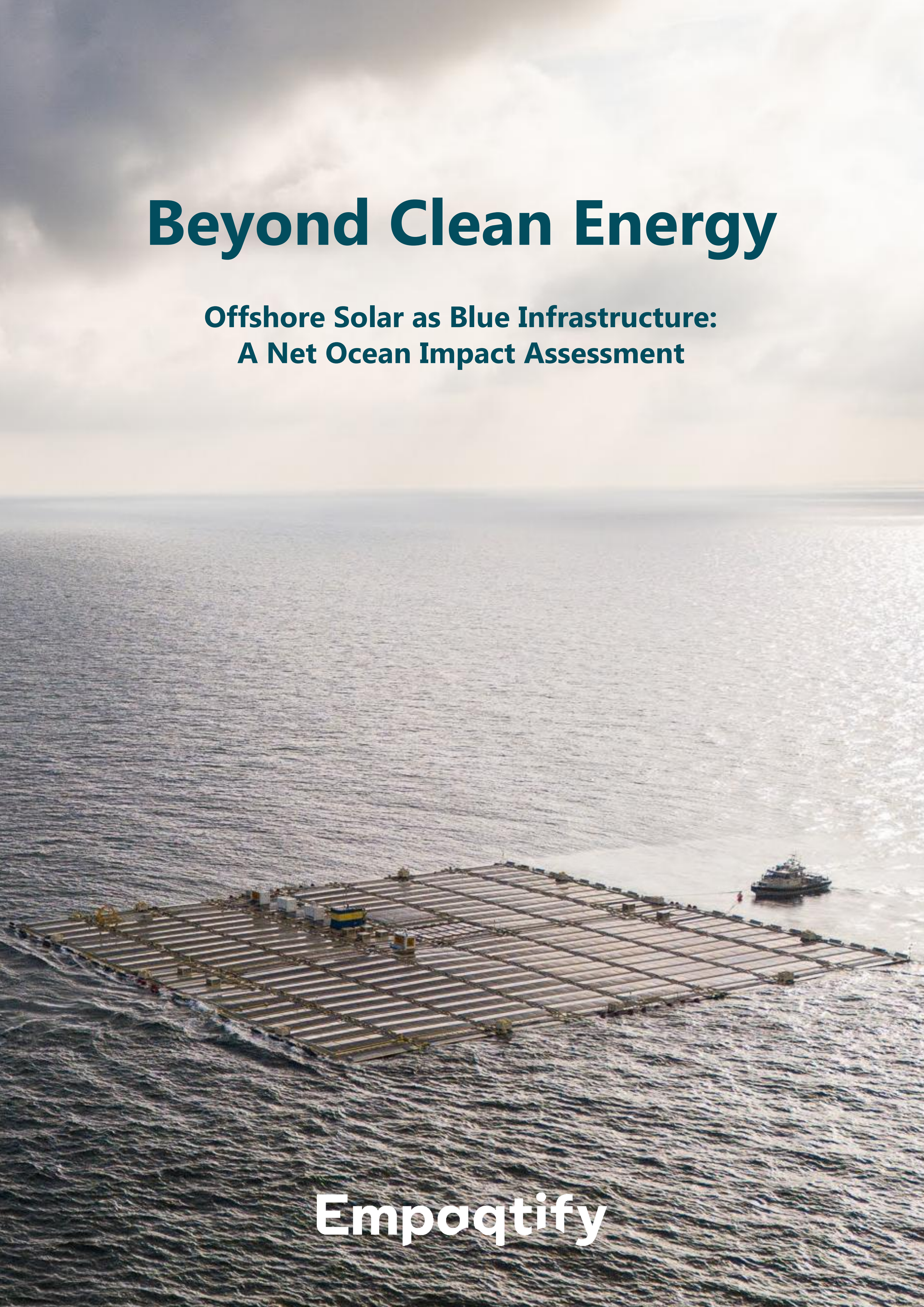

Beyond Clean Energy

Offshore Solar as Blue Infrastructure: A Net Ocean Impact Assessment

Empaqtify

Contents

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Empaqtify GmbH
Hüttenwiesstrasse 18
9016 St. Gallen
Switzerland

info@empaqtify.com
www.empaqtify.com

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About Empaqtify

Empaqtify is an independent advisory firm working at the intersection of science, strategy, and capital. The firm develops structured analytical frameworks that help organisations and investors understand how projects and portfolios interact with environmental and social systems.

Empaqtify's work is guided by a simple objective: accelerating positive change that is measurable, investable, and scalable. By translating scientific evidence into decision relevant insights, the firm supports investors and organizations in evaluating environmental risks, identifying measurable impact opportunities, and communicating results in a transparent and credible manner.

To support this, Empaqtify develops methodologies that bridge environmental assessment and investment decision making. These approaches help translate complex environmental interactions into structured analyses that can inform infrastructure development, innovation portfolios, and capital allocation decisions.

In the context of this report, Empaqtify developed the analytical framework, structured the Net Environmental Benefit Analysis (NEBA) methodology, and led the interpretation and synthesis of the results presented here. The assessment builds on scientific studies, technical documentation, and environmental analyses conducted by Oceans of Energy and its research partners. Oceans of Energy provided background data, technical context, and scientific inputs that informed the literature review and scoring process. Empaqtify's role focused on applying the NEBA framework, structuring the comparative risk and benefit assessment, and translating the findings into a transparent and capital-relevant analytical narrative.

Through this work, Empaqtify contributes to more informed investment and policy decisions in areas where environmental performance and capital deployment increasingly intersect, including climate infrastructure, ocean systems, and the broader blue economy.

Contact

Empaqtify | Hüttenwiesstrasse 18

9016 St. Gallen | Switzerland

info@empaqtify.com

www.empaqtify.com

Executive Summary

Key Findings

- **Offshore solar can function as blue infrastructure,** combining renewable energy generation with measurable ocean ecosystem benefits.
- **Operational zones can support marine biodiversity**, as reduced seabed disturbance and new structures create refuge conditions**.**
- **Environmental risks are limited and manageable**, largely confined to installation activities and the project footprint**.**

Offshore solar is emerging as scalable renewable energy infrastructure within the growing blue economy[1–3]. For investors and regulators, the relevant question is no longer limited to climate performance alone. It is whether offshore solar introduces manageable ecological risk and whether it can generate **measurable positive ocean impact alongside energy production**[4].

