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Causality of Risk Assessment Attributes under Uncertainty in Taiwan's Offshore Wind Farms Development

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Abstract: This study contributes to investigating the causality of risk assessment attributes under uncertainty for the offshore wind farms development in Taiwan. The investigation of risk assessment attributes for the offshore wind farms development has increasingly attracted more notice as multi-faceted challenges from socioeconomic, safety, and environmental perspectives emerged. Yet, the literature is lacking a multi-perspective viewpoint of the determining attributes and an examination of the attributes' interrelationships using qualitative information. To fill this gap, this study aims to identify the valid attributes based on the multi-perspectives of feasibility, environment, economic, and safety risks, and investigate the attributes' interrelationships. Thus, this study employs the fuzzy Delphi method to obtain valid risk assessment attributes and adopts a fuzzy decision-making trial and evaluation laboratory method to examine the attributes' interrelationships while identifying the multi-perspective-based crucial attributes. The results indicate that human safety, impact on marine environment, and navigation safety are crucial risk aspects to be assessed. From the practical point of view, this study found that safety of ship crews and passengers, safety of maintenance crews, local fishery industry, public trust in environmental regulations, and change of income for fishermen are the important risk criteria to be prioritized when developing offshore wind farms.

Keywords: offshore wind farms; risk assessment; fuzzy Delphi method; fuzzy decision-making trial and evaluation laboratory; human and navigation safety; impact on marine environment

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1. Introduction

The importance of risk assessment has gained great attention in recent years due to several benefits for the success of a project development such as hazard recognition and control, contingency plans establishment, and strategic risk retention [1–3]. Offshore wind farms (OWFs) are among the promising global industries that are effective at generating a high level of energy with higher productivity and less impact as opposed to the traditional methods. OWFs are being promoted in Taiwan but the development has faced several challenges since its early phase such as rejection from the community, disruption to the fishery, potential displacement of wildlife, and concerns on navigation safety [4–6]. Chung [7] claimed that Taiwan's government has placed a great investment in the form of political and financial resources into developing OFWs; however, diverse risks have been slowing down the development. Specifically, from the feasibility perspective, the risks are associated with damages to fishermen's rights because of an overlapping landscape with the traditional fishing grounds, which raises risks that affect the fishing industry in general, leading up to public resistance or acceptance and change of income [8,9]. Moreover, from the environmental perspective, Maxwell et al. [10] claimed that risks in the form of noise disturbance and marine life habitat loss due to improper maintenance and construction of an obstacle in navigable waters are prone to happen. Additionally, from a safety standpoint, risks from a collision between service vessels and the turbines are among the possible causes of structural damages even at the lowest speed, which may endanger human and navigational safety [11,12]. Risks from an economic perspective are related to cost of investment, consideration of cost–benefit analysis, operation and maintenance costs, and also cost of failures [13,14]. These risks relate to a situation in 2021 where Taiwan's government, in an effort to meet the 2025 target of 5.7 gigawatts from OWFs, took a less considerate action when deciding to develop OWFs in a targeted area. Only after receiving the Environmental Protection Administration's approvals were contentious issues regarding the potential effects on fisheries, shipping activities, and marine ecology taken into consideration and discussed, which was too late. As an effect, criticism surfaced and was focused on how the government should consider the requirements and operations of shippers and fishermen before approving new power projects. Thus, reflecting on the issues, this study sees the importance of assessing the risks of the Taiwan's OWF development which stem from multiple perspectives to overcome the difficulties and prevent any controversies during the decision-making processes.

Risk assessment is a process that focuses on identifying potential threats to asset performance, which is often associated with uncertainties within a system. Van Hoof et al. [15] argued that uncertainties are unavoidable, especially in the context of OWFs' maritime safety impacts due to the inherent randomness of the system and lack of knowledge of the system. Prior studies asserted that assessing the risks potentially provides the decision makers with a mitigation strategy against failures within OWF development [1,12]. Moreover, the assessment is not only for avoiding the negative consequences of natural events but also results in the benefits of other aspects. Rawson and Brito [6] claimed that the need for further exploration of risk assessment is advantageous to decision makers for making informed, evidence-based, and reliable decisions on the safety of the OWF developments, by relying on the risk analysis' outputs and safety studies. However, the literature addressing the risks tends to assess them separately. Wu et al. [16] argued there is a lack of a comprehensive exploration in the literature that includes the risks from multiple perspectives. Therefore, this study conducts a risk assessment from a diverse risk-based perspective, namely, feasibility, environmental, economic, and safety risks.

Nevertheless, there is unclear and inconsistent knowledge as to which risks need to be prioritized in developing OWFs, as studies have highlighted different determining attributes. For instance, studies focusing on assessing the feasibility risks on the social impact found that public acceptance from the local residents plays a huge role in developing OWFs [8,17]. However, similar studies on improving the social impact have indicated that employment stability is among the most important attributes [18,19]. Studies addressing the environmental risks focused on the natural occurrences causing technical durability and damages [12,16]; yet these studies had not considered the people residing in the immediate surroundings. From the economic perspective, many studies focused on exploiting the economic risks and figuring out a strategy to reduce costs generated by operation and maintenance activities [2,13]; meanwhile, Tuyet and Chou [14] suggested that the risks should not be limited to cost consideration but also government subsidies. Regarding the safety risks, Xue et al. [20] argued that studies on the site selection of OWFs in busy waterways are still scant, especially against the influencing factors such as the navigation safety. Overall, Brignon et al. [21] pointed out that risk-based assessment, which focuses on describing the likelihood of negative consequences, is effective when there is a lot of uncertainty and little knowledge, making the decision-making process difficult and unreliable.

The literature has examined the attributes and indicated that the uncertainty of decision-making information in OWFs' risk assessment is attributed to two reasons [16,20]. Firstly, uncertainty emerges in the planning and feasibility study stage which primarily involves the pre-estimation of future circumstances. Secondly, the uncertainly is implied in the decision-making information provided based on experience and knowledge of experts which are subject to ambiguity. To tackle this challenge, studies have recommended several tools, such as adopting fuzzy set theory and multi-criteria decision-making methods that are heavily based on expert judgement [6,19]. Therefore, this study employs an integration of methods including the fuzzy Delphi method (FDM) and fuzzy decision-making trial and evaluation laboratory (FDEMATEL). Initially, a multi-layer of risk assessment attributes for OWFs is developed by combing prior studies. For validation, the FDM is used to deal with the wide range of risk attributes and results in a multi-perspective valid framework through selecting and eliminating the less important attributes [22]. FDEMATEL is an effective method to not only identify the driving attributes but also the interrelationships among each attribute [23,24]. Thus, the study's objectives are as follows:

- To develop a valid framework of risk assessment attributes with qualitative information;
- To examine the attributes' cause and effect interrelationships under uncertainty;
- To identify important multi-perspective-based criteria for offshore wind farm development in Taiwan.

The concept of risk assessment is in the literature and the attributes have been widely addressed. However, a lack was identified in examining the attributes' interrelationships from multiple perspectives and connecting this with the OWFs' site selection prioritization under uncertainty. Therefore, this study proposes three main contributions that cover the theoretical and practical points of view by answering the aforementioned study's objectives. The theoretical contribution will be focused on expanding the literature, especially on assessing risk attributes of the Taiwan's OWFs development; in the meantime, the practical contributions will be concentrated on providing the practitioners and decision makers with useful insights to lessen the risks in practices during the OWFs development.

