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MODELING AND ANALYSIS OF FLOATING SOLAR PANELS WITH TRACKING SYSTEM FOR HYDROELECTRIC PLANTS IN THE AMAZON REGION OF BRAZIL

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Abstract. *Renewable energy sources are gaining global attention as solutions to the challenges of fossil fuels. Solar, wind, hydro, geothermal, and biomass energy harness continuously replenished resources, curbing environmental impacts and lessening reliance on non-renewables. An emerging concept in solar energy is the installation of floating photovoltaic plants on water bodies, using platforms to mount solar panels. However, variable solar radiation intensity due to location requires efficient utilization, and intermittency can be mitigated by energy storage. Adaptable solar panel positioning, through tracking systems, is crucial for optimizing sunlight exposure. While these systems are common on land, their application in floating plants is complex. This study aims to evaluate the potential benefits of incorporating solar tracking systems in floating photovoltaic plants, specifically in the Amazon region of Brazil. Mathematical models and simulations will analyze panel dynamics under equatorial conditions, in order to improve energy production efficiency, and sustainability of Amazon floating solar installations. This research contributes to the advancement of renewable technology and sustainable energy practices in the region.*

Keywords: *Renewable energy sources, photovoltaic plants, dynamical analysis, solar tracking systems, floating photovoltaic plants.*

1. INTRODUCTION

As the world faces a pressing global energy crisis and strives to combat the detrimental impacts of climate change, the adoption of renewable energy sources has emerged as a key solution (Pawar *et al.*, 2021; Hammoumi *et al.*, 2022; Alberti *et al.*, 2023). Within this context, the Amazon region of Brazil stands out as an extraordinary opportunity for sustainable power generation by capitalizing on solar energy (de Freitas, 2022). This can be achieved through the strategic integration of advanced floating solar panels integrated within existing hydroelectric plants (Rauf *et al.*, 2020; Piancó *et al.*, 2022; Vidović *et al.*, 2023). This innovative fusion of solar photovoltaic technology and hydroelectric infrastructure has tremendous potential to revolutionize energy production in the Amazon, taking advantage of its abundant sunlight resources and using the already established hydroelectric facilities (Rashid *et al.*, 2022; Claus and López, 2023).

This study focuses primarily on performing a thorough modeling and dynamic analysis of floating solar panels equipped with specialized tracking systems (Ferrer-Gisbert *et al.*, 2013; Yasmeena and Das, 2015). These systems are purposefully designed for integration with hydroelectric plants located within the Amazon region. The main goal is to evaluate the behavior and performance of this integrated system, with the aim of improving its overall efficiency and maximizing its power generation capabilities (Trapani and Millar, 2016). Through this analysis, the potential of this innovative technology for its contribution to sustainable energy generation in the Amazon is exploited.

By using some techniques Choi *et al.* (2021, 2022); Abbasnia *et al.* (2022); Exley *et al.* (2022), this study aims to investigate the dynamic characteristics of floating solar panels with tracking systems. Factors such as solar irradiation patterns, water flow dynamics, and the distinct environmental conditions found in the Amazon region will be considered (Choi *et al.*, 2023; Prinsloo *et al.*, 2023). By comprehensively understanding of the interaction between variables such as angles of inclination, angular velocities, and solar irradiation position, it is possible to pave the way for sustainable and efficient energy solutions in the Amazon. This work aims to focus on the modeling and dynamic analysis of floating solar panels with tracking systems aimed at integration with a hydroelectric plant in the Amazon region of Brazil to determine

how waves affect azimuth and elevation angles, and thus the overall efficiency on the solar panel.

This work is organized into four sections as follows. First, in Section 2, it is presented the solar panel model with tracking system and their equations. In Section 3, a numerical simulation of the motion of the floating solar panel with a tracking system was conducted, obtaining information regarding the angular velocities of the system, tracking angles and the. Finally, the final remarks and future works are discussed.

