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Application of Floating Photovoltaic Systems in Dams in Rio Grande do Norte: Feasibility Study

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ABSTRACT
The reduction of costs and the technological evolution of photovoltaic modules over the last few years have allowed a significant growth of the photovoltaic solar source in the world. In this scenario , the installation of photovoltaic systems in water bodies appears as another application alternative , with potential efficiency gains . This project aims to study the technical and environmental feasibility of deploying floating photovoltaic solar power plants in dams located in the state of Rio Grande do Norte, taking into account its possible benefits , as well as limitations and challenges . In order to achieve the project's objectives , a bibliographical review on floating photovoltaic systems was initially carried out, a statistical survey of dams that contemplate the state of Rio Grande do Norte was carried out, a map of the location of the dams was made , a comparison between models of floating plants was carried out, verifying by type of dam , studies will be carried out on the regional energy demand and contemplative supply systems, physical chemistry and biological analysis of the water bodies , a study of energy potential and possible destinations , a study of the economic viability of the models and the creation of a quality index using environmental and technical data. The dams are more concentrated in the center of the state and not on the coast , being possible locations for setting up the plants . Three main types were found : floats for support and direct attachment of photovoltaic modules, floats added with metallic structures to support photovoltaic modules, and membranes and designed mats . Data from 46 dams were found and the main activities identified were : supply ; ebb culture ; and fishing activity .

Keywords: *photovoltaic energy, sustainability, water reservoirs, floating systems.*

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I. INTRODUCTION

The growing energy demand and the increased use of non-renewable energy sources end up increasing the emission of greenhouse gases, causing climate change and intensification of global warming. Morelli (2012) states that non-renewable energies are those found in nature in limited quantities and become extinct with their exploitation. For this reason, it is important to create sustainable alternative measures with the objective of adapting human activities in the scope of energy generation, creating a possibility of expanding the use of renewable energy (CONEJERO, CALIA AND SAUAIA, 2015).

One of the justifications for carrying out this project is related to water problems that areas of the semiarid region of the Northeast face with equipment that can reduce evapotranspiration from dams. The production and commercialization of energy from floating solar plants can also be interesting in semiarid dams, since in addition to being in a region of high insolation, they can represent economic gains by reducing evaporation in reservoirs and revenue gains for states and municipalities from the sale of energy generated in the dams (LOPES, 2020).

For investments in floating photovoltaic plants to prove economically viable, interesting from the point of view of energy generation and an alternative for reducing evaporation in reservoirs, it is essential to carry out studies on the potential benefits that floating photovoltaic plants can bring, especially to semi-arid areas (LOPES, 2020).

The dams that are the subject of this study are located in the state of Rio Grande do Norte, as it has a semi-arid climate as its predominant climate, and the average annual temperature ranges from 24.7°C to 28.1°C, sunshine of 245 hours/month, annual evaporation between 1900 and 2850 mm, average annual precipitation between 420 and 1560 mm (SERHID, 2006).

The Brazilian Northeast is characterized by long periods of drought, high temperatures and rainfall deficit. The combination of these climatic factors with anthropogenic factors, such as deforestation and greenhouse gas emissions, results in the natural phenomenon of drought, which is often associated with environmental degradation (BEZERRA, 2016).

Silva and Nobre (2016) state that the main characteristics of the drought phenomenon include the reduction and irregularity of rainfall. Bezerra (2016) highlights that high temperatures, a characteristic peculiar to the Northeast region, result in a considerable increase in evapotranspiration rates.

Morelli (2012) says that alternative energy sources emerge as local solutions capable of meeting human needs without destroying the environment. The solar energy system consists of photovoltaic cells that convert sunlight into electrical current, and these systems can operate autonomously and are generally integrated into built environments such as roofs of buildings and houses, but they can also be portable (HERNANDEZ et al. 2014).

