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Analysis of Biological, Chemical, and Physical Parameters to Evaluate the Effect of Floating Solar PV in Mahoni Lake, Depok, Indonesia: Mesocosm Experiment Study

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ABSTRACT

Waters provide essential needs both for human societies as well as natural ecosystems. Floating solar PV (FPV) applications on water bodies are currently in strong demand worldwide. Floating solar PV system is a new concept in renewable energy with the solar plants by harnessing available water surface, such in dams, lakes, and other water bodies. Although the floating solar PV industry is becoming more and more popular, the study on the biological, chemical, and physical properties effects of using FPV cover on natural water coverage – especially in tropical countries – has not been widely carried out yet. This paper aimed to evaluate the effect of floating solar PV on temperature, DO (dissolved oxygen), TDS (total dissolved solids), total phosphorus concentration, and chlorophyll-a concentration using mesocosm experiments to understand the biological, chemical, and physical process under closed environment. The experiment was conducted in a natural water body, Mahoni Lake, in which a total amount of 7 water samples were collected from each mesocosms. The results show that the floating solar PV reduces the average temperature, DO, conductivity, TDS, and chlorophyll-a concentration changes (p-value < 0.05); and the floating solar PV does not directly reduce the average total phosphorus concentration due to high probability of thermal stratification (p-value > 0.05).

Keywords: floating solar PV, mesocosm, natural water, ecosystem.

INTRODUCTION

In recent years, the fast development of renewable energy and the demand to reduce greenhouse gases have initiated solar-powered developments all across the globe. The Indonesian government aims to widen the solar-powered utilizations in Indonesia up to 6.5 GW in 2025. In this context, photovoltaic energy (PV) is one of the most promising energy sources because of its eco-friendly and sustainable characteristic [Patil et al., 2017; Sahu et al., 2016]. Floating solar PV system is a new concept in renewable energy that is still in development, produced from the combination of PV plants technology and floating technology [Sahu et al., 2016]. Floating solar PV system is a new solar plant harnessing the available water surface, such in dams, lakes, and other water bodies [Choi, 2014]. Floating solar PV have additionally been demonstrated to achieve several environmental advantages, including reducing vaporization in water bodies or reservoirs [Santafé et al., 2014; Taboada et al., 2016] and enhancing water quality by covering water surface to limit the increase of algae [Chang et al., 2014]. A number of studies have developed advanced mathematical models to study the effect of covering the surface area with floating solar PVs on the ecological effects of reservoirs [Haas et al., 2020; Santafé et al., 2014] or fish ponds [Château et al., 2019] in subtropical countries. Floating solar PV system technology is still in its early stage of development, in which it is still poverty of study and long-term statistical data of FPV coverage effect on the environment, especially on natural water.

In order to solve the aforementioned problems, an experimental study regarding the effect of floating solar PV system (solar photovoltaic system deployed on water bodies) on changes of the biological, chemical, and physical parameters in Mahoni Lake using mesocosm experiments was presented. The understanding of complex interactions in natural water ecosystems is often limited by the methodological approaches used. The more complex the ecologic, the more coherent the experimental setup should be [Šorf et al., 2013]. The term enclosed experimental ecosystem is used when the purpose of an enclosed experiment, whether carried out in laboratory or in field, is to explore the interactions between organisms, or between organisms and their chemical as well as physical environment [Petersen & Kemp, 2019]. Many studies use these enclosed experiments to examine the ecosystem responses to factors such as nutrient addition [Tonetta et al., 2018; Zingel et al., 2018], light limitation [Gillette et al., 2014; Winder et al., 2012], climate change [Landkildehus et al., 2014; Stewart et al., 2013], and others. In situ mesocosms are used to observe the effects of floating solar PV cover as a way to evaluate and investigate the biological, chemical, and physical processes under closed environment. The authors consider that closer interactions among bench and field studies might be beneficial by means of contributing to a better scientific understanding of the effect of floating solar PV in a particular manner [Machado et al., 2019].

The research implements mesocosm experiments to understand the biological, chemical, and physical changes in natural water due to the floating solar PV coverage. The data obtained by the authors is a comparison of the data between the mesocosm covered by FPV and the mesocosm which is not covered by FPV. A variety of parameters were analyzed to determine water quality, including variables such as, water temperature, DO (dissolved oxygen), TDS (total dissolved solids), total phosphorus, and chlorophyll-a concentration. Trends in the parameters were recorded over time and compared to those taken from mesocosms without FPV cover.