2. A FLOATING SOLAR PANEL WITH A TRACKER SYSTEM

The floating photovoltaic plant is composed of a series connection of floating modules that form a flexible platform, as can be seen in Figure (1), in which the walking and the main floating modules move in relation to each other when subjected to the effects of waves. The floats provide support to ensure that the structure remains on the water surface. The photovoltaic (PV) panels are mounted under the main floating modules separated by a row of walking modules, Figure (1(b)). The floating modules are constructed from plastic materials that resist UV light, are safe for the environment, require minimal maintenance, and have strong durability, such as high-density polyethylene (HDPE). The anchoring mechanism ensures the stability of the floating photovoltaic (FPV) plant, restricting excessive motion to avoid harm to the plant or nearby floating entities. In freshwater initiatives, materials such as artificial fiber cords, stretchable rubber cables, or a mix of these are employed.

In the analysis of the dynamics of the floating system, it was considered only one of the components comprising the main floating and the PV panel. Figure (1(c)) illustrates a solar panel with a tracker system under a main floating module. First, the point O is taken as a reference, \mathcal{I} , with the axis (x, y, z) and $\{\hat{i}, \hat{j}, \hat{k}\}$ centered in O . The structure rotates around the axis y with angular velocity, ω , constant. The solar panel rotates¹ around $x \equiv x_1$ in a positive way, with angular velocity $\dot{\theta}$ and angle θ in the reference system \mathcal{B}_1 with (x_1, y_1, z_1) and $\{\hat{i}_1, \hat{j}_1, \hat{k}_1\}$. The center of mass of the panel is represented by the point O and the distance from the point A to this point along the axis x is ℓ and the distance from the point B to the point A along the axis y_1 is h .



(c)
 Figure 1. Floating solar panel with a tracker system.

¹According to the right-hand rule of axis rotation.

By defining the transformation matrices between the coordinate systems \mathcal{I} and \mathcal{B}_1 :

$$\begin{array}{c} \mathcal{I} \\ (x, y, z) \end{array} \longrightarrow \begin{array}{c} \mathcal{B}_1 \\ (x_1, y_1, z_1) \end{array}$$

$${}^{\mathcal{I}}\mathbf{T}^{\mathcal{B}_1} = \mathbf{T}_\theta = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta & \sin \theta \\ 0 & -\sin \theta & \cos \theta \end{bmatrix}$$

The vectors of angular velocities are given by:

$${}^{\mathcal{I}}\boldsymbol{\omega}_{\mathcal{B}_1} = \begin{bmatrix} 0 \\ \omega \\ 0 \end{bmatrix}, \quad {}^{\mathcal{I}}\boldsymbol{\Theta}_{\mathcal{B}_1} = \begin{bmatrix} \dot{\theta} \\ 0 \\ 0 \end{bmatrix}, \quad {}^{\mathcal{I}}\boldsymbol{\Omega}_{\mathcal{B}_1} = \begin{bmatrix} \dot{\theta} \\ \omega \\ 0 \end{bmatrix}$$

where $\boldsymbol{\Omega}$ is the vector of angular velocities resulting from the sum of $\boldsymbol{\Theta}$ and $\boldsymbol{\omega}$.

The model of the floating module used in this study is similar to that presented by Jambersi *et al.* (2017). It is considered that the floating system oscillates around a line of static equilibrium and is subjected to forces resulting from the action of the lake waves. These efforts have been modeled as concentrated forces acting at two points, F (frontal) and R (rear) of the float. Despite the nomenclature used here, waves “impact” first at the R point and “exit” through the F point. Figure (2) shows the FBD (free-body diagram) of floating in this situation.

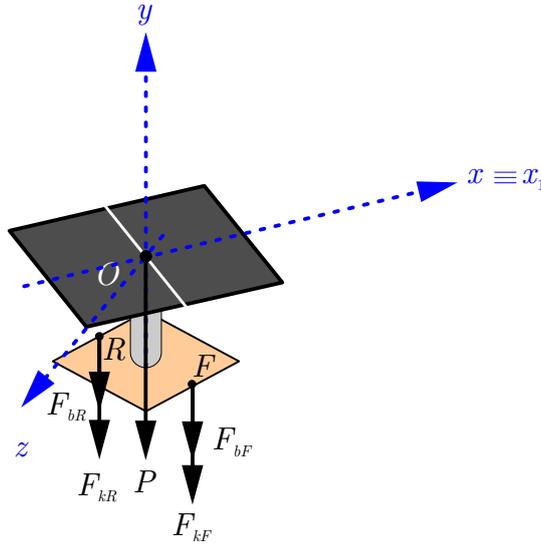


Figure 2. Free body diagram of the floating solar panel (represented here with a simple geometry), subjected to restoring forces applied at F and R.

