Offshore Solar Photovoltaic Potential Around India: Evidence, Marine Constraints, and Deployment Pathways—A Critical Review

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ABSTRACT

Offshore solar photovoltaic (PV) systems may broaden renewable-electricity options where coastal demand, land competition and maritime space intersect. India is a relevant case because of its extensive coastline, substantial solar resources and varied marine environments; however, offshore PV remains an emerging technology rather than an established commercial pathway. This critical review synthesises the India-specific resource evidence identified in the cited literature, evaluates the transferability of international marine-floating-PV research, and examines the engineering, environmental, social, economic and governance conditions that determine whether offshore resource can become deployable electricity. The principal India-focused baseline identified in the literature is the 2017 assessment by Solanki et al., which used ERA-Interim data for 2015–2016 and reported mean global horizontal irradiation (GHI) of 5.49 kWh/m²/day, with comparatively favourable radiation along Gujarat and Tamil Nadu. These are published historical findings, not new estimates produced by this review. Subsequent reviews highlight wave and wind loading, fatigue, corrosion, biofouling, mooring performance, maintenance access and extreme-weather survivability as central design concerns. Public resources such as the INCOIS Integrated Marine Energy Atlas, ERA5, the Global Solar Atlas and GEBCO can support future spatial screening, but their availability does not itself establish a validated national estimate of offshore-PV capacity. The review develops an evidence-to-siting framework that distinguishes theoretical solar resource, technology-specific technical potential, environmentally and socially constrained potential, and economically deployable potential. It also identifies a practical research pathway combining multi-source resource comparison, metocean characterisation, transparent exclusion mapping, uncertainty analysis, site validation and monitored demonstration projects. The available evidence supports the need and feasibility of further assessment, but does not justify a bankable national capacity figure or a claim that all Indian EEZ waters are suitable for development.

Keywords: offshore solar photovoltaic; marine floating photovoltaics; Indian Exclusive Economic Zone; solar resource assessment; marine engineering; geospatial siting; renewable energy

INTRODUCTION

The global energy transition increasingly requires renewable technologies that can expand without intensifying competition for land, freshwater, and ecologically sensitive terrestrial landscapes. Solar photovoltaic (PV) power has become a central option because of modular deployment, a broad range of scales, and the potential for continued cost reductions. Yet utility-scale PV development can be constrained by land acquisition, competing agricultural uses, habitat fragmentation, transmission access, and the geography of electricity demand. Floating PV has therefore attracted attention as a way to use water surfaces, initially on reservoirs and other inland water bodies and increasingly in coastal and offshore settings. Offshore floating PV (OFPV) is not simply terrestrial PV placed on a float: it is a marine energy system exposed to waves, currents, wind, salt spray, corrosion, biofouling, storms, difficult maintenance access, and potentially complex maritime regulation (Claus & López, 2022; Huang et al., 2025).

India offers a relevant setting for examining this emerging technology. The country has substantial solar-resource potential and extensive coastal and maritime zones, with large population centres, ports, industrial clusters,

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fisheries, and energy infrastructure concentrated along or near the coast. At the same time, its marine environments are heterogeneous. The Arabian Sea coast, Bay of Bengal coast, island territories, gulfs, estuaries, and open-ocean regions differ in wave climate, cyclone exposure, water depth, bathymetry, marine ecology, port activity, and grid access. A single national average of solar irradiation cannot represent these spatial differences, nor can it establish whether a location is technically, environmentally, and economically suitable for an offshore array.

An India-specific offshore solar assessment appeared in 2017. Using ERA-Interim solar-radiation data at approximately 0.125-degree resolution for January 2015 through December 2016, it mapped annual mean global horizontal irradiation (GHI) and estimated solar-energy output in the Indian Exclusive Economic Zone (EEZ). The paper reported a mean GHI of 5.49 kWh/m²/day and identified Gujarat and Tamil Nadu as regions with relatively high irradiation (Solanki et al. (2017)). The contribution is important as a baseline, but the two-year radiation period, the age of the reanalysis product, and the emphasis on resource distribution mean that its reported output should not be interpreted as a present-day estimate of deployable capacity. Its theoretical energy estimates also require careful scrutiny of unit conventions, assumed array coverage, conversion efficiencies, spacing, losses, and exclusion areas before being used in planning.

Research on marine PV has progressed since that early national assessment. Reviews of marine floating PV discuss structural concepts, environmental loads, wave–structure interaction, anchoring and mooring, reliability, and the need for technology adaptations relative to inland floating systems (Claus & López, 2022; Shi et al., 2023). A broader interdisciplinary review of floating solar identified ocean-based applications as an area where evidence remains less mature than inland floating PV (Wei et al., 2025). A 2025 review focused on reliable floating solar systems at sea identifies mechanical and electrical risks and highlights structural integrity and biofouling as key issues (Huang et al., 2025). A global offshore-FPV assessment has further connected technical potential, costs, and deployment pathways, illustrating that the resource question needs to be linked to system configuration and economics rather than considered in isolation (Rodríguez-Gallegos et al., 2025).

This paper addresses the intersection of these strands. It does not assume that a large maritime area translates directly into a large usable PV resource. The central analytical distinction is between (a) theoretical resource, (b) technical potential under specified technology and operating assumptions, (c) environmentally and socially constrained potential, and (d) economically deployable potential. Each stage progressively introduces evidence that narrows the set of candidate locations. This distinction is essential because resource maps are often mistaken for capacity estimates, while capacity estimates may omit the exclusions and costs that determine whether projects could be built and operated responsibly.

The purpose of the review is to synthesise the evidence on offshore solar PV around India and identify the data, methods, and governance requirements for a robust national assessment. The review has five objectives: (1) map the existing evidence base on offshore PV resource assessment in India and comparable marine settings; (2) compare datasets and methodological choices used to estimate solar resource and potential output; (3) synthesise technical and metocean constraints that shape system reliability; (4) examine environmental, maritime, social, economic, and grid considerations relevant to siting; and (5) propose a reproducible evidence-to-siting framework and research agenda for India.

