Critical Risk Factors Associated with Investment in a Renewable Energy Scheme

(A Life Cycle Risk Analysis of an Offshore Wind farm in a Net- Zero Community)

Abstract

Following concerns about climate change, investment in renewables has become essential to achieve net-zero targets. However, there is a gap between essential and actual market share of renewable energy schemes due to associated risks. This research investigates Critical risk factors of investment in a Renewable energy scheme (The case of offshore wind in a net-zero community)". The purpose of the research is to contribute mitigating risks of Renewable energy "in general" and "specific" to Offshore Wind farms to attract more investment. The study follows a combination of a literature review and structured interviews to identify and shortlist risks and then utilizes AHP method to evaluate major risks quantitatively. Based on the findings, Policy risks, Economic, Infrastructure and Technology, Financial and Environmental risks are respectively the most important risk categories for renewable energy investment. Moreover, the study highlights the importance of environmental risk especially for Offshore Wind farms due to nature of the infrastructure, location and severe weather conditions affecting operation and maintenance.

Keywords: Renewable energy, Investment risk, offshore wind

1 Introduction

1.1 Background of the Study

Since the Paris Agreement set ambitious targets to address the impacts of climate change, investing in renewable energy has become an integral part of the sustainable development (Wing and Jin 2015, Karunathilake, Hewage et al. 2019). Furthermore, according to the United Nations Climate Conference (Cop26) held in Glasgow, the goal is to achieve net zero emissions worldwide by the 2050. The energy sector accounts for almost 3 quarters of global gas emissions (Ritchie, Hannah; Roser, Max; Rosado, Pablo;, 2020). Achieving this goal will require global moving to clean energy 4 to 6 times faster than ever before according to the International Energy Agency (IEA) and IRENA (Hamilton, 2021). Figure 1 illustrates that wind power raised to second in the decade since 2010 and coal collapsed to under 2% by the end of 2019 in UK. This means that wind power is the second most common source of electricity in the UK after natural gas growing from 3% to 21% (Wilson, et al., 2020). These figures highlight the tremendous opportunities for investment in wind power in UK. This transition could further be accelerated by the abundant availability of wind energy in UK due to geographic location. However, still this speed of transformation is not sufficient to gain the ambitious net zero emissions by 2050. This shift will require more investment motivations for renewable energy and minimizing the associated risks.

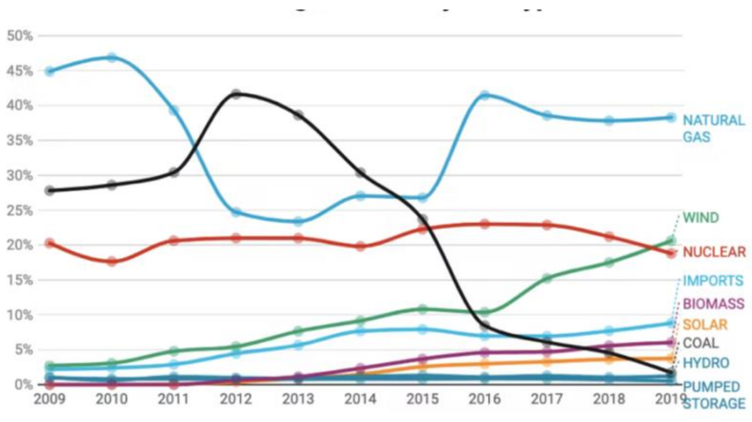

Figure 1:UK electrical generation by fuel type %. Source: Elexon and National Grid

Thus, although some important advances and incentives like financial risk management instruments are available for project investors to encourage them in renewable energy projects, there is still a gap between the essential and current market share of renewable energy. The reason is that investment community still cannot fully grapple with the underlying risk involved in this new investment class (Amenc, Goltz et al. 2010).

The purpose of this study is to provide renewable energy stakeholders with an overview of the risks, to quantify the value of the risks, and to contribute mitigating risks "in general" and "specific" to Offshore Wind plants to attract more investment. It can also be further developed to set the most effective risk response strategies to encourage investors towards zero emission power generation that supports a sustainable planet and ecosystem.

1.2 Climate Change and Emergence of Renewable Energy Investment Agenda

Climate change has become the most important global challenge caused by the consumption of fossil fuels as one of the major contributors to climate change. Cleaner energy solutions are critical to a sustainable future. The development of renewable energies is considered a significant measure to mitigate global climate change through mitigation of CO2 gas emissions (Cong 2013). On the other hand, the use of renewable energy improves the efficiency of the economies at macro-economic levels. It is defined as a simple sustainable resource that will be available free over the long term and can be used for any application without negative side effects (Dincer 1999, Charters 2001). Renewable energy implies minimal environmental impact and production of secondary side-wastes (Aleixandre-Tudó, Castelló-Cogollos et al. 2019).

According to the latest report from Intergovernmental Panel on Climate Change in Glasgow (Cop26), urgent action is needed to substantially reduce emissions causing global warming. RE is the most promising method to get rid of fossil fuels soon (Hussain, Arif et al. 2017, Madi, Pope et al. 2019).

On the other hand, although fossil fuels are not sustainable and have severe environmental and health problems (Curtin, McInerney et al. 2019, Yang, Pang et al. 2021), they are still the main contributor to the energy sector in many countries. The rapid growth of the global population and consequently an exponential growth in energy demand along with renewable energy investment risks are factors that limit fast growth in this emerging market (Olabi and Abdelkareem 2022). The development of renewable energy production and consumptions has been agreed by world key players (governments, commercial organizations, and academic partners) as the best way to deal with climate change and growing energy demand. (Aleixandre-Tudó, Castelló-Cogollos et al. 2019).

1.3 Limits and Characteristics of Renewable Energy Project

RE projects have several characteristics. First, availability is highly dependent on geographic location (Woldeyohannes, Woldemichael et al. 2016). In addition, according to (Chang 2013) , due to the high investment cost of renewable energy, it relies heavily on government subsidies to compete with conventional energy. The profitability of a RES project is highly dependent on the price at which its output is sold to the national grid which is not in investors control (Known as a feed-in tariff). Third, there is power supply uncertainty and variability. This means low-capacity factors due to fluctuations in power generation and the volatility of future revenue streams. Fourth, the project's novelty and new technology limits it to a small number of small provider groups.