This report provides an independent reference for funders, regulators, and other stakeholders evaluating offshore solar projects. It synthesizes available scientific evidence and applies a structured **Net Environmental Benefit Analysis (NEBA)** framework to compare ecological risks and ecological gains associated with offshore solar installations, based on technology developed by Oceans of Energy.

Four investor-relevant questions guide the assessment:

- Are **ecological risks** local, limited, and manageable?
- Do **ecological benefits** persist throughout the operational life of the infrastructure?
- Can these interactions be measured and **reported using recognised impact frameworks**?
- Can offshore solar function as **marine infrastructure** that generates both energy and measurable ecosystem value?

The results reveal a consistent pattern across marine ecosystem domains and biological groups. Ecological risks are predominantly local in spatial extent, moderate in intensity, and frequently reversible. **Most risks occur during installation activities and remain confined** to the project footprint and its immediate surroundings.

At the same time, offshore solar introduces ecological mechanisms that may generate **measurable ocean ecosystem benefits**. Reduced seabed disturbance within operational safety zones and the introduction of structural habitat can support benthic recovery and enhance local biodiversity. Across all assessed biological groups, aggregated **benefit scores exceed risk scores** under the defined assessment assumptions.

Evidence from marine conservation practice demonstrates that marine ecosystems can recover relatively quickly when pressures such as seabed disturbance and intensive fishing are reduced. In a comparable way, offshore solar installations create operational zones where disturbance is reduced, and structural elements may function as reef-like habitat. These **interactions can be validated through targeted ecological monitoring**.

By structuring ecological risks and benefits within a transparent analytical framework, this report helps inform investment and permitting decisions. The findings position offshore solar not only as renewable energy infrastructure, but as marine-interacting infrastructure capable of delivering measurable ocean outcomes that may support emerging **blue economy** investment strategies and **sustainable ocean finance** mechanisms.

From Risk Assessment to Net Ocean Impact

Marine infrastructure projects have traditionally been evaluated through risk based environmental assessments focused primarily on identifying potential harm and defining mitigation measures[5]. While this approach remains essential for permitting and environmental compliance, it provides only a partial view of how infrastructure interacts with marine ecosystems.

At the same time, investment strategies in the ocean economy are evolving[2]. Blended finance and blue finance initiatives increasingly require **a structured articulation of ocean impact to inform capital allocation and risk assessment**[1,4]. Investors and development finance institutions seek greater clarity on how infrastructure projects influence ecosystem conditions, not only in terms of potential harm but also in terms of measurable ecological outcomes.

A NEBA expands the assessment lens beyond risk alone. Instead of asking only what negative impacts may occur, it evaluates how ecological risks compare to ecological gains within a single structured framework[6]. By systematically identifying and scoring ecological interactions, the approach provides a transparent basis for comparing impacts across ecosystem domains and biological groups.

The objective is not to claim inherent net positivity. Rather, it is to provide a balanced and evidence based ecological profile that supports proportionate regulatory oversight and more informed investment decision making.

What is a Net Environmental Benefit Analysis (NEBA)?

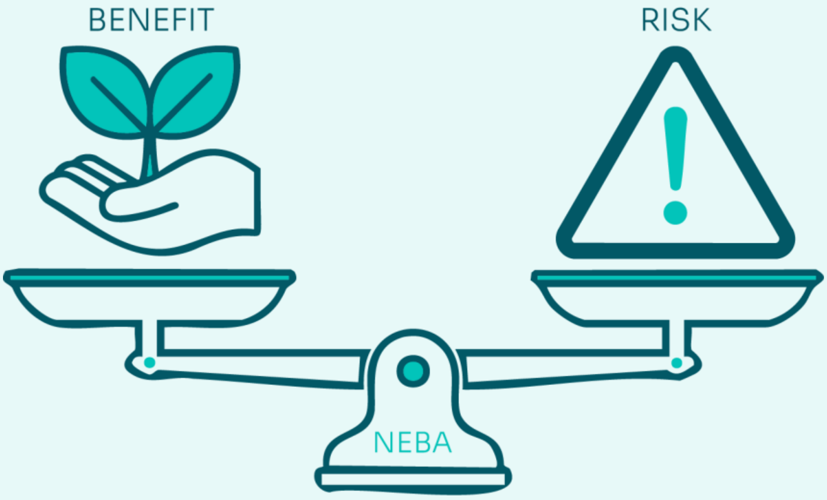
A NEBA is a structured approach used to evaluate both ecological risks and ecological gains associated with a project or intervention[6].

Traditional environmental assessments often focus primarily on identifying potential negative impacts. A NEBA goes one step further. It systematically identifies all relevant ecological interactions - positive and negative - and evaluates them using consistent criteria. This enables transparent comparison of trade-offs rather than one-sided impact characterisation.

In practical terms, a NEBA helps answer a more complete question:

How do the ecological risks of a project compare to its ecological benefits?

By structuring impacts across defined criteria and making uncertainty explicit, a NEBA provides a balanced and evidence-based foundation for regulatory review and investment decision-making.



Framework and Case Study Context

The assessment applies a structured NEBA framework to examine how offshore solar infrastructure interacts with marine ecosystems and to evaluate its **ocean impact profile**. The approach builds on the NEBA methodology previously developed and applied by Empaqtify to evaluate marine interventions[6].

By systematically identifying ecological interaction mechanisms and evaluating their characteristics, the framework allows both ecological risks and potential ecological gains associated with marine infrastructure to be evaluated within a single analytical structure (Figure 1).

To ensure transparency and analytical robustness, the assessment draws on a broad evidence base. Ecological interactions associated with offshore solar were identified through a systematic review of available scientific literature, supported by technical documentation and analogous studies of offshore infrastructure. In total, **the assessment draws on 94 scientific references** covering marine ecology, offshore energy systems, and environmental interaction mechanisms.

