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STUDY OF THE ENERGY MATRIX OF MINAS GERAIS CONSIDERING THE CONTRIBUTION OF NUCLEAR POWER PLANTS

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ABSTRACT

The integrated energy planning is a very important tool for long-term study, projections and reviews of the energy mix of a country or region. By dealing with energy supply and demand projections is therefore related to the needs of society and its development indice within a context of sustainability. The aim of this study is to provide information about the Minas Gerais electric matrix and propose solutions for the need of future energy import. In this way, it is proposed a possible deployment of nuclear power plants, in parallel with wind and solar energy, for the necessary energy expansion in the face of population growth framework and energy use in Minas Gerais. Thus, the study tends to contribute to decision-making related to public policies.

1. INTRODUCTION

The integrated energy planning is a very important tool for the long-term study of energy supply and demand, preparation of projections and assessment of the energy mix of a country or region and contributes to decision making. Therefore, knowledge of the state energy availability is indispensable for energy supply planning stage, when it will seek to equate the service of energy demand with solutions that minimize costs and maximize social and economic benefits to Minas Gerais. Decisions bring impacts to all agents and influence the future of the systems. These decisions, in most cases, are taken before a climate of uncertainty and need systematic processes for decision support, especially on the future prospects.

With the predominance of hydropower in Brazil, obtaining a steady energy supply along the seasons has been a historic challenge to planning decisions of the power sector operation due to the seasonal fluctuations of significant amplitude of the hydroeletric power. In the state of Minas Gerais, particularly, the production of electricity is predominantly derived from hydropower stations. 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 [1].

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The state of Minas Gerais was divided according to the Development of Territories determined by the current state government. There are 853 municipalities divided into 17 territories, defined from socio-economic and geographical criteria, shown in Fig. 1 [2]. The state's division into territories is fundamental for assessing implementation of energy parks of any kind.

