elements of regionalization was represented by road distances between elements of regionalization. Among the objectives of this spatial division process are:

decentralization of administration, coordination of a cooperative effort between the three levels of government (State, region, and municipality) aiming at contributing in the solution of regional problems, mobilization of regional potential to generate jobs and income and also the preparation and implementation of plans, programs and projects for sustainable development in each region (FJP, 1996) [3].

2 –POTENTIALS OF THE REGIONS

The State of Minas Gerais has a large hydro potential in its 58.6 thousand square km. The main river basins that compose the hydro-network are the Rio Doce, the Grande, the Jequitinhonha, the Mucuri, the Paraíba do Sul, the Paranaíba, the Pardo and the São Francisco river basins. In Figure 2, watersheds belonging to each planning region are presented.
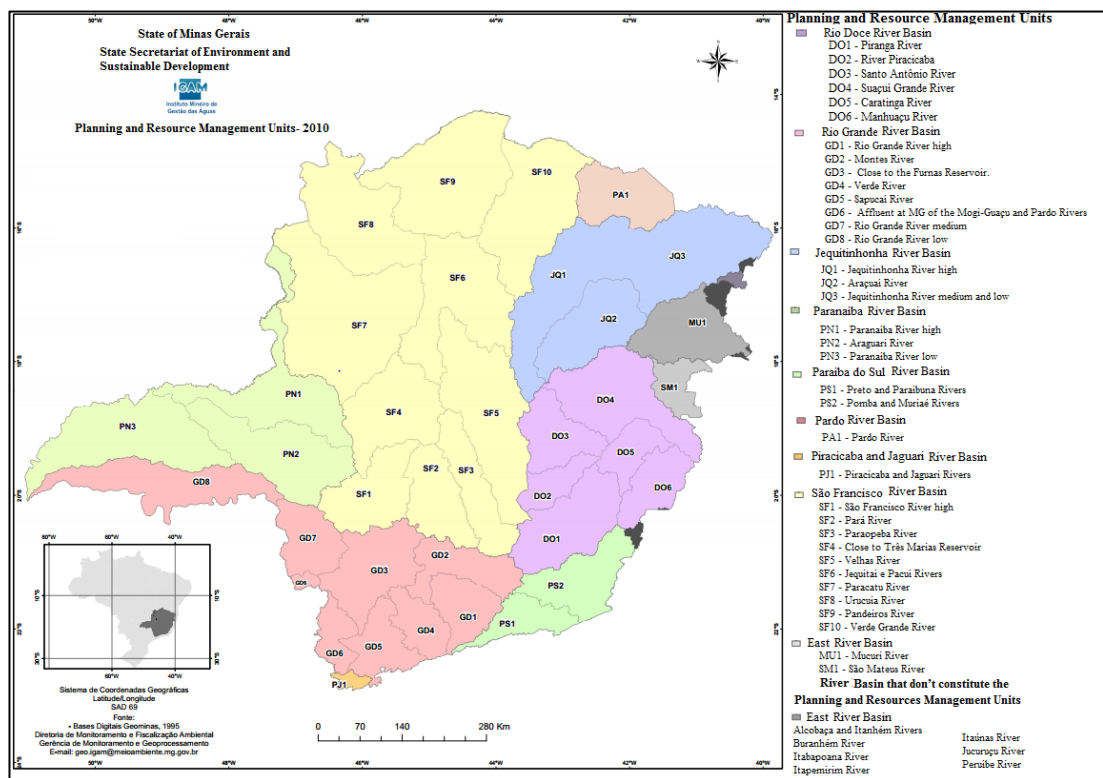
Figure 2 - Planning and Resource Management Units (IGAM, 2010). [5].

The Rio Doce basin, comprising an area of 71,500 km² is located at the eastern part of Minas Gerais. The Rio Grande basin belongs to the Brazilian Rio Paraná basin and has total area of 86,300 km² and covers 1,360 km, The Rio Jequitinhonha basin

covers much of the northeastern part of the state and a small portion of southeastern region of the state of Bahia, with a total area of 65,000 km². The Rio Mucuri catchment basin covers 14,900 km². The Rio Paraíba do Sul catchment basin in Minas Gerais reaches 280,000 km². The Paranaíba eatchment basin, main tributary of the Paraná river, runs for approximately 1,070 km from its source to the junction to the Rio Grande river. Notice that most of the largest hydro power stations in Brazil are located in the Paranaíba and in the Rio Grande basins. Moreover, the São Francisco catchment basin is the third basin in Brazil, it covers an area of 230,000 km².