The rest of the study is organized as follows. Section 2 presents the literature review, proposed measures, and proposed method. Section 3 consists of expert characteristics, and methodology. Section 4 presents the results. Theoretical and practical implications are discussed in Section 5. Section 6 presents the conclusion, study's limitations, and future directions for future studies.

Industrial Background

The geographical location of Taiwan provides the island nation with excellent winds in the form of airflow and monsoon from southwest in summer and northeast in winter [19]. The government announced the "Thousands of Wind Turbine Projects" and the "Demonstration Method of Offshore Wind Power Generation" [8]. Offshore wind generation is expected to be pushed using the land first, offshore later, shallow sea first, and deep sea later strategies, with the goal of increasing Taiwan's energy independence and lowering carbon dioxide emissions. The lack of fossil energy supplies is posing a serious threat to Taiwan's energy security. OWFs have the potential to partially replace thermal and nuclear power generation. Offshore wind generating capacity in Taiwan is anticipated to reach 3000 MW, or 7.3 percent of total installed capacity in 2016. However, problems started to occur as the government planned a 15 MW OWF as a pilot project, including protests from fishermen addressing their concern on the environmental impacts on marine life and fishery viability due to lack of risk assessment [18]. Other studies have suggested assessing the other risks related to the economic, social, and safety criteria beside the impact on the wildlife and fishery industry, such as government funding, local employment, and navigation safety [6,14]. Thus, it is imperative to address these risks.

2. Literature Review

This section reviews the literature on risk assessment and presents the proposed measures, and proposed method.

2.1. Risk Assessment

The concept of risk is based on the likelihood that a phenomenon with negative consequences possibly occurs, which is affected by a wide range of attributes. As a result, risk reduction entails minimizing the consequences of future incidents. Chartres et al. [3] described risks as collective events or hazard's consequences and the likelihood of these events to occur. Prior studies have addressed the consequences as represented by social, regulatory, economic, and environmental implications [1,25]. Therefore, risk assessment is described as a process of identifying potential causes of negative impacts that might threaten the firm's performance and assets as an essential prerequisite to achieve development success [16,26,27]. Brignon et al. [21] detailed that the assessment relies on describing the possibility of adverse effects and is useful in making predictions by eliminating any uncertainties. Wu and Zhang [12] argued that the importance of assessing risks is due to the characteristics of new projects that are subject to a lack of reference information; thus, this creates a challenge for developers especially during construction and operation. However, Rawson and Brito [6] recognized that the existing studies typically consider certain risks from a narrow point of view amongst many others, meaning that a holistic perspective is scarce in the literature. Thus, this study involves a risk assessment of multiple perspectives to address the scarcity.

2.2. Offshore Wind Farm Risk Assessment

Assessing the risks in order to mitigate a failure during a project development requires intensive attention on the many attributes which have been studied in separate studies. At present, there are not many studies working on risk-based attributes holistically. For instance, Shafiee [1] believed that developing OWFs feasibility risks should be considered in mitigating the risks to avoid the negative consequences and to increase production and lower the cost. Virtanen et al. [28] indicated that environment risks are critical to consider due to the natural impacts from the operation and maintenance. Wu et al. [16] studied the economic risks in OWFs from the micro-economic risks in terms of investment in the early phases of development. Nevertheless, in addition to these three risks, studies argued that OWF development is restricted by safety risks in relation to the navigation and safety of human resources [20,29]. Therefore, this study attempts to assess the risks of OWFs from perspectives of feasibility risks, environment risks, economic risks, and safety risks. Specifically, feasibility risks include public acceptance and societal impact. Environment risks are described by the impact on the marine environment and marine life. Economic risks refer to government subsidies and economic impacts. Human safety involves navigation safety and human safety. However, these risks were studied separately, thus lacking a holistic understanding.

The feasibility risks involve risks of acceptance or resistance by stakeholders including by the public and societal impact. Prior studies have indicated that feasibility risks should not be limited to regulations or policy and financial feasibility, but acceptance from the public or residents living nearby the OWF sites needs to be taken into consideration [12,30]. Billing et al. [17] measured public acceptance by incorporating public opinion, response, trust, and preference. Gatzert and Kosub [2] claimed that the risks involve potentially adverse changes in public acceptance or resistance, which result in acceptance or resistance to construction changes in policy schemes. However, Dalton et al. [9] argued that little is known about the potential societal impacts of wind farms on people who have historically used the places where the wind farms are proposed. There are a few studies that addressed the risks from the external perspective of the firm, such as the consequences on local employment that is affected by the change of the environmental condition due to the

OWF's construction [31,32]. Lo et al. [19] asserted that the impact on the local fishery industry and employment must not be neglected.

Studies have addressed the environmental risks from the perspective of natural occurrences and technical damages due to severe weather or environmental conditions [12,16], such as a case of a serious salt spray corrosion affecting the technical durability and technical damages from external forces. However, Leung and Yang [33] emphasized the importance of taking the environmental risks due to the OWF operations into consideration and suggested not narrowing the risks to the impact on the firm's operation and maintenance, but rather the other way around. Though prior studies have focused on the marine environment risks from the perspective of marine life and nature displacement [4,29], Virtanen et al. [28] suggested the risks should also involve the people living in the immediate surroundings of the OWF sites.

Prior studies have exploited the economic risks as a strategy to reduce costs that are potentially caused by operational failures and maintenance [2,13]. Shafiee and Dinmohammadi [34] placed the attention on the economic risk assessment by considering the economic dependence, such as power production losses and logistics and transportation costs, which indicated an expandable exploration and suggested that the economic risks should be incorporated with other aspects. Wu et al. [16] assessed the micro-economic risks by focusing on the costly initial investment in the construction technology and professional equipment procurement. However, studies argued that economic risks should also incorporate the government subsidies to complement the technical feasibility in developing OWFs [14,19].

Safety risks concern the safety of the human resources working on site and the grid connection equipment connecting the wind farms to the electricity grid. Degradation breakdowns result in high maintenance or replacement costs and major power loss, while natural disasters pose catastrophic safety risks to employees and equipment. As a result, according to Shafiee [1], reducing the likelihood as well as the amount of potential risk events during system operation becomes crucial. Moreover, many OWFs, particularly those that are connected to the grid in series, require a high level of safety. Any failure in one of the units in a serial power grid leads the entire system to fail. The safety risks are also linked to the navigation safety from passing vessels which is crucial and must be considered [20,30]. However, there are few studies that include the criteria concerning the safety of the external stakeholders such as the ship crews or passengers and residents [8,29].

In sum, the investigation of risk assessment is based on the perspectives of feasibility, the environment, the economy, and safety risks. This study includes these risks within a framework in the hope of obtaining a holistic understanding to address the aforementioned lack in the literature.

2.3. Proposed Measures

This section consists of the aspects and criteria for OWF risk assessment. There are a total of eight aspects and thirty-two criteria. The aspects include public acceptance, societal impact, impact on marine environment, impact on marine life, government subsidy, economic impact, navigation safety, and human safety.

Public acceptance denotes a risk in establishing and maintaining a relationship between a local community and a development organization. In exchange for their approval or support of the organization or activity, the community holds the development organization to particular standards. The rise of public trust in an organization, the public opinion of an activity, public preference to ownership of the organization, and the public response to the action all contribute to public acceptance [5,17]. Studies have highlighted that the importance of considering public acceptance brings an effective impact on lowering the risks, especially during the initial development of a project [5,30]. However, there are no definite findings on public acceptance in the case of offshore installations, which is greatly reliant on the location of the offshore wind farm. In addition, Dalton et al. [9] argued that little is known about the possible consequences of wind farms on people who have traditionally utilized the places where wind farms are proposed, and just a few studies have incorporated their perspectives and preferences. Thus, public acceptance is considered and assumed to have a driving effect toward eliminating the OWF development risks.

