

Article

Balancing Offshore Wind Energy Development and Fishery Community Well-Being in Taiwan: A Life Cycle Sustainability Assessment Approach

Wen-Hsiang Liu

Department of Land Economics, National Chengchi University, No. 64, Sec. 2, Zhinan Rd., Wenshan District, Taipei 116011, Taiwan; tonyliu11106@gmail.com

Abstract: Taiwan has been actively advancing offshore wind energy, with significant progress in deep-sea and large-scale turbine development. However, this growth poses challenges to coastal fishery communities, particularly regarding the protection of fishery rights and livelihoods. This study employs the Life Cycle Sustainability Assessment (LCSA) framework to evaluate the impact of offshore wind farm (OWF) on fishery rights in Taiwan. Through an extensive literature review, we identify key indicators influencing fishery rights within the OWF context. To ensure a comprehensive analysis, expert surveys from diverse fields provide additional insights into these impacts. By aligning our findings with international frameworks, the International Finance Corporation (IFC) Performance Standards (PS) and the Equator Principles (EP), this research underscores the significance of integrating both local concerns and global standards in OWF development. In the lifecycle of long-term, large-scale OWF projects, PS1 of the IFC PS is the most widely applicable standard, whereas P2, P4, P5 and P9 of the EP plays a central role in ensuring compliance and operational efficiency. This study uniquely integrates local fishery rights into global frameworks, bridging regional socio-economic concerns with international sustainability standards—a novel approach to balancing offshore wind development with community interests. Ultimately, this research emphasizes the importance of balancing renewable energy advancement with the preservation of fishery rights.



Academic Editor: Marc A. Rosen

Received: 8 February 2025

Revised: 1 March 2025

Accepted: 14 March 2025

Published: 27 March 2025

Citation: Liu, W.-H. Balancing Offshore Wind Energy Development and Fishery Community Well-Being in Taiwan: A Life Cycle Sustainability Assessment Approach. *Sustainability* **2025**, *17*, 2980. <https://doi.org/10.3390/su17072980>

Copyright: © 2025 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Keywords: LCSA; offshore wind; fishery rights; renewable energy; international finance corporation standards; equator principles

1. Introduction

1.1. Background of Development in Offshore Wind

In 2021, the United Nations Climate Change Conference (COP26) was held in Glasgow, Scotland. Key commitments included phasing out fossil fuels and reducing methane emissions by 30% by 2030. The reality of climate change and the energy crisis has led many countries to turn their attention to developing renewable energy. Wind is one of the cleanest energy sources and currently the largest renewable energy in the market [1,2]. On 19 November 2020, the European Commission released a long-term strategy for offshore wind energy, setting ambitious goals: 60 GWp offshore wind farm (OWF) should be installed by 2030 and 300 GWp by 2050 [3]. Wind energy has fewer restrictions on land use, while competition for marine space is relatively greater [4]. Onshore wind farms are becoming increasingly saturated, and offshore areas also face the challenge of having insufficient traditional wind (near-coastal) sites. The trend of wind energy development

is from the coast to the coast and then to the deeper areas of the sea [4,5]. Offshore wind technology includes traditional fixed foundation wind turbine technology and emerging floating wind technology [6]. Offshore energy developments also raise concerns about competition for access to resources and can lead to conflicts between existing (e.g., fishing) [7]. Taiwan is densely populated with limited land for the construction of energy plants and limited environmental carrying capacity. However, the development of rich offshore wind resources in the Taiwan Strait is one of the best wind farms in the world [8]. Taiwan National Development Council also launched the “Taiwan 2050 Net-Zero Emission Path and Strategy” in 2022, which increases the renewable energy capacity target from 20% in 2025 to 60% or more in 2050, mainly relying on wind and solar energy. Moreover, Taiwan is gradually establishing the vigorous development of offshore wind energy, moving toward floating and large-scale units [9,10].

1.2. The Impact of Offshore Wind Farm on Fishery Rights

Taiwan government revised the Renewable Energy Development Act, widens the limit of usage rights over ocean spaces, thereby expanding the scope for offshore wind energy projects beyond the traditional territorial boundaries [11]. (According to Taiwan’s Fisheries Act, fishing refers to the industry involved in the capture or cultivation of aquatic plants and animals, along with its associated processing and marketing sectors [12]. The concept of fishing rights discussed here further refers to the direct or indirect impacts on coastal communities, marine fishers, and related industries throughout the life cycle of offshore wind farm.) As this extension of usage rights over broader ocean areas progresses, it brings to the forefront a complex issue of legal rights, ownership, and usage claims. Addressing these concerns becomes increasingly challenging, as there is still a lack of relevant laws, regulations, and experience in managing relationships among various stakeholders [13]. Taiwan has 126,055 fishing households and 319,783 people employed in the fishery industry. Offshore fishery production accounts for more than half of the total annual fishery yield, with 475,111 out of 874,696 metric tons. Coastal fishery production also accounts for about 13%. Non-inland fishery production accounts for about 70% [14]. Taiwan’s fisheries are mainly marine fisheries, and changes in the use of marine rights are almost inevitable to affect Taiwan’s fisheries. The land development model is being applied to the ocean, and marine space is showing a gradual occupancy trend [15]. The development of renewable energy, such as wind energy, triggers complex economic and social changes, making land a focal point of controversy due to the demand for and nature of land use [16]. Weak land tenure systems and regulations tend to favor renewable energy project developers rather than developing communities [4]. Offshore wind development is a multiple intersection of energy generation, fishing, and conservation needs [17]. The use of marine space involves many stakeholders. Wind farms are not the only consideration in marine space, and expanding new energy sources will affect interactions with existing spaces [18,19]. Fishermen, who are also mostly coastal residents, are one of the core stakeholders in OWF. The siting of wind projects typically hinders fishing activities previously carried out in prime fishing grounds [15,20]. Whether offshore wind interferes with fishing is a major concern for fishermen [21]. Fishing closures in wind farms will result in fishing losses and will almost certainly lead to the displacement of fishing activities [22]. All fishermen see their livelihoods threatened by fishing closures around OWF [23]. The development of offshore wind farms in Taiwan has already triggered the most intense conflicts among coastal residents and fishermen [15].

1.3. Life Cycle Stages of Offshore Wind Farm in Taiwan

The life cycle of OWF in Taiwan can be divided into four main stages: development, construction, operation and maintenance, and decommissioning (see Figure 1) (Figure 1 illustrates all life cycle stages of OWF projects, including their duration and the critical milestones for obtaining necessary permits. It is important to note that the sub-stages within each main stage are not strictly delineated, which is why the progress bars for sub-stages do not align precisely with the boundaries of the four primary stages). The development stage, which typically lasts three to five years, serves as a critical starting point for wind farm construction, encompassing technical, economic, and social planning and coordination. Initially, developers must obtain approval and complete the Environmental Impact Assessment (EIA), a process that typically takes around two years. Following this, they engage in competitive bidding processes to secure development rights. Subsequently, they apply for construction and associated permits, requiring an additional two years. In addition, developers are required to conduct geological, wind and meteorological surveys while simultaneously preparing detailed design timelines, a phase that can take between two and three years. More importantly, they must also develop equity financing and project financing plans to ensure financial feasibility. Besides, according to Taiwanese government regulations, developers must reach compensation agreements with local fishers before construction begins. These agreements cover economic benefit planning, fishery compensation, and benefit distribution throughout the wind farm's life cycle. Given the complexity of assessing fishery losses and allocating compensation resources, achieving a fair and scientifically-based resolution poses significant challenges for developers.

