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Challenges, opportunities, and evolution of transition towards more sustainable energy systems in Mato Grosso State, Brazil

Electrical energy is crucial to socioeconomic growth, since it can serve the population for a variety of purposes. Due to territorial size and distribution issues, the initial energy production methods in Mato Grosso State, Brazil, were significantly critical. However, the availability of water has encouraged the development of hydroelectric projects. On the other hand, socio-environmental issues brought on by those activities have resulted in conflicts. This paper addresses a bibliographic survey on Mato Grosso's energy matrix and discusses the main challenges, opportunities, and evolutions of electricity, which are built on a foundation of the state's history and information available and gathered from state and federal agencies. Tables and graphs characterize values and expressive data of the state's energy matrix potential, identifying the hydric matrix as the primary source of power generation and the other sources as secondary ones. The state has shown a significant potential for energy production, although issues and constraints regarding distribution incentives towards renewable sources must be increased and complement energy generation at lower costs and impacts.

Keywords: Energy matrix; Mato Grosso State; Renewable sources.

Desafios, oportunidades e evolução da transição para sistemas energéticos mais sustentáveis no estado do Mato Grosso, Brasil

A energia elétrica é crucial para o crescimento socioeconômico, pois pode atender à população para várias finalidades. Devido ao tamanho territorial e problemas de distribuição, os métodos iniciais de produção de energia no estado de Mato Grosso, Brasil, eram significativamente críticos. No entanto, a disponibilidade de água tem incentivado o desenvolvimento de projetos hidrelétricos. Por outro lado, questões socioambientais decorrentes dessas atividades resultaram em conflitos. Este artigo aborda um levantamento bibliográfico sobre a matriz energética de Mato Grosso e discute os principais desafios, oportunidades e evoluções da eletricidade, que se baseiam na história do estado e nas informações disponíveis e coletadas de agências estaduais e federais. Tabelas e gráficos caracterizam valores e dados expressivos do potencial da matriz energética do estado, identificando a matriz hídrica como a principal fonte de geração de energia e as outras fontes como secundárias. O estado tem mostrado um potencial significativo para a produção de energia, embora questões e restrições relacionadas a incentivos para fontes renováveis devam ser aumentadas e complementar a geração de energia com custos e impactos mais baixos.

Palavras-chaves: Matriz energética; Mato Grosso; Fontes renováveis de energia.

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INTRODUCTION

Since the shift from agrarian subsistence to contemporary industrial society, a reliable and economical energy supply has been essential for economic development. Energy is fundamental for industrial and commercial prosperity, as well as for enhancing social and economic well-being, since raised living standards, reductions in poverty, and improved human wellbeing depend on it. The current production and consumption of energy are reliant on finite resources and viewed as environmentally unsustainable. However, no technique for the production or conversion of energy is risk- or waste-free. Some pollution is privately or publicly produced throughout the energy chain, from resource intake to the provision of energy services, frequently exerting negative effects on human health and the environment. Despite a technology under use not producing hazardous emissions, it may produce emissions and waste at later stages of its life cycle (IAEA, 2005).

Hydraulic energy, which currently accounts for approximately 65% of the nation's total energy production, has made Brazil one of the world's most renewable resource energy-producing nations, i.e., the third-largest global hydraulic potential, which results from its physical and geographic location and water resource availability (ANEEL, 2023). On the other hand, Mato Grosso state differs from the other Brazilian states due to its location within the Amazon, Tocantins-Araguaia, and Paraguay hydrographic basins. Since its electric matrix is dependent on renewable sources - primarily hydraulic energy - it displays a unique scenario in terms of power installed capacity.

A current construction of new hydraulic plants is challenging due to great social and environmental challenges. According to Cavaliero et al. (2005), one of the benefits of using renewable energy sources for the environment is the possible decrease in greenhouse gas emissions, particularly carbon dioxide (CO2) emissions. The contribution to the decentralized power generation is driven by the substantial increase in demands for electricity use. Some challenges are associated with a satisfactory supply through the construction of large hydraulic plants.