Societal impact refers to a risk in failing to meet human needs and stabilizing social order through policies resulting in significant socioeconomic benefits such as employment opportunities [10,19]. Unless paired with the right policies, the risk is difficult to lower. Zhang et al. [8] suggested that positive impacts on society that potentially lower the OWF development risk come in the form of reward and compensation targeted to the affected community, including the people whose economy relies on the fishing industry within the OWF's development area. However, despite this potential, a further exploration should be conducted, as society often expresses disappointment through protest during OWF development due to unmet compensation [18]. Furthermore, the issue of overlapping traditional fishing grounds and OWF locations has triggered a problem in the form of breaching the fishermen's rights and affecting the local economic stability. Lo et al. [19] claimed that central government and local authorities have a role in promoting OWF development with relevant regulations and policies, which potentially result in lowering the risk in relation to harming the fishing industry. Therefore, this study includes societal impacts and describes this aspect with the risks to local employment, local fishing industry, change of income for fishermen, and policy planning.

Impact of OWFs on marine environment refers to possible risks on the immediate surrounding area where the OWFs are proposed to be developed. Snyder and Kaiser [13] argued that there are positive and negative risks of OWFs on the environment where the negative impact is found within the local area, and the positive impact is global and focused on replacing other forms of electricity generation. The negative risks have been associated with destructive consequences on the natural surrounding environment, usually caused not only by the operating activities, but also the construction phases of OWFs [29,33]. For example, the risks involve oil spillage, chemical substance discharge, and climate change. In addition, the impact on the marine environment may potentially carry a risk that affects the residents in the form of noise and visual impacts [4,33]. However, these studies argued that the impact on the environment seems minor compared to fossil fuel usage. Nevertheless, the impacts on nature and humans should not be overlooked due to the potential development in the future.

Impact on marine life is focused on the risks carried by the OWF development on the marine creatures and habitat near the construction site [9,19]. Prior studies have investigated the impact and pointed out that some creatures such as marine mammals are sensitive to pile-driving pulses at a considerable distance caused during the OWFs' construction and operation; yet, further exploration is needed as a result of increasing development and construction [4,33]. Zhang et al. [8] pointed out that a correlated consequence of the impact on the marine life displacement is with the fishery dynamics and the change in diversity, which effectively leads to an economic aspect on the fishing industry. Therefore, this study assumes that the impact on marine life is an important aspect of risk to be considered toward successful OWF development. The risks of impact on marine life are described with underwater noise impact on marine life, wildlife displacement, sound vibration underwater, and pile-driving during construction.

The government subsidy brings an economic risk in terms of getting an offer of subsidy on capital cost by adopting a feed-in-tariff to promote the OWF development in the forms of Net Present Value, Internal Rate of Return, and Payback Period. Tuyet and Chou [14] described that these economic criteria are based on government subsidies and levies, capital costs, actual generated power, maintenance costs, costs incurred during hurricanes, and other significant characteristics including market electricity pricing and time value of money. The most important criterion in evaluating these economic criteria is cash flow. The cost–benefit relationship of offshore wind systems is used to calculate cash flow. The risk of this subsidy may affect the interest from investors placing investment. The existing capital cost subsidy is insufficiently enticing to investors, and the current feed-in-tariff subsidy is applied similarly to all areas of Taiwan, independent of their unique conditions. Nevertheless, although the majority of studies demonstrate that offshore wind energy is technically possible [34,35], there is a lack of economic viability with government subsidies.

Economic impact is explained with risks related to cost including cost investment, cost-to-benefit ratio, cost of operating and maintenance, and failure cost [19,34]. Prior studies claimed that the risks of high cost can be tackled by sharing the platform for other purposes. For instance, Legorburu et al. [35] proposed a sharing platform for OWFs which results in several benefits including economic savings in the shared infrastructure, operation and maintenance costs, and risks. The economic impact from developing OWFs tends to be deemed lower in cost where studies have made a comparison with other energy sources [10,19]. However, Xue et al. [20] indicated that the selection and installation of wind turbines, as well as the building of auxiliary electrical equipment, will inevitably return to the issue of economic feasibility over the course of a wind farm's whole life cycle. This indicates that the economic risks in terms of costs need to be explored in relation to other influencing aspects.

Navigation safety is focused on the safety risks on the navigating vessels that might influence the installation and maintenance of the offshore wind turbines and the vessels themselves. Xue et al. [20] argued that the problem as to whether different types of wind turbines adapt to the navigation environment of neighboring seas is also important to consider. Thus, studies have been paying close attention to the wind turbine choices for the wind farms. The navigation safety is measured with the turbine spacing, distance from fairway, turbine height and size, and number of turbines in a landscape [20,30,36]. Díaz et al. [37] compared and conducted an analysis of multicriteria to determine the potential OWF's site selection features based on metocean, logistics and facilities, and management (proximity to nearest shore or coast, shipping lanes or fairway, proximity to habitats and subsea facilities) groups of criteria. In the area of OWFs, there are navigation safety issues that might result in collision incidents. Because of the OWFs' installation position, the waves, wind, and current may be affected, which might cause navigation vessels to drift and lose control [29,38]. Dalton et al. [9] pointed out that navigational risks should not be neglected in the literature as the effects might relate to not only the safety but also other aspects such as the changes in catch availability of targeted organisms. Therefore, this study assumes that navigational safety needs to be included and further explored in relation to other aspects.

Human safety is risked by any damage due to collisions; these not only result in destroying the wind turbine and vessel's structure, causing pollution to the environment, but also lead to serious injuries or fatalities. Prior studies have presented the hazards associated to the health and safety of humans, such as safety of maintenance crews, safety of ship crews or passengers, and safety during construction [2,29]. However, there are shortcomings in the literature regarding the human safety in OWFs which are indicated by a lack of adequate assessment model of measures involving their safety.

In sum, the risk assessment is measured in a framework by risk-related aspects including public acceptance, societal impact, impact on marine environment, impact on marine life, government subsidy, economic impact, navigation safety, and human safety, as shown in Appendix A.

2.4. Proposed Method

Prior studies have used either a quantitative or qualitative method, or a combination of both, to suggest risk assessment attributes for the OWFs' development. Legorburu et al. [35] studied the potential aspects based on technological development options, environmental benefits, and market and legal framework using Geographic Information Systems followed with statistical tools. Banach et al. [39] reviewed the literature to identify the effects of OWFs on seaweed cultivation and used in-depth interviews and workshops with the experts to address the public and private standards for feed production. Dalton et al. [9] combined a choice experiment survey and focus groups of recreational boaters to figure out the recreational boaters' preferences for boating trips in relation to OWFs. Cronin et al. [5] conducted a survey using hard-copy questionnaires circulated around the targeted locations for most relevant responses to obtain public perception of OWFs. Billing et al. [17] used mixed methods of qualitative and quantitative approaches by using quantitative data from survey questionnaires and qualitative data from a workshop in order to obtain community perceptions of multi-use OWFs installations.

Moreover, multi-criteria decision-making methods have been used in some studies. For instance, Lo et al. [19] adopted grey DEMATEL to overcome the uncertainty of the evaluation environment and to map the interdependency among the criteria, and applied grey DANP to calculate the weight based on the influence level from the DEMATEL results. Xue et al. [20] explored the attributes using a fuzzy Bayesian network-based multiple-attribute decision making model. However, these proposed methods have not addressed the attributes' validity and interrelationships. Thus, this study integrated the FDM and FDEMATEL to construct a valid set of risk assessment attributes and assess the attributes' interrelationships for fostering the OWFs' development. Chen et al. [40] claimed that the FDM is an effective approach based on experts' judgement for validating the attributes through an elimination process. Tseng et al. [41] suggested that FDEMATEL is effective in visualizing the attributes' interrelationships, and it calculates the power of each influence. Therefore, the integration of these methods is appropriate to address the study's objectives.