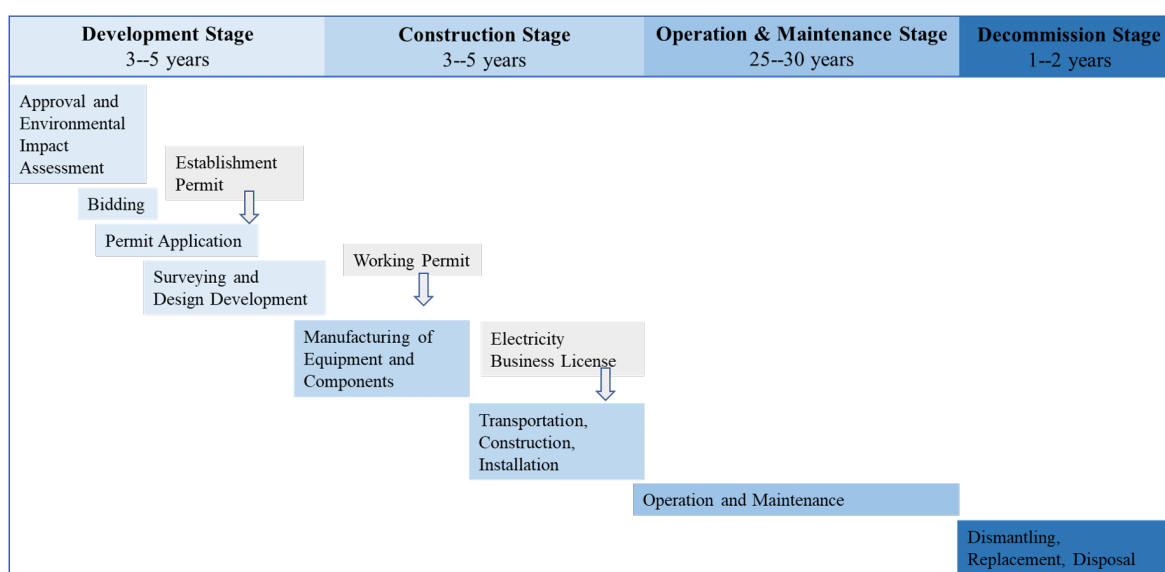


Figure 1. Life cycle of OWF stages.

The construction stage, typically lasting three to five years, involves the manufacturing of equipment and components, which takes about two to three years, as well as transportation, construction, and installation, also requiring approximately two to three years. This stage encompasses multi-dimensional engineering activities on land and at sea. Onshore activities include constructing substations and laying underground cables to connect to the power grid. Nearshore activities involve building offshore substations and installing subsea cables, while offshore activities require constructing underwater foundations and transporting and installing wind turbines. These operations may impact the surrounding environment and alter local fishing practices, necessitating appropriate mitigation strategies to minimize adverse effects.

The operation and maintenance stage is the longest in the wind farm life cycle, typically lasting 25 to 30 years, and involves routine operations, periodic maintenance, and ocean weather monitoring. This stage begins with initial trial operations and transitions into formal commercial operations. To support fishery communities, developers may enhance local benefits through initiatives such as artificial reef projects or community support programs. Additionally, continuous monitoring and evaluation of the wind farm's impact on fishery resources and ecosystems are essential to achieve the dual goals of sustainable energy production and ecological conservation.

Finally, the decommissioning stage occurs when the equipment reaches the end of its life cycle and involves the dismantling, replacement, and proper disposal of turbines and associated infrastructure. In stark contrast to the decades-long operation and maintenance phases, this stage is typically completed within 2 years, making it a rapid yet critical process. However, despite its short duration, decommissioning requires careful evaluation of its impacts on surrounding fisheries and ecosystems, alongside the development of targeted mitigation and restoration plans. Overall, the life cycle of OWF in Taiwan is highly complex, necessitating multi-stakeholder negotiation and benefit reconciliation to balance energy development, ecological protection, and fishery community well-being, ultimately contributing to comprehensive sustainable development goals.

2. Methodology

2.1. Life Cycle Sustainability Assessment

Life Cycle Sustainability Assessment (LCSA) is an analysis of the overall three benefits of an industry within a regional scope. It integrates the environmental, economic, and social aspects of a product, system, or technology to assess its sustainability. LCSA assesses a project from raw material extraction to end-of-life disposal, i.e., “from cradle to grave” [24]. Life Cycle Assessment (LCA) is the only internationally standardized environmental assessment method. ISO 14040:2006 [25] provides a complete technical framework for LCA. Since the ISO 14040 standards were introduced, research output on environmental LCA has rapidly increased, and LCA methodology has continually evolved and matured over decades. Life Cycle Costing LCC considers the costs across the entire life cycle of a product for all relevant stakeholders, including suppliers, manufacturers, consumers, and end-of-life disposal. In developed countries, the demand for LCC is increasing in both public and private sectors. It is widely applied to assess the total costs of large infrastructure projects. Social Life Cycle Assessment (SLCA) is a technique to assess social impacts and potential impacts considering stakeholders that may be directly or indirectly affected by social and socioeconomic aspects over a product or service life cycle. Theoretically, SLCA can be applied to any product or service. Like LCC, SLCA does not have an international standard like ISO 14040 for LCA. However, the UNEP/SETAC Life Cycle Initiative’s “Guidelines for Social Life Cycle Assessment of Products” serves as the most widely used guidance, representing a developed standard [26–30].

$$LCSA = LCA + LCC + SLCA, \quad (1)$$

Our scope is to apply LCSA methodology to evaluate the sustainability of OWF development in Taiwan, focusing on the three dimensions: environmental, economic, and social. Specifically, the study seeks to uncover the key elements that influence the relationship between OWF development and the protection of fishery rights. Our goal is to provide a comprehensive, internationally aligned understanding of how offshore wind energy projects interact with fishery rights. The study emphasizes the coexistence of humanitarian values and sustainable development, ensuring that OWF projects are not only efficient and environmentally responsible but also respectful of local communities’ well-being.

2.2. Criteria for Indicators Selection

Taiwan's offshore wind energy projects lack a comprehensive analysis of evaluation indicators in the existing literature. To address this gap, we refer to research on life cycle methods in the fields of renewable energy and large-scale construction projects, drawn from international journals [31–40]. We systematically organize and summarize these studies, as detailed in Table 1, to provide a structured foundation for our analysis. The selection of criteria and indicators for evaluating the sustainability of OWF requires a comprehensive approach that considers environmental, economic, and social dimensions. By integrating the findings from international research, we ensure that the LCSA methodology can provide a balanced and holistic evaluation of the sustainability of OWF projects in Taiwan. This methodology enables decision-makers to evaluate the complex interplay between offshore wind energy development and the protection of fisheries, ensuring that energy development is aligned with sustainable resource management and community well-being.

To identify the most relevant sustainability indicators, this study conducts a survey based on existing literature. Indicators that meet a predefined consensus threshold are selected for evaluation. The most common definition for consensus was percent agreement, with 75% being the median threshold to define consensus, as reported in 25 studies [41]. In some studies, participants were required to reach at least 80% agreement to fall within the consensus category, which is commonly applied in forecasting or when the topic lacks a clear consensus [42]. For group-level comparisons or research purposes, values of 0.60, 0.70, or 0.80 are often used as minimum standards for reliability coefficients, with values at or above these thresholds considered sufficient [43]. We set the consensus threshold at 80%, ensuring that only indicators with substantial support are included. The survey table is shown in Appendix A. By combining survey and literature, this study provides a rigorous framework for selecting sustainability indicators. This methodology ensures that the chosen criteria accurately reflect community values and serve as a reliable basis for evaluating offshore wind energy projects in Taiwan.