Mato Grosso state despite having an exceptional climate potential, characterized by high temperatures practically throughout the year, the state still depends mostly on hydraulic energy to meet its energy needs. This apparent contradiction between a favourable environment for solar photovoltaic energy generation and the current predominant energy sources deserves a deeper analysis and the formulation of a hypothesis to understand the underlying reasons for this reality. In this context, we can conjecture that the lack of diversification in Mato Grosso's energy matrix may be related to a series of factors, such as political, economic, and technical issues.

This hypothesis raises important questions about the state's energy policies and the need to explore energy sources that are more compatible with its climate environment abundant in sunlight.

Therefore, alternative sources of renewable energy must be considered so that those demands can be satisfied. This paper reports on a bibliographic survey on the energy matrix in the state, considering its main alternatives and the main difficulties for its obtaining.

METHODOLOGY

The qualitative research conducted was based on a survey into the literature, the development of power plants, and their history. Hydropower, solar photovoltaic energy, and some types of biomasses, such as sugarcane bagasse, rice rusks, and others in Mato Grosso state were considered renewable alternative energy sources for the purposes of this research. Data were chosen and acquired through access portals made available by government organizations at federal and state levels, as well as from articles, dissertations, and theses, among other sources.

Study area

Mato Grosso state, whose total area is 903,357,908 km², is located in the Midwest of Brazil, between the latitudes of 06°00 S and 19°45 S and 50°06 W and 62°45 W. Its 33,112,897 ha make it the third-largest federative entity in Brazil, comprising 56.23% of the Midwestern Region and 10.61% of the total country. In 2021, 3,567,234 people were estimated to be living in the state, whose population density is 3.36 people per km².

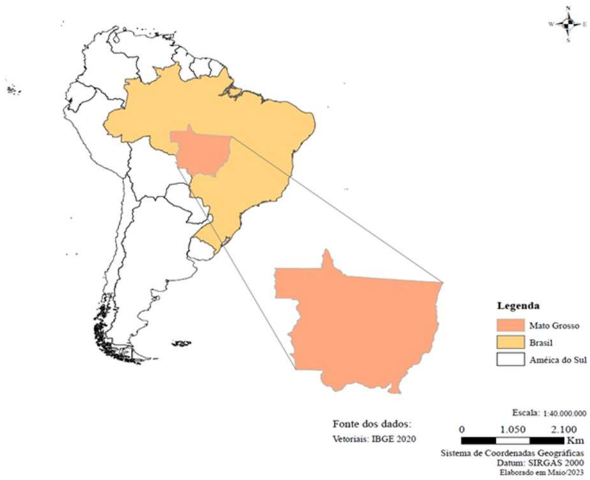

Figure 1: Location of Mato Grosso State, Brazil.

A short history of intervention in Mato Grosso's electric sector

Although steam was the first and only choice for power generation in the late 19th and early 20th centuries, the potential of Mato Grosso's hydraulic matrix was significant. As a result, its capital Cuiabá and some institutions were provided with energy and a system for collecting water from the Cuiabá River and distributing it to reservoirs in the city and in Porto district. "Hidráulica do Porto" (Port Hydraulic) was the energy source created when firewood was burned to producing steam (CEMAT, 2011).

At the beginning of the 20th century, the possibility of generating electricity through hydroelectric plants emerged. However, it was hampered by difficulties for importing the necessary equipment from Europe because of World War I, which lasted from 1914 to 1918 (CEMAT, 2011).

Both production and distribution of energy services are still inefficient. The first hydroelectric plant in the state, located in the Casca River in Chapada dos Guimarães municipality, with 900KW capacity, was built in June 1926. The project took approximately two years and a large amount of money, although it was later eclipsed by the construction of more substantial hydroelectric plants in the state (MONTI, 2014). However, the size of the building cannot be overlooked given the constraints and knowledge available at the time. The facility, formerly known as Casca I, opened in 1928, was decommissioned in 2005, and recognized by the state as a historical and cultural public heritage property in 2009 (CEMAT, 1983).

3.5 KW Casca II hydropower plant was installed between 1954 and 1958. Centrais Elétricas Mato-Grossenses S.A. - CEMAT was established in the same year for the development of studies and projects, construction and operation of power plants, transmission lines, and electricity distribution, as well as for engagement in business activities associated with those operations (MONTI, 2014). Casca III Hydroelectric Plant, with a 12,420 MW capacity, was inaugurated in 1971.

