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Risk Analysis and Management of Construction and Operations in Offshore Wind Power Project

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Abstract: Many countries have increased the use of renewable energy and strongly promoted offshore wind power (OWP). However, OWP in Asia is in the preliminary stage of development, for which no precedents exist. The literature on wind energy generation has mostly investigated the causes of onshore wind turbine accidents and risk prevention, and more work on the risks associated with domestic OWP is required for energy market development. According to statistics on international wind power accidents, most offshore accidents occur in the construction and operation stages. Therefore, this work investigates risk management in the construction and operations of offshore windfarms in Taiwan. The goal is to help decision-makers to understand better the risks of the industry and so more effectively manage them. In this study, risk factors are identified from organizing data in the literature, and research methods and action strategies are developed. Research and analysis follow the risk management steps in the PMBOK® Guide (A Guide to the Project Management Body of Knowledge). The risk rankings and preventive measures that are based on the results of this study can serve as references for relevant industry personnel in island cities and nearby Asian countries to reduce risk in the management of OWP projects.

Keywords: offshore wind turbine; wind energy development; renewable energy planning; risk management; construction and operations; analytic hierarchy process (AHP); risk impact-frequency analysis (RIFA)

Citation: Chou, J.-S.; Liao, P.-C.; Yeh, C.-D. Risk Analysis and Management of Construction and Operations in Offshore Wind Power Project. *Sustainability* **2021**, *13*, 7473. https://doi.org/10.3390/su13137473

Academic Editor: Chunjiang An

Received: 18 May 2021
Accepted: 26 June 2021
Published: 5 July 2021

1. Introduction

Taiwan has for long time depended on imported fossil fuels to generate power, causing increasingly severe air pollution in the country. To increase renewable energy usage and mitigate air pollution, the government proposed the Four-Year Plan for the Promotion of Wind Power. According to the latest statistics from 4C Offshore, an international offshore wind power (OWP) consultancy, the best offshore windfarms of the world are almost all located in the Taiwan Strait [1]. Such favorable natural conditions around Taiwan has increased the government's determination to develop OWP.

Although the Taiwanese government has constructed a total of 349 wind turbine generator systems, all are onshore windfarms. In the absence of OWP experience, the industry inevitably faces more risks in its initial implementation than it would otherwise. The design of wind turbines in Taiwan follows European standards, leading to several incidents of wind turbine collapse and damage to blades in onshore windfarms in Taiwan as a result of typhoons [2–5]. When wind power is developed offshore, the environment and climatic conditions at sea, which are much harsher than onshore, will seriously influence construction and operation and pose a major challenge for each windfarm project.

Since OWP in Asia is currently in an early stage of development, no examples are available. Nonetheless, the literature has largely studied the causes of onshore wind turbine accidents and preventive measures, and room for discussion about OWP risks remains.

Moreover, successful risk management cases in Europe are available as the reference for OWP projects in Taiwan. For instance, Anaya-Lara et al. specified a risk that the trip signal of the busbar circuit breaker is blocked by the protection of the feeders [6]. One can mitigate this risk by the feeders using directional circuit protection (compliance with grid code requirements).

This work developed action strategies and used risk management to analyze risks and countermeasures in the construction and operation phases of OWP in Taiwan. The researchers prepared a list of risks from the result of this study and proposed preventive measures to serve as a reference for stakeholders in subsequent OWP projects in Taiwan or other Asian countries. The rest of this paper is organized as follows: Section 2 presents statistics on relevant accidents in international wind power industries and applications of risk management; Section 3 introduces research and analytical methods; and Section 4 categorizes OWP risk factors and establishes a risk breakdown structure (RBS). Section 5 explains the design of the questionnaire and discusses its survey results. Section 6 considers risk response techniques and proposes preventive measures. Finally, Section 7 draws conclusions and makes suggestions for future research.

2. Literature Review

Using the keyword "offshore", a historical data search of a database of 2559 global wind power accidents [7] from 1980 to 28 September 2019 on the Caithness Windfarm Information Forum (CWIF) website was carried out. A total of 161 OWP accidents were found. Since the accident types of the cases defined by CWIF is too specific, this work reclassified the accident types based on the natures of influenced objectives. The following statistics were obtained:

- Industrial safety accidents (56 cases): personnel injury and death caused by human error or unforeseeable circumstances.
- Equipment/facility accidents (55 cases): damage or failure of windfarm equipment or facilities.
- Lifting accidents (ten cases): accidents that occurred in lifting operations.
- Transportation accidents (12 cases): accidents involving working vessels.
- Environmental impact accidents (eight cases): pollution generated by the development of windfarms, or the biological, ecological, or environmental effects of their operation.
- Other accidents (20 cases): accidents with minor effects or public discontent.

"Other accidents" had minor effects on windfarms. After the 20 "other accidents" were eliminated, the total number of accidents was 141. Figure 1 presents the proportions of the various types of accidents. The stages of windfarm lifecycle in which the 141 accidents occurred were further identified. Most accidents, 109, occurred in the operation and maintenance stage; 30 occurred in the construction stage and two occurred in the development and planning stage, revealing that the risk is highest during the construction and operation stages.

Based on the aforementioned statistics, "industrial safety accidents" and "equipment/facility accidents"—the most common accidents were analyzed. The OWP industry involves offshore operations, and therefore involves great difficulty and hazards, which increase the number of industrial safety accidents. Of the 56 cases of industrial safety accidents, 12 were fatal and 44 involved human injury. Most of the equipment/facility accidents, which are the second most frequent, involved nacelle (25 cases); eight involved blades, eight involved cables, seven involved offshore substations, four involved foundations, and three involved towers.

Unlike European countries, Taiwan is frequently hit by typhoons and seismic activities. Hence, the keywords "earthquake", "typhoon", and "hurricane" were used to perform another search of the CWIF global wind power accident database. Although no accident that was caused by an earthquake was found, 15 and six onshore wind power accidents that had been caused by typhoons and hurricanes, respectively, were found. These findings indicate that strong gusts that are caused by tropical cyclones directly affect wind turbines.

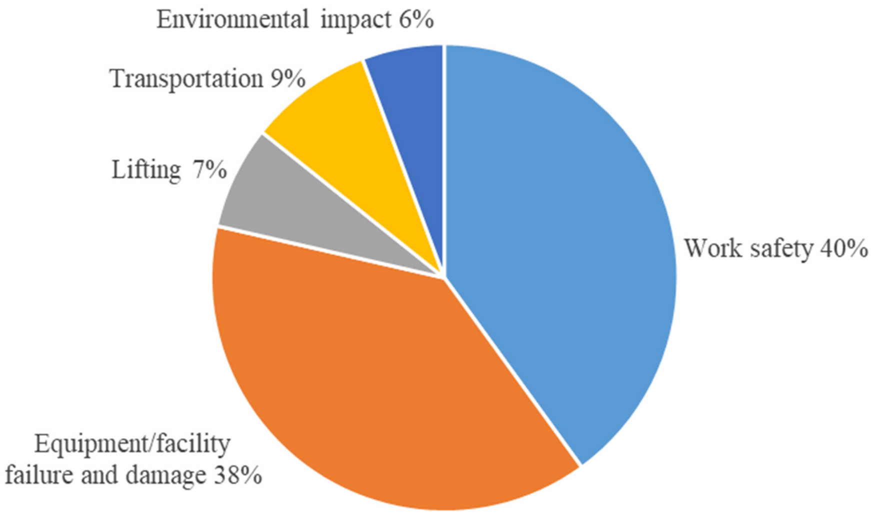

Figure 1. International OWP accident statistics (excluding "other accidents").