The terms F_{kF} and F_{kR} represent the hydrostatic stiffness forces, or vertical lift/restore (buoyancy) forces, caused by the action of lake waves, acting at the points F and R on the float. F_{bF} and F_{bR} are the hydrodynamic damping forces, also caused by the incidence of lake waves acting at the points F and R , of a dissipative nature. Due to the restoring nature of these efforts, these forces always act in the opposite direction of motion and in the vertical direction (axis y of the inertial reference system), and their magnitudes vary with time. These magnitudes are given by:

$$F_{kF} = k_F (y_F - w_F) \quad (1)$$

$$F_{kR} = k_R (y_R - w_R) \quad (2)$$

$$F_{bF} = b_F (\dot{y}_F - \dot{w}_F) \quad (3)$$

$$F_{bR} = b_R (\dot{y}_R - \dot{w}_R) \quad (4)$$

where k_F and k_R are the hydrostatic stiffness constants, in [N/m], b_F and b_R are the hydrodynamic damping constants, in [Ns/m], y_F and y_R are the displacements, \dot{y}_F and \dot{y}_R the instantaneous velocities, w_F and w_R the amplitudes, \dot{w}_F and \dot{w}_R are the velocities of the waves, with respect F and R .

To determine wave forces in an aquatic FPV framework, it is crucial to take into account wave motion principles. Among them, the Airy wave model is particularly prevalent. Eq. (5) illustrates the variations in water level in real time due to a wave moving in the x direction:

$$\eta(x, t) = \frac{H}{2} \cos\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right) \quad (5)$$

where t is the time, H is the wave height, λ is the wavelength, and T is the wave period.

The angular momentum, \mathbf{H}_O , by considering the center of mass, O , is given by:

$${}_{\mathcal{I}}\mathbf{H}_O = {}_{\mathcal{I}}\mathbb{I}_O \boldsymbol{\Omega} + \underbrace{m {}_{\mathcal{I}}\mathbf{r}_{O-O}}_{=0} \times {}_{\mathcal{I}}\mathbf{v}_O = \begin{bmatrix} 6.8736 & -0.0053 & 2.9999 \\ -0.0053 & 5.8159 & 0.0009 \\ 2.9999 & 0.0009 & 14.5383 \end{bmatrix} \begin{Bmatrix} \dot{\theta} \\ \omega \\ 0 \end{Bmatrix} = \begin{Bmatrix} 6.8736\dot{\theta} - 0.0053\omega \\ -0.0053\dot{\theta} + 5.8159\omega \\ 2.9999\dot{\theta} + 0.0009\omega \end{Bmatrix} \quad (6)$$

where ${}_{\mathcal{I}}\mathbb{I}_O$ is the tensor of inertia of the solar panel and whose values can be extracted within the CAD software where the floating solar panel was modeled. Since point O was considered as the center of mass, the position vector from the center of mass to point O is zero.

The gyroscopic torque can be calculated using:

$${}_{\mathcal{I}}\boldsymbol{\Omega} \times {}_{\mathcal{I}}\mathbf{H}_O = \begin{Bmatrix} 2.9999\dot{\theta}\omega + 0.0009\omega^2 \\ -2.9999\dot{\theta}^2 - 0.0009\omega\dot{\theta} \\ -0.0053\dot{\theta}^2 + 5.8159\omega\dot{\theta} - 6.8736\dot{\theta}\omega + 0.0053\omega^2 \end{Bmatrix} \quad (7)$$

The Euler equation can be easily calculated. This equation relates the sum of external torques applied in relation to the center of mass with the rate of change of angular momentum also calculated in relation to the center of mass of the float. So:

$${}_{\mathcal{I}}\dot{\mathbf{H}}_O = {}_{\mathcal{I}}\mathbb{I}_O \frac{d}{dt} ({}_{\mathcal{I}}\boldsymbol{\omega}) + {}_{\mathcal{I}}\boldsymbol{\Omega} \times ({}_{\mathcal{I}}\mathbb{I}_O \boldsymbol{\omega}) + m {}_{\mathcal{I}}\mathbf{r}_{O-O} \times {}_{\mathcal{I}}\mathbf{a}_O = {}_{\mathcal{I}}\mathbf{T}_O \quad (8)$$

So the motion equations can be obtained in a matricial form as:

$$\begin{bmatrix} m & 0 \\ 0 & (I_{xx} + I_{yx} + I_{zx}) \end{bmatrix} \begin{Bmatrix} \ddot{y} \\ \ddot{\theta} \end{Bmatrix} = \begin{Bmatrix} -(F_{kF} + F_{kR} + F_{bF} + F_{bR}) \\ [(F_{kF} + F_{bF}) - (F_{kR} + F_{bR})] \frac{\ell}{2} \cos \theta \end{Bmatrix} \quad (9)$$

where I_{xx} is the moment of inertia, I_{yx} and I_{zx} are the product of inertia.

