Impact Estimation of Offshore Floating Solar Parks on Algae using Ordinary Differential Equations

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Abstract—**Floating solar park deployment increasing as the demand for clean energy increases around the world. These solar parks introduce a new avenue of investment for the clean energy producers, nevertheless increasing offshore floating solar parks affects the marine ecosystem. In this paper mathematical model related to the effect of solar irradiance on the process of photosynthesis is discussed using MATLAB simulation. Along with that growth model of algae is also discussed and simulated that can estimate an impact on marine ecosystem due to halted growth of algae based on solar park size.**

Index Terms— Offshore floating solar parks, Marine ecosystem, Algae, Renewable energy

I. INTRODUCTION

The growing energy demand opens the gate for the development of new energy harvesting resources. The world is shifting from conventional energy sources to renewable energy sources. So, technological advancements to meet energy demands from renewable energy sources urged the producers to make it available on large scales. Photovoltaic panels are one of the prime instrument to harvest electric energy from the sun. Installation of Photovoltaic panels in solar parks requires a lot of lands that is ultimately a costly option for generating electrical energy on large scale. Offshore photovoltaic panel installation will reach 1.9 gigawatts of total global installed capacity at the end of 2025. To avoid the use of land, countries with higher populations are looking at offshore photovoltaic plants at large scales for solar power generation [1].There are different types of solar installations to gain energy from the sun. The installations are classified into the ground mounted, rooftop mounted, pole mounted, canal mounted, offshore and floating topology.

Ground-mounted solar panels are those that use the ground base for their installation. Ground-mounted panels are generally not flat and are mounted on 30º mostly, along

with that sun-tracking (seasonal or daily) is easy in this topology of installation. There are few benefits that ground-mounted topology offers including easy maintenance, increased efficiency, future expansion, angle liberty, and fewer infrastructural changes. On the other hand, ground-mounted topology requires large space and structure that ultimately increases cost. Rooftop mounted solar panels use rooftops of buildings for their installation. This type of installation topology is an exceptional preference for smaller infrastructures because they don't occupy the land. Installation of solar panels by rooftop lower the temperature of domestic residences by controlling the sun rays in hot and humid climate regions. Rooftop topology has very few financial impacts as compared to the ground-mounted topology. Pole-mounted topology is based on structures consist of racks and steel beams. Pole-mounted solar installations are easy to install and feasible for movement. Generally, pole-mounted structures are helpful in dual-axis tracking.

On-ground solar plants requires a large amount of land. The installation of solar panels on canals has many benefits. Initially, it stops the evaporation of fresh water that can be utilized for agricultural purposes, secondly, a large amount of land can be saved along solar panel temperature can be maintained that ultimately increase the output of the solar panel. Solar energy received by the ocean is 70% out of total energy received by the earth. Solar energy can be extracted by using photovoltaic technology in the ocean due to the high cost of land for solar installation [1]. Several reasons can benefit the land requirement but on the other hand, marine life can be affected by the chemicals used in photovoltaic panels and stoppage of light towards oceans. For power generation purposes floating solar panels plants have been established to meet the space constraint problem on land-based solar power plants. However, the generation from floating solar power plants is costly and requires efficient operation and maintenance procedures to obtain an uninterruptable power supply. Effective conversion efficiency while the

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operation is the most important component of solar floating power plants. The major parts for establishing the floating power plants are pontoon, floats, mooring systems, solar PV modules, and cables [2].

Pontoons are used to lift heavy loads. Several pontoons combine to create a large floating setup on which solar panels can be mounted [3]. A mooring system is used to keep the solar panels' floats aligned to avoid any disturbance with high tides. Solar panels with low corrosive materials should be installed with a floating cable and connector system, because corrosion and tuff environmental conditions may affect the strength of the floating power system [4]. Other than cost and installation hindrances, environment and safety are a serious concern for aquatic life that includes quality deterioration due to high-density polyethylene, accidents related to underwater cables, and biodiversity of the whole system may be affected. Moreover, one of the important factors is reduction in the growth of algae due to the non-availability of the sun that can halt the photosynthesis process.