The contribution is an India-centred critical synthesis for researchers in renewable energy, marine engineering, geospatial analysis, energy policy and coastal planning. It distinguishes published findings from transferable international evidence and from recommendations proposed for future GIS and engineering work. It does not claim to report a completed PRISMA systematic review or new spatial estimates.

Conceptual Scope and Definitions

Offshore PV and adjacent technologies

Terminology in this field is not fully standardised. Floating PV usually refers to modules mounted on floating structures on inland water bodies, including reservoirs and lakes. Marine floating PV refers to systems deployed in sheltered coastal waters or more exposed marine environments. Offshore PV may be used broadly for solar

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installations at sea, including nearshore platforms and arrays located within territorial waters or the EEZ. In this review, offshore PV refers to PV arrays deployed on floating or marine-supported structures in coastal and offshore waters around India. Inland reservoir floating PV is included only where its design, performance, policy, or environmental evidence is transferable to marine systems; it is not treated as direct evidence of offshore feasibility.

The Indian EEZ is a legal maritime zone rather than an automatically available development area. National jurisdiction does not remove the need to comply with applicable maritime, environmental, defence, navigation, fisheries, port, subsea-cable, and coastal-zone requirements. The study should therefore use legal boundaries as a spatial frame for analysis, not as a claim that all cells within the EEZ are available for energy development.

Four levels of potential

Level	Meaning	Evidence required	Typical misuse to avoid
Theoretical resource	Solar energy incident on a defined marine area.	Radiation datasets, temporal coverage, uncertainty and spatial resolution.	Treating irradiation as electricity output.
Technical potential	Potential output under a defined PV design, performance ratio, array layout and marine operating envelope.	Module performance, temperature, shading, spacing, wave/wind survivability, losses, mooring and O&M assumptions.	Ignoring marine reliability or assuming full-area coverage.
Environmentally and socially constrained potential	Technical potential after exclusion or mitigation of protected, sensitive, busy or livelihood-critical areas.	Marine protected areas, habitats, fisheries, shipping, ports, defence, cables, consultation and impact assessment.	Assuming an EEZ cell is unencumbered because it is offshore.
Economic/ deployable potential	Projects that can plausibly be financed, connected, permitted, built and operated.	CAPEX/OPEX, financing, grid connection, energy yield, insurance, permitting, supply chain and uncertainty.	Equating resource potential with bankable capacity.

CRITICAL LITERATURE REVIEW

Offshore solar resource assessment in India

The 2017 India-specific study by Solanki et al. is the most directly relevant starting point located for the current review. It used ERA-Interim radiation data for a two-year period and a GIS workflow to map GHI classes and estimated output across the Indian EEZ. Its reported mean GHI of 5.49 kWh/m²/day and the identification of Gujarat and Tamil Nadu as relatively high-radiation regions provide a baseline for comparing later data products. However, an assessment based on two years cannot fully represent interannual variability, and the use of an older reanalysis product limits direct comparability with contemporary datasets. The results should therefore be revisited using longer time series, updated reanalysis, satellite-based solar products, and uncertainty checks rather than simply reproduced as a current potential estimate.

A further issue is the distinction between solar resource and system generation. GHI measures incoming shortwave radiation on a horizontal surface. Actual PV generation depends on plane-of-array irradiance, module orientation and tilt, module temperature, conversion efficiency, soiling or salt deposition, downtime, electrical losses, curtailment, and availability. Offshore settings may provide some cooling advantages, but these cannot be assumed to offset all marine losses. Wave-driven motion, structural loads, corrosion, access limitations, and extreme-weather downtime may reduce energy yield or increase lifecycle costs. Therefore, an offshore potential study should state its PV performance model, system assumptions, and loss budget explicitly.

The Global Solar Atlas provides high-resolution solar resource and PV-output layers for broad screening, but the World Bank/Solargis products are designed as standardised solar-resource and PV-potential datasets. Their assumptions and spatial resolution should be inspected before using them offshore, especially when a land-

oriented PV model is applied to marine cells. These products can inform a baseline or provide comparison layers, but they should not replace marine-specific generation modelling and metocean screening.

Global marine floating PV research

Marine floating PV is an emerging technology with several design families rather than a single mature configuration. Designs may adapt floating platforms, flexible membranes, modular pontoons, tension-leg or semi-submersible concepts, or hybrid structures. Design choice depends on wave climate, water depth, distance from shore, access requirements, array size, installation methods, and maintenance strategy. Reviews emphasise that marine structures must be designed for combined aerodynamic and hydrodynamic loads, cyclic loading, mooring response, fatigue, and extreme events. Inland FPV engineering assumptions cannot be transferred unchanged to exposed marine conditions (Claus & López, 2022; Shi et al., 2023).

Claus and López (2022) review key design issues for floating PV in the marine environment and note the scarcity of established standards and published methods for some design questions. Their synthesis highlights environmental load estimation and structural response as foundational uncertainties. Shi et al. (2023) review marine floating PV development, innovative structural concepts, potential synergies, and obstacles to deployment. Huang et al. (2025) focus on system reliability and identify mechanical and electrical risks, structural integrity, and biofouling as critical topics. Together, these studies show that the challenge is not only whether sufficient sunlight exists, but whether a system can survive marine exposure while remaining maintainable and economically productive.

A broad interdisciplinary review of floating solar plants covered more than 900 publications and identified ocean-based applications as a notable research gap relative to inland FPV (Wei et al., 2025). This is a useful framing for the India case: although the floating-solar literature is large, only a portion is directly applicable to offshore environments, and a smaller portion directly evaluates Indian maritime conditions. A systematic review must therefore code study setting and transferability rather than treating all floating PV studies as equivalent evidence. A 2025 systematic review of floating-solar siting identified 118 criteria across 36 studies and found that protected areas and water-body function commonly appeared as exclusion criteria, while solar resource and distance to transmission infrastructure were frequent assessment criteria (Forester et al., 2025). That review provides an important methodological foundation, but the India-focused offshore problem requires additional emphasis on marine exposure, extreme-event design, maritime use, and the transferability of inland-water siting criteria.

