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Scenarios and Expansion perspectives for Small Hydropower Plants (SHPS) in the State of Rondônia (Brazil)

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***Abstract*— *To meet the demand for electricity, it is necessary to maintain a distributed energy matrix, focusing on renewable sources, taking into account the socio-environmental premises. By 2026, energy consumption in the country can reach 741 TWh and hydraulic power is the main source of supply. With great potential to be explored, especially in the state of Rondônia (Brazil), the Small Hydropower Plants (SHPs) are one of the main candidates in contributing to the growing energy demand. It is imperative that energy efficiency techniques and technologies, such as repowering, be used by public policies in order to promote sustainable development.*

Keywords*— Small Hydropower Plants (SHPs). Energy Efficiency. Repowering. Sustainable Development.

I. INTRODUCTION

On the horizon of DEEP 2026 to meet the increscent demand of electricity it is required to keep a distributed energy matrix with the focus in renewable sources (hydraulic, wind, solar, and biomass), according to the social and environmental premises. The renewable sources are projected to account for 90% of electricity generation in 2026.

The national electric generation is strongly represented by the hydraulic generation according to table 1.

Together, Hydropower Plants, Small Hydropower Plants, and Generating Hydropower Plants are responsible for 64% of all electricity generated, 3.62% corresponding to SHPs and GHPs. According to the National Energy Plan (NEP) 2030 the major part of hydraulic potential to be harnessed is found in the North region. Bringing a series of economic, social, and environmental challenges. Such challenges require planning and participation from various sectors: government, academia, NGOs, local communities, etc.

The hydroelectricity still has a lower cost compared to other renewable sources besides providing energy security, complementarity with other renewable sources, operational flexibility, and maintenance of a low carbon electrical matrix (EPE, 2017).

However, this generation depends of the hydrological conditions. In 2015 for example, due to the unfavorable hydrological condition, it was necessary to increase generation in thermoelectric plants, which generated almost 65 MtCO2e in the National Interconnected System

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(NIS). Under normal conditions emissions for 2020 and 2026 are estimated to be 24 and 37 MtCO2e respectively (EPE, 2017).

Table 1 - Capacity of Brazil's generation.

Projects in Operation				
Type	**Amount**	**Granted Power (kW)**	**Supervisei Power (kW)**	**%**
HPS	693	691.131	690.133	0.43
UGP	1	50	50	0
EG	546	13.450.139	13.427.343	8.35
SHP	427	5.178.959	5.130.531	3.19
PSGP	2258	1.433.573	1.426.773	0.89
HPP	218	101.892.288	97.075.157	60.37
TPP	2999	42.630.823	41.049.179	25.53
TPP (Nuclear)	2	1.990.000	1.990.000	1.24
TOTAL	**7144**	**167.266.963**	**160.799.166**	**100**

Source: ANEEL, 2018.

To be considered Small Hydropower Plant (SHP) the undertaking must meet certain criteria, which in turn have changed over time. In the current context ANEEL through Normative Resolution No. 673/2015 defines that, to be considered projects with SHP characteristics they must: Be intended for self-production or independent production; Installed power exceeding 3,000 kW and not exceeding 30,000 kW; and Reservoir area up to 13 km² excluding the regular riverbed gutter.

In the following the potential, contributions, and perspectives of Small Hydropower Plants in the promotion of regional development of the State of Rondônia will be addressed.

II. MATERIAL AND METHODS

This study was conducted through detailed bibliographic and documentary research. In order to understand the current scenario of SHPs in the state of Rondônia. As well as their historical development of implementation and operation.

The main national public policies related to the electricity sector were also analyzed: the 2026 Ten Year Energy Expansion Plan, and the 2030 National Energy Plan.

The references are based on dissertations, theses, journal articles, and informations from specialized websites. As the next step of this study it is expected to perform economic, technical, and regional feasibility analysis of methods, and technologies for energy gain in the state SHPs.

