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Use of Remote Sensing, GIS, DPSIR Framework and SWOT Analysis for Impact Assessment of Marine Renewable Energy Sector with a Focus on Floating Solar Photovoltaic Systems in India

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About the Research paper

The increasing cost of finding undeveloped land with good solar potential has led to the rise of Floating Solar Photovoltaic (FSPV) plants as an alternative method to land-based plants. FSPV projects face lower competition for potential sites, making them a more attractive option. While the long-term maintenance and durability of FSPV are still being monitored, the systems offer several advantages compared to the traditional ground-mounted items, like water conservation through reduced evaporation, increased electricity generation due to the cooling effect on the panels, and shorter installation times. Given the abundant availability of water bodies and the limited availability of land, there is significant potential for the installation of FSPV systems.

The paper is an attempt to highlight FSPV, which is a relatively a new and innovative approach to harnessing solar energy. By evaluating the performance of FSPV systems, this research paper provides useful insights into their strength and weaknesses in terms of efficiency, reliability, and potential for large-scale adoption. This information can be crucial for policymakers and investors interested in exploring the viability of FSPV projects.

Feedback

We strive for constant improvement and encourage our readers to provide their valuable feedback/suggestions. Please send us your suggestions, comments, and questions about this report to iced@cag.gov.in.

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Declaration

DECLARATION FORM

I Swapnil Deo, hereby declare that the Research Paper titled **"Case study on "Use of Remote Sensing, GIS, DPSIR framework and SWOT analysis for impact assessment of Marine Renewable Energy Sector" with a focus on Floating Solar Photovoltaic Systems in India"** submitted to ICED Jaipur is my original work and no part of it has been published anywhere else in the past. The facts and figures given in the paper are true and authentic to the best of my knowledge. I concur with the modifications/corrections carried out during evaluation of paper based on inputs provided by me.

(SIGNATURE)

DATE: 10/08/2023

Foreword

Sustainability of the environment requires every Supreme Audit Institution to constantly upscale its audit focus on an audit of issues related to the environment. Given its cross-cutting, dynamic, and multi-disciplinary nature; capacity building and inputs informed by research becomes an essential pre-requisite for human resource management and reporting on public accountability in these areas. Strategic objectives of International Centre for Environment Audit and Sustainable Development (iCED), *inter-alia*, include the sharing of knowledge related to the environment among government agencies and public auditors and undertaking research in the area of environment and sustainable development.

In this direction, iCED, apropos of the policy guidance of the Office of the Comptroller and Auditor General of India seeks to encourage internships, and provides opportunities to students from universities and institutions to research at iCED for short durations. Such research is a vital component of iCED's participative pedagogic methodologies on environmental audit.

In May 2022, iCED pioneered an Occasional Research Paper Series to foster a dynamic and research-oriented trajectory to its capacity-building efforts. As a part of these efforts, in August 2022, we published a comprehensive compendium of studies and research conducted by interns at iCED, in the format of a detailed Compendium Report. This work provided a cornucopia of diverse issues of environmental concern and focus areas for sustainable development; ranging from Bio-diversity, Industrial and E-Waste Management, Climate Change, Renewable Energy Challenges, and Issues of Urbanisation including Urban Air Pollution and Urban Flooding, etc.

In continuation of this research-oriented trajectory in the area of environment and sustainable development in iCED, I am happy that young interns at iCED have once again chosen emerging issues on which we now present our Latest Occasional Research Paper **# 9.** Centered on "Use of Remote Sensing, GIS, DPSIR framework and SWOT analysis for impact assessment of Marine Renewable Energy Sector with a focus on Floating Solar Photovoltaic Systems in India"**,** this ORP will serve as a repository of reference material for auditors working in the field of audit of environment and sustainable development. It will enable them to leverage the usage of new tools, methodologies and approaches in the area. I trust that this ORP will enhance our understanding about the environment and provide a fresh audit perspective for the audit of environment and sustainability-related issues.

As the contributors are young students, sharing their ideas with audit professionals can also be a mode of outreach that can enliven the discourse on an audit of the environment. It is also worth stressing that the value of these inputs is to bring a spirit of zest-full inquiry from young voices to our structured processes. We would be delighted to receive your feedback and valuable insights.

Needless to say, with this publication, iCED once again reaffirms its dedication to being a specialised hub of dynamic in-house research, under the aegis of the Comptroller and Auditor General of India. It also opens a new pathway into research in the multi-faceted complexity of the Blue Economy and its Audit, where iCED now acts as a Centre of Excellence.

14th December 2023 **(SAYANTANI JAFA)**

Jaipur **Additional Deputy C&AG and Director General, iCED**

Message from the Director (Training and Research)

With the growing emphasis on the development of sectors of Blue Economy, coastal countries are exploring new avenues to enhance the growth of the economy of coastal States and the livelihood of coastal communities. Marine Renewable Energy sources provide ample hope to the coastal communities as a sustainable source of energy for the promotion of ocean-based livelihood. Nevertheless, in view of the cost-inhibitions posed by some of the technologies, floating solar photovoltaic cells for example, interventions of Government and private sector become crucial for their adoption and spread.

In pursuit of its goal to become a global Centre of Excellence in the field of environment and sustainable development, International Centre for Environment Audit and Sustainable Development (iCED) has gained momentum in conducting in-house research through the engagement of interns, young professionals, and Research Associates.

With respect to the internship programme in the field of environment and sustainable development, since 2017-18, iCED has attracted the interest of young minds willing to engage in the promotion of environmental sustainability. Two volumes comprising research done by the interns have been prepared and placed on the website of iCED under the Occasional Research Paper Series since August 2022.

This Occasional Research Paper on **"Use of Remote Sensing, GIS, DPSIR framework and SWOT analysis for impact assessment of Marine Renewable Energy Sector with a focus on Floating Solar Photovoltaic Systems in India"** highlights the Global and Indian FSPV systems through a case study approach. The plants chosen for this study are Kayamkulam Project (92 MW) of NTPC, Kerala in India, and Yamakura Dam Floating Solar Farm (13.7 MW), in Japan. Further, an assessment of environmental aspects relating to the marine Renewable Energy sector, specially focusing on Floating Solar Photovoltaic Systems in India using Drivers, Pressures, State, Impacts, and Responses (DPSIR) framework and Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis has also been incorporated in this case study.

This paper serves as a good source of information on Floating Solar Photovoltaic systems and provide many new inputs/ perspectives/ tools and approaches which can be suitably adopted during various stages of audits, covering this sector of Blue Economy.

(Dr. NANDA DULAL DAS)
Director (Training and Research)

Acknowledgement

I wish to express my deepest gratitude and sincere thanks to Ms. Sayantani Jafa, Additional Deputy Comptroller and Auditor General and Director General, iCED, for giving her invaluable guidance throughout the research work. I would like to express sincere gratitude to Dr. Nanda Dulal Das, Director (Training and Research) for his valuable supervision and guidance and constructive suggestions and inputs for this research work carried out during my internship at iCED. I also offer my sincere thanks for the help and feedback offered by Shri Jayant Sharma, Consultant and Shri Vikas Dhir, Assistant Administrative Officer (Research), iCED. This Research Paper would not have been possible without their generous support, constructive feedback, and constant encouragement.

(Swapnil Deo)
Intern, iCED

Contents

Abbreviations

- CAPEX : Capital Expenditure
- CERC : Central Electricity Regulatory Commission
- CUF : Capacity Utilisation Factor
- DPSIR : Drivers, Pressures, State, Impacts, and Responses
- FSPV : Floating Solar Photovoltaic
- GDP : Gross Domestic Product
- GIS : Geographic Information System
- GW : Gigawatt
- ICB : International Competitive Bidding
- IDC : Interest During Construction
- ILO : International Labour Office
- Km : Kilometer
- kWp : kilowatt peak
- LCOE : Levelised Cost of Energy
- MNRE : Ministry of New and Renewable Energy
- MRE : Marine Renewable Energy
- Mtoe : Million Tonnes of Oil Equivalent
- MU : Million Units
- MW : Megawatt
- MWh : Megawatt hour
- NDTI : Normalised Difference Turbidity Index
- NDVI : Normalised Difference Vegetation Index
- NDWI : Normalised Difference Water Index
- PLI : Production Linked Incentive
- REC : Renewable Energy Certificate
- RGCCPP : Rajiv Gandhi Combined Cycle Power Plant
- RPO : Renewable Purchase Obligation
- SDG : Sustainable Development Goals
- SWOT : Strengths, Weaknesses, Opportunities and Threats
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Abstract

The uncertainty surrounding geopolitical relationships, India's commitment to generate 500 Gigawatt of Renewable Energy by 2030 (Ministry of New and Renewable Energy, 2022)*, and its goal to achieve carbon neutrality by 2070 are reasons to explore new forms of Renewable Energy in India, such as Marine Renewable Energy* (Ministry of Environment, Forest and Climate Change, 2022).

Limited and uncertain global price of fossil fuel resources, coupled with a higher energy demand, has shifted the focus towards marine Renewable Energy. This form of energy is advantageous as it is low cost, has potential to provide a continuous source of energy, and is environment friendly. However, when implementing Renewable Energy projects on land, the government and project partners face several challenges. These include land availability, land development and acquisition, substation capacities, and timely clearances for the project and evacuation. Furthermore, factors such as solar radiation, and wind flow, suitability of locations for solar and wind energy projects varies across regions. In some cases, although the projected locations have higher solar radiation, the energy yield is lower due to heating of solar panels and higher surface temperatures. To address these issues, an innovative approach has emerged, suggesting the installation of solar power plants on different water bodies, such as canal tops, lakes, dam backwaters, and reservoirs, which are typically government-owned. This paper provides a comprehensive review of FSPV power plants, covering aspects such as post-installation impact assessment (using multi-criteria analysis NDVI, NDTI, and NDWI), Capital Expenditure, Levelised Cost of Electricity, Performance Ratio, and Capacity Utilisation Factor. Additionally, the paper discusses the Drivers, Pressures, State, Impacts, and Responses (DPSIR) framework and conducts a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis for floating solar photovoltaic systems.

Use of Remote Sensing, GIS, DPSIR Framework and SWOT Analysis for Impact Assessment of Marine Renewable Energy Sector with a Focus on Floating Solar Photovoltaic Systems in India

CHAPTER-I

1.1 Introduction

The alarming pace and magnitude of Climate Change impacts are increasingly evident on a global scale. Emerging and developing economies face the greatest vulnerability due to limited technological capacity and financial accessibility for climate adaptation and mitigation. Even then, there has been a huge uptick in the amount of climate action and governments are emphasising renewable and sustainable energy to reduce the adverse environmental effects.

India's burgeoning population and economy necessitate a substantial increase in energy supply to meet the growing demand. According to the latest data 97 per cent of Indian households are electrified (Ministry of Health and Family Welfare, 2021). However, India needs to import a large quantity of fossil fuel resources to meet its energy demand. Development of marine renewable energy can help reduce India's dependence on imported fossil fuels and enhance its energy security. Marine renewable energy refers to renewable energy that is installed and operated at sea and requires access to offshore grid and distribution systems. It is the world's largest untapped renewable energy resource (NREL, 2021). It can include offshore wind, tidal stream, tidal range, and wave energy technologies. Floating photovoltaic energy is a new and emerging Renewable Energy source. It uses the surface of water bodies to install floating photovoltaic panels.

India's 18,000 km^2 of water reservoirs are capable of producing 280 Gigawatt (GW) of solar energy via Floating Solar Photovoltaic plants (The Energy and Resources Institute, 2020). Compared to the whole solar energy industry, the Floating Solar Photovoltaic addition is insignificant, but every contribution is valued in the Renewable Energy market. Floating photovoltaic plants are an emerging form of photovoltaic systems that float on the surface of water reservoirs, quarry lakes, canals, tailing ponds, etc. **The design of the anchoring systems- which are used to keep in place**

the floating platforms, depends on a wide range of factors such as water level and its variability, bathymetry[1], soil conditions, float type, and wind load (TERI, 2019)**.**

The Ministry of New and Renewable Energy (MNRE) is the central agency for determining policy on the generation and promotion of Renewable Energy. It has created several policies and programmes to encourage the growth of marine Renewable Energy. Further, the National Electricity Policy of 2005 and the Electricity Act of 2003 gave India's growth of Renewable Energy a statutory foundation (Ministry of Power, 2005).

The topic "**Floating Solar Photovoltaic Energy**" is chosen as a case study, because of the fact that installed Floating Solar Photovoltaic (FSPV) systems are expanding globally and becoming a feasible choice for many countries. In India, the government has identified numerous sites across the country for solar energy projects based on solar radiation data. However, most of these locations are characterised by hot and dry conditions (Desai, 2017). Although these areas exhibit higher solar radiation levels, the energy output of these sites is reduced due to the heating of peripheral equipment around the solar panels. To address this issue, FSPV systems have been introduced, which involve deploying solar panels on water bodies. Implementing floating solar technology is crucial to maintain a consistent pace of development aligned with India's national targets for solar capacity expansion.

The primary focus of this study is to highlight the Global and Indian FSPV systems through a case study approach. The plants chosen for this study are Kayamkulam Project (92 MW) of NTPC, Kerala and Yamakura Dam Floating Solar Farm (13.7 MW), Japan.

Furthermore, the study also examines the impact of installing FSPV systems on water bodies and the growth of green vegetation using indices from satellite images, using the green, red, Near Infra-Red (NIR), Mid Infra-Red (MIR) bands of Sentinel 2 and Landsat 8 and Landsat 9 imageries. Some of these Indices are the Normalised Difference Vegetation Index (NDVI), Normalised Difference Water Index (NDWI), and Normalised Difference Turbidity Index (NDTI). The NDVI is a simple, but effective index for assessing the extent of concentration of green vegetation. The NDWI is used to monitor changes related to water content in water bodies. Additionally, the

[1] Bathymetry is the study of underwater depth of ocean floors, lake floors, or river floors. In other words, bathymetry is the underwater equivalent to hypsometry or topography.

Normalised Difference Turbidity Index (NDTI), which is the ratio of red and green bands in the solar spectrum, is utilised to identify water turbidity (Siddique, 2019).

1.2 Literature Review

Floating Solar Photovoltaic systems have numerous advantages over land-based photovoltaic systems. Desai et al. (2017) have highlighted challenges like land acquisition, land availability, and timely clearances, among others, towards the establishment of land-based solar photovoltaic cells (Desai, 2017). Considering the highlighted challenges while installing solar photovoltaic, FSPV systems serve the dual purpose of increasing the efficiency and power output. Nimesh Kumar et al. have compared the land-based photovoltaic, floating solar photovoltaic, and hybrid hydel-floating solar photovoltaic to study the cost-efficiency and sustainability of these systems (Nimesh Kumar Singh, 2022).

The World Bank in a study report has identified the proper site selection for an FSPV plant as a pre-requisite for successful project development. Feasibility studies are essential to identify the site during early-stage concept development. Early data collection allows project developers to make informed assessments of a project's viability. The aim at this stage is to choose the promising site for the project (World Bank Group, ESMAP and SERIS, 2019).

Since the FSPV systems not only reduce land costs, but also increase power generation due to the natural cooling effect of water, Srivastava et al. has focused on the design parameters of floating platforms, and the impact of panel shading on ecosystems (Srivastava, 2022). Kumar et al. (2021) aimed to stimulate interest among various policy developers, energy suppliers, industrial designers, ergonomists, project developers, manufacturers, health and safety professionals, executing agencies, training entities, and investment institutions of the FSPV plant to implement effective governance planning and help them to participate in their ways to assure sustainable growth (Kumar, 2021).