The 2025 global assessment by Rodríguez-Gallegos and colleagues integrates offshore PV potential, cost competitiveness, and deployment pathways. Its relevance lies in connecting physical resource to economic and technical screening. However, global models cannot substitute for local conditions in India, where cyclones, monsoon variability, coastal bathymetry, port congestion, fisheries, marine protected areas, grid infrastructure, and regional supply chains differ across coastlines. A national assessment should adapt rather than mechanically import global suitability thresholds.

Solar-resource and meteorological datasets

Solar-resource assessment can draw on satellite-derived products, reanalysis, ground observations, and modelled PV-output layers. These data types differ in spatial and temporal resolution, physical variables, periods covered, and uncertainty. Reanalysis products combine models and observations to provide internally consistent historical estimates. ERA5 offers hourly atmospheric and sea-state variables from 1940 onward, including surface solar radiation, wind, and wave-related parameters. It is useful for analysing seasonal variability and extreme conditions, but its grid resolution is coarser than local offshore engineering studies may require; its uncertainty should be evaluated for the specific coast and variable used.

The Global Solar Atlas provides long-term average solar-resource and PV-output maps. It can support screening,

intercomparison, and baseline estimates. The World Bank's global PV potential work also demonstrates the value of separating theoretical resource from practical PV potential and cost-related considerations (Energy

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Sector Management Assistance Program [ESMAP], 2020). Nevertheless, a standard PV-output layer may embody assumptions designed for conventional installations. Offshore application requires checking whether module temperature, wind cooling, array spacing, marine availability, storm shutdown, and structural downtime are adequately represented.

The INCOIS Integrated Marine Energy Atlas of Indian EEZs is especially relevant because it compiles satellite measurements and model-simulated parameters verified against observations and places multiple marine-energy variables on a common grid. INCOIS notes that its estimates are intended to guide identification of marine-energy resource areas and warns that site-specific field studies, techno-legal and techno-commercial evaluation, and environmental assessment are necessary before implementation. The atlas is thus a valuable contextual resource, but the presence of marine-energy information should not be interpreted as a ready-made offshore PV suitability map.

Bathymetry influences mooring feasibility, anchoring strategy, installation costs, cable routes, and structural design. GEBCO provides global gridded bathymetry and a source-type identifier grid. The gridded surface is useful for national-scale screening, but local engineering design requires higher-resolution hydrographic surveys and geotechnical information. A 15-arc-second global grid is not a substitute for site investigations where bathymetric complexity or seabed conditions materially affect mooring.

Marine hazards, reliability, and climate variability

The Indian coastline experiences pronounced seasonal and regional differences in monsoon conditions, winds, waves, and tropical cyclones. For offshore PV, the hazard environment affects structural survival, mooring loads, fatigue, downtime, insurance, and maintenance logistics. A national screening process should not rely only on mean wind or average significant wave height. It should also examine distributions, seasonal extremes, return-period conditions where data permit, and the joint occurrence of wind, waves, currents, and water levels. For exposed sites, structural design conditions are likely to be driven by extremes rather than mean climate.

ERA5 can support broad-scale historical characterisation, but extreme-value analysis requires careful attention to resolution, bias, event representation, and the length of the record. A review should record whether studies use mean climate, percentile thresholds, hindcasts, design storms, or coupled hydrodynamic models. For a future Indian GIS study, ERA5 could provide initial spatial screening while regional ocean models, buoy observations, and engineering hindcasts refine the most promising candidate areas. A simple suitability score should not mask the possibility that a site with high irradiance is technically unsuitable because extreme waves or cyclone loads exceed a given platform's design envelope.

Marine exposure also creates corrosion and biofouling risks. Saltwater and salt spray can degrade metallic components, electrical connections, coatings, and connectors. Biofouling can alter hydrodynamic loads, add weight, damage materials, and increase maintenance needs. Salt deposition on module surfaces can affect optical performance, while humidity and moisture can accelerate electrical degradation. These mechanisms are well-recognised marine engineering concerns, but their quantitative effect on Indian offshore PV lifetime and energy yield remains uncertain without long-term field evidence. The review should distinguish documented marine engineering risks from measured performance losses in deployed offshore PV arrays.

Environmental and ecological considerations

Offshore PV can reduce direct competition with terrestrial land uses, but it is not impact-free. Potential interactions include shading of the water column, altered light penetration, local changes in mixing and temperature, habitat disturbance from anchoring and cables, construction noise, vessel traffic, collision or entanglement risks for some fauna, and interactions with sensitive marine habitats. The magnitude and direction of effects will depend on array coverage, depth, water clarity, local ecology, platform design, and operating practices. Evidence from reservoirs or sheltered waters may help generate hypotheses but should not be treated as direct proof of effects in open marine ecosystems.

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Environmental screening should identify protected areas, coral reefs, seagrass beds, mangroves, turtle nesting and migratory corridors where relevant, important marine mammal areas, and other sensitive habitats. It should also consider cumulative effects when arrays are deployed alongside ports, offshore wind, shipping, aquaculture, and subsea infrastructure. Environmental exclusion areas and buffers should be grounded in applicable regulation, ecological evidence, and consultation rather than chosen only for cartographic convenience.

The principle of avoiding sensitive locations at the initial screening stage is generally more defensible than assuming every impact can be mitigated later. Yet exclusion mapping must be transparent: the data source, date, spatial precision, legal status, and buffer assumptions should be documented. A coarse national dataset may miss local habitat features, while some sensitive locations may have incomplete public mapping. This creates a need for uncertainty flags and field verification rather than a false appearance of complete knowledge.

Maritime uses, livelihoods, and spatial competition

India's coastal and maritime spaces support fisheries, shipping, port operations, defence and security activities, tourism, offshore infrastructure, and coastal livelihoods. An offshore PV array could displace or restrict some activities, while creating potential synergies with ports, offshore wind, aquaculture, or nearshore industrial demand in other circumstances. These outcomes cannot be inferred from resource data alone. The social and economic appraisal should identify who benefits, who bears risk, whether fishing access is restricted, and how construction and maintenance vessels interact with existing maritime uses.