III. RESULTS AND DISCUSSION

3.1 Scenarios and Perspectives of Expansion

The South and Southeast regions, which possess the largest economic development in Brazil (the biggest GDP) also present the greatest number of hydroelectric projects installed as in the figure 1.

The consumption of energy in Brazil tends to grow in the next years. According to the projections of the Decennial Energy Expansion Plan (DEEP) 2026, the energy consumption in the country, which in 2016 was 516 TWh will be 741 TWh in 2026 with an average growth of 3.7% per year. The plan still reinforces that this valuation may be higher if the country's economy shows growth above the expected.

According to the ERC (2017) in the list of expansion candidates there are proposals for SHP and GHP projects with an estimated 300 MW growth in the segment annually. These projects are submitted to the Investments Decision Model (IDM), whereas that there is a possibility that this 300 MW potential could be expanded.

Besides that, the plan highlights the importance of repowering projects or the addition of generating units to existing hydropower plants and reversible hydropower plants.

The figure 2 shows the indicative of the energy load expansion in the SIN with an annual average increase of 2,700 MW.

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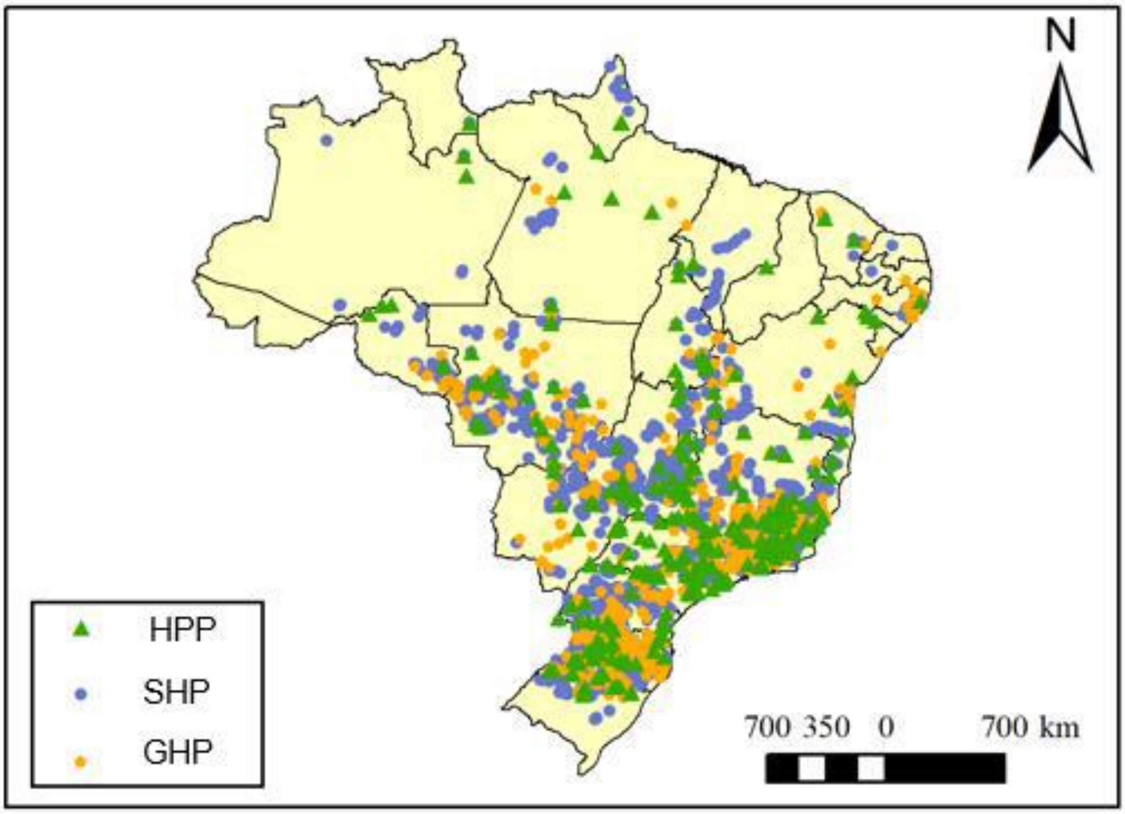

Fig.1 - Hydropower Undertakings in Brazil map

Source: SIGEL (2018). Elaboration: The author.