Table 1. LCSA Criteria

Category	Criteria	Authors
Environmental LCA	Resource Depletion	[32,35,39,40]
	Material Recyclability	[37]
	Climate Change	[31–40]
	Emission/Pollution	[31,32,34–37,39,40]
	Wastes	[31,32]
	Land Use	[31,33,34,37,38]
Economic LCC	Efficiency	[33,34,38]
	Levelised Cost	[31,33–35,37–40]
	Capital Cost	[32,35,36,38–40]
	Total Annualised Costs	[35–40]
Social SLCA	Job Creation	[31,32,34,37,38,40]
	Worker Safety	[31,32,39,40]
	Society Acceptance	[32,39]
	Energy Security	[34,37–40]
	Human Health	[31,32,37–39]

2.3. International Standards

Our approach involves incorporating an analysis of the relationship between the final indicators and the standards established by the International Finance Corporation (IFC) and the Equator Principles (EP). Specifically, after completing the refinement of the indicators through LCSA and literature review, we then assess which indicators align

with the IFC and EP standards. This is crucial for three main reasons: first, as outlined in the introduction, ensuring financial feasibility during the development stage requires the formulation of equity financing and project financing plans; second, these projects, particularly in Taiwan, often involve collaboration with international companies, making adherence to global financing standards essential; third, both the IFC and the EP themselves are aligned with sustainability principles, reinforcing the need for these standards in the context of OWF projects.

Due to the large scale of the OWF, construction costs are quite high and require significant investment. Project financing relies on the project's own generated cash flow as a repayment source and collateral for creditors. It usually involves multi-party cooperation and risk sharing. As a borrower in project financing, the developer must submit reports that meet the sustainability standards of the IFC and the EP to demonstrate that the project follows environmental and social sustainability and effectively manages environmental and social risks. This is critical to gaining the trust and support of financial institutions, which act as lenders in project financing.

IFC is a member of the World Bank Group and is responsible for promoting investment and development from the private sector in developing countries. Currently, the 2012 version of the IFC Performance Standards is the latest and most widely used version by IFC and other financial institutions that have adopted the EP. The IFC Performance Standards include eight standards that cover different aspects of environmental and social sustainability. The Equator Principles (EP) consist of 10 principles that form a voluntary risk management framework adopted by financial institutions to identify, assess, and manage environmental and social risks in project financing. For OWF, a Supplemental Lender Information Package (SLIP) is required to address the significant gaps between the project's Environmental Impact Assessment (EIA) and the requirements set by Equator Principles Financial Institutions (EPFI). The EP applies to all projects financed by EPFI, irrespective of their sector, location, or size.

3. Results

3.1. Environmental Dimensions

Our results regarding the environmental dimension are summarized in Table 2 below. The construction of OWF, which involves the installation of turbines, platforms, cables, and related infrastructure, consumes significant resources such as metals, minerals, and fossil fuels. The resource depletion indicator measures the abiotic energy consumption associated with these activities, including the extraction and use of natural resources. This indicator is relevant as the use of local resources during the construction phase may affect the availability of resources critical to the fishing industry. If recyclable or environmentally friendly materials are used in this process, it is a positive benefit. The selection of abiotic energy consumption and use of recyclable or environmentally friendly materials as indicators is closely related to fishery rights, as both influence the sustainability of marine ecosystems that fishers depend on. The Climate Change indicator, we simplify the impact by measuring the core positive benefit of this project in terms of the potential reduction in carbon dioxide (CO₂) emissions. It reflects how OWF help mitigate global warming. This reduction supports both human livelihoods and the sustainability of fisheries by preserving marine ecosystems, thereby protecting the living rights of fishing communities. Although we assume that the OWF brings positive benefits to Taiwan's energy and climate, we cannot ignore the environmental pollution generated by the project because it produces green energy. As mentioned earlier, OWF includes not only offshore wind turbines but also factories or equipment for transmission and processing. First, large wind turbines have an impact on the marine environment. The shading of sunlight in the marine area by the wind

turbine platforms, the destruction of marine topsoil by fixed wind turbines, noise pollution, and the discharge of pollutants, etc., can cause ecological damage to marine life. The areas selected for wind farm are also fishing areas, and the fish caught there reach human tables, which may also have biological toxicity to humans. The submarine cables and onshore factories along the coast also change the coastal environment to some extent. This is why in our indicators, we select the measurement of pollution such as acidification potential, eutrophication potential, human toxicity potential, marine aquatic ecotoxicity potential, and terrestrial ecotoxicity potential. Another criticism of wind turbines is noise pollution. To some extent, offshore wind turbines may have less noise pollution impact on humans, but the noise generated still has an impact on coastal residents, surrounding organisms, or possibly passing vessels. In addition, OWF may also generate a certain amount of solid waste, causing marine pollution. These indicators not only measure environmental health but also assess the economic and social dimensions of the project, including the living conditions, livelihoods, and rights of fishermen, as well as the broader impacts on industries such as tourism and coastal economies. By evaluating these impacts, we can better understand how the OWF might influence the sustainability of marine resources, disrupt local economies, and affect the livelihoods of those dependent on fishing and other coastal industries. The last indicator is the amount of land use, which is the land (land is not limited to onshore land but also includes marine space) occupied and used due to the OWF, involving not only the ocean but also the seabed and the coast. In addition to wind turbines and wind turbine platforms, cables, factories, etc. are also needed to work together to ultimately convert wind energy and deliver electricity. Land space is the carrier of intersecting interests of human activities, and its use may lead to conflicts over legal rights. These conflicts can arise over questions of who owns and controls the sea—whether it belongs to the state, private developers, or fishing communities. Such disputes can particularly affect fishery rights and developer land use rights, as the areas occupied by the OWF may overlap with established fishing zones. These legal conflicts may impact the livelihoods of fishermen, the sustainability of fishing activities, and the rights of developers, requiring careful consideration and management of competing interests.

Thus far, all indicators of LCA appear to be closely linked to Performance Standard 1 (PS1): Assessment and Management of Environmental and Social Risks and Impacts. PS1 requires relevant personnel to identify, assess, and manage the environmental and social risks and impacts of their projects. This entails developing a system to manage these risks and impacts and engaging with stakeholders throughout the project lifecycle. Similarly, the guidance provided in PS3 (Resource Efficiency and Pollution Prevention) regarding the effective utilization of resources, pollution prevention, use of clean technologies, waste reduction, and conservation of water and energy aligns well with LCA principles. Furthermore, the handling of land use specified in PS5 (Land Acquisition and Involuntary Resettlement) corresponds to our land indicators. PS6 (Biodiversity Conservation and Sustainable Management of Living Natural Resources) directs projects to protect biodiversity and manage living natural resources sustainably, minimizing adverse impacts on biodiversity, which resonates with concerns addressed in the Resource depletion and Climate change Emission/Pollution indicators.

The EP provide more procedural guidance, particularly relevant in project assessment. Principle 1 (Review and Categorization) emphasizes that assessment criteria should be categorized by severity and scale, which should be applicable to the assessment results of LCA's Climate change and Emission/Pollution indicators. The content of Principle 2 (Environmental and Social Assessment) underscores the need for financial institutions to exercise thoroughness and prudence in environmental assessments. Principle 4 (Environmental and Social Management System and Equator Principles Action Plan) interlinks both

environmental and social aspects, jointly examining and reporting to address risks. Most environmental indicators of LCA reflect this principle.