Further, to assess the performance of FSPV systems, Kumar et al. have highlighted various performance indicators such as Performance Ratio, Capacity Utilisation Factor (CUF), Ideality Factor, feasibility, financial sustainability, economics, challenges, environment, policies, Levelised Cost of energy (LCOE) and cash flows of FSPV plants (Kumar, 2021), (Srivastava, 2022). Kumar et al. (2021) also explains the CUF as the ratio of the actual output from an FSPV plant over the year measured in kWh to the highest achievable output measured in kWh under ideal circumstances annually. The LCOE and Net Present Value (NPV) have been used to discuss the economic viability (Kumar, 2021).

Photovoltaics have their impact on the environment (both positive and negative). Along with technical and economic feasibility, it is important to assess the environmental conditions of Floating Solar Photovoltaic systems.

As mentioned in the introduction, NDVI employs a band-rationing technique to find the extent of green growth and water bodies with few band combinations of remotely sensed data. Meera Gandhi et al. has discussed vegetation change detection in the Vellore district using remote sensing and GIS (NDVI) (Meera Gandhi.G, 2015). It has also been observed in this study that the NDVI has been used widely to examine the relation between spectral variability and the changes in vegetation growth rate. It has also been useful in determining the production of green vegetation as well as detecting vegetation changes.

In addition to the above research papers, other research papers/case studies have also been referred to, in this research study.

1.3 Objectives

The objectives of this research study are:

- To study the current status of Renewable Energy with a special focus on FSPV plants in India and Japan, and to compare the pre- and post-installation changes in FSPV Project areas.
- To analyse the performance of FSPV vis-à-vis other solar plants.
- To study the advantages and potential barriers to the development of FSPV through the Drivers, Pressures, State, Impacts, and Responses (DPSIR) framework and Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis.

1.4 Current Status of Renewable Energy (FSPV) in India

According to MNRE (The Hindu Businessline, 2019), Marine Renewable Energy is produced using various forms of ocean energy such as tidal, wave, ocean thermal energy conversion among others.

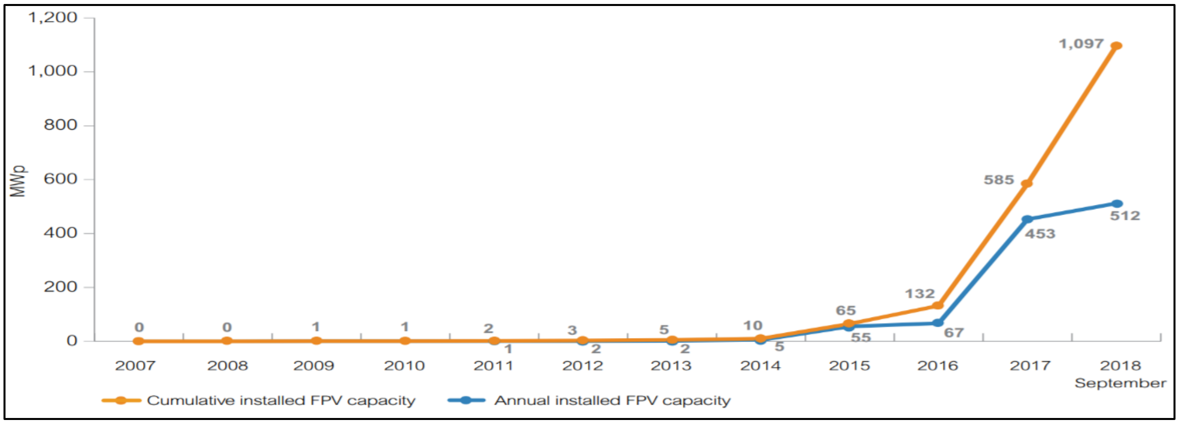


Figure 1: Global growth of Floating solar power, Image source: *(Broom, 2019)*

India is a coastal nation with about 7500 km long coastline, which offers considerable potential for Marine Renewable Energy (MRE). Figure 1 shows cumulative installed FSPV capacity and annual installed capacity at global level. In India, the cumulative installed power capacity of solar energy has increased from 2.63 GW in 2014 (MNRE, 2018) to 70,096 MW (70.096 GW) in June 2023 (MNRE, 2023).

Table 1: State-wise estimated potential of FSPV in the country

Name of State	Number of reservoirs	Total area of reservoirs (km^2)	Potential of FSPV (In GW)
Jammu and Kashmir	3	4	0.041
Himachal Pradesh	5	379	2.647
Punjab	12	96	0.525
Haryana	1	1	0.005
Rajasthan	106	1228	19.71
Madhya Pradesh	328	2884	30.779
Gujarat	223	1247	27.04
Maharashtra	568	3137	57.891
Telangana	116	1928	18.529

Goa	3	24	0.187
Karnataka	171	2147	33.513
Kerala	40	434	6.090
Tamil Nadu	78	472	8.027
Andhra Pradesh	67	1020	17.266
Chhattisgarh	167	589	11.577
Andaman and Nicobar Islands	1	1	0.009
Odisha	142	877	17.755
West Bengal	7	120	2.327
Meghalaya	4	17	0.171
Manipur	1	0.6	0.003
Assam	2	10	0.098
Nagaland	1	16	0.160
Bihar	13	46	1.377
Jharkhand	31	354	3.315
Uttar Pradesh	56	1157	18.122
Uttarakhand	5	86	2.556
Total	**2127**	**17,874.6**	**279.725**

Source: (Mohammed Abdul Majid, 2021)

Table 1 demonstrates state-level FSPV potential, with Maharashtra, Gujarat, Karnataka, and Madhya Pradesh having more than 150 GW of potential.

Floating Solar Photovoltaic systems in India

In 2023, the total installed Renewable Energy capacity has touched 168.96 GW, with 64.38 GW in solar power capacity. The share of non-fossil fuels in the total electricity production during the year 2022-23 and current year (up to May 2023) was 25.44 per cent and 22.45 per cent respectively (MNRE, 2023). The idea of FSPV systems was first introduced in India in the year 2011, as a small pilot project, by the Tata Power Solar Systems Limited. In the following year, in 2012, a second pilot project was created on the banks of the river Sabarmati in the State of Gujarat. Vikram Solar Limited installed India's first 10 Kilowatt (kW) FSPV plant at Rajarhat in Kolkata in 2014. The Arka Renewable Energy College, Kolkata and the New Town Kolkata Development Authority supervised the development of this project. The facility has a yearly capacity of around 14 Megawatt hours (MWh) (Misra, 2023).

The second FSPV plant in India was installed in the Banasura Sagar Reservoir near Wayanad, Kerala, in January 2016. The plant was constructed on a hollow concrete structure capable of supporting 4500 tonnes of weight. It was the first significant FSPV plant in India with a 500 kWp capacity, covering 1.25 acres of water surface. In 2017, on the lake next to the Rajiv Gandhi Combined Cycle Power Plant (RGCCPP) in Kayamkulam, Kerala, the National Thermal Power Corporation (NTPC) installed a 100 kWp FSPV plant. M/s Swelect Energy Systems Ltd., Chennai erected the system at a 0.32 acre water surface with assistance from NTPC Energy Technology Research Alliance (NETRA) and NTPC in just 22 days (Misra, 2023).

NTPC Ramagundam is currently the country’s largest Floating Solar Power Plant Project in Telangana with a capacity of 100 MW (Ministry of Power, 2022).

In Panipat, Haryana, Indian Oil Corporation Limited (IOCL) built a grid-connected 100 kWp fixed tilt FSPV plant. The floating framework supported many arrays of solar PV modules in the power plant. The facility is housed in a raw water reservoir (RWH) in IOCL's Naphtha Cracker unit (Misra, 2023).

CHAPTER-II

Assessment of the Environmental conditions of Kayamkulam FSPV Project (92 MW) Area of NTPC and Yamakura Dam Floating Solar Farm (13.7 MW), Japan,pre- and post-installation scenario

2.1 Kayamkulam FSPV Power Project (92 MW), NTPC, Kerala

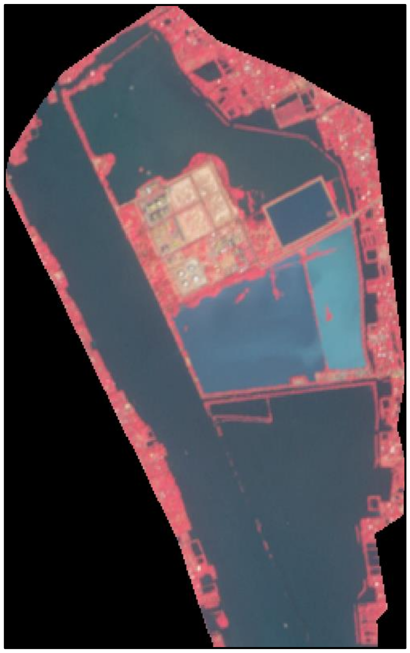
This study focuses on the tools and techniques of Remote Sensing and Geographic Information System (GIS) for analysing the impacts of pre- and post-installation scenarios of the Kayamkulam Project (92 MW), NTPC, Kerala and the Yamakura Dam Floating Solar Farm, Japan, on the environment.

Image 1: (A) Pre-installation image, 1st May 2020 (B) Post-installation image, 11th May 2023 ***(Google Earth)***

Image 1(A) shows the pre-installation state on May 1, 2020, while Image 1(B) shows the post-installation phase on May 11, 2023, of the Kayamkulam plant, NTPC (92 MW), Kerala.

The Kayamkulam FSPV Project is built on reservoirs owned by the Rajiv Gandhi Gas-based Power Station of NTPC (NTPC Renewables, n.d.). This plant lies at latitude 9° 23’ 61” N and longitude 76° 43’ 09” E. The plant is located in the Achankovil River, which is also part of the **National Waterways 3** Kottapuram-Kollam segment. This is India's first National waterway in the country having 24 hours navigation facilities at the entire stretch (IWAI, 2018). The work on this FSPV plant was done by Tata Power Solar Systems Limited (70 MW) and Bharat Heavy Electricals Limited (BHEL) (22 MW). The floating solar station's output will be sold to the Kerala State Electricity Board (KSEB) Limited for ₹ 3.16 per kWh (The Hindu, 2022). The project's implementation cost is estimated at ₹ 465 crore. A total of 2.16 lakh solar panels are placed on the floating structure. After the 100 MW plant at Ramagundam in Telengana, the Kayamkulam facility is stated to be the NTPC's second-largest floating solar power project. The FSPV plant's construction began in 2020, and operations began in 2022 (The Hindu, 2022).

In order to determine the environmental impact of the Kayamkulam Plant in Kerala, a multi-criteria analysis using NDVI, NDWI, and NDTI has been done. The study has used QGIS software and Sentinel 2 imageries with 10 per cent cloud coverage.



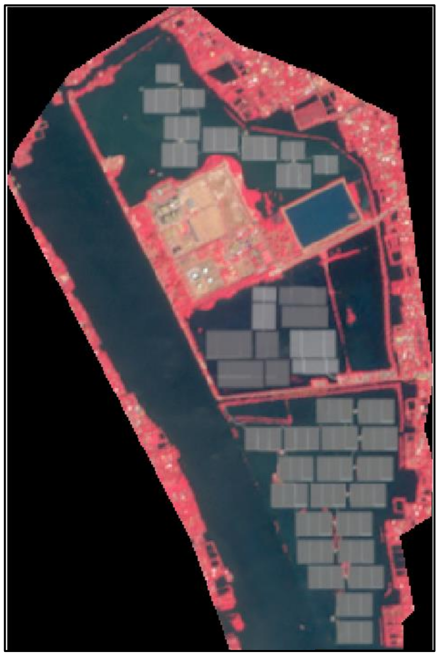


Image 2: (A) False Colour Composite (FCC) as on 28th February 2020

(B) FCC as on 27th February 2023

Image 2 displays the pre- and post-installation phases of the Kayamkulam plant in Kerala using Sentinel-2 map images. The images are represented using false colours derived from bands 3, 4, and 8, obtained from Sentinel Hub. The False Colour Composition allows the examination of indices such as NDVI, NDWI and NDTI. These indices provide valuable information related to vegetation, water content, and thermal characteristics of the area.

2.1.1 NDVI

The NDVI, which is well-known, efficient, and frequently used, indicator for measuring greenery. It correlates chlorophyll absorption in red wavelengths with near-infrared leaf scattering in green leaves. The NDVI has a value range of -1 to 1. Water is represented by NDVI values that are negative (values close to -1). Values close to zero (-0.1 to 0.1) typically represent rocky, sandy, or snowy deserts. Low, positive values (between 0.2 and 0.4) correspond to shrub and grassland, but high values (values approaching 1) correspond to temperate and tropical rainforests. It works well as a stand-in for actual living greenery (Sentinel Hub., n.d.).

The normalised difference vegetation index, abbreviated NDVI is defined as:

NDVI = $\frac{NIR - Red}{NIR + Red}$

Where: NIR is Near-infrared

Red is Red band

For Sentinel-2 maps, the index looks like this:

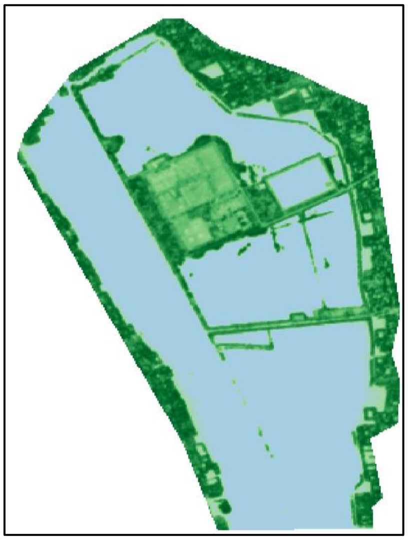
NDVI= $\frac{B8-B4}{B8+B4}$

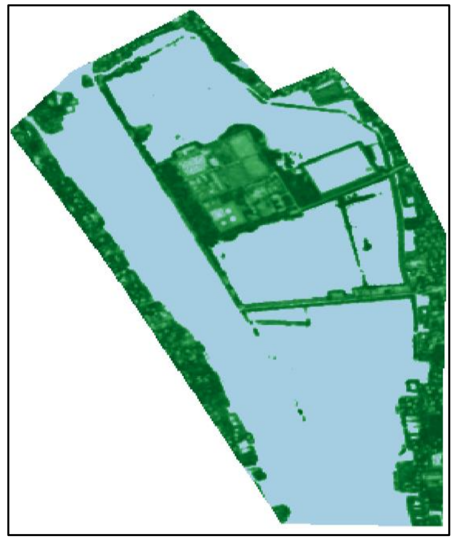
Where: B8 = Near-infrared = band 8

B4 = Red band = band 4

Value between 0 and -1 is represented by Blue and value between 0 and 1 is represented by Green. The same formula is used to calculate and compare NDVI values of the Kayamkulam plant, Kerala in their pre- and post-installation phases.

NDVI Values of Kayamkulam plant area and Achankovil River





A B

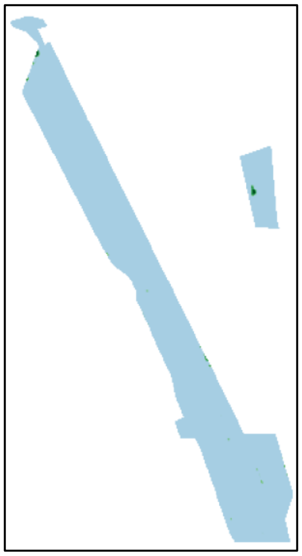
Image 3: NDVI Values of Kayamkulam plant area and Achankovil River as on (A) 28th February 2020 and (B) 27th February 2023

Table 2: NDVI Values in Pre- and Post-installation Period

Date	NDVI Minimum Value	NDVI Maximum Value
28th February 2020 (pre-installation)	-0.48	0.81
27th February 2023 (post-installation)	-1	0.91

Image 3 illustrates the area utilised by the Kayamkulam Plant for project installation, as well as the areas that remain unused. In the image, water bodies are represented by the colour blue, while the green colour represents vegetated areas. As per Table 2, the minimum NDVI value, has decreased from -0.48 to -1. This change suggests an increase in water levels in the area. This could be due to factors such as alterations in water flow or the creation of water reservoirs as part of the project. The presence of more blue colour in the post-installation phase indicates a rise in water bodies. The maximum NDVI value, representing the extent of green vegetation, has slightly increased from 0.81 to 0.91. This indicates a slight growth or expansion of vegetated areas. The presence of more green color in the post-installation phase suggests an increase in vegetation cover.