1.4 Barriers and Risks to Renewable Energy Investment

Decision makers face different uncertainties and risks while making RE investment decisions. Renewable energy is considered free, always available and derived from natural resources. It also plays a key role in strengthening sustainable solutions that significantly limit greenhouse gas (GHG) emissions (Juszczyk, Juszczyk et al. 2022). Therefore, it makes sense to use such technology, not only to save costs, but above all to save the planet. However, the introduction of renewable energy technologies (RET) into a country's energy mix is not a simple process, it is very difficult, complex, and multifaceted. Such socio-technical transitions include Changes in current technology and regulatory regimes, time-consuming and costly investments in infrastructure, introduction of supportive energy policies, and awareness-raising measures in society. (Olabi and Abdelkareem 2022). A worldwide study of renewable energy trends (Aleixandre-Tudó, Castelló-Cogollos et al. 2019) indicate that although the renewables are instinctively considered to be clean and sustainable, the sustainable development of renewable power is however dependent on several conditions, including economic factors (development and utilization costs), technological factors (Dincer 2000), social acceptance (Wüstenhagen, Wolsink et al. 2007) and environmental constraints (Wüstenhagen, Wolsink et al. 2007) along with other factors (Carley 2009). An Empirical study of barriers in Finland and Poland (Carley 2009) focusing on socio-economic and regulatory issues indicate that energy policies play a central role in adoption of renewables. It is also claimed that RETs[1] require the whole ecosystem to support their successful diffusion.

Another study of challenges and risks of a renewable project with a focus on wind power in Malaysia (Goh, Lee et al. 2014) indicates that economic risk and loss of revenue, also the technical risk play destructive roles in building up the project (Goh, Lee et al. 2014). The initial cost of running a project is high (Goh, Lee et al. 2014). Therefore, a strong financial management will be necessary. This cost will be increased if wind energy needs to be connected to the main power grid, so a larger wind farm will be required. On the other hand, the technical skills play an important role during the wind-turbine installation and after sales services. Even though many of the manufactures claim that wind turbine can be at least last for 20 years; sometimes the problems in sensor, gearbox or even control system can be happened due to wear

[1] Renewable Energy Technologies

and tear condition (Hau 2013). This situation can be worsened in offshore wind by considering accessibility problem and safety issues for human that will increase the maintenance cost of the project (Fairgrieve, Wellard et al. 2021)

The power generated by REs must exceed the demand to maintain the stability of the electrical system due to volatile nature of the energy source (Purvins, Zubaryeva et al. 2011). So, the importance of storage systems and batteries for continuous power supply during periods of low wind density can be emphasized. Other risk factors that can adversely affect investment decisions for wind projects are policies, rules and regulations, and social acceptance such as negotiations with the agriculture and fisheries sectors. Another barrier is funding risk. An evaluation of renewable power carried out in Southern and Eastern Mediterranean Countries in 2021, via a survey of 142 stakeholders in public and personal quarter, shows that despite of the truth that there may be a developing power demand, untapped herbal sources and political commitments to the renewables, non-public funding in renewables continues to be limited. It is also claimed that there is a perception gap between public and private sector about the risks. Furthermore, the research emphasizes that the category of financial risks in both private and public sector is significant. Resolving this problem will require a greater cooperation between the public sector and development finance institutions, not only one establishing financing facilities but also on drafting bankable PPAs[2] and other project documents (Salles, Melo et al. 2004)

According to the research conducted in developed and developing countries with a focus on Sub-Saharan Africa Countries (SSA), RE investment risks can be different on location, stakeholders, or project phases (Abba, Balta-Ozkan et al. 2022).

[2] Power Purchase Agreements

1.5 Renewable Energy Investment in a Net- zero Community

The energy system of a net-zero community is planned with the objective of supplying the community's entire energy demands with locally available RE resources. The planning process is highly complex because it is associated with uncertainties and risks (Wing and Jin 2015). Although renewables are known as sources of clean energy with zero or near-zero emissions during the operational phase (Thompson and Duggirala 2009), their technologies may lead to certain environmental impacts during their construction and operation phases (Raadal, Gagnon et al. 2011, Amponsah, Troldborg et al. 2014). Sunlight and wind are obviously clean, but the infrastructure needed to capture them is not. In 2017, the World Bank released a report modelling the increase in materials extraction needed to build enough solar and wind turbines to generate about 7 terawatts of electricity annually by 2050 which is enough to power about half of the global economy. By doubling the numbers, we can estimate what it takes to achieve zero emissions. The results are astonishing. 34 million tons of copper, 40 million tons of lead, 50 million tons of zinc, 162 million tons of aluminium, and over 4.8 billion tons of iron (Hickel September 2019).

In the last 10-15 years there has been a significant change in the approaches taken around the UK to the planning and management of offshore resources. The Sixth Carbon Budget, published in 2020 by the Committee for Climate Change, also puts the expansion of low-carbon energy supplies at the centre of its recommendations. It proposes fast transition of UK electricity to zero carbon by 2035 and offshore wind becomes the backbone of the whole country’s energy system. It raises the anticipated 40GW of OSW by 2030 target to 100GW, or more, by 2050. To meet this, offshore wind developments will have to deploy at scale in deeper water (Fairgrieve, Wellard et al. 2021). However, the offshore wind plants investment is associated with significant risks especially in environmental aspects that it is often neglected by previous studies.

1.6 Gap Analysis

In the previous studies, most of investment risk in RES focus on Policy and regulatory and financial risks. Some other focus on technological aspects of Investment risks. The environmental consequences of developing a RE infrastructure are often neglected. Furthermore, prior studies identify Investment risk without quantifying the value of the risk. This research has a holistic approach to identify investment risks in a renewable scheme by investigating environmental risks along with other categories in the project lifecycle. It is also the first research on scoring risks for offshore wind power generation assets in a net zero community.

2 Materials and Methods

To achieve research goal, the study follows a quantitative approach in 3 methodological steps illustrated in the Figure 2.