Wind power technology mostly originates in Europe, so design standards are based on European wind and environmental conditions, without considering tropical cyclones and earthquakes. Therefore, typhoons and hurricanes have caused many onshore wind turbine accidents around the world. Although the damage directly to onshore wind turbines by earthquakes has not been reported, one investigation recorded wind turbine tilting that was caused by soil liquefaction at an onshore windfarm in Kashima, Japan, as a result of an earthquake on 11 March 2011 [8]. Kao and Pearre [9] suggested that Japan is not suitable for conventional, fixed offshore wind turbines because most of its coastal waters are very deep and typhoons and earthquakes occur frequently.

Similarly, a comprehensive analysis by Shih [10] revealed that the Changbin area in Taiwan, which has the highest density of promising offshore windfarms, is a zone with a high probability of soil liquefaction, in which only a small fraction of the area has low or no liquefaction. Therefore, whether offshore wind turbines in Taiwan can withstand typhoons and earthquakes has yet to be determined.

The International Electrotechnical Commission (IEC) and DNV GL, a global certification company, are responsible for developing international design standards and validation rules for wind turbines. However, as the number of global wind turbine accidents has increased, the integrity of safety considerations in these design standards and validation rules has been questioned. Accordingly, Quarton and Negro et al. [11,12] investigated the effectiveness of international design standards. The IEC and DNV GL have also realized that tropical cyclones and seismic conditions can affect windfarm operation and established task forces to develop solutions, and revised existing standards and guidelines [13,14].

The PMBOK® Guide (A Guide to the Project Management Body of Knowledge) defines risk as an uncertain event or situation that, upon occurrence, has a positive or negative effect on a project objective [15]. The objective of risk management is to increase the probability and effect of positive events and reduce the probability and effect of negative events. The steps in risk management include risk management planning, risk identification, qualitative/quantitative risk analysis, risk response planning, and risk monitoring and control. After the latter four steps are completed, monitoring is required to identify newly arising risks. Once new risks arise, a reevaluation must be carried out to determine whether a new risk affects any existing risk factors; if so, then adjustment and improvement are required. The entire process should be recorded, reviewed, and reported.

OWP industry exists high potential risks and uncertainties. To prevent and mitigate them, Sinha and Steel [16] analyzed the root causes of the offshore wind turbine failures as a basis for evaluating the risk and priority number of a failure, thus assisting in prioritizing maintenance works. Leimeister and Kolios [17] reviewed risk and reliability analysis methods, such as the analytic hierarchy process (AHP), for the systematic assessment of uncertainties in the OWP industry. Park and Kim [18] investigated South Korea's energy transition policy and revealed that frequently changing government policies and support programs are greatest hindrances in OWP development. Mauleón [19] assessed photovoltaic and wind energy roadmap by discussing its learning rates, risk, and social discounting in detail.

To evaluate construction risks, several studies have used the AHP. AHP can solve complex problems of multicriteria decision-making in various research fields. Garbuzova-Schlifter and Madlener [20] carried out online questionnaire surveys with engineering, procurement, and construction (EPC) experts to understand common risk factors in government-sector EPC projects in Russia, and used the AHP to perform qualitative risk analysis.

Additionally, Wang et al. [21] established an AHP risk assessment framework to compare alternatives to cross-sea routes (a tunnel project and a bridge project) between Guangdong and Hainan Provinces. Yucesan and Kahraman [22] used the Pythagorean Fuzzy AHP (PFAHP) to evaluate risks for hydropower plants and considered measures to prevent the top three risks. Eskander [23] used questionnaire surveys and AHP to perform an uncertainty assessment and rate risks in the bidding and construction phases of projects in Egypt and Saudi Arabia.

Gatzert and Kosub [24] examined the risks and risk management of onshore and offshore wind parks in Europe from the perspective of an investor. They firstly identified risk factors in the literature and then conducted a risk evaluation and proposed risk management measures. They also conducted interviews with experts to identify the major risks and barriers as well as to rank the risks. The results of their analysis revealed that policy and regulatory changes are the major risks to renewable energy investments. However, the European investment environment differs substantially from that in Asia. The emerging OWP market in Asia would benefit greatly from research on risk management.

3. Methods

Figure 2 presents the research framework and methods employed in this study. After identifying the research objective, accident data collection and literature review were simultaneously conducted to derive research gaps by deductive and inductive approaches. Then, questionnaires were designed to solicit expert inputs regarding the impact and frequency of the risks of OWP. Risk impact-frequency analysis (RIFA) and AHP were then utilized to highlight salient risks. Lastly, the identified risks were prioritized and delineated with suggested preventive measures accordingly.

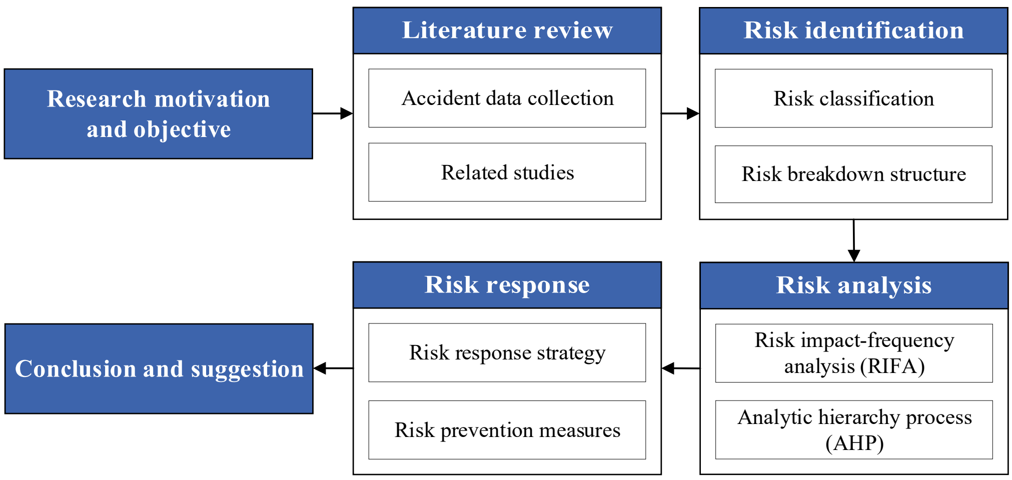

Figure 2. Research flowchart and methodology.

3.1. Questionnaire Survey

A questionnaire survey is a method for collecting information using written questions. It can be sent to a wide range of respondents for the purposes of this investigation, enables the rapid analysis of collected information to identify stakeholder needs. The general process of administering a questionnaire survey is as follows: design the questionnaire, select the survey participants, distribute the questionnaires, retrieve and review the questionnaires, and conduct a statistical analysis of, and theoretical research into the survey results.

In this work, owing to the small number of survey participants and low-complexity survey questions, an interview questionnaire was used. The survey participants were experts with experience of OWP or business owners in the industry. Researchers visited the participants in person to explain the purpose of the survey and to introduce the questions, helping them to understand them and answer them quickly. Appropriate explanation, guidance, and opportunities for follow-up questions enabled the researchers not only to find out respondents' countermeasures against risk, but also to present complex questions and obtain more in-depth feedback.

Risk impact-frequency analysis (RIFA) and AHP were used to conduct a post-survey analysis of risk factors. To understand respondents' responses for the purposes of risk management, the researchers used semistructured interviews. In a semistructured interview, after respondents have been asked a series of structured questions, open-ended questions obtain more complete information.

In this study, the questionnaire survey comprised two major sections. The first section comprised structured questions; theoretical foundations of RIFA and AHP were used to design fixed-alternative questions for risk factors. Such questions reduce the response time of respondents and facilitate the quantitative study of responses using numerical rating options. The second section comprised open-ended questions posed to experts to elicit their personal perspectives and practical experiences.

3.2. Risk Impact-Frequency Analysis

Risk impact-frequency analysis (RIFA) is based on importance–performance analysis (IPA). The primary indicators in IPA, "importance" and "performance", were changed to "impact" and "frequency", which are two key indices of risk impact level and of occurrence of risk. These two indices were used to prioritize risk treatment actions and determine appropriate management methods.