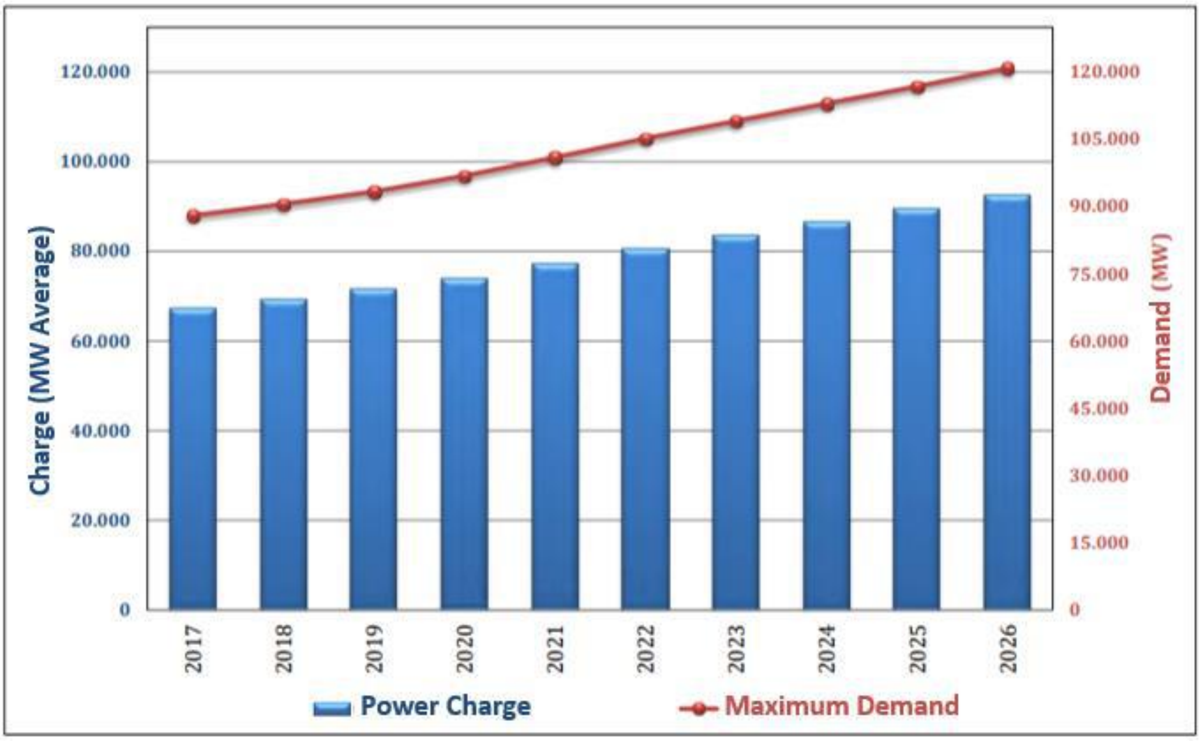

Fig.2 - Energy charge projection

Source: Energy Research Company (2017).

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With the indicated increase the ERC (2017) recognizes the importance of matrix diversification and transmission network quality in order to provide reliable power supply.

In the case of electrical losses it is expected greater difficulty in making investments to reduce losses. Keeping the level of this indicator constant in the first five years. In the second five years the greater economic growth generates investments that lead to the reduction of losses (ERC, 2017).