MATERIALS AND METHODS

The study focuses on the biological, chemical, and physical assessment to the impact of floating solar PV system carried out by mesocosm experiment. The mesocosm experiment was performed at the epilimnion zone of Mahoni Lake (6°21’48.8304” S; 106°49’31.3824” E) in Universitas Indonesia, Depok City, Indonesia. Mahoni Lake has average depth of 1.5 m with surface area of 52,996 m^2. This lake has the first floating bifacial photovoltaic module in Indonesia. The floating solar PV has a total capacity of 9.36 kWp and has 36 solar panels, including 27 panels of Bifacial Floating Solar PV type (BFSPV) and 9 panels of Monofacial Solar PV (MFSPV). It covers an area of 170 m^2, and is also equipped with 180 kg weight anchor on the north side and 80 kg in the south on both sides. This floating PV faces north side, with a PV tilt angle of 10° [Syahindra et al., 2021; Widayat et al., 2020].

The mesocosm had the dimensions of L×W×H = 50×50×100 cm, ± 200 L in volume, and the water inside the mesocosm was taken from Mahoni Lake, excluding the sediments. Each water was taken at the same depth of the lake to avoid damage to biological community and to maintain similar biological composition for every replication [Tonetta et al., 2018]. The mesocosm was made by isolating it, where it was made impossible for water to flow inward, which may cause the water in mesocosm and lake water to mix. To study the effect of FPV cover, mesocosms were tied strongly to pontoon/floater of solar panel and were placed under the following conditions: (1) covered/placed under FPV panels with 100% shading rate (P1 and P2) and (2) without FPV panel with 0% shading rate (NP1 and NP2) (seen in Figure 1).

The mesocosm experiment was conducted from March 25th to April 15th 2021. The study was done both directly (in situ) and in the laboratory (ex situ). Between 10:00 and 12:00 AM, a total of 7 water samples were collected from each of the four mesocosms at 30 cm depth with approximately 500 mL volume to analyze their contents of total phosphorus and chlorophyll-a in the laboratory. Chlorophyll-a (Chl-a) was determined by using DMSO and 90% acetone extraction method and was measured by Ultraviolet-Visible (UV-Vis) spectrophotometry. The determination of total phosphorus was performed adopting the amino acid method (adapted from Standard Methods for the Examination of Water and Wastewater).