NDVI Values of river area not used for project installation purposes



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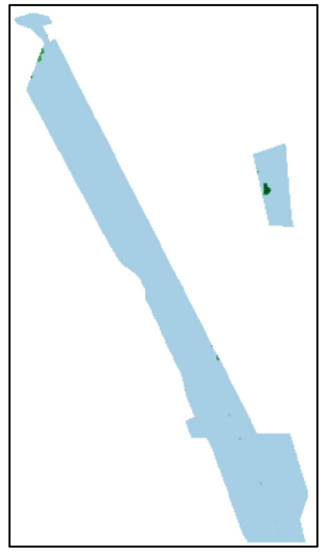


B

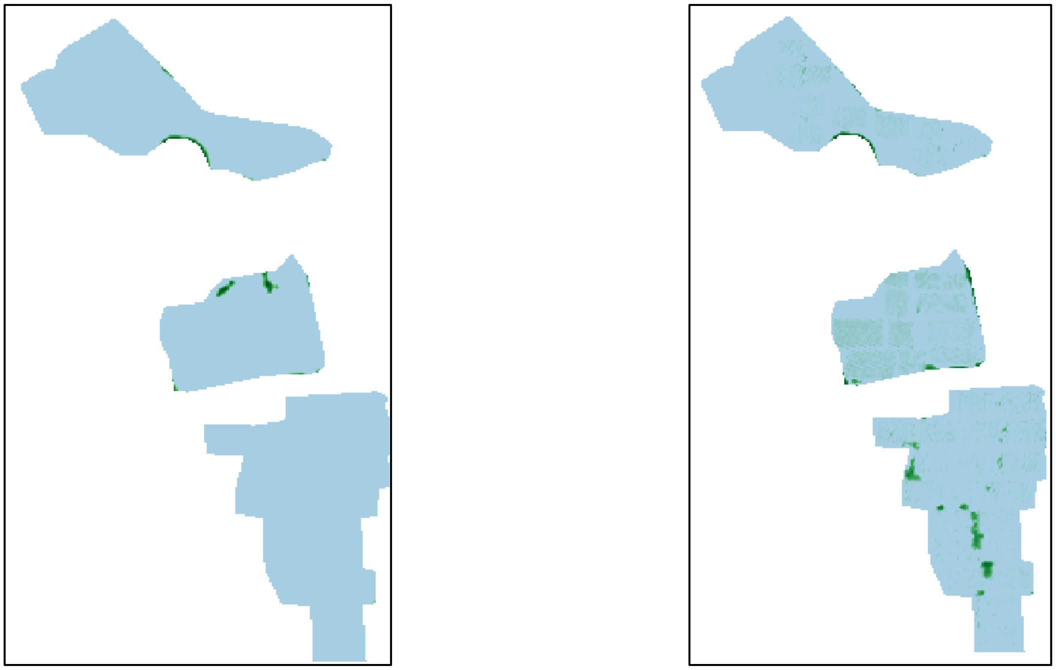
Image 4: Natural water flow area, (A) As on 28th February 2020 and (B) As on 27th February 2023

Table 3: NDVI Values of Achankovil River area

Date	Minimum Value	Maximum Value
28th February 2020 (pre-installation)	-0.49	0.63
27th February 2023 (post-installation)	-0.97	0.83

Image 4 focuses on the project area used by the Kayamkulam Plant for installation purposes, as well as the area not utilised by the plant. The areas have been separately masked in Images 4 and 5. In Image 4, the masked area represents the Achankovil River, specifically National Waterways 3, which runs parallel to the plant's reservoir. NDVI data has been calculated to analyse changes in vegetation between the pre- and post-installation phases of the Kayamkulam Project. Based on the data in Table 3, the minimum NDVI value ranges from -0.49 to -0.97. This significant decrease indicates a rise in the water level of the Achankovil River. On the other hand, the maximum NDVI value varies from 0.63 to 0.83, which suggests an increase in vegetation concentration by 0.20 on the NDVI scale.

NDVI Values of Panel area



A B

Image 5: NDVI of FSPV panel area, (A) As on 28th February 2020 and (B) As on 27th February 2023

Table 4: NDVI Values in the FSPV area

Date	Minimum Value	Maximum Value
28th February 2020 (pre-installation)	-0.48	0.71
27th February 2023 (post-installation)	-0.86	0.76

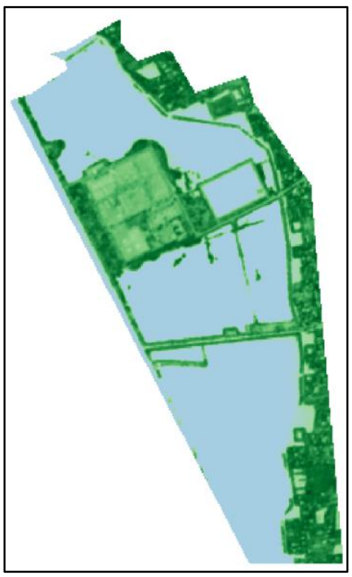
In Image 5, the pre-installation and post-installation phases of the Kayamkulam plant's FSPV panel area are depicted. As per Table 4, the above NDVI data highlights the variation in minimum and maximum values, ranging from -0.48 to -0.86 and 0.71 to 0.76, respectively.

Comparing the minimum value recorded on 28th February 2020 (-0.48) to the value observed on 27th February 2023 (-0.86), there is a decrease of -0.38. This significant change suggests that the water level in the area has risen. Additionally, there is a slight increase in green vegetation around the panel area, as indicated by the difference in maximum NDVI values between 28th February 2020 and 27th February 2023.

Based on these findings, it can be concluded that the water level has increased in the vicinity of the FSPV panel area, as reflected by the change in minimum NDVI values. Furthermore, there is evidence of increased green vegetation around the panels, as indicated by the variation in maximum NDVI values over the specified time period.

It's important to consider other factors that may contribute to these observations, such as seasonal changes, and climate patterns, etc.

NDVI Values of whole area of Kayamkulam FSPV plant



A

B

Image 6: NDVI of Overall Project Area, (A) As on 28th February 2020; (B) As on 27th February 2023

Table 5: NDVI values of Overall Project area

Date	**Minimum Value**	**Maximum Value**
28th February 2020 (pre-installation)	-0.48	0.81
27th February 2023 (post-installation)	-1	0.87

Image 6 represents the whole area of the Kayamkulam Plant. The minimum NDVI value in Table 5 as of 27th February 2023 has been changed from -0.48 to -1, which indicates that the water level has increased in the vicinity. Furthermore, the maximum NDVI value on 27th February 2023 has increased by 0.06 compared to the maximum value recorded on 28th February 2020 (0.81). There has been an increase in green vegetation, reflected by the higher maximum NDVI value. It is important to consider other factors that may have influenced these changes, such as seasonal variations, environmental conditions, or the impact of the plant's installation etc.

2.1.2 NDWI

NDWI is an index commonly used to monitor changes in water content in water bodies. It utilises the fact that water bodies tend to strongly absorb light in the visible to near-infrared electromagnetic spectrum. By comparing the green band and near-infrared band of remote sensing imagery, NDWI can effectively highlight the water bodies. McFeeters proposed NDWI for the first time in 1996 (McFeeters, 2013). NDWI is particularly useful for detecting and monitoring changes in water bodies, such as lakes, rivers, and reservoirs. Index values greater than 0.5 usually correspond to water bodies. Vegetation usually corresponds to smaller values and built-up areas values range between zero and 0.2 (Sentinel Hub., n.d.).

McFeeters has asserted that values of NDWI greater than zero are assumed to represent water surfaces, while values less than, or equal, to zero are assumed to be non-water surfaces (McFeeters, 2013). The normalised difference water index, abbreviated NDWI is defined as:

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

Where: NIR is Near-infrared

Green is Green band

For Sentinel-2, the index looks like this:

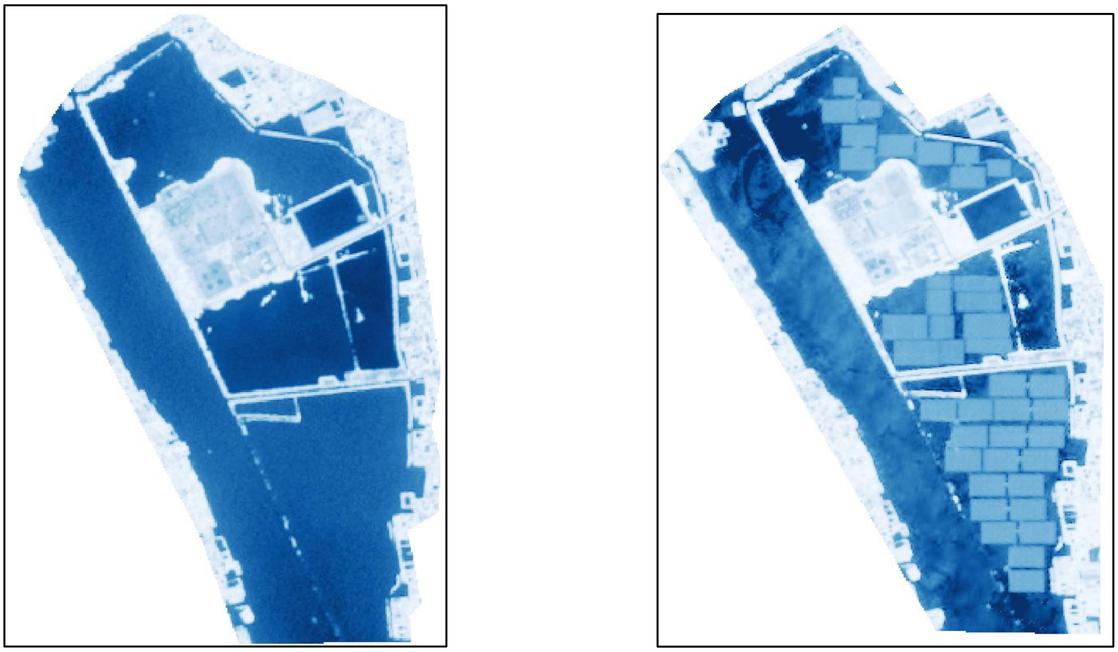
$$NDWI = \frac{B3 - B8}{B3 + B8}$$

Where: B8 = Near-infrared = band 8

B3 = Green band = band 3

The same formula is used to calculate and compare NDWI values of the Kayamkulam plant, Kerala in their pre- and post-installation phases.

NDWI Values of Kayamkulam plant area and Achankovil River



A B

Image 7: NDWI of plant area and Achankovil River (A) As on 28th February, 2020; (B) As on 27th February 2023

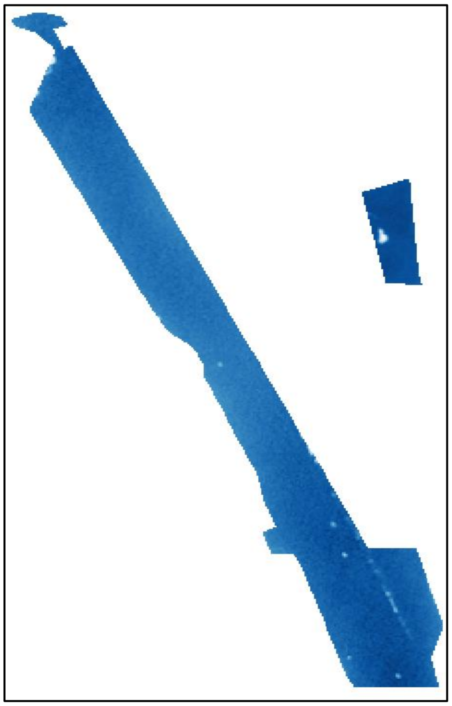
Table 6: NDWI Values of Overall Project area

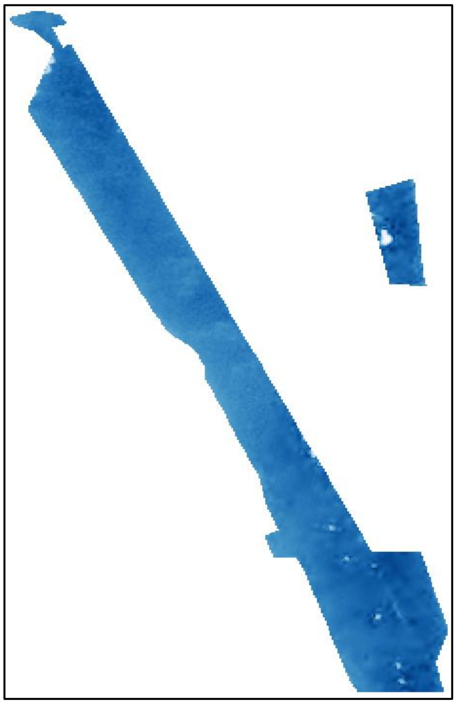
Date	Minimum Value	Maximum Value
28th February 2020 (pre-installation)	-0.71	0.56
27th February 2023 (post-installation)	-0.78	1

In Image 7, the NDWI values of the whole plant area and the Achankovil River are represented. As per the data in Table 6, the minimum NDWI value has decreased from -0.71 to -0.78 between 28th February 2020 to 27th February 2023. This change is indicative of the increase in non-water surfaces, such as land or other land cover types, in the studied area.

On the other hand, the maximum NDWI value has changed from 0.56 to 1. A value of 1 indicates the highest potential for water presence. This significant increase in the maximum NDWI value suggests that there has been a rise in the water level within the area, particularly in the Achankovil River. It is indicative of increase in the water surface area to facilitate the functioning of the FSPV panels, which rely on water bodies for their operation.

NDWI Values of river area (Area not used for project installation purposes)





A B

Image 8: NDWI of Masked area, (A) As on 28th February 2020; (B) As on 27th February 2023

Table 7: NDWI Values for the Achankovil River area

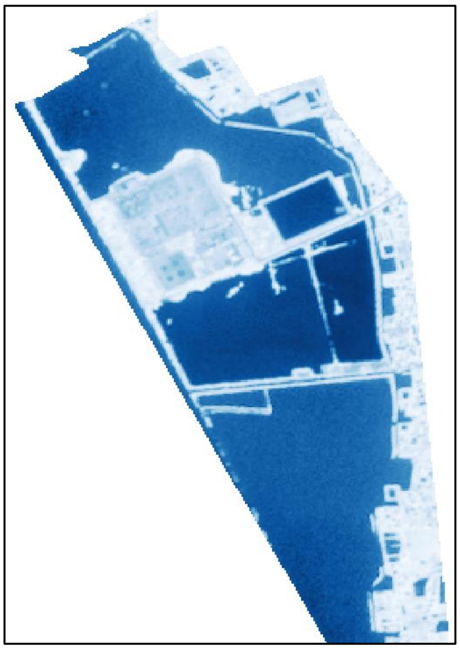
Date	Minimum Value	Maximum Value
28th February 2020 (pre-installation)	-0.53	0.61
27th February 2023 (post-installation)	-0.73	0.98

In Image 8, the NDWI values of National Waterways 3, which runs parallel to the reservoir, are depicted. The masked area in the image represents the portion that is not used for project installation purposes.