Ideally there should be greater agility in the actions aimed at reducing electrical losses in the SIN. Especially considering that according to the International Energy Agency (IEA) in 2014 the average loss in transmission and distribution of electricity in the world was of 8.26%. In the same year the loss registered in Brazil was 15.78%. Countries like China and the United States have losses below 6% (THE WORLD BANK, 2018).

As for the care of vegetation some new projects of transmission lines are minimizing the impact, reducing deforestation, affecting only the towers area, and the service range in a way that enables the cable launch where later the natural recovery of native vegetation occurs. In some cases in protected areas the cables are even released with the aid of helicopters or unmanned aerial vehicles.

Trough Figure 3 it is verified that the renewable sources including the SHPs will present the highest rate and growth over the ten-year horizon. This diversification contributes to the reliability of the energy supply because it makes it less susceptible to seasonal changes.

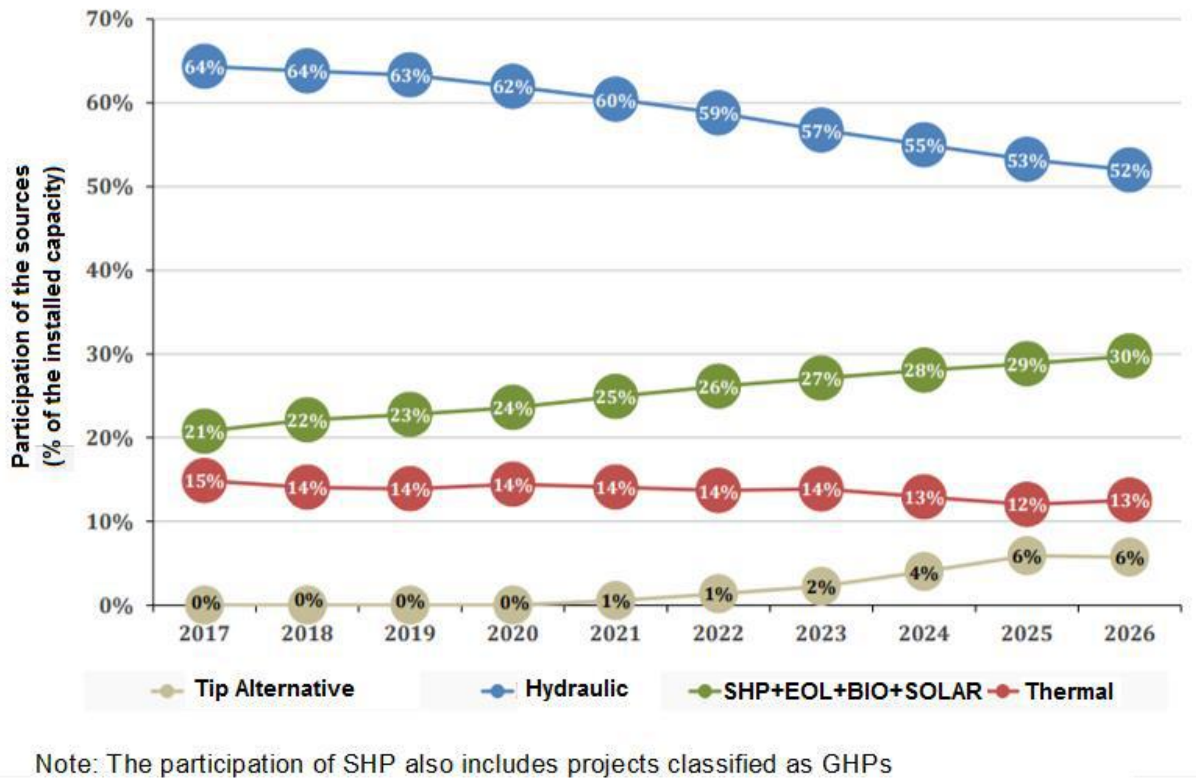

Fig.3 - Participation of the sources

Source: Energy Research Company (2017).