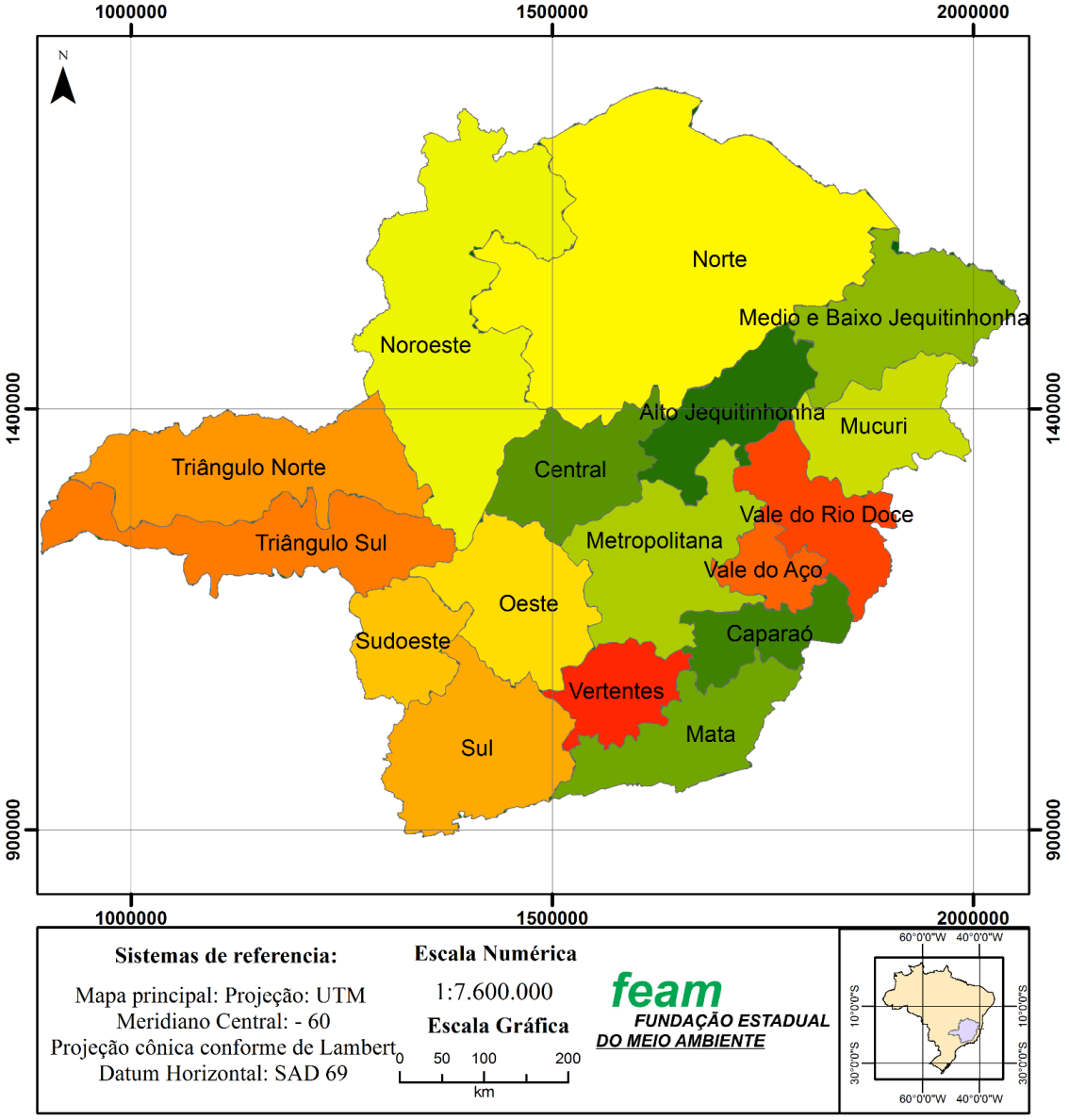

Figure 1: Map of the State of Minas Gerais: Territories of Development [2].

2. URANIUM RESERVES IN BRAZIL

With the policy started with the privatization process of the 1980s and settled with several Constitutional amendments, the economic benefits arising from activities and products related to nuclear energy, in which Brazil could stand out, cancel almost completely. In this way, Brazil is in a peripheral place and no relief in relation to the

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international stage when it comes to a great strategic advantage of opportunity, both in relation to its energy mix, as the export of technology and nuclear material [3].

Brazil has large uranium reserves which allow the supply domestic needs in the long term and the availability of surplus to the foreign market. According to the INB (Nuclear Industries of Brazil), Brazil has the seventh largest uranium geological reserve in the world with about 309,000 t of U_3O_8 in the states of Bahia, Ceará, Paraná and Minas Gerais (Fig. 2), among other occurrences, since only 25% of the territory was prospected [4].

Figure 2: Installations and Deposits of Uranium in Brazil.
Source: adapted from [4]

The nuclear fuel demand whole manufacturing cycle comprising complex industrial process. Today, Brazil dominates the technology of the fuel cycle, including the isotopic enrichment of uranium. This phase is the main in economic terms; it demands the majority of investments in the nuclear fuel cycle and is especially important in political and strategic terms [5].

3. GENERAL MINAS GERAIS ENERGY MATRIX

The State of Minas Gerais has a large hydro potential in their 586,000 km^2. Thus, about 90% of the electricity produced in Minas Gerais is hydroelectric and the rest is thermal origin generated in power plants of fuel oil, natural gas and cogeneration plants.

In the Fig. 3 is shown the flow of electrical power from primary source to final consumption in 2012. It is observed that the hydroelectric plants accounted for 96.5% of the electricity generated with the remainder generated by thermal plants. In addition,

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it was necessary to import 1.783 million tep (the conversion of electricity in toe was taken by physical equivalent of 0.086 tep / MWh) [6].