The amount of energy produced was still minimal. Isolated micro hydroelectric facilities continued to provide power to Mato Grosso's rural districts and were gradually shut down at the beginning of the 1960s. Therefore, the Brazilian National Interconnected Electric System (SIN), characterized by the implementation of transmission lines and new, more contemporary hydroelectric plants, should gradually be connected to the state's regions, according to the electric sector's policy (MONTI, 2014).

Until the end of the 1970s, a large portion of the state underwent a protracted transformation. The demands of towns such as Juara, Corumbá, Sinop, Colder, and Poconé were met during this phase through the establishment and management of many thermal plants powered by diesel engines by CEMAT (MONTI, 2014).

According to Paes et al. (2011), a severe flood occurred in the Cuiabá River watershed in 1974, resulting in significant property damage and casualties in the cities of Cuiabá and Várzea Grande. Basic research for the construction of three upstream reservoirs close to Cuiabá was accelerated and flood control was the primary goal, followed by electricity production.

Small Hydroelectric Plants (SHP) were built across the state in the 1980s and 1990s. The construction of Braço Norte Hydroelectric Plant (HPP), which would serve the Colder region, started in 1984. HPP Coluene, in Paranatinga area, had a 1240 KW capacity and Itamaraty Group's Juba I and Juba II plants were constructed in the early 1990s for meeting the energy demands of the company and selling extra energy to CEMAT to be distributed to Quatro Marcos and Tangará da Serra districts. Aripuan Hydroelectric Plant, with a 5400 KW capacity, was built in Juna, in the Aripuan River (MONTI, 2014; MARTINE, 1994).

In 2000, ELETROBRAS built Manso Hydroelectric Plant (HPP), with a 210 MW capacity on the primary tributary of the Manso River, on the Cuiabá River. It was the first sizable hydroelectric plant created for the Multiple Use of Manso (APM-Manso) and produced energy while regulating floods and droughts in the downstream (SIQUEIRA et al., 2014; PROMAN, 2023). After a ten-year hiatus, the project was resumed in 1997.

A large raise in electricity consumption was caused by the region's growing agriculture between 2000 and 2017, which stimulated the development of additional hydroelectric projects. The 1820 MW Teles Pires Hydroelectric Power Plant was officially opened in 2011, in the Teles Pires River, between the states of Mato Grosso and Pará. One of the biggest hydroelectric facilities in Brazil, it provides electricity to almost 2.7 million homes.

Potential sources for electricity generation in Mato Grosso State

According to Energy Research Company - EPE (2022), Brazil stands out historically due to its high percentage of renewable energy sources in comparison to the other countries. Over the past 20 years, the share of Brazilian renewable energies has remained above 40%.

Mato Grosso state has been strategically positioned regarding the evolution of energy production, particularly in hydropower generation, due to the availability of large hydrographic basins such as the rivers of Amazon, Paraguay, and Tocantins-Araguaia. Consequently, both energy supply and generation of energy from the hydraulic potential created by the existing water matrix have rapidly expanded.

The implementation of new technologies can potentially contribute to the security of the nation's energy supply (Federal University of Mato Grosso - UFMT - Interdisciplinary Center for Studies in Energy Planning - NIEPE, 2019).

According to ANEEL (2023), Mato Grosso state is distinguished by its production of primary energy from renewable sources (Figure 2). The energy matrix shows that hydroelectric generation accounts for 74.00%, fossil fuel generation accounts for 13.91%, and natural gas accounts for 12.84% of the total. Additionally, 11.61% of the matrix are composed of biomass. while the market share of wood fuel has dropped to 3.39% (Table 1).

Nine sugarcane mills have used sugarcane bagasse to generate power, which has also been employed for the generation of electricity in nine sugar and alcohol plants. The total power granted is 200.928 kW, corresponding to 4.87% of the total installed capacity of electricity produced (Table 1).

