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Feasibility study of floating solar panels over lakes in Bengaluru City, India

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Sustainable energy production has become an issue of prime concern for regions across the globe. With all the global bodies urging nations to explore and adopt clean sources of energy, India's enormous solar potential provides a sustainable source of energy, replacing conventional sources that are both polluting and rapidly depleting. To produce large amounts of solar energy, solar parks spanning across large areas are required, making it impossible to serve in highly populated cities like Bengaluru, where spacious lands are not available. The rooftop solutions contribute very minimally towards the city's energy demand because of the dense urban cover and congested planning. But the city has a large number of water bodies including tanks, large lakes and reservoirs. This paper studies the floating solar photovoltaic (FSPV) technology to provide an alternative solar route to harness sustainable energy. In this study, 32 lakes within the city limits were considered spanning across 3294 ac of lake area and analysed for the climatic suitability of FSPV systems, solar output assessment and estimation of evaporation losses. The study found that the FSPV systems adopted on lakes with a coverage ratio of 0.5–0.6 could meet an average of 26% of the city's annual power demand.

Keywords: infrastructure planning/renewable energy/town and city planning

Notation

A, B, C parameters of Antoine equations

E_L lake evaporation (mm/day)

ξ_a actual vapour pressure of overlying air at a specified height (mmHg)

e_w saturated vapour pressure at the water surface temperature (mmHg)

K_M Mayer's coefficient accounting for various other factors with a value of 0.36

P saturated vapour pressure (mmHg)

T mean temperature (celsius)

u_9 monthly mean wind velocity in about 9 m above ground (km/h)

1. Introduction

India is exposed to an enormous potential of solar energy; it is estimated to be around 5000 trillion kWh over India's land area. Currently, solar energy is being harvested by way of solar thermal plants, terrestrial solar parks and roof-mounted photovoltaic (PV) systems. Globally, since the first floating solar photovoltaic (FSPV) system was installed in 2007 in Japan, the market has undergone exponential growth and is currently projected to reach at least 3 GW capacity by 2024 (Acharya and Devraj, 2019). With the Indian government aiming to achieve 175 GW of renewable energy by 2022, of which 100 GW from solar is planned under the National Solar Mission (IEA, 2021), such long-term development goals and the PV module prices reaching affordable rates make it a viable option to harness the solar energy potential to meet the energy

demands. Bengaluru is projected to be the fastest-growing regional economy in the world, with the city's gross domestic product growth forecasted to reach 8.5% year by year, by 2035 (Oxford Economics, 2020). This high-paced development would increase the city's energy demand and also lead to larger competing uses for land. Rooftop solar initiatives have failed to gain traction in the city due to residential complexes, which form the majority of urban spaces, having a very small ratio of roof space to available floor space (Ishwara *et al.*, 2017). The rooftop installations require continuous public participation, as funding the solar set-up and maintenance must be managed largely by the consumers or property owners. Added to this is the prolonged time needed for a return on the invested capital. In some regions with high population densities, the PV applications in rooftops face stiff competition from rooftop gardening (Liu *et al.*, 2017). Due to these reasons, consumers are not encouraged to adopt rooftop solar solutions. With the lack of available of large parcels of land to establish terrestrial solar parks and some implementation problems faced in rooftop solar installations, FSPV technologies widen the scope of solar power integration into grids. This study aims to investigate the scope of FSPV systems in providing sustainable energy by focusing on understanding the compatibility of FSPV systems in the regions that have high population densities and competing uses for available land in the case of Bengaluru City. The study checks for the climatic suitability and energy capacity of FSPV systems over water bodies involving tanks, lakes and reservoirs in the Bengaluru region. The methodology primarily focuses on the estimation of solar energy output, evaporation losses and cost estimation for the lakes

considered in the study. The workflow adopted includes the study of the climatic variables of temperature, wind velocity, solar radiation and its suitability with the Ciel & Terre floating system. This study does not account for the field studies on the considered water bodies and the impact of the FSPV cover on the lakes' ecosystem.

2. Literature review

This section aims to present a brief review of the parameters that control the FSPV technology during the design, implementation and maintenance stages of projects.