The **case study** evaluates offshore solar technology deployed by Oceans of Energy. The organization has operated pilot scale offshore solar installations under high wave conditions since 2019, including a world's first 0.5 MW (football field) sized installation within an operational offshore wind park in 2025 (Figure 2). Their system consists of interconnected modular photovoltaic platforms anchored to the seabed through a permanent mooring system. Electricity is converted offshore (DC to AC) and exported via subsea cable infrastructure. The **design lifetime is approximately 25 years**, with full retrieval foreseen at end of life. The organization supplies standardized offshore solar systems of sizes 1, 5, 15 and 50 MW and aims to deliver up to 200 MW floating islands in the future, which will be 1 x 1 km in size. This configuration reflects emerging commercial formats for hybrid wind solar integration within offshore wind parks, allowing solar platforms to be placed between wind turbines and connected through shared export infrastructure.

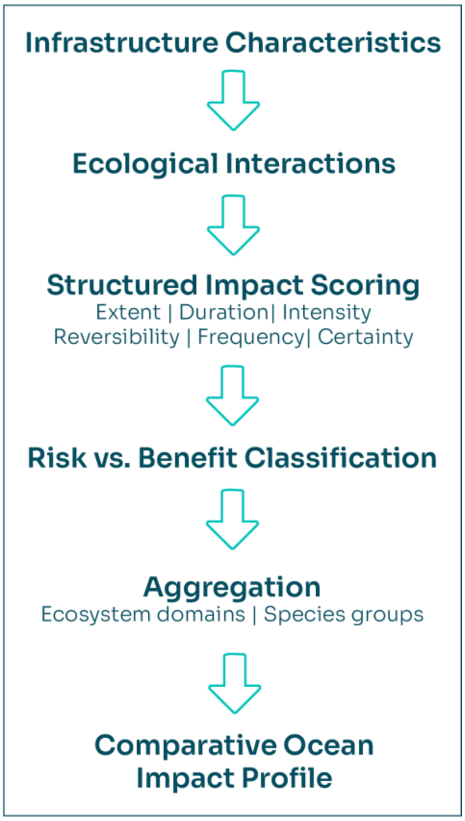


Figure 1 | Structure of the NEBA framework. Infrastructure characteristics generate ecological interactions that are evaluated through structured impact scoring. The resulting scores are aggregated across ecosystem domains and species groups to produce a comparative ocean impact profile.

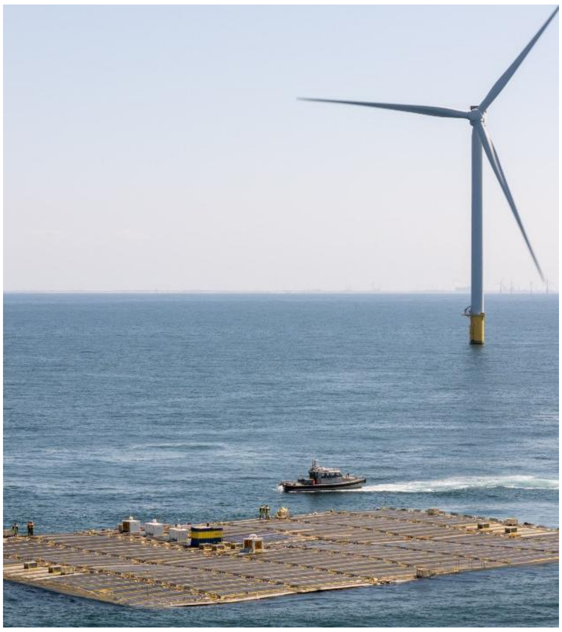


Figure 2 | Offshore solar platform by Oceans of Energy, installed within an offshore wind park in the North Sea.

The NEBA presented in this report assumes a representative commercial scale deployment of approximately **1 km² and 200 MW** installed capacity.

From an ecological interaction perspective, **key system characteristics** include:

- Absence of bottom contact fishing methods in deployment area
- Introduction of artificial hard substrate through floating and mooring components
- Partial shading of the water column
- Local hydrodynamic modification
- Installation related seabed disturbance

These mechanisms form the basis for risk and benefit scoring. Each identified ecological interaction was assigned to one of **seven key marine ecosystem domains** (Figure 3a): Community & Foodweb, Megafauna & Commercial Species, Ocean Conditions, Primary Production, Seabed Health, Structural Habitat, and Water Quality.

In addition to the ecosystem domains, interactions were also grouped by the ecological receptors, reflecting the **five main species group** affected by the impact (Figure 3b): Marine Mammals, Fish, Birds, Benthic Organisms, and Planktonic Organisms.

Lastly, each identified interaction was assessed across **six impact criteria** (Figure 4) and scored on a scale from 1 to 5 (see text box on page 8 for scoring framework):

Spatial extent - The geographical scale over which an effect is expected to occur, ranging from site-specific effects limited to the project footprint to basin-wide effects (e.g. North Sea).

Duration - The persistence of an effect, from short-term or event-driven responses to effects that persist beyond the operational phase or result in permanent change.

Intensity - The magnitude of ecological change, ranging from negligible effects with no measurable ecological relevance to major alterations of habitats or ecosystem functioning.

Reversibility - The potential for ecological recovery once the initiating pressure is removed, from rapid and complete recovery to irreversible change.

Frequency - How often an effect occurs during the project lifetime, ranging from rare or exceptional events to continuous presence during operation.

Certainty - The strength of the scientific evidence supporting the assessed effect, ranging from impacts inferred primarily from expert judgement or limited analogue studies to effects supported by robust empirical observations or well-established causal relationships.