The authors Silva Farias, Silva and Carvalho (2021) explain that the development of new renewable sources is not limited to meeting environmental commitments or obligations, but also aims to develop technologies in the country. The aforementioned authors also say that it is essential that renewable energies are included in the energy policies of countries, since they play an important role in the sustainability of the energy system (MORELLI, 2012).

This project aims to study the technical and environmental feasibility of implementing floating photovoltaic solar plants in dams located in the state of Rio Grande do Norte.

II. MATERIAL AND METHODS

To achieve the project objectives, a bibliographic review was initially carried out on floating photovoltaic systems implemented in Brazil and other countries. Afterwards, a statistical survey of dams in the state of Rio Grande do Norte was carried out. In this survey, geographic coordinates were used to create a map of the location of the dams through the Qgiz platform , using SIRGAS 2000.

The location data were published by the National Department of Works Against Droughts (DNOCS), as well as other data on the dams. Information was sought and filled in a table: Name of the reservoir, municipalities of location, latitude and longitude in degrees, minutes and seconds, use of water from the dam, capacity in m³, area of the river basin in km², runoff coefficient in %, maximum height of the dam in meters, and dead volume in m³.

An analysis is being carried out regarding the impacts resulting from the implementation of a floating photovoltaic plant, a location map with a route between dams, a comparison between models of floating plants checking by type of dam, a study of regional energy demand and contemplative supply systems, a physical-chemical and biological analysis of water bodies, a study of energy potential and possible destinations, a study of the economic feasibility of the models and the creation of a quality index using environmental and technical data.

A quality index was created using environmental and technical data to select the most suitable reservoir for installing solar panels.

The selected environmental data were: Water Quality Index - IQA and Trophic State Index - IET. And the technical data: Dam area and Dam use (end-use activity of the water stored in the dam). Table 01 describes the values of the aspects that vary from 0 to 3, where 0 are the unfavorable parameters and 3 are the most suitable for implementing the system.

Table 01: Values for aspect variation.

Variation of aspects	IET	IQA	Dam area	Use of the dam
0	Supereutrophic or Hypereutrophic	Excellent	Less than 50km²	Human supply
1	Mesotrophic or eutrophic	Good	Up to 100 km²	Fishing activity
2	Oligotrophic	Reasonable	From 100 to 1,000 km²	Ebb culture
3	Ultraoligotrophic	Bad or terrible	Over 1,000 km²	Irrigation

An Ultraoligotrophic environment consists of clean bodies of water with very low productivity and insignificant concentrations of nutrients that do not cause harm to water use. Therefore, it is interesting to place floating plates without harming the ecosystem, hence the score of 3 on the index.

A hypereutrophic environment is a water body that is significantly affected by high concentrations of organic matter and nutrients, with a marked impairment of its uses, associated with episodes of algal blooms or fish kills, with undesirable consequences for its multiple uses, including livestock activities in riverside regions. In this case, if the environment is already eutrophic, simply removing the presence of sunlight will not improve the quality of the water, since the water itself is already rich in nutrients. A score of 0 on the index is given so that the water body does not suffer further impacts.

Regarding the IQA, if the water body presents excellent quality for supply, then it is not interesting to impact this water body, with the risk of modifying the quality parameters, having a score of 0 in the index. On the other hand, a water body with poor or very poor quality should have a use that does not harm the quality, and has a utility that benefits the region, hence the score of 3 in the index.

Regarding the area, the more surface area you have available, the better it is to occupy with the panels, so that it does not take up a large part of the area and there is enough for the panels to meet the energy demand.

Regarding use, if the water is being used for supply, it is not advisable to use it so as not to impact the quality parameters as the monitored parameters are more restricted, therefore being given a score of 0 in the index.

With the appropriate value for each aspect, a sum is performed, as per table 02, and the result of the sum leads to a conclusion, described in table 03.

Table 02: Example of summation.