IPA is a method of business analysis that was jointly developed by Martilla and James [25] to examine the performance of products and services. Since IPA is a simple and easy-to-understand method of analysis, it has been extensively applied in various fields to collect customers' opinions by evaluating the degrees of importance and satisfaction they attribute to products and services. Measures for improvement are then identified from differences between the degrees of importance and satisfaction.

IPA draws a two-dimensional importance–performance graph (Figure 3), on which an item's position represents importance and performance, providing researchers with a reference for prioritizing product and service quality improvements. Usually in an importance–performance graph, "importance" is on the X-axis (horizontal axis) and "performance" is on the Y-axis (vertical axis). The coordinate plane is divided into four quadrants as follows: first quadrant: Keep Up the Good Work; second quadrant: Concentrate Here; third quadrant: Low Priority; and fourth quadrant: Possible Overkill.

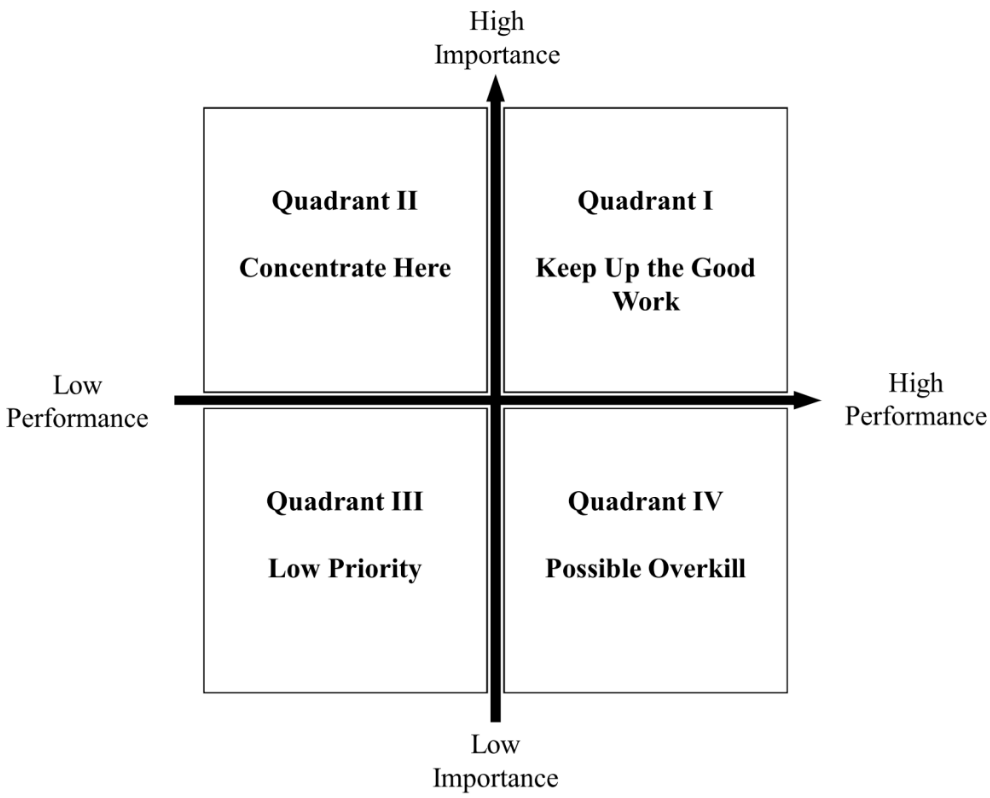

Figure 3. Importance–performance analysis.

3.3. Analytic Hierarchy Process

In 1971, Saaty developed the AHP as part of establishing a contingency plan for the United States Department of Defense. The method is applied to decision-making problems that involve uncertain situations and numerous evaluation criteria [26–29]. From 1972 to 1978, the theory of AHP was refined through continual application, revisions, and verification. In 1980, the theory was organized and published as a book and slowly became increasingly used in fields such as business, engineering, and public decision-making [30].

The AHP was developed to systemize complex problems, to provide hierarchical decomposition of the problems from various perspectives, and to use quantitative calculations to determine the context of the problems, with the purpose of comprehensively assessing the problems. Identifying questionnaires with higher credibility using a consistency test is more logical than general approaches, and considers more comprehensively various dimensions of the problems, providing useful information for decision-makers. The AHP uses a tree-shaped hierarchical structure to divide a complex problem into several simple subproblems in a hierarchy. Each subproblem can be independently analyzed, and can be of any type as long as they are used in the final decision.

Once the hierarchy of the subproblems is established, the decision-making expert systematically evaluates its scale and assigns a weight to each part of the hierarchy according to their relative importance in the hierarchy. This is then used to establish a pairwise comparison matrix to find eigenvectors and eigenvalues [30]; the eigenvector represents the priority of each part of the hierarchy. This information suffices for decision-makers and enables identification of the selection criteria or standards, and analyses that are required for decision-making, thereby reducing the risk of decision-making errors.

The application of the AHP to problems can be divided into the following five steps; (1) problem and goal establishment; (2) hierarchical structure establishment; (3) questionnaire design and investigation; (4) consistency checking; and (5) prioritization and decision-making. Based on Saaty's assessment of the AHP and scale recommendations, factors on the same hierarchical level are compared pairwise to determine their relative importance. This ratio scale between two factors can be divided into equally important, slightly important, important, very important, and absolutely important, with assigned numbers of one, three, five, seven and nine, respectively. Four other scales were established between the five basic scales and given numbers of two, four, six, and eight, yielding a total of nine scales. Table 1 presents the meaning of each scale.

Table 1. AHP ratio scale.

Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favor one activity over another
5	Essential	Experience and judgement strongly favor one activity over another
7	Very important	One activity is favored very strongly over another; its dominance is demonstrated in practice
9	Extremely important	The evidence favoring one activity over another is as strong as possible
2, 4, 6, 8	Intermediate values	Compromise between two importance score is required

4. Risk Identification

4.1. Risk Categorization

Several methods of risk categorization exist. Systematically distinguishing risk factor properties to differentiate among risk categories supports a clear understanding of stakeholder identities, enabling the development of suitable countermeasures. This study collects and summarizes potential risk factors in the OWP industry from the work of CWIF [7], Gatzert and Kosub [24], Ahlgren and Grudic [31], Aon UK Limited [32], Swiss Re [33], EWEA [34] and Risktec [35]. Preliminary judgments of each risk attribute are made to divide risks in the construction and operation phases and could be divided into the three categories of technical, commercial, and force majeure (Table 2). The "technical" category comprises technological risks that are related to equipment, machinery, design, transportation, construction, installation, commissioning, operation, and maintenance. The "commercial" category comprises risks related to finance, contracts, markets, and operations. The "force majeure" category includes unforeseeable risks such as natural disasters, political events, and regulations.

Table 2. Categorization of risks in construction and operations.

Risk Category	Description	Major Stakeholders
Technical	Technology-related risks, such as related to equipment, machinery, design, transportation, construction, installation, commissioning, operation, and maintenance	Government, banks, developers, suppliers, contractors, and insurance firms
Commercial	Commercial risks such as related to finance, contracts, markets, and operations	
Force majeure	Unforeseeable risks such as natural disasters, political events, and regulations	

4.2. Risk Breakdown Structure

The risk breakdown structure (RBS) is a systematical graphic representation of identified risk factors by category; this representation helps personnel who are responsible for identifying risks to understand situations rapidly and it facilitates the discussion and evaluation of risk factors. When a project ends, newly added risks and learning experiences can be entered into the graph to provide a reference for future projects. In this study, risk factors that are commonly mentioned in the literature are selected. Next, brainstorming with reference to current OWP development in Taiwan yields 14 risk factors. The risk categories to which these factors belong are identified, and an RBS is established (as displayed in Figure 4) to facilitate subsequent risk analysis.