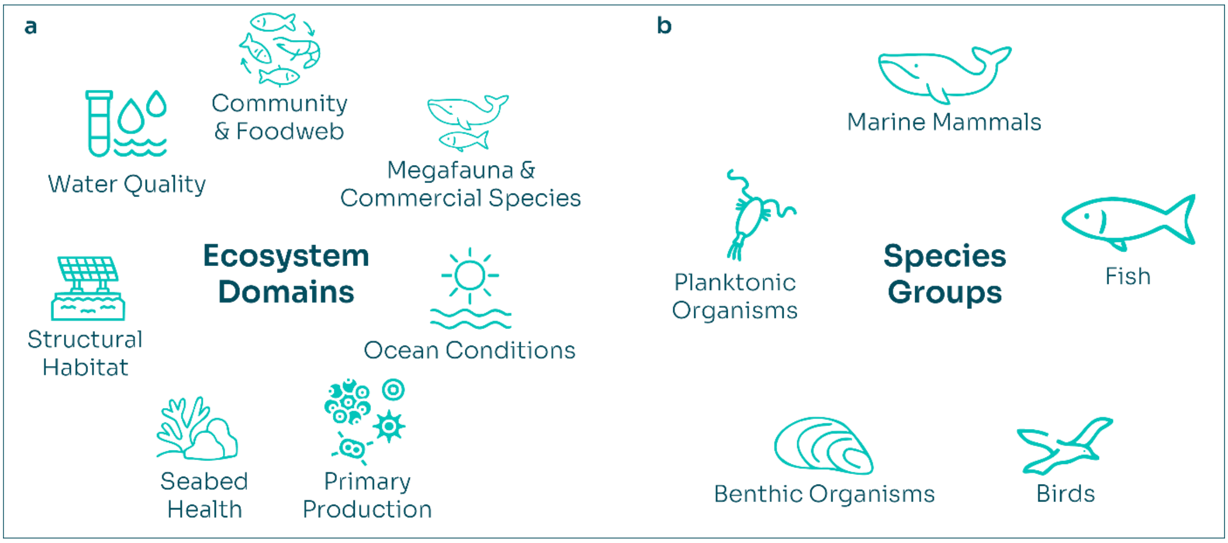


Figure 3 | Key **(a)** marine ecosystem domains and **(b)** species groups affected by offshore solar.

The results were then consolidated to enable clear comparison of how different components of the marine system may experience risks or benefits. The framework is designed to support **transparency and comparability** rather than to generate a single composite index. Explicit scoring of certainty ensures that empirical strength is visible and uncertainty is not concealed.

The complete inventory of ecological interactions, literature references, scoring rationale, and aggregation logic is provided in the Supplementary Dataset, allowing full transparency of the underlying assessment and **enabling independent review** of the ecological evidence base.

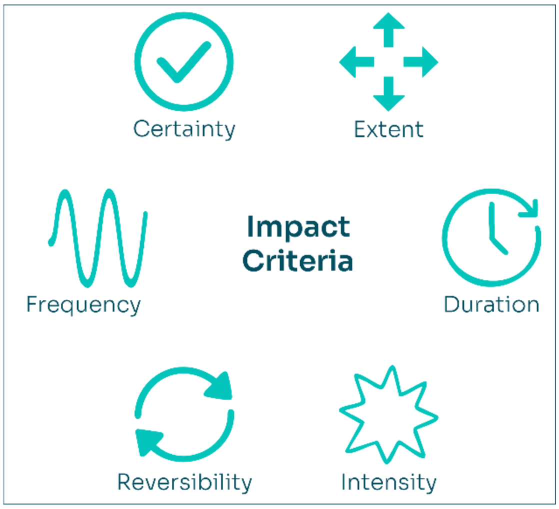


Figure 4 | Impact criteria used to assess the impact of ecological interactions of offshore solar

Impact Scoring

Criteria are scored from 1–5, with higher scores indicating broader, longer-lasting, or more substantial effects. Certainty scores reflect the strength of available evidence. Full scoring details are provided in the Supplementary Dataset.

Extent
1 = Site specific - *Limited to the project footprint*
2 = Immediate surroundings - *Slightly beyond project boundary (mooring area; hundreds of meters)*
3 = Local scale - *Detectable in the broader local environment (kilometers)*
4 = Regional scale - *Affects a defined section of the region (tens of kilometers)*
5 = Basin-wide - *Detectable across a large marine region (hundreds of kilometers)*

Duration
1 = Instantaneous - *Very short events (hours–days)*
2 = Short - *Temporary persistence (weeks–months)*
3 = Medium - *Lasts throughout the operational lifetime*
4 = Long - *Persists beyond operation with residual effects*
5 = Permanent - *Irreversible long-term change*

Intensity
1 = Negligible ecological change - *Minimal measurable ecological change*
2 = Minor ecological change - *Small change affecting habitat or a single species group*
3 = Noticeable ecological change - *Clear change in habitat, populations, or interactions*
4 = Substantial ecological change - *Strong change affecting habitat, multiple species, or processes*
5 = Major ecological change - *Fundamental alteration of ecosystem structure or functioning*

Reversibility
1 = Fully reversible - *Returns to original state once activity stop*
2 = Reversible - *Recovery expected within months to ~1 year*
3 = Slow reversibility - *Recovery takes several years and may remain incomplete*
4 = Limited reversibility - *Only partial recovery possible within decades*
5 = Irreversible - *Permanent ecological change*

Frequency
1 = Rare - *Single or exceptional event during project lifetime*
2 = Occasional - *Occurs irregularly under specific conditions*
3 = Regular - *Recurring periodically (e.g., seasonal)*
4 = Frequent - *Repeated during most operational phases*
5 = Continuous - *Persistent throughout operation*

Certainty
1 = Very low - *No empirical data; based on expert judgement*
2 = Low - *Limited or indirect evidence; weak analogues*
3 = Moderate - *Some empirical or model-based support*
4 = High - *Consistent evidence from multiple sources*
5 = Very high - *Strong empirical confirmation across studies*

Ecological Profile of Offshore Solar

The ecological profile of offshore solar is shaped by a limited number of identifiable physical mechanisms. These generate differentiated patterns of risk and benefit across marine domains and species groups (Figure 5, Table 1).

Three structural characteristics define the overall profile.

First, most risks are spatially confined to the project footprint and immediate surroundings.

Second, installation phase disturbances are time bound, while operational phase interactions persist throughout the lifetime of the infrastructure.

Third, aggregated benefit scores exceed risk scores across all assessed biological subject groups under the defined deployment scenario.

The following sections summarise how these interactions translate into risk and benefit patterns across the assessed marine ecosystem domains and species groups.

Seabed Health

Seabed Health shows the **strongest relative predominance of benefits**. The primary mechanism driving ecological gains is the reduction of direct seabed disturbance within operational safety zones underneath and surrounding the floating installation. Where bottom trawling or similar extractive activities are restricted, sediment resuspension decreases and benthic habitats are subject to less physical and chronic disruption. Over time, this cumulative disturbance avoidance can support recolonisation by invertebrates, increased structural stability of the seabed, and potential increases in benthic biomass.