3. FLOATING SOLAR PANEL SIMULATION WITH TWO-AXIS TRACKING SYSTEM

This section presents numerical simulations of the equations that govern the motion of the floating photovoltaic solar panel. The simulations aim to demonstrate how the horizontal and vertical angles of the panel behave as the sun occupies different positions, as well as to assess the behavior of the angular velocities of this system. Finally, the simulations also analyze the energy generated by the solar panel during the operational regime.

For the integration of the equations, the Runge-Kutta method was used, along with null initial conditions for $\theta(0)$ and $\dot{\theta}(0)$. The integration step used was $\Delta_t = 0.005$ s. The weight is $m = 33.3$ kg, the dimensions of the module are $2.384 \times 1.303 \times 0.033$ m, the water density is 1000 kg/m³, the solar intensity is 1000 W/m² (Vitória do Xingu - Pará, latitude -3.1984° and longitude -52.5688°), the wave height considered is 0.5 m, the wind speed is 5 m/s, the air density is 1.225 kg/m³, and the wave amplitude is 5° . Definition of minimum and maximum frequencies: the domain must be defined as a way to characterize the largest number of waves possible, since the relationship between frequency and period is inverse and the incidence of swell waves in Belo Monte lake is not considerable. In the case of this work, the domain used was between 0.3 and 1 Hz Sobrinho *et al.* (2011). The values of the waves used in this work can be found in de Oliveira Mattosinho *et al.* (2021).

Figure (3(a)) shows the behavior of the azimuth angle of the tracker. The azimuth angle of a floating solar panel with a tracking system is an important parameter that determines the panel's orientation in the horizontal plane. It is measured in radians and represents the angle between the direction of the panel's face and the true north. The optimal azimuth angle for a floating solar panel would typically be towards the geographical south, as this orientation allows the panel to receive the maximum amount of sunlight throughout the day. However, with a tracking system, the panel can dynamically adjust its azimuth angle to follow the movement of the sun across the sky. By continuously tracking the sun's position,

the floating solar panel with a tracking system can maintain an optimal azimuth angle, ensuring that the panel's surface is directly facing the sun for the highest possible solar energy capture. This tracking capability allows the panel to maximize its energy output by effectively utilizing the available sunlight, even as the sun moves from east to west during the day. In Figure 3(b) it is possible to see the elevation angle of the solar panel. The elevation angle refers to the vertical angle at which the panel is tilted or inclined relative to the horizontal plane. It plays a crucial role in optimizing the solar panel's performance by maximizing the direct exposure to sunlight throughout the year. This adjustment allows the solar panel to capture the maximum amount of solar energy throughout the year. By optimizing this angle, the system can achieve higher energy efficiency and contribute to the overall sustainability of solar power generation.