Table 2. Environmental Indicators Table.

Issue	Indicators	Units	IFC Performance Standards/Equator Principles
Resource Depletion	Abiotic resource depletion potential (elements)	kg Sb eq./GWh	PS1 PS3 PS6/P2 P4
	Abiotic resource depletion potential (fossil fuels)	MJ/GWh	PS1 PS3 PS6/P2 P4
Material Recyclability	Usage of recycled materials	Point or %	PS1 PS3/P2 P4
	Usage of environmental materials	Point or %	PS1 PS3/P2 P4
Climate Change	Global warming potential	kg CO ₂ eq./GWh	PS1 PS3 PS6/P1 P2 P4
Emission/Pollution	Acidification potential (SO ₂ , NO _x , HCl and NH ₃ etc.)	kg SO ₂ eq./GWh	PS1 PS3 PS6/P1 P2 P4
	Eutrophication potential (N, NO _x , NH ₄ ⁺ , PO ₄ ³⁻ , etc.)	kg PO ₄ eq./GWh	PS1 PS3 PS6/P1 P2 P4
	Human toxicity potential	kg DCB eq./GWh	PS1 PS3 PS6/P1 P2 P4
	Marine aquatic ecotoxicity potential	kg DCB eq./GWh	PS1 PS3 PS6/P1 P2 P4
	Terrestrial ecotoxicity potential	kg DCB eq./GWh	PS1 PS3 PS6/P1 P2 P4
	Noise pollution	Db eq./GWh	PS1 PS3 PS6/P1 P2 P4
Solid Wastes	Solid wastes	m ³	PS1 PS3 PS6/P1 P2 P4
Land Use	Land requirement	km ² /GWh	PS1 PS5/P2 P4

3.2. Economic Dimensions

The results for the economic dimension are summarized in Table 3. The first key indicator for evaluating the performance of OWF is the conversion of input energy to useful output energy, which measures how efficiently wind farms convert wind energy into electricity. The efficiency of an OWF plays a critical role in its economic performance. Higher energy conversion efficiency directly impacts the financial viability of the project by maximizing energy output while minimizing operational costs. The development of a wind farm is a complex and lengthy process, with operating time being a crucial factor. Operating time refers to the period after construction is completed and the wind farm becomes fully operational. It is a key determinant of both the financial and environmental performance of the project, as it defines how long the wind farm can generate electricity and provide a return on investment. Longer operating times lead to higher energy production efficiency and better financial outcomes, making it essential to optimize this phase for maximum performance and sustainability. Taiwan's offshore wind power projects, which require large-scale financing, must effectively balance costs and benefits. We assess both aspects using key indicators commonly discussed in the literature and relevant to our analysis. These indicators include Levelized Cost of Energy (LCOE), capital cost, and total annualized cost. Levelized Cost of Energy (LCOE) provides a comprehensive measure of the per-unit cost of electricity over the project's lifetime, facilitating comparisons between offshore wind power and other energy sources while assessing its economic competitiveness. Capital costs represent the initial investment required and are essential for understanding the financial burden and potential return on investment, especially considering the high upfront costs associated with offshore wind projects. Total annualized costs account for ongoing operational and maintenance expenses, providing insights into the long-term financial sustainability of the project and its ability to remain cost-competitive over time. Financial

Incentives and Assistance, such as subsidies and Renewable Obligation Certificates (ROCs), are crucial for offsetting high initial costs and enhancing the financial viability of the project. These incentives reduce financial risks and improve the competitiveness of offshore wind power. All of these indicators directly influence the economic performance of OWF, which in turn impacts the revenue streams for stakeholders, including investors, developers, and local businesses. Moreover, the economic incentives tied to efficient energy production can have indirect socio-economic effects, potentially influencing local investment patterns and the development of additional wind energy infrastructure. The economic impact on local communities, industries, and employment opportunities is closely linked to the operational efficiency of OWF, underscoring the broader implications for regional development.

Table 3. Criteria and Indicators Table.

Criteria	Indicators	Units	IFC Performance Standards/Equator Principles
Energy Efficiency	Converting Input Energy to Useful Output Energy	GWh	PS1/P1 P2 P5 P7 P8 P9 P10
Immediacy	Operating Time	years	PS1/P1 P2 P3 P5 P7 P8 P9 P10
Cost	Levelised Cost	\$/GWh	PS1/P1 P2 P5 P7 P8 P9 P10
	Capital Cost	\$/GWh	PS1/P1 P2 P5 P7 P8 P9 P10
	Total Annualised Costs	\$/GWh	PS1/P1 P2 P5 P7 P8 P9 P10
Financial Incentives	Financial Incentives and Assistance (e.g., ROCs, taxpayer burdens)	\$/GWh	PS1 PS2 PS7 / P5

PS1 emphasizes that stakeholders should have information exchange throughout the entire project lifecycle. The financial, economic, and operational conditions disclosed by LCC indicators should be transparent and publicly available. This aligns perfectly with the spirit conveyed by EPs' P1–P3. P3 (Applicable Environmental and Social Standards) states that regardless of the project, standards should be consistent with the country, society, industry background, combined with practical situations, and not rigidly applied based on theories or past experiences. P3 is particularly meaningful for offshore wind bidding projects entered by international companies into Taiwan and subsequent process guidance. P5 (Stakeholder Engagement) directly underscores the importance of all stakeholders in the project, including not only government, enterprises, and other industries but also livelihood issues. We should not overlook the voices of fishermen and residents. This also requires adherence to principles such as P7 (Independent Review), P8 (Covenants), P9 (Independent Monitoring and Reporting), and P10 (Reporting and Transparency) in the conduct of various meetings or procedures.

3.3. Social Dimensions

The findings related to the social dimension are presented in Table 4. Taiwan's offshore wind power projects involve multiple stakeholders and carry the vision of solving the energy crisis and mitigating climate change. This project is not only relevant to coastal residents and fishermen but also has various direct or indirect impacts on society as a whole. The first consideration is the contribution of the project to social employment. On one hand, offshore wind power affects fishing operations and has a negative impact on fishermen's livelihoods. But on the other hand, perhaps the related electricity and energy industries can create some jobs. The unemployment rate is an important indicator of social stability, and it is necessary to calculate how many jobs this project creates or loses. In addition, worker safety is also a very important social issue. Our indicators include employee injury frequency and major accident rate. The second issue is social

acceptance, which may require extensive social surveys to achieve. This indicator relates to whether society supports the construction of offshore wind power. Protests that occur due to non-acceptance may ultimately lead to project shutdowns. Social acceptance includes multiple factors, such as aesthetic effects, where coastal wind turbines detract from the aesthetics of the coastline. It could also be the NIMBY effect. Or there may be objections related to land or human rights, etc. From the macro perspective of national energy strategy, offshore wind power projects may have energy security benefits for society. Nuclear, wind, and photovoltaic power generation increase energy security to some extent: for nuclear, this is due to its inherent fuel storage capacity (the energy density is 290 million times that of natural gas), while wind and photovoltaic power reduce fossil fuel import demand by up to 0.2 toe/MWh [37].

Table 4. Social Indicators Table.