The National Electric Energy Agency (NEEA) recognizes, through Technical Note No. 026/2011 that repowering studies of existing generating units can bring gains in energy operation and add availability to the National Interconnected System. In addition to meeting isolated systems especially in the case of SHPs.

According to the 2027 Ten Year Energy Expansion Plan the Northern region does not have its mapped SHP potential (ERC 2018).

3.2 SHPs' benefits for the state of Rondonia

The SHPs have played a very important role in Rondônia specially in the towns. The city of Vilhena (RO) received the first SHP of the state with an installed capacity of 2600 kW. The Rio Vermelho SHP was inaugurated in 1987. Previously the electricity was totally provided through Small Thermal Power Plants (STPPs). Two years later in 1989 it was inaugurated the HPP Samuel located in the city of Candeias do Jamari (RO).

Due to the implementation of the Small Hydropower Plants there were a quantitative and qualitative increase in the State's electric generation guaranteeing the 24-hour supply in several cities.

According to the Generation Information Bank (GIB) and the NEEA (2019) the state of Rondonia has 17 SHPs in operation, 1 under construction (Apertadinho) and 3 with not started works (Machadinho I, Cachoeira Formosa and Urubu).

The installed capacity of the 17 SHPs in Rondônia is 151,421 kw with total flooded area of 7,351.4 ha. If GHPs are considered 21,712 kW of power is added. In addition to the SHPs Rondônia has four HPPs in operation, namely: Samuel HPP, Rondon II HPP, Santo Antônio HPP, and Jirau HPP, with an installed capacity of 7,608,250 kW as shown in Table 2.

Table 2 - Projects in operation in the state of Rondônia (Brazil).

Projects in operation			
Type	**Quantity**	**Capacity (kW)**	**%**
HPS	13	23.417	0.28
SHP	17	151.421	1.82
PSGP	1	20	0
HPP	4	7.608.250	91.47
TPP	46	534.737	6.43
TOTAL	**81**	**8.317.846**	**100**

Source: GIB (2019)

Besides the Small Hydropower Plants in operation another four are expected to start operating. One under construction (Apertadinho SHP in the city of Vilhena with 30 MW of installed capacity) and three others in not started construction: Machadinho I (10,5 MW), Cachoeira Formosa (12,3 MW), and Urubu (21 MW). The HPP Tabajara with an installed capacity of 400MW located in the city of Ji-Paraná is expected to start operating in 2025 (NEEA 2019).

3.3 SHPs' contribution to the Regional Development

The SHPs contribute to the energetic and social development of Brazil. According to the NEEA (2017) a research conducted by the Agency's technical field points out that in the 176 cities with SHPs analyzed the Municipal Human Development Index (MHDI) went from 0,594 to 0,712 in the period of 2000 to 2010 surpassing the values of other cities in the same microregion.

In 2016 the Superintendent of Generation Concessions and Authorizations of NEEA Hélvio Guerra, stated that the Small Hydropower Plants are important for putting more power into the energy matrix. From a strategic point of view a SHP is more viable than a large plant. They are distributed in the national territory, generate local jobs, and do not require large transmission lines. The SHPs are projects with totally national technology which allows to foment the Brazilian industry.

According to the BREGA (2017) which stands for Brazilian Renewable Energy Generation Association (ABRAGEL in portuguese) the SHPs can supply the current difficulties of the HPPs by reducing: transmission and distribution losses, and delays in licensing / construction.

Compared to other forms of power generation Bacellar (2017) points out that besides the already mentioned advantages of SHPs such as lower environmental impacts, better water use, reduction of losses in transmission lines, decentralization of production, and generation of local jobs, These are usually implemented by small and medium investors rather than large banking institutions.

By building Small Hydroelectric Plants it is possible to reduce dependence on large Hydroelectric Plants, reducing the overall vulnerability of the system in case of unfavorable hydrological cycles; Attending in a more efficient way the needs of small consumer centers, whether if they are urban, rural or industrial and induce investments under the influence of the project, contributing to local development (SOUZA VALENCIO 2005).