In recent years, due to severe environmental impacts generated by the installation of hydroelectric reservoirs, coupled with the physical restrictions and the imposition of strict environmental, most of the new hydro plants are run-of-river. These plants have low capacity reservoirs that cannot regularize water flows, they are usually constructed downstream of the large reservoirs. Thus, an immediate corollary of these limitations is the reduced ability to regulate the generation. Therefore, the tendency is that the regulating capacity of the reservoirs becomes increasingly constrained as the load increases. Clean energy resources that can operate during the dry season are necessary. Currently, this complementary operation occurs with thermal power plants fueled with fossil fuels, in most cases with a high variable cost. [7].

The Wind Atlas of Minas Gerais (Atlas Eólico de Minas Gerais), issued in May 2010 by Companhia Energética de 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 in heights of 50 m, 75 m and 100 m, respectively [8]. Besides the potential identified, this study indicated a more detailed assessment in four areas that are technically favorable for the installation of wind turbines (Figure 3).
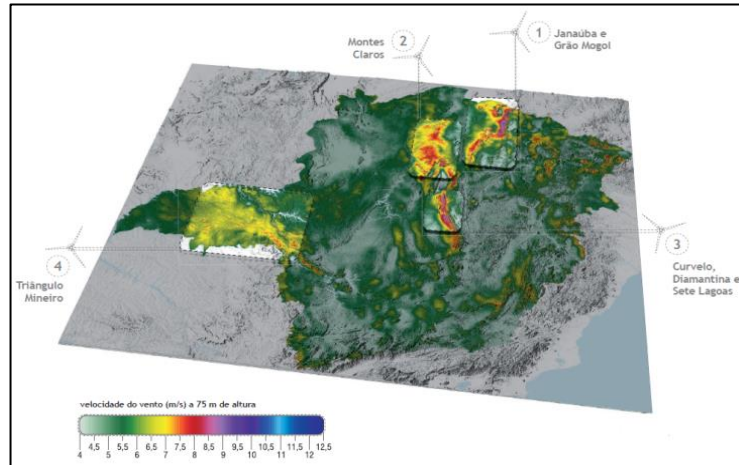
Figure 3- Promising areas in Minas Gerais for Wind Power projects. (CEMIG, 2010) [8].

Measurement data by Cemig over the past decades, throughout the territory of Minas Gerais, show that the predominant winds is one in which the average speed during the day is higher than average speed at night. However, at plateau sites and in locations of higher average speed, the predominant wind regime is reverse. Most of the state's stronger winds occur during Winter and Spring. The Solarimetric Atlas of Minas Gerais (Atlas Solarimétrico de Minas Gerais), published in 2012 by Cemig, in partnership with Aneel, shows the average time of insolation in Minas Gerais, and allows the determination of the average annual solar radiation, that is between 4.5 and 6.5 kWh/m²/day, with maximum values observed in the northern region of the state and minimum values in the southeastern region. Moreover, annual average radiation values do not show any seasonal variation. As Figure 4 shows, most of the state is favorable for the installation of solar power plants, with daily average radiation between 5.5 to 6.5 kWh/m²/day. [9].
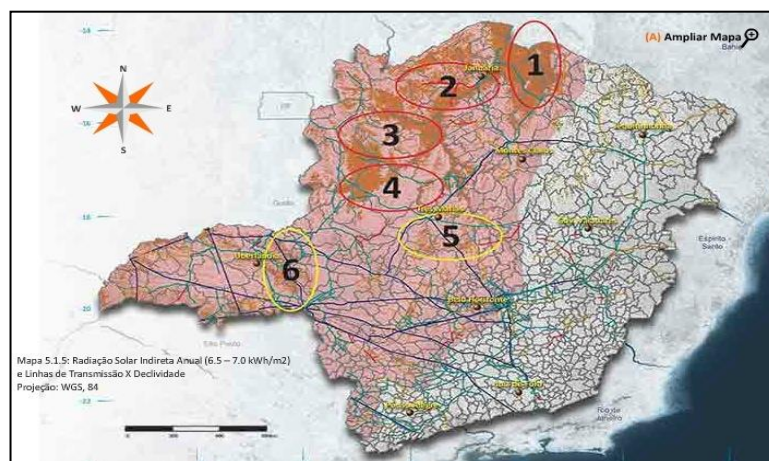

Figure 4 – Promising areas in Minas Gerais for solar plants (Cemig, 2012). [9].