2.1 Performance of floating solar photovoltaic systems

This section discusses the performance of FSPV systems used across various types of water bodies. This section also compares the behaviour of FSPV systems relative to ground-based PVs. Comparing ground-mounted PV with FSPV in the state of Hapcheon, China, the performance of 100 and 500 kW FSPV was compared with that of 1 MW PV plant 60 km south of Hapcheon, having similar global horizontal irradiance (GHI) and mean temperature. It is observed that 100 kW FSPV has an efficiency of 17.6% as compared to 13.5% of overland PV (Chio, 2014). The efficiency of any solar panel depends on its module temperature. The water-cooling effect ensures ambient working temperature for the FSPV module. It is observed that there is a 3.5°C difference between land-based PVs and FSPVs (Liu *et al.*, 2017). It is also confirmed that FSPV systems produce at least 10% more energy than other land-based systems studied (Kamuyu *et al.*, 2018). The reliability of 100 and 500 KW shows that nominal power declines at the rate of 13.9% after 25 years. The lifetime of the PV module is currently in the range of 25 years and may reach 30 years in the near future. Power module warranty typically guarantees that after the first 10–12 years, the output power of the module will be at least 90% of its initial nominal power and that after 20–25 years of operation, the output power of the module will be at least 80% of its initial nominal power (Green *et al.*, 2012). A full-scale floating plant is located near Alicante, Spain, which was built in an agriculture reservoir to study the behaviour of the system. The top of the reservoir has a surface area of 4700 m², but only 7% of such area has been covered with a fixed solar system. The cost of setting up FSPV systems was nearly 30% higher than a conventional grid (Ferrer-Gisbert *et al.*, 2013). This is due to the need for additional components such as mooring systems and supporting platforms. Added to this is the material requirement of FSPV systems to resist harsher environments than land conditions. In a study conducted by Rosa-Clot *et al.*, the authors estimated the cost of setting up 1 MW (1048 KW) fixed floating PV to be US\$1 081 398 (Rosa-Clot *et al.*, 2017). With the enhanced performance of FSPV relative to terrestrial PV, the focus moved towards optimising the systems supporting the PV modules in a water environment.

2.2 Review of floating solar photovoltaic technologies

The first floating structure dates back to 2007 (Trapani and Redón Santafé, 2015). In the initial days, pontoons were used to mount the FSPV system. Although robust in its structure, it was expensive and not specifically designed for the FSPV (Rosa-Clot and Tina, 2018). Only recently, an alternative approach to utilise high-density

polyethylene (HDPE) as a floating structure with galvanised steel supporting it became very popular due to its low manufacturing cost (Sahu *et al.*, 2016). Few plants were set up with this technology, which proved to be successful (Cazzaniga *et al.*, 2018). Other companies followed suit and proposed an innovative solution to use plastic as the base material (Trapani and Redón Santafé, 2015). One such company, Ciel & Terre, utilised 100% HDPE and build a modular, robust floating structure (Rosa-Clot and Tina, 2018). This became widely popular and currently has the most installed capacity (Oliveira-Pinto and Stokkermans, 2020). It meets the criteria of modularity, flexibility, robustness and safety, and thus, this floating structure has been adopted for the study. Both the enhanced performance of FSPV and the availability of scalable supporting structures meant that the focus moved towards accurately estimating the solar energy at a given site.

2.3 Energy-estimation methods of floating solar photovoltaic generation

With governments and institutions across the world incentivising the implementation of clean energy, these efforts have led to the availability of open-source energy estimation software. Widely used open-source software includes RETScreen (Natural Resources Canada), PVWatts (National Renewable Energy Laboratory, USA) and PVGIS (European Commission). PVWatts was incorporated in the study, due to the availability of NREL's international data set, its features to create intuitive shapes on lake bodies in addition to having produced energy corrected to PV cell temperature, allowing for realistic forecasts (Psomopoulos *et al.*, 2015).