3. Methodology

This section presents the industrial background, fuzzy Delphi method, and fuzzy decision-making trial and evaluation laboratory.

3.1. Experts' Characteristics

As shown in Appendix C, this study assembles a panel of 15 experts from the industry at the managerial level based on years of experience, with 7 years minimum at positions working in the industry, as well as academicians who have done in-depth research in the field of offshore wind farms and risk assessment, who were chosen using a purposive sampling method based on extensive professional and academic experience and knowledge. To avoid biases from the academics, in the expert selection process the academic experts must have done field research in the field of OWFs. This expert group was approached to provide feedback through e-mail correspondence and interview on the importance and selection of OWF development risk assessment criteria as proposed by this study.

3.2. Fuzzy Delphi Method

Based on expert comments, the FDM is used to improve the questionnaire's reliability and validity [42]. The number of experts varies in different studies; commonly the number is between 10–20 experts and there is no specific proportion for the background of the experts [43–45]. For example, Marlina et al. [45] involved 10 experts including eight experts from the government and two from non-governmental organizations. As shown in Table 1, the method allows quantitative input in the form of language preferences to be transformed into crisp values, utilizing triangular fuzzy numbers (TFNs). Prior studies used TFNs for examining expert judgements in multi-attribute decision-making approaches [22,23,40]. Furthermore, the FDM closely mirrors expert opinions.

Table 1. Triangular fuzzy numbers linguistic scale/terms.

Linguistic Terms (Importance)	Corresponding Triangular Fuzzy Numbers
No importance	(0.0, 0.1, 0.3)
Low importance	(0.1, 0.3, 0.5)
Moderate	(0.3, 0.5, 0.7)
Important	(0.5, 0.7, 0.9)
High importance	(0.7, 0.9, 1.0)

To address the linguistic preferences of the experts, the FDM is used [46]. TFNs are created by translating the linguistic terms (see Table 1). The expert y evaluates the significance of attribute x using linguistic preferences scaled from 'no importance' to 'high importance' in a five-point Likert style scale, which then are transformed into TFNs as $w = \left(l_{xy}; m_{xy}; u_{xy}\right)$; $x = 1, 2, 3, \ldots, n$; $y = 1, 2, 3, \ldots, t$; where l, m, u, respectively, stand for 'lower limit', 'middle limit', and 'upper limit' of the transformed linguistic information using corresponding TFNs.

Afterwards, w_x represents the weight of attribute x and is defined as

$$w_x = (l_x; m_x; u_x) \tag{1}$$

where $l_x = \min\left(l_{xy}\right)$, $m_x = \left(\prod_1^t m_{xy}\right)^{1/t}$, and $u_x = max\left(u_{xy}\right)$.

The following equation is then used to obtain the value of O_x which is the defuzzification step using the average of aggregated weights of w_x:

$$O_x = \frac{l_x + m_x + u_x}{3} \tag{2}$$

Finally, in order to establish which attributes are legitimate, the threshold $\mu = \sum_{x=1}^{n}(O_x/n)$ is created. When $O_x \geq \mu$, the attribute x is valid and thus accepted. If $O_x \leq \mu$, the attribute x is rejected.

3.3. Fuzzy Decision-Making Trial and Evaluation Laboratory

The fuzzy DEMATEL approach is used to simplify the intricate relationships between attributes by transforming expert linguistic preferences into fuzzy values. Using a pairwise comparison, the relationships between each pair of attributes in the attribute set $A = \{a_1, a_2, a_3, \ldots, a_n\}$ are clarified. The fuzzy direct relation matrix is put up using linguistic preferences that vary from VLI (very low influence) to VHI (very high influence), as shown in Table 2. There are y members in the committee, and the fuzzy weight $\tilde{x}_{ij}^{y}$ refers to how the i^{th} attribute affects the j^{th} attribute information provided by an expert y^{th}.

Table 2. FDEMATEL linguistic terms' transformation table.

Scale	Linguistic Preferences	Corresponding Triangular Fuzzy Numbers
VLI	Very low influence	(0.0, 0.1, 0.3)
LI	Low influence	(0.1, 0.3, 0.5)
M	Moderate	(0.3, 0.5, 0.7)
HI	High influence	(0.5, 0.7, 0.9)
VHI	Very high influence	(0.7, 0.9, 1,0)

The weighted values are then aggregated using the fuzzy membership function $\tilde{g}_{ij}^{y} = \left(\tilde{g}_{1ij}^{y}, \tilde{g}_{2ij}^{y}, \tilde{g}_{3ij}^{y}\right)$. The following equation is used to convert the appropriate fuzzy numbers:

$$A = (a\tilde{g}_{1ij}^{y}, a\tilde{g}_{2ij}^{y}, a\tilde{g}_{3ij}^{y}) = \left[\frac{\left(g_{1ij}^{y} - ming_{1ij}^{y}\right)}{\Delta}, \frac{\left(g_{2ij}^{y} - ming_{2ij}^{y}\right)}{\Delta}, \frac{\left(g_{3ij}^{y} - ming_{3ij}^{y}\right)}{\Delta}\right] \tag{3}$$

where $\Delta = maxg_{3ij}^{y} - ming_{1ij}^{y}$

The left (lv) and right (rv) values are converted into normalized values, and the normalized crisp values (ncv) are determined using the equations below:

$$(lv_{ij}^{n}, rv_{ij}^{n}) = \left[\frac{ag_{2ij}^{y}}{(1 + ag_{2ij}^{y} - ag_{1ij}^{y})}, \frac{ag_{3ij}^{y}}{(1 + ag_{3ij}^{y} - ag_{2ij}^{y})}\right] \tag{4}$$

$$ncv_{ij}^{y} = \frac{\left[lv_{ij}^{y}\left(1 - lv_{ij}^{y}\right) + \left(rv_{ij}^{y}\right)^{2}\right]}{\left(1 - lv_{ij}^{y} + rv_{ij}^{y}\right)} \tag{5}$$

The synthetic value obtained by applying the following equation to each expert's individual preference is used to compute their preference:

$$\tilde{g}_{ij}^{y} = \frac{\left(ncv_{ij}^{1} + ncv_{ij}^{2} + ncv_{ij}^{3} + \ldots + ncv_{ij}^{y}\right)}{y} \tag{6}$$

An $n \times n$ initial direct relation matrix $(IDRM)$ is obtained as $IDRM = \left[\tilde{g}_{ij}^{y}\right]_{n \times n}$, where $\tilde{g}_{ij}^{y}$ represents the extent to which criterion i influences criterion j. Then, $IDRM$ is normalized $(NIDRM)$, as follows:

$$NIDRM = \omega \otimes IDRM \tag{7}$$

where $\omega = 1/{}_{1 \leq i \leq y}^{max} \sum_{j=1}^{y} \tilde{g}_{ij}^{y}$.

The following equation is used to calculate the total interrelationship matrix $(TIRM)$:

$$TIRM = NIDRM(1 - NIDRM)^{-1} \tag{8}$$

where $TIRM = \left[tirm_{ij}\right]_{n \times n}$ $i,j = 1,2, \ldots, n$.