Fisheries require particular attention because marine space is not an empty surface. Fishing grounds, seasonal routes, small-scale fishing access, landing sites, and customary use may not be represented adequately in formal spatial datasets. A GIS layer showing distance from shore or shipping lanes cannot substitute for stakeholder engagement. In a national screening framework, livelihood-sensitive areas should be mapped where credible data exist, and data gaps should trigger consultation rather than automatic classification as low-conflict space.

Grid connection is another major constraint. Offshore arrays require export cables, landing points, onshore substations, and potentially reinforcement of the transmission network. Distance to shore alone is an incomplete proxy: cable corridors may intersect protected habitats, navigation channels, fishing grounds, and other infrastructure. The economic feasibility of an offshore project will depend on the distance and route to a viable connection, power evacuation capacity, demand profiles, and potential integration with other offshore renewables. For early screening, proximity to substations and coastal load centres may be useful indicators, but a project-level assessment needs cable-route engineering and grid studies.

Economics and deployment maturity

The levelised cost of electricity (LCOE) for offshore PV is shaped by more than the cost of modules. Relevant components include floating structure, mooring and anchoring, installation vessels, offshore electrical systems, export cables, corrosion protection, insurance, maintenance access, weather-related downtime, replacement, and decommissioning. Offshore costs are especially sensitive to scale, distance from shore, water depth, wave climate, and the availability of ports and specialist vessels. Comparisons with land-based PV are meaningful only if system boundaries, capacity factors, financing assumptions, project lifetime, and grid costs are comparable.

The technology remains less mature than conventional land-based PV and inland FPV. This means that apparent precision in a national economic-potential estimate can be misleading if input costs are borrowed from other marine technologies or assumed constant across very different locations. A systematic review should report whether a study's cost estimate is based on a real project, engineering design, techno-economic model, or broad extrapolation. It should also capture the year of currency values, currency conversion, discount rate, lifetime, capacity factor, and sensitivity analysis. Cost values from different studies should not be pooled without harmonising assumptions.

A plausible Indian deployment pathway may begin with demonstration projects in comparatively sheltered, accessible, and grid-proximate waters, subject to environmental and maritime screening. Such demonstrations

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could validate wave-response models, corrosion assumptions, marine operations and maintenance, local supply chains, and actual energy yield. More exposed sites could be considered only as technology and design standards mature. This is a staged development hypothesis, not a conclusion that any particular site is already suitable.

Research Gap, Questions, And Objectives

Research gap

The evidence points to four connected gaps. First, the direct India-specific offshore solar assessment identified in this review is an important but dated baseline that used a two-year radiation period. Second, the broader marine floating-PV literature has developed rapidly in structural design, reliability, and global potential modelling, but much of it is not calibrated to Indian coastal and EEZ conditions. Third, resource assessments, engineering studies, environmental considerations, and policy analysis often operate in separate literatures, making it difficult to distinguish theoretical resource from deployable potential. Fourth, public datasets exist, but there is a need for a transparent framework explaining which dataset supports which decision, at what scale, with what limitations and uncertainty.

The novelty claim should therefore be carefully bounded: this review does not claim to be the first study of offshore solar in India, nor the first review of marine floating PV globally. Its proposed contribution is an India-centred, interdisciplinary synthesis that maps the chain from resource to practical siting, evaluates transferability of evidence, and specifies a reproducible evidence architecture for a future GIS-based assessment.

Research questions

1. What direct empirical and model-based evidence exists on offshore solar resource and PV potential around India?
2. How do the solar datasets, temporal periods, spatial resolutions, and PV-system assumptions used in published assessments affect comparability?
3. Which marine engineering, metocean, environmental, maritime-use, grid, and economic constraints most strongly shape the feasibility of offshore PV?
4. Which public secondary datasets can support a reproducible India-wide screening framework, and what are their limitations?
5. What methodological and governance priorities should guide the next generation of offshore PV assessment and demonstration in India?

Review objectives

- Identify and classify the literature on offshore PV and closely related floating PV applications relevant to India.
- Critically compare direct offshore resource assessments and assess their assumptions, data periods, and limitations.
- Synthesise evidence on marine structural reliability, extreme weather, ecology, maritime use, grid integration, and costs.
- Build an evidence-to-siting framework that separates theoretical, technical, constrained, and economic potential.
- Identify the evidence and data requirements for a reproducible future national assessment, while making clear which analyses have not yet been undertaken.

Comparative evidence map of the principal cited sources

Source	Evidence type / setting	Contribution reported in the cited manuscript	India transferability	Limitations / appraisal status
Solanki et al. (2017)	Direct India-specific offshore	ERA-Interim (2015–2016); approx. 0.125°; mean GHI 5.49 kWh/m²/day; Gujarat	Directly relevant to Indian EEZ resource baseline	Two-year period; historical result; not a current capacity or

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	solar resource assessment	and Tamil Nadu identified as relatively favourable		bankability estimate. Full validation details require full-text extraction.
Claus & López (2022)	Marine floating-PV design review	Design issues and environmental loads for floating PV in marine settings	Transferable engineering concepts; local Indian design validation required	Review-level evidence; no India-specific operating validation reported in the source manuscript.
Shi et al. (2023)	Marine floating-PV development review	Structural concepts, potential synergies and deployment obstacles	Transferable technology overview	The source manuscript does not provide a harmonised quantitative comparison or study-level appraisal.
Wei et al. (2025)	Interdisciplinary floating-solar literature review	More than 900 publications covered; ocean-based applications identified as less mature than inland FPV	Useful for evidence-maturity context; not India-specific	Broad floating-solar scope; offshore evidence must be separated from inland FPV.
Forester et al. (2025)	Systematic review of floating-solar siting	118 criteria across 36 studies; protected areas and water-body function commonly considered; solar resource and transmission distance frequent criteria	Methodological transfer only; marine-specific constraints need additional treatment	Siting evidence includes inland-water contexts; transferability to exposed sea conditions is limited.
Huang et al. (2025)	Marine floating-solar reliability review	Mechanical and electrical risks, structural integrity and biofouling highlighted	Transferable reliability concerns	No India-specific long-term operational dataset identified in the source manuscript.
Rodríguez-Gallegos et al. (2025)	Global offshore-FPV potential and cost assessment	Integrates technical potential, cost competitiveness and deployment pathways	Global methods can inform Indian scenario design, subject to local calibration	Global assumptions should not be applied to India without checking cyclone, metocean, ecology, grid and cost conditions.