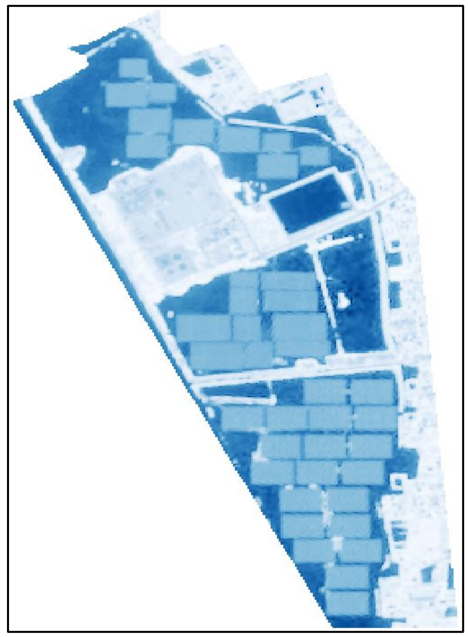
Based on the information in Table 7, the minimum NDWI value changes from -0.53 to -0.73. This decrease in the minimum value indicates areas that are increased in non-water surfaces, such as land or other land cover types, along National Waterways 3. On the other hand, the maximum NDWI value changes from 0.61 to 0.98. This significant increase in the maximum value suggests a rise in the water level of the river along with National Waterways 3. A higher value of 0.98 indicates a greater extent of water presence in the studied area.

These findings highlight the changes in the water level of the river, as reflected by the variations in the minimum and maximum NDWI values. The decrease in the minimum value indicates non-water surfaces, while the increase in the maximum value suggests a higher water level in the river.

NDWI Values of FSPV plant area



A



B

Image 9: NDWI of FSPV plant area (A) As on 28th February 2020; (B) As on 27th February 2023

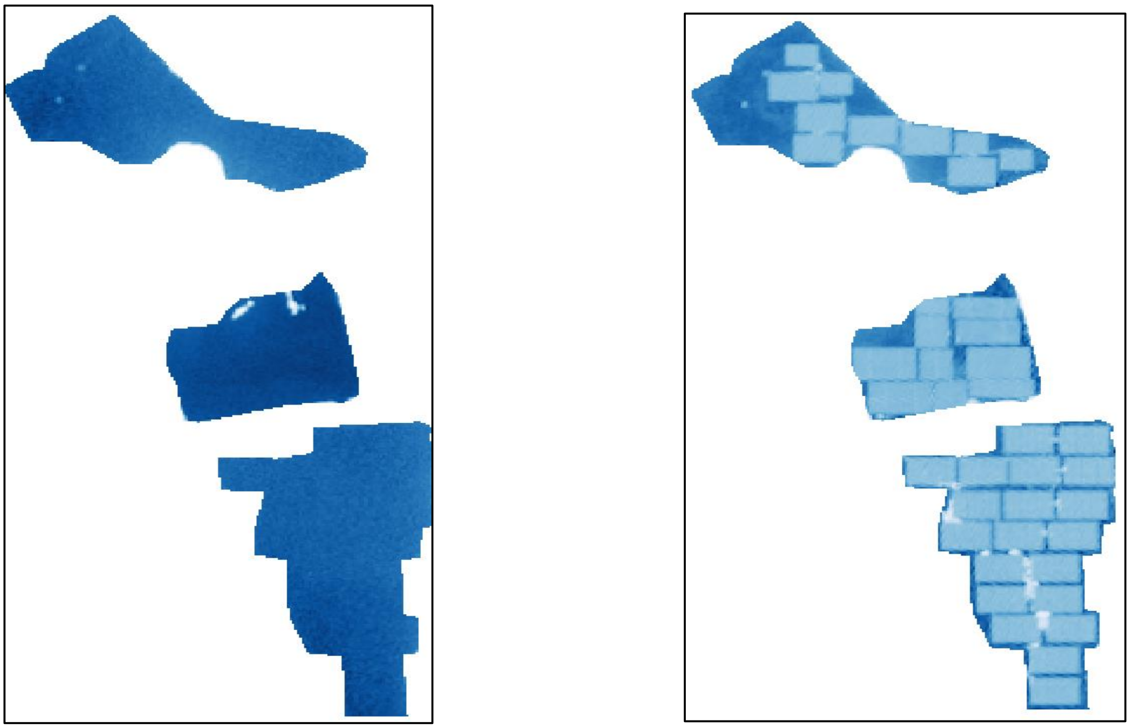
Table 8: NDWI Values of the FSPV Plant area

Date	Minimum Value	Maximum Value
28th February 2020 (pre-installation)	-0.71	0.56
27th February 2023 (post-installation)	-0.76	1

In Image 9, the NDWI of the RGCCPP area is depicted. The information suggests changes in the minimum and maximum NDWI values, indicating variations in the area.

According to the data in Table 8, the minimum NDWI value changes from -0.71 to -0.76. This slight decrease in the minimum value suggests a rise in non-water surfaces. Additionally, the maximum NDWI value changes from 0.56 to 1. This significant increase in the maximum value indicates a rise in the water level within the area. The installation of the FSPV system can contribute to this phenomenon by reducing the rate of evaporation from the water bodies. As a result, there is a higher concentration of water, leading to an increased maximum NDWI value. These findings suggest that there have been changes in the land cover and water level within the RGCCPP area.

NDWI Values of Masked area (Panel area)



A **B**

Image 10: NDWI of FSPV Panel area, (A) As on 28th February 2020; (B) As on 27th February 2023

Table 9: NDVI Values of the Panel Area

Date	Minimum Value	Maximum Value
28th February 2020 (pre-installation)	-0.61	0.55
27th February 2023 (post-installation)	-0.65	0.89

In Image10, the NDWI of the FSPVs panel area is represented. The information mentioned above describes changes in the minimum and maximum NDWI values, indicating variations in the FSPV area. According to the data in Table 9, the minimum NDWI value changes from -0.61 to -0.65. This slight decrease in the minimum value suggests a rise in non-water surfaces, possibly related to civil construction activities in the FSPV area. Additionally, the maximum NDWI value changes from 0.55 to 0.89. This significant increase in the maximum value indicates a rise in the water level within the FSPV area.

The installation of the FSPV systems can contribute to this phenomenon by reducing the rate of evaporation from the water bodies they are deployed on. This reduction in evaporation leads to a higher concentration of water, resulting in the increased maximum NDWI value.

2.1.3 NDTI

The NDTI is a valuable tool for monitoring changes in water quality, specifically related to turbidity. By utilising the red and green bands of the electromagnetic spectrum, the NDTI provides a means to accurately assess the level of turbidity in the water bodies. The NDTI is calculated using high-resolution multispectral satellite images, such as those obtained from the Sentinel-2 satellite. The index is designed to have a range from -1 to 1, with pure water and extremely muddy water represented at the respective extremes. This range enables the quantification and characterisation of turbidity levels within the studied areas.

Turbidity refers to the cloudiness or haziness of water caused by the presence of suspended particles, such as sediment, organic matter, or other debris. It is a measure of the interference or obstruction of light transmission through the water column. Higher levels of suspended materials lead to increased turbidity, which affects the clarity and transparency of the water.

On a map representing the NDTI, the higher values that are getting close to +1 typically display blue and represents either a high impurity content, whereas lower values that go all the way to -1 represents less impurity content (Siddique, 2019). It indicates a lower level of impurity or turbidity in the water, implying cleaner or clearer water conditions.

The normalised difference turbidity index, abbreviated NDTI is defined as:

$$\text{NDTI} = \frac{Red - Green}{Red + Green}$$

Where: Green is Green band

Red is Red band

For Sentinel-2, the index looks like this:

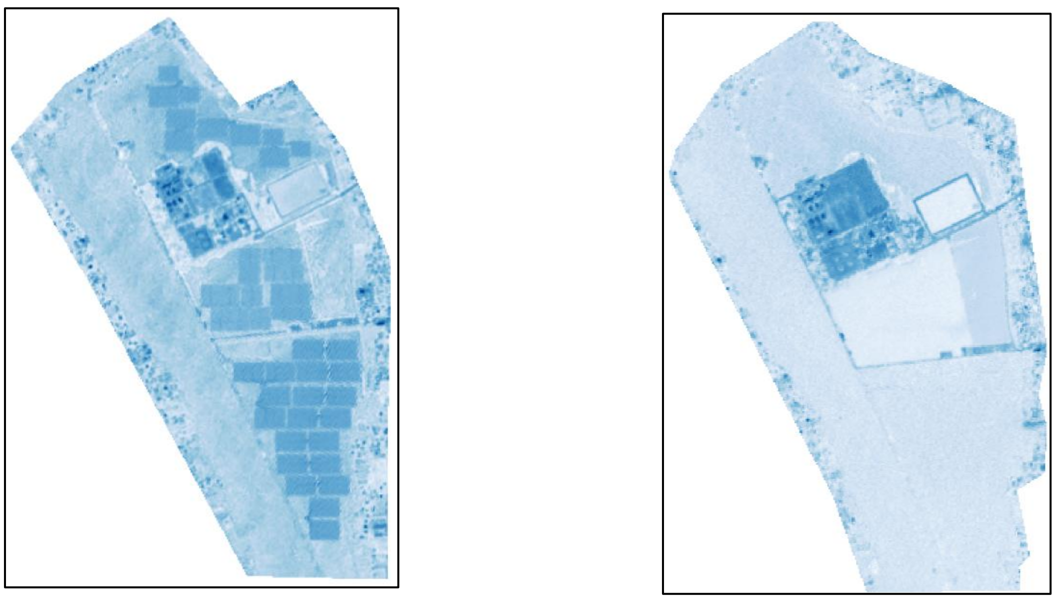
$$NDTI = \frac{B4 - B3}{B4 + B3}$$

Where: B4 =Red band = band 4

B3 = Green band = band 3

The same formula is used to calculate and compare NDTI values of the Kayamkulam plant, Kerala in their pre- and post-installation phases.

NDTI Values of the whole plant area



A B

Image 11: NDTI of plant area and Achankovil River; (A) As on 28th February 2020; (B) As on 27th February 2023

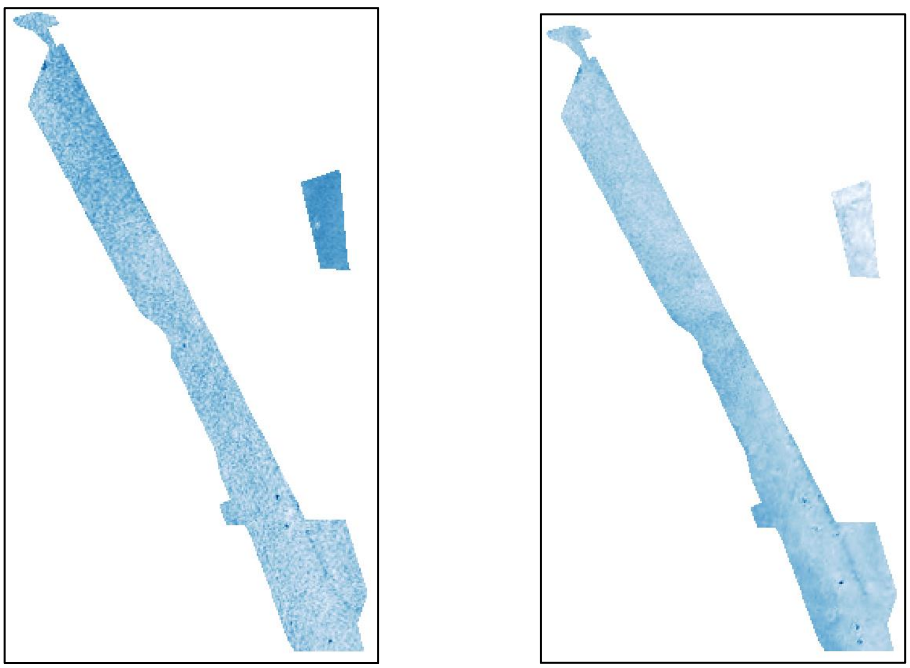
Table 10: NDTI Values of Overall Project Area

Date	Minimum Value	Maximum Value
28th February 2020 (pre-installation)	-0.28	0.39
27th February 2023 (post-installation)	-0.52	0.40

In Image11, the NDTI comparison for whole plant area (along with Achankovil River) on different dates reveals changes in the minimum and maximum values. As per the Table 10, the minimum value changes from -0.28 to -0.52, indicating a decrease in turbidity or impurity content. The decrease in the minimum NDTI value suggests a reduction in impurities or sediments present in the water.

Regarding the maximum value, there is a slight change from 0.39 to 0.40. This suggests that in certain patches of the area, there may be a presence of sediments or impurities that cause a slightly higher NDTI value. It's important to note that while the change is minimal, it highlights areas where there might be variations in water quality.

NDTI Values of river area (Masked area not used for project installation purposes)



A B

Image 12: NDTI of unused water area, (A) As on 28th February 2020; (B) As on 27th February 2023

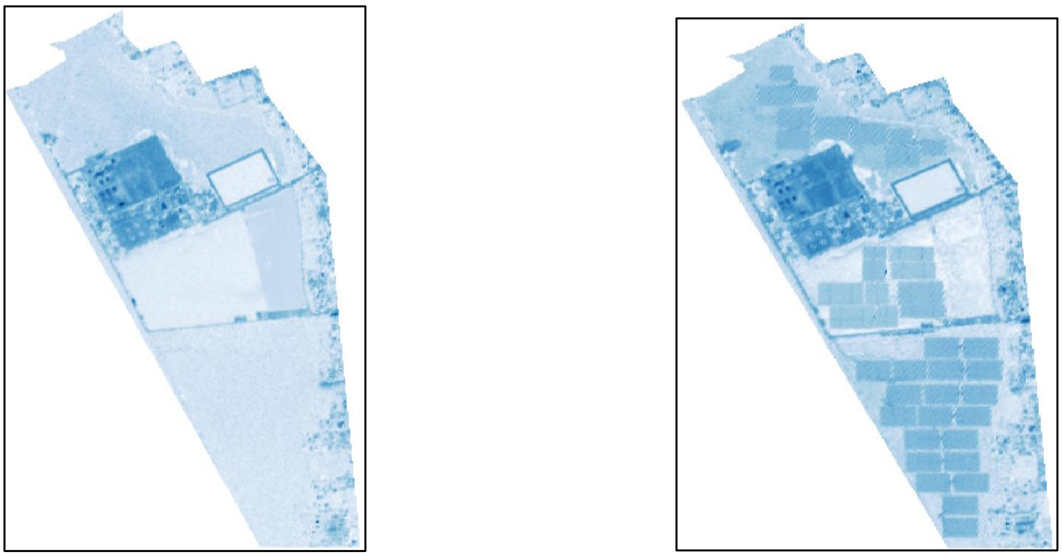
Table 11: NDTI Values of the Achankovil River area

Date	Minimum Value	Maximum Value
28th February 2020 (pre-installation)	-0.24	0.02
27th February 2023 (post-installation)	-0.38	0.14

In Image 12, the NDTI analysis of National Waterways 3, which runs parallel to the reservoir, reveals changes in the minimum and maximum values. As per the Table 11, the minimum value changes from -0.24 to -0.38, indicating a shift in water quality. The decrease in the minimum NDTI value suggests a change in the quality of water in the National Waterways 3 area. This indicates a decrease in turbidity or impurity content.

Regarding the maximum value, there is a slight change from 0.02 to 0.14. The value shows increase in turbidity. Lower value indicates clear water and higher value is representative of highly turbid water. Increased other anthropogenic factors may contribute to changes in water quality, resulting in a slight variation in the NDTI maximum values.