Photosynthesis is an essential process on Earth. It is the process where the Photosynthetic organisms absorb light and transform it into some useful organic molecules, which are the main elements of all the living organisms living on earth. It is estimated that the process of photosynthesis produces approximately 100 billion tons of biomass yearly which is supposed to be equal to one hundred times the weight of the total human population on the earth presently [5]. Photosynthetic organisms known as photoautotrophs are organisms that are capable of photosynthesis. Among all the photoautotrophs, cyanobacteria and eukaryotic microalgae are the most optimistic feedstock for the sustainable making of materials linked with bio-based items such as fuel, feed, and high-value metabolites; moreover, the process for CO2 can be initiated by this for wastewater treatments [6].

Algae is a distinctive organism that has massive potential to produce biomass energy. Seaweed, the most familiar form of algae, can produce energy in the process of photosynthesis at a much faster rate than any other photoautotroph. It can produce energy up to 30 times faster than any other Photosynthetic organism [7]. Mostly Algae can be grown in ocean water. It does not require arable land that could potentially grow food crops. In the process of photosynthesis, Algae produce oxygen and absorb pollutants that are in the form of carbon emissions.

Most of the Algae species are unicellular living in different environments that include freshwater aquatic environments and seawater. In marine and freshwater environments photosynthetic algae are found that include dinoflagellates and diatoms. Algae growth extended when it has better access to sunlight that's why they float near the seashore Algae has great ecological importance as it is a great source of oxygen because it produces oxygen as by-product in the process of photosynthesis. Utilization of algae as a food that has high nutritional content for aquatic

animals. Marine life heavily relies on algae because it provides food to small organisms that utilize as a portion of food for huge species Algae can be worked as a pollution indicator there are some factors that allow algae to show traces related to types of pollutant present in water. Huge types of algae inspire the development and spread of marine life as they provide habitats for several species. Algae can also be utilized as the litmus test for climate change because it absorbs carbon dioxide [8]. But due to large scale floating PV, the algal growth is reduced that ultimately effects the marine life [15].
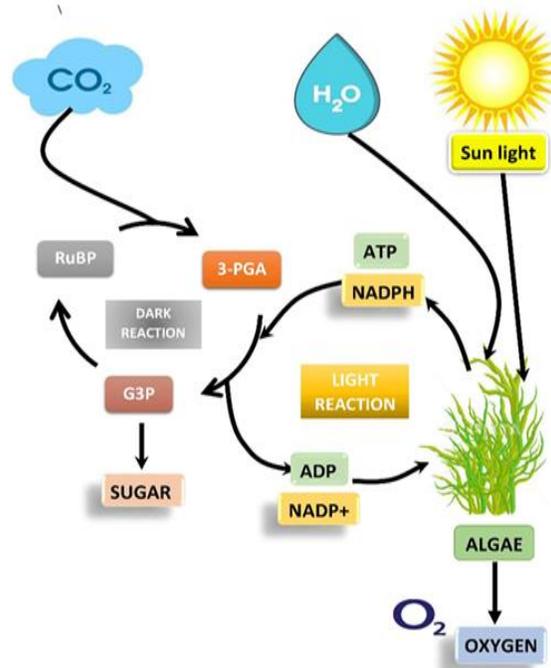

*Fig. 1 Photosynthesis process depicting light and dark reaction*

II. MATERIALS AND METHODS

The System of Ordinary differential equations (ODEs) is used to describe changes of concentration of various species with respect to time. The Mathematical models that based on ODEs are commonly use in real world phenomena especially in dynamics system. For this purpose, a mathematical model has introduced for the accommodation of solar mechanisms in higher plants and also in green algae [16]. Furthermore, a mathematical model has also constructed to define the growth of microalgae in Cylindrical Photo bioreactor [17]. In this paper, a mathematical model based on system of ODEs, is discussed to understand the outcome of radiant flux density at different levels and the CO2 concentration in photosynthesis of underwater plants [9, 10]. Figure 1 shows the complete photosynthesis process under water.