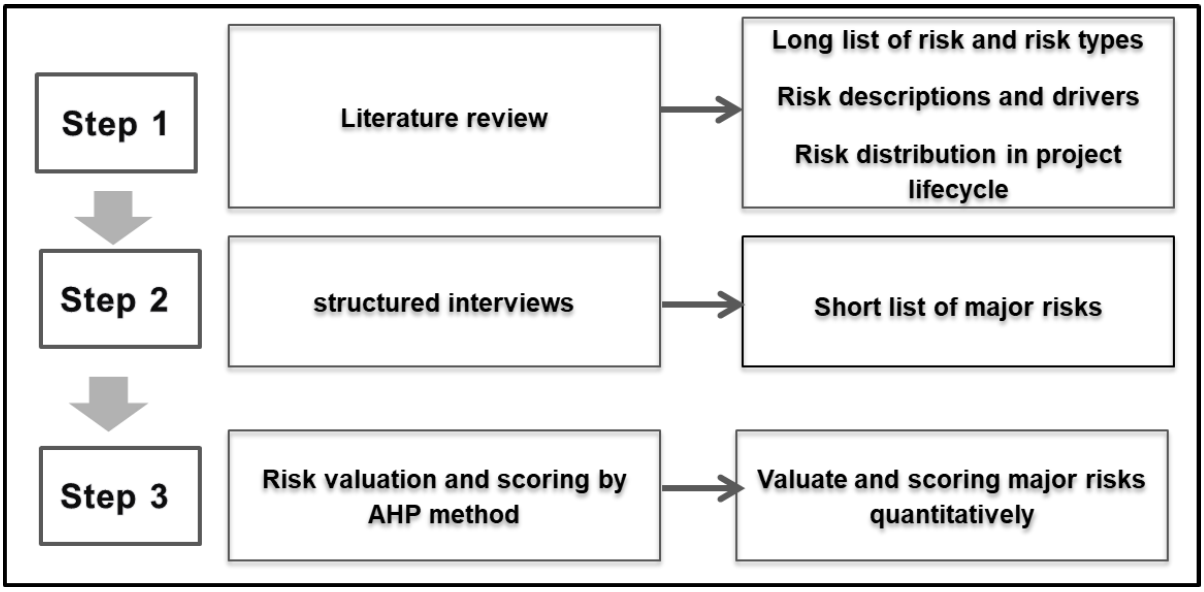

Figure 2: Methodological approach in 3 steps

The research design obtains a quantitative approach. In the first step, a comprehensive literature review on renewable energy risks was performed to identify elements of risks in different categories, risk descriptions and drivers and risk distribution in the RE project lifecycle. 9 risk types were identified to categorizing risks. In the second step, a structured interview with 13 sector experts was conducted to make a short list of major risks. A structured interview is a data collection method that is based on a collection of predetermined questions in a set of order. In this method despite the other types of interviews including unstructured and semi-structured, the questions are planned, and they are often quantitative in nature (George 2022). This type of interviews is less flexible. However, it is most suitable when the researcher has a clear understanding of a topic and seeks for more efficient way of collecting data in terms of time and resources (George 2022). As there was significant prior research around RE risks, the researcher found structured interview the most suitable way to collect data. Appendix A indicates the interview questions. The type of questions in this method is often close ended (dichotomous or multiple-choice), with very simple open-ended questions (George 2022). The researcher used the Linked In platform to identify potential interviewees. This happened through convenience sampling and direct messaging to potential interviewees explaining about the aim and scope of the research using keywords such as “renewable energy”. The author also identified 4 interviewees by snowballing. A Likert scale (Joshi, Kale et al. 2015) was utilized for close ended questions to determine the significance of the risks and interviewees were free to add their opinion for any other risks and their importance level.

The largest portion of interviewees were from UK and the majority including 54% were from wind power sector.

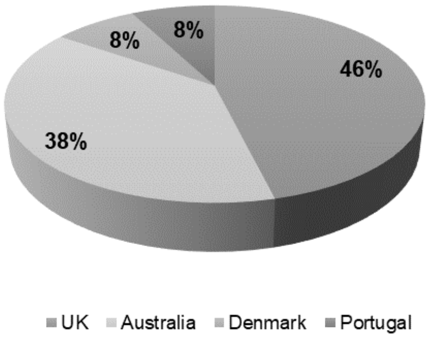

Figure 3: Country considerations for interview participants

Table 1:energy sector considerations for interviewees

Wind power	54%
Solar	8%
Water	8%
etc.	30%

After identifying principal risks and sub criteria's, in third step a survey of 14 participants was conducted to valuate risk quantitatively. To develop risk scoring for shortlisted risks a Multi Criteria Decision Making (MCDM) technique called Analytical Hierarchy Process (AHP) was utilized. AHP is a powerful yet simple and flexible method for making collaborative decisions making in business (Oguztimur 2011). The fundamental part of AHP Procedure form pair-wise comparisons of alternatives. When individual performance indicators are to be combined in an overall key performance indicator, AHP offers a method for determining weights for subjective or objective preference indicators. The method derives ratios from paired combination of individual preference indicators, which results in a ratio scale and consistency index (CI) (Gupta and Tiwari 2016).

3 Results:

3.1 Risk identification, categorization, and lifecycle analysis according to the literature review and structured interviews:

As a result of literature review a long list of 17 risks under 9 risk categories were identified. Also, interviews introduced 3 more risks to the list to be further analysed in the lifecycle of the project. These 3 risks are highlighted in Table 2. The table indicates 20 risks and their placement in the Project lifecycle including Pre-development, Development and Operation and Maintenance phases. It is obvious that the density of the risk in the front end of the RE Project is higher. It means that front loaded risk distribution makes it difficult to get appraisal for the project.

Table 2:Risk distribution by category over project lifecycle

Risk type (Category)	Risk descrption	Project Lifecycle		
		Pre-dev	Dev	O&M
Policy and Regulation	Changing policies	◆		
	Insufficient and ineffective regulatory resources and incentives.	◆		
Economic	Additional investment cost	◆		
	Unstable Macro-economic conditions (interviews)	◆	●	
Financial and Physical Resources	Uncertainty about funding	◆	●	
	Lack of raw materials and supply chain disruption (interviews)		●	
Infrastructure and Technical	Lack of suitable grid infrastructure.	◆	●	
	Immature Electricity storage tech	◆		▲
	Lack of technical skills and Technology requirements		●	▲
Operational and Maintanance	High O&M cost			▲
	Lack of maintenance skills of technicians and engineers			▲
	Safety issues and human life for maintenance.			▲
Market	Sensitivity of competitiveness of RE to prices of conventional energy sources	◆		
	Variability of Power supply	◆		▲
	Limited market size and consumer data availability.	◆		
Environmental	Climate change and natural disasters disruption (interviews)			▲
	Displacing Coastal and Marine Infrastructure (Commercial Fisheries , Shipping and Navigation)	◆		▲
	Loss of habitats and species			▲
Social	lack of Social acceptance	◆		
Credit and Enterprise	lower revenue in renewable energy and damage to reputation	◆		▲
		Pre-Development risk	Development Risk	Operation & Maintanance Risk
		◆	●	▲

On the other hand, majority of risk types including Policy and regulation, economic and financial issues exist in the early stages of the project. By moving to the next stages, technical and operation risks become more important. Also, environmental, and social risks are in both project appraisal and later stages. All risks factors identified are according to the following section.