NDTI Values of FSPV plant area



A ***B***

Image 13: NDTI of FSPV plant area, (A) As on 27th February 2020; (B) As on 28th February 2023

Table 12: NDTI Values of FSPV Plant area

Date	**Minimum Value**	**Maximum Value**
28th February 2020 (pre-installation)	-0.28	0.39
27th February 2023 (post-installation)	-0.39	0.44

In Image 13, the NDTI analysis of plant area reveals changes in the minimum and maximum values. As per the Table 12, the minimum value changes from -0.28 to -0.39, which indicates less impurity content. This implies that there is a reduction in turbidity or the presence of suspended sediment, leading to improved water quality. While the maximum value varies from 0.39 to 0.44, which indicates slight increase in impurity contents. This could indicate the presence of factors such as sedimentation or changes in water conditions that result in a higher NDTI value.

NDTI Values of FSPV panel area

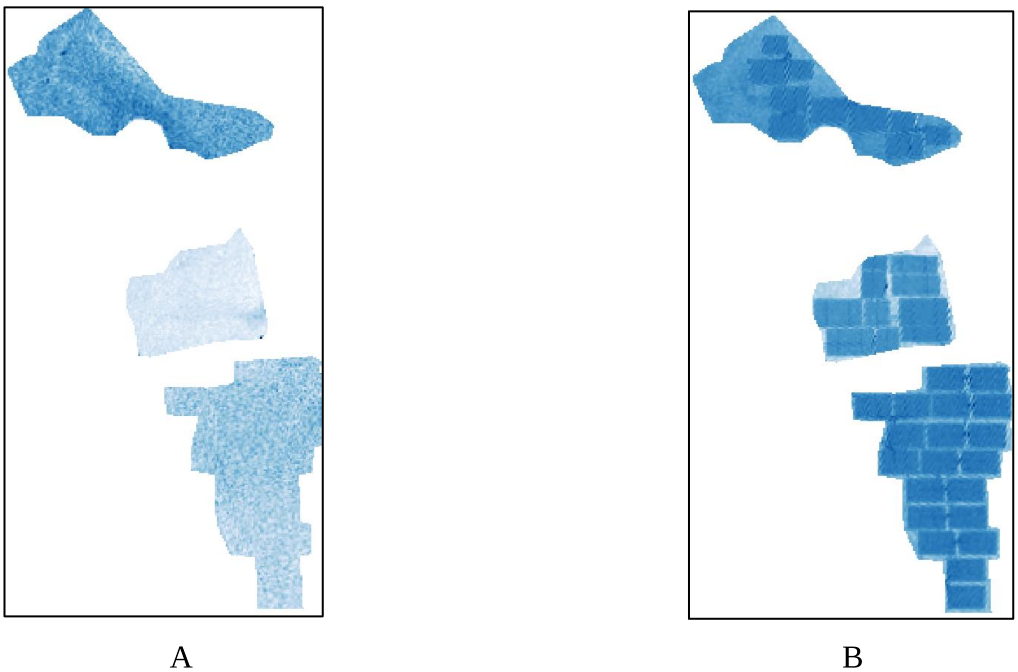


Image 14: NDTI of FSPV panel area, (A) As on 27th February 2020; (B) As on 28th February 2023

Table 13: NDTI Values of the FSPV Panel area

Date	Minimum Value	Maximum Value
28th February 2020 (pre-installation)	-0.24	-0.004
27th February 2023 (post-installation)	-0.45	0.15

In Image 14, the NDTI comparison for FSPV panel on different dates reveals changes in the minimum and maximum values. Based on the data in Table 13, the minimum NDTI value changes from -0.24 to -0.45, indicating a decrease in impurity content. This suggests that there is an improvement in water quality, with a reduction in turbidity or suspended sediment. However, the maximum NDTI value varies from -0.004 to 0.15, indicating an increase in impurity content. This suggests that there may be areas within the analysed region where turbidity or sediment content has increased, leading to higher NDTI values.

2.2 Yamakura Dam Floating Solar Farm (13.7 MW), Japan

A

B

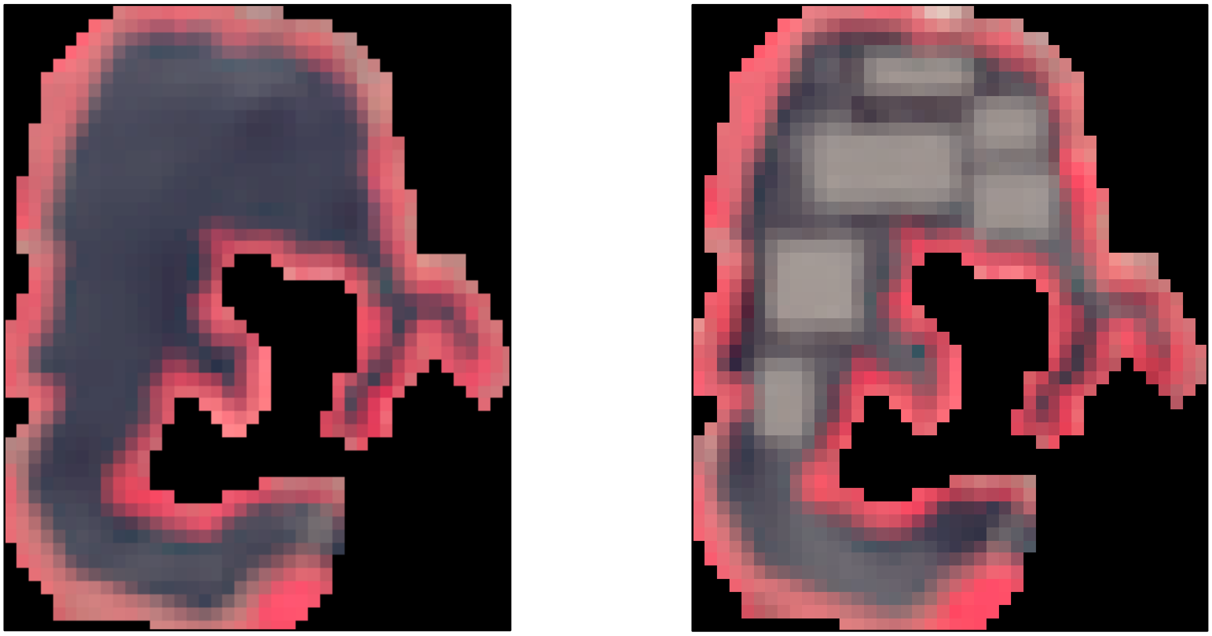
Image15: Yamakura Dam Floating Farm Japan; (A) As on 1st January 2015-pre, (B) As on 1st May 2023-post

Image 15 displays the pre-installation and post-installation phases of Yamakura Dam Solar Farm. The Yamakura Dam Floating Solar Farm plant of Japan is constructed over the surface of the reservoir, which is managed by the waterworks bureau of Chiba Prefecture for its industrial use (LUFKIN, 2015). This plant lies at latitudes 35° 49’ 28” N and longitude[2] of 140° 13’ 13” E. Image16 (below) shows the False Colour Composite image of the plant, which has been taken from Landsat-8 satellite. False colour map of Landset-8 shows bands 3, 4 and 5. These three bands have been used to determine the NDVI, NDWI and NDTI of the plant and compare its pre- and post-installation environmental impacts.

In Landsat-8 map:

- Band 5= Near-infrared band
- Band 4= Red band
- Band 3= Green band

[2]Latitude and longitude taken from Google Earth.



A B

Image 16: False Colour Composite map of Yamakura Dam Floating Solar Farm (A) As on 16th May 2017; (B) As on 16th May 2023

2.2.1 NDVI

The normalised difference vegetation index (USGS), abbreviated NDVI, for Landsat-8, looks like the following:

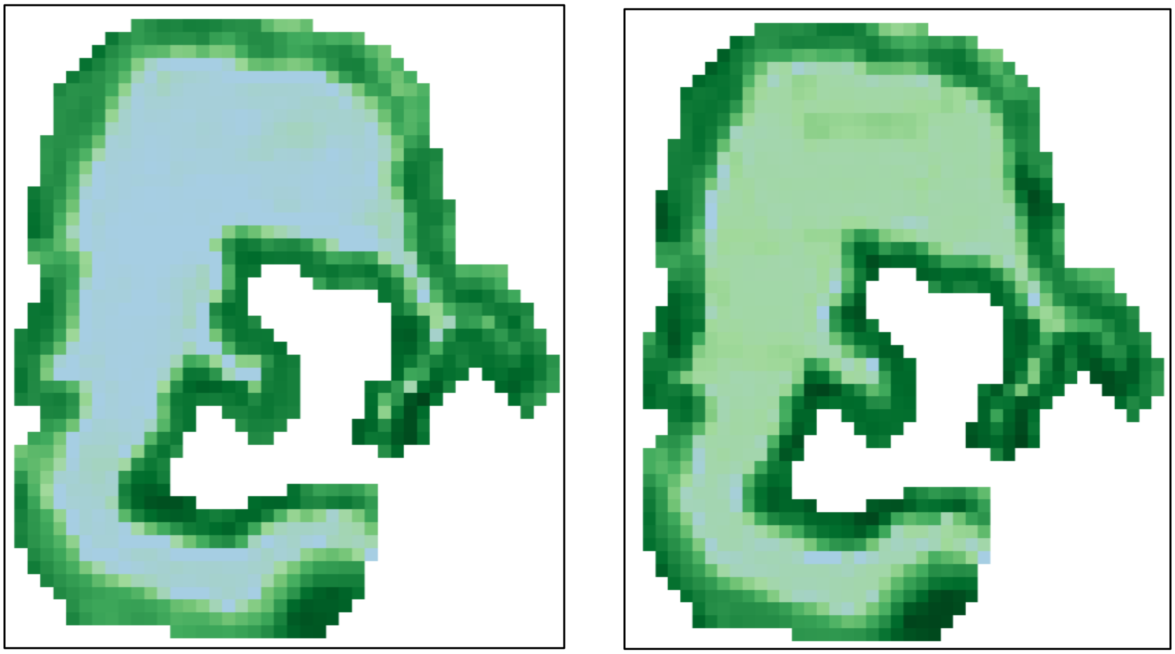
NDVI= $\frac{B5-B4}{B5+B4}$

Where: B5 = band 5 = Near-infrared

B4 = band 4 = Red band

The same formula has been used to calculate and compare NDVI values of the Yamakura plant, Japan in their pre- and post- installation phases.

NDVI Values of Plant area



A B

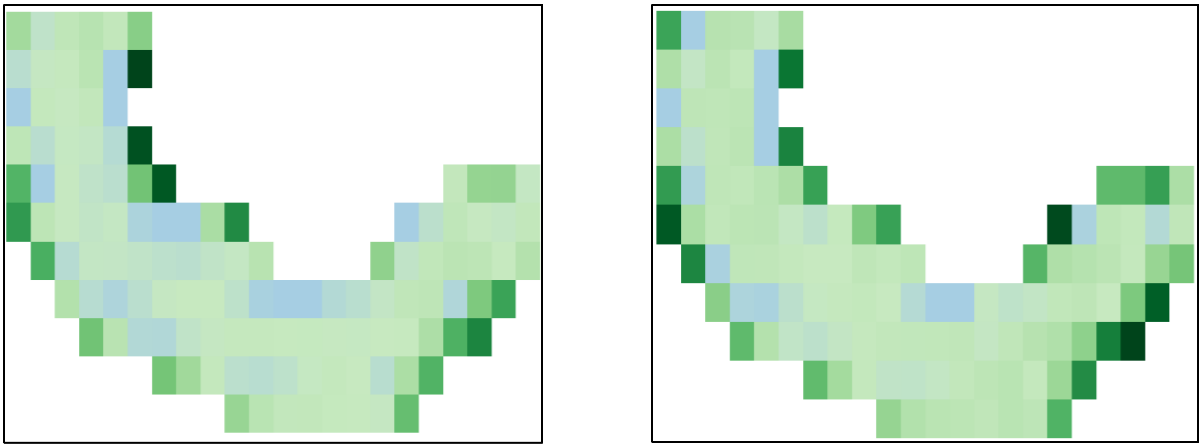
Image 17: NDVI of Plant area, (A) As on 16th May 2015; (B) As on 16th May 2023

Table 14: NDVI Values of the Plant area

Date	Minimum Value	Maximum Value
16th May 2015 (pre-installation)	-0.36	0.91
16th May 2023 (post-installation)	-0.41	0.88

Image 17 represents the whole plant area on different dates. As per Table 14, the minimum NDVI value changes from -0.36 to -0.41, and there is a slight rise in the water level. The maximum NDVI decreases from 0.91 to 0.88, which reveals a slight decrease in vegetation.

NDVI Values of unused water area



A B

Image 18: NDVI of unused water area: (A) As on 16th May 2015; (B) As on 16th May 2023

Table 15: NDVI Values of Unused Water area

Date	Minimum Value	Maximum Value
16th May 2015 (pre-installation)	-0.19	0.57
16th May 2023 (post-installation)	-0.11	0.43

Image18 represents the unconstructed water area of the reservoir. The figure displays the changes in the minimum and maximum NDVI values. As per Table 15, it can be observed that the minimum NDVI value ranges from -0.19 to -0.11, which indicates a slight decrease in water level. Additionally, the maximum NDVI value decreases from 0.57 to 0.43, indicating a slight decrease in the extent of vegetation cover. This decrease in vegetation can be attributed to the changes in the water level or other factors affecting plant growth in the area. Overall, the graph suggests a slight decline in both water level as well as vegetation cover based on the changes in the minimum and maximum NDVI values depicted in Image 18.

2.2.2 NDWI

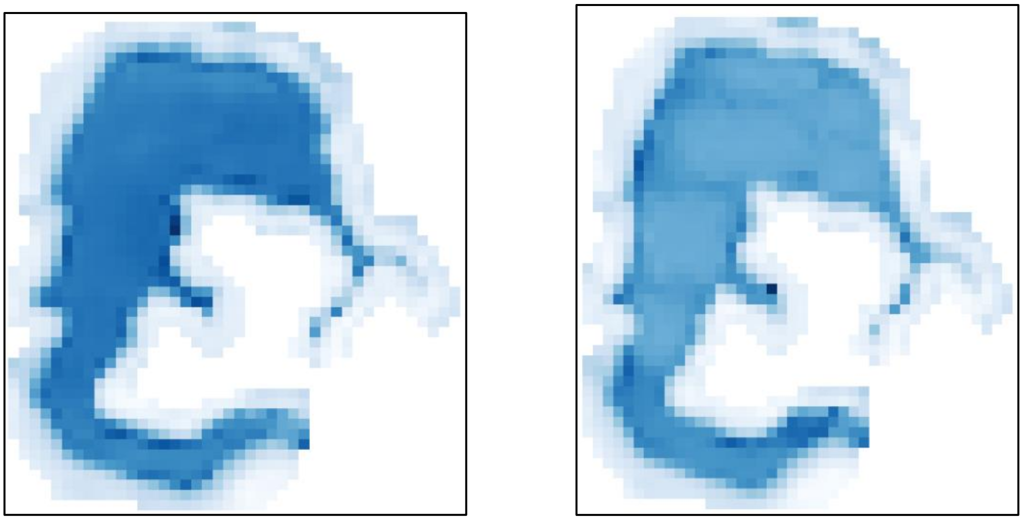
The normalised difference water index, abbreviated NDWI, for Landsat-8, looks like the following (Sentinel Hub., n.d.):

NDWI= $\frac{B3 - B5}{B3 + B5}$

Where: B5 = band 5 = Near-infrared

B3 = band 3 = Green band

NDWI Values of Plant area



A **B**

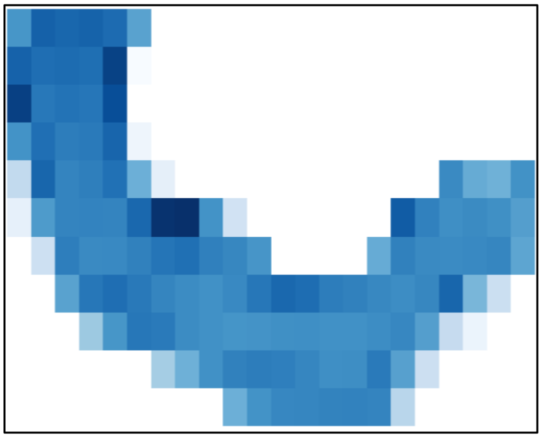
Image 19: NDWI of Plant area: (A) As on 16th May 2015; (B) As on 16th May 2023

Table 16: NDWI Values of the Plant area

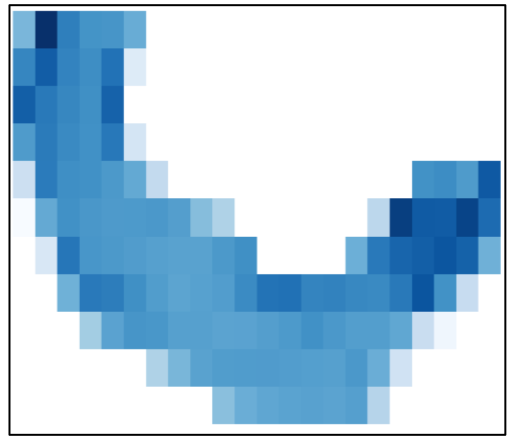
Date	Minimum Value	Maximum Value
16th May 2015 (pre-installation)	-0.77	0.58
16 May 2023 (post-installation)	-0.79	0.52

Image 19 represents the NDWI image of the plant area. The NDWI values provide insights into the presence of water bodies, vegetation, and built-up areas within the image. As per Table 16, the minimum NDWI value ranges from -0.77 to -0.79. These values suggest a slight increase in non-water surfaces, such as vegetation or built-up areas. The slight variations in the minimum value could be attributed to minimal civil construction within the plant area. Furthermore, the maximum NDWI value changes from 0.58 to 0.52, indicating a minimal decrease in the water level. This implies that the water bodies within the plant area have experienced a slight reduction in their extent.