Finally, the equation below is used to create the (α) and the dependent value (β):

$$\alpha = \left[\sum_{i-1}^{n} tirm_{ij}\right]_{n \times n} = [tirm_{i}]_{n \times 1} \tag{9}$$

$$\beta = \left[\sum_{j-1}^{n} tirm_{ij}\right]_{n \times n} = \left[tirm_{j}\right]_{1 \times n} \tag{10}$$

A causal interrelationship diagram is shown using $(\alpha + \beta)$ and $(\alpha - \beta)$ as the horizontal and vertical axes, respectively. The level of significance of each attribute is specifically specified by $(\alpha + \beta)$; the greater the value of $(\alpha + \beta)$ assigned to an attribute, the more significant it is. Then, $(\alpha - \beta)$ is to determine if the qualities belong to the cause or effect group. The attribute belongs to the cause group if $(\alpha - \beta) > 0$; otherwise, it belongs to the effect group.

4. Results

This section presents the results of the FDM for validity and FDEMATEL for aspects of interrelationship and top criteria.

4.1. Attributes Validity

Initially, this study proposed 32 criteria. As a result, the FDM arrived at a confirmed set of 16 criteria, as summarized in Appendix B, which includes the weight and threshold values for the selection and elimination process of the initial set. Experience and judgement from the expert panel were used for evaluation and then converted to the corresponding TFNs. The FDM managed to refine the important criteria with the threshold $\mu = 0.3903$, as seen in Appendix B. The 16 accepted criteria were then subsequently renamed. The FDM sorts the invalid attributes. The valid attributes are represented in Table 3. The linguistic preferences are transformed to TFNs. The TFNs are defuzzified into precise and crisp values, where the defuzzification process follows Equation (2).

Table 3. Valid attributes.

Perspectives		Aspects		Criteria
Feasibility risks	A1	Public acceptance	C1	Public trust in environmental regulations
	A2	Societal impact	C2	Local fishery industry
			C3	Change of income for fishermen
			C4	Policy planning
Environmental risks	A3	Impact on marine environment	C5	Chemical substance discharge
			C6	Noise impact on residents
	A4	Impact on marine life	C7	Sound vibration underwater
			C8	Pile-driving during construction
Economic risks	A5	Government subsidy	C9	Internal Rate of Return (IRR)
	A6	Economic impact	C10	Cost of investment
			C11	Cost-to-benefit ratio
			C12	Cost of operating and maintenance
Safety risks	A7	Navigation safety	C13	Turbine spacing
	A8	Human safety	C14	Safety of maintenance crews
			C15	Safety of ship crews or passengers
			C16	Safety during construction

4.2. Cause and Effect Model

With the application of FDEMATEL, and after generating the total normalized crisp values using Equations (3)–(5), the direct relationship matrix and normalized direct matrix for the aspects are generated using Equation (7), which aggregated the normalized crisp values from all experts, as shown in Tables 4 and 5, respectively.

Table 4. Direct relationship matrix of aspects.

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**
A1	0.769	0.160	0.223	0.342	0.308	0.266	0.136	0.175
A2	0.669	0.849	0.132	0.212	0.056	0.472	0.421	0.200
A3	0.634	0.649	0.849	0.267	0.081	0.209	0.264	0.767
A4	0.184	0.159	0.234	0.813	0.440	0.342	0.180	0.226
A5	0.080	0.131	0.455	0.370	0.866	0.347	−0.015	0.122
A6	0.156	0.285	0.098	0.136	0.505	0.905	0.047	0.060
A7	0.315	0.146	0.261	0.175	0.081	0.446	0.861	0.692
A8	0.598	0.697	0.548	0.460	0.516	0.564	0.264	0.876

Table 5. Normalized direct relationship matrix of aspects.

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**
A1	0.207	0.043	0.060	0.092	0.083	0.071	0.037	0.047
A2	0.180	0.228	0.036	0.057	0.015	0.127	0.113	0.054
A3	0.170	0.174	0.228	0.072	0.022	0.056	0.071	0.206
A4	0.049	0.043	0.063	0.219	0.118	0.092	0.048	0.061
A5	0.022	0.035	0.122	0.099	0.233	0.093	−0.004	0.033
A6	0.042	0.077	0.026	0.037	0.136	0.243	0.013	0.016
A7	0.085	0.039	0.070	0.047	0.022	0.120	0.232	0.186
A8	0.161	0.187	0.147	0.124	0.139	0.152	0.071	0.235

Equations (8)–(10) are employed to create the total interrelationship matrix and show the cause–effect diagram based on $(\alpha + \beta)$ and $(\alpha - \beta)$, as shown in Table 6. $(\alpha + \beta)$ is depicted on the horizontal axis indicating the prominence, meanwhile $(\alpha - \beta)$ represents the vertical axis, showing the influence of the relationship. The same two equations were repeated to obtain the cause and effect diagram based on the values of $(\alpha + \beta)$ and $(\alpha - \beta)$ for the criteria assessment.

Table 6. Total interrelationship matrix and cause–effect interrelationships among aspects.

	A1	A2	A3	A4	A5	A6	A7	A8	α	β	$(\alpha+\beta)$	$(\alpha-\beta)$
A1	0.536	0.317	0.312	0.359	0.368	0.403	0.204	0.303	1.891	2.681	4.572	−0.790
A2	0.619	0.613	0.335	0.376	0.349	0.578	0.365	0.388	2.291	2.357	4.649	−0.066
A3	0.825	0.762	0.725	0.552	0.507	0.681	0.424	0.753	3.372	2.114	5.486	1.257
A4	0.380	0.347	0.344	0.529	0.446	0.467	0.235	0.348	2.047	2.186	4.232	−0.139
A5	0.320	0.320	0.398	0.369	0.545	0.430	0.148	0.290	1.953	2.215	4.167	−0.262
A6	0.280	0.307	0.221	0.239	0.395	0.555	0.136	0.200	1.441	2.559	4.000	−1.119
A7	0.560	0.465	0.443	0.413	0.414	0.632	0.529	0.622	2.295	1.375	3.671	0.920
A8	0.861	0.827	0.693	0.674	0.730	0.879	0.448	0.818	3.785	2.082	5.866	1.703

The results, as depicted in Figure 1, reveal that the causal group consists of human safety (A8), impact on marine environment (A3), and navigation safety (A7); whereas public acceptance (A1), societal impact (A2), impact on marine life (A4), government subsidy (A5), and economic impact (A6) belong to the effect group, implying that the aspects that belong to the effect group cannot independently be improved without the improvement of the aspects in the cause group. Based on the total interrelationship matrix, each aspect has a different power toward the others, for instance A8 shows to have a strong power toward A1, A2, and A6, and indicates a medium power toward A3, A4, and A5. A3 shows to have a strong power toward A1 and medium power toward A2, A6, and A8. As for the weak power-based interrelationships, A7 weakly affects A6, A8, and A1, while A3 affects A4 and A5.