Note: This evidence map is limited to sources already cited in the supplied manuscript. The entries summarise claims recorded in that manuscript and should be checked against each original full text before final resubmission; they are not the result of a completed database search or formal risk-of-bias appraisal.

METHODOLOGY

Review design and reporting standard

Review approach and scope. This manuscript is presented as a critical integrative review of the literature and public-data documentation cited in the manuscript, rather than as a completed systematic review. The distinction is important: the source manuscript did not contain database export files, a deduplication log, screening decisions, full-text exclusion records or a completed study-level quality appraisal. These materials were not available in the files supplied for revision. Accordingly, this revision does not report PRISMA identification or screening counts, inter-reviewer agreement, a final included-study total, or quantitative evidence-frequency claims. PRISMA 2020 (Page et al., 2021) is retained as the reporting standard that should be followed if the authors undertake and document a full systematic review in a subsequent version.

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Evidence provenance and interpretation. Statements in the synthesis are separated into three categories: (i) direct India-specific evidence, principally the published 2017 offshore solar assessment; (ii) transferable international evidence from marine-floating-PV and floating-solar reviews; and (iii) author-proposed methodological or policy recommendations. Dataset descriptions are treated as documentation of data availability, not as proof that a dataset has been processed or validated for offshore-PV generation. No new GIS analysis, PV-yield simulation, environmental overlay, cost model or site-suitability classification was undertaken for this manuscript.

Information sources

The bibliography retained in this review includes peer-reviewed research and official dataset documentation identified in the source manuscript. The cited sources include the India-specific resource assessment by Solanki et al. (2017), marine-FPV reviews by Claus and López (2022), Shi et al. (2023) and Huang et al. (2025), the interdisciplinary floating-solar review by Wei et al. (2025), the floating-solar siting review by Forester et al. (2025), and the global offshore-FPV assessment by Rodríguez-Gallegos et al. (2025). Official resources cited include ERA5, the Global Solar Atlas, GEBCO and the INCOIS Integrated Marine Energy Atlas. This is a bounded synthesis of the cited source set, not a claim that every relevant record in Scopus, Web of Science or other databases has been identified.

Search strategy

Search concepts for future systematic updating. To make a subsequent systematic review reproducible, searches should combine terms for (A) offshore or marine PV, (B) India and its maritime geography, and (C) resource, engineering, environmental, spatial-siting or economic assessment. The following Scopus-style query is a proposed search string; it must not be described as executed unless the database search is actually run and its export retained.

TITLE-ABS-KEY(("offshore solar" OR "offshore photovoltaic*" OR "marine photovoltaic*" OR "marine floating photovoltaic*" OR "offshore floating PV" OR "floating solar" OR "floating photovoltaic*" OR "ocean solar") AND (India OR Indian OR "Arabian Sea" OR "Bay of Bengal" OR "Indian Ocean" OR "exclusive economic zone" OR EEZ) AND (potential OR resource OR assessment OR GIS OR suitability OR techno-economic OR reliability OR wave OR cyclone OR environment OR policy))

A complementary global technology search should omit the geographic block so that marine design, wave-loading and ecological studies with transferable methods are not missed. For a completed systematic review, the authors should record the database interface, exact query, date and time, filters, export format, number of records returned, deduplication method, screening decisions, full-text exclusion reasons and citation-chasing procedures. Those records are required before a PRISMA flow diagram or comprehensive evidence claim can be supplied.

Eligibility criteria

Criterion	Include	Exclude / handle separately
Topic	Offshore or marine PV; resource assessment; design; reliability; costs; environmental and spatial siting evidence.	Studies unrelated to PV or with no transferable marine relevance.
Geography	India, Indian EEZ, Indian coastal waters, or global studies with clearly transferable methods.	Geographic studies whose methods or conditions have no stated relevance to offshore PV.
Study type	Peer-reviewed research, systematic reviews, engineering studies, official technical reports, public dataset documentation, and relevant policy documents.	Promotional material without traceable methods; unsupported opinion pieces.
Technology	Marine floating PV and offshore solar; inland FPV only for explicitly transferable evidence.	Conventional rooftop/ground PV with no relevant methodological or contextual contribution.

Evidence	Study with identifiable data, methods, analysis, design, or policy content.	Duplicate records, inaccessible records with insufficient metadata, and abstracts with no assessable methods.
Language and date	English-language sources, with no arbitrary lower date limit for seminal evidence; search current to the actual run date.	Other languages may be logged and assessed if translation is feasible; exclusions must be reported.

Screening and selection

A completed systematic review should export all records, remove duplicates using a documented rule, and screen titles/abstracts followed by full texts against pre-specified criteria. Full-text exclusion reasons should be retained. Where feasible, two reviewers should independently screen records or a sample; for a single-author review, a second-pass check and an explicit limitation should be reported. These steps are recommended here but are not represented as completed in the present revision.

Data extraction

For each included source, an extraction sheet should capture bibliographic details, geography, marine setting, technology, objective, spatial and temporal scale, data source and period, solar variables, PV assumptions, metocean variables, siting constraints, economic assumptions, validation, key findings and limitations. Each item should be labelled as direct Indian evidence, transferable international evidence, official dataset documentation or an author-proposed recommendation. The comparative table added to this revision is deliberately limited to information explicitly available in the cited manuscript references; it does not substitute for extraction from the full texts of every study.