NDWI Values of Unconstructed water area



A



B

Image 20: NDWI of Unconstructed water area: (A) As on 16th May 2015; (B) As on 16th May 2023

Table 17: NDWI Values of Unconstructed Water area

Date	Minimum Value	Maximum Value
16th May 2015 (pre installation)	-0.39	0.42
16th May 2023 (post installation)	-0.35	0.33

Image 20 displays the NDWI of the unconstructed water area in the plant area. The image represents the changes in the minimum and maximum NDWI values. As per Table 17, it can be observed that the minimum NDWI value ranges from -0.39 to -0.35. The increase in the minimum value suggests a reduction in the presence of water or an expansion of non-water surfaces. Additionally, the maximum NDWI value changes from 0.43 to 0.33, indicating a decrease in the water level. This implies that there has been a slight reduction in the reflectance from water bodies within the unconstructed water area, which can be due to turbidity or other growth in the water.

2.2.3 NDTI

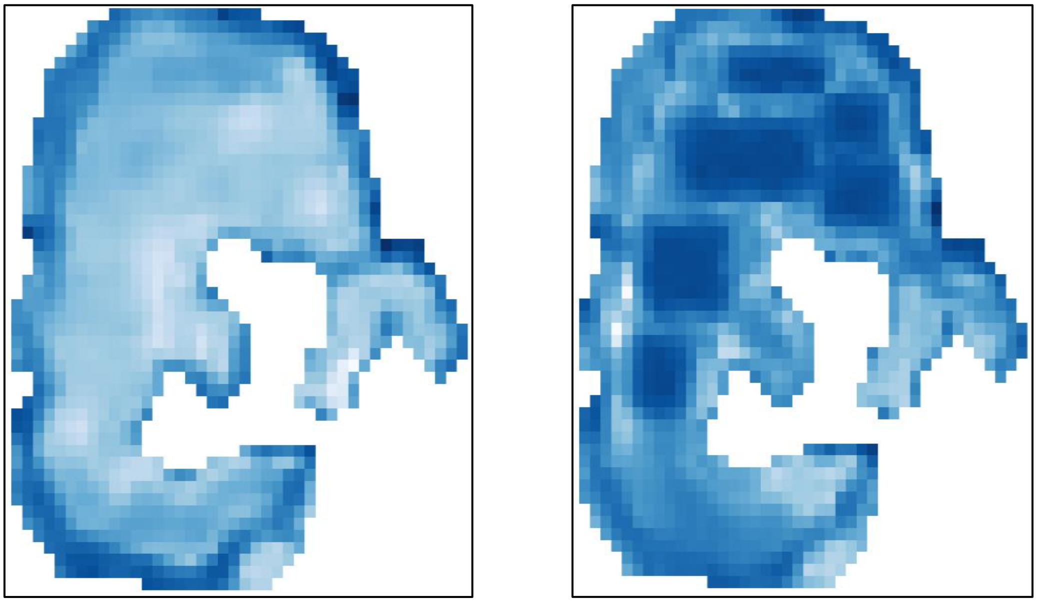
The normalised difference turbidity index, abbreviated NDTI, for Landsat-8, looks like the following:

NDTI = $\frac{B4 - B3}{B4 + B3}$

Where: B4 = Red band = band 4

B3 = Green band = band 3

NDTI Values of plant area



A B

Image 21: NDTI of pant area: (A) As on 16th May 2015; (B) As on 16th May 2023

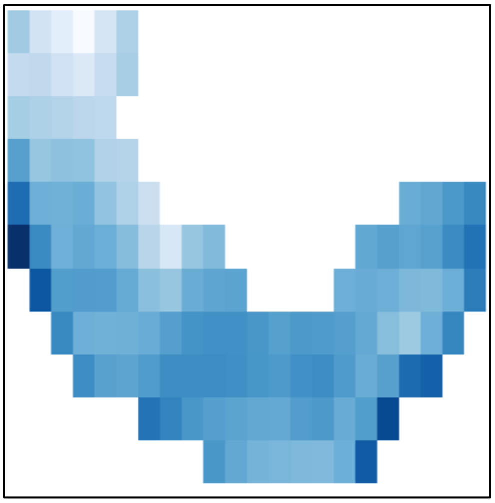
Table 18: NDTI Values of the Plant area

Date	Minimum Value	Maximum Value
16th May 2015 (pre-installation)	-0.45	0.07
16th May 2023 (post-installation)	-0.49	0.07

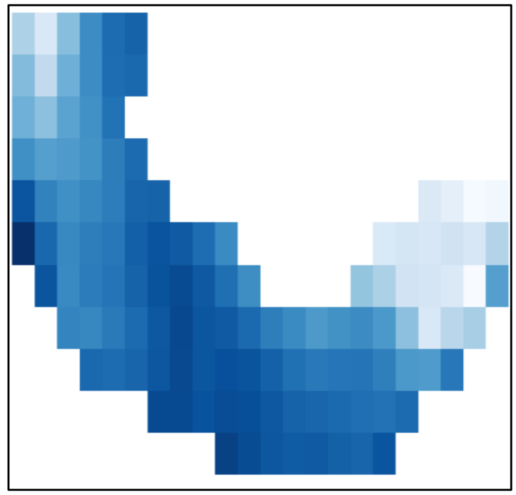
Image 21 displays the NDTI for the plant area of the Yamakura Floating Solar power plant. The NDTI values provide information about the level of impurity or turbidity in the water, with higher values indicating a higher impurity content and lower values representing less impurity. As per Table 18, the minimum NDTI value ranges from -0.45 to -0.49. These values indicate a slight change towards less impurity in the water within the plant area. This suggests that there has been a minor improvement in the water quality, resulting in cleaner or clearer water conditions.

Furthermore, the maximum NDTI value remains unchanged (0.07) for both the pre and post-installation phases of the plant. This indicates that there has been no significant change in the impurity level or turbidity of the water.

NDTI Values of water area



A



B

Image 22: NDTI of water area; (A) As on 16th May 2015; (B) As on 16th May 2023

Table 19: NDTI Values of the Water area

Date	Minimum Value	Maximum Value
16th May 2015 (pre-installation)	-0.34	-0.06
16th May 2023 (post-installation)	-0.33	-0.05

As mentioned above, on a map, the higher values that are getting close to +1 typically display blue and represent either a high impurity content, whereas the lower values that go all the way to -1 represent less impurity content. Image 22 shows NDTI for the plant and unconstructed areas of the Yamakura Dam Floating plant. From the values in Table 19, it is clearly determined that there is a slight change in the turbidity of water in pre- and post-installation scenarios. These values indicate a slight change towards more impurity in the water within the plant area. The above analysis using NDVI, NDWI and NDTI would be more meaningful if a weighted average of the pre-installation and post-installation values were compared to have an overall estimation of water quality and the growth of vegetation in the project areas. General indications from the analysis suggests that for both the plant areas in India and Japan, quality of water has improved, as can be derived from the reduced reflectance in the NIR band, while vegetation growth is more prominent in the Indian scenario with a slight decrease in the Yamakura project area.

CHAPTER-III

Performance of Floating Solar Plants vis-à-vis Other Solar Plants

Analysing the performance of floating solar plants in comparison to other solar installations is crucial. Temperature and wind speed play significant roles in influencing the efficiency and power output of land-based photovoltaic (PV) systems. High temperatures can lead to a decrease in the efficiency of solar cells, as the excess heat can negatively impact the conversion of solar energy into electrical energy. When the temperature of the solar cells increases, their performance tends to decline. Similarly, wind speed can affect PV system efficiency by influencing panel cooling. Higher wind speeds can enhance the cooling of the panels, which helps to dissipate excess heat and maintain lower operating temperatures. On the other hand, lower wind speeds can impede the cooling process, leading to a rise in temperature and potentially reducing the overall efficiency of the system.

To accurately assess PV system performance, temperature and wind speed data are often adjusted or normalised to align with water surface temperature. This adjustment helps provide a more accurate representation of the operating conditions and allows for more precise calculations of the performance ratio (PR). The temperature can affect the PR value, with variations ranging from ±2 per cent to ±10 per cent (Kumar, 2021).

The energy generation capacity of a plant depends largely on two factors: the amount of solar radiation obtained and the number of clear sunshine days encountered by the plant's site. These two factors also affect CUF. According to the MNRE report of 2013, the CUF of solar PV plants in India is 11 to 31 per cent. The Central Electricity Regulatory Commission blueprint for New Tariff Regulations for Renewable Projects 2020, indicated minimum CUF for solar plants in India as 21 per cent, 23 per cent for thermal plants and 19 per cent for FSPV plants (Table 20). The quantity of sunlight and the air temperature have an impact on the CUF.The Maximum Auxiliary Consumption is actually the total electricity consumed internally to run the plant. Plant load factor and CUF are considered equivalent parameters in most studies. The table below shows the CUF comparison of FSPV plants with other power plants in India. The CUF might reach 23.74 per cent, according to a preliminary financial and economic estimate for energy storage systems and floating solar PV of India (Kumar, 2021).

Table 20: Capacity Utilisation Factor (CUF) of various power plants in India

Sl. No.	Projects	Minimum CUF (Percentage)	Maximum Auxiliary Consumption (Percentage)
1.	FSPV	19	0.25
2.	Solar thermal power	23	10
3.	Solar Power	21	0.25

Source: (Kumar, 2021)

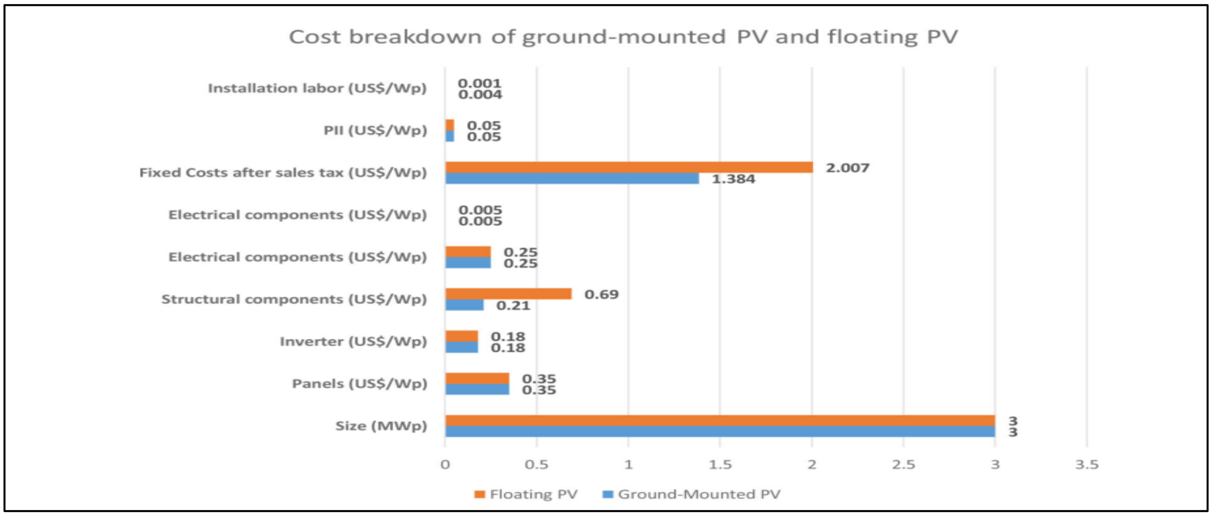


Figure 2: Cost breakdown between ground-mounted and FSPV (Kumar, 2021)**.**

The cost breakdown between ground-mounted SPL versus FSPV has been presented in Figure 2 above. The cost of FSPV system depends on mooring, which might increase prices in a significant manner. Due to the necessity to build up the soil and building up of foundation, the ground-mounted project can take up to eight weeks to install. On the other hand, the FSPV systems are estimated to take a week to install. FSPV maintenance and operation are estimated same as ground-mounted projects.

CHAPTER-IV

Scope and Methodology

The Study of Kayamkulam Solar Power Plant Project (92 MW), NTPC, Kerala has been analysed based on the following performance indicators:

4.1 Capital Expenditure (CAPEX)

For the installation of Kayamkulam Solar Power Plant, a Memorandum of Understanding (MoU) was signed between KSEB Limited and NTPC. NTPC initiated the procurement process for the implementation of FSPV projects in two phases i.e., 22 MW and 70 MW FSPV project at RGCCPP in Kayamkulam, Kerala. The procurement was conducted through two separate International Competitive Bidding (ICB) tenders.

The conclusion of the tendering process was carried out through a Reverse Auction among the shortlisted agencies. Finally, the project has been awarded to:

- M/s BHEL for 22 MW floating Solar Project.
- M/s Tata Power Solar Systems Limited for 70 MW floating Solar Project.

Table 21: Capital cost of the entire Project of Kayamkulam Floating Solar Plant

Capital cost of the Project	Phase-1 (22 MW) ₹ in lakh/MW	Phase-2 (70 MW) ₹ in lakh/MW
Preliminary cost	3.00	3.00
Land cost- Leasehold	0	0
Land cost- Freehold	0	0
EPC cost	500.51	489.77
Infrastructure cost	0	72.53
Project Management (@ 0.50 per cent)	2.52	2.83
Contingency (@ 0.50 per cent)	2.53	2.84
Interest During Construction (IDC) Period	14.81	5.63
Capital cost (including IDC) per MW	523.36	576.60
Capital cost for Project (₹ in lakh)	**11,514.00**	**40,361.96**
Total Capital cost for Project (₹ in lakh)	**51,875.96**	

Table 21 shows the Capital cost[3] of "The Floating Solar PV Project at NTPC-RGCCP, Kayamkulam, Kerala approved by Central Electricity Regulatory Commission (CERC) (Central Electricity Regulatory Commission, 2022).