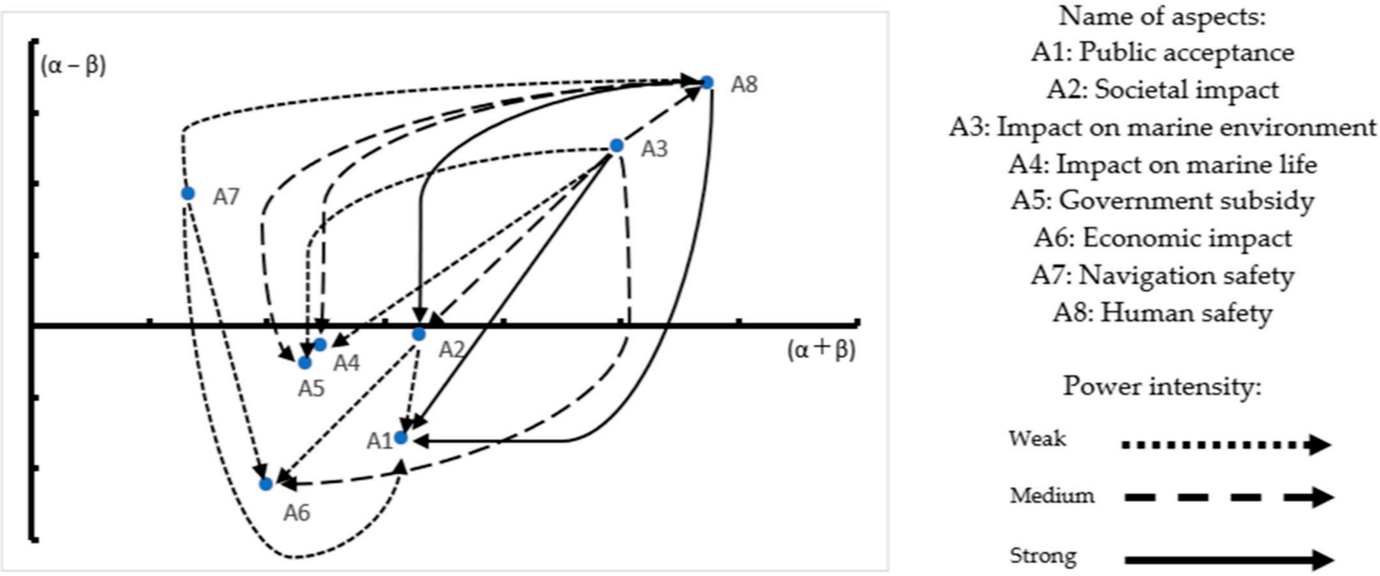

Figure 1. Risk assessment cause and effect model of aspects.

Undergoing a similar procedure, the crucial criteria are obtained. Table 7 presents the cause–effect model for the criteria.

Table 7. Cause–effect model for criteria.

Criteria	α	β	$(\alpha+\beta)$	$(\alpha-\beta)$
C1	1.891	1.654	3.545	0.238
C2	2.097	1.631	3.728	0.466
C3	1.815	1.700	3.514	0.115
C4	1.679	2.077	3.755	−0.398
C5	1.275	1.567	2.842	−0.292
C6	1.656	1.478	3.134	0.179
C7	1.479	1.614	3.092	−0.135
C8	1.280	1.512	2.792	−0.232
C9	1.442	1.604	3.046	−0.162
C10	1.124	1.768	2.892	−0.644
C11	0.697	1.834	2.531	−1.137
C12	0.869	1.634	2.503	−0.765
C13	1.669	1.256	2.926	0.413
C14	2.481	1.449	3.930	1.032
C15	2.649	1.427	4.075	1.222
C16	1.536	1.435	2.970	0.101

The findings indicate that safety of ship crews or passengers (C15), safety of maintenance crews (C14), local fishing industry (C2), public trust in environmental regulations (C1), and change of income for fishermen (C3) are the top criteria, as depicted in Figure 2 below.

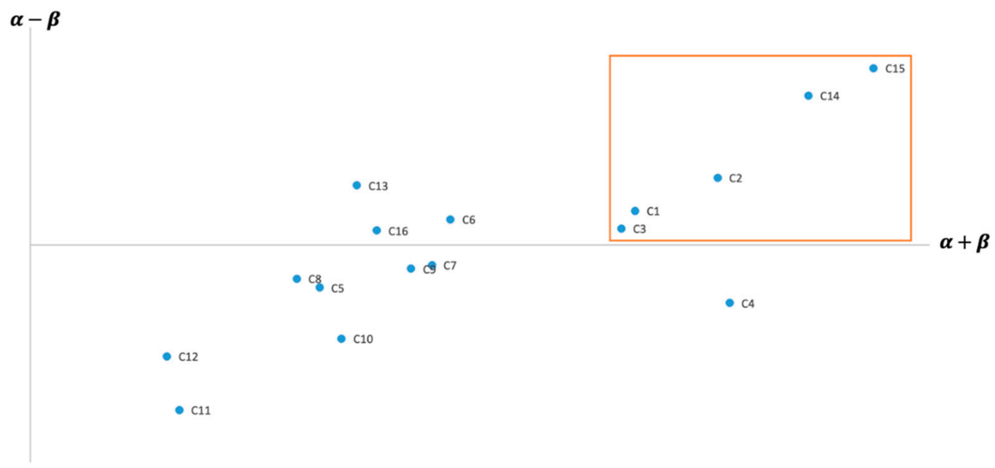

Figure 2. Cause–effect diagram for criteria.

5. Discussion

This section discusses the theoretical and practical implications based on the findings. The theoretical implications are based on the three driving aspects included in the causal group as drawn in the upper side of the diagram in Figure 1, including human safety (A8), impact on marine environment (A3), and navigation safety (A7). Meanwhile the practical implications are based on the top five criteria shown in Figure 2 which include safety of ship crews and passengers (C15), safety of maintenance crews (C14), local fishing industry (C2), public trust in environmental regulations (C1), and change of income for fishermen (C3).

5.1. Theoretical Implication

The results presented in Figure 1 and Table 6 represent the theoretical implications based on how the aspects are interrelated to each other. Further, the results demonstrate the significance of the aspects to affect risk assessment in developing OWFs, and the intensity power of each of the interrelationships. Thus, referring to Table 6, the most critical aspect is human safety (A8), which has the highest $\alpha - \beta$ value of 1.703. The aspect is implied to have more impact than any other aspects in the cause group. Figure 1 also indicates that an improvement of this aspect will have a significant impact toward public acceptance (A1), societal impact (A2), and economic impact (A6). Therefore, human safety is an aspect that needs to be primarily considered when assessing the risks for OWF development. Nevertheless, human safety refers to ensuring the safety of people who are present in the nearby area of the development. Human safety is potentially affected by the activities of passing vessels within the range of development area. In other words, human safety is based off any potential risk of damage caused by any collisions that might result in serious injuries or even fatalities. In lieu of this, prior studies have shown a similar argument pointing out that this aspect should be linked to the activities during construction, maintenance, and operations that may not only damage the environment but also harm the safety of humans at any stage of the development [2,29]. Moreover, this study suggests that human safety corresponds to navigation safety, as prior studies have pointed out that the hazards associated to the health and safety of humans are potentially caused by collisions of the structure with the navigating vessels [9,20]. In addition, ensuring the concentration on the risk of human safety strongly affects acceptance by the public regarding the development, societal impact, and economic impact. Therefore, lowering the risk of harming people's safety during the different phases of the development potentially fosters the overall success of OWF development.

The next critical aspect, according to the results seen in Table 6, is impact on marine environment (A3) with $\alpha - \beta$ value of 1.257. The results also indicate that improvement of this aspect will significantly improve public acceptance (A1), which might imply that the local community understands the importance of protecting the marine environment either for an economic reason or an environmental one. Therefore, the risk of impact on the environment is imperative to be considered in assessing the risks for developing OWFs. The marine environment is at risk of being negatively impacted due to destructive activities during the different phases of development including the construction, operations, and maintenance. Prior studies have agreed that the marine environment is heavily impacted by incidents such as oil spillage, discharge of chemical substance, and visual and noise disturbances [4,29,33]. However, it has been argued that the impact on the marine environment is not merely negative on a global scale, which is concentrated on OWFs being an environmentally friendlier alternative energy-generating source compared to the other inland sources [13]. Nevertheless, taking the impact on the marine environment into account is a necessary step during a risk assessment. Furthermore, the impact corresponds to giving strong effects toward how the public socially accepts the development of OWFs, meaning when assessing the risk on the marine environment, the aspect of public acceptance should not be neglected.