3.1.1 Policy and regulation risks

3.1.1.1 Changing policies

Changing Policies risk refers to the possible losses brought by the changes in regulations about access policy, price policy, feed-in- tariff, tax, and industry regulation, at the national level in renewable energy investment projects. In UK and other Net-zero communities although there has been long term planning and commitment to invest in REs, the policies are still changing in many countries considering the level of development in those countries and maturity of RE technology. Limited duration of subsidies due to limited mechanism lifespan, excessive focus on competition and low costs, mechanism uncertainty, unresolved planning and electricity grid network issues and policy uncertainty or excessive change are some indicators of policy failure in adopting renewable energy (Wood and Dow 2011).

3.1.1.2 Insufficient or ineffective regulatory resources and incentives

Government policies are very important for investment decisions and incentives are the trigger factor. Without appropriate incentives and regulation, renewable energy investment could decline precipitously (Ozorhon, Batmaz et al. 2018). According to interviews, renewable energy development policies and regulations can be inadequate or excessive, complex, and inefficient. Over the last decade, Over the past decade, most political parties have formally embraced environmental protection and renewable energy after worrying about climate change. As a result, developed countries have taken many measures to promote the development of renewable energy, including incentive measures such as R&D funds, tax breaks, subsidies, quota schemes, and tradable green certificates. measures have been taken (Liu and Zeng 2017). An effective funding policy can contribute to the smooth running of a project. This can take the form of public guarantees for bank loans, the issuance of “green bonds” or the establishment of public investment banks for RES projects. Additionally, significant progress has been made in simplifying the issuance of building permits with the aim of streamlining the bureaucratic process for deploying the RES system. It can also standardize all environmental assessment procedures so that all permitting bodies apply the same practices (Eleftheriadis and Anagnostopoulou 2015). For the case of wind power, from pre-application to final determination of the necessary consents, the process is estimated to take from between 3-5 years for commercial wind farms (Fairgrieve, Wellard et al. 2021). Policies, rules and regulations are the factors that either accelerate or slowdown a wind-power project (Goh, Lee et al. 2014).

3.1.2 Financial and physical resources risks

3.1.2.1 Uncertainty about funding

Fund management is a key factor that influences the progress of a project. Renewable energy projects require high investment costs and, as a result, sufficient and secure financial resources. Investors do not tend to fund all their investments in equities. A significant proportion of the investment is financed by loans. Therefore, the reliability and availability of investments for good credit and affordability are very important in investment decisions. Initial costs to implement renewable projects can be high (Eleftheriadis and Anagnostopoulou 2015). Strong and affordable financial support is therefore essential and always motivates the project. Securing affordable funding is essential to the smooth implementation of the project. According to an investor perspective survey (Urbani, Jreich et al. 2021), financial risk is a significant risk specially for the private sector.

3.1.2.2 Lack of raw materials and supply chain disruption

This risk was not listed as an outcome of literature review. However, it was introduced by one of the interviewees located in UK. Considering UK long-term system planning, policies, and regulation to massively deliver offshore wind power, there is a concern about how to supply raw materials including metals and microchips as a critical resource for wind turbines to respond the high amount of demand (Appleton & Slee, 2022). This situation becomes even worse while there is a lack of microchips after pandemic and Russia-Ukraine conflict.

3.1.3 Economic risks:

3.1.3.1 Additional cost of renewable energy

The economic aspect is fundamental to investing. All investors develop projects that generate economic returns. They put a certain amount of money and time into the project, so the financial metrics should be satisfactory. Although the introduction of renewable energy has an ultimate environmental goal, the basic goal of the project is to generate economic benefits. In addition, banks approve loan applications if economic factors, including indicators such as internal rate of return (IRR), net present value (NPV), and return on equity (ROE), are met. Increased investment budgets correspond to increased loan volumes, funding costs, and equity injection rates. Therefore, the "cost of investment" is also considered an important factor in the decision-making process (Ozorhon, Batmaz et al. 2018). The additional costs of renewable energy compared to conventional energy sources make investments less profitable and make them more dependent on government subsidies and incentives to compete with fossil fuels- (Liu and Zeng 2017). It contains all cost components of a RE investment including engineering costs due to technology novelty, construction costs, financing cost and taxes, operation, and maintenance costs (Ozorhon, Batmaz et al. 2018).

3.1.3.2 Unstable Macro-economic conditions

The other economic barrier is uncertain macro-economic situation. In UK while the macroeconomic situation today is far more stable than some many years ago, the fallout from Covid-19 and the recent round of fiscal deficit and currency erosion are raising the spectre of renewed instability. It can be supposed that Macro-economic conditions of a nation such as inflation rate, gross domestic product (GDP) growth rate and interest rates not only might affect the RE investments, but it can also affect many industries and investments occasionally. So, it is not a specific RE risk. For the case of offshore wind power in UK as an exploiting and fastest-growing source of energy (Appleton and Slee 2022), supplying raw materials and metals have become an issue because of economic crisis resulting from pandemic and Russia-Ukraine conflict (interview). Investors examine those figures in their decision making.

3.1.4 Infrastructure and Technology risks

3.1.4.1 Lack of suitable grid infrastructure

Infrastructure is one of the most important factors in RE investment. Due to the absence of a grid connection mechanism for renewable energy, its available energy cannot be supplied to (or from) the national electricity grid (Eleftheriadis and Anagnostopoulou 2015). According to the interviews for the case of offshore wind, the construction seabed is not most of the time connected to the electricity grid nor have adequate infrastructure to connect to distribution network.

The energy sector's physical infrastructure is typically huge, expensive, and does not provide an adequate return on private investment. It also has the characteristics of a public good and may be underserved by the private sector (Egli 2020). On the other hand, in the absence of a stable national energy plan, private investors are reluctant to invest in grid upgrading due to unguaranteed returns (Eleftheriadis and Anagnostopoulou 2015). Power grid capacity, underdeveloped power grids, and lack of connectivity of coastal areas to the main power grid for offshore wind farms are considered to be the main obstacles to the deployment of RES technologies (Jacobsson and Jacobsson 2012, Steinbach 2013).

3.1.4.2 Immature storage technology

To maintain the stability of the electrical system, the power supply should be more than the demand. Renewable energy production is less predictable. It can fluctuate seasonally and even hour to hour as local weather changes. By using storage technology the average power generated would not drop and not affect the power quality of the system (Purvins, Zubaryeva et al. 2011). Storage technology can reduce the cost of electricity for nations' economies while providing local and global environmental benefits. Lower storage costs increase both electricity cost savings and environmental benefits. However, although there are some advances in a grid-scale energy storage product to boost flexibility and resilience in grids, Storage technology is still immature and relevantly progressing (Shaqsi, Sopian et al. 2020).