A. The Mathematical Model for Light-Dependent Reactions

The photosynthesis process includes light-dependent reactions, solar energy captured from the sun is converted

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into chemical energy in the form of NADPH and ATP. The chlorophyll in the plants absorbs sunlight and transfers the solar energy to the electrons to produce NADPH (nicotinamide adenine dinucleotide phosphate hydrogen). It is the initial product of the process of photosynthesis and is used to boost the further reactions of photosynthesis.

$$2H_2O + 2NADP^+ + I \rightarrow 2NADPH + 2H^+ + O_2$$
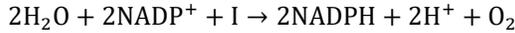
The equation shows that irradiation from the sun causes electrons to flow from water to NADP+ and produces NADPH with oxygen formation.

$$NADP^+ + I \xrightarrow{a_1} NADPH$$
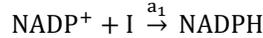
The proposed model of light-dependent reaction is based on the fact that the light dynamics-dependent reactions are determined by only the dynamics of the concentration of NADP+ and NADPH.

The total concentration of NADP+ and NADPH depends on the radiant flux density I. So, NADPH formation rate is directly proportional to the product of the concentration of NADP+ and radiant flux density.

$$N_{max}(I) = [NADP^+] + [NADPH]$$

The mathematical model for the light-dependent reaction are:

$$NADP^+ + I \xrightarrow{a_1} NADPH$$

$$NADPH + PGA \xrightarrow{a_2} NADP^+$$
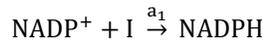
In dark reaction 3-phosphoglyceric acid (PGA) is formed and a_1, a_2 are the parameters in the reaction. If N represents the concentration of NADPH and M represents the concentration of PGA then the differential equation of light-based reaction can be written as:

$$\frac{d}{dt}[NADPH] = a_1 I[NADP^+] - a_2[NADPH][PGA]$$

$$\frac{d}{dt}N = a_1 I[N_{max} - N] - a_2 NM \qquad (1)$$

Above equation is the differential equation for the dynamics of light reaction of photosynthesis.

B. The Mathematical Model for Dark Reactions

The dark reaction of photosynthesis is dependent on ATP and NADPH that were produced from the light reactions. Reaction uses ATP and NADPH to produce high-energy sugars.

A molecule of carbon dioxide combines with a five-carbon acceptor molecule, ribulose-1, 5-bisphosphate (RuBP). The resulting six-carbon compound splits into two molecules of   PGA. The energy of ATP and NADPH that was produced in the light reaction is used to convert the PGA molecules into molecules of a three-carbon sugar, glyceraldehyde-3-phosphate (G3P). Initial carbon dioxide acceptor RuBP is produced in the other phase of this reaction. Mathematical model of dark reactions based on fact that the production rate of RuBP is equal to the production rate of G3P and the maximum constant rate is observed for the reproduction of RuBP.

It can now be formulated according to our assumption

$$M_{max} = [RuBP] + [PGA]$$

The reactions of the proposed model of dark reaction are:

$$CO_2 + RuBP \xrightarrow{a_3} 2PGA$$

$$2PGA + 2NADPH \xrightarrow{a_4} 2G3P + 2NADP^+$$
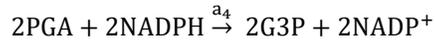
a_3 and a_4 are the dynamic parameters.

If R represents the concentration of RuBP and C represents the concentration of CO_2, then the differential equations of dark reaction are:

$$\frac{d}{dt}R = -a_3 CR$$

$$\frac{d}{dt}M = a_3 CR - a_4 NM$$

$$\frac{d}{dt}[G3P] = a_4 NM$$

According to the assumption, the production rate of G3P is equal to the production rate of RuBP, so the net rate of change of RuBP can be written as:

$$\frac{d}{dt}R = -a_3 CR + a_4 NM$$

It can be observed that

$$\frac{d}{dt}R = -\frac{d}{dt}M$$

$$\frac{d}{dt}M = a_3 C(M_{max} - M) - a_4 NM \qquad (2)$$

Above is the differential equation for the dynamics of the dark reaction of photosynthesis.

Hence the differential equations of the proposed model are equations (1) and (2):

$$\frac{d}{dt}N = a_1 I[N_{max} - N] - a_2 NM$$

$$\frac{d}{dt}M = a_3 C(M_{max} - M) - a_4 NM$$

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These Ordinary differential equations are the optimal prediction for rate of change of the process of photosynthesis that helps to determine the growth of algal cell due to installation of PV system.

Normalizing the above differential equations

$$\dot{n} = a_1 I(1 - n) - a_2 nm \qquad (3)$$

$$\dot{m} = a_3 C(1 - m) - a_4 nm \qquad (4)$$

$(\cdot)$ represents the derivatives with respect to time.