The last critical aspect in the cause group that has an effective influence toward developing OWFs is the concern on navigation safety (A7) with $\alpha - \beta$ value of 0.920. This aspect is highlighted on the necessity that the safety of the people to be taken into account during a risk assessment for OWFs development. The safety refers to the vessels or vehicles that navigate within the range area of where the development is located offshore, bringing a risk of collisions or damages to the structure or the vessel which potentially harms the marine environment and humans. The influence from the passing vehicles might affect the installation, operation, and maintenance activities. In addition, this finding is supported by prior studies that pointed out that other aspects, such as different types of technology features and marine life, influence the adaptation of navigation environment [9,20]. Therefore, based on the results, assessing and considering the risk of navigation safety during the development planning moderately affects other aspects including the impact on the economy, human safety, and public acceptance.

In sum, this study suggests that the aspects of human safety, impact on marine environment, and navigation safety be prioritized when assessing risks for OWF development. These aspects should also be interconnected to others in terms of their effects on other related aspects such as public acceptance, societal impact, and economic impact.

5.2. Practical Implications on Taiwan's Offshore Wind Farm Development

The discussion of this study's practical implications refers to the results presented in Figure 2 and Table 7, which show the top five criteria located in the cause group based on the highest $\alpha - \beta$ values. The following discussion of practical implications is divided into the risk perspectives to which the criteria belong. Safety of maintenance crews (C14) and safety of ship crews or passengers (C15) are discussed under the safety risk perspective with $\alpha - \beta$ values of 1.032 and 1.222, respectively; meanwhile, local fishery industry (C2), public trust in environmental regulations (C1), and change of income for fishermen (C3) are discussed under the feasibility risk perspective with $\alpha - \beta$ values of 0.466, 0.238, and 0.115, respectively. Overall, these findings imply that there are five top practical risk criteria that need greater attention than the others if the OWFs' development in Taiwan is expected to be a success. By prioritizing these top risk criteria, most of the unanticipated obstacles during the OWF development should be able to be avoided. Thus, the following is the practical implications discussion.

5.2.1. Practical Implication from Safety Risk Perspective

The findings from the safety risk perspective include safety risks of maintenance crews and ship crews or passengers.

The discussion of maintenance crew's safety risk relates to relevant cases in Taiwan in 2020 when a piling hammer and pile suddenly fell off the construction vessel during hammering operations for the Changhua offshore wind farm in Taiwan, which halted the project development while carrying out further investigation. The incident highly exposed the on-site crews to high risks due to the snap loads following the drop. Another case took place in Taiwan's OWFs in Penghu which have experienced an incident involving a fatality of an on-site crew member due to a hydraulic door. This highlights the importance of prioritizing the safety of maintenance crews on the site during operations. An effective risk assessment for this criterion is imperative for site managers and contractors by ensuring that all the crew on site are properly informed and educated about the risks and hazards that may arise while performing their duties, in particular regarding electrical hazards and how to work with specific tools and materials. A proper provision of personal protective equipment for the crews during the maintenance process should be a bare minimum of standards of operation. In practice, when a scenario such as a blade failure occurs, the maintenance crews are unable to immediately reach the wind farm due to its location. During an unfriendly weather situation, these maintenance crews might have to face a risky situation which potentially causes personal injuries which range from electroshock and mechanic wounds, to falls into water and falls from heights. For better safety insurance, the contractors or site managers should support the crews with a certified personal fall arrest system. In the open offshore or sea, the weather conditions are dynamic, such as storms with lighting strikes, strong winds, and huge waves; these conditions require proper monitoring using data trends as an attempt to anticipate and predict the weather changes in the near future for proper maintenance scheduling.

Additionally, the safety of ship crews or passengers of the navigating vessels needs prioritizing as one of the top risk criteria to foster the OWF development. In Taiwan, the safety of crews can be maximized by meeting the legal framework for health and safety at work specialized for OWFs, preferably from The Central Occupational Safety and Health Center under the Occupational Safety and Health Administration, Ministry of Labor. This finding is focused on prioritizing lowering the risk of injuries and fatalities at all the phases of development. In the surrounding waters, there is an ocean-bound commute that goes through the various conditions of weather and sea, making the concern of crew or passenger safety rise in terms of severity. For instance, during a crew transfer from vessel to turbine, risks related to safety of the ship crews or passengers might be due to collisions with the turbine structure or a large wave, motion sickness, mental stresses, or other illnesses triggered by the changing environment and journey from shore to turbine. The process of transfer itself is one of the most common health and safety hazards for ship or workboat crews. The transfer refers to when the ship or boat pulls up against the turbine and the crew disembarks and climbs onto the turbine. Therefore, it is necessary that the ship or boat stays stable to create a steady standing base for the crews or passengers. However, if the correct data is obtained, these safety risks should be able to be mitigated. Operators should improve their understanding of when bow slippage is most probable by constantly assessing the boat's stability when parking against a turbine.

5.2.2. Practical Implication from Feasibility Risk Perspective

The risks from the feasibility perspective consist of risks faced by relevant stakeholders of OWFs that are potentially affected by the project development and constructions. The results emphasize local fishing industry communities, public communities, and fishermen. In Taiwan, cases have proven that during the planning and construction of OWFs there have been challenges in forms of protests from the affected stakeholders. Therefore, with the results, this study highlights the importance of lowering the risks that involve the interests of relevant stakeholders of the public or local communities.

The local fishing industry is found to play a significant role in OWFs development. A significant increase in power generated by the OWFs often motivates their development over the risk towards the existence of local fishing industry. This relates to a case in Yunlin County, Taiwan, in 2020, when the wind energy developers failed to have transparent communication with the local fishing communities during the planning which left the community members in the dark. The criticism from the communities was mainly based on their unawareness of how the OWFs' construction would impact their livelihoods. OWF development generally causes significant changes to the environment, including a change or discharge of habitat of the organisms, which potentially disrupts the fishing industry by the coastal communities whose finances hugely depend on the industry. Moreover, the OWF development's disruptions include an increased competition over fishing sea area for fishermen, change of habitats for fish, and a reduced area of fishing access due to turbine structure's safety restrictions. Therefore, in reducing the conflicts between the two parties, the developers and regulators should consider giving open access to fishermen for fishing within the project areas, providing a compensation for the disrupted fishing activities, and offering employment options for the disrupted industry.

Furthermore, the findings show that there is a need to consider the risk of losing public trust in environmental regulations. The importance of having public trust in the regulations that protect the environment is related to the level of acceptance by the communities during the project planning and development processes. This risk should not be neglected as environmental communities (e.g., Changhua Environmental Protection Union protesting in 2021) are becoming more outspoken and demanding towards Taiwan's Environmental Protection Administration due to their concern on the impacts of constructions that cause environmental degradation such as algal reef damage, toxic materials, and air pollution. During the transition of the development, the government should work on convincing the public by educating them about the relevant environmental regulations and help promote the significant benefits of having a renewable energy whose operations and development are relatively less environmentally harmful as compared to the other technology. This study further suggests that the communities must benefit greatly as well from the regulations applied to the development to ensure their activities in relation to the project areas are not significantly disrupted and compensated. In other words, the environmental regulations are not merely focused on regulating the environmental certifications and review works for OWF projects prior to construction, but also identifying and assessing any alternatives and the impacts on the other aspects including social, economic, and culture of the communities.