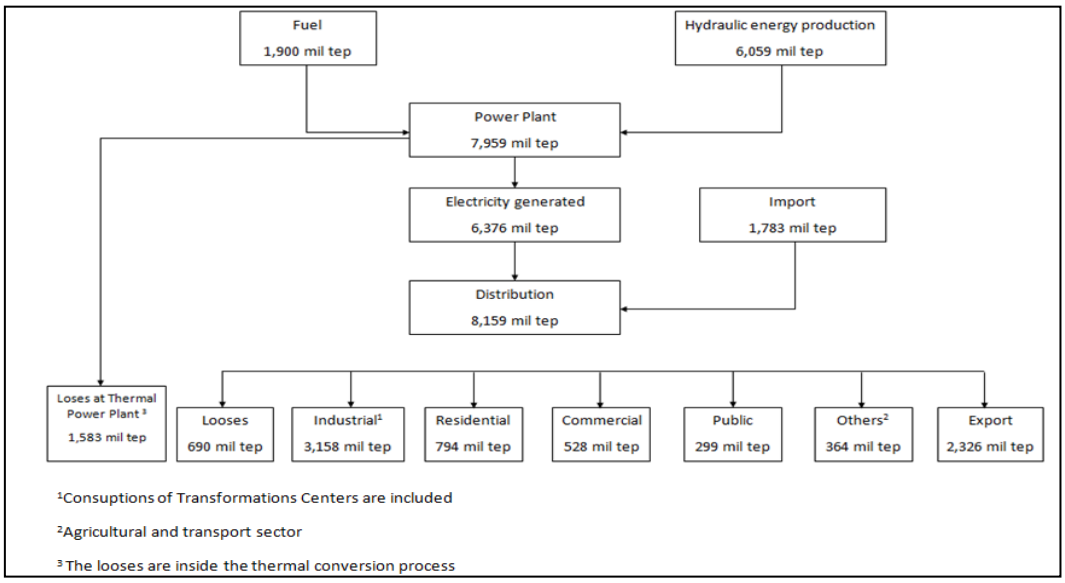

Figure 3: Flow of electrical power of hydro and thermal for the State of Minas Gerais in 2012. Source: adapted from [6].

According to Fig. 4, the industrial sector had the highest state of energy demand, 23.589 million tep, which represented 62.9% of the total, an increase of 2.4% compared to 2011. About the total demand by industries, 29.3% came from wood and derivatives, 20.0% of oil, oil products and natural gas, 18.3% of the coal and derivatives, 16.9% derived from sugarcane, 12.4% from hydro source and 2.8% from other sources. Firewood, coal and derivatives together represented 47.7% of total demand of the industrial sector. This is due mainly to the representation of steel in the mining scenario, major consumers of charcoal and coal coke [6].

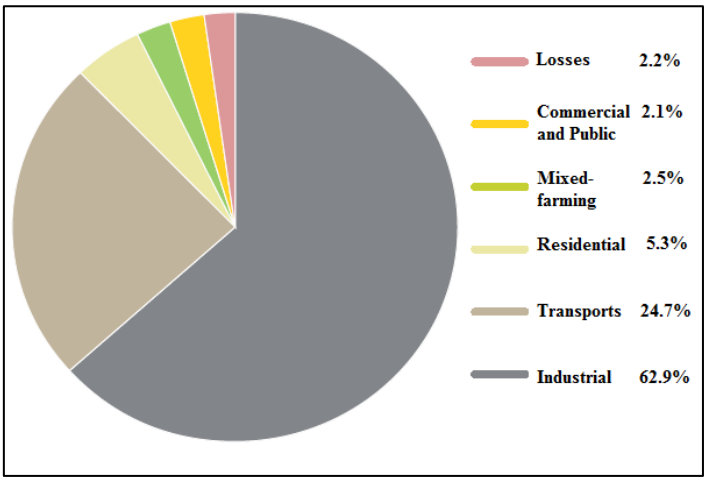

Figure 4: Energy demand in Minas Gerais in 2012.
Source: adapted from [6].

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Figure 5 shows the evolution of supply and consumption of electricity in Minas Gerais until the year 2012 highlighting the great demand in the industrial sector.