Extraction domain	Fields to record
Bibliographic	Authors, year, title, journal/publisher, DOI/URL, publication type.
Study context	Country, coastline/sea, water depth, distance offshore, sheltered/exposed setting.
Solar resource	GHI, DNI, GTI/plane-of-array irradiance, dataset, period, resolution, validation.
PV modelling	Technology, tilt, module assumptions, array spacing, performance ratio, losses, yield metric.
Marine conditions	Wind, waves, currents, cyclone/extreme events, temperature, salinity, corrosion, biofouling.
Siting constraints	Bathymetry, protected areas, fisheries, navigation, ports, defence, cables, grid access.
Economics	CAPEX/OPEX, LCOE, financing, project life, energy price, uncertainty and sensitivity.
Evidence strength	Validation, model transparency, uncertainty, transferability to India, major limitations.

Quality appraisal

Quality and confidence appraisal. A completed review should appraise sources according to study type. Resource assessments should be examined for data provenance, temporal representativeness, spatial resolution, validation, reproducibility and uncertainty. Engineering studies should be examined for load cases, fatigue, mooring design and failure modes. Techno-economic studies should be checked for cost year, system boundary, financing, availability, grid connection and sensitivity analysis. Environmental studies should be assessed for ecological context, sampling design, impact pathways and uncertainty. No formal high/moderate/low quality score is assigned in this manuscript because the complete source texts and appraisal records were not supplied.

Synthesis approach

Synthesis method. The review organises the cited evidence into five connected domains: solar resource; marine engineering and operational reliability; environmental and maritime-use constraints; economics and grid integration; and governance and data availability. Numerical findings are reported only where the cited

manuscript provides a traceable published value. Estimates from different datasets or studies are not pooled because their periods, spatial coverage, definitions, system boundaries and assumptions are not harmonised.

A future quantitative GIS assessment should produce separate outputs for resource opportunity, technical-operational suitability and environmentally/socially constrained opportunity, with economic scenarios reported separately. Hard exclusions, conditional constraints and continuous cost/performance variables should not be collapsed into one opaque score. Criteria weights and thresholds should be evidence-based and sensitivity-tested. This is a proposed analytical design; no suitability map or GIS-derived capacity is presented in this review.

Proposed GIS framework for secondary-data integration

The proposed GIS workflow is a research recommendation, not an analysis performed for this article. It would define a consistent maritime boundary and grid; acquire long-term solar-radiation and PV-output data, ERA5 wind and wave variables, GEBCO bathymetry and relevant INCOIS layers; document spatial and temporal harmonisation; calculate seasonal and annual statistics and extreme-event indicators; apply transparent environmental and maritime-use constraints; estimate output under explicitly defined PV configurations; and test sensitivity to datasets, periods, thresholds and exclusions. Candidate areas would then require validation with observations, higher-resolution regional models, hydrographic surveys, engineering design and stakeholder consultation.

Ethics, reproducibility, and data management

This critical review uses published research and public secondary-data documentation and reports no new human-participant research. If future work incorporates interviews or surveys with fishers, coastal communities or other stakeholders, appropriate ethics approval, informed consent and data-protection procedures will be required. For reproducibility, a subsequent systematic review should archive search exports, deduplication records, screening decisions and extraction sheets; a subsequent GIS study should archive source versions, licences, coordinate systems, processing scripts and derived layers where reuse is permitted.

Results: Evidence-Informed Synthesis Framework

The synthesis below is restricted to the sources and published findings identified in the supplied manuscript. It is not a completed systematic-review result set: no comprehensive database search, deduplication, full-text screening or formal quality appraisal is claimed. The comparative evidence table summarises the role of the principal cited sources and explicitly records where the supplied manuscript does not provide enough detail to compare methods or validation.

What the direct India evidence establishes

The direct India-specific study cited in the manuscript is Solanki et al. (2017), “Assessment of offshore solar energy along the coast of India”. It used ERA-Interim radiation data for January 2015–December 2016 at approximately 0.125-degree resolution and mapped global horizontal irradiation across the Indian EEZ. The paper reported a mean GHI of 5.49 kWh/m²/day and identified Gujarat and Tamil Nadu as comparatively favourable radiation regions. These values describe the published study period and method; they are not recalculated or independently validated here. They provide a historical baseline, not a present-day estimate of deployable capacity.

The most important limitation is that radiation-only mapping does not fully address deployability. If a large offshore area is multiplied by an assumed conversion factor, the resulting energy number can appear enormous while obscuring constraints such as array spacing, wave survival, seabed conditions, environmental exclusions, export-cable routing, grid capacity, and vessel access. A national review should scrutinise any area-to-capacity calculation for explicit assumptions, unit consistency, realistic coverage ratios, and treatment of losses. Where assumptions cannot be reconstructed, the estimate should be reported as difficult to compare rather than used as a definitive planning figure.

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Resource potential and methodological comparability

Comparability depends on the variable, product, period, resolution and conversion model. GHI is not equivalent to plane-of-array irradiance, annual mean irradiation is not hourly electricity generation, and a PV-output layer is not necessarily a marine-specific yield estimate. ERA5, satellite-derived climatologies and standard PV-potential products should therefore be compared over a common period and with their assumptions documented before differences are interpreted as physical differences in resource.

The INCOIS Integrated Marine Energy Atlas is an India-focused institutional resource for marine-energy context. The source manuscript identifies it as a compilation of satellite and model-simulated parameters with observational verification. Before using any particular layer in an offshore-PV model, researchers must verify the layer's variable definition, spatial and temporal coverage, resolution, validation record, access conditions and licence. The atlas is not presented here as a validated national offshore-PV capacity estimate.

Technical and operational constraints

The cited marine-FPV reviews consistently identify a coupled set of engineering concerns: wave and wind loading, platform motion, mooring and anchoring, cyclic fatigue, corrosion, biofouling, electrical exposure and difficult maintenance access (Claus & López, 2022; Shi et al., 2023; Huang et al., 2025). These mechanisms interact. A more robust platform may increase capital cost and mass; additional mooring may reduce some failure risks while increasing installation complexity and seabed disturbance; and remote sites may combine high solar resource with greater downtime and maintenance costs. The evidence supports technology-specific screening, not a universal wave-height threshold applicable to every platform design.