3 – METHODOLOGY

Initially, hydroelectric generation is calculated considering locational issues and historical electricity generation data of the last ten years. These data were provided by ANEEL, CEMIG, and Operador Nacional do Sistema Elétrico – ONS (National Operator of the Brazilian Power System). Monthly average electricity generation of each power plant are calculated and plotted.

In the sequel, photovoltaic solar generation is calculated, assuming that total power of the solar plant associated with the hydroelectric plant is 50% of the analyzed hydroelectric power. The software Pvsystis is used to this end. This software has the database of solar radiation Meteonorm 6.1, which gives access to various sources of weather data on the web and includes a tool to easily import other data. The inputs to the program are the latitudes and longitudes of hydroelectric power plants associated. The solar equipment chosen for simulation are polycrystalline modules from Kyocera and inverters from GE Power Conversion and Power Electronics, with several output powers and voltages. The output of Pvsystis include average monthly amount of electricity generation for each plant. Finally, the calculation of wind power generation considers that total wind power plant is 50% of the associated hydroelectric power, the same as for solar. Wind speed data close to the associated hydroelectric power plants supplied by Instituto National de Meterologia – Inmet (the Brazilian Institute of Meteorology) are used. These data are measured at a height of 10 meters. Extrapolation of the wind speeds for a height of 120 meters is done, assuming a coefficient of roughness of the soil equal to 0.19 (average roughness class) from the formula below:

$$V_Z = V_r * \left(\frac{z}{z_r}\right)^n$$

where: V_z = velocity for the height Z; Z = height to be extrapolated; V_r = velocity measurement; Z_r = height where the velocity was measured; n = coefficient of roughness of the soil.

Software Windographeris was used for processing the data of wind speed. Information provided by the software were: frequency of occurrence of each wind

speed, the parameters "k" and "c" of the Weibull distribution and performance data of Enercon turbines related to wind speeds. The turbine was chosen to simulate the Enercon E115 with rotor diameter of 110 meters and rated power of 3,050 W. Average wind power generation is calculated.

4 – RESULTS AND DISCUSSION

The results of the study show that only for a small number of hydroelectric plants complementarities with wind or solar sources can be considered as a potential to be explored. One can notice that an important source of error is given by wind speed data at 10 meters high. Extrapolation in this condition is approximate. Notice that even with no significant complementarities, solar and wind plants increase the total power of the particular project. This fact is referred as repowering of the original plant. In the sequel, results obtained by planning region are shown.

The Central Region is the most populated, sharing 35.6% of the total population of the state, which is concentrated predominantly in urban areas. The main poles are Barbacena, Belo Horizonte, Conselheiro Lafaiete, São João Del Rey and Sete Lagoas. It is also the most prosperous region, accounting for 46.6% of GDP, 60% of exports and 52.1% of formal employment. The simulation results of the power plants for this region are shown in Figure 5.
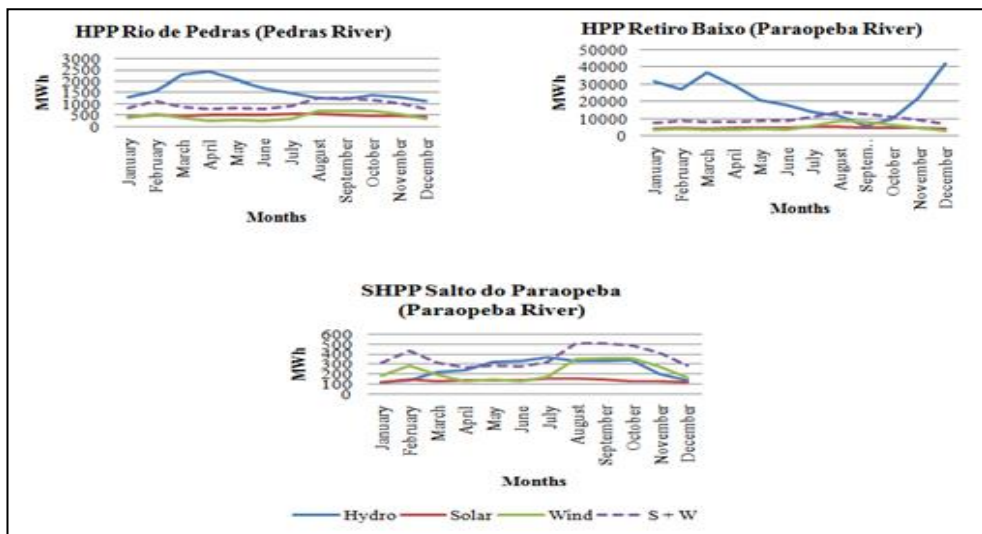