2.4 Impact of floating solar panels on evaporation

Due to increasing concern over climate change, the conservation of water becomes extremely vital. An FSPV structure has its application in reducing water evaporation from water bodies. The rate of evaporation mainly depends on two factors: vapour pressure of air temperature and wind speed at a height of 10 m (Rosa-Clot *et al.*, 2017). FSPV systems can help save up to 33% of the water from evaporating on a natural lake (Sahu *et al.*, 2016). A feasibility study considering 1 MW FSPV was carried out over the Kishore Sagar dam in Kota, Rajasthan, India. The authors estimated the plant to generate 18, 38, 519 kWh of energy per year while saving 37 million litres of water from evaporation (Mittal *et al.*, 2017). A similar study aimed at analysing large reservoir potential across the whole of India. It was found that for each square kilometre of area, 1250 million litres of water per year could be saved from evaporating (Sharma and Kothari, 2016). On analysing electrical generation and reduction in evaporation at a reservoir in Spain, it is seen that when the entire structure was covered with FSPV, it generated 425 000 kWh per year, saving 5000 m³ of water by covering a 4490 m² surface reservoir with floating PVs, which is 25% of the total reservoir capacity (Redón Santafé *et al.*, 2014).

2.5 Environmental impacts of floating solar photovoltaic systems

The benefits of setting FSPV plant outweigh the drawbacks, especially in an urban landscape where lakes offer a stable environment for FSPV

systems to perform and maintain due to proximity with technical logistics. Although there has been concern regarding FSPV having an impact on the quality of water and flora-fauna due to increased turbidity on installing mooring and shallowers (Serrano *et al.*, 2016) the scale of the impact is site specific. Moreover, since waterbodies under consideration are lakes within the city bounds, the footprint of the project would be small, thus causing minimum to no harm to flora-fauna while increasing water quality by reducing algal bloom and decreasing the evaporation rate (Oliveira-Pinto and Stokkermans, 2020; Pimentel Da Silva and Branio, 2018). Even under these site conditions, precautions have to be taken to ensure that the material to be used is recyclable and the water to be used for cleaning is non-detergent. Furthermore, regular check and maintenance would allow the proper and efficient functioning of the FSPV system.

The various aspects of FSPV integration covering performance, energy-estimation and environmental benefits have been extensively studied for large water bodies, like reservoirs and dams. There have been no similar studies conducted on smaller water bodies in urban areas. This study explores the suitability of using a large number of small waterbodies for solar energy generation in the urban set-up of Bengaluru City. The study solely covers energy estimation, quantifies the evaporation losses and provides a cost estimate. However, it does not include field studies and the environmental impact of solar panels on the lakes' ecosystem.

3. Suitability of floating solar photovoltaic systems for Bengaluru City

Bengaluru is located at an elevation of 920 m on two river basins, namely, Cauvery and Dakshina Pinakini. The natural flow of water is away from the city into the neighbouring valleys. This historically allowed the development of well-connected cascading water management systems spreading across the city, resulting in the excess of 200 water bodies involving irrigation ponds and large storage lakes. Since the 1990s, due to rapid urbanisation, the city has sprawled extensively and, in the process, several lakes have been converted into stadiums, administrative buildings, sewage-treatment units and so on. Although, with governments extensively focusing on rejuvenation projects, currently, the city has over 197 lakes in existence. The following points address the benefits of having FSPV systems:

- Addressing summer power demand, FSPVs would generate maximum power during the summer months, and be vital in supplying power to peak summer demand. The power generated would be amidst demand centres, reducing the burden on the state's thermal plants located far away. The life cycle greenhouse gas emissions due to PV are estimated to be 46 g carbon dioxide (CO₂) per kilowatt-hour compared to 164 g carbon dioxide per kilowatt-hour, which are emitted out of thermal plants, effectively reducing carbon footprint by 70% (NREL, 2012).
- The presence of FSPV modules causes shading over the water surface, reduced temperature and intercepted winds. This reduces the rate of evaporation and saves large quantities of water that can

be used by the local population for both potable and non-potable uses, depending on the quality of the lake (Sahu *et al.*, 2016).