Risks occur primarily during installation through anchor placement and cable laying. These effects are local and reversible once installation is complete. An additional factor is scale. As floating farms increase in size, seabed disturbance from mooring systems does not increase proportionally, as anchors and mooring lines do not scale linearly with the surface area of the installation. Larger installations therefore tend to reduce the relative footprint of seabed infrastructure per unit of energy generated.

From a capital perspective, this domain provides a measurable basis for reporting habitat protection exposure.

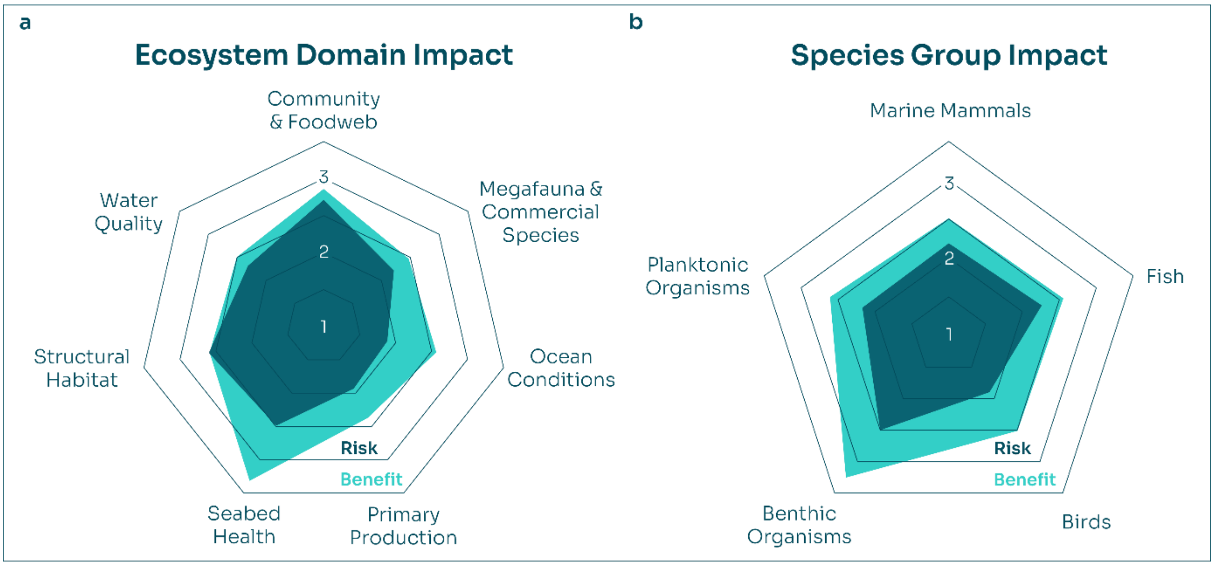


Figure 5 | Impact scores of offshore solar on main **(a)** ecological domains and **(b)** species groups. See Table 1 for scores and associated certainty values.

Table 1 | Impact scores and associated certainty values for ecological risks and benefits of offshore solar.

	Risk		Benefit	
	Impact Score	**Certainty**	**Impact Score**	**Certainty**
Ecosystem Domain				
Community & Foodweb	2.7	3.1	2.9	3.0
Megafauna & Commercial Species	2.2	3.7	2.5	2.9
Ocean Conditions	1.9	3.4	2.6	2.8
Primary Production	1.9	3.3	2.4	3.4
Seabed Health	2.5	3.3	3.3	3.4
Structural Habitat	2.6	2.5	2.6	3.3
Water Quality	2.3	3.6	2.5	3.2
Species Group				
Marine Mammals	2.2	3.4	2.5	3.2
Fish	2.3	3.5	2.6	3.2
Birds	1.9	4.2	2.5	3.1
Benthic Organisms	2.5	3.2	3.3	3.7
Planktonic Organisms	2.2	3.9	2.6	3.4

Structural Habitat

Structural Habitat reflects the introduction of artificial hard substrate through floating infrastructure and mooring systems, altering habitat configuration within the footprint of the installation and creating new ecological niches. The assessment indicates a predominance of benefits associated with increased structural complexity, additional substrate availability, and the development of biofouling communities that can support local biodiversity. Potential risks relate to shifts in species composition and gradual structural modification of the seabed environment. However, these interactions remain local, design-dependent, and reversible upon removal of infrastructure, rather than indicative of broader habitat degradation.

Community and Food Web

While Structural Habitat describes the physical modification of the environment, Community and Food Web captures how ecological communities respond to the presence of floating infrastructure. Submerged surfaces support the development of biofouling communities such as algae, mussels, barnacles, and other invertebrates. These organisms add habitat complexity and food resources, attracting mobile species including shrimp, crabs, and fish, thus increasing local trophic interactions.

The combination of new hard substrate, structural shelter, and operational exclusion zones can create a reef-like habitat effect. This may provide a partial refuge from certain pressures, particularly bottom-contact disturbance, and can increase local fish presence and biomass. In some contexts, these effects may also contribute to spillover benefits into adjacent areas, depending on site conditions and surrounding fishing pressure.

Benefits in this domain are therefore linked to increased habitat complexity and trophic interactions during the operational phase. Potential risks mainly relate to aggregation effects and local redistribution of species rather than broader ecological decline. These responses are typically local in scale and moderate in magnitude.

Megafauna and Commercial Species

This domain captures interactions with larger mobile species, including marine mammals and commercially relevant fish species. Potential risks are primarily associated with installation activities such as vessel presence, temporary underwater noise, and short-term habitat disturbance during anchor placement and cable laying. These interactions are typically local and time-limited, and established mitigation measures such as seasonal scheduling, acoustic monitoring, and operational buffers can reduce disturbance to sensitive species.

During the operational phase, offshore solar installations may introduce several mechanisms that support local marine life. The presence of structural habitat and associated biofouling communities can increase local prey availability and attract fish and invertebrates to the installation area. Operational safety zones that limit bottom-contact fishing may further reduce disturbance pressures and create areas of partial refuge for marine organisms.

Benefits in this domain are therefore linked to increased local habitat availability and reduced fishing pressure within installation areas. Potential risks mainly relate to temporary disturbance during installation or local behavioural responses of mobile species to infrastructure presence. Overall, these interactions remain spatially limited and manageable through site selection, monitoring, and established environmental management practices.