The challenges to beat in energy storage are high cost of implementation, Lack of standardization in storage systems and outdated regulatory policy and market design

3.1.4.3 Lack of technical skills and Technology requirements

RES is a technology -intensive industry and technology is one of the main risk types of renewable energy investment. The cost of technology and return of investment are determined by the maturity, applicability, and progressiveness of the technology, which also are the driving force of renewable energy development. For instance, if an enterprise, obtains R & D and innovation capacity, mature and adaptive product technology, it can win the market competitive advantage . Immature technology could lead to higher risk, lower revenues, or higher maintenance costs due to the technology's novelty and unpredictability (e.g., faster degradation).

Research indicates that although the technology of wind plants is relatively becoming mature in the recent decade, due to higher complexity than solar PVs, still there has been no decrease in the importance of technology risk for wind plants (Liu and Zeng 2017). According to (Egli 2020), for onshore wind, new turbine designs have also led to an increase in technology risk. Not only have resource estimations become more difficult as hub heights have increased, but unknown wind speeds and turbulences have also created technology risk (e.g., damages or interrupted generation). That's the reason why some investors hesitate to use new turbines.

3.1.5 Operation and maintenance risk

3.1.5.1 High O&M cost including component failure, vulnerability to weather conditions in offshore wind plants

Operation and maintenance costs are one of the most important expenses of RE investments. The wind turbine might breakdown due to the sensor fault, the gearbox problem, and all the wear and tear problems. In offshore wind there is an increased cost of maintenance because of accessibility problems. To overcome this risk, a comprehensive and less costly operation and maintenance contract is beneficial to the investors. On the other hand, an operation and maintenance contract with a high payment amount would be a burden for the project cash flow (Egli 2020).

3.1.5.2 Safety issues and human life for maintenance

Another risk especially in maintenance phase of the project is human life and safety. This must be the priority of every investment. Investors must consider the precautions for the safety issue especially in O&M phases. Necessary fund must be allocated for safety. The maintenance and repairing tasks are recommended to be automated in offshore wind farms which will impose additional cost to the project lifecycle(Goh, Lee et al. 2014).

3.1.5.3 Lack of maintenance skills of technicians and engineers

Novelty nature of the project and new technologies makes it limited to some small groups of vendors and workforce. This issue can lead to lack of maintenance skills (Fairgrieve, Wellard et al. 2021).

3.1.6 Market risks:

3.1.6.1 Sensitivity of competitiveness of RE to prices of conventional energy sources

RE projects has higher investment cost or capital cost of energy generation comparing with conventional fossil resources (Chang 2013). It can negatively affect the future revenue and competitiveness of their development for investor. Even now with a global commitment to develop RE and policy incentives, and a noticeable reduction in the cost of technology involved, the cost is still high compared to traditional energy sources because the related technologies are still evolving by continuous advancements (Abba, Balta-Ozkan et al. 2022).

3.1.6.2 Variability of Power supply

Renewable energy sources are variable unreliable in power supply due to their nature. This risk can affect the market factors by lower revenues due to inaccurate resource potential estimation (e.g., wind speed or solar irradiation). In most renewable energy technologies, generation is fluctuated and unreliable due to nature of the resources compared to conventional energy sources. This issue increases the uncertainty for covering the future continuous market demand and expected revenues.

3.1.6.3 Limited market size and uncertainty about market

Confidence in the market and its future is a crucial factor to invest. The investors tend to enter in stable markets rather than unstable and fluctuating ones. Market uncertainty, dependency on energy exports, lack of market visibility and viability comparing fossil fuels are other factors that can discourage investors to adopt renewable energy projects.

For the case of offshore wind in UK the policies and consequently market factors are relatively more stable now. However, in some countries since the national policies and regulations are not supportive enough to invest in RES, foreign investors will be reluctant to initiate an investment (Van der Gaast, Begg et al. 2009).

3.1.7 Environmental risks:

3.1.7.1 Climate change and natural disasters disruption

This risk as relatively important risk for offshore wind plants as they are more exposed to severe weather conditions including strong storms, tides, and power of waves because of location.

3.1.7.2 Excessive extraction of raw materials

This risk was introduced through interviews and analysed more in literature. The transition to renewables requires a dramatic increase in the extraction of metals and rare-earth minerals, with a high ecological and social cost (Van der Gaast, Begg et al. 2009). Raw material extraction and processing always impact on the environment, resulting as they do in soil degradation, water shortages, biodiversity loss, damage to ecosystem functions and global warming exacerbation. This category of risk is often neglected by previous research which is an important risk for offshore wind farms.

3.1.7.3 Loss of habitats and species

Although RE is clean in nature, the infrastructure and development process might cause serious problems for the natural environment, which should be considered by the investors and must be in line with the standards. For instance, shadow flicker effect of wind turbines, fish passage necessities in Hydroelectric Power Plants (HPPs) and biodiversity requirements are the issues to be considered (Hickel September 2019).

3.1.7.4 Displacing Coastal and Marine Infrastructure

The giant structure in seabed can displace Commercial Fisheries, Shipping and Navigation.

3.1.8 Social risks:

3.1.8.1 Lack of Social acceptance

Investors must consider the reflections of the projects on the society. There have been certain protests for social impacts of the projects. Regulations of public authorities are stricter now than they were in the past. Therefore, social acceptability must be obtained before starting an investment.

Lack of public awareness about environmental and economic benefits, insufficient knowledge of RES technologies, doubts about the economic viability of RES installation projects and concerns regarding aesthetic issues, such as landscape distortions are the main causes of social risks (Ozorhon, Batmaz et al. 2018).

Thus, the support of public sector is crucial to the construction of renewable energy projects specifically wind farms. The occupied land or seabed might have other interests from fishery and shipment industry, government or even military.

3.1.9 Credit and Enterprise risks

Lower revenue comparing to conventional fossil fuels due to additional cost of RE investment can threaten enterprise reputation and cash flow. This risk is not a major risk at this climate by continuous technological advances in RES leading to lower cost of construction and Investment.

3.2 Shortlisted risks through structured interviews:

In the second step, risk factors were shortlisted in to 7 risks through conducting structured interviews with 13 RES stakeholders from around the world. The interviewees were asked to rank the risk types in a 5-scale scoring model (very low, low, moderate, high, and very high) to understand their relative importance. Also, they were free to add more risks and their related importance level. The outcomes of the interviews determined the most important risks. We aggregated the risks scales to obtain a shortlist of 7 risks to further analysis with AHP method.