Environmental aspects	Scoring	Sum of aspects
IET	0	Σ (0+1+2+3)
IQA	1	
Technical aspects	-	
Dam area	2	
Use of the dam	3	

Table 03: Conclusion for variation in the sum range.

Range variation of the summation	
0-4	Tank not suitable for fixing floating solar panels
5-8	Reservoir indicated with observations for fixing floating solar panels
9-12	Tank highly recommended for fixing floating solar panels

Using this index, it was possible to choose the most suitable reservoirs for implementing the system.

III. RESULTS AND DISCUSSIONS

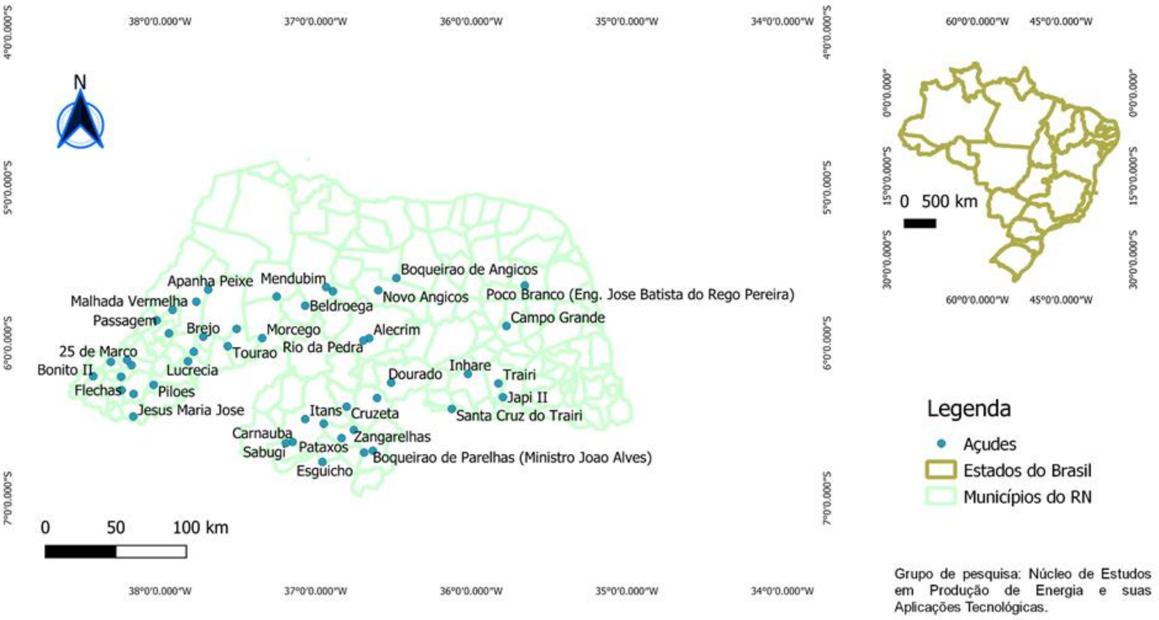
Lopes (2020) states that when compared to ground-mounted photovoltaic plants (UFVS), floating photovoltaic plants, because they are installed on a body of water, perform greater heat exchange, ensuring that the module's operating temperature is lower and, thus, increasing the overall efficiency of the system. The author also reports that temperature is a factor that directly impacts the electrical generation performance of photovoltaic modules.

Rego (2020) says that, therefore, the impacts on reducing evaporation can be interesting in places with low water availability. However, it is worth remembering that, in large bodies of water, module coverage is not expected to be relevant in terms of fraction of the total area. Thus, reducing evaporation, although it is an additional benefit of floating plants, is not the solution to this issue.

It is not possible to dissociate energy generation from water consumption. Some generation sources use more water (such as hydroelectric power), but solar power has low water consumption, only 0.02 m^3/MW h (cubic meter per megawatt hour), consuming water only for washing panels and suppressing dust when necessary, in addition to the water used in the production of solar panels (HERNANDEZ et al. 2014).