Primary Production

Primary Production is influenced primarily by shading beneath the floating platforms. Reduced light penetration beneath floating platforms may locally influence phytoplankton growth directly under the installation footprint, particularly in conditions with limited water mixing. This drives moderate risk scores in this domain.

At the same time, operational effects such as reduced wave disturbance and turbulence around the installation can lower suspended sediment concentrations, locally improving water clarity and light penetration in adjacent areas. In addition, biofouling communities and biodeposition beneath the structures can enhance nutrient recycling processes that support primary production in the surrounding water column.

Overall, these effects remain spatially limited to the installation footprint and its immediate surroundings. Impacts are therefore local and design-dependent and do not indicate broader regional disruption of primary productivity processes.

Ocean Conditions and Water Quality

Ocean Conditions and Water Quality capture small-scale physical and chemical interactions associated with floating infrastructure. The presence of platforms and mooring systems can slightly alter local surface dynamics, mixing patterns, and sediment movement within the immediate footprint of the installation. Risk scores in this domain are primarily associated with temporary sediment resuspension during the installation phase and the potential for limited changes in temperature distribution or sediment dynamics at very local scales.

Operational phase effects are generally minor and remain spatially contained. Under standard monitoring and environmental management practices, risks related to leaching of toxins or water quality degradation remain low. At the same time, biofouling communities developing on submerged structures may contribute modestly to nutrient uptake and cycling, for example through filter-feeding organisms such as mussels.

Overall, these interactions remain localised and do not indicate large-scale alteration of regional oceanographic processes or water quality conditions. Impacts are therefore limited in extent and manageable through established practices

Subject Level Patterns

Across biological subject groups, aggregated benefit scores exceed risk scores under the defined deployment assumptions, indicating a generally positive ecological interaction profile.

Benthic organisms exhibit the strongest relative benefit profile. Reduced trawling pressure within operational zones and the introduction of structural substrate support recolonisation, biofouling development, and increased habitat complexity on and around the seabed. Installation-related disturbance contributes to risk scoring, but these effects are temporary and spatially limited.

Fish show a predominance of benefits. Floating infrastructure increases structural complexity and can create reef-like habitat conditions that attract fish and enhance local biomass. Operational exclusion from certain fishing activities may further support local refuge effects. Risks are primarily associated with temporary disturbance during installation and potential aggregation effects around the structures.

Birds also display positive impact scores. Floating infrastructure can provide resting or roosting opportunities and may indirectly attract prey species through local ecological aggregation effects. Potential risks relate mainly to behavioural disturbance or interaction with structures, but these effects remain limited in scale and do not dominate the overall scoring profile.

Planktonic organisms are influenced primarily by shading and localised changes in water mixing beneath the floating platforms. Reduced light availability directly under the structures contributes to moderate risk scores, while associated changes in turbidity and nutrient recycling may provide modest localised benefits in adjacent areas.

Marine mammals show a balanced and positive interaction profile. Floating platforms may provide temporary haul-out opportunities or areas of increased prey availability, while risks are mainly associated with installation noise and vessel activity. During the operational phase, interaction pathways are generally limited and of lower intensity.

Strength of Evidence

The explicit scoring of certainty ensures that areas supported by robust empirical evidence are clearly distinguished from interactions that remain context-dependent or less extensively studied. Overall certainty scores are moderate to high across the assessed domains, reflecting a growing but still evolving evidence base for the ecological interactions associated with floating offshore infrastructure. Higher certainty is associated with well-documented mechanisms such as biofouling development, habitat complexity effects, and trawling exclusion benefits for benthic communities. Lower certainty occurs in domains influenced by site-specific oceanographic conditions, such as planktonic responses to shading or local hydrodynamic changes. Overall, the scoring reflects a robust understanding of the main ecological pathways while acknowledging that some interactions remain context dependent and may vary with location, design, and operational practices.

Alignment with Ocean Impact Metrics and SDGs

To translate ecological findings into investment-relevant language, this assessment aligns its results with the **Ocean Impact Navigator**, developed by 1000 Ocean Startups[4]. The Navigator provides a structured framework for measuring and reporting ocean-related impact across natural capital, climate, and socio-economic dimensions and is increasingly used by ocean impact investors, blended finance vehicles, development finance institutions, and regulators.

Aligning the NEBA findings with this framework enables the ecological profile of offshore solar to be evaluated using **recognised ocean impact metrics** that guide capital allocation and impact reporting in the blue economy. The strongest alignment occurs with **three Navigator indicators** (Figure 6):

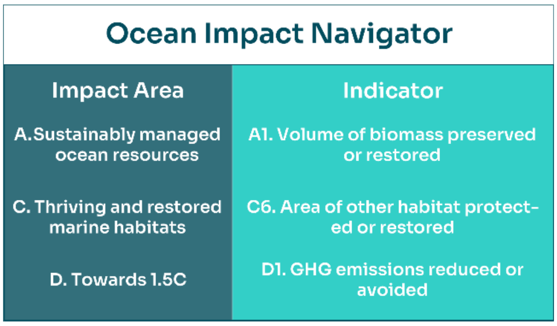
Area of other habitat protected or restored

Reduced seabed disturbance underneath the solar farm creates a defined area in which bottom-contact activities and physical disruption are significantly reduced over the lifetime of the installation. This provides a measurable and time-bound basis for reporting habitat protection within marine investment portfolios.

Volume of biomass preserved or restored

Structural habitat creation and reduced seabed disturbance can support benthic recolonisation and the development of biofouling communities. In some contexts, floating infrastructure may facilitate the formation of mussel or oyster aggregations, increasing benthic biomass and strengthening ecosystem functioning. These organisms also store carbon in calcium carbonate shells, providing an additional pathway for long-term carbon storage.

Importantly, parts of this habitat enhancement may persist beyond the operational lifetime of the installation. Unlike some offshore energy technologies where seabed protection structures are removed during decommissioning, benthic habitat that develops around floating solar infrastructure may remain after removal, supporting durable ecological benefits.



Ocean Impact Navigator

Impact Area	Indicator
A. Sustainably managed ocean resources	A1. Volume of biomass preserved or restored
C. Thriving and restored marine habitats	C6. Area of other habitat protected or restored
D. Towards 1.5C	D1. GHG emissions reduced or avoided

Figure 6 | Alignment of offshore solar with ocean impact areas and indicators defined in the Ocean Impact Navigator by 1000 Ocean Startups[4].