This evidence supports a technology-specific screening approach. Instead of applying a single wave-height cutoff to all locations, a future Indian assessment should relate metocean conditions to a defined design class or technology envelope. Candidate areas may be grouped into sheltered nearshore, moderately exposed, and highly exposed settings, but thresholds should be grounded in design studies and local environmental data. Extreme wind and waves should be treated as engineering design variables, while seasonal mean conditions inform energy yield and operational accessibility. The review should flag where published studies provide only conceptual design rather than validated performance.

Environmental and social constraints

Environmental and maritime constraints determine whether resource can be used responsibly. Potential issues include shading and changes to light penetration, anchoring and cable disturbance, construction noise, vessel traffic, and interactions with sensitive habitats. Protected areas, coral reefs, seagrass, mangroves, turtle-related areas and other sensitive features should be screened using authoritative, current spatial data. Fisheries, customary maritime use and seasonal access may be incompletely mapped; an absence of mapped data must not be interpreted as an absence of impact. Local consultation and field baseline studies remain essential.

The evidence base also requires a transferability hierarchy. Studies of inland floating PV can inform electrical design, module cooling, anchoring concepts in sheltered water, and some environmental questions. They cannot establish survival under open-ocean waves or cyclone conditions. Similarly, offshore wind data may help characterise metocean conditions and grid infrastructure, but wind-farm siting criteria do not automatically apply to PV platforms. The completed review should explicitly label these evidence transfers and discuss the assumptions that make them credible or weak.

Economic and grid constraints

Offshore-PV economics must be evaluated across the complete project lifecycle. Relevant cost components include floating structures, moorings, marine installation, export cables, offshore electrical systems, corrosion protection, insurance, maintenance, weather-related downtime, replacement and decommissioning. Costs are likely to vary with water depth, distance from shore, wave climate, port access, scale and grid conditions. The

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cited source set does not provide a harmonised set of India-specific offshore-PV cost estimates; therefore, no comparative LCOE or bankability claim is made here.

Grid proximity is a useful first-order screening variable, but the nearest shoreline is not necessarily the cheapest or least-impactful connection point. Cable routes may cross sensitive habitats or existing infrastructure, and onshore substations may lack available capacity. A national potential estimate should therefore present a range of connection scenarios or clearly state that grid integration is not modelled. Project-level economic feasibility ultimately requires transmission studies, cable-route engineering, permitting, and a realistic offshore operations plan.

Evidence maturity and confidence

The cited evidence is uneven in maturity. Solar-resource products are available for broad screening, but offshore-PV-specific validation and intercomparison remain necessary. Marine engineering research is developing, yet design performance and long-term operating evidence under Indian conditions are limited in the cited material. Offshore-PV-specific ecological evidence and India-specific bankability evidence are also insufficient to support precise national conclusions. These are qualitative observations about the cited source set, not formal scores from a completed systematic appraisal.

Evidence domain	Preliminary maturity judgement	Why the judgement is provisional	Priority next step
Solar-resource data	Moderate to high for broad screening	Public gridded products exist, but offshore PV-specific validation and intercomparison are needed.	Compare ERA5, satellite climatology and available observations over a common period.
Marine engineering	Moderate but technology-dependent	Design and review literature exists; local validation and long-term operating evidence are limited.	Link site conditions to explicit design envelopes and failure modes.
Extreme weather	Moderate for broad-scale reanalysis; variable for design use	Reanalysis can screen regional patterns but may not resolve local extremes adequately.	Use buoy data, regional hindcasts and engineering design conditions.
Environmental impact	Low to moderate for offshore-PV-specific effects	Many pathways are plausible, but long-term field evidence is limited.	Establish baseline ecology and monitor demonstration projects.
Economics and bankability	Low to moderate	Costs depend on design, location, insurance, grid, and limited commercial operating history.	Use transparent scenarios, sensitivity analysis and real project data.
Governance and maritime uses	Context-dependent	Official maps exist for some uses; fisheries and customary use data can be incomplete.	Combine official spatial layers with stakeholder consultation.

DISCUSSION

Implications for India's offshore solar strategy

India should not frame offshore-PV development solely as a question of how much sea area receives strong sunlight. The policy-relevant question is where a defined technology can produce reliable electricity at acceptable lifecycle cost and with acceptable environmental and social effects, given actual marine conditions and grid access. A staged approach—resource validation, metocean characterisation, technology-specific design,

environmental and maritime screening, and monitored demonstration—is more defensible than a national capacity target derived from gross EEZ area.

The 2017 India assessment remains a useful historical baseline, but updated work should compare longer time series and multiple products rather than force new estimates to reproduce the historical mean. Differences should be interpreted in relation to the observation period, dataset, grid resolution, variable definition and PV-model assumptions. A national map should prioritise further investigation; it should not be treated as a substitute for local hydrographic surveys, engineering design, ecological baseline studies or stakeholder consultation.

The INCOIS atlas can help connect marine observations and renewable-energy planning, but its layers must be assessed individually for relevance to PV generation and site screening. Public data availability improves transparency; it does not remove the need for site-level evidence. In particular, coarse bathymetry and metocean grids are suitable for broad screening only and should not be used as engineering design inputs without higher-resolution validation.

From resource maps to a transparent suitability model

A transparent suitability framework should report at least three distinct outputs: (1) solar-resource opportunity; (2) technical and operational suitability for a specified platform/design envelope; and (3) remaining opportunity after environmental, maritime-use and grid constraints. Economic scenarios should be layered on separately. This preserves trade-offs: high irradiance may coincide with high cyclone exposure, ecological sensitivity, difficult access or expensive grid connection.