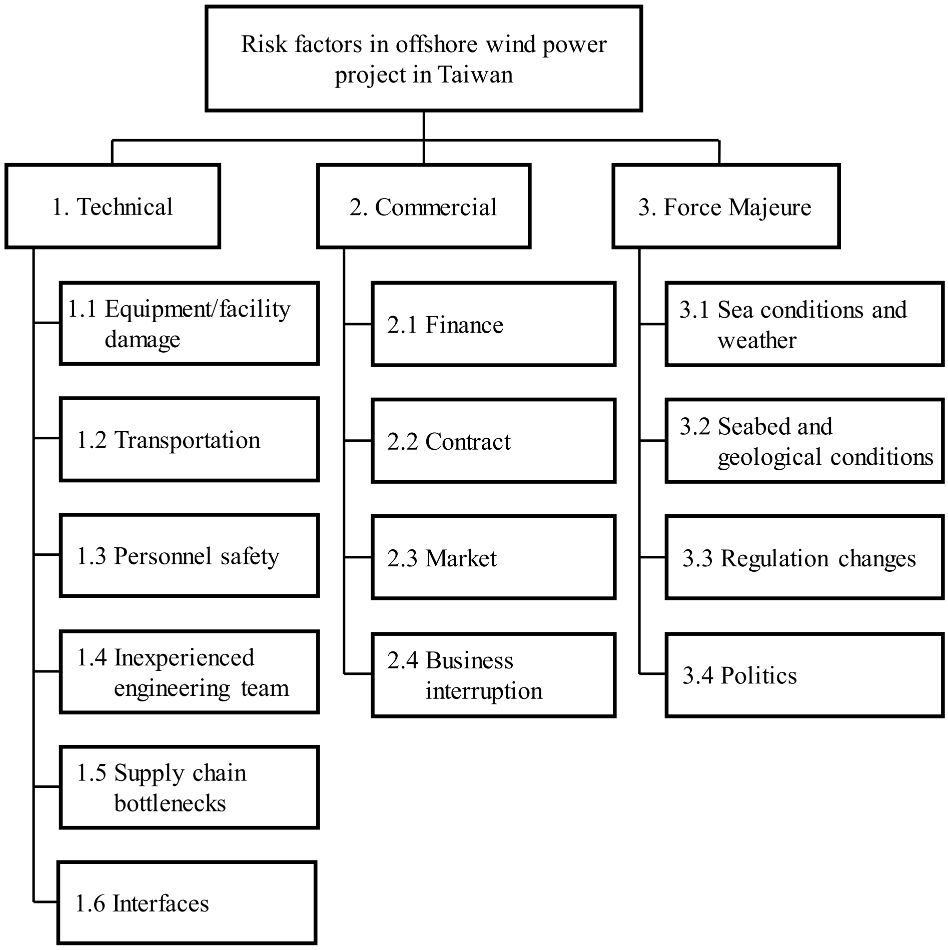

Figure 4. Risk breakdown structure.

5. Risk Analysis

5.1. Questionnaire Design Logic and Interviewee Backgrounds

Based on the established RBS, the content of the questionnaire was developed to determine the impact and frequency of each risk factor. The researchers visited and interviewed industry experts, and then completed written questionnaires to capture the interviewees' views. Finally, the researchers asked questions to gain an in-depth understanding of the respondents' practical experiences. In the interviews, the researchers explained to the interviewees the purpose of the interview, the questionnaire design philosophy, the definitions of risk categories, the RBS, and the risk factors. Therefore, the interviewees understood the entire risk hierarchy framework and the definitions of risk factors before the interviews began.

After inquiries were made into the willingness of each respondent to be interviewed, seven interviewees were recruited, comprising three developers, two maritime contractors, one consulting firm, and one insurance firm (Table 3). The consulting firm, NIRAS, was interviewed on behalf of another developer, Copenhagen Infrastructure Partners (CIP). The insurance firm, AON, had been commissioned by two other developers, Swancor and Taiwan Power Company (TPC), to plan risk management and insurance. Industry experience of these interviewees ranges from 15–20 years. The interviewees are senior managers who develop strategies, organize the team, execute plans, and resource control from different stakeholders' perspectives.

Table 3. Backgrounds of interviewees in Taiwan.

Industry	Agency	Title	Notes
Developers	TPC	Project Manager	Windfarm under construction
	wpd	Director	Windfarm under construction
	EnBW	Project Development Director	Windfarm development awaiting approval
Maritime contractors	Jan de Nul	Business Development Manager	Currently working at two windfarms
	Boskalis	Regional Manager	Currently working at a windfarm
Consulting	NIRAS	Project Manager	Consulting for a developer, CIP
Insurance	AON	Associate Director	Risk management consulting for two developers, Swancor and TPC

The interview questionnaire comprised four parts. In the first part, RIFA questions were asked to elicit the impact and frequency of each risk factor. The second part consisted of AHP questions; in contrast to general AHP questionnaire designs, a bottom-up approach was taken to design the questionnaire content and a paired comparison of risk factors on the third level of the RBS was carried out. In the third part, the AHP was extended to make an overall paired comparison of the three major risk categories on the second level of the RBS, increasing the effectiveness of the questionnaire. The fourth part comprised essay questions to elicit relevant experiences of the interviewees.

Stakeholders in Taiwan who were involved in development were prioritized as interviewees to visit, followed by developers who were actively seeking to become involved in development. Although these potential developers had not yet obtained concessions for windfarm development, the windfarms to be developed had undergone preliminary sea condition surveys and passed environmental impact assessments. The experience that these developers had gained in foreign countries and their risk management plans for the Taiwan environment made the viewpoints of these developers valuable for reference.

5.2. RIFA Questionnaire Results and Analysis

The interview questionnaire with a RIFA design was used to survey the "impact" and "frequency" of 14 risk factors, which were then scored using a five-point Likert scale. Based on the results of the interview questionnaire, the seven scores for each risk factor were summed and averaged; the resulting mean represented the average score from all participants. Finally, the average score of each risk factor was plotted on two-dimensional plane coordinates. The relative position of a factor represented its risk performance, providing detailed information about the risk management priorities of the stakeholders.

Table 4 presents the calculated rankings of the impact and frequency of each risk factor. With respect to risk impact, "3.4 Politics" had the highest average score of 4.57 points, and so was the risk factor with the greatest impact. Regarding risk frequency, "3.1 Sea condition and weather" received the highest average score of 3.57 points, and thus was the risk with the highest frequency of occurrence.

Based on the RIFA average score for each risk factor, "Impact" was represented on the vertical axis and "Frequency" was represented on the horizontal axis. The mean of the maximum and minimum average scores was taken as a midpoint, which effectively defined four quadrants. Finally, the average scores of the impact and frequency of each risk factor were plotted onto the two-dimensional diagram (Figure 5).

Table 4. RIFA risk factor ranking.