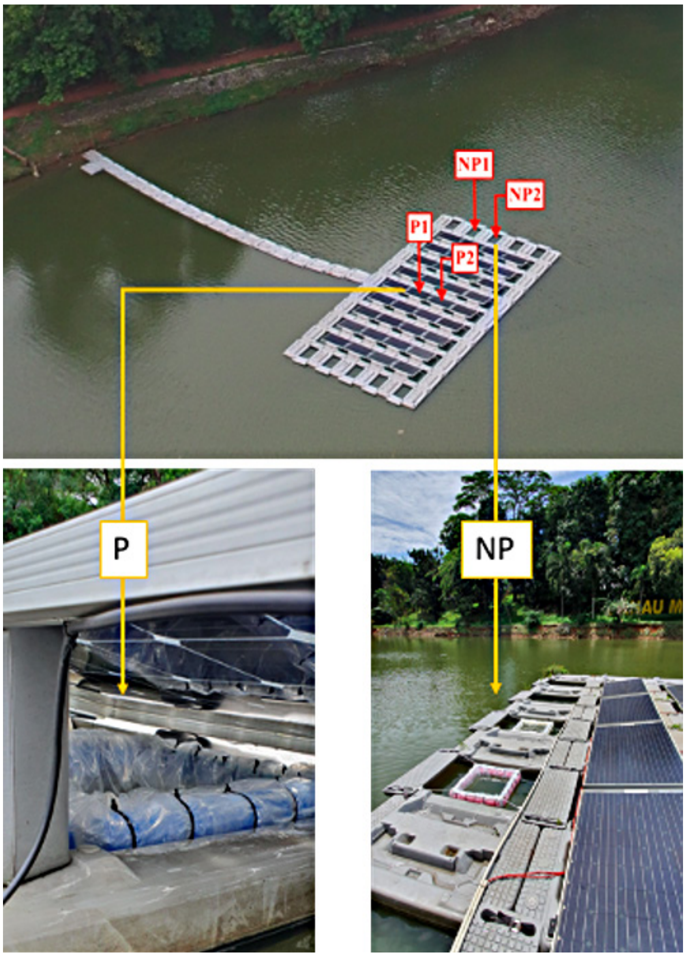

Figure 1. Mesocosm deploy points

Temperature measurement was done using digital thermometer, DO measurement was done using DO Meter Lutron PDO-519, and TDS measurement was done using Datalogger device Lutron WA-2017SD. A two-sample t-test is used to determine the statistical difference evaluation of all parameters between mesocosms with 100% FPV cover (P) and mesocosms without FPV cover as control (NP). Statistical evaluation was conducted using Microsoft Excel version 16.43.

RESULTS AND DISCUSSION

According to the data acquired from sampling, the temperature parameter was affected by climate/weather during sampling. As it can be seen from the graph in Figure 2, the water temperature of NP1 and NP2 were higher than the water temperature of P1 and P2 (p-value < 0.05). According to sampling documentations, during the second and third sampling, which were on March 29th and April 1st, respectively, the weather was cloudy (no visible sun); hence, there was no significant temperature difference between NP1 and NP2 as well as P1 and P2 during the aforementioned period of days. On the other hand, during the first and fourth through seventh sampling, which was on March 25th and April 5th through April 15th, the weather was sunny, thus contributing to a significant temperature difference between NP1 and NP2 as well as P1 and P2. Air temperature shifts to water temperature through convection, and also rises with global radiation during the day [Château et al., 2019]. P1 and P2 were placed under FPV modules with lower water temperature due to fewer air circulation [Lereng, 2018]. Ponds or shallow lakes generally tend to have thermal stratification because the water in shallow water bodies often mixes [Rocha et al., 2009; Wetzel, 2001]. However, in this case, since P1 and P2 systems were placed under FPV modules and they received fewer air circulation, the probability of thermal stratification occurring on those mesocosm systems were higher.

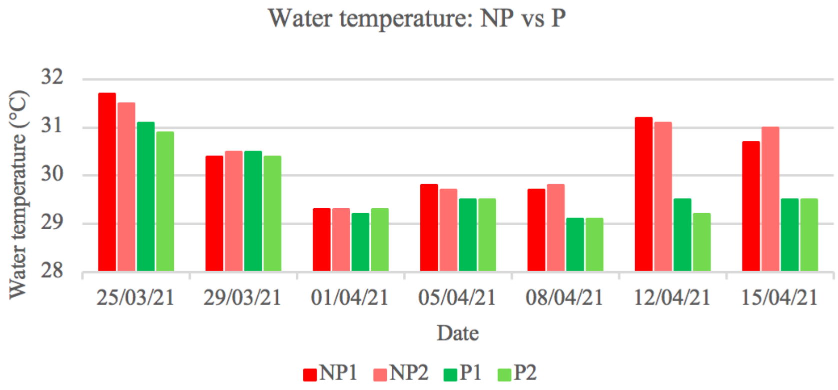

Figure 2. Change of temperature during the measurement period (22 days)

Dissolved oxygen (DO) infiltrates into water through diffusion from atmosphere and serves as a side product of photosynthesis by algae and other aquatic plants [Gorde & Jadhav, 2013]. As it can be seen in the graph in Figure 3, the DO concentrations in NP1 and NP2 were higher compared to the DO concentrations in P1 and P2 (p-value < 0.05). The monitored results indicate that the parameters of DO in P1 and P2 are lower than the water quality standards for lake water class 2 under new Government Decree No. 22 Year 2021, which is 4 mg/L. The light that covers water surface certainly affects the change of dissolved oxygen concentration [Li et al., 2011]. During the day where there was light from the sun, dissolved oxygen was affected by algae photosynthesis process [Château et al., 2019; Yeh et al., 2014]. Covering water bodies could obstruct sunlight from reaching water which eventually affected the change of dissolved oxygen in water [Li et al., 2011]. Dissolved oxygen was affected by algae photosynthesis, thus the dissolved oxygen in NP had a higher value than the dissolved oxygen in P.