- Excessive algal growth limits light penetration through the water, adversely impacting the growth of plants and survival of fishes, choking the entire ecosystem in the long run. The reduction of light controls algal growth. Hence, FSPV creates less favourable conditions for algal blooms, improving the quality of lakes. The limit to which algal blooms can be eliminated depends on the coverage area of solar panels (Haas *et al.*, 2020).
- With the electric vehicle (EV) industry gaining traction in the state, the government is expecting to attract US\$4.24 billion of investment, and incentives are being given for establishing charging infrastructure (Commerce and Industries Department – Government of Karnataka, 2017). Charging stations can be based on photovoltaic-electric vehicle (PV-EV) integration using FSPV systems that would be widespread across the city. This would help in the electrification of vehicles and also drastically reduce the payback period of floating solar projects as a whole (Singh *et al.*, 2019).
- Most lakes in the city have restrictions to be used for swimming, fishing or any recreational activity. Such water bodies are not considered in the study. The water bodies in the city used for annual religious activities and navigation purpose are also not considered in the study.

FSPV has a wide range of benefits over land-based systems, such as the use of redundant areas, improved performance of PVs by 10–20%, less prone to external shading, less soiling (coverings that could obstruct light like dust and leaves) losses and easier installation (Sahu *et al.*, 2016). The above-mentioned benefits will increase the premium of lakes apart from recreation in an urban set-up, encouraging better protection and conservation of lakes through strict law enforcement.

4. Data and methodology

The workflow mainly focuses on two control parameters. Firstly, the climatic parameters of wind velocity, solar radiation and temperature are studied. The variation of climatic parameters in the study area is compared and checked for compatibility with the floating system. It then considers the lake bodies and forecasts the energy produced using PVWatts. Later, the evaporation losses are quantified using Mayer's model. Lastly, a preliminary cost estimate is provided using the total coverage area and the PV module specifications. The workflow incorporated in estimating energy, evaporation losses and the cost is shown in Figure 1.

4.1 Floating solar photovoltaic system design

4.1.1 Floating photovoltaic system

The authors considered a versatile technology called Hydrelia® patented by Ciel & Terre. The PVs are mounted on a floating structure, composed of several floats connected together. The floating platform is composed of primary floats for supporting the PVs and secondary floats for maintenance, buoyancy and spacing the PVs appropriately. These are interconnected using fiberglass pins. The floats can be used along with 60/72 cells' PV modules. A hole in the middle, for

Figure 1. Overview of methodology. PV, photovoltaic

Figure 2. Hydrelia floating structure

passively cooling and ventilating the PV panel, is provided in the primary float, as shown in Figure 2. PV modules can be attached to the

float using aluminium/fiberglass rails. The anchoring system involves two methods: one at the bottom of the lake in case of shallow depth bodies, and the other being on the shore when the depth is extensive. The construction involves no heavy machinery; the materials used are non-corrosive and are UV resistant, and they can withstand high wind velocities up to 58.3 m/s (Dizier *et al.*, 2018) and can also be used in lakes that are used for drinking water purposes, as it is tested to be BS: 6920:2000 compliant (BSI, 2000). The maximum tolerable water flow is 1 m/s, considering waves and their dynamic effects. The tested cooling processes involve immersion cooling, forced water circulation and spraying. According to the specifications of Hydrelia, ASM-7-PERC-AAA modules are chosen as the test PV modules, and their specifications were used in all calculations.

4.1.2 Floating solar losses

The Central Electricity Regulatory Commission's report (Sharma, 2011) on the performance of solar plants in India has extensively studied the behaviour of existing terrestrial and floating solar plants in the country. The report's recommended values were considered for soiling, shading, wiring, nameplate rating, for snow, mismatch, connections, light-induced degradation, age and availability, as shown in Table 1.

4.2 Bengaluru's energy demand

BESCOM (Bangalore Electricity Supply Company Limited) is responsible for delivering power to the city and seven other districts, namely, Bangalore Rural, Chikkaballapura, Kolar, Davanagere, Tumkur, Chitradurga and Ramanagara. It has a demand roughly close to half of the total energy demand of the state, out of which the city accounts for 50%. In total, Bengaluru alone constitutes 25% of the state's energy demand (BESCOM, 2018). The mean monthly demand of Bengaluru City supplied by BESCOM for the year 2018–2019 is shown in Figure 3. The power demand of the city witnesses peaks in February, March and April. This can be attributed to the increased usage of fans, air conditioners and also pumps. The power demand reduces in the monsoon season due to reduced cooling needs for domestic and commercial purposes.