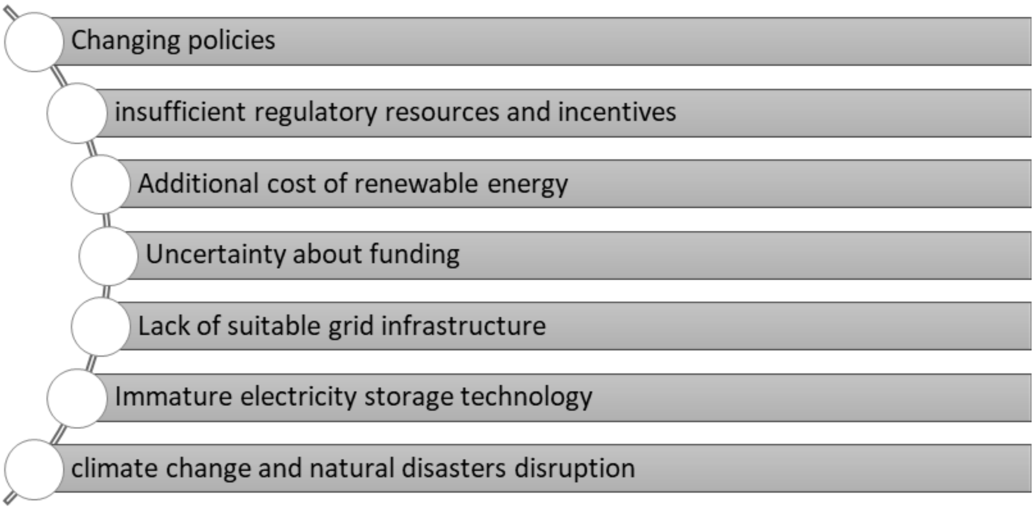

Figure 4:Shortlisted top 7 risks according to the interviews

3.3 Quantitative risk analysis by AHP method

In the third step, AHP method utilized to score the risks quantitatively through conducting a survey. A survey of 14 participants ranked the importance of the risks through 21 pairwise comparisons by each participant. The experts were in different renewable energy sectors from different countries. However, most respondents (57%) were from UK working in wind power (57%). In this stage, evidence from interviews was utilized to understand and interpret data in the survey as the amount of the survey population was not large and will be followed in a future paper.

AHP was deployed in the following five stages according to (Eleftheriadis and Anagnostopoulou 2015):

- First stage: Identify risks to compare

The top 7 risks derived from interviews identified and classified in 5 categories to score quantitatively by AHP method.

- Second stage: Formation of Matrix

The second step was the formulation of the pair-wise comparison in a matrix of (n*n), n=7 in a questionnaire for experts to provide their judgments based on a nine-point scale (Ghimire and Kim 2018).

Table 3:AHP scoring Scale

Intensity of interest	Description
1	Both elements are equally important
3	One element is slightly more important the other element
5	One element is moderately more important the other element
7	One element is considerably more important the other element
9	One element is extremely more important the other element
1/3,1/5,1/7,1/9	for inverse results

Participants should provide answers for the upper triangle based on table 6. To fill the lower triangular matrix, the reciprocal values of the upper diagonal will be used. If $a_{ij}$is the element of row i and column j of the matrix, then the lower diagonal is filled as in (1). Then, the whole matrix will be completed according to Matrix A for instance (2). So, each participant needs to have $n\ (n-1)/2$ comparisons to complete the questionnaire.

$$a_{ji} = \frac{1}{a_{ij}} \qquad (1)$$

$$A = \begin{pmatrix} 1 & 1/3 & 5 \\ 3 & 1 & 7 \\ 1/5 & 1/7 & 1 \end{pmatrix} \qquad (2)$$

- Third stage: pairwise comparison and scoring

Based on the survey data collected, a pair-wise comparison matrix was constructed for each respondent. Then comparative judgments were combined by applying the geometric mean to form the aggregated judgment matrix (Amenc, Goltz et al. 2010). So, again we will have a 7 by 7 reciprocal matrixes from paired comparison.

- Fourth stage: normalizing aggregated matrix

In this stage, the elements of each column were added up to get the following matrix.

Table 4:Aggregated matrix

Risk	Risk 1	Risk 2	Risk 3	Risk 4	Risk 5	Risk 6	Risk 7
Risk 1	1.00	5.05	4.93	4.21	5.05	6.27	4.93
Risk 2	0.20	1.00	3.94	3.11	4.19	3.33	5.05
Risk 3	0.20	0.25	1.00	3.73	3.78	3.25	4.89
Risk 4	0.24	0.32	0.27	1.00	4.26	3.85	4.11
Risk 5	0.20	0.24	0.26	0.23	1.00	3.11	4.61
Risk 6	0.16	0.30	0.31	0.26	0.32	1.00	2.95
Risk 7	0.20	0.20	0.20	0.24	0.22	0.34	1.00
Sum	**2.20**	**7.36**	**10.91**	**12.80**	**18.81**	**21.15**	**27.53**

Then, to get normalized relative weight of each risk, each element of the matrix was divided by the sum of its column. The normalized principal Eigen vector (w) can be obtained by averaging across the rows. The normalized principal Eigen vector is also called priority vector. Since it is normalized, the sum of all elements in priority vector is 1. The priority vector shows relative weights among the things that we compare (w).

Table 5:Priority vector derived from normalized matrix

Risk	Risk 1	Risk 2	Risk 3	Risk 4	Risk 5	Risk 6	Risk 7	Priority vector (w)
Risk 1	0.45	0.69	0.45	0.33	0.27	0.30	0.18	**0.38**
Risk 2	0.09	0.14	0.36	0.24	0.22	0.16	0.18	**0.20**
Risk 3	0.09	0.03	0.09	0.29	0.20	0.15	0.18	**0.15**
Risk 4	0.11	0.04	0.02	0.08	0.23	0.18	0.15	**0.12**
Risk 5	0.09	0.03	0.02	0.02	0.05	0.15	0.17	**0.08**
Risk 6	0.07	0.04	0.03	0.02	0.02	0.05	0.11	**0.05**
Risk 7	0.09	0.03	0.02	0.02	0.01	0.02	0.04	**0.03**
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

- Fifth stage; inconsistency check

Aside from the relative weight, the consistency of answers should be checked. To do that, Principal Eigen value should be computed as in (3):

$$Aw = \lambda max \times w \qquad (3)$$

Where A is the comparison matrix of size n × n, for n criteria, also called the priority matrix, and w is the Eigenvector of n × 1, also called the priority vector, which is the weight. λmax is the maximum Eigenvalue (Saaty 1994, Amenc, Goltz et al. 2010).