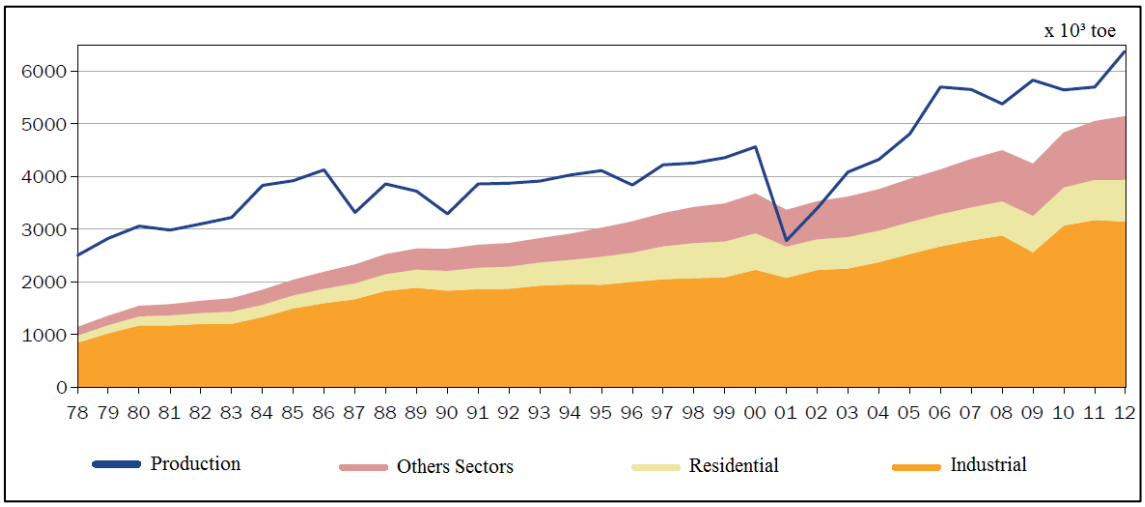

Figure 5: Trends in supply and consumption of electricity in MG.
Source: adapted from [6].

In Minas Gerais were built large reservoirs capable of storing water in the wet season, which are converted into electrical energy in the dry season, maintaining a settlement in the effluent flow. In recent years, there is a tendency that the regulating capacity of the reservoirs will become increasingly restricted because the load will increase, but the volume of the tanks measured by the energy stored, will not.

The Brazilian electricity system and, included in it, is that of Minas Gerais, is quickly changing from a hydroelectric base, with thermal generation facilities operating as a reservation as backup, to a hydrothermal system where the thermal park will have to dispatch the base. In this sense, plants with low variable costs have higher economic value [7].

In a study conducted by a joint team from the Energy Planning Program of COPPE / UFRJ (PPE) and the Federal University of Itajubá (UNIFEI) on Energy Matrix of Minas Gerais from 2007 to 2030 [8] were considered two energy demand scenarios disaggregated by sector for the state of Minas Gerais:

- A scenario, called Reference, maintaining development momentum of the energy consumption sectors without major structural changes in energy use, observing trend movements unless the occurrence of structural changes already under way;
- Another scenario, called Alternative, which opens space for the promotion of more efficient practices in the use of energy, gradual evolution of the industrial park for the production of higher added value items, improving the general living conditions of the population, use of technology cleaner, etc.

In the period 2025-2030, the demand increase is almost entirely met by imports, with little increase in power generation within the state. According to the Reference scenario, "Minas Gerais becomes from net exporter to a net importer of electricity in the end of

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the review period, importing about 17% of electricity consumed," as shown in Tab. 1 [8].

Table 1: Demand and generation of electricity in Minas Gerais - Reference Scenario [8]

	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030
Demand	3.7%	3.8%	4.1%	4.3%	4.5%
Generation MG	3.7%	3.8%	4.1%	4.3%	0.7%
Dependence (Liquid Import /Demand	-	-	-	0.06%	17.1%

In the Alternative Scenario is shown that the demand for electricity in Minas Gerais grows at an annual average rate of 3.81%, while the generation grows 3.43%. In this way, the state arrives in 2030 also as a net importer electricity, with 8.7% of its demand met by imports, as shown in Table 2.

These numbers are little bigger than the reference scenario due to higher installed capacity of bagasse generation. And according to the study, this ability makes up for the lower generation and fuel oil to natural gas, as well as reduces the need for electricity import from other states. Another factor that occurs in this scenario is the exhaustion of the hydroelectric potential in the state, which follows the same trend of the previous scenario with characteristic evolution a little different.

Table 2: Demand and generation of electricity in Minas Gerais - Alternative Scenario [8]

	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030
Demand	3.4%	3.7%	3.8%	3.9%	4.2%
Generation MG	3.4%	3.7%	3.8%	3.9%	2.3%
Dependence (Liquid Import /Demand	-	-	-	-	8.7%

Analyzing the data obtained in this study about electricity demand and generation in the state of Minas Gerais in the period 2025-2030, it is noted that in both scenarios there will be need for energy imports from other states to meet the internal demand. Based on the energy matrix of the data of Minas Gerais, in 2030 there will be a shortfall of about 14.14 million MWh of electricity, equivalent to 11% of the total demand of the state.