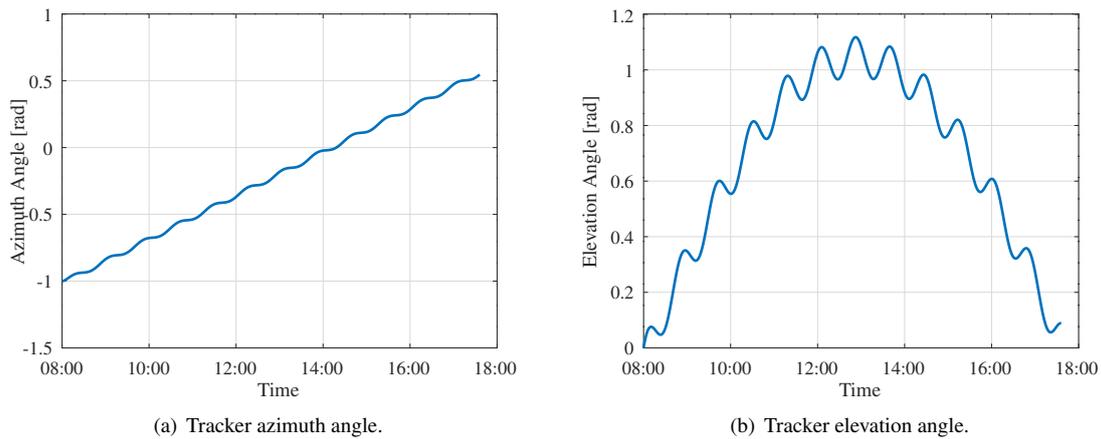


Figure 3. Azimuth and Elevation angles of the solar panel.

Figure 4 shows the azimuth and elevation angular velocities, ω and $\dot{\theta}$ respectively. Although long, the velocities are compatible with the motion of the sun. Waves introduce disturbances in the azimuth and elevation velocities, which, in turn, can introduce spikes or irregularities in the azimuth velocity as the tracking system compensates. If these disturbances are significant and frequent, it is possible to see more jagged or oscillatory behavior in the velocities profiles.

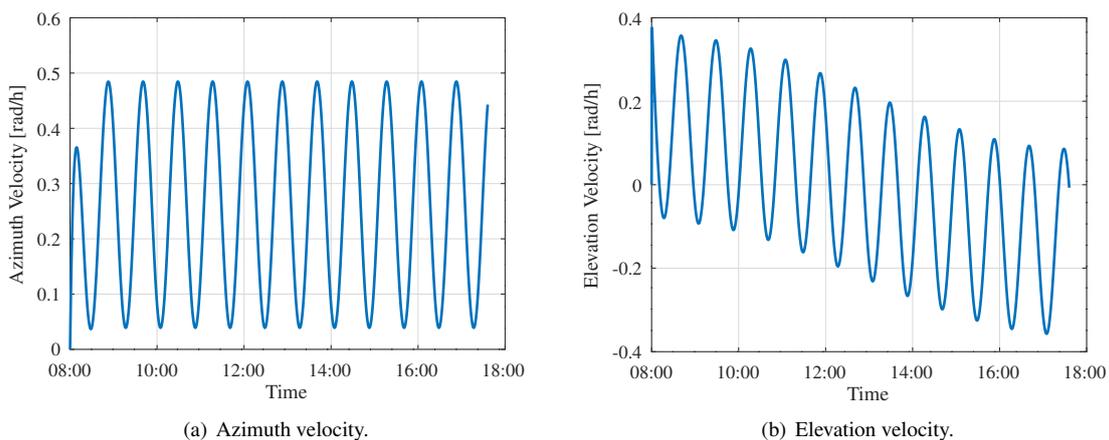


Figure 4. Angular velocities of the solar panel.

Figure 5 shows the cumulative energy generated in one day. At the start of the day, the cumulative energy generated will be zero or very low. As the Sun begins to rise, energy generation will start and continue to accumulate. There will be a gradual increase as the sun moves towards its zenith. Around midday (solar noon), when the Sun reaches its highest point in the sky (its zenith), the potential for energy generation is at its maximum. If the tracking system works perfectly and wave disturbances are minimal, the photovoltaic system will capture the maximum amount of sunlight, leading to the steepest slope on the cumulative energy graph.

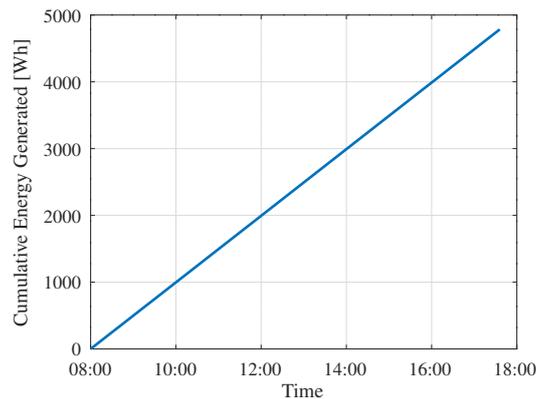


Figure 5. Energy Generated by the Solar Panel.