$n = \dfrac{N}{N_{max}}$ is the normalized concentration of NADPH

$m = \dfrac{M}{M_{max}}$ is the normalized concentration of PGA

When radiant flux density become zero because of solar panel installation, the rate of change of NADPH is highly affected. Due to which it halts the formation of NADPH and with the passage of time, the stored NADPH will completely diminish.

$$\dot{n} = -a_2 nm$$

Previous equation shows that the NADPH is affected by radiant flux density that ultimately minimize 3-PGA formation.

$$\dot{m} = a_3 C(1 - m) - a_4 nm$$

C. The Mathematical Equation for Growth Rate

If any of the external factors do not affect the growth of the algal cell, then the rate of growth of the algal cell is directly proportional to the number of the algal cells present at any particular time [12 13]. If N represents the numbers of cells of algae at any time t then its differential equation will be:

$$\frac{dN}{dt} \propto N$$

$$\frac{dN}{dt} = \mu N$$

where μ is the constant of the growth rate of the algal cell. After integrating the above equation from 0 to any time t,

$$N_t = N_0 e^{\mu t}$$

The cell number of algae doubles at any time interval td,

$$N_t = 2N_0$$

It yields,

$$2N_0 = N_0 e^{\mu t_d}$$

$$t_d = \frac{\ln 2}{\mu}$$

Let's suppose t_d is one day then the value of $\mu = 0.693$

$$\frac{dN}{dt} = 0.693N \qquad (5)$$

For large scale solar PV plants, the growth of algal cell are also experimented by using water column model [13]. Along with that same can be done for combined floating PV and off shore wind farms [14].

III.   RESULTS

The graph in figure 2 shows that when the radiant flux density is 0 due to the floating solar parks the formation of NADPH decreases day by day. As the concentration of NADPH is decreasing, the concentration of PGA is also being affected. As a result of no formation of NADPH in light reaction, the process of photosynthesis will be halted, which affect the life of algae. When the algae start dying, it will create a huge impact on the environment especially on the aquatic animals which depend on the algae and use it as their food.
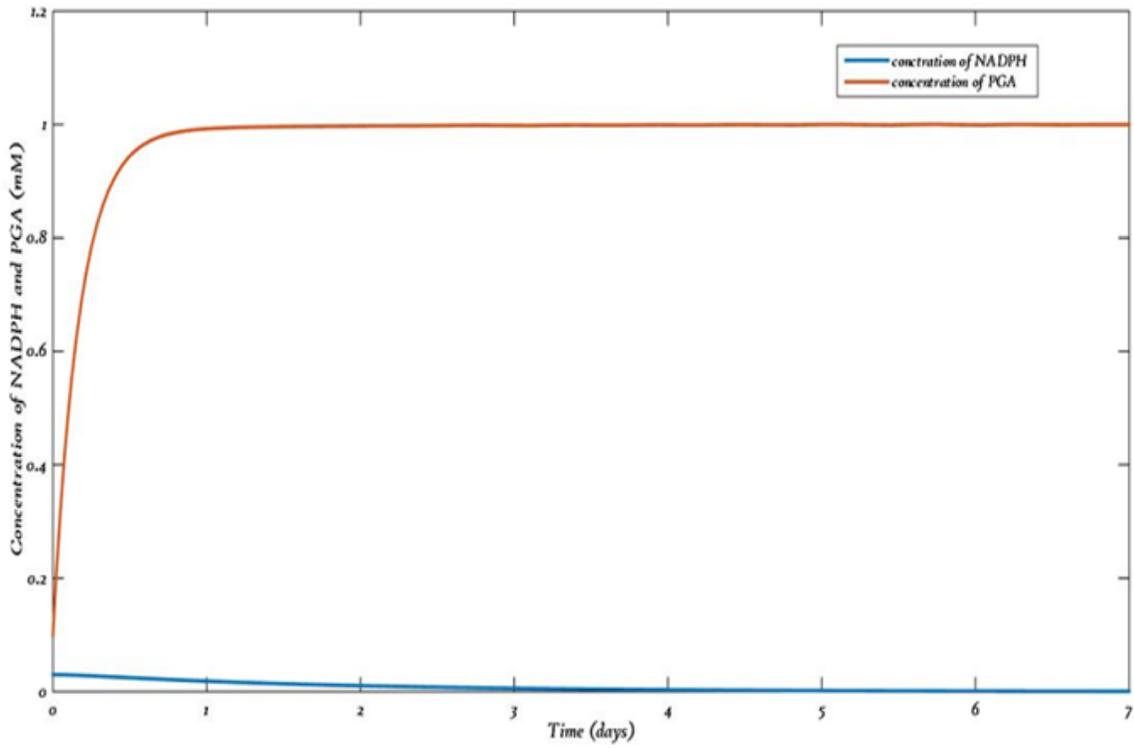
Fig. 2 Concentration of NADPH & 3-PGA at I=0 w/m²