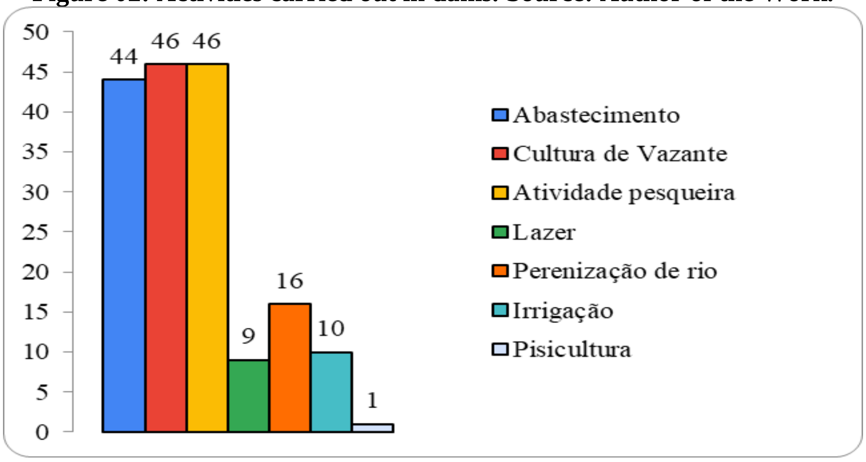
The Secretariat of Water Resources of the State of Rio Grande do Norte (SERHID, 2006) emphasizes that the construction of dams in large and medium-sized reservoirs was a decisive measure to reduce the vulnerability of areas subject to scarcity and irregular rainfall. To clarify the locations of the dams, a map of the location of the dams in Rio Grande do Norte was prepared, as shown in Figure 01.

Figure 01: Map showing the location of dams. Source: Author of the Work.



It can be seen in Figure 01 that the dams are more concentrated in the center of the state and not on the coast, precisely because there is low rainfall and higher temperatures, which are possible locations for the installation of floating plants. A technical file was also prepared with some information presented below in Figure 02.

Figure 02: Activities carried out in dams. Source: Author of the Work.



It is worth noting that 46 dams were found, 100% of which are used for floodplain cultivation and fishing activities. Among the dams is the Armando Ribeiro Gonçalves reservoir, which according to Mosca (2008) is the largest reservoir in the state of Rio Grande do Norte and is responsible for the accumulation of approximately 53% of all surface freshwater dammed in the state. The author points out in his study that it is very likely that the primary planktonic production of the reservoir is more limited by the availability of light than by the availability of nutrients.

1. Index application

Using the index, the only result considered “Reservoir highly recommended for fixing floating solar panels” was the Poço Branco Reservoir (Eng. José Batista do Rêgo Pereira, according to table 04 with the description of the parameters used. Followed by table 05 with the calculation of the reservoirs.

Table 04: Parameters for calculating the Poço Branco Reservoir. Source: technical file: SERHID (2006).

Technical Sheet			Quality	
Dam name	**Use**	**Watershed area (km²)**	**IET**	**IQA**
Poço Branco Reservoir (Eng. José Batista do Rêgo Pereira)	Supply; Flood cultivation; Fishing activity; Control of periodic floods that inundate more than 8,000 ha of the Ceará-Mirim valley River perennialization	2,040.00	Ultraoligotrophic	Bad

Table 05: Calculation of the Poço Branco Reservoir reservoir.

CALCULATION					
IET	**IQA**	**AREA**	**USE**	**SUMMARY**	**CONCLUSION**
3	3	3	0	9	Tank highly recommended for fixing floating solar panels

Even though the Poço Branco Reservoir has a value of 0 because one of its uses is for human consumption, the other parameters had their maximum value, with a possible value between 9 and 12, classified as a "Reservoir highly recommended for fixing floating solar panels".