4. FINAL REMARKS

The modeling and analysis of floating solar panels systems integrated in a hydroelectric plant in the Amazon region of Brazil present significant potential to improve renewable energy generation. By integrating solar panels on the water surface of hydroelectric reservoirs, this approach takes advantage of underutilized resources and offers several advantages. The implementation of floating solar panels with tracking systems should allow an improvement of sunlight capture throughout the day, maximizing energy production.

This work presented the dynamic model of a floating solar panel with a tracking system. Through numerical simulations, the behavior of the elevation and azimuth angles of the floating solar panel, as well as their respective velocities, could be studied. This allowed an understanding of the dynamics of this mechanical system and its potential implementation at the Belo Monte hydroelectric power plant. The tracking system successfully detected and tracked the apparent position of the Sun during periods of high solar irradiation. Additionally, the system incorporated a mechanism to handle exceptions during low irradiation intervals, aiming to minimize unnecessary movements in the tracker by either seeking or avoiding them.

It is possible to observe that the trajectory of the Sun across the sky sets the baseline for potential energy collection. When the Sun is at its zenith (maximum elevation), the potential solar irradiance on a perfectly aligned photovoltaic panel is at its peak. This time is often around solar noon, but not always exactly at 12 PM due to the equation of time, latitude, and other factors. As the day progresses, the solar irradiance potential decreases as the sun approaches sunset. The tracking system attempts to keep the photovoltaic panel oriented toward the sun, maximizing energy collection. In the absence of any disturbances (like waves), a perfect tracking system would ensure that the photovoltaic panel is always normal to the Sun's rays, ensuring maximum energy capture. The difference between a fixed and a tracking system can be significant in terms of energy capture over a day. Waves introduce disturbances that deviate the photovoltaic panel from its ideal orientation. This reduces the energy collection as the panel becomes misaligned with the sun. The magnitude of this effect depends on the amplitude and frequency of the wave disturbances. Larger waves or faster wave patterns can cause more significant misalignments.

To consider low irradiation intervals, it is necessary to address moments when the Sun is low on the horizon or when other conditions (e.g., cloud cover) significantly reduce the solar irradiance. These conditions can have an impact on the effectiveness of a tracking system and consequently on the energy generated by the solar panel. To this end, a more detailed and in-depth analysis of the tracking system control system needs to be carried out. The idea is to create a control system and combine with the use of solarimetric charts. To do this, it is necessary to survey the types of sensors that can be used and how to combine them.

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REFERENCES

- Abbasnia, A., Karimirad, M., Friel, D. and Whittaker, T., 2022. "Fully nonlinear dynamics of floating solar platform with twin hull by tubular floaters in ocean waves". *Ocean Engineering*, Vol. 257, p. 111320.
- Alberti, E.L., Paludo, R., Portella, K.F., Bragança, M.D.G.P., Rocha, G.P.U., Mazur, M.M. and Portella, A.C.F., 2023. "New concept on 100.74 kWp floating solar photovoltaic plant and a real mechanical failures assessment: Case of