4.3 Suitability of climatic parameters

Climate parameters are important in assessing the suitability of an area for FSPV projects. Temperature controls the efficiency of energy conversion. Wind velocity is a design parameter that determines the specification of supporting platforms. Finally, solar radiation determines the amount of energy received at the location.

Table 1. System losses considered for analysis

Losses	Value: %
Soiling	1
Shading	3
Mismatch	1
Wiring	1
Light-induced degradation	1.5
Miscellaneous	2.5

Figure 3. Mean monthly demand to be supplied by BESCOM

4.3.1 Temperature

The city records an average annual temperature of 23.5°C, and the variation of monthly mean temperature is depicted in Figure 4. Generally, module performance is rated at 25°C, beyond which the module output decreases. The city would provide an ambient temperature range and contribute to reduced losses due to temperature variation. Ideally, solar plants having at least 4 h of sunshine are best suited for PV working. Bengaluru receives a yearly average of 8.5 h of sunshine (Tyagi, 2009), making it a suitable location for adopting FSPV systems.

4.3.2 Wind velocity

According to the India Meteorological Department (IMD) data, the average annual wind velocity is 2.67 m/s (Tyagi, 2009). The monthly wind velocity data is shown in Figure 6. The wind complements the cooling effect of water and ensures the higher working efficiency of the system. Higher winds are naturally experienced during the monsoon season. The city experiences much lower velocities compared to the maximum allowable wind speed for the Hydrelia system of 58.3 m/s, and hence, there would be a less need for structural reinforcement to withstand wind loads.

4.3.3 Floating solar photovoltaic system solar radiation

The city receives an annual average solar radiation ranging between 5.5 and 6 (kWh/m²)/day. The monthly variation of daily mean

Figure 4. Mean monthly air temperature

sunshine hours is shown in Figure 5. In this study, GHI was firstly obtained from the IMD database, which is based on ground measurement at the city's measuring station, and secondly, the NREL database, which is based on satellite measurements, that is often regarded to slightly overestimate values. The optimum database considering both is shown in Figure 7.

4.4 Water bodies considered

The lakes considered were primarily based on size criteria having an area greater than 20 ac. Also considering the scope of establishing electric charging stations within Bengaluru City, lakes having lesser areas closer to commercial areas were also considered. In total, 32 lakes (Table 2) spread across the city, covering industrial areas; residential colonies and also lakes adjacent to the airport were considered. The average power generated per day in megawatts (MW) was derived from the expected total annual output of the alternating current (AC) energy (kilowatt-hour per year) of the system. The spatial spread of the lakes is shown in Figure 8.

4.5 Performance of floating solar photovoltaic system

4.5.1 Energy yield assessment

PVWatts, an estimation tool developed by the national laboratory of the US Department of Energy was used in assessing the energy output. It estimated the annual energy yield based on the monthly

Figure 5. Mean monthly variation of daily sunshine hours

Figure 6. Mean monthly wind velocity

average values of global solar radiation on a horizontal surface. The open-source software was synchronised with the Indian database, and validation studies showed an annual deviation ranging between -4 and -6% (Psomopoulos *et al.*, 2015). The study considered fixed solar modules having a nominal efficiency of 15% and an area coverage ratio of 0.5 – 0.6 . Figure 9 shows the expected mean monthly solar output. Naturally, high output is witnessed during the summer months and reduced output during the monsoon season. The

Figure 7. Mean monthly solar radiation

analysis showed an average of 459 MW of power from 3954 ac of the lake area. Among the 32 lakes considered, 7 lakes produced more than 25 MW and 9 lakes had a capacity lesser than 5 MW. On average, 8.5 ac of land was needed to generate 1 MW of power. Notably, Bettakote Lake, located adjacent to the city's airport, has a capacity of 13 MW, which can compensate at an average of 65% of the demand and contribute to the existing rooftop solar capacity of 8.35 MW, enabling complete sustainable functioning of the airport (Philip, 2018). Compared to the total demand of the city, the lakes can collectively generate an average of 26% of the power to be supplied. The monthly variation of the percentage of solar power of the demand is depicted in Figure 10. These values were obtained from total monthly output of AC energy (kWh/month) across all water bodies considered.