3.1. Analysis of Alternative Energy Sources

The Energy Matrix of Minas Gerais from 2007 to 2030 defines the need to rethink energy use in the Minas Gerais economy, reduce external dependence, evaluate new technologies for energy efficiency and add greater value to the industry with the

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implementation of an energy planning and by environmental territories. To meet this need to avoid future import of electricity it is necessary to analyze alternative energy sources.

In the case of wind and solar energy, the Territory of the Northern, the Northwest and Jequitinhonha of Minas Gerais present great technical viability and ensure social and economic development associated due to lack of investment in these territories, but for this to happen it is necessary that the federal and Minas Gerais governments present subsidies for the sector [1].

Today, these subsidies are insignificant when compared to subsidizing fossil fuels. There is also the problem of these sources are intermittent not ensuring constant energy. To better meet the electricity demand the plants should have a hybrid environment.

4. PROPOSAL FOR INCLUSION OF NUCLEAR ENERGY IN MINAS GERAIS MATRIX

Various factors have placed the nuclear option in discussion in the world, mainly due to the obvious increase in global energy consumption and the environmental need to reduce greenhouse gas emissions. The experience gained from past accidents, technological advances relating to the safety, life extension of nuclear projects and treatment of fuel spent reinforce the nuclear option as a concrete alternative. Moreover, a nuclear power plant can produce energy with high capacity factor.

It is worth mentioning the possibility of deployment of nuclear energy in Minas Gerais. Nuclear power stations need access to cooling water. Thus, as the location for siting of nuclear power plants in Minas Gerais, the highlight is the region of the São Francisco River, being the third largest river basin in Brazil and because the Northern Territory of Minas Gerais (Fig. 1) is a poor region of socioeconomic development.

Eletronuclear has proposed building two new nuclear plants in the northeast and two more near Angra in the southeast. At the end of 2009, it commenced initial siting studies. Early in 2013 two sites were under final appraisal: one in the northeast on a large dam on the Sao Francisco River between Pernambuco and Bahia states for up to 6600 MWe, and one in the north of Minas Gerais state in the southeast of the country, for 4000-6000 MWe. Each of the eight units planned by Electronuclear will need approval by the National Congress; therefore a lot of careful groundwork with communities is being undertaken before any announcement [2].

Table 3: Brazilian power reactors under construction and proposed [9]

Reactor	Model	Gross capacity - Mwe	Comercial operation
Northeast, Pernambuco	PWRx4	6,000-6,600	2020s
Southeast, Minas Gerais	PWRx4	4,000-6,000	2020s

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The Figure 7 shows a merely illustrative of how it could be a facility with installed capacity of 6,600 GW and annual output of 50.52 million MWh which could supply totally the future deficit (14.14 million MWh). This is a site proposed by Eletronuclear in the Brazil northeastern Brazil, but that could be adapted to the Northern Territory of Minas Gerais [9].

Such a project can bring big local benefits, assisting in increased employment and local income, tax revenues, and strengthening of this municipality as a reference for development in this Territory. As the value necessary to prevent the import of electricity is high, an integrated energy planning is needed to assess the development situation of these territories within an environmental and social context. The consideration of energy plants with electricity generation by means of the three sources, namely wind, solar and nuclear supply could meet demand and contribute significantly to the development of the mentioned territories.

Figure 7: Simulation of a Nuclear Power Plant in the São Francisco River.
Source: adapted from [9].

According to Eletronuclear calculations in 2012 [9], the total investment in a nuclear park like this would be around R$ 42 billion. The annual gross income would be approximately R$ 7.2 billion; the total annual cost would be $3.1 billion and the profit margin would then be R$ 4.1 billion, including investment of time around 17 years [9].

While there is the need for a long debate for decision making, it is essential to consider the nuclear generation as an alternative to a long-term perspective. After all, objective questions such as the size of the world's uranium reserves and the relative stability of the price of the mineral, sustain the interest in this form of energy.

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The stages of nuclear development involve [9]:

- Selection of the site and technology;
- Planning for licensing;
- Forming of the capital structure;
- Project for funding;
- Execution of project.

4.1. Possible Impacts

The possible impacts of the installation of nuclear power plants, as well as any other complex for power generation, should be carefully considered. The items listed below were based on a document prepared by the Department of Energy and Climate Change from United Kingdom, entitled National Policy Statement for Nuclear Power Generation for the installation of new nuclear plants in the UK [10].