Table 06 shows the classification of the other reservoirs, with 23 not indicated and 22 indicated with reservations.

Table 06: Classification of other reservoirs.

Tank not suitable for fixing floating solar panels	Reservoir indicated with observations for fixing floating solar panels
Açude Alecrim	Açude Boqueirão de Angicos
Açude Apanha Peixe	Açude Boqueirão de Parelhas (Ministro João Alves)
Açude Beldroega	Açude Caldeirão de Parelhas
Açude Bonito II	Açude Campo Grande
Açude Brejo	Açude Cruzeta
Açude Carnaúba	Açude Dourado
Açude Esguicho	Açude Encanto
Açude Inharé	Açude Engenheiro Armando Ribeiro Gonçalves
Açude Jesus Maria José	Açude Flechas
Açude Malhada Vermelha	Açude Gargalheiras (Marechal Dutra)
Açude Morcego	Açude Itans
Açude Novo Angicos	Açude Japi II
Açude Pau dos Ferros	Açude Lucrécia
Açude Pilões	Açude Marcelino Vieira
Açude Rio da Pedra	Açude Mendubim
Açude Sabugi	Açude Passagem
Açude Santa Cruz do Apodi (Governador Aluísio Alves)	Açude Passagem das Traíras
Açude Santa Cruz do Trairí	Açude Pataxós
Açude Santana (Gangorra)	Açude Riacho da Cruz II
Açude Tourão	Açude Rodeador
Açude Umari (Senador Jessé Pinto Freire)	Açude Santo Antônio de Caraúbas
Açude 25 de Março	Açude Trairí
Açude Zangarelhas	

As there were 22 reservoirs classified as "Reservoir indicated with observations for fixing floating solar panels", it should be observed on a case-by-case basis, as there was a "super indicated" reservoir, then the study was based on it, as it has favorable characteristics for fixing floating panels.

The Poço Branco Reservoir is located in the Ceará-Mirim State Hydrographic Basin. The Ceará-Mirim River Hydrographic Basin is located in the state of Rio Grande do Norte, occupying an area of 2,635.70 km² (Ceará-Mirim River Hydrographic Basin Committee). The basin encompasses 16 municipalities, namely: Angicos, Fernando Pedroza , Pedro Avelino, Pedra Preta, Caiçara do Rio dos Ventos, Riachuelo, Santa Maria, Jardim de Angicos, Bento Fernandes, João Câmara, Poço Branco, Taipu, Ielmo Marinho, Ceará-Mirim and Extremoz.

2. Plates

In the Data Portal for Cities (2022), the consumption of the city of Poço Branco was searched, arriving at energy consumption data of 39TJ, for a population of 15,058 inhabitants in 2022, generating a per capita consumption of Gj of 2.6.

Based on 2022 data from the Data Portal database that provides information on consumption and carbon emissions, we can obtain the information that the city of Poço Branco had an annual consumption of 39 TJ. To convert terajoules (TJ) to kilowatt-hours (kWh), we use the following relationship:

1 TJ = 277,777.78 kWh.

Therefore, to convert 39 TJ to kWh:

39 TJ × 277,777.78 kWh/TJ ≈ 10,825,000 kWh

So 39 TJ is approximately 10,825,000 kWh.

Considering this annual consumption value, we will divide it by 12 months to find out the monthly demand and then divide it by the power of a common panel used in large solar generation plants to find out the number of panels needed.

To calculate monthly consumption and the number of photovoltaic panels required, we will follow the steps:

Monthly demand ⇒ 10,825,000 kWh / 12 months ⇒ 902,083kWh/month

If we consider that the photovoltaic panel has a power of 1000 W (or 1 kW), we will recalculate the number of panels needed:

Monthly production of a 1000 W panel: A 1000 W panel can generate around 400 kWh per month, depending on the location and solar irradiation

Calculation of the number of panels: Number of panels ⇒ 10,825,000 kWh / 400 kWh ⇒ 2,255

Therefore, approximately 2,255 photovoltaic panels of 1000 W each would be needed to meet the monthly demand of 902,083 kWh.