Criteria	Indicators	Units	IFC Performance Standards/Equator Principles
Job Creation	Number of jobs directly created	Person-years/GWh	PS1 PS2 PS7/P5
	Number of jobs indirectly created	Person-years/GWh	PS1 PS2 PS7/P5
Health & Safety	Worker injuries	No. of injuries/GWh	PS2/P5 P9
	Severe accidents	No. of fatalities/GWh	PS2/P5 P9
	Human health costs	DALYb/GWh	PS2/P5 P9
Society Acceptance	Residents' satisfaction with the project	Point or %	PS1 PS4 PS5 PS7 PS8/P5 P6 P10
Energy Security	Imported fossil fuel potentially avoided	toe/GWh	PS1/P5 P9

Although SLCA indicators are fewer, they are highly comprehensive. The first indicator, Job creation, is related to PS1, PS2 (Labor and Working Conditions), and PS7 (Indigenous Peoples). Worker safety is more specifically aligned with PS2. The society acceptance indicator may directly relate to the following principles: PS1; PS4 (Community Health, Safety, and Security), which requires clients to protect the health, safety, and security of the communities affected by their projects; PS5, which includes providing fair compensation and assistance to those displaced by the project; PS7 (Indigenous Peoples), which requires respecting the rights and cultures of indigenous peoples, including obtaining their free, prior, and informed consent before undertaking any project that could adversely affect them; PS8 (Cultural Heritage), which requires protecting cultural heritage from the adverse impacts of projects, including identifying and assessing cultural heritage resources and developing measures to avoid or minimize impacts. The energy security indicator incorporates more compliance with PS1.

All SLCA indicators should comply with EPs' P5, P9, which require financial institutions to ensure that independent environmental and social consultants or experts regularly monitor the compliance and performance of each project and report the results to financial institutions and other relevant stakeholders. Safety is an important compliance performance. Society acceptance, to some extent, reflects P6, which requires the establishment of grievance mechanisms that address concerns of affected communities, although relying solely on surveys may not be sufficient. The transparency principle of P10 is a key element of public trust in the project.

4. Conclusions

The comparison Figure 2 highlights that the IFC PS and the EP serve as complementary frameworks for ensuring sustainability in development projects, though they exhibit notable differences in emphasis and application. The IFC PS is more detailed and compre-

hensive, addressing environmental and social issues through its eight standards, which prioritize long-term impacts such as resource depletion, material recyclability, climate change, social acceptance, and biodiversity conservation. Mainly, PS1 has the strongest applicability. On the other hand, EP provide a more pragmatic and streamlined approach, emphasizing financial and operational aspects like cost, financial incentives, and energy security. The EP, primarily guided by its ten principles, often prioritizes immediate and tangible outcomes relevant to financial institutions, such as compliance through P2, P4, P5 and P9. While the EP addresses key sustainability concerns, its application tends to focus more on facilitating due diligence processes and ensuring short- to medium-term accountability, which makes it less comprehensive compared to the IFC PS in addressing broader environmental and societal dimensions.

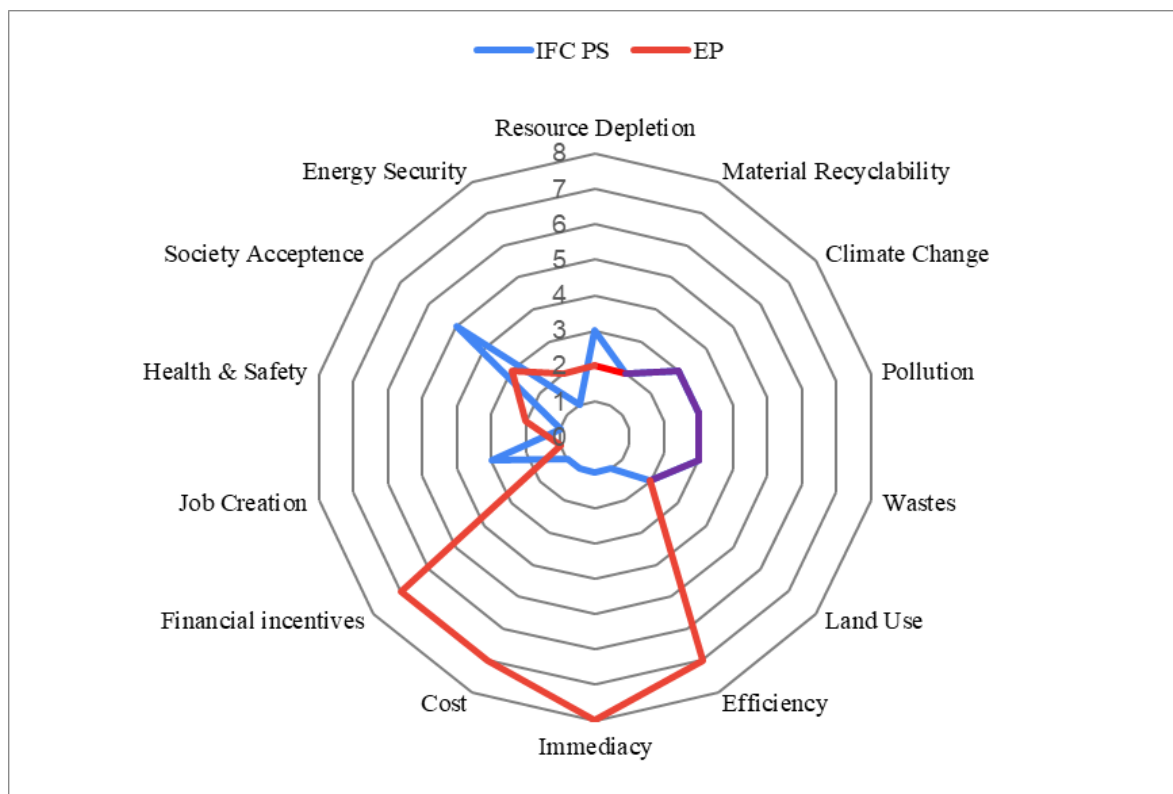


Figure 2. Frequency Comparison Map of IFC Performance Standards and Equator Principles.

In practice, the choice between adopting the IFC PS or EP often depends on the nature of the project and its stakeholders. Projects led by institutions with a strong emphasis on comprehensive sustainability, particularly in developing regions, may lean more toward the IFC PS. Conversely, projects driven by financial institutions seeking operational compliance and risk mitigation may find the EP more aligned with their priorities. Both frameworks are widely adopted globally, but the IFC PS tends to be more influential for projects requiring in-depth environmental and social impact assessments, whereas the EP is more commonly integrated into project finance transactions with a focus on efficiency and immediacy. For large-scale, long-term OWF projects, securing financial support is crucial. This study provides key recommendations based on high-frequency international standards for the government.

The development of OWF represents a critical step toward achieving energy transition and sustainability goals. However, it also presents challenges, particularly for coastal fishery communities and the broader social-ecological system. This study, applying the LCSA framework, reveals the complex impacts of OWF projects across environmental, economic, and social dimensions. Our findings highlight the importance of balancing

renewable energy development with the protection of fishery rights and environmental sustainability. Environmental indicators show that while OWFs contribute to climate change mitigation through reduced carbon emissions, they also cause ecological disruptions, such as habitat alteration and pollution, which can negatively affect marine ecosystems and fishery resources. Economic evaluations underscore the need for operational efficiency and cost management in OWF projects, while also emphasizing the role of financial incentives in enhancing project feasibility. Social indicators emphasize the complex dynamics between societal acceptance, job creation, and potential conflicts over land and resource use.