4.5.2 Estimation of evaporation losses

Water preservation and evaporation reduction occur due to the installation of floating solar systems on lakes, dams, irrigation ponds and reservoirs. The area covered by FSPV will result in the reduction of evaporation over the lakes. Evaporation loss has been studied over lakes using Mayer's empirical formula given by Equation 1 (Subramanya, 2013):

Table 2. List of lakes considered for the study

Sl. number	Lake name	MW	Land area: ac
1	Manchanbele Reservoir	27	232
2	Thippagondanahalli Reservoir	55	468
3	Kaggadasapura Lake	8	51
4	Huvineane	12	107
5	Konnasandra	3	23
6	Gunjur	6	48
7	Begur	6	53
8	Hulimavu	4	32
9	Bhimana Kuppe Kere	4	37
10	Kengeri Lake	2	18
11	Vrishabhavathi Reservoir	52	462
12	Sulikere	7	55
13	Hennagara Lake	22	189
14	Muthanallur Lake	18	153
15	Bellandur Lake	37	219
16	Varthur Lake	20	168
17	BTM Lake	17	147
18	Yele Mallappa Shetty Lake	30	261
19	Hesaraghatta tank	50	426
20	Kasavanalli	3	22
21	Venkatala	14	137
22	Jakkur Lake	8	60
23	Allalasandra	2	16
24	Yelahanka Lake	12	125
25	Kundalahalli Lake	2	8
26	Hebbal Lake	4	34
27	Suvarnamukhi Reservoir	6	48
28	Rachenahalli Lake	6	55
29	Agara Lake	4	34
30	Bettakotte Lake (adjacent airport)	13	116
31	Rayasandra Lake	5	42
32	Annekal Lake	9	78
	Total	459	3924

Figure 8. Spatial distribution of lakes

Figure 9. Mean monthly variation of output

Figure 10. Monthly variation of output/demand

$$1. E_l = K_M(e_w - e_a) \left(1 + \frac{u_9}{16}\right)$$

where E_l is the lake evaporation (mm/day), e_w is the saturated vapour pressure at the water surface temperature (mmHg), e_a is the actual vapour pressure of overlying air at a specified height

(mmHg), u_9 is the monthly mean wind velocity in about 9 m above ground (km/h) and K_M is the coefficient accounting for various other factors with a value of 0.36.

The actual vapour pressure and mean monthly temperature were obtained from the IMD data for evaluating the depth of lake evaporation per day.

The saturated vapor pressure was calculated using the Antoine equation given by Equation 2 (Thomson, 1946):

$$2. \quad R = 10^A - \frac{R}{C + T}$$

where P is the saturated vapour pressure (mm of mercury (Hg)); T is the mean temperature ($^{\circ}\text{C}$); and A , B and C are Antoine equation parameters (Table 3).

Using the above formula, a reduction in evaporation loss is calculated and the final result has been summarised. Since the tilt angle of the panel is nearly zero, the result approximately spreads over the entire surface area. Annually, 22 866 653 m^3 of water would be saved due to a reduction in evaporation calculated over 32 lakes. The monthly variation on evaporation losses is depicted in Table 4.

4.6 Cost estimation

The cost of solar panels has seen an exponential decrease over the last decade. It is predicted that solar panels will decline in price by 4.4% each year through 2022. Most utility-scale solar farms will be installed for prices as low as US\$0.50 per watt in India (World Bank Group; Energy Sector Management Assistance Program; Solar Energy Research Institute of Singapore, 2019). Many manufacturers have a selling price of solar panels in the range of US\$0.4–0.44 per watt for 335 W monocrystalline solar panels. To generate 459 MW of solar energy from FSPV, a total of 3 788 890 panels would be needed to be set up. This amounts to US\$500–560 million of investment in solar panels alone, as summarised in Table 5. Due to the variability of cost in inverters, floaters, anchoring and transportation, the price of setting up a plant can go up to US\$0.82 per watt. Evidently enough,

as the system size increases, the levelled cost of electricity does not differ significantly from that of ground-mounted systems (Westoff and Lacey, 2017).