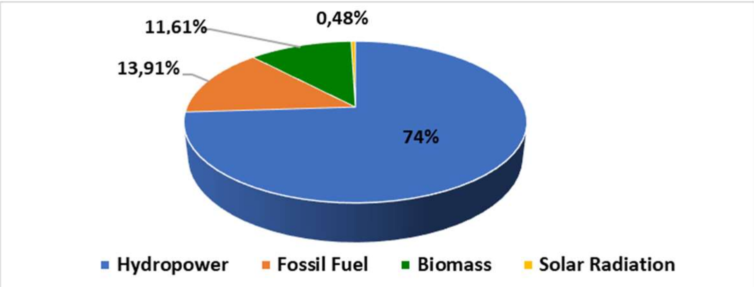

Figure 2: Percentage of the energy matrix of Mato Grosso State. **Source:** ANEEL (2023).

Table 1 shows the evolution of the installed capacity of photovoltaic generation, indicating high growth with 315 projects installed (domestic and commercial) and representing 0.48% of energy in the state.

Table 1: Energy Matrix of Fuel Sources.

Source	Type	Fuel	Amount	Power Granted (kW)	% Power Granted
Hydro	Hydropower	Hydropower	141	3.050.293,75	74,00%
Fossil Fuel	Natural Gas	Natural Gas	1	529.200,00	12,84%
Fossil Fuel	Oil	Diesel Oil	49	44.229,00	1,07%
Biomass	Agricultural Crop	Sugarcane Bagasse	9	200.928,00	4,87%
Biomass	Forest	Firewood	4	139.535,00	3,38%
Biomass	Forest	Wood Waste	10	133.975,00	3,25%
Biomass	Animal Residues	Biogas - AR	3	3.260,00	0,08%
Biomass	Agricultural Crop	Rice Rusks	1	1.200,00	0,03%

Solar	Solar Radiation	Solar Radiation	315	19.608,95	0,48%
Total			**533**	**4.122.229,70**	**100,00%**

Source: ANEEL (2023).

Alternative sources for electricity generation in Mato Grosso State

Investments in the development of alternative and renewable energy sources must be made so that the energy demands can be met. Mato Grosso state, one of the top agricultural producers, underutilizes the inputs used in the production of alcohol and sugar, resulting in an approximately 2,584 GWh annual energy waste (ANEEL, 2023).

Biomass is classified as a clean and renewable energy source, showing a good alternative for diversifying the energy matrix. Its use is advantageous due to direct combustion and minimal socio-environmental impacts; however, it achieves low efficiency. When used for energetic purposes, it is categorized into three groups, namely floral, agricultural, and reject urban areas, whereas the one used for agricultural purposes includes agroenergetic cultures and waste products and byproducts from agricultural, agroindustrial, and animal production activities. The energy potential of each of such groups depends on both the raw material used and the processing technology adopted for its obtaining (World Energy Council – WEC, 2005).

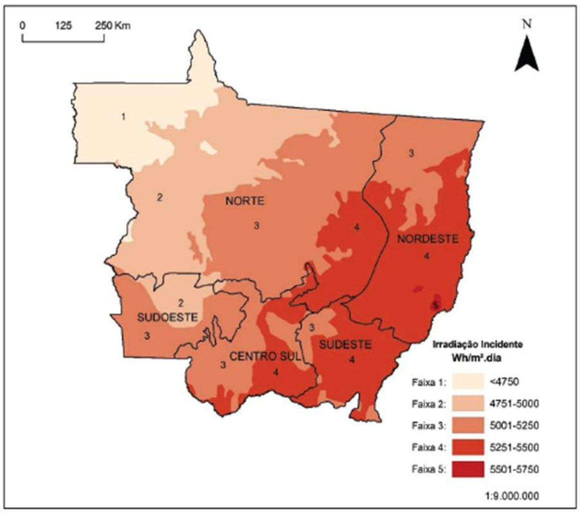

Figure 2: Average inclined solar irradiation intensity displaced by mesoregion in Mato Grosso state.
Source: NIEPE – UFMT (Interdisciplinary Center for Energy Planning Studies at the Federal University of Mato Grosso) in 2019.

According to Table 1, the electrical energy derived from sugar cane biomass is distributed through five sub-alcohol manufacturing facilities, of which three are located in the Southeastern region and produce alcohol and sugar towards meeting its demand for electricity through complementary production. The entire installed power is 200,928 kW, i.e., 4,87% of the total installed capacity of the state's electricity generation (ANEEL, 2023).