Criteria should be classified as hard exclusions, conditional constraints or continuous variables. Hard exclusions require a clear legal or evidence-based basis; conditional constraints require further study, consultation or mitigation; continuous variables such as distance to shore or wave climate may influence performance and cost without automatically excluding a location. Each classification should be documented and sensitivity-tested.

Weights and thresholds should be transparent. If expert judgement is used, the panel composition and elicitation procedure should be reported. If a multi-criteria method is used, consistency and sensitivity should be examined. A composite index should never replace publication of its component layers and uncertainty information.

The importance of extreme-event-aware design

Annual mean climate is insufficient for structural feasibility. Extreme winds and waves may govern survivability even where mean conditions are favourable. Long-term energy-yield analysis and structural-design analysis should therefore use appropriately selected data and methods. ERA5 can support broad historical characterisation, while site design may require buoy observations, regional hindcasts, return-period estimates and detailed bathymetry. The present review does not quantify return-period loads or future climate risks for any Indian site.

Climate change may alter sea-level conditions, storm characteristics, wave climate and access windows over a project lifetime. Future assessment should stress-test design and maintenance assumptions against suitable climate scenarios and downscaling methods. Such scenario analysis is a research priority, not a quantified result of this review.

Environmental and livelihood safeguards as design inputs

Environmental safeguards should be integrated before site and technology choices become fixed. Initial screening should identify sensitive habitats and areas where impacts are uncertain and require further assessment. Construction, operation, cable installation, anchoring and decommissioning may have different impact pathways. Cumulative effects should be considered where offshore PV could coexist with ports, offshore wind, aquaculture, shipping or subsea infrastructure.

Social legitimacy is also a feasibility condition. Fisheries, coastal communities, port authorities, navigation stakeholders and local governments may bear costs not reflected in electricity-cost estimates. Early engagement

can reveal seasonal use patterns and customary access not captured in public spatial layers. Future project appraisal should document livelihood dependencies, conflict pathways, potential benefit-sharing and grievance mechanisms.

Research priorities and a practical roadmap

A practical research roadmap has four stages. First, complete an auditable evidence review with database exports, screening logs and study-level appraisal. Second, undertake national GIS screening using harmonised solar, metocean, bathymetric, ecological, maritime-use and grid layers, with explicit uncertainty. Third, validate priority locations through high-resolution observations, engineering design, ecological baselines and stakeholder consultation. Fourth, establish monitored demonstration projects that publish energy yield, availability, failures, maintenance costs and environmental observations.

The most useful early demonstration may not be the site with the highest theoretical output. A comparatively accessible site with manageable sea states, port and grid proximity, lower environmental conflict and practical monitoring access may generate more valuable learning. Demonstrations should test platform and mooring performance, corrosion protection, electrical safety, storm preparedness, maintenance logistics, end-of-life recovery and ecological monitoring. Negative results should also be reported.

What the review can and cannot conclude

The cited literature supports the conclusion that offshore solar resource assessment around India is feasible and warrants further investigation. It does not establish a national bankable-capacity figure. The 2017 assessment supplies a historical resource baseline; marine-FPV reviews identify reliability and operational constraints; global studies demonstrate the value of integrating resource, cost and deployment conditions. India-specific planning must connect these strands with local metocean, ecological, maritime-use, grid and governance evidence.

This revised manuscript is intentionally framed as a critical integrative review because the supplied files do not contain the search exports, screening log or appraisal records needed to substantiate a completed systematic review. To resubmit it specifically as a systematic review, the authors must complete and report those steps, update the evidence table from full-text extraction, and provide the actual PRISMA flow counts. The current revision does not represent those tasks as completed.

Limitations

This review is limited to the sources and dataset documentation cited in the supplied manuscript; it is not an exhaustive systematic review. Database exports, deduplication records, title/abstract and full-text screening logs, exclusion reasons and formal quality-appraisal sheets were not supplied and therefore could not be independently checked or completed for this revision.

The direct India-specific offshore-solar assessment identified in the cited source set dates to 2017 and uses a two-year radiation period. Additional studies or official assessments may exist beyond the references considered here. The review therefore avoids claiming comprehensive coverage or novelty based on an exhaustive search.

International marine-FPV findings may not transfer directly to India because wave climates, cyclone exposure, water depth, ecology, ports, electricity markets and regulation differ. Public datasets also vary in resolution, temporal coverage, licensing and uncertainty. Environmental and livelihood information, particularly fisheries and customary maritime use, may be incomplete; missing data must be treated as uncertainty rather than evidence of no impact.

Offshore-PV costs remain sensitive to technology maturity, design, financing, insurance, maintenance, grid connection and local supply chains. Without verified Indian project data and a harmonised cost model, precise LCOE comparisons would be premature. This review also performs no new GIS analysis and calculates no new PV output, capacity or suitable sea area. These require separate reproducible modelling and site validation.

CONCLUSION

Offshore solar photovoltaic development around India is a potentially important research and planning opportunity, but feasibility cannot be inferred from maritime area or solar irradiation alone. The India-specific assessment by Solanki et al. (2017) reported a mean GHI of 5.49 kWh/m²/day for its 2015–2016 study period and identified Gujarat and Tamil Nadu as relatively favourable radiation regions. This is a historical published result, not a current estimate of bankable offshore capacity.

The central contribution of this critical review is an India-centred evidence-to-siting framework linking solar resource to technology-specific marine reliability, environmental and social constraints, grid access and lifecycle economics. ERA5, the Global Solar Atlas, GEBCO and the INCOIS Integrated Marine Energy Atlas can support future screening, but they do not replace harmonised modelling, site-specific validation, ecological baseline studies or consultation with maritime users. The framework distinguishes theoretical resource, technical potential, environmentally and socially constrained potential, and economic deployability, with uncertainty reported at each stage.

The most defensible pathway is staged: complete and document the systematic evidence search if a systematic-review designation is retained; conduct national screening with transparent data and assumptions; validate priority areas using high-resolution marine observations and engineering studies; and develop carefully monitored demonstrations before making large-scale deployment claims. The present manuscript should be submitted as a critical integrative review unless and until the formal systematic-review workflow has been completed and documented.

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