- study at Santa Clara hydroelectric power plant reservoir in southern Brazil”. *Sustainable Energy Technologies and Assessments*, Vol. 60, p. 103455.
- Choi, S.M., Lee, G.R., Park, C.D., Cho, S.H. and Lim, B.J., 2021. “Wind load on the solar panel array of a floating photovoltaic system under extreme hurricane conditions”. *Sustainable Energy Technologies and Assessments*, Vol. 48, p. 101616.
- Choi, S.M., Park, C.D., Cho, S.H. and Lim, B.J., 2022. “Effects of wind loads on the solar panel array of a floating photovoltaic system – experimental study and economic analysis”. *Energy*, Vol. 256, p. 124649.
- Choi, S.M., Park, C.D., Cho, S.H. and Lim, B.J., 2023. “Effects of various inlet angle of wind and wave loads on floating photovoltaic system considering stress distributions”. *Journal of Cleaner Production*, Vol. 387, p. 135876.
- Claus, R. and López, M., 2023. “A methodology to assess the dynamic response and the structural performance of floating photovoltaic systems”. *Solar Energy*, Vol. 262, p. 111826.
- de Freitas, B.M.R., 2022. “What's driving solar energy adoption in Brazil? Exploring settlement patterns of place and space”. *Energy Research and Social Science*, Vol. 89, p. 102660.
- de Oliveira Mattosinho, G., de Freitas Maciel, G., de Oliveira Ferreira, F. and Vieira, A.S., 2021. “Estimativa de altura de ondas geradas por ventos no reservatório de Belo Monte – PA / Predicting wind waves’s height in Belo Monte reservoir – PA”. *Brazilian Journal of Development*, Vol. 7, No. 8, pp. 80255–80271.
- Exley, G., Page, T., Thackeray, S.J., Folkard, A.M., Couture, R.M., Hernandez, R.R., Cagle, A.E., Salk, K.R., Clous, L., Whittaker, P., Chipps, M. and Armstrong, A., 2022. “Floating solar panels on reservoirs impact phytoplankton populations: A modelling experiment”. *Journal of Environmental Management*, Vol. 324, p. 116410.
- Ferrer-Gisbert, C., Ferrán-Gozálvez, J.J., Redón-Santafé, M., Ferrer-Gisbert, P., Sánchez-Romero, F.J. and Torregrosa-Soler, J.B., 2013. “A new photovoltaic floating cover system for water reservoirs”. *Renewable Energy*, Vol. 60, pp. 63–70.
- Hammoumi, A.E., Chtita, S., Motahhir, S. and Ghzizal, A.E., 2022. “Solar PV energy: From material to use, and the most commonly used techniques to maximize the power output of PV systems: A focus on solar trackers and floating solar panels”. *Energy Reports*, Vol. 8, pp. 11992–12010.
- Jambersi, A.B., Pereira, J.A., Turra, A.E. and da Silva, S., 2017. “Modelo dinâmico de um módulo da planta solar fotovoltaica flutuante instalada no lago da usina hidrelétrica de Porto Primavera-SP”. In *Conferência Brasileira de Dinâmica, Controle e Aplicações, DINCON 2017*.
- Pawar, P., Pawale, P., Nagthane, T., Thakre, M. and Jangale, N., 2021. “Performance enhancement of dual axis solar tracker system for solar panels using proteus ISIS 7.6 software package”. *Global Transitions Proceedings*, Vol. 2, No. 2, pp. 455–460.
- Piancó, F., Moraes, L., dos Prazeres, I., Lima, A.G.G., Bessa, J.G., Micheli, L., Fernández, E. and Almonacid, F., 2022. “Hydroelectric operation for hybridization with a floating photovoltaic plant: A case of study”. *Renewable Energy*, Vol. 201, pp. 85–95.
- Prinsloo, F., Schmitz, P. and Lombard, A., 2023. “System dynamics characterisation and synthesis of floating photovoltaics in terms of energy, environmental and economic parameters with WELF nexus sustainability features”. *Sustainable Energy Technologies and Assessments*, Vol. 55, p. 102901.
- Rashid, F.L., Al-Obaidi, M.A., Hussein, A.K., Akkurt, N., Ali, B. and Younis, O., 2022. “Floating solar stills and floating solar-driven membranes: Recent advances and overview of designs, performance and modern combinations”. *Solar Energy*, Vol. 247, pp. 355–372.
- Rauf, H., Gull, M.S. and Arshad, N., 2020. “Complementing hydroelectric power with floating solar PV for daytime peak electricity demand”. *Renewable Energy*, Vol. 162, pp. 1227–1242.
- Sobrinho, M.D., Trovati, L.R., de Freitas Maciel, G., de Oliveira, J.N., Albertin, L.L., Oliveira, B.M., Lima, G.B., Oliveira, E.B. and Cunha, E.F., 2011. “Monitoramento de ondas em reservatórios com sensor de pressão e comparação com dados de ADCP-waves”. In *Anais do XIX Simpósio Brasileiro de Recursos Hídricos*.
- Trapani, K. and Millar, D., 2016. “Floating photovoltaic arrays to power the mining industry: A case study for the mcfaulds lake (ring of fire)”. *Environmental Progress & Sustainable Energy*, Vol. 35.
- Vidović, V., Krajačić, G., Matak, N., Stunjek, G. and Mimica, M., 2023. “Review of the potentials for implementation of floating solar panels on lakes and water reservoirs”. *Renewable and Sustainable Energy Reviews*, Vol. 178, p. 113237.
- Yasmeena, S. and Das, G.T.R., 2015. “A review on new era of solar power systems: Floatovoltaic systems or floating solar power plants”. *Journal on Instrumentation and Control Engineering*, Vol. 3, No. 1, pp. 1–8.

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