In general, it is possible to highlight:

- **Flood risk** - Nuclear power stations need access to cooling water, that is, nuclear power stations are most likely to be developed on coastal or estuarine sites. Without appropriate mitigation measures the potential effects of climate change make these sites at greater risk of flooding than if they were located inland. The significance of the effects will depend on the detailed design and site characteristics of the proposed new nuclear power station. Therefore, the site must be protected from the risks of flooding over their operational lifetime. This could result in positive effects, since the measures taken to mitigate the risk of flooding at a new nuclear power station may also protect existing developments in the area.
- **Water quality and resources** - Potential adverse effects on water resources including effects on riverside processes, hydrodynamics and sediment transport must be considered. Adverse effects could occur through increased demand, particularly during construction. Indirect effects include thermal impact of cooling water discharges. This is directly connected with a set out policy in respect of biodiversity and geological conservation. The significance of these effects depends on the location of the site, proximity to water bodies and the existing water surplus/deficit status within the region.
- **Change in the riverside** - This will include identifying impacts on the processes on the banks of the river, intertidal deposition and soil development processes that maintain terrestrial and aquatic habitats.
- **Landscape and visual impacts** - The nuclear sites are generally in less populated areas that may have value for visual amenity and as landscape resources; they are coastal/river sites; and the scale of the facilities means that the scope for visual mitigation is quite limited. Probably the main visual impact on the landscape is due to the cooling towers.
- **Socio-economic** - The construction, operation and decommissioning of energy infrastructure may have socio-economic impacts. It is noted that nuclear power stations involve large scale construction projects at the beginning of their life. In general, the effects are positive and significant from the local economic point of view and less significant at the regional scale except where there are clusters of potentially suitable sites for new nuclear power stations.

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- **Human health and well-being** - The operation of a new nuclear power station is not associated with significant noise, vibration or air quality impacts. These effects could be significant only during activities of construction. Radiation from nuclear power stations requires careful management during and beyond the operational life of the power station. However, safety systems in place in the designs of new nuclear power stations and compliance with a strong legislative and regulatory regime decrease the risk of radiological health detriment posed by nuclear power stations. In common with other major industrial processes, the construction, operation and decommissioning of new nuclear power stations could affect health care provision. For example, the facility could increase demand on health monitoring services.

Currently, the availability of new reactors, said Generation III +, especially the AP1000 by Westinghouse, the ESBWR (Economic Simplified Boiling Water Reactor) by GE-Hitachi, the EPR (European Pressurized Water) by Areva, has facilitated the construction of nuclear plants. These new generations of reactors must use fuel with higher enrichment, seeking the sustainability of nuclear generation: greater operational life and generate less waste, which will tend to reduce the required amount of mineral. In addition, new technologies, combined with the experience of many years, have passive safety systems and simplification of reactors in terms of quantity of components to allow greater security.

5. CONCLUSIONS

This study presented an overview on the energy situation in the State of Minas Gerais in the long term, based on multiple data sources. Studies concerning the data of Energy Matrix of Minas Gerais demonstrate the possibility, for about 2030, to occurr a deficit of approximately 14.14 million MWh of electricity, equivalent to 11% of the total state demand. To address the need to avoid future import of electricity in the state of Minas Gerais, alternative energy sources for electricity generation will be required. In the case of wind and solar energy, the Northern Territory, Northwest and Jequitinhonha present great technical feasibility and can provide an associated social and economic development, unlike the current situation of lack of investment in these territories. But it is necessary that the federal government and the government of Minas Gerais present subsidies for the sector. Today, these subsidies are insignificant when compared to subsidizing fossil fuels. There is also the problem of these sources are intermittent not ensuring firm energy. To better meet the electricity demand it is necessary to consider a hybrid energy park.

The installation of a complex of nuclear power plants in the Northern Territory generating 50.52 million MWh could help increase employment and local income tax revenues, and strengthening the development in this Territory.

As the value necessary to prevent the import of electricity is high, an integrated energy planning is necessary to assess the situation of the State Development Territories within an environmental and social context. The creation of plants with electricity generation by means of the three sources, namely wind, solar and nuclear supply could meet

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demand and contribute to the development of Minas Gerais territories, particularly the territories of the North, Northwest and Jequitinhonha. However, a more detailed study on the impacts of these sources and well defined public policies are needed.

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