Lastly, the findings indicate that change of income for fishermen is a crucial risk criterion to assess for OWF development. The majority of fishermen are affected by the project development, and replacement fishing grounds are normally used as a strategy and provided as compensation to maintain their income following displacement from the OWFs. However, in practice, these replacement fishing grounds do not effectively maintain their income, and in fact, the displacement has resulted in conflicts between the two parties. The same case occurring in Yunlin County, Taiwan, as previously mentioned, further caused a significant change to the fishermen income; for example, a fisher who would have normally earned an average of NTD 600,000 per month eventually has only earned as low as NTD 80,000 a month; this case was hugely due to a failure in transparently communicating the OWF's project construction planning by the developers. Thus, this study suggests that the fishermen's income can be optimized through a ground sharing concept of the turbine structure which is free from cable routes to avoid any potential hazards to the fishermen and structural damage to the technology. In addition, the income can be increased by engaging the fishermen in the environmental monitoring and seabed survey by taking advantage of their knowledge and familiarity with the waters and their dynamics.

6. Conclusions

Risk assessment of the OWF development in Taiwan needs to be focused on multiple perspectives to address the existing multifaceted challenges. Several hindering factors include a rejection from coastal community members, impacts on the economy and environment, especially of the fishery industry, and safety related concerns. Nevertheless, the Taiwanese OWF development is promising owing to the ability to generate higher productivity of power with lesser impact in contrast to the other power generating methods. There are scores of papers on risk attributes assessment that demand further exploration. This study aims to propose a framework constructed based on risk-based attributes, identify effective risk aspects to be prioritized, and provide practical insights toward the Taiwanese OWFs constructors or site managers based on the top risk criteria. Either qualitative or quantitative approaches are employed. The abundance of attributes from the literature are combed and tackled using the FDM for the purpose of validation and reliability, while FDEMATEL is applied for understanding the cause–effect interrelationships of the attributes.

This study arrives at a legitimate risk assessment framework consisting of eight aspects with 16 criteria grouped as feasibility, environmental, economic, and safety risks viewpoints after an elimination procedure from the suggested original set of attributes. The results show that the aspects of human safety, impact on marine environment, and navigation safety belong to the causal group. Furthermore, the results identified the top risk criteria consisting of safety of ship crews or passengers, safety of maintenance crews, local fishing industry, public trust in environmental regulations, and change of income for fishermen.

Theoretical and practical implications are presented. It is necessary to ensure the assessment of safety risks of humans present in the development or project areas by minimizing any chance of injury or fatality, and because the aspect is linked to the public acceptance, impact on the society and economy. Moreover, the impact on the environment should be properly assessed in order to lower the risk of any environmental damage or inconvenience. Navigation safety is highlighted as a risk to be properly assessed for the development because it not only affects human health and safety but also other aspects including economic impact and public acceptance. In practice, more attention should be paid to the risks of ship and maintenance crews and passengers. Meeting the standards that regulate the health and safety of humans that are affected by the OWFs' project development should be the bare minimum within the operations. Local fishermen and coastal communities are also at stake to be affected by the development. Specifically, the local fishing industry and the income of the fishermen should be prioritized when assessing the risks. In addition, public trust in environmental regulations should not be neglected because people are concerned about the environmental impacts and issues that may bring disadvantages in the near and long future.

This study's limitations are present. The attributes of risk assessment in the literature are abundant and this study selected a number of studies that should be able to be expanded to a bigger number for more attributes collection. The number of experts involved is limited to 15 respondents; therefore, the future study might extend to more respondents and more diverse positions in the relevant industry. The Taiwanese OWF developments are unique to their own characteristics and challenges; thus, the results are not generalizable to be applied in another country.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Initial attributes of offshore wind farms risk assessment.

Perspective	Aspects	Criteria		Reference
Feasibility risks	Public acceptance	C1	Public opinion of wind turbine power generation	[17,30]
		C2	Public response to installation	[17]
		C3	Public opinion of nearby fishing	[17]
		C4	Public trust in environmental regulations	[17]
		C5	Public preference to ownership	[17]
	Societal impact	C6	Local employment	[19]
		C7	Local fishing industry	[8,30]
		C8	Change of income for fishermen	[8,35]
		C9	Policy planning	[19]
Environment risks	Impact on marine environment	C10	Oil spillage	[19,29]
		C11	Chemical substance discharge	[29]
		C12	Noise impact on residents	[33]
		C13	Visual impact on residents	[4,33]
		C14	Climate change	[33]
	Impact on marine life	C15	Underwater noise impact on marine life	[8,9,19]
		C16	Wildlife displacement	[4,9,13,33]
		C17	Sound vibration underwater	[4]
		C18	Pile-driving during construction	[4]
Economic risks	Government subsidy	C19	Net Present Value (NPV)	[14]
		C20	Internal Rate of Return (IRR)	[14]
		C21	Payback Period (PP)	[14]
	Economic impact	C22	Cost of investment	[19]
		C23	Cost-to-benefit ratio	[19,35]
		C24	Cost of operating and maintenance	[14,19,29]
		C25	Failure cost	[34]
Safety risks	Navigation safety	C26	Turbine spacing	[20]
		C27	Distance from fairway	[20]
		C28	Turbine height and size	[30]
		C29	Number of turbines in a landscape	[30]
	Human safety	C30	Safety of maintenance crews	[29]
		C31	Safety of ship crews or passengers	[29]
		C32	Safety during construction	[2]

Appendix B

Criteria screening out.

Initial Criteria	l_x	u_x	O_x	Decisions
C4	0.0185	0.8565	0.4329	Accepted
C7	−0.0086	0.8836	0.4396	Accepted
C8	0.3373	0.9127	0.5407	Accepted
C9	−0.0934	0.9684	0.4608	Accepted
C11	0.0213	0.8537	0.4322	Accepted
C12	0.0373	0.8377	0.4282	Accepted
C17	0.0280	0.8470	0.4305	Accepted
C18	0.0016	0.8734	0.4371	Accepted
C20	0.0437	0.8313	0.4266	Accepted
C22	0.0346	0.8404	0.4289	Accepted
C23	0.0144	0.8606	0.4339	Accepted
C24	0.0157	0.8593	0.4336	Accepted
C26	−0.0250	0.9000	0.4437	Accepted
C30	0.2957	0.9543	0.5511	Accepted
C31	0.3043	0.9457	0.5489	Accepted
C32	0.2957	0.9543	0.5511	Accepted
		Threshold	0.3903	

Appendix C

Experts' characteristics.

Expert	Position	Years of Exp.	Education Level	Industry/Academia
1	Senior research commissioner	36	Doctoral	Industry
2	Deputy director	29	Doctoral	Industry
3	Assistant professor	7	Doctoral	Academia
4	Assistant professor	15	Doctoral	Academia
5	Professor	33	Doctoral	Academia
6	Engineer of material E&O	30	Masters	Industry
7	Researcher	7	Masters	Academia
8	Associate professor	14	Doctoral	Academia
9	HSSE supervisor	9	Bachelor	Industry
10	HSE supervisor	10	Bachelor	Industry
11	Deputy PSFO	12	Masters	Industry
12	Research assistant	6	Masters	Academia
13	Assistant professor	9	Doctoral	Academia
14	Planning assistant	7	Masters	Industry
15	HSSE and PSFO manager	17	Masters	Industry

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