Figure 5: Results for complementarities projects of the Central Region. (Self, 2014)

It is observed that the complementarities of the sources is not significant. The potential complementarity of Small Hydro Power Plant (SHPP) Salto do Paraopeba is 92%, for the Hydroeletric Power Plants (HPP) Rio de Pedras is 0.10% and for the HPP Retiro Baixo plant is 6.5%.

The Mata Region meets 11.1% of the state population. About 81% of the regional population lives in urban areas, main cities are: Carangola, Juiz de Fora, Manhuaçu, Muriaé, Ponte Nova, Ubá and Viçosa. The simulation results of the power plants for this region are shown in Figure 6. It is observed that complementarities of sources are significant only for Anna Maria plant. The potential complementarity of resources for SHPPAnna Maria is 29%, for SHPP Guary is 6.9% and for the SHPP Paciência is 4.1%.
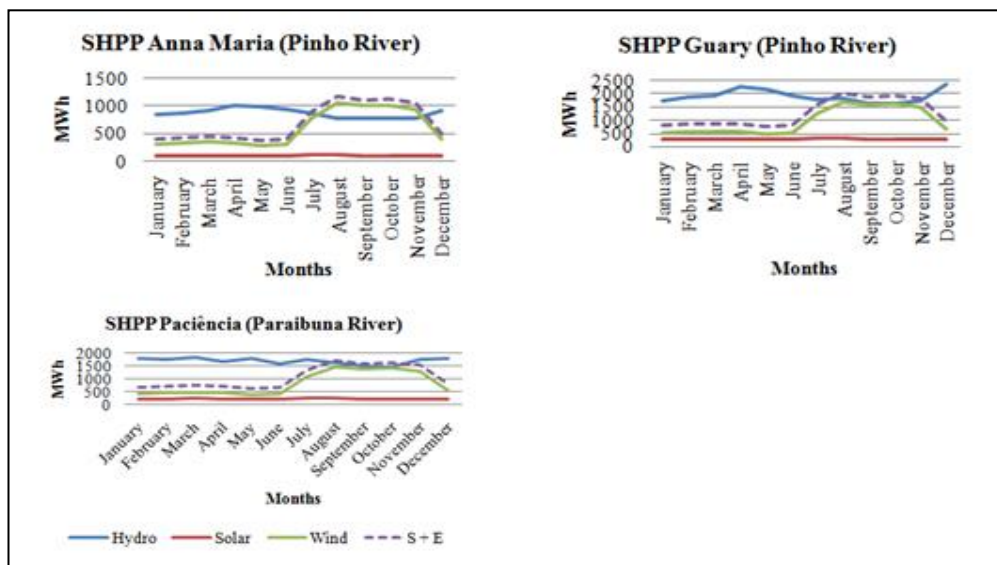
Figure 6: Results for complementarities projects of the Mata Region. (Self, 2014)