Consistency Index as deviation or degree of consistency is obtained as in (4):

$$CI = \frac{\lambda max - n}{n-1} \qquad (4)$$

According to the data obtained from previous stage, λmax = 8.26 and the size of comparison matrix is *n* = 7, thus the consistency index is as in (5)

$$CI = \frac{8.26-7}{6} = 0.21 \qquad (5)$$

Knowing the Consistency Index, the next question is how we use this index. Again, (Saaty 1990) proposed that we use this index by comparing it with the appropriate one. The appropriate

Consistency index is called Random Consistency Index (*RI*). The standard values of RI for up to 10 criteria are shown in Table 8 (Chang 2013).

Table 6:Random Consistency Index (*RI*)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Then, Consistency Ratio is formulated according to (6)

$$CR = \frac{CI}{RI} \qquad (6)$$

Thus:

$$CR = \frac{0.21}{1.32} = 15.9\% \qquad (7)$$

According to (Wind and Saaty 1980), if the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, we need to revise the subjective judgment.

Summarizing our survey data, *CI* = 0.21 and *RI* for *n* = 7 is 1.32, then CR= 15.9%

According to (Doumont 2002, Saaty and Ozdemir 2003, Chang 2013), while the CI computed for the survey is slightly more than 10%. It can be acceptable in practice due to the following issues (Opydo, n.d.).

- Mistakes: A simple lack of concentration or pressing a wrong button can introduce inconsistency. We are human and it is easy to make mistakes when you enter several comparisons.
- Lack of knowledge: When we don't have enough information to make consistent comparisons, or we are uncertain. In this case, we use our judgment, and our judgment is sometimes not as accurate as we would like.
- Human nature: We are human beings, we are inconsistent. This isn't a problem if we're not too much inconsistent.

- Discrete scale: In AHP, we do pairwise comparisons using a special scale which contains the values 1 to 9. This can introduce inconsistency.
- Capped scale: Imagine that you answer that A=4*B and B=5*C. To be consistent you should answer that A=20*C but maximal value that you can use is 9. Again, the AHP methodology forces you to be inconsistent.

That's why in practice making the pair-wise comparisons for many participants, CR ends up being higher than 0.1. According to (Klaus D., Goepel;, 2013), Based on a sample of nearly 100 respondents in different AHP projects, the median value of CR is 16%. Also, there seems to be a tendency of increasing CR with the number of criteria, *i.e.,* the median value significantly increases for more than 5 criteria.

Thus, the researcher accepted the results since risk ranking results were confirming interview outcomes and it is slightly more than 10% and within acceptable range from viewpoint of practitioners due to the reasons mentioned before.

4 Discussion

Through pairwise analysis of AHP method, the following weight values are derived for 7 top risks derived from interviews. The quantitative ranking of the risks is exactly aligned with interview results. So, although the consistency ratio of AHP analysis is slightly more than 10%, in practice it is acceptable because the results confirm the previous findings.

On the other hand, it is observed that although policy and regulation are decreasing in importance due to long term planning and commitment to meet net-zero targets, it is still the most important cluster by 58% weight value. This result can be expected since the financial, market and economic factors like availability of funding, subsides and energy prices are strongly connected to the policies and regulations. Furthermore, it can be claimed that grid infrastructure availability and who is going to invest on it, building permissions and access to the land and seabed are respectively infrastructure and environmental risks that are again connected to policy and regulation. Economic risk has second priority by the value of 15%. It is not surprising because the main objective of any investment is making profit. However, RE has reputation for additional investment cost comparing to fossil fuels due to technology novelty and more complexity. The study demonstrates that infrastructure and technical risk is slightly more important than financial risk respectively with 12.4% and 11.6% value. It shows the importance of availability of grid infrastructure in investment decision making as it imposes a huge amount of money and threatens the viability of the investment especially for private sector. Furthermore, storage technology still needs more advancement to reduce the volatility and increase the flexibility of power supply system. Finally, Environmental cluster is becoming one of the most important risks in renewable energy due to the nature of the offshore wind infrastructure, location and weather conditions affecting operation. In addition, it can be claimed that offshore wind plants development has more environmental consequences. First, they are more subject to the matter of components' failure due to strong storms, tides, and power of waves. Second, fishery industry and life of habitats could be negatively affected by offshore wind plants because of their location. Finally, fast transition to renewable energy needs a huge amount of material extraction and processing especially metals in offshore wind farms.

Furthermore, Market risk and O&M risks are respectively seen the next important risks from perspective of interviewees. However, the significance of these 2 clusters is claimed to be moderate. So, they are not included in top 7 risks to be rated by AHP method. However, results obtained from interviews indicate that renewable energy in wind sector is more exposed to operation and maintenance risk due to location, weather conditions and giant structure. Offshore wind plants are specifically expensive. Turbines in the water must be more resistant to corrosion, easy to maintain, and have high storm resistance. So, the anchoring system and the structure of the tower must be able to handle the turbulence inherent in the middle of the sea. Finally, social acceptance and enterprise risk are the lowest risks graded by interviewees.