Mato Grosso has a hot climate throughout the year, characterized by high temperatures and mainly bright skies, according to NIEPE - UFMT (Interdisciplinary Center for Energy Planning Studies at the Federal University of Mato Grosso), in 2019. The state shows potential for the development of photovoltaic solar energy, despite not being located in the region of Brazil that receives most sun radiation. Although the state has abundant water resources, the search for alternative energy sources has been driven by the rising energy needs of humanity. Both area capacity and climatic factors clearly make it appropriate for the use of photovoltaic energy (Figure 2).

RESULTS

The current generation of renewable energy in Mato Grosso is responsible for approximately 80% of the total potential granted in the state and the three main matrices of generation are hydraulics, biomass, and solar.

According to Dias et al. (2018), since future hydroelectric plants are expected to follow run-of-river designs as environmental measures rather than sizable reservoirs, water streamflow systems are fully utilized only during the rainy season in Brazil. During dry periods, such a generation faces even more serious problems, including economic growth, unequal water availability, and scarcity.

As reported by ANEEL (2023), 533 electric energy generation businesses operate in the state, producing 4.122.229,70 kW. The state has a large-scale, multi-proprietor system, represented by Hydroelectric Power Plant (HPP), Small Hydroelectric Plants (SHP), Hydroelectric Generating Plant (HGP), Photovoltaic Solar Power Plant (PVPP), and Thermal Power Plant for Electricity Generation (TPP) (Table 2) for the production, transmission, and distribution of energy (Table 2).

The five mesoregions of the state, namely Central-South, Southeast, Southwest, North, and Northeast are developed differently, according to the Energy Balance of Mato Grosso state and Mesoregions (2021). Table 2 shows the geographical distribution of the main projects, predominantly developed in the Amazon Basin and the Paraguay Basin, totalling 141 projects with hydroelectric origin, divided into 69 SHPs, 60 HGP, and 12 large HPPPs (ANEEL, 2023).

Table 2: Operational plants in Mato Grosso state.

Fonte	Número Empreendimentos	Potência Outorgada (kW)	Potência Fiscalizada (kW)	% (Potência Fiscalizada)
UHE	12	1.877.650,00	1.877.650,00	46,03%
PCH	69	1.100.154,00	1.099.016,00	26,94%
CGH	60	72.489,75	72.489,75	1,75%
UFV	313	19.608,95	19.608,95	0,48%
UTE	77	1.052.317,00	1.011.952,00	24,81%
Total	**533**	**4.122.219,70**	**4.080.716,70**	**100%**

Source: ANEEL (2023).

Mato Grosso state stands out due to its production of renewable energy, according to ANEEL (2023). Table 3 shows power plants under construction to be implemented and constructions not yet started. All such projects can raise capacity to even higher levels.

According to ANEEL (2023), a 1,665,257.00 kW increase in the state's power generation capacity is planned for the next few years, based on 30 projects still in the planning stages and 11 ones under construction, as illustrated in Table 3.

Table 3: Power plants under construction and construction not started in Mato Grosso state.

Source	**In Construction**		**With Construction Not Started**	
	Granted Power (kW)	**Number of Projects**	**Granted Power (kW)**	**Number of Projects**
HGP	4.600,00	2	6.400,00	2
WPP	6.040.845,00	153	18.885.420,00	444
SHP	412.076,00	31	1.107.212,65	77
PVPP	5.800.675,80	140	102.096.003,60	2392
HPP	49.998,00	1	262.000,00	3
TPP	4.658.470,00	46	3.551.710,00	46
NPP	1.350.000,00	1	0,00	0
Total	**18.316.664,80**	**374**	**125.908.746,25**	**2964**

Source: ANEEL (2023).

The 32 municipalities with Small Hydroelectric Plants (SHPs) represent 26.94% of the electricity of the state. 15 municipalities, namely Alta Floresta, Aripuan, Brasnorte, Campo Novo do Parecis, Campos de Júlio, Comodoro, Diamantino, Juará, Juna, Nova Maringá, Nova Ubiratã, Novo Mundo, Paranatinga, Planalto da Serra, and Sapezal are located in the northern mesoregion. The six projects of the southeastern mesoregion include Alto Taquari, Jaciara, Juscimeira, Poxoréo, Ribeirozinho, and Rondonópolis. The Central-Southern mesoregion is represented by Chapada dos Guimares, Nortelândia, Nova Marilândia, and Santo Antônio do Leverger, whereas Araputanga, Barra do Bugres, Indiava, Nova Lacerda, and Tangara da Serra comprise the Southwestern mesoregion. Finally, the northeastern mesoregion encompasses the municipalities of Campinapolis and Novo São Joaquim (Figure 3A).