Risk Category	Risk Factors		Impact		Frequency	
			Ave.	Rank	Ave.	Rank
1. Technical	1.1	Equipment/facility damage	4.143	3	2.714	6
	1.2	Transportation	4.143	3	2.143	13
	1.3	Personnel safety	4.286	2	2.143	13
	1.4	Inexperienced engineering teams	3.571	11	2.857	4
	1.5	Supply chain bottlenecks	3.714	10	2.857	4
	1.6	Interfaces	3.429	12	3.429	2
2. Commercial	2.1	Finance	3.429	12	2.286	11
	2.2	Contract	3.857	7	2.571	8
	2.3	Market	3.429	12	2.429	9
	2.4	Business interruption	4.143	3	2.286	11
3. Force Majeure	3.1	Sea conditions and weather	4.143	3	3.571	1
	3.2	Seabed and geological conditions	3.857	7	2.429	9
	3.3	Regulatory changes	3.857	7	2.714	6
	3.4	Politics	4.571	1	3.000	3

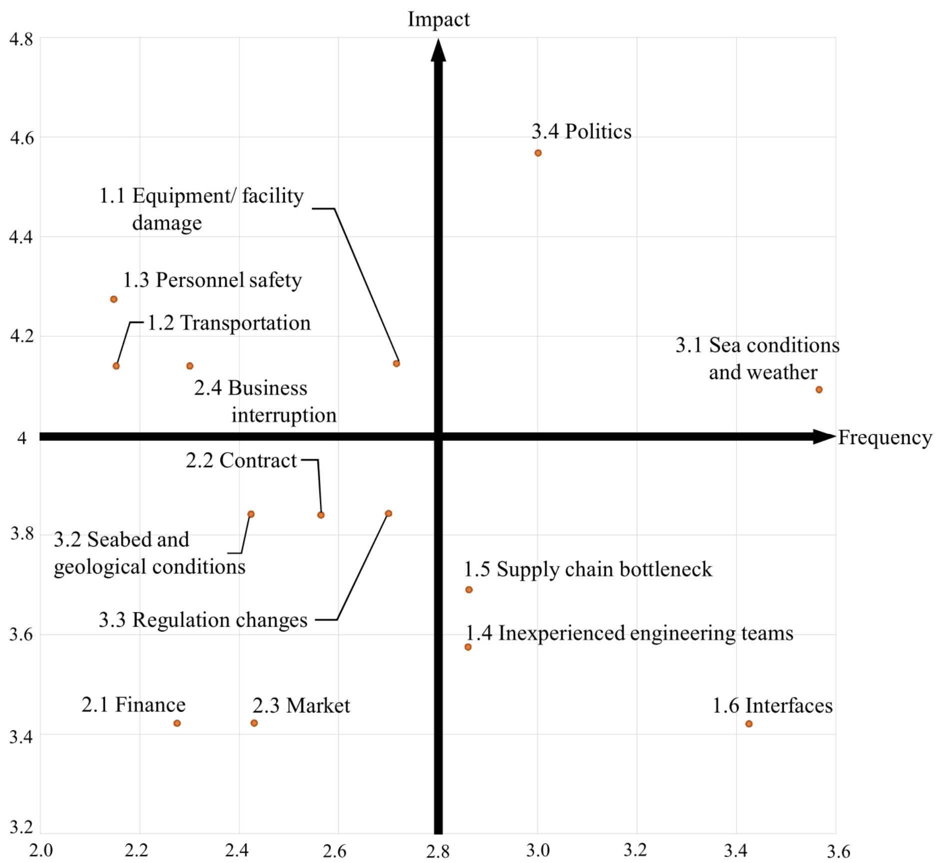

Figure 5. RIFA two-dimensional diagram.

5.3. AHP Questionnaire Results and Analysis

A total of seven experts with experience of OWP practices in Taiwan were invited to complete the interview questionnaires. The experts provided ratio scales for each risk factor, and their priority vectors and maximum eigenvalues were calculated to yield the relative weights of the risk factors. A consistency test was performed; the absolute weight of each risk factor was calculated, and priority ranking was carried out based on the weight scores. Calculations were made using the seven sets of survey results to obtain risk category rankings and risk factor rankings, which are represented in Table 5. The result of the analysis revealed that in the second-level "risk categories", "Force Majeure" had the highest absolute weight score, whereas of the third-level "risk factors", the top three were "3.4 Politics", "3.1 Sea conditions and weather", and "2.1 Finance."

Table 5. AHP risk category and risk factor rankings.

Risk Category	Weight	Category Rank	Risk Factor	Weight	Factor Rank
1. Technical	0.231	3	1.1 Equipment/facility damage	0.024	13
			1.2 Transportation	0.015	14
			1.3 Personnel safety	0.085	7
			1.4 Inexperienced engineering teams	0.038	11
			1.5 Supply chain bottlenecks	0.039	10
			1.6 Interfaces	0.029	12
2. Commercial	0.349	2	2.1 Finance	0.115	3
			2.2 Contract	0.093	6
			2.3 Market	0.041	9
			2.4 Business interruption	0.100	4
3. Force majeure	0.421	1	3.1 Sea conditions and weather	0.116	2
			3.2 Seabed and geological conditions	0.096	5
			3.3 Regulation changes	0.084	8
			3.4 Politics	0.125	1

5.4. Comprehensive Ranking Based on Combined RIFA and AHP Results

The RIFA quadrant diagram is a risk assessment graph that is generated using the impact and frequency of risk as the coordinates. However, the relative importance of risk factors from the quadrant diagram is difficult. Although the AHP pertains to the relative ranking of importance that is based on comparisons between risk factors, interviewees were often unable to consider questions in a consistent manner during the survey; additionally, risk impact, and frequency could not be evaluated together. Therefore, the RIFA quadrant diagram was combined with the absolute weights that were obtained using the AHP to yield a comprehensive ranking (Table 6). In the future, in the handling of the risk factors in the four quadrants, the weights and relative rankings of risks within those quadrants may provide a reference.

Table 6. Comprehensive ranking based on combined RIFA and AHP.

Quadrant	Risk Factor	Weight	Quadrant Rank
I. High impact-high frequency	3.4 Politics	0.125	1
	3.1 Sea conditions and weather	0.116	2
II. High impact-low frequency	2.4 Business interruption	0.100	1
	1.3 Personnel safety	0.085	2
	1.1 Equipment/facility damage	0.024	3
	1.2 Transportation	0.015	4
III. Low impact-low frequency	2.1 Finance	0.115	1
	3.2 Seabed and geological conditions	0.096	2
	2.2 Contract	0.093	3
	3.3 Regulation changes	0.084	4
	2.3 Market	0.041	5
IV. Low impact-high frequency	1.5 Supply chain bottlenecks	0.039	1
	1.4 Inexperienced engineering teams	0.038	2
	1.6 Interfaces	0.029	3

6. Risk Response

6.1. Responses to Risks in Each Quadrant of the RIFA Diagram

Based on the researchers' knowledge of IPA, the four quadrants of the RIFA diagram were specified according to the response that they demanded. The response to risks in each quadrant was specified in the RIFA diagram (Figure 6).