3.4 SHPs' socio-environmental impacts

According to Braga et al (2005) the lake formed upstream of the barrage, which is necessary in most constructions of the SHPs. It changes the aquatic ecosystem because the flow is altered reducing its velocity and turbulence. Although the flooded area is much smaller than in the case of HPPs.

The accumulation of sediment in the flooded area upstream of the barrage causes siltation and can also cause damage downstream of the barrage such as an erosion of the canal banks (CARVALHO 2008).

According to Maia (2006), the sediment accumulation in the reservoirs also has an economic impact. As the accumulation capacity is reduced implying a reduction in energy potential. Besides that the life of the reservoir is shortened and if siltation reaches the water outlet the equipment can be damaged by the abrasion.

The siltation can also cause increased cavitation phenomena in hydraulic turbine blades as well, due to the drop in pressure levels.

In the analysis of impacts caused by SHPs the risk of barrage disruption should also be considered. The tragedy occurred in the state of Rondônia in 2008 with the disruption of the Apertadinho SHP barrage located in the city of Vilhena on the Comemoração river caused severe damage to the region.

The disruption of the Apertadinho SHP barrage which occurred in the final phase of construction caused 1,501.4 hectares of deforestation. Causing damage to native vegetation and fauna but only 271.1 hectares were classified as a deforestation by the National Institute for Space Research (NISR) through the PRODES monitoring system, that is, less than 20% of the total was detected (COSTA, 2017).

After a decade of the accident the perpetrators have not yet borne the damage and most of the impacted area has not yet been recovered.

The DEEP 2026 itself points out that because the cities in the Northern region have less dense urban networks they are more sensitive to the pressure on infrastructure from large projects such as UPPs a clear example of what happened with the city of Porto Velho with the plants of Santo Antônio and Jirau.

3.5 Alternatives for energy gain in the SHPs from the state of Rondônia

In the attempt of reducing new social and environmental impacts from hydropower projects and still attend the growing demand for electricity there are some alternatives through technological innovations among them the repowering process can be highlighted.

According to Oliveira (2012, p. 1) repowering can be defined as an intervention or set of interventions in the structures, hydraulic circuits, and electromechanical equipment involved in the energy conversion process of a hydroelectric project already built with simultaneous gain of power and efficiency reconciled with economic and socio-environmental benefits.

The repowering is a procedure that somehow increases the electrical generation of an existing hydroelectric facility.

According to Oliveira (2012) all hydroelectric projects whether HPP, SHP, or GHPs to a greater or lesser extent may undergo a process of repowering either by undersizing or temporary failure. The useful life of hydroelectric projects can be analyzed through Figure 4.