Hydroelectric Generating Plant (HGP) projects are hydroelectric developments with power equal to or lower than 5.0 MW that require no concessions, permissions, or authorizations from authorities, but only a simple communication, according to Article 6 of Law 13.360 of November 17, 2016 (BRAZIL, 2016). They are spread across 15 towns in the state and account for 1.75% of the energy. Aripuan, Campos de Jlio, Nova Ubirat, Sapezal, and Comodoro are mesoregions in the north, whereas Campinápolis, Novo So Joaquim, and Santo Antônio do Leste are part of the northeastern mesoregion. Tesouro, Alto Araguaia, Itiquira, and Jaciara belong to the Southeastern mesoregion. Nova Lacerda and Salto do Céu are part of the Southwestern mesoregion, whereas Santo Antônio do Leverger is the only municipality in the Central-Southern mesoregion (Figure 3B).

Thermal power plants (TPPs) continue to encompass 24.81% of the state's energy production matrix, despite a large increase in sustainable energy alternatives (Figure 3C). Photovoltaic solar power plants (PVPPs) have grown significantly in recent years, although even with 313 projects, they still account for only 0.48% of the energy. They are currently one of the most promising energy options, but largely underutilized (Figure 3C)

Despite being more dispersed, hydroelectric power plants (HPP) contribute with 46.03% of the power generation. The number of hydroelectric plants is smaller, but they represent the largest amount of energy in kW, comprising almost half of the value of all hydroelectric energy generated in the state (Figure 3D).

Mato Grosso state will encompass 572 projects for the delivery of electricity after the power plants under construction and those not yet launched have been built, representing 2.13% of the total energy in

Brazil (ANEEL, 2023) (Table 4).