5. Conclusion

Solar energy is the most readily available source of clean energy over most parts of India. Using FSPV systems, this energy can be harnessed on areas that have no competitive use and is often closer to areas of consumption compared to conventional power plants. Bengaluru City's widespread lake network and ambient climatic conditions for PV modules can contribute towards harnessing clean energy and lead the city towards a sustainable future. A conservative assessment of the feasibility of such systems carried out in the present study is summarised in the following points:

- The 3924 ac of land considered over 32 lakes within the city at a coverage ratio of 0.5–0.6, amounted to an annual average output of 459 MW of power. An average of 8.5 ac is needed per megawatt, compared to 7 ac/MW at the state's biggest terrestrial solar park in Pavagada, Tumkur, Karnataka, India.
- The FSPV systems adopted in the city would meet an average of 26% of the city's power demand, and due to the spatial spread of the lakes being within the vicinity of the city, this would significantly reduce the transmission losses and costs.
- The floating solar plants would also save water due to evaporation, resulting in annual savings of approximately 22 866 million litres.

By moving towards FSPV integration into the city, the community could benefit in the following ways:

- FSPV systems encourage a faster and more economic development of solar projects, as it reduces the burden of land

Table 3. Antoine equation parameters

A	B	C
8.07131	1730.63	233.426

Table 5. Summary of cost analysis

Annual energy generation: KWh	Number of panels	Cost of solar panels: cr. ₹ (1 ₹ = US\$0.013)
4 088 504 383	3 788 890	3681–4062

Table 4. Monthly variation of evaporation losses

Month	Mean temperature: $^{\circ}\text{C}$	Vapour pressure: hPa	Vapour pressure: mm Hg	Saturated vapour pressure at given temperature: mm Hg	Wind speed: km/h	Evaporation: mm/day	Loss every month: m^3
January	20.59	22.14	12.73	19.93	7.20	3.76	1 737 313.20
February	22.96	24.08	13.01	22.41	7.25	4.92	2 271 770.05
March	25.65	26.43	13.95	25.78	7.33	6.21	2 867 251.57
April	27.01	27.87	16.26	28.05	6.99	6.10	2 818 031.43
May	26.40	27.14	17.38	26.88	9.84	5.52	2 551 036.46
June	24.20	24.93	17.64	23.58	16.47	4.34	2 005 025.21
July	23.35	24.00	17.55	22.31	16.99	3.53	1 630 152.76
August	22.99	24.14	17.53	22.49	13.27	3.27	1 508 773.04
September	23.48	24.37	17.42	22.81	9.89	3.14	1 448 482.33
October	23.03	24.11	17.03	22.46	7.40	2.86	1 320 686.12
November	21.77	22.91	15.40	20.89	6.90	2.83	1 305 999.63
December	20.22	21.80	13.74	19.53	7.34	3.04	1 402 131.75
Annual total water loss							22 866 653.55

acquisition on the governments and encourages timely competition of projects (due to the less probability of prolonged legal disputes regarding acquisition) by contractors.

- Given the spatial spread of the lakes, PV-EV-based charging stations can be established, reducing the payback period of the plants, enhancing accessibility for electric vehicle users in urban areas and encouraging start-ups, as well as addressing mobility issues using micro-mobility vehicles.

Despite all the positive impacts, there is a need for detailed studies on the impact of floating solar systems on the aquatic ecosystem, stratification of lakes and food chain disruptions. Since most of the floating solar plants are in their nascent stages of operation, a simulation of their biological activities and studying their behaviour would ensure the holistic suitability of FSPV systems. There is a need to scientifically relate the biotics of an ecosystem with the coverage ratio of solar panels to ensure a balanced trade-off between energy production and environmental protection. Another aspect is to quantify the visual pollution of FSPV systems and ensure that they can be incorporated by preserving the aesthetics of the surroundings. Lastly, with increasing solar projects across the nation, hazardous PV waste is estimated to reach 0.04 Mt by 2030 and 4.5 Mt by 2050 (Sinha *et al.*, 2017). It is vital for stringent recycling policies to be enacted to ensure the lifetime sustainability of solar projects.

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