Figure 7 | Sustainable Development Goals (SDGs) aligned with offshore solar deployment.

Greenhouse gas emissions reduced or avoided

Renewable electricity generation from offshore solar contributes directly to climate mitigation by displacing fossil fuel-based electricity generation. Photovoltaic systems can also achieve higher efficiency in cooler marine environments, with higher energy yields for offshore solar compared to land-based installations.

From a **Sustainable Development Goal (SDG)** perspective, offshore solar contributes across several key objectives (Figure 7).

Most directly, it supports **SDG 7 (Affordable and Clean Energy)** by expanding renewable electricity capacity in coastal and offshore environments, particularly where land availability is constrained.

Climate mitigation benefits align with **SDG 13 (Climate Action)**, through the displacement of fossil fuel-based electricity and associated reductions in greenhouse gas emissions.

The ecological findings of this assessment support alignment with **SDG 14 (Life Below Water)**, particularly through reduced seabed disturbance, structural habitat creation, and the potential enhancement of benthic ecosystems.

Beyond environmental outcomes, offshore solar can also contribute to **SDG 8 (Decent**

Work and Economic Growth) and **SDG 9 (Industry, Innovation and Infrastructure)**, through the development of offshore renewable supply chains, marine engineering capabilities, and resilient coastal energy infrastructure.

Taken together, offshore solar demonstrates a dual alignment with climate mitigation and marine stewardship objectives. The structured NEBA framework strengthens this alignment by grounding sustainability claims in measurable ecological pathways and recognised ocean impact metrics that are increasingly used in impact reporting and sustainable finance frameworks.

Spatial Efficiency and the 30×30 Ocean Target

The global 30×30 target aims to conserve at least 30% of marine and coastal areas by 2030 (CBD, 2022). Increasing the energy output of already allocated offshore energy zones is therefore an important pathway for expanding renewable energy without placing additional pressure on marine space.

Co-locating offshore solar within offshore wind farms offers a highly space-efficient solution. Offshore solar can achieve power densities of 100–200 MW/km², compared to ~5–10 MW/km² for offshore wind, due to turbine spacing constraints[8,9]. As a result, allocating only a small fraction of wind farm area to solar can add generation capacity comparable to the wind farm itself[10–12]. This approach can effectively double installed capacity while leveraging existing infrastructure and grid connections[13], permitting frameworks, as well as governance regimes.

By increasing renewable energy output per unit of ocean space, co-located offshore solar can support both energy system expansion and marine conservation objectives, aligning renewable deployment with broader ocean governance strategies.

Capital and Regulatory Implications

For investors and regulators, the relevance of the NEBA framework is practical. It translates offshore solar's ocean interaction profile into a **decision-ready balance** of downside risk, reportable impact, and monitoring requirements. Across the assessed configuration, ecological risks are predominantly local in extent, moderate in intensity, and frequently reversible. At the same time, several benefit-related processes, particularly reduced seabed disturbance and structural habitat formation, persist throughout the operational lifetime of the installation.

The framework distinguishes clearly between **installation-phase effects** and **operational-phase interactions**. Construction-related disturbance, including sediment resuspension and installation noise, is time-bound and manageable through established mitigation and monitoring practices. Operational interactions are characterised by ongoing local ecological processes, including reduced seabed disturbance within safety zones and the creation of reef-like structures that provide habitat for marine organisms.

This distinction is important for both regulatory design and capital allocation. **Time-limited construction risks** can be addressed through targeted permitting conditions, while **longer-term operational interactions** form part of the project's **ecological contribution**. Investors gain confidence from knowing that most risks are localised and manageable, while several ecological benefits persist throughout the project lifetime.

In particular, reduced seabed disturbance and structural habitat formation are structurally embedded in the project design. By limiting bottom-contact activities within operational zones, floating solar installations create areas where physical disturbance is reduced over extended periods. Similar mechanisms are observed in Marine Protected Areas, where reduced disturbance can support ecosystem recovery and spillover effects into surrounding waters.

The domain- and subject-level assessment also enables targeted regulatory focus. Seabed and benthic interactions are primarily driven by disturbance reduction and habitat development, supporting long-term ecosystem recovery. By contrast, bird and marine mammal interactions are more closely linked to installation activities and site conditions, allowing for targeted mitigation and monitoring.

The explicit treatment of certainty further strengthens transparency. Effects supported by stronger evidence can inform stable, reportable impact metrics, while areas of lower certainty can be addressed through adaptive monitoring as projects scale.

Capital markets are increasingly integrating biodiversity frameworks, sustainable finance taxonomies, and ocean impact metrics into investment decision-making[1,7]. As a result, **infrastructure capable of demonstrating both climate and nature-positive outcomes is gaining strategic relevance**. The growing integration of ocean-related sustainability metrics into sustainable finance taxonomies and biodiversity reporting frameworks may further increase the attractiveness of infrastructure capable of delivering measurable ocean outcomes for blended finance, development finance, and sustainability-linked investment structures. Offshore solar should therefore be evaluated not only as renewable energy capacity, but as **marine-interacting infrastructure capable of delivering measurable climate mitigation benefits while contributing to defined ocean impact outcomes**.

Taken together, the NEBA results support evaluation of offshore solar through both a stewardship and risk-management lens, enabling responsible scaling within defined ecological constraints while providing the clarity increasingly required by capital providers and permitting authorities[1,7].

Societal Co-Use and Marine Spatial Integration

Beyond ecological interactions, offshore solar represents a spatial intervention within a multi use marine environment[2]. As the technology scales, it has the **potential to become the next major step in renewable energy deployment**, building on offshore wind while reshaping how marine space is used and governed through co-location and multiple-use approaches.

Floating solar installations introduce clearly defined operational areas and safety zones in which certain activities are restricted while others remain compatible. This spatial clarity is central to both governance and investment considerations, as it defines how projects interact with other ocean users.

One important integration pathway is **co-location with existing offshore wind farms**. Deploying offshore solar within established wind farm zones can reduce additional space claims at sea while leveraging existing infrastructure, access regimes and marine spatial planning frameworks.