To sum up, our results are summarized in Figure 3. We have identified key indicators that need to be prioritized when considering fishery rights, and we have outlined international principles that should guide OWF development for better outcomes. We also evaluated how OWF projects can achieve sustainable development across multiple dimensions and provided policy recommendations for decision-makers. Specifically, we offer a comprehensive set of evaluation indicators, rules, and a theoretical framework for global OWF projects. These tools are designed to assist in assessing and balancing the environmental, economic, and social impacts of OWF development, ensuring alignment with both local priorities and global sustainability standards. Policymakers, developers, and stakeholders must collaborate to address the challenges outlined in this study, ensuring that OWFs can serve as a catalyst for a sustainable and equitable energy future in Taiwan. Future research will focus on ongoing OWF projects in Taiwan, utilizing more detailed surveys and score analysis to quantify the positive and negative impacts of each indicator. This will provide a clearer understanding of the extent to which these indicators influence project outcomes, enabling more precise policy recommendations and mitigation strategies.

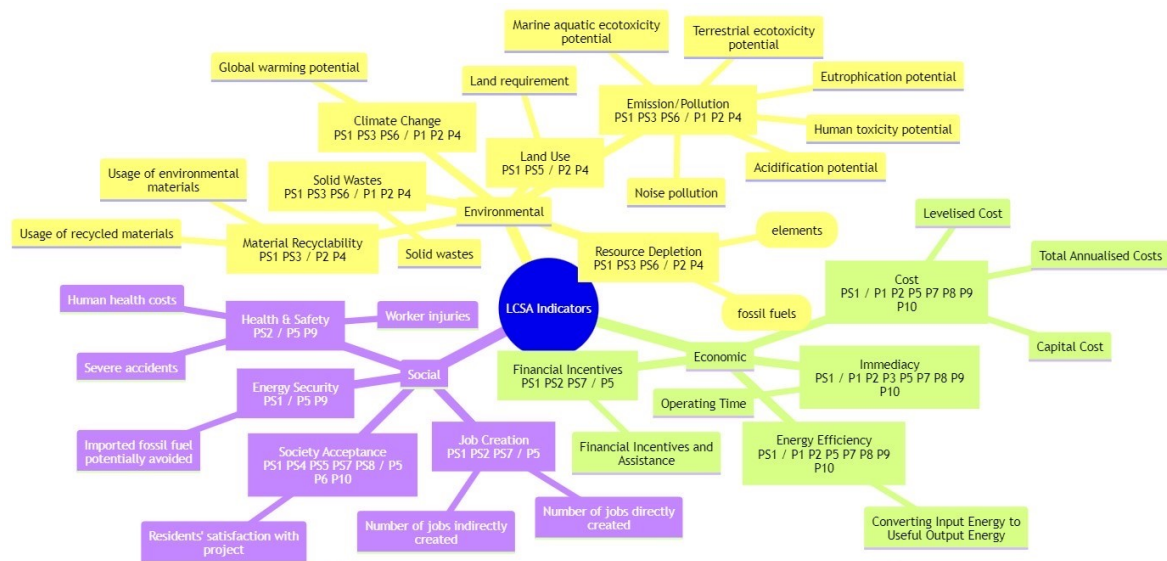


Figure 3. Integrated Impacts with indicators and standards.

Funding: This research received no external funding

Institutional Review Board Statement: This study involved an anonymous survey, in which no personally identifiable information was collected, and participants voluntarily completed the questionnaire. Before starting the survey, all participants were provided with a brief description of the study's purpose, and their consent was implied by their decision to proceed with the questionnaire. No personally identifiable information was collected, and all responses were anonymized. Participation was voluntary, and the study complied with Taiwan's Human Subjects Research Act (HSR Act) and Personal Data Protection Act (PDPA). Ethical approval was not required, as no human subjects, personal data, or identifiable information were involved.

Informed Consent Statement: The data presented in this study are available on request from the corresponding author.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The author declares no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

LCSA	Life Cycle Sustainability Assessment
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
SLCA	Social Life Cycle Assessment
OWF	Offshore Wind Farm
IFC	International Finance Corporation
PS	Performance Standards
EP	Equator Principles
EPFI	Equator Principles Financial Institutions
EIA	Environmental Impact Assessment

Appendix A. Survey Tables

Indicator	PS1	PS2	PS3	PS4	PS5	PS6	PS7	PS8
Abiotic resource depletion potential (elements)	☐	☐	☐	☐	☐	☐	☐	☐
Abiotic resource depletion potential (fossil fuels)	☐	☐	☐	☐	☐	☐	☐	☐
Abiotic resource depletion potential (water)	☐	☐	☐	☐	☐	☐	☐	☐
Usage of recycled materials	☐	☐	☐	☐	☐	☐	☐	☐
Usage of environmental materials	☐	☐	☐	☐	☐	☐	☐	☐
Global warming potential	☐	☐	☐	☐	☐	☐	☐	☐
Acidification potential	☐	☐	☐	☐	☐	☐	☐	☐
Eutrophication potential	☐	☐	☐	☐	☐	☐	☐	☐
Human toxicity potential	☐	☐	☐	☐	☐	☐	☐	☐
Marine aquatic ecotoxicity potential	☐	☐	☐	☐	☐	☐	☐	☐
Terrestrial ecotoxicity potential	☐	☐	☐	☐	☐	☐	☐	☐
Noise pollution	☐	☐	☐	☐	☐	☐	☐	☐
Solid wastes	☐	☐	☐	☐	☐	☐	☐	☐
Land requirement	☐	☐	☐	☐	☐	☐	☐	☐
Energy conversion efficiency	☐	☐	☐	☐	☐	☐	☐	☐
Operating time	☐	☐	☐	☐	☐	☐	☐	☐
Levelised cost	☐	☐	☐	☐	☐	☐	☐	☐
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐
Total annualised costs	☐	☐	☐	☐	☐	☐	☐	☐
Financial incentives and assistance	☐	☐	☐	☐	☐	☐	☐	☐
Number of jobs directly created	☐	☐	☐	☐	☐	☐	☐	☐
Number of jobs indirectly created	☐	☐	☐	☐	☐	☐	☐	☐
Worker injuries	☐	☐	☐	☐	☐	☐	☐	☐
Severe accidents	☐	☐	☐	☐	☐	☐	☐	☐
Human health costs	☐	☐	☐	☐	☐	☐	☐	☐
Residents' satisfaction with the project	☐	☐	☐	☐	☐	☐	☐	☐
Imported fossil fuel potentially avoided	☐	☐	☐	☐	☐	☐	☐	☐

Figure A1. Survey table of IFC Performance Standards.

Indicator	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Abiotic resource depletion potential (elements)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Abiotic resource depletion potential (fossil fuels)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Abiotic resource depletion potential (water)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Usage of recycled materials	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Usage of environmental materials	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Global warming potential	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Acidification potential	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Eutrophication potential	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Human toxicity potential	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Marine aquatic ecotoxicity potential	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Terrestrial ecotoxicity potential	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Noise pollution	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Solid wastes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Land requirement	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Energy conversion efficiency	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Operating time	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Levelised cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Total annualised costs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Financial incentives and assistance	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Number of jobs directly created	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Number of jobs indirectly created	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Worker injuries	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Severe accidents	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Human health costs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Residents' satisfaction with the project	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Imported fossil fuel potentially avoided	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Figure A2. Survey table of Equator Principles.