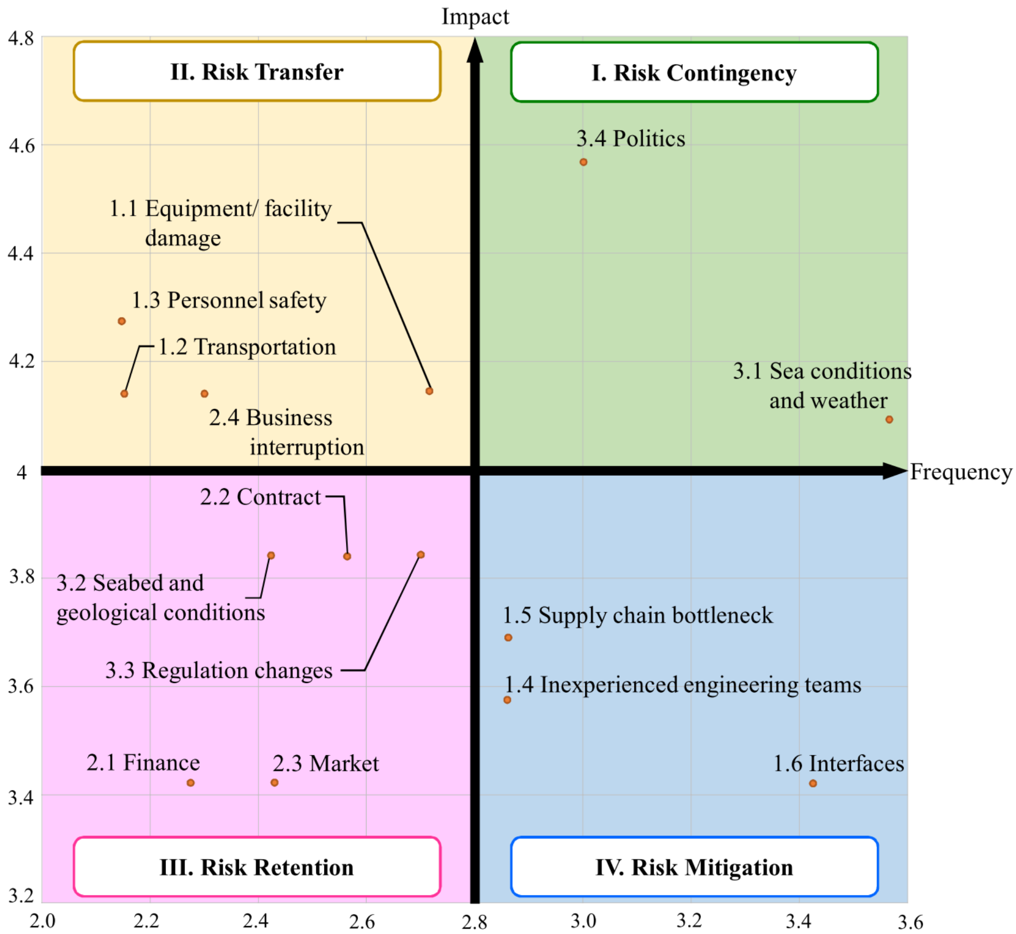

Figure 6. Risk responses in RIFA quadrant diagram.

First quadrant: Risk Contingency

Risk factors in this quadrant pose high potential threat and have severely negative impacts; they should be strategically avoided as much as possible. If they cannot be avoided, contingency plans should be made for priority implementation in emergencies.

Second quadrant: Risk Transfer

Although risk factors in this quadrant have a relatively low frequency, their high impact may cause complete shutdown of wind farm or major property loss. Therefore, a third party should be found to bear jointly responsibility for the risk response and to transfer the possibly negative effect of the risk. Available transfer tools include insurance, performance guarantees, warranties, and other guarantees. During construction, partners can be found, or work can be subcontracted to other contractors to reduce risks.

Third quadrant: Risk Retention

Risks in this quadrant are tolerable, or the cost of treating them exceeds potential losses. Therefore, these risks are tolerated and temporarily untreated. However, risk loss may be quantified in advance and added to operating costs, or a contingency reserve may be allocated as a remedial measure.

Fourth quadrant: Risk Mitigation

Although risks in this quadrant have a relatively low impact, their frequency is relatively high. Hence, the root causes of these risks must be identified; before risk loss, active risk management measures should be taken to reduce its possibility and/or severity.

6.2. Measures to Prevent Risk Factors

Equipment/facility damage: Equipment and facilities are critical assets of windfarm projects, and severe damage to them inhibits construction and operations. To counteract damage caused by weather factors, designs must consider natural conditions. To prevent damage by human error, quality control in production, transportation, and construction should be optimized. Contracts can include longer warranty periods and make the manufacturers responsible for maintenance services during these periods.

Transportation: Personnel, equipment, and facilities are commonly affected by the weather or sea conditions during transport. Personnel casualties or damage to equipment or facilities during transportation and installation can severely affect the construction schedule or operation of a windfarm. Therefore, professional operators must be commissioned for fastening, loading, and unloading, and transportation and marine warranty surveying (MWS) must be performed in a manner consistent with international insurance conventions to ensure the safety of offshore construction personnel, machinery, and ships.

Personnel safety: This risk was the most strongly emphasized by stakeholders. During interviews, all experts assigned the greatest weight to this risk and emphasized that health, safety, and environment (HSE) management must be strict and uncompromising. To avoid this risk, personnel must receive professional safety training and tasks must be specified according to the weather and sea conditions.

Inexperienced engineering teams: Taiwanese firms lack experience of OWP and are unfamiliar with European standards for windfarms. Therefore, domestic firms must cooperate with foreign companies, which possess great experience of OWP. Domestic and foreign firms can cooperate with each other in joint ventures, and domestic firms can commission foreign professional firms to assist with guidance and to review drawings. Some developers hire domestic and foreign consultants to provide the general counsel on windfarms to ensure the quality of their construction.

Supply chain bottlenecks: The government has formulated regulations for localization in which requirements are stricter in later stages. Several experts worried that production capacity and quality cannot meet demand. Therefore, in addition to calling on the government to retain flexibility in localization, they seek a more practical approach of tight control of the product capacity and delivery schedule and quickly assisting suppliers in solving bottleneck problems.

Interfaces: The interfaces in offshore windfarm construction are numerous and complex. Cooperating with international firms and exploiting their respective strengths while providing mutual support can reduce the risks that are posed by construction interfaces.

Finance: Windfarms require large investments and syndicated financing. The use of a financial model to make preliminary calculations to verify operational and financial stability and safety during a project life cycle can reduce the negative impacts and frequency of risks. Therefore, stakeholders must prepare financial plans and take hedging measures before making investments, increasing capital in factories to expand them, or executing projects.

Contract: Since the stakeholders in OWP in Taiwan include the government, foreign firms, and domestic firms, all parties must understand fully the provisions in relevant contracts, regardless of whether they are written in Chinese or foreign languages. Furthermore, because of the stricter contract requirements that are imposed by European developers, some experts worry that Taiwanese firms focus only on technology and price competitiveness when doing quotation work, neglecting contractual responsibilities and obligations. Therefore, all parties should carefully study and fully understand the contents of contracts, determine whether they can accept the contract terms, and seek legal advice when necessary.

Market: The entire OWP market may be influenced by such factors as changes in government incentive policies, price competition, and climate change. Market risk directly influences a firm's operations and financial status, and particularly those of stakeholders with financing needs. Presently, developers sell electricity to the Taiwan Power Company at renewable energy purchase rates without having to worry about market risk. However, domestic suppliers must carefully assess future market changes and implement short-, medium-, and long-term market strategies and planning.

Business interruption: Most historical cases of disrupted operations involved severe injuries to personnel and damage to equipment or facilities. Therefore, in addition to strengthening windfarm management to prevent casualties, the joint venture represents a viable approach to apportioning some risk-related stress among partners.

Sea conditions and weather: According to actuarial data [36], natural disasters are the primary cause of losses, disrupted operations, and delays in construction. The design of offshore windfarms follows European regulations, which may not be suitable for Taiwan's environment. Therefore, the specific climatic conditions of Taiwan must be addressed in the design. Additionally, offshore construction and operations in poor weather should be avoided to protect personnel.

Seabed and geological conditions: Although windfarm developers provide geotechnical reports to contractors as a design reference, the drilling points in these reports are only samples and not comprehensive. Therefore, geological drilling should be conducted at the location of each wind turbine foundation, and corresponding analysis and simulation should be carried out, so that the design parameters can be adjusted to ensure effective design. Seabed investigations must be performed prior to construction to ensure construction safety.

Regulation changes: Although several windfarm construction projects have been implemented, some regulations remain controversial. To respond to possible regulatory changes, some interviewees suggested such methods as paying attention to regulatory issues, providing subjective as well as objective opinions at appropriate times, and planning alternative solutions and contingency measures according to the various potential impacts of problems.

Politics: The experts believed that this risk has the greatest impact. Therefore, the most likely political situations should be addressed in exclusion clauses in contracts. Such clauses allow contracting parties for discussion. Additionally, current events should be closely monitored to provide early warnings of problematic situations, and various relevant scenarios should be simulated. When such situations occur, negotiations with government authorities can be attempted.