The South Region is the second most populous region of Minas Gerais, sharing 13.2% of the state population. The simulation results of the power plants of this region are presented in Figure 7. It is observed that complementarities of the sources are not significant. The potential complementarity of SHPP Congonhal I is 8.5% and for the SHPP Xicão is 7.1%.
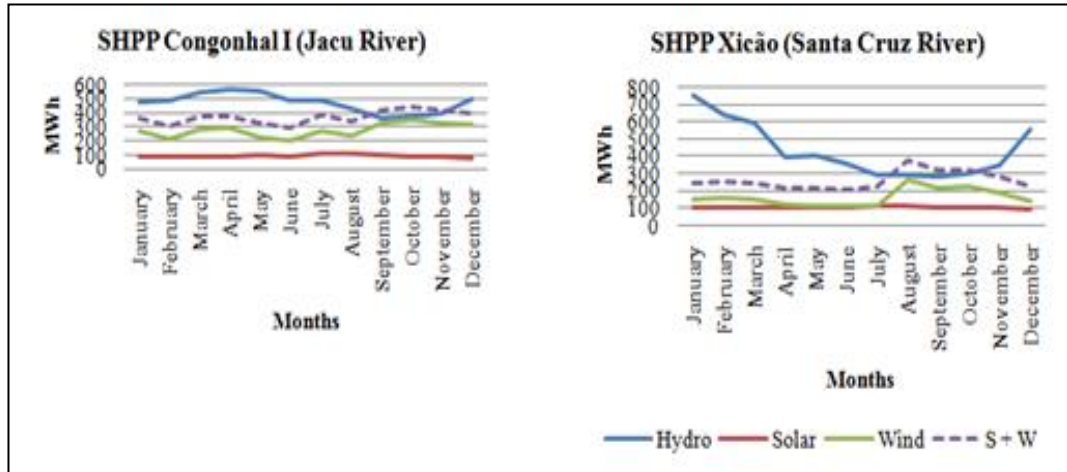
Figure 7: Results for complementarities projects of the South Region. (Self, 2014)

The Triângulo Mineiro Region has the highest GDP per capita among the ten regions of Minas Gerais and its main poles are Ituiutaba, Uberaba and Uberlândia. The simulation results of the power plants for this region are shown in Figure 8. It is observed that complementarities of the sources is very significant. The potential complementarity of the SHPP Salto Morais is 39.7% and for the HPP São Simão is 100%.
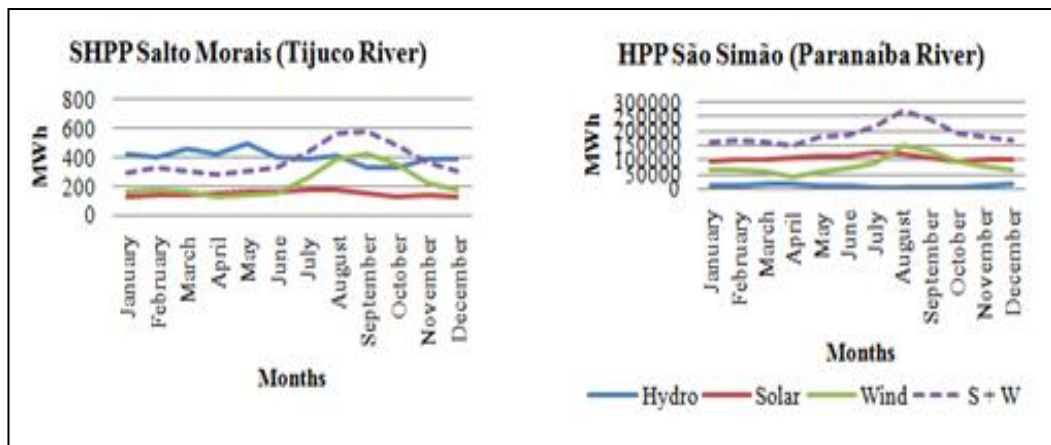
Figure 8: Results for complementarities projects of the Triangulo Mineiro Region. (Self, 2014)

The Alto Parnaíba Region is the second least populated region of Minas Gerais and has in Patos de Minas, your municipality polo. The region accounts for 4.0% of GDP, 3.0% of formal employment and 6.1% of exports from the state. The simulation results of the power plants for this region are shown in Figure 9. It is

observed that complementarities of sources is significant. The potential complementarity of SHPP Pai Joaquim is 48.3%.
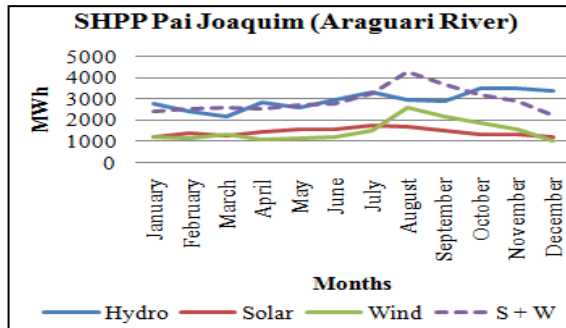