This is a large amount of panels if used to supply the entire city, however if it is to meet small demands, such as the city's public buildings, as it has a lower energy demand, it may become viable. The panels to be placed under the liquid surface of the dam require a floating structure, as shown in the models presented below.

3. Models

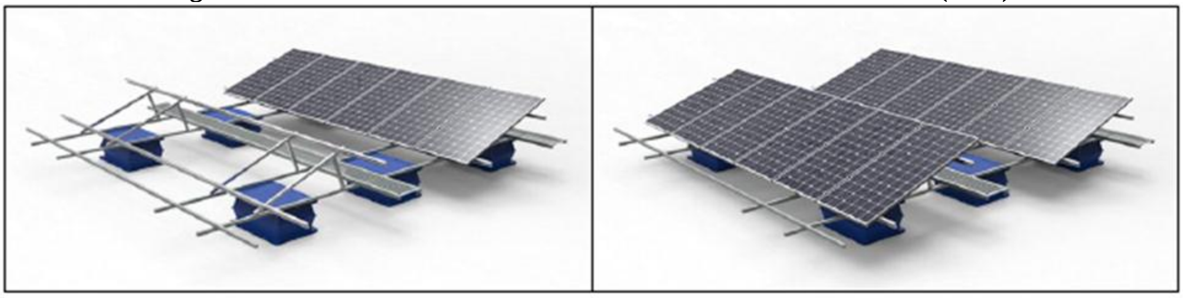
Through the comparison considering the models of floating plants verifying the types of dam, the following models were found, presented below.

Sunlution (2019) presents, as shown in Figure 03 and Figure 04, floats for supporting and directly fixing photovoltaic modules. This type of float allows easier access to the installed modules as it has non-slippery surface passages and requires little depth for anchoring. Therefore, a dam that is not so deep would possibly be suitable for the system.

Figures 03 and 04: Direct module attachment type floats. Source: Sunlution (2019).

Scotra (2019) presents floats with metal structures added to support the photovoltaic modules, as shown in Figure 05 and Figure 06. The floats provide the necessary buoyancy to keep the system on the surface of the water, while the metal structures serve as a base for fixing the modules.

Figures 05 and 06: Floats added to metal structures. Source: Scotra (2019).



Ocean Sun (2019) comes with a proposal for membranes and mats designed to withstand mechanical stress and sun exposure, covering the water surface and creating a base for the installation of the modules, shown in Figure 07 and Figure 08.

Figures 7 and 8: Membrane floats and mats. Source: Ocean Sun (2019).

The three floats have specific characteristics and can be compared with the table prepared by the research group, which contains data from 46 dams, to check the depth.

IV. CONCLUSION

Data were found for 46 dams. Among the dams, the main activities identified were: use for supply; floodplain cultivation; and fishing activity.

Dams are more concentrated in the center of the state and not on the coast, and are possible locations for the installation of floating power plants. With the application of the index, the Poço Branco Reservoir (Eng. José Batista do Rêgo Pereira) was selected, and it was classified as a highly recommended reservoir for the installation of floating solar panels. Of the other 45 reservoirs, 23 were classified as “Reservoir not recommended for the installation of floating solar panels” and 22 as “Reservoir recommended with observations for the installation of floating solar panels”. Exactly 50% were not recommended and 50% were recommended, and of the 50% recommended, only 1 reservoir had no reservations.

The city of Poço Branco had an energy consumption of 10,825,000 kWh in 2022. It would be necessary approximately 2,255 photovoltaic panels of 1000 W each to supply the monthly demand of 902,083 kWh. Three main types were found: floats for direct support and fixation of the photovoltaic modules, floats added with metal structures to support the photovoltaic modules, and engineered membranes and mats.

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