7. Conclusions and Recommendations

In this study, literature was reviewed to understand international accidents in OWP field and to identify common risk factors. Typical risk management steps were taken in this work, relevant risks were identified, risk factors were categorized by their attributes, and the RBS was established. Next, interview questionnaires that applied RIFA and AHP were designed. Seven OWP experts were interviewed to obtain their inputs to the questionnaires as a key data for analysis. The questionnaire results were analyzed to obtain risk impact, risk frequency and rankings of risk factors based on three analysis results (RIFA, AHP, and RIFA + AHP), which can be used to assist stakeholders in rapidly assessing risk treatment priorities. A two-dimensional diagram was generated from the RIFA results, and risk response strategy appropriate to each quadrant in this diagram were specified: the first quadrant was associated with risk contingency, the second with risk transfer, the third with risk self-retention, and the fourth with risk mitigation. Preventive measures for each risk factor were then suggested.

The top three risk factors based on the result of each analysis and corresponding preventive measures were identified as the primary contribution of this study. The RIFA results revealed that the top two high-impact factors were political risk and personnel safety risk which were followed in joint third place by equipment/facility damage risk, transportation risk, business interruption risk, and sea conditions and weather risk (Table 7). The top three factors with respect to frequency were sea conditions and weather risk, interface risk, and political risk (Table 8). The AHP analysis results revealed that the three most important factors were political risk, sea conditions and weather risk, and financial risk (Table 9).

Table 7. Top three risk factors with the greatest impact and corresponding preventive measures (based on RIFA results).

Rank	Risk Factor	Preventive Measure
1	Politics	Most likely political situations can be addressed in exclusion clauses in contracts, allowing contracting parties for discussion. Close attention should be paid to current events to provide early warnings and various relevant situations should be simulated; negotiations with government officials can be attempted when such situations arise.
2	Personnel safety	Receive professional safety training; enhance HSE management, and avoid working in unfavorable weather.
3	Equipment/facility damage	Damage caused by weather and sea conditions should be considered in the design of windfarm. Damage caused by human error can be mitigated by improving quality control during manufacturing, transportation, and construction; contracts can include longer warranty periods for equipment and facilities.
	Transportation	Have professional firms perform fastening, loading and unloading, and transporting; purchase relevant insurance to protect against economic losses; and execute MWS as required by regulations to ensure the safety of offshore personnel, machinery, and ships.
	Business interruption	Improve windfarm management to avoid casualties, and use joint ventures to apportion risk among partners.
	Sea conditions and weather	Consider Taiwan's unique climatic conditions in design and avoid offshore operations in unfavorable weather.

Table 8. Top three risk factors with the highest frequency and corresponding preventive measures (based on RIFA results).

Rank	Risk Factor	Preventive Measure
1	Sea conditions and weather	Consider Taiwan's unique climatic conditions in design and avoid offshore operations in unfavorable weather.
2	Interfaces	Cooperation between domestic and foreign firms enables mutual technological support, and can help communication and integration for vertical interface and horizontal interface.
3	Politics	Most likely political situations can be addressed in exclusion clauses in contracts, allowing contracting parties for discussion. Close attention should be paid to current events to provide early warnings and various relevant situations should be simulated; negotiations with government officials can be attempted when such situations arise.

Comprehensive results of RIFA combined with AHP analysis revealed the top two factors in the first quadrant to be political risk and sea conditions and weather risk, with no third top factor. The top three factors in the second quadrant were business interruption risk, personnel safety risk, and equipment/facility damage risk; those in the third quadrant were financial risk, seabed and geological conditions risk, and contract risk. Finally, those in the fourth quadrant were supply chain bottleneck risk, inexperienced engineering team risk, and interface risk (Table 10). The aforementioned results can serve as a reference for stakeholders with various purposes.

Table 9. Top three risk factors with the highest importance and corresponding preventive measures (based on AHP analysis results).

Rank	Risk Factor	Preventive Measure
1	Politics	Most likely political situations can be addressed in exclusion clauses in contracts, allowing contracting parties for discussion. Close attention should be paid to current events to provide early warnings and various relevant situations should be simulated; negotiations with government officials can be attempted when such situations arise.
2	Sea conditions and weather	Consider Taiwan's unique climatic conditions in design and avoid offshore operations in unfavorable weather.
3	Finance	Stakeholders must perform financial planning and take hedging measures before making investments, increasing capital, and executing projects.

Table 10. Top three risk factors in each quadrant in RIFA diagram and corresponding preventive measures (based on combined RIFA and AHP analysis results).

Quadrant	Rank	Risk Factor	Preventive Measure
I	1	Politics	Most likely political situations can be addressed in exclusion clauses in contracts, allowing contracting parties for discussion. Close attention should be paid to current events to provide early warnings and various relevant situations should be simulated; negotiations with government officials can be attempted when such situations arise.
	2	Sea conditions and weather	Consider Taiwan's unique climatic conditions in design and avoid offshore operations in unfavorable weather.
II	1	Business interruption	Improve windfarm management to avoid casualties, and use joint ventures to apportion risk among partners.
	2	Personnel safety	Receive professional safety training, enhance HSE management, and avoid working in unfavorable weather.
	3	Equipment/facility damage	Damage caused by weather and sea conditions should be considered in the design of windfarm. Damage caused by human error can be mitigated by improving quality control during manufacturing, transportation, and construction; contracts can include longer warranty periods for equipment and facilities.
III	1	Finance	Stakeholders must perform financial planning and take hedging measures before making investments, increasing capital, and executing projects.
	2	Seabed and geological conditions	Conduct geological drilling at the location of each wind turbine foundation, and carry out corresponding analysis and simulation should be carried out, so that the design parameters can be adjusted to ensure effective design. Perform seabed investigations before construction to ensure construction safety.
	3	Contract	Contracting parties must carefully study and fully understand the contents of contracts, and determine whether they can accept its terms. If necessary, they should seek legal advice.
IV	1	Supply chain bottlenecks	Stakeholders must closely monitor suppliers and assist in solving bottleneck problems in a timely manner.
	2	Inexperienced engineering teams	Domestic firms should cooperate with foreign firms, such as by joint contracting; domestic firms may commission professional international firms to provide guidance and review document. Developers can find domestic and foreign consulting firms to provide as general counsel on windfarms to ensure construction quality.
	3	Interfaces	Cooperation between domestic and foreign firms enables mutual technological support, and can help communication and integration for vertical interface and horizontal interface.

Although this study provided risk ranking, risk responses and risk prevention measures, risk factors are diverse and risk management steps must be followed to evaluate plans based on prevailing conditions. Along with appropriately various risk management tools and techniques, effective preventive measures can undoubtedly be identified. This work revealed that insurance currently covers most of OWP risks. However, insurance is a means of transferring risk, and can only provide economic compensation for risk losses. Therefore, practically, scientific methods must be used to develop specific action plans for risk management and to maximize safety at the lowest possible cost.

Offshore wind power in Taiwan is in an early stage of development. Hence, not all relevant domestic risks could be identified for examination and analysis. A weight analysis of potential risk factors could only be performed using expert questionnaire surveys and interviews, with the purpose of identifying objective methods for responding to risks and corresponding preventive measures. We hope that in the near future, as domestic offshore windfarms are built and become commercially operational, other researchers interested in this field will visit relevant industry personnel and benefit from their accumulated experience. These researchers may record in detail the risks that those personnel have experienced in Taiwan as well as their solutions, and conduct more in-depth investigations of risk management in each stage of construction or operation. We believe that such investigations will contribute greatly to future OWP development in other countries in Asia.

Author Contributions: Conceptualization, J.-S.C.; data curation, C.-D.Y.; formal analysis, J.-S.C. and C.-D.Y.; funding acquisition, J.-S.C.; investigation, J.-S.C., C.-D.Y. and P.-C.L.; methodology, J.-S.C. and P.-C.L.; project administration, J.-S.C.; resources, J.-S.C.; supervision, J.-S.C.; validation, J.-S.C., P.-C.L. and C.-D.Y.; visualization, J.-S.C.; writing—original draft, J.-S.C. and C.-D.Y.; writing—review and editing, J.-S.C. and P.-C.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Science and Technology, Taiwan, under grant 108-2221-E-011-003-MY3.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments: The authors would like to thank the Ministry of Science and Technology, Taiwan, for financially supporting this research.