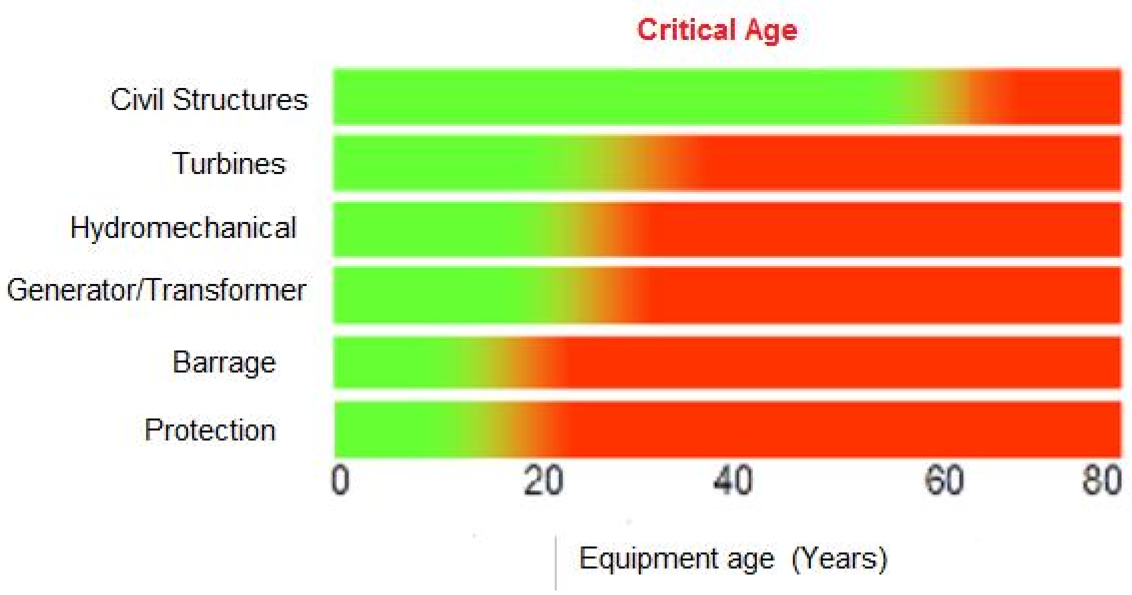

Fig.4 - Critical age of equipment and main structures of a Project

Source: Oliveira (2017).

According to Figure 4 it is verified that this would be an interesting alternative for SHPs in the state of Rondônia especially those built in the 80s and 90s.

The repowering can be used to redefine the initially designed nominal power with the aid of technological innovations and more current design concepts or to increase operating power by identifying gaps in the initial design without incorporating new technologies into the generating unit (ERC 2008).

In developed countries the repowering process has already been performed routinely to obtain energy gains. According to the "Blue Age for a Green Europe" project developed in 2002 through SHP repowering techniques it would be possible to increase the installed capacity by 1111 MW (VUKOSLAVČEVIĆ, 2017).

For Maldonado et al. (2006), with the repowering it is possible to maximize the energy efficiency of the plant without generating major social and environmental impacts. Considering that the impacts have already been consolidated and there is no need for compulsory removal of riverine populations. Moreover when there is no change in reservoir level any hypothesis of river bank erosion is discarded.

The viability of the project depends on a multidisciplinary analysis in the technical, economic, and environmental aspects. The viability of the repowering procedure can be analyzed through indicators such as: age of the enterprise, operation and maintenance costs, productivity (generation), operating flexibility, and utilization of available hydraulic potential against current technologies. (OLIVEIRA 2017).

Through the case study carried out by Oliveira (2017) at SHP Lajeado, Tocantins it was observed that with the repowering the installed power increased from 1.8 MW to 8.0 MW and the project cost - additional R $ / kW ratio - was lower than the average investment cost that would be required for a new project.

IV. FINAL CONSIDERATIONS

As presented the SHPs have played a major role in supplying electricity to the state of Rondônia. In a scenario where the use of fossil sources for electricity generation is increasingly criticized it is necessary to increase the capacity of projects that use renewable sources.

However the State Sustainable Development Plan (SSDP) itself from Rondonia 2015 - 2030 does not present guidelines that match this perspective and can really contribute to maximizing the sustainable development process.

Faced with the difficulties of environmental licensing of new hydroelectric projects which can sometimes even make the projects unfeasible it is essential to think of public policies focusing on alternatives for expanding generation capacity without the installation of new HPPs or SHPs through for example, repowering projects.

In addition through repowering it is possible to reduce new social and environmental impacts from hydroelectric projects and still attend the growing demand for electricity. Also to intervene in projects that are underused either due to poor dimensioning or depreciation. Enforcing the concept of "optimum utilization" of hydraulic potential according to Law No. 9,074 / 95.

At long last it is highlighted the importance of conducting research that provides increased energy efficiency in the local projects ensuring in this process legitimate participation of the society with the enhancement of economic and regional development.

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