Operational safety zones typically restrict bottom contact fishing within the installation footprint. While this reduces local seabed disturbance, fishing effort may shift to adjacent areas depending on site conditions and fishing intensity. Early coordination with fisheries authorities and stakeholders is therefore important to manage redistribution of activity and minimise conflict.

At the same time, floating infrastructure can create ecological conditions that support fisheries opportunities. Structures may function as artificial habitat, attracting fish and increasing local biomass. Where fishing pressure is reduced within operational zones, these areas may also act as **partial refuges with potential spillover effects** into surrounding waters under suitable conditions.

Biofouling communities that develop on submerged structures, including mussels and other filter feeding organisms, may further influence local ecosystem dynamics. In some contexts, this may support compatible passive fisheries or aquaculture activities such as crab or lobster pots or small-scale sea ranching concepts, subject to safety, permitting and ecological safeguards.

Navigation and shipping considerations represent another key spatial factor. Floating solar installations must avoid interference with established shipping routes and safety corridors. Where appropriately sited, the physical footprint remains predictable and manageable within existing maritime governance frameworks. In offshore wind zones where access is already controlled, co-located floating solar can often be integrated without introducing entirely new regulatory regimes.

More broadly, floating solar **contributes to evolving models of marine spatial governance**. Operational zones introduce areas of modified use intensity that interact with conservation areas, offshore wind development, fisheries and other ocean activities. These interactions require coordination but remain compatible with existing marine spatial planning approaches.

From an investment perspective, the key implication is **spatial predictability**. Offshore solar occupies clearly bounded areas, operates under defined regulatory regimes and interacts with other ocean users in identifiable ways, supporting permitting clarity and reducing regulatory uncertainty.

Offshore solar should therefore be understood not only as renewable energy infrastructure but as a **governed component of the broader ocean economy**. When carefully planned, it can support **multiple use spatial strategies** by combining renewable energy generation with compatible ocean activities while maintaining clear operational boundaries and transparent management of trade-offs.

Conclusion

This assessment applied a structured Net Environmental Benefit Analysis (**NEBA**) framework to evaluate offshore solar through **a comparative lens of ecological risks and ecological gains**. Unlike conventional environmental assessments that focus primarily on potential harm, the NEBA approach provides a broader perspective by examining how infrastructure interacts with marine ecosystems as a whole.

The results indicate that offshore solar introduces identifiable and manageable risks that are predominantly local in scale, concentrated during installation, and frequently reversible. At the same time, the technology generates measurable ecological benefits beyond renewable electricity generation. Reduced seabed disturbance within operational zones and the presence of structural habitat create persistent ecological interactions throughout the project lifetime. Across all ecological subject groups assessed, **aggregated benefit scores exceed risk scores** under the defined deployment assumptions.

This **dual profile delivering clean electricity while generating measurable ocean impact** is increasingly relevant for capital allocation. The NEBA framework enables transparent evaluation of both environmental exposure and ecological contribution by structuring impacts across scale, duration, reversibility and certainty. This supports clearer due diligence, credible sustainability reporting, and proportionate regulatory oversight.

The analysis also highlights the role of marine spatial integration. Co-location with offshore wind farms and other multiple use approaches **can increase renewable energy output per unit of ocean space** while limiting additional spatial claims at sea.

When evaluated through a structured net environmental lens, offshore solar emerges not only as a renewable technology, but as marine infrastructure capable of advancing climate mitigation while contributing to measurable ocean ecosystem outcomes.

Key Takeaways

- **Scalable climate and blue economy infrastructure.** Offshore solar combines large scale renewable electricity generation with measurable ocean impact outcomes, positioning it as infrastructure aligned with emerging climate, biodiversity, and blue economy investment frameworks.
- **Positive interaction with marine ecosystems.** Project areas reduce seabed disturbance and can create conditions that support marine life. Overall, the assessment finds that ecological benefits outweigh risks.
- **Manageable environmental risk profile.** Ecological risks are predominantly local, concentrated during installation, and frequently reversible under established mitigation and monitoring practices.

References

1. WEF. *The Ocean Economy Imperative: Defining Value, Managing Risk and Mobilizing Investment*. https://reports.weforum.org/docs/WEF_Ocean_Economy_Imperative_2026.pdf (2026).
2. OECD. *The Ocean Economy to 2050*. https://www.oecd.org/en/publications/the-ocean-economy-to-2050_a9096fb1-en.html (2025).
3. Wen, Y., Wu, J., Lin, P. & Low, Y. M. The role of offshore wind and solar PV resources in global low-carbon transition. *Sci. Adv.* **11**, 5580 (2025).
4. WEF. *The Ocean Impact Navigator - A New Impact Measurement Framework For The Ocean Innovation Ecosystem*. https://www.1000oceanstartups.org/navigator (2023).
5. Glasson, J., Therivel, R. & Chadwick, A. *Introduction to Environmental Impact Assessment*. (Routledge, London, 2012).
6. Egger, M. *et al.* Evaluating the environmental impact of cleaning the North Pacific Garbage Patch. *Sci. Rep.* **15**, (2025).
7. UNEP. *Ocean Investment Protocol*. (2025).
8. Meit, J., Amato, J. C. S. & Vlaswinkel, B. Offshore Solar in High Seas - Assessment of Resource Complementarity for a Case in Malta. in *IET Conference Proceedings* vol. 2023 24–30 (Institution of Engineering and Technology, 2023).
9. Vlaswinkel, B., Roos, P. & Nelissen, M. Environmental Observations at the First Offshore Solar Farm in the North Sea. *Sustainability* **15**, (2023).
10. Jin, Y. *et al.* Geographically constrained resource potential of integrating floating photovoltaics in global existing offshore wind farms. *Advances in Applied Energy* **13**, (2024).
11. AERO. *Position Paper: The Offshore Floating Solar for Italy*. (2025).
12. López, M., Rodríguez, N. & Iglesias, G. Combined floating offshore wind and solar PV. *J. Mar. Sci. Eng.* **8**, (2020).
13. Golroodbari, S. Z. M. *et al.* Pooling the cable: A techno-economic feasibility study of integrating offshore floating photovoltaic solar technology within an offshore wind park. *Solar Energy* **219**, 65–74 (2021).