The levelised tariff calculated based on the parameters mentioned in RE Tariff Regulations 2020 is ₹ 3.51/kWh for 22 MW and ₹ 3.58/kWh for 70 MW. The weighted average tariff calculated for 92 MW is ₹ 3.56/kWh (Central Electricity Regulatory Commission, 2022). However, the levelised tariff approved by CERC was ₹ 2.91/kWh for Phase-1 and ₹ 2.94/kWh for Phase-2 as per petition no. 341/GT/2019 (Central Electricity Regulatory Commission, 2022).

4.2 Capacity Utilisation Factor (CUF)

NTPC had claimed a CUF of 25.11 per cent for the 22 MW Phase-1 and 27.24 per cent for the 70 MW Phase-2 of the Project. These CUF values represent the expected percentage of electricity generation from the installed capacity over a specific period (Central Electricity Regulatory Commission, 2022).

The quoted annual quantity generation by successful contractor M/s BHEL for 22 MW Phase-1 was 48.42 MU and by M/s Tata Power Solar Systems Limited for 70 MW phase-2 was 167.5 MU during reverse auction based on reference global solar radiation at the project sites. The guaranteed annual generation, as submitted during the reverse auction process, is considered for the computation of CUF and the calculation of the levelised tariff.

4.3 Performance Ratio

The Performance Ratio is used frequently to compare the efficiency of grid-connected PV systems at different locations and with different module types. It describes the ratio of the actual energy yield (final electrical energy) of a PV system and its nominal energy output. The nominal power

[3] The records for the capital cost has been taken from CERC records. Regulation 12 of the RE Tariff Regulations 2020 specifies the definition of **Capital Cost** as follows: Norms for capital cost, as specified in relevant chapters of these regulations, shall be inclusive of land cost, pre-development expenses, all capital work including plant and machinery, civil work, erection, commissioning, financing cost, interest during construction, and evacuation infrastructure up to inter-connection point.

of a PV system is usually expressed in kilowatt peak (kWp) and is based on the power of the PV modules in the PV system measured under Standard Testing Conditions[4] (STC).

PR = $\frac{\boldsymbol{AO}}{\boldsymbol{NO}}$ ………………………………………………………………………………………(1)

Where: PR is the Performance Ratio

AO is the Actual Reading of the plant output.

NO is the Nominal Calculated Plant Output.

According the data from CERC (Central Electricity Regulatory Commission, 2022),as per the tariff approved by the commission in 2022, the net life time generation from project for 22 MW SPV project is 1198.52 MU considering a life span of 25 years as per the available data. It results in annual generation rate of 47.94 MU.

For Phase-1:

- PLF (Plant Load Factor) = 25.11 per cent or 0.25
- Power = 47.94 MU

According to formula of conversion for MW into MU:

Power (MU) = Energy (MW) x 24 (hrs.) x 365 (days) x PLF/1000

Energy = 21.89 MW…………………………………………………………………(2)

The net life time (25 Years) generation from project for 70 MW SPV project is **4136.96 MU**. It results in annual generation rate of 165.47 MU.

For Phase-2:

- PLF = 27.24 per cent or 0.27
- Power = 165.47 MU

Power (MU) = Energy (MW) x 24 (hrs.) x 365 (days) x PLF/1000

Energy = 69.96 ……………………………………………………………………..(3)

Putting value from (2) and (3) in equation (1),

PR = $\frac{21.89 + 69.96}{92}$ = 99.83 per cent or 0.99

[4] The *standard test conditions*, or STC of a photovoltaic solar panel is used by a manufacturer as a way to define the electrical performance of their photovoltaic panels and modules.

4.4 Levelised Cost of Energy (LCOE)

The LCOE, also referred to as the Levelised Cost of Energy or the Levelised Energy Cost (LEC), is a measurement used to assess and compare alternative methods of energy production. The LCOE of an energy-generating asset can be thought of as the average total cost of building and operating the asset per unit of total electricity generated over an assumed lifetime (CFI, 2023).

Table 22: Calculation of LCOE

20 MW Part 1						70MW Part 2				
NPV	INITI-AL	Present Value of costs	Total cost	**Net gener-ation**	Total Net gene-ration (for 20 MW)	INITIAL	Present Value of costs	Total cost	**Net genera-tion**	Total Net generati-on for 70 MW
	Rs/ lakhs	11514	Rs/lakhs	MU	MU	Rs/ lakhs	40361.96	Rs/ lakhs	MU	MU
1	11514	**79.83**	12914.59	2.18	1090	40361.96	**87.95**	41892.61	2.37	4147.5
2		**77.60**		2.18			**85.49**		2.37	
3		**75.37**		2.18			**83.04**		2.37	
4		**76.77**		2.18			**84.21**		2.37	
5		**74.68**		2.18			**81.90**		2.37	
6		**72.60**		2.18			**79.59**		2.37	
7		**70.52**		2.18			**77.28**		2.37	
8		**68.45**		2.18			**74.98**		2.37	
9		**66.38**		2.18			**72.69**		2.37	
10		**64.32**		2.18			**70.40**		2.37	
11		**62.27**		2.18			**68.12**		2.37	
12		**60.22**		2.18			**65.85**		2.37	
13		**58.18**		2.18			**63.58**		2.37	
14		**56.15**		2.18			**61.32**		2.37	
15		**54.12**		2.18			**59.07**		2.37	
16		**37.92**		2.18			**41.19**		2.37	
17		**35.91**		2.18			**38.96**		2.37	
18		**34.88**		2.18			**37.80**		2.37	
19		**34.97**		2.18			**37.87**		2.37	
20		**35.21**		2.18			**38.12**		2.37	
21		**40.30**		2.18			**43.70**		2.37	
22		**40.56**		2.18			**43.96**		2.37	
23		**40.84**		2.18			**44.24**		2.37	
24		**41.12**		2.18			**44.52**		2.37	
25		**41.42**		2.18			**44.82**		2.37	
Total				**54.50**					**59.25**	

The above data in Table 22 is related to Net Present Value (NPV) of total cost over the lifetime and NPV of electrical energy produced over the entire lifetime of Kayamkulam plant which has been derived from CERC (Central Electricity Regulatory Commission, 2022). The lifetime taken by CERC is 25 years. The LCOE has been calculated (Table 23) by using the formula as under:

$$\text{LCOE} = \frac{NPV\ of\ Total\ costs\ over\ lifetime}{NPV\ of\ electrical\ energy\ produced\ over\ lifetime}$$

The LCOE has been worked out to be 481.822 $\frac{Rs/Lakh}{MU}$ = 52.02 $/MW

*MU = million unit = gigawatt-hour

Table 23: Summary of Results

Indicators	Results	Remarks
CAPEX	₹ 51,875.96 lakh	When compared to Ramagundam FSPV in Telangana's Peddapalli district with CAPEX of ₹ 423 crore, Kayamkulam FSPV is costlier.
Performance Ratio (PR)	101.6 per cent	The PR of this plant is above than the national average of 64.15 per cent, for the thermal power plants of India (Ministry of Power, GOI, 2023).
CUF	25.55 per cent for Phase-1 27.24 per cent for Phase-2	The CUF of this plant is above the national average of 19 per cent for the floating solar power plant (Ranjan, 2020).
LCOE	481.822 $\frac{Rs/Lakh}{MU}$ = 52.02 $/MW	The LCOE of this plant is below the national average of 59.3 $/MWh (value of 2022), for the floating solar power plant. Therefore, it is much more cost-effective.

CHAPTER-V

DPSIR Framework

5.1 Potential, Challenges Using DPSIR Framework

The DPSIR framework serves as an analytical tool to assess concerns pertaining to FSPV systems. It enables a comprehensive evaluation of issues involved in the development of FSPV systems by examining the underlying driving forces and pressures affecting the environment, the resulting state of the environment and its impacts, and the responses taken. DPSIR also helps identify the interconnections between each of these elements. A generic DPSIR framework for FSPV systems is shown below in Figure 3.

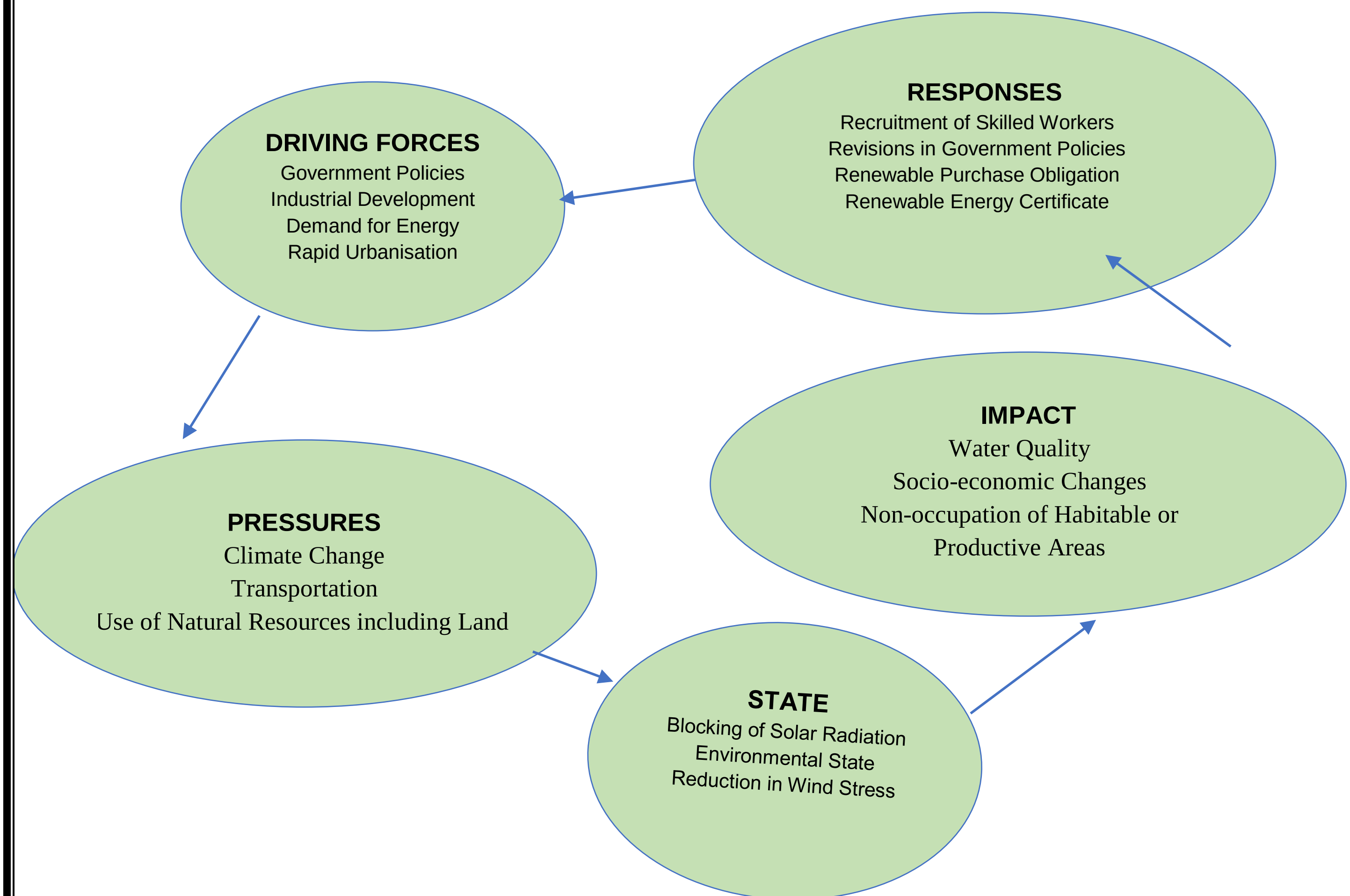


Figure 3: A Generic DPSIR Diagram for a FSPV Plant

The DPSIR framework is useful for describing the relationships between the origins and consequences of environmental problems. To understand their dynamics, it is also useful to focus on the links among various DPSIR elements (Figure 3 above). DPSIR framework will also be helpful in determining and assessing the links between human pressures and changes in state of marine and coastal ecosystems due to the development of MRE like FSPV.

5.1.1 Drivers: Smith et al. (2016), has described Drivers as the highest level "Driving Forces", encompassing overarching government policies to specific sectoral activities (Smith CJ, 2016). By examining the different levels of drivers, an attempt is made to provide a comprehensive understanding of the social, demographic, and economic factors that influence human activities and their environmental impacts in this study. The policies by the government can be considered as driving forces at the highest level, as they provide the overarching framework for economic and social development. At a mid-level, various sectors such as fishing, tourism etc. play a significant role in shaping human activities and have a direct impact on the environment. Understanding the drivers within these sectors is crucial for assessing their environmental implications and identifying potential strategies for sustainable practices (Smith CJ, 2016). Rapid urbanisation, growth of industries and demand for energy are major factors which also guide the driving force relating to the formulation of government policies, towards the development of FSPVs.

5.1.1.1 Electricity Demand

As per data from the Ministry of Power, Government of India (Ministry of Power, GOI, 2023), India is generating approximately 43 per cent of its total electricity from renewable and nuclear energy sources and the remaining 57 per cent from fossil fuels. The electricity generation target (including RE) for the year 2023-24 has been fixed as 1750 Billion Units (BU). It indicates a growth of around 7.2 per cent over the actual generation of 1624.158 BU for the previous year (2022-23). The generation during 2022-23 was 1624.158 BU as compared to 1491.859 BU generated during 2021-22, representing a growth of about 8.87 per cent. Indeed, the data highlights the current electricity generation mix in India, with a significant portion still coming from fossil fuels, providing an opportunity for the Renewable Energy sector.

Therefore, the policy of the Government of India has also focused on the development of non-fossil fuel-based energy sources to meet its climate goals under the Paris Agreement (2015), paving the way towards the establishment of FSPV systems, since they are a much cleaner form of energy aimed at decarbonisation.

5.1.1.2 Industrial development

There are four major points that act as drivers for India's industrial energy consumption (Figure 4). They are as follows:

i. Urban population
ii. Real industrial value-added
iii. Chemical production
iv. Steel production

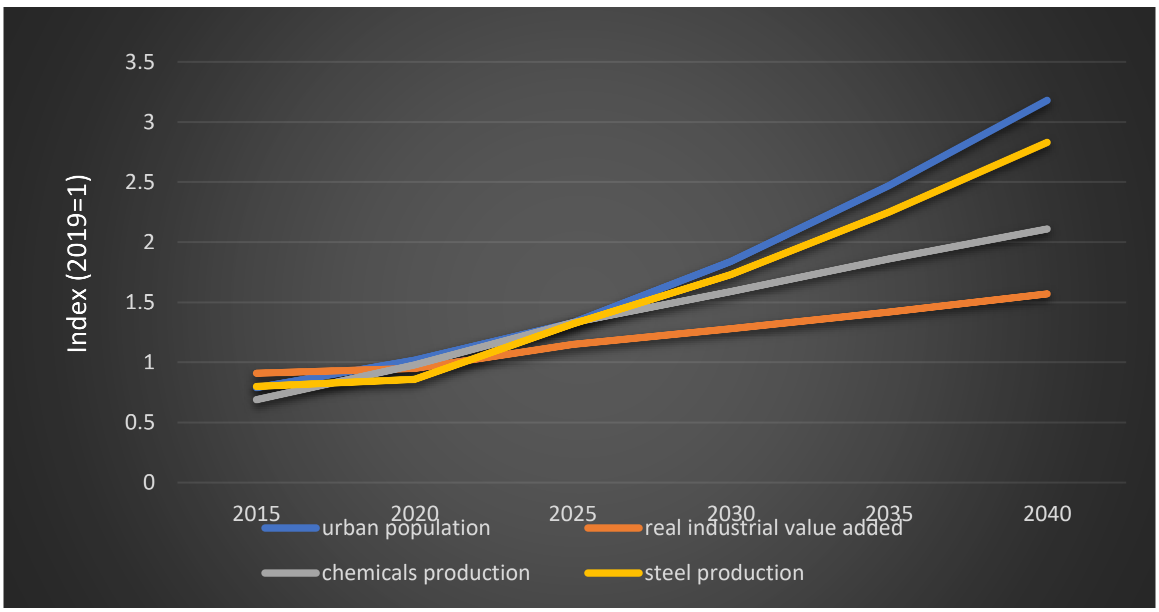


Figure 4: Drivers of India's effect energy consumption in the Stated Policies Scenario, 2015-2040
Image source: (IEA, 2021)

5.1.2 Pressures: In the context of the research on FSPV plants, the pressure can be understood as the consequences or impacts of the driving forces, which in this case include the construction and operation of the plants. Pressures are the stresses that human activities leave on the environment. These pressures can have both positive and negative effects on the environment. One of the pressures highlighted by Smith et al. in their study is the changes in flora and fauna around the MRE Plant. The construction and operation of FSPV plants may lead to alterations in the local ecosystem, including changes in the composition and distribution of flora and fauna. These changes can have both direct and indirect impacts on biodiversity and ecological processes (Smith CJ, 2016).