Indicator	Description
Abiotic resource depletion potential (elements)	This indicator measures the potential depletion of non-renewable elements such as metals used in the project. It is expressed as the equivalent amount of antimony (Sb) per kilowatt-hour (Gwh) of energy produced.
Abiotic resource depletion potential (fossil fuels)	This assesses the depletion of fossil fuels, considering the consumption and potential exhaustion of fossil resources due to the project. The value is expressed in megajoules (MJ) per kilowatt-hour (Gwh) of energy produced.
Abiotic resource depletion potential (water)	This evaluates the water use and scarcity implications associated with the project, measuring the potential depletion of freshwater resources. The value is expressed in 1,4-dichlorobenzene (DCB) equivalents per Gwh of energy produced.
Usage of recycled materials	This indicates the proportion of materials used in the project that are made from recycled sources, aiming to reduce environmental impact and encourage sustainable material sourcing. It can be represented as a point score or percentage.
Usage of environmental materials	This measures the proportion of materials with a low environmental impact used in the project, promoting sustainable practices. The value is expressed either as a point score or percentage.
Global warming potential	This quantifies the greenhouse gas emissions that contribute to global warming and climate change due to the project. The emissions are expressed as the equivalent amount of carbon dioxide (CO2) per Gwh of energy produced.
Acidification potential	This measures the potential for acid rain formation due to sulfur dioxide (SO2) emissions from the project. The value is expressed in SO2 equivalents per Gwh of energy produced.
Eutrophication potential	This assesses the potential for nutrient pollution leading to eutrophication in water bodies, causing excessive growth of algae. The impact is expressed in phosphate (PO4) equivalents per Gwh of energy produced.
Human toxicity potential	This evaluates the potential toxicity impacts on human health, considering the harmful substances that may be released during the project. The value is expressed in 1,4-dichlorobenzene (DCB) equivalents per Gwh of energy produced.
Marine aquatic ecotoxicity potential	This measures the potential toxicity impacts on marine ecosystems, assessing the harm caused by toxic substances released into the marine environment. The value is expressed in DCB equivalents per Gwh of energy produced.
Terrestrial ecotoxicity potential	This evaluates the potential toxicity impacts on terrestrial ecosystems, such as soil and land-based organisms, from the project. The value is expressed in DCB equivalents per Gwh of energy produced.
Noise pollution	This evaluates the noise generated by the project, which can affect both human populations and wildlife. The level of noise is measured in decibels (dB) equivalent per Gwh of energy produced.
Solid wastes	This quantifies the amount of solid waste generated by the project, including waste materials from construction, operation, and decommissioning. It is expressed in cubic meters (m³).

Figure A3. Description of Indicators (Part 1).

Land requirement	This measures the amount of land area required for the project's infrastructure, such as the construction of wind turbines, substations, and other facilities, relative to the energy produced, expressed in square kilometers per GWh.
Energy conversion efficiency	This assesses the efficiency of the energy conversion process, indicating how well the project transforms raw resources (such as wind) into usable electricity. It is typically expressed as a percentage or point score.
Operating time	This indicates the operational lifespan of the project, from initial construction to decommissioning, measured in years.
Levelised cost	This measures the cost of electricity production over the project's lifecycle, accounting for all costs such as capital, operations, and maintenance, and is expressed in dollars per gigawatt-hour (GWh) of energy produced.
Capital cost	This quantifies the initial investment required to establish the project, including construction, equipment, and installation costs. The cost is expressed in dollars per GWh of energy produced.
Total annualised costs	This represents the total annualized financial costs of the project over its lifetime, including capital, operational, and maintenance costs, expressed in dollars per GWh of energy produced.
Financial incentives and assistance	This evaluates the financial support available for the project, such as government subsidies, tax breaks, or other incentives that reduce overall costs. It is expressed in dollars per GWh of energy produced.
Number of jobs directly created	This measures the number of jobs directly created by the project, such as for construction, operation, and maintenance, expressed in person-years per GWh of energy produced.
Number of jobs indirectly created	This quantifies the indirect employment generated by the project, such as jobs in the supply chain, transportation, or ancillary industries, expressed in person-years per GWh of energy produced.
Worker injuries	This evaluates the number of injuries that occur among workers during the project's development and operation, expressed as the number of injuries per GWh of energy produced.
Severe accidents	This measures the number of fatalities resulting from severe accidents during the project, expressed as the number of fatalities per GWh of energy produced.
Human health costs	This assesses the health impacts on workers and surrounding communities, expressed as Disability-Adjusted Life Years (DALY) per GWh, a measure that accounts for both premature mortality and health impairments.
Residents' satisfaction with the project	This indicator measures the satisfaction and acceptance level of local residents with the project, indicating community support or opposition, and can be expressed as a point score or percentage.
Imported fossil fuel potentially avoided	This quantifies the reduction in the use of imported fossil fuels due to the energy produced by the project, contributing to energy security and reducing dependency on external energy sources. The value is expressed in tonnes of oil equivalent (toe) per GWh.

Figure A4. Description of Indicators (Part 2).

References

- Gielen, D.; Gorini, R.; Wagner, N.; Leme, R.; Gutierrez, L.; Prakash, G.; Asmelash, E.; Janeiro, L.; Gallina, G.; Vale, G.; et al. *Global Energy Transformation: A Roadmap to 2050*; Hydrogen Knowledge Centre: Derby, UK, 2019. Available online: <https://scispace.com/papers/global-energy-transformation-a-roadmap-to-2050-4mhal7a4ea> (accessed on 5 February 2025).
- Leung, D.Y.C.; Yang, Y. Wind energy development and its environmental impact: A review. *Renew. Sustain. Energy Rev.* **2012**, *16*, 1031–1039.
- Guillemoles, J.-F.; Azais, P.; Retiere, N.; Ravel, G. Priority Research Programme on Technologies for Advanced Energy Systems (TASE). *J. Abbr.* **2022**. Available online: <https://hal.science/hal-03816585> (accessed on 5 February 2025).
- Lamhamedi, B.E.H.; de Vries, W.T. An Exploration of the Land–(Renewable) Energy Nexus. *Land* **2022**, *11*, 767. [CrossRef]
- Ahmed, N.A.; Cameron, M. The challenges and possible solutions of horizontal axis wind turbines as a clean energy solution for the future. *Renew. Sustain. Energy Rev.* **2014**, *38*, 439–460.
- Henderson, A.R.; Witcher, D. Floating offshore wind energy—A review of the current status and an assessment of the prospects. *Wind Eng.* **2010**, *34*, 1–16. [CrossRef]
- Yates, K.L.; Bradshaw, C.J.A.; Hassan, S.M.D.; Kuokkanen, T.; Soininen, N.; Mackelworth, P.; Green, D.R.; Payne, J.; Cigliano, J.A.; Ballard, H.L.; et al. *Offshore Energy and Marine Spatial Planning*; Routledge: London, UK, 2018.
- Tseng, Y.-C.; Lee, Y.-M.; Liao, S.-J. An integrated assessment framework of offshore wind power projects applying equator principles and social life cycle assessment. *Sustainability* **2017**, *9*, 1822. [CrossRef]
- 4COffshore. Taichung Feng Miao. Available online: <https://www.4coffshore.com/windfarms/taiwan/taichung-fengmiao-taiwan-tw0d.html> (accessed on 7 April 2024).
- National Development Council. Taiwan 2050 Net Zero Emission Path and Strategy. Available online: https://www.ndc.gov.tw/en/Content_List.aspx?n=B154724D802DC488#:~:text=Taiwan's%202050%20net%2Dzero%20emissions,by%20%2212%20Key%20Strategies# (accessed on 20 April 2024).
- Planning and Development Department. National Ocean Policy White Paper. Available online: https://obamawhitehouse.archives.gov/sites/default/files/national_ocean_policy_implementation_plan.pdf (accessed on 15 November 2024).
- R.O.C. Ministry of Justice. Laws and Regulations Database of the Republic of China. Available online: <https://law.moj.gov.tw/LawClass/LawAll.aspx?pcode=M0050001> (accessed on 15 November 2024).
- Chiau, W.Y. The development of offshore wind farms in Taiwan: A marine policy perspective. *J. Nat. Dev. Stud.* **2019**, *18*, 55–124.
- Fishery Agency, Ministry of Agriculture. 2022 Fishery Statistical Yearbook. Available online: <https://openknowledge.fao.org/items/ac663f12-4be2-4562-9e0b-8317e9e89c6e> (accessed on 28 May 2024). [CrossRef]