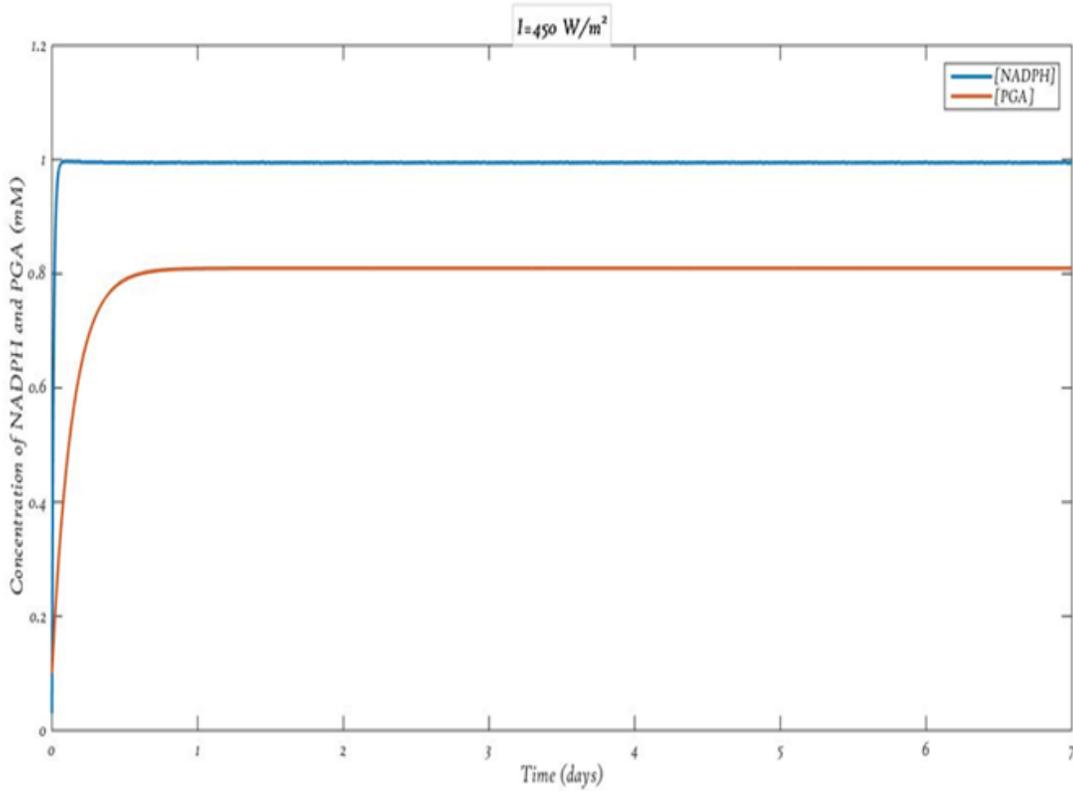*Fig. 3 Concentration of NADPH & 3-PGA at I=450 w/m²*

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The graph in figure 3 shows that when the radiant flux density is in the normal range the process of photosynthesis is also in a regular pattern. The perfect amount of formation of NADPH in light reaction also leads to the perfect amount of formation of PGA in Dark reaction.

When the photosynthesis process shows an even behavior, the life of algae is stable, which is good for the environment of the marine ecosystem and the life of sea animals remains sustainable if all other external factors don't affect the growth of the algae.

The figure 4 shows that as time increases the growth of algal cells also increases and within 12 hours, the number of the algal cell will be approximately three thousand.