Figure 9: Results for complementarities projects of the Alto Paranaíba Region. (Self, 2014)

The Midwest Region is responsible for 4.5% of GDP, 2.1% of exports and 6.1% of formal employment and income generation its concentrated in the service sector. Divinópolis is considered the polo city. The simulation results of the power plants for this region are shown in Figure 10. There is a slight complementarity to SHPP Anil and considerable complementarity to SHPP Oliveira. The potential complementarity of SHPP Anil is 1% and the SHPP Oliveira is 64.9%.
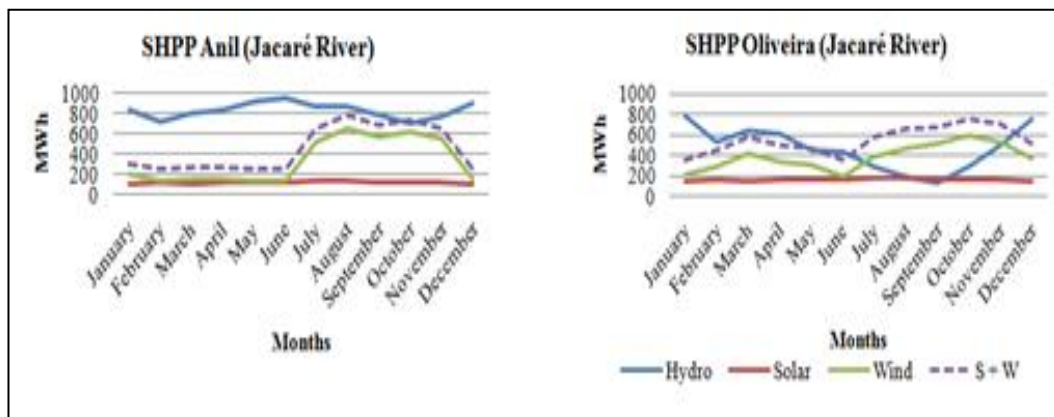

Figure 10: Results for complementarities projects of the Midwest Region. (Self, 2014)

The North Region of Minas Gerais is responsible for 4.0% of GDP, 2.4% of exports and 3.6% of formal employment; income generation its concentrated in the service sector. The city of Montes Claros is the polo of the region. The simulation results of the power plants for this region are shown in Figure 11. There is a slight complementarity to SHPP Machado Mineiro and Santa Marta, and considerable complementarity to SHPP Pandeiros. The potential complementarity of SHPP

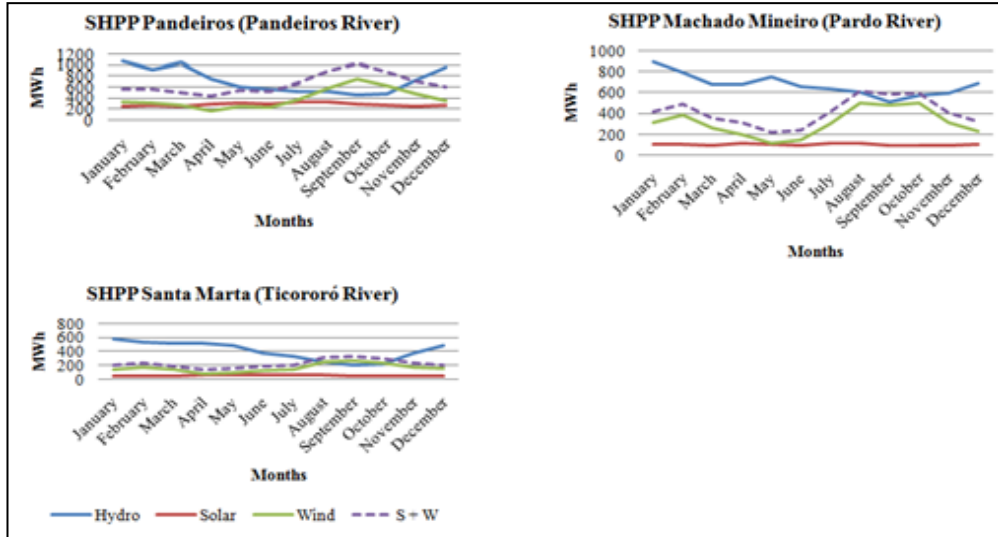Machado Mineiro is 2.6%, the SHPP Pandeiros is 41.7% and the SHPP Santa Marta is 11.4%.