15. Lu, H.-Y. Rethinking the Conflict between Offshore Wind Farm and Nearshore Fishery from a Temporal Perspective. *J. Archaeol. Anthropol.* **2022**, *97*, 123–168.
16. Labussière, O.; Nadaï, A. Spatialities of the energy transition: Intensive sites making earth matter? *Energy Res. Soc. Sci.* **2018**, *36*, 120–128.
17. Ryan, B.J. Security spheres: A phenomenology of maritime spatial practices. *Secur. Dialogue* **2015**, *46*, 568–584.
18. Baka, J. Making space for energy: Wasteland development, enclosures, and energy dispossessions. *Antipode* **2017**, *49*, 977–996.
19. Yenneti, K.; Day, R.; Golubchikov, O. Spatial justice and the land politics of renewables: Dispossessing vulnerable communities through solar energy mega-projects. *Geoforum* **2016**, *76*, 90–99. [[CrossRef](#)]
20. Heidenreich, S. Out of sight, out of mind? Controversy over offshore wind energy in Norway's news media. *Sci. Cult.* **2016**, *25*, 449–472. [[CrossRef](#)]
21. Kiriara, S. Questionnaire survey on opinions about offshore wind farms in fishermen of Aomori Prefecture, the northern part of Honshu Island, Japan. In *Grand Renewable Energy Proceedings*; Japan Council for Renewable Energy: Tokyo, Japan, 2018; p. 251. Available online: https://www.jstage.jst.go.jp/article/gre/1/0/1_251/_article/-char/ja/ (accessed on 15 November 2024).
22. Stelzenmüller, V.; Diekmann, R.; Bastardie, F.; Schulze, T.; Berkenhagen, J.; Kloppmann, M.; Krause, G.; Pogoda, B.; Buck, B.H.; Kraus, G. Co-location of passive gear fisheries in offshore wind farms in the German EEZ of the North Sea: A first socio-economic scoping. *J. Environ. Manag.* **2016**, *183*, 794–805. [[CrossRef](#)]
23. Haggett, C. Understanding public responses to offshore wind power. *Energy Policy* **2011**, *39*, 503–510. [[CrossRef](#)]
24. Klöpffer, W. Life cycle sustainability assessment of products: (with Comments by Helias A. Udo de Haes, p. 95). *Int. J. Life Cycle Assess.* **2008**, *13*, 89–95. [[CrossRef](#)]
25. International Organization for Standardization (ISO). *ISO 14040:2006; Environmental management—Life cycle assessment—Principles and framework*. ISO: Geneva, Switzerland, 2006.
26. UNEP. *Renewable Energy: Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*; United Nations Environment Programme: Nairobi, Kenya, 2011.
27. United Nations Environment Programme. *Towards a Life Cycle Sustainability Assessment*; UNEP: Nairobi, Kenya, 2011.
28. UNEP. Global Guidance Principles for Life Cycle Assessment Databases. In *Life Cycle Initiative*; United Nations Environment Programme/Society of Environmental Toxicology and Chemistry: Nairobi, Kenya, 2011.
29. United Nations Environment Programme/Society of Environmental Toxicology and Chemistry. *Guidelines for Social Life Cycle Assessment of Products*; UNEP/SETAC Life Cycle Initiative: Nairobi, Kenya, 2011.
30. United Nations. Sustainable Development Goals: 17 Goals to Transform Our World. Available online: <https://www.un.org/sustainabledevelopment/> (accessed on 15 July 2018).
31. Hirschberg, S.; Dones, R.; Heck, T.; Burgherr, P.; Schenler, W.; Bauer, C. *Sustainability of Electricity Supply Technologies Under German Conditions: A Comparative Evaluation*; Paul Scherrer Institut: Villigen, Switzerland, 2004.
32. May, J.R.; Brennan, D.J. Sustainability assessment of Australian electricity generation. *Process. Saf. Environ. Prot.* **2006**, *84*, 131–142. [[CrossRef](#)]
33. Evans, A.; Strezov, V.; Evans, T.J. Assessment of sustainability indicators for renewable energy technologies. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1082–1088. [[CrossRef](#)]
34. Genoud, S.; Lesourd, J.B. Characterization of sustainable development indicators for various power generation technologies. *Int. J. Green Energy* **2009**, *6*, 257–267. [[CrossRef](#)]
35. Gujba, H.; Mulugetta, Y.; Azapagic, A. Environmental and economic appraisal of power generation capacity expansion plan in Nigeria. *Energy Policy* **2010**, *38*, 5636–5652. [[CrossRef](#)]
36. Jeswani, H.K.; Gujba, H.; Azapagic, A. Assessing options for electricity generation from biomass on a life cycle basis: Environmental and economic evaluation. *Waste Biomass Valoriz.* **2011**, *2*, 33–42. [[CrossRef](#)]
37. Stamford, L.; Azapagic, A. Life cycle sustainability assessment of electricity options for the UK. *Int. J. Energy Res.* **2012**, *36*, 1263–1290.
38. Maxim, A. Sustainability assessment of electricity generation technologies using weighted multi-criteria decision analysis. *Energy Policy* **2014**, *65*, 284–297.
39. Santoyo-Castelazo, E.; Azapagic, A. Sustainability assessment of energy systems: Integrating environmental, economic and social aspects. *J. Clean. Prod.* **2014**, *80*, 119–138.
40. Atilgan, B.; Azapagic, A. An integrated life cycle sustainability assessment of electricity generation in Turkey. *Energy Policy* **2016**, *93*, 168–186.
41. Diamond, I.R.; Grant, R.C.; Feldman, B.M.; Pencharz, P.B.; Ling, S.C.; Moore, A.M.; Wales, P.W. Defining consensus: A systematic review recommends methodologic criteria for reporting of Delphi studies. *J. Clin. Epidemiol.* **2014**, *67*, 401–409. [[CrossRef](#)]

42. Taylor, E. We agree, don't we? The Delphi method for health environments research. *HERD Health Environ. Res. Des. J.* **2020**, *13*, 11–23. [[CrossRef](#)]
43. Kottner, J.; Audigé, L.; Brorson, S.; Donner, A.; Gajewski, B.J.; Hróbjartsson, A.; Roberts, C.; Shoukri, M.; Streiner, D.L. Guidelines for reporting reliability and agreement studies (GRRAS) were proposed. *Int. J. Nurs. Stud.* **2011**, *48*, 661–671.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.