Total dissolved solid (TDS) indicates nutrition concentration within solution in part per million (ppm) or parts per thousand (ppt). TDS measurement indicates the amount of dissolved ion in water. TDS contains beneficial mineral and organic molecules such as nutrition [Weber-Scannell & Duffy, 2007]. According to the graph in Figure 4, TDS values of NP1 and NP2 were lower than P1 and P2 (p-value < 0.05). The high TDS values of P1 and P2 may be caused by the large amount of nutrition concentrations dissolved in water, with phosphorus being one of them [Li et al., 2011]. The accumulation of unused dissolved nutrient (phosphorus, nitrogen, etc) content in water might cause TDS value increase on the mesocosm system.

Phosphorus, like nitrogen, is a crucial nutrition for all living things. As seen in the graph in Figure 5, total phosphorus on all four mesocosm systems showed a significant decrease. Shallow water bodies usually only have small tendency to undergo thermal stratification, due to how it often mixes [Rocha et al., 2009; Wetzel, 2001]. However, because all four mesocosms were made under isolation, it

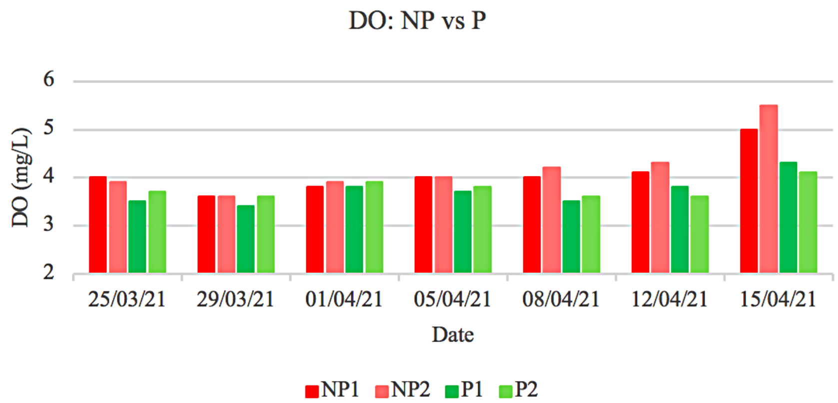

Figure 3. Change of dissolved oxygen during the measurement period (22 days)

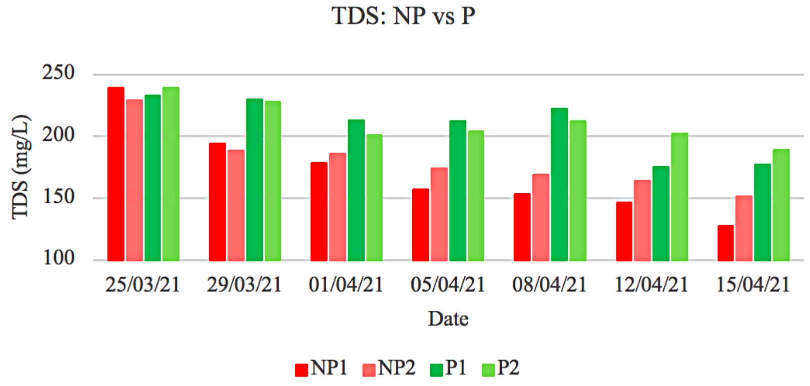

Figure 4. Change of total dissolved solid during the measurement period (22 days)

was impossible for mixing to happen, which caused high probability of thermal stratification to occur. During stratification, diluted phosphorus sedimented from epilimnion to hypolimnion. After the particles sedimented, the only time when phosphorus reemerged to the water surface was during seasonal change (turnover) [Havens et al., 2007].

Chlorophyll pigment analysis in water algae was an important biological measurement, usually used to determine total biomass in water. According to Figure 6, the chlorophyll-a concentrations in P1 and P2 were lower than the chlorophyll-a concentrations in NP1 and NP2 (p-value < 0.05). In P1 and P2, where mesocosm was covered by floating solar panel with 100% coverage, the chlorophyll-a concentration decreased due to the decline of photosynthesis process in the mesocosm system. Meanwhile, in NP1 and NP2 where there was no obstruction between sunlight and water system, the chlorophyll-a concentration