Conflicts of Interest: The authors declare that they have no conflict of interest.

References

1. 4C Offshore. Global Offshore Wind Speeds Rankings. Available online: https://www.4coffshore.com/windfarms/windspeeds.aspx (accessed on 31 August 2019).
2. Chou, J.-S.; Chiu, C.-K.; Huang, I.K.; Chi, K.-N. Failure analysis of wind turbine blade under critical wind loads. *Eng. Fail. Anal.* **2013**, *27*, 99–118. [CrossRef]
3. Chou, J.-S.; Ou, Y.-C.; Lin, K.-Y. Collapse mechanism and risk management of wind turbine tower in strong wind. *J. Wind Eng. Ind. Aerodyn.* **2019**, *193*, 103962. [CrossRef]
4. Chou, J.-S.; Ou, Y.-C.; Lin, K.-Y.; Wang, Z.-J. Structural failure simulation of onshore wind turbines impacted by strong winds. *Eng. Struct.* **2018**, *162*, 257–269. [CrossRef]
5. Chou, J.-S.; Tu, W.-T. Failure analysis and risk management of a collapsed large wind turbine tower. *Eng. Fail. Anal.* **2011**, *18*, 295–313. [CrossRef]
6. Anaya-Lara, O.; Campos-Gaona, D.; Moreno-Goytia, E.; Adam, G. *Offshore Wind Energy Generation: Control, Protection, and Integration to Electrical Systems*; John Wiley & Sons, Ltd.: Hoboken, NJ, USA, 2014.
7. CWIF. Wind Turbine Accident and Incident Compilation. Available online: http://www.caithnesswindfarms.co.uk/fullaccidents.pdf (accessed on 31 August 2019).
8. Arakawa, C. Recent Development and Challenges of Wind Turbine Technology. Available online: https://www.jst.go.jp/sicp/ws2012_denmark/presentation/presentation_16.pdf (accessed on 17 September 2019).
9. Kao, S.-M.; Pearre, N.S. Administrative arrangement for offshore wind power developments in Taiwan: Challenges and prospects. *Energy Policy* **2017**, *109*, 463–472. [CrossRef]
10. Shih, C.-J. *Evaluation of Liquefaction Potential in Western Taiwan Offshore Wind Farm*; National Cheng Kung University: Tainan, Taiwan, 2013.

11. Quarton, D. *An International Design Standard for Offshore Wind Turbines: IEC 61400-3*; Garrad Hassan and Partners, Ltd.: Bristol, UK, 2005.
12. Negro, V.; López-Gutiérrez, J.-S.; Esteban, M.D.; Matutano, C. Uncertainties in the design of support structures and foundations for offshore wind turbines. *Renew. Energy* **2014**, *63*, 125–132. [CrossRef]
13. DNV GL. Reducing Cyclone and Earthquake Challenges for Wind Turbines-New Wind Industry Project to Develop Joint Guideline. Available online: https://www.dnvgl.com/news/reducing-cyclone-and-earthquake-challenges-for-wind-turbines-144220 (accessed on 31 August 2019).
14. IEC. Wind Energy Generation Systems-Part 3-1: Design Requirements for Fixed Offshore Wind Turbines. Available online: https://webstore.iec.ch/publication/29360 (accessed on 31 August 2019).
15. PMI. Chapter 11 Project Risk Management. In *PMBOK® Guide*, 5th ed.; Project Management Institute: Philadelphia, PA, USA, 2013; pp. 309–354.
16. Sinha, Y.; Steel, J.A. A progressive study into offshore wind farm maintenance optimisation using risk based failure analysis. *Renew. Sustain. Energy Rev.* **2015**, *42*, 735–742. [CrossRef]
17. Leimeister, M.; Kolios, A. A review of reliability-based methods for risk analysis and their application in the offshore wind industry. *Renew. Sustain. Energy Rev.* **2018**, *91*, 1065–1076. [CrossRef]
18. Park, J.; Kim, B. An analysis of South Korea's energy transition policy with regards to offshore wind power development. *Renew. Sustain. Energy Rev.* **2019**, *109*, 71–84. [CrossRef]
19. Mauleón, I. Assessing PV and wind roadmaps: Learning rates, risk, and social discounting. *Renew. Sustain. Energy Rev.* **2019**, *100*, 71–89. [CrossRef]
20. Garbuzova-Schlifter, M.; Madlener, R. AHP-based risk analysis of energy performance contracting projects in Russia. *Energy Policy* **2016**, *97*, 559–581. [CrossRef]
21. Wang, T.; Wang, S.; Zhang, L.; Huang, Z.; Li, Y. A major infrastructure risk-assessment framework: Application to a cross-sea route project in China. *Int. J. Proj. Manag.* **2016**, *34*, 1403–1415. [CrossRef]
22. Yucesan, M.; Kahraman, G. Risk evaluation and prevention in hydropower plant operations: A model based on Pythagorean fuzzy AHP. *Energy Policy* **2019**, *126*, 343–351. [CrossRef]
23. Eskander, R.F.A. Risk assessment influencing factors for Arabian construction projects using analytic hierarchy process. *Alex. Eng. J.* **2018**, *57*, 4207–4218. [CrossRef]
24. Gatzert, N.; Kosub, T. Risks and risk management of renewable energy projects: The case of onshore and offshore wind parks. *Renew. Sustain. Energy Rev.* **2016**, *60*, 982–998. [CrossRef]
25. Martilla, J.A.; James, J.C. Importance-performance analysis. *J. Mark.* **1977**, *41*, 77–79. [CrossRef]
26. Saaty, T.L.; Kearns, K.P. *Analytical Planning: The Organization of Systems*; Pergamon: Oxford, UK, 1985.
27. Saaty, T.L. Highlights and critical points in the theory and application of the Analytic Hierarchy Process. *Eur. J. Oper. Res.* **1994**, *74*, 426–447. [CrossRef]
28. Saaty, T.L. Rank from comparisons and from ratings in the analytic hierarchy/network processes. *Eur. J. Oper. Res.* **2006**, *168*, 557–570. [CrossRef]
29. Saaty, T.L.; Rokou, E. How to prioritize inventions. *World Patent Inf.* **2017**, *48*, 78–95. [CrossRef]
30. Saaty, T.L. Analytic hierarchy process. In *Encyclopedia of Biostatistics*; John Wiley & Sons, Ltd.: Hoboken, NJ, USA, 2005. [CrossRef]
31. Ahlgren, E.; Grudic, E. *Risk Management in Offshore Wind Farm Development*; Chalmers University of Technology: Gothenburg, Sweden, 2017.
32. Aon UK Limited. *Offshore Wind Risk Management and Insurance*; Aon UK Limited: London, UK, 2018.
33. Swiss Re. Offshore Wind Farm Discussion-Insurance Challenge and Case Review. Available online: https://www.ctci.org.tw/8831/ (accessed on 8 August 2019).
34. EWEA. Where's the Money Coming from? Financing Offshore Wind Farms. Available online: https://www.ewea.org/offshore2013/wp-content/uploads/Financing_Offshore_Executive_Summary.pdf (accessed on 15 July 2019).
35. Risktec. De-Risking Offshore Wind Energy. Available online: https://risktec.tuv.com/risktec-knowledge-bank/enterprise-risk-management/de-risking-offshore-wind-energy/ (accessed on 4 June 2019).
36. Aon UK Limited. *Insurance and Risk Overview for Offshore Wind Farms*; Aon UK Limited: London, UK, 2019.