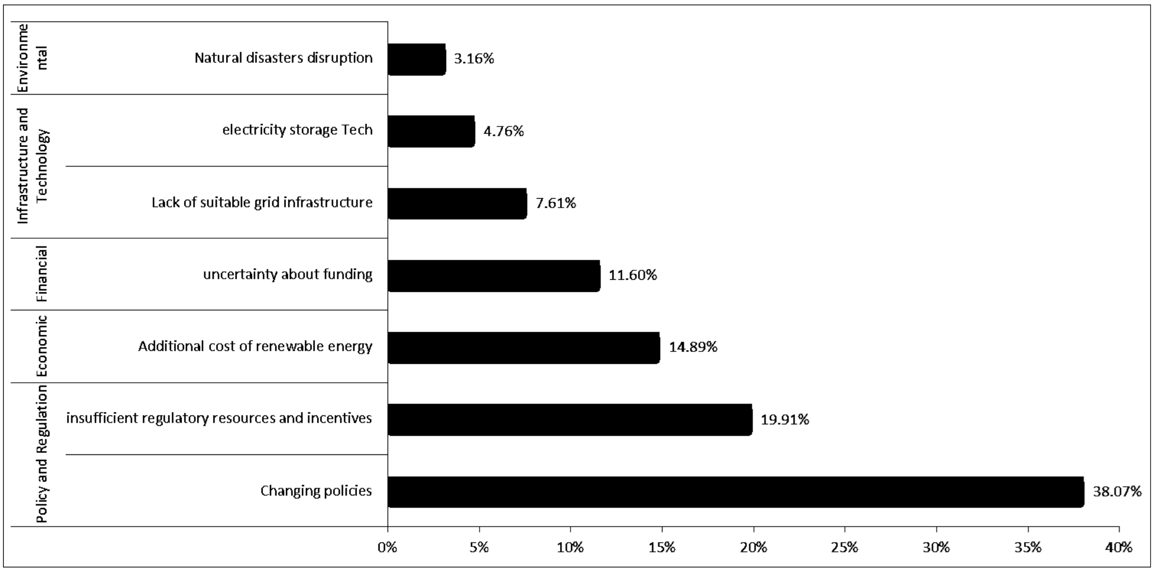

Figure 5:Risk weights values through AHP analysis

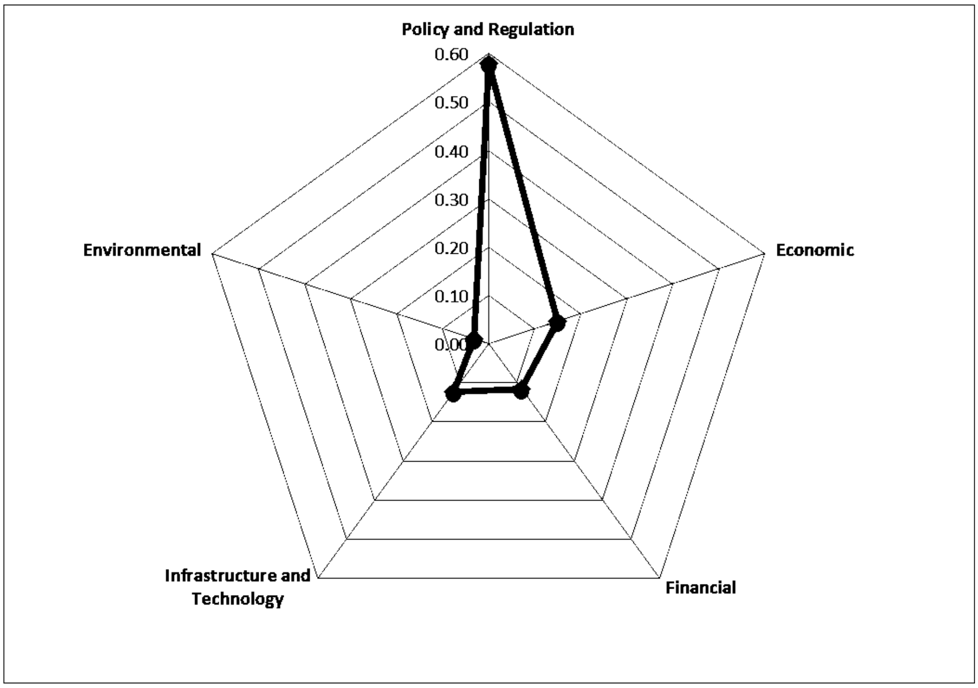

Figure 6:Risk Categories weight values through AHP analysis

5 Conclusion and Suggestion for Future Work

Renewables are clean sources of energy which not only address climate change and global warming crisis by reducing greenhouse gases but also lead to less air pollution and improved health in society. In a net zero community the aim is to cutting greenhouse gas emissions to as close to zero as possible. So, Investment in renewable energy is a must for a clean future. However, the market share of renewables at this state is not sufficient to achieve the net-zero ambitious goals by 2050. The reason is due to some significant risks associated with investment in renewable energies. The main purpose of this research is to identify critical risk factors of investment in a RES in general and specific to offshore wind power to attract more investment. For this purpose, in the first phase an extensive literature review conducted in combination with interviews with RE experts. A total number of 20 risks determined under 9 categories named policy and regulation, financial and physical resources, economic, infrastructure and technology, Operation and maintenance, market, environmental, social, and finally credit and enterprise risks. Then, after interviews, 7 shortlisted major risks were rated quantitatively by using AHP analysis. In AHP method, a pairwise comparison of risks performed by RE stakeholders to assess the relative importance weights. According to the results, the policy and regulation cluster is found to be most important risk followed by economic, infrastructure and technical, financial, and environmental risk. It can be claimed that Policy is the most influential risk because economic, financial and market factors and even environmental and social permissions are strongly connected with policies. So, the higher weight of this risk is not surprising. Also, economic risk is reasonable to be the next important factor as it is the most critical criteria for investors while RE energy has a reputation for additional cost of investment. The technology and infrastructure and financial risk have the same weight with slightly more risk perception in technology and infrastructure. Current research indicates that lack of grid infrastructure and who is going to invest on it and immature battery technology is an important risk factor for RE. In addition, accessibility problems to grid infrastructure trigger this risk in offshore wind plants because of the location. Furthermore, the study shows that environmental risks are relatively new and important risks for offshore wind due to the nature of the structure, location and being prone to severe weather conditions.

It is suggested that the study be expanded further by increasing the sample size and categorized in countries. It is obvious that countries committed to be net- zero by 2050, have different policies and incentives along with different level of technology maturity. Also, the study demonstrates present market sentiments and should be updated periodically to retain its practical importance. Furthermore, future research can investigate appropriate risk response plans to mitigate risks.

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7 Appendix A: Interview questions

Basic respondent information:

1. Which country do you live?
2. What is your organizational role/position?
3. Which renewable energy sector are you working in?

Risk assessment:

Please indicate level of risk regarding Investment in Renewable Energy Scheme (RES) generic risks and the more relevant risks for those aspects that are specific to OSW (Offshore Wind Turbines). You are free to add your insights in additional comments.

Level of risk: Very Low (VL), Low (L), Moderate (M), High (H), Very High (VH)

1. Changing policies including access policy, price policy, feed-in-tariff, tax, and industry regulation, at the national level.
2. Insufficient or ineffective regulatory resources and incentives.
3. Additional cost of renewable energy.
4. Uncertainty about funding and financial support.
5. Lack of suitable grid infrastructure
6. Immature electricity storage technology
7. Lack of technical skills and technology requirement
8. High Operation & Maintenance cost
9. Lack of maintenance skills of technicians and engineers
10. Safety issues and human life for maintenance
11. Sensitivity of competitiveness of RE to prices of conventional energy sources
12. Variability of Power supply
13. Limited market size and uncertainty about market.

14. Displacing Coastal and Marine Infrastructure (Commercial Fisheries, Shipping and Navigation)
15. Loss of habitats and species in offshore wind plants.
16. lack of social acceptance
17. lower revenue in renewable energy and damage to reputation

Please provide your opinion on any other Risks and their significance levels.