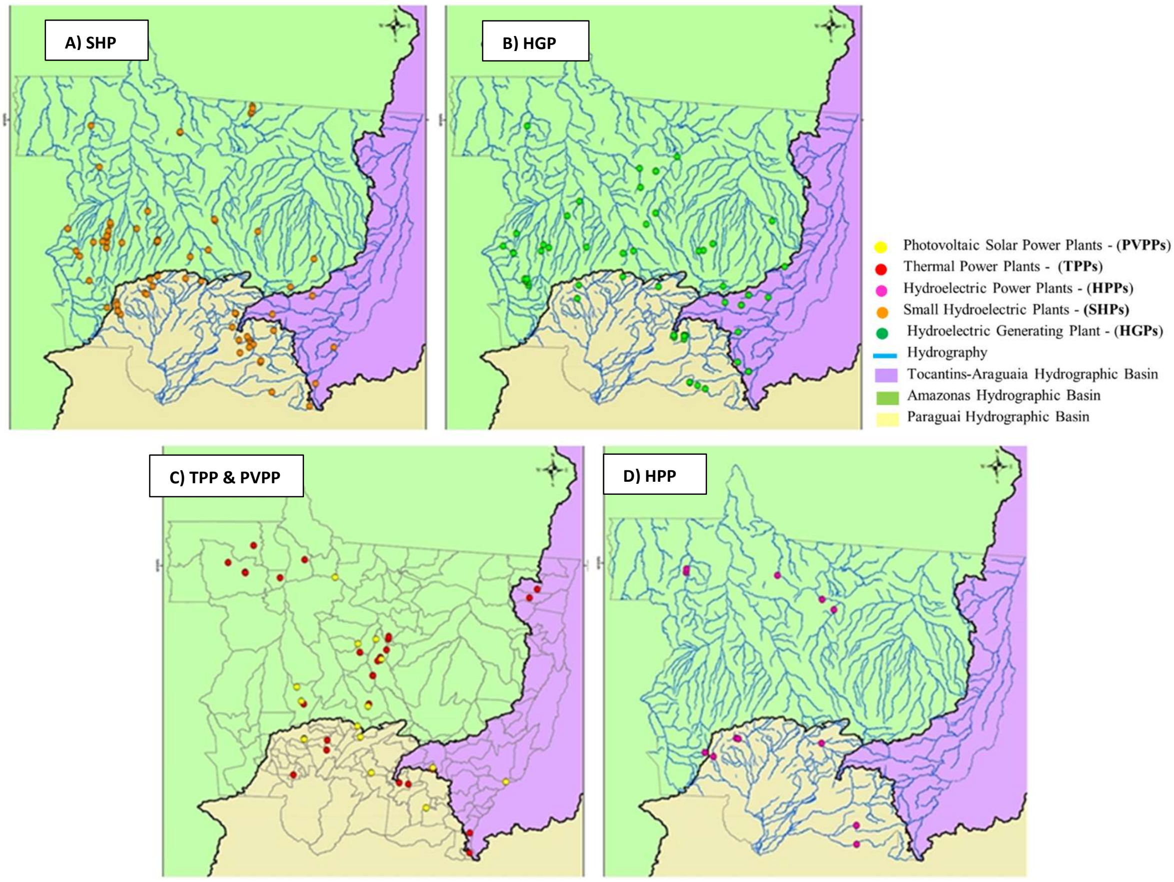

Figure 3: Distribution of electricity generation projects in Mato Grosso state – Brazil. **Source:** ANEEL (2023).

Table 4: Number of projects, authorized power, and monitored power after the completion of the power plants.

Source	Number of Projects	Granted Power (kW)	Supervised Power(kW)	% (Supervised Power)
HPP	12	1.877.650,00	1.877.650,00	46,03%
SHP	69	1.100.154,00	1.099.016,00	26,94%
HGP	60	72.489,75	72.489,75	1,75%
PVPP	313	19.608,95	19.608,95	0,48%
TPP	77	1.052.317,00	1.011.952,00	24,81%
Total	**533**	**4.122.219,70**	**4.080.716,70**	**100%**

Source: ANEEL (2023).

DISCUSSION

Attention has been drawn to the way investments in other energy sources can contribute to the replacement of the hydroelectric matrix. As a regional consumption model, Mato Grosso has long been dependent on fossil fuel subsidies (diesel, fuel oil, and natural gas) and petroleum derivatives, driven by the transportation industry and intensive agricultural activity.

Due to its third-largest hydrographic area in Brazil, the state benefits from an abundance of water resources, with potential to store water during times of high demand, prevent flooding, and build massive power plants, thus producing clean and sustainable energy.

The risks of dam failure would cause severe environmental and human damages, such as flooding or interference with land, infrastructure, and rural communities, forced population displacement, interference with physical and territorial organization, intensification of population flow (immigration and emigration), interference with socio-cultural and political organizations and economic activities, among others.

According to the data, the hydroelectric system continues to generate 74.00% of the state's energy. The use of biomass, which accounts for 11.62% of the state's energy production, is a sustainable option, since this fuel is made from wood and forest wastes, animal sources (biogas), and agricultural waste (sugarcane bagasse and rice husks). Energy production is possible through the use of the state's vast agricultural potential. When compared to the production of hydroelectric electricity, the photovoltaic energy market, which accounts for 0.48%, has substantially expanded due to the state's favourable climatic circumstances. However, fossil fuels still account for 13.91 %.

The tables also provide details on power plants under development and those whose construction has not yet started (Table 3). However, some plants are still in the process of authorization, registration, and granting - the entire process is available on ANEEL website.

Mato Grosso has been searching for alternatives and can potentially implement the energy matrix towards becoming the leading state in the generation of green energy in the country. Energy transition is part of a strategy for reductions in greenhouse gases and will imply a profound transformation in infrastructure and energy use, involving environmental challenges.

CONCLUSIONS

The state of Mato Grosso despite having an exceptional climate potential, characterized by high temperatures practically throughout the year, the state still depends mostly on hydraulic energy to meet its energy needs. It has a comparative advantage in the use of renewable sources for its electricity generation, but the projected long-term demand growth and the prioritization of hydroelectric energy usage may cause the state to miss the opportunity to establish an electrical grid predominantly based on unconventional sources of clean and renewable energy, such as solar, wind, and biomass.

In this context, we can conjecture that the lack of diversification in Mato Grosso's energy matrix may be related to a series of factors, such as political, economic, and technical issues.

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