The installation of FSPV panels in water bodies can potentially affect sedimentation patterns, alter light penetration, and modify water flow dynamics. These physical changes can, in turn, influence the habitats and ecological functioning of the aquatic ecosystem.

In the ambit of the research on FSPV plants, pressures are the human activities that exert pressure on the environment as a result of production processes. Chemical pollution is a potential risk associated with PV solar installations. During the installation, maintenance and operation of floating photovoltaic systems, there is a possibility of sudden or gradual release of chemicals. These chemicals can be present in the composition of the PV panels, as well as in the floats or electrical and mechanical equipment of the FSPV components. Another concern is the risk of oil and fuel leakage or spillage during the installation and maintenance of FSPV systems. This can occur when boats are used for transporting the floats to the designated location within the water body (Hamid M. Pouran, 2022).

Electrical equipment, especially those in direct contact with water, may create electric fields that can impact the environment. It is important to consider the potential effects of these electric fields on aquatic ecosystems. Fire incidents, use of fire extinguishers and the sinking of FSPV floats can also result in the release of chemicals into the water ecosystem, posing a risk to the environment. Addressing these potential risks and concerns requires careful planning, adherence to environmental regulations, and the implementation of proper mitigation measures.

5.1.3 State: In the context of this research, the "State of the Environment" refers to the quality and condition of various environmental compartments such as air, water, soil, and others. Peter Kristensen emphasises that the state of the environment is determined by the physical, chemical, and biological conditions within these compartments (Kristensen, 2004). This includes evaluating the physical, chemical, and biological characteristics of the environmental compartments affected by the presence and operation of the FSPV plants, which can include the development of stagnant water, characterised by reduced Dissolved Oxygen.

5.1.3.1 Blocking of Solar Radiation

The FSPV systems have a dual impact: First, they decrease the amount of solar radiation reaching the water surface, and second, they shield the water from the effects of wind mixing. Consequently, this will lead to modifications in water body temperature and stratification. Normally, wind speed and solar radiation have opposing effects on the thermal structure of the water body (Armstrong, 2020).

5.1.3.2 Environmental State

FSPV systems offer several benefits, such as reducing excessive evaporation from water bodies Iran (Mohammad Fereshtehpour a, 2021). However, they also have both positive and negative environmental impacts. It has been observed in a research study that, by covering only 10 per cent of the five main reservoir lakes with FPV systems, enough water would be saved from evaporation to fulfill the domestic water needs of a city with one million inhabitants (Ghosh, 2022). Installation of FPV not only leads to water savings but also results in enhanced concentrations of chlorophyll and nitrate (Abdelal, 2021). There are potential risks such as sudden or gradual releases of chemicals, as well as oil/fuel leakage into water from PV panels. Floating Solar Panels may also block a significant amount of sunlight, affecting underwater plants and algae.

5.1.3.3Reduction in Wind stress

Reduced wind speeds generally result in increased stratification and surface warming of water bodies. On the other hand, decreased solar radiation leads to enhanced cooling of the surface water (Kalff, 2002).

5.1.4 Impact: 'Impact' is the changes in the physical, chemical, or biological state of the environment that determine the quality of ecosystems and the welfare of human beings (Kristensen, 2004). Changes in flora and fauna are studied in detail in the earlier part of the paper using multi-criteria analysis i.e. NDVI, NDWI, and NDTI.

The impacts can be diverse and may include alterations in ecosystem functioning, disruptions to the life-supporting abilities of ecosystems, and implications for human health. Additionally, these impacts can have economic and social implications for the society.

5.1.4.1 Socio-economic change

An important socio-economic impact of the FSPV system installation is the potential for job creation. The solar industry creates both direct and indirect jobs including PV and float manufacturing, installation, maintenance, retail services and electrical devices. Total number of jobs created by the PV solar industry can vary based on factors such as project size, local labour market conditions, policy frameworks, and technological advancements. However, those employed by the PV solar and hydropower sectors can provide significant overlapping and transferrable skills to the FSPV power plants.

5.1.4.2 Water Quality

Based on the multi-criteria analysis in this research using NDWI and NDTI, in certain scenarios, there has been improvement in water quality, which in turn affects the living organisms inside water bodies.

Qasim Abdelal has observed in research that power produced by floating panels was higher than that produced by land mounted 55 per cent of the time (on average) when measured under the same conditions. Under the panels, the water quality showed improvement. Due to the limited exposure, the average reduction in chlorophyll concentration was 61 per cent. Nitrate concentrations decreased slightly in the floating system (up to 14 per cent in the covered system) (Abdelal, 2021).

The synergy that a floating solar system creates between the sun and the water can be used to the advantage of wineries, dairy farms, fish farms, mining enterprises, wastewater treatment plants, irrigation districts, and water agencies (Sudhakar, K., 2019).

5.1.4.3 Non-occupation of habitable or productive areas

FSPV systems offer the advantage of adaptability. They can be installed on water reservoirs, providing a solution to reduce land disputes.

This aspect is particularly significant in countries like Japan, where finding suitable locations for ground-mounted solar farms can be challenging due to high costs or uneven terrain, which can pose safety risks for PV systems.

Analysis using GIS has revealed that in Japan, the total land area available for the development of PV and wind turbine projects is approximately 3,428 km^2, which accounts for only 0.9 per cent of all contiguous land. Within this limited area, approximately 72 per cent of the land may require these systems to compete with other development projects, including each other (H. Obane, 2020). These limitations further underscore the importance of utilising alternative options such as FSPV installations on water bodies like drinking water reservoirs.

By utilising reservoirs for FSPV systems, Japan and other countries facing similar challenges can leverage existing water surfaces to generate solar power. This not only addresses land scarcity but also provides a potentially safer and more cost-effective option for solar energy generation.

5.1.5 Responses: Peter Kristensen has explained that ‘response’ by society or policymakers is the result of an undesired impact and can affect any part of the chain between driving forces and impacts (Kristensen, 2004). In this study, policy changes are introduced due to the impacts of FSPV, which is currently at a very nascent stage.

In the context of this study, the term "response" refers to the actions taken by society or policymakers in reaction to the undesired impacts caused by FSPV projects. These responses can occur at any stage along with the chain between the driving forces (such as government policies and industry goals) and the impacts on the environment and society. As the functioning of FSPV plants evolve, the possible course corrections would become prominent, as few studies have been done in the Indian scenario, post-operationalisation of the FSPVs. These structural frameworks are detailed in the subsequent sections.

5.1.5.1 Sensitisation/Awareness

Effective marketing strategies have the power to influence individuals to reduce their energy consumption. For example, in the United States, it is estimated that behavioural changes in the residential sector could potentially save up to 20 per cent of household energy demand. Similarly, in India, lifestyle changes have the potential to save between 3.4 and 10.2 terawatt-hours (TWh) of energy annually by 2030, as per one estimate (IEA, 2022).

Numerous lessons have been gained regarding awareness and behavior change campaigns to maximise their effectiveness. It is evident that good design plays a crucial role, as simply transmitting information is insufficient to drive behaviour change. Poorly designed campaigns frequently fail to deliver the desired impact. The selection of the message, the tone used, the campaign's overall design, and the channels through which it is transmitted all have a profound influence on the resulting effect on behaviour. Therefore, careful attention to these elements is essential for achieving desired behavioural changes.

5.1.5.2 Recruitment of skilled workers

Due to a shortage of skilled labour in the MRE sector, it is essential for the government to actively promote training programmes at reputable institutions in the country.
These are skilling imperatives for the future employment in MRE.

5.1.5.3 Government Policies

Policies like Production Linked Incentive (PLI) scheme, Renewable Purchase Obligation (RPO), Renewable Energy Certificate (REC), and Kusum Yojana are practical and financially viable Government's policies/schemes for Renewable Energy. These can be considered as responses to handle the generation of Renewable Energy. The return on investment on these policies/schemes is attractive.

5.1.5.4 Production Linked Incentive (PLI)

The Government has allocated a total capacity of 39,600 MW for domestic solar PV module manufacturing to 11 companies under the PLI scheme for high-efficiency solar PV Modules (Tranche-II). The scheme has a budget of ₹ 14,007 crore for manufacturing 7,400 MW Renewable Energy by October 2024 followed by 16,800 MW capacity by April 2025. This initiative is projected to attract an investment of ₹ 93,041 crore and create a significant number of jobs. It is estimated that 1,01,487 jobs will be generated, with 35,010 indirect employment and 66,477 indirect employment. The scheme not only helps in reducing the impact of global supply chain shocks but also aligns with the Hon'ble Prime Minister's vision of an ***Atmanirbhar Bharat*** (self-reliant India) by reducing import dependence on fuel (Ministry of Power, 2023).

5.1.5.5 Renewable Purchase Obligation (RPO)

Under Section 86 (1) (e) of the Electricity Act 2003 (EA 2003) and the National Tariff Policy 2006, the Renewable Purchase Obligation (RPO) is a regulatory mechanism that requires obligated entities to procure a specific percentage of their electricity from Renewable Energy sources. RPOs are divided into Solar RPOs and Non-Solar RPOs. With the goal of achieving 175 GW of Renewable Energy by 2022, including 100 GW of solar energy capacity, the Ministry of Power has announced the target RPO trajectory up to that year. All Obligated Entities in all States and

Union Territories are required to adhere to and meet the RPO targets set forth for solar and non-solar power. Obligated Entities (which include Discoms, Open Access Consumers, and Captive Power Providers) must obtain a minimum proportion of their electricity from Renewable Energy sources as per RPO targets (MNRE, n.d.).

5.1.5.6 Renewable Energy Certificate (REC)

To bridge the gap between the availability of Renewable Energy resources in a State and the obligations of entities to meet their RPO, a market-based instrument known as Renewable Energy Certificates (RECs) was introduced. The primary purpose of RECs is to promote Renewable Energy generation and facilitate compliance with the RPO. Each REC is equivalent to one MWh of electricity generated from renewable sources. RECs are further categorised into Solar and Non-Solar RECs. Solar RECs are issued to eligible entities that generate electricity from solar, as a Renewable Energy source. Non-Solar RECs, on the other hand, are issued to eligible entities that generate electricity from renewable sources other than solar.

These schemes and policy changes, therefore, reflect Government responses toward the promotion of non-Renewable Energy resources, including FSPVs, while decarbonising the energy sector gradually.

CHAPTER-VI

SWOT Analysis (Other Framework)

SWOT as an acronym for Strengths, Weaknesses, Opportunities, and Threats, is considered as the most renowned tool for assessment of overall business and environment (Sudhakar, K., 2019).

Strengths (S) and Weaknesses (W) are internal factors over which some measures of control exist. Opportunities (O) and Threats (T) are external factors over which essentially no control exists. To understand the strengths and weaknesses and to identify both the opportunities and threats faced, SWOT analysis is a useful technique.

6.1 Strengths (Internal, Positive Factors)

1. When compared to ground mount and rooftop systems, Floating solar power generating systems typically generate more electricity due to the cooling effect of the water.
2. The floating platforms are designed and engineered in such a way that they can withstand extreme physical stress, including typhoon and storm conditions.
3. The FSPV panel installations reduce water evaporation and algae growth by shading the water.
4. Geographically any water body with abundant sunlight can be used to install floating plants.
5. Floating platforms can withstand ultraviolet rays and resists corrosion, since they are 100 per cent recyclable, utilising high-density polyethylene.
6. Local environment is conserved by non-usage of land.
7. Easy to erect and easy for faster deployment.
8. Floating photo voltaic panel helps in resisting excessive evaporation from water bodies. They also control the algae bloom, which helps in keeping the water clean.

6.2 Weaknesses (Internal, Negative Factors)

1. Long-term maintenance requirements and durability of floating solar PV are yet to be seen.
2. Possible Ecological and adverse impacts on the water ecosystem.
3. Relatively new and immature technology.
4. Lack of experience and knowledge/shortage of skilled workers.
5. Lack of cooperation from local distribution utilities.

6. Solar energy concentration levels on a floating platform.
7. High waves and salt water may possibly cause damage to the solar panels over a period.
8. It is not possible to ramp up energy production when there is high energy demand as in the case of thermal energy power plants.

6.3 Opportunities (External, Positive Factors)

1. Growing innovations in floating technology.
2. Creation of job opportunities.
3. There are increasing concerns about land neutral energy generation and energy independence.
4. Great potential and increasing awareness for floating PV.
5. Since water bodies are easily available and without any land issues, they act as the main accelerators for floating PV Solar systems.
6. When compared to installed land PV, there is an increased efficiency in the case of FSPV.
7. Stable floating PV platforms results in minimum operation and maintenance cost.
8. The emergence of new markets and investments in India, China, Thailand, Malaysia and other developing countries (Sudhakar, K., 2019).

6.4 Threats (External, Negative Factors)

1. Large dependency on land-based PV generation.
2. Lack of testing and standard procedures of floating solar.
3. Untested Technology for the long run.
4. No promotion and support through a separate policy by governments.
5. Cost concerns and lack of financial resources.
6. Cumbersome maintenance and repair.
7. Floating solar farms help in generating electricity only when sun is shining. Due to this, it is one of the major drawbacks of solar energy. This contributes to its low-capacity factor.

CHAPTER-VII

Importance to Audit

The Research paper will help in understanding the initiatives taken by the Government in prioritising Renewable Energy sector through its various programmes. The study would help in developing an Audit Toolkit based on performance of Floating Photo Voltaic, impact of FSPV in post-installation scenario, DPSIR framework and SWOT analysis. Furthermore, this can also serve as a source of inputs for the Comptroller and Auditor General’s audits to assess the importance of these indices and be utilised for auditing paradigms.

The research paper has several potential benefits. Firstly, it provides a comprehensive overview of the government's efforts to prioritise Renewable Energy, which can help policymakers, researchers, and industry professionals gain insights into the initiatives and their effectiveness. It serves as a valuable resource for understanding the policies, programs, and incentives implemented to promote Renewable Energy.

Moreover, by incorporating the DPSIR framework, the research paper can assess the driving forces behind the government's Renewable Energy initiatives, the pressures exerted on the environment, the current state of Renewable Energy adoption, the impacts on various sectors, and the responses or measures taken by the government to address challenges and enhance performance. This holistic analysis can contribute to a better understanding of the Renewable Energy landscape and inform decision-making processes.

It can provide guidelines, methodologies, and indicators for evaluating the effectiveness and efficiency of programs, identifying gaps or areas of improvement, and ensuring accountability in the implementation of Renewable Energy policies.

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