Figure 11: Results for complementarities projects the North Region. (Self, 2014)

The Rio Doce Region accounts for 6.3% of the GDP of Minas Gerais, whose sectoral distribution reveals the predominance of services. About 80% of the regional population lives in urban areas, with emphasis on the cities of Governador Valadares and Caratinga hubs of the region. The simulation results of the power plants for this region are shown in Figure 12. There is a considerable complementarity to SHPP Poquim. The potential complementarity of HPP Aimorés is 2.5%, the HPP Mascarenhas is 3.9%, the SHPP Paiol is 17.4% and the SHPP Poquim is 35.2%.
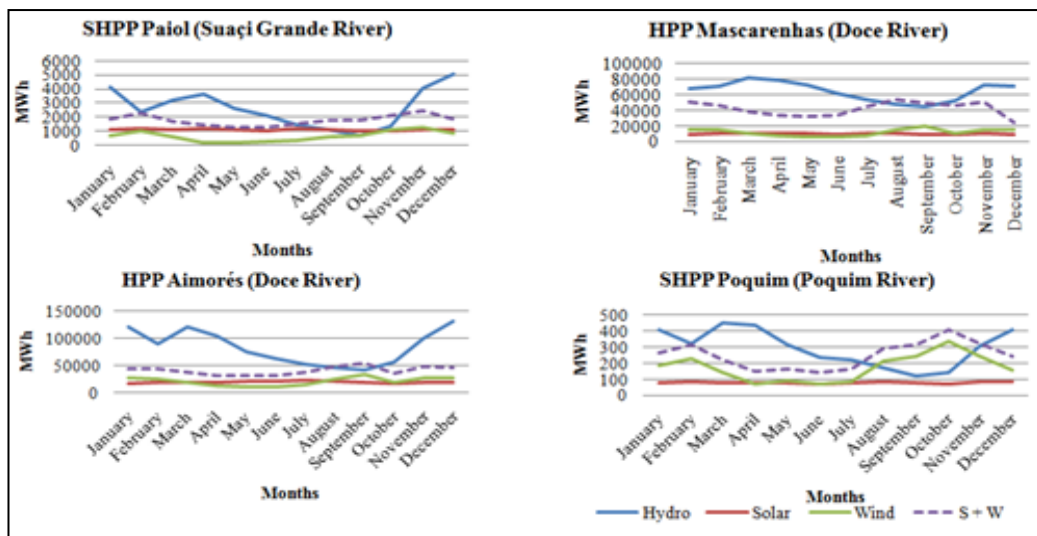

Figure 12: Results for complementarities projects of the Rio Doce Region. (Self, 2014)

5 – CONCLUSION

The restrictions imposed to build new large reservoirs due to major environmental impacts, have been gradually reducing the ability to give adequate power generation pattern along the year. Since most of the major reservoirs are located in the State of Minas Gerais, there is a great challenge for the state in order to provide supplementary generation during the dry season. The most effective way of complementing generation is with the insertion in the energy matrix of other seasonal sources of generation such as wind and solar. Notice that wind power has proven to be extremely competitive with conventional sources of electricity generation in Brazil, as demonstrated in recent energy auctions.

This study presented an analysis by planning regions of the state of Minas Gerais, aiming at contributing to public policies for sustainable development. The results show that only for few hydroelectric plants there is significant complementarities in hydro, wind and solar sources. In the case of wind power, further studies most be conducted, order to obtain better data at 20 meters, which could lead to other results. In the case of solar power, there was no significant complementarity, but the increase in energy production in the venture. In both cases this result is striking, given that all hydroelectric plants have few shares increased power of plants. Join the initial project construction of photovoltaic solar plants and wind power plants could generate a potential increase in energy without inferring large environmental impacts and enjoy the surrounding areas.

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