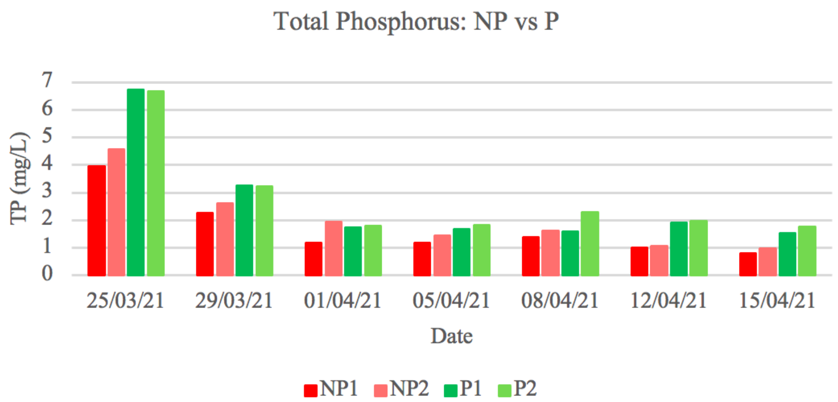

Figure 5. Change of total phosphorus concentrations during the measurement period (22 days)

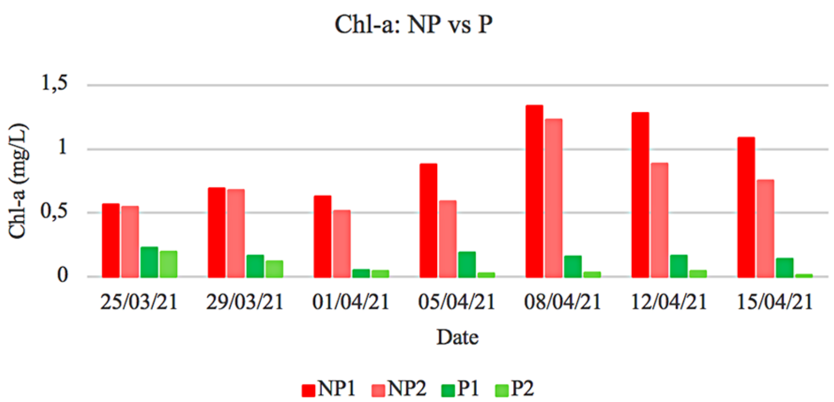

Figure 6. Change of chlorophyll-a concentrations during the measurement period (22 days)

had a fluctuative increase. Generally, the effect of physical coverage on water could prevent algae photosynthesis in water [Yeh et al., 2014]. Floating solar panel may affect ecology because photosynthesis was controlled by light. Extreme coverage could reduce all kinds of pelagic zone primary producer such as microalgae that eventually might have a negative impact on the entire food chain [Haas et al., 2020]. According to World Health Organization (WHO) and the water quality standards for lake water class 2 under new Government Decree No. 22 Year 2021, the chlorophyll-a concentrations in P1 and P2 at the end of the research had reached the maximum chlorophyll-a concentration limit to be considered safe in water recreation environment and freshwater fish farming. If primary producer concentration was continuously low, it would be significantly disadvantageous, because microalgae was an important part of lake's food chain: hence, it potentially could endanger the entire ecosystem.

CONCLUSIONS

According to the results of the study, it can be noted that mesocosms with 100% FPV cover (P) have lower the average temperature, DO, conductivity, TDS, and chlorophyll-a concentration changes (p-value < 0,05) compared to the mesocosms without FPV cover (NP). Compared to mesocosms without FPV cover, the total phosphorus value from mesocosm with 100% FPV coverage is slightly lower. It was caused by the dissolved phosphorus which is likely to undergo thermal stratification from the surface layer to the low temperature layer (from epilimnion to hypolimnion). However, shading with FPV cannot effectively reduce the nutrients in the mesocosm system.

Extreme coverage of water bodies, as simulated in this study (in this case 100% coverage) using floating solar PV, can reduce the dissolved oxygen content and also decrease the value of chlorophyll-a concentrations to the minimum safe limit for the aquatic environment, otherwise it will potentially threaten the aquatic ecosystem under the solar panels. These parameters are crucial for the health of aquatic ecosystems. Therefore, it can be concluded that floating solar PV can have a negative impact on the ecosystem of the natural water body below it to a certain degree. However, for water bodies such as reservoirs/dams designated for drinking water, this can be a useful solution that can benefit from the absence of algae [Haas et al., 2020]. Another solution is to carry out periodic aeration in the water bodies below floating solar PV to increase the dissolved oxygen levels in the water [Chang et al., 2014].

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