The average production of the algae is 12.800 kg/m3 but the plantation of solar parks will badly affect the production of algae which can create an unfriendly impact on the environment.
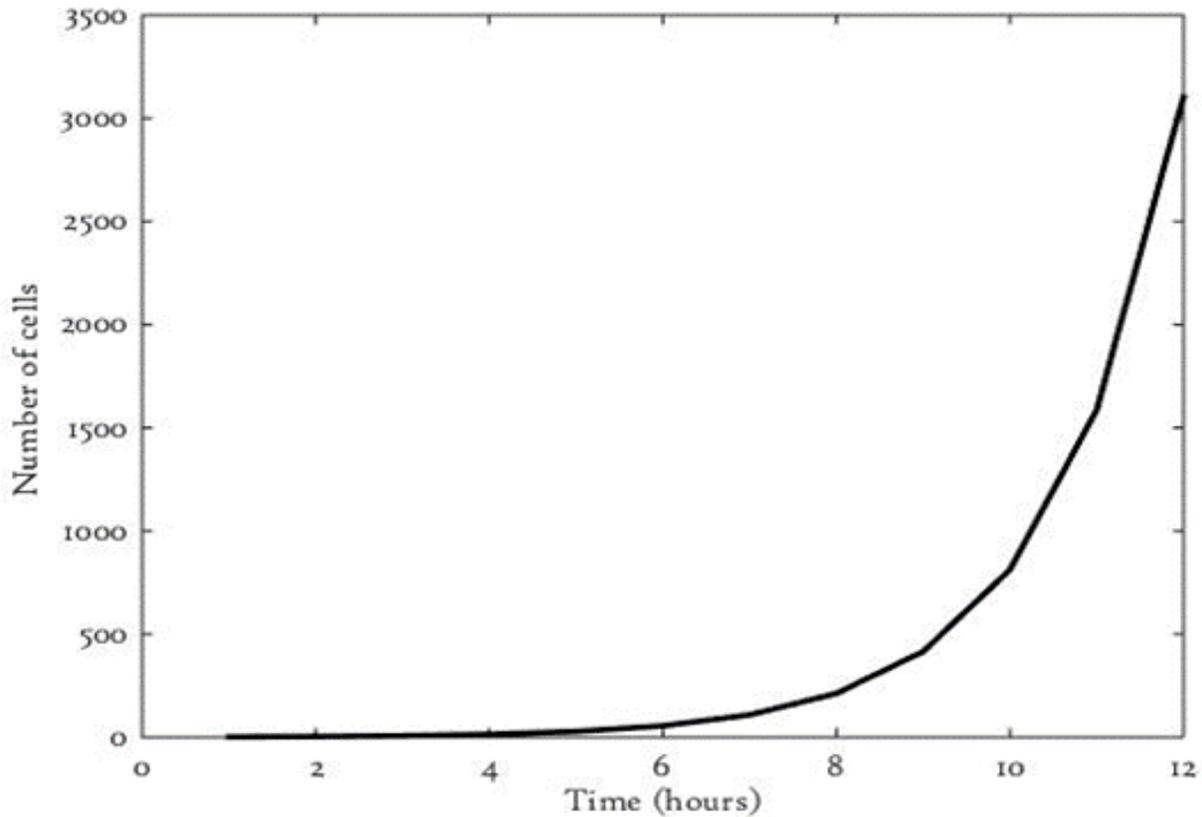

Fig. 4 Exponential growth of algal cell

IV. CONCLUSION

The increasing demand of green energy urges investors to build offshore floating solar parks because relying on fossil fuels is not an easy call for the world. But along with that environmental impacts need to be studied to avoid any damage to marine life and the ecosystem.

In this paper environmental impacts due to offshore floating solar power plants on green algae growth are discussed with the help of a mathematical model which shows that an absence of solar irradiance halts the process of NADPH formation.

Lack of NADPH affects the formation of PGA that ultimately stops the whole photosynthesis process. The area covered by floating offshore solar parks stops the growth of algae and oxygen production that eventually affects the food chain of those living organisms that relays on algae for their food. Specifically due to use of different elements in solar panel production also affects plant growth over time.

In summary, it is important that along with technical and economic effects discussion of floating solar power more studies should be carried out to relate the impact of floating solar power on marine life.

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