ARCADIS OST I OFFSHORE RENEWABLE ENERGY		Summary of Climate Change Risk Assessment				
Scope	CCRA	Version	0.0	Author	Reviewed	Approved
Department	Permit/ Legal	Date	2021/05/27	HKO	CSU	SCL

Summary of the Climate Change Risk Assessment on the Offshore Windfarm Project « Arcadis Ost 1 » on behalf of Parkwind Ost GmbH

Purpose of this document

As a renewable energy business, Parkwind Ost GmbH (hereinafter “Parkwind”) is committed to protecting the environment and promoting responsible environmental practices and improving these practices continuously. Parkwind therefore ensures to comply with all applicable environmental laws and regulations, as well as international standards and practices within the renewable energy sector.

Parkwind is striving to always conduct its business in a socially responsible manner, acting as an ethical and responsible employer and business partner.

In April 2021, Parkwind contracted the independent ESG consultant Mott MacDonald, to conduct a Climate Change Risk Assessment (CCRA) for the offshore wind farm “Arcadis Ost 1” (‘AO1’ or ‘Project’) in line with the Equator Principles IV (EPIV) 2020[1] to determine i) Current and anticipated climate-related risks (considering the materiality of either ‘physical’ or ‘transition’ risks, or both) facing the project’s operation over the project’s contract period and ii) Plans, interventions and /or processes appropriate to managing those risks.

This document provides a summary of the ‘Arcadis Ost 1 Offshore Wind Farm CCRA’ (Mott MacDonald, 2021) in line with the requirements for Category A and, as appropriate, Category B projects. For these projects, the CCRA is to include consideration of relevant climate-related ‘Physical Risks’ as defined by the Task Force on Climate-Related Financial Disclosure (TCFD).

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[1] « The Equator Principles (EPs) is a risk management framework, adopted by financial institutions, for determining, assessing and managing environmental and social risk in projects. » (https://equator-principles.com/)

Introduction

The CCRA has been undertaken to demonstrate compliance with the Equator Principles IV (EPIV). The CCRA is assessing potential adverse effects from Global Warming and Climate Change. The scope of the CCRA has been defined using the Equator Principle's guidance note on climate change risk assessment[2]. In line with that guidance, the scope of work is to include consideration of climate-related 'Physical Risks' as defined by the Task Force on Climate-Related Financial Disclosure (TCFD)[3].

The assessment identified current and anticipated climate-related risks (considering the materiality of either 'physical' or 'transition' risks, or both) facing the project's operation over the project's contract period and evaluates plans, interventions and /or processes appropriate to managing those risks.

The key steps of the CCRA include:

- An assessment of the baseline climate
- An assessment of future climate change projections for Germany and the Baltic Sea
- Identification of climatic vulnerability of project components
- Qualitative assessment of the likelihood of climate impacts and severity of plausible climate impacts to the project to identify material risk
- A review of potential adaptation and resilience options

Project Description

The Project site is located within the 12 Nautical Miles zone North-East of the island of Rügen in the Baltic Sea, with associated onshore infrastructure on Rügen island.

Construction of the Arcadis Ost 1 offshore wind farm is projected to be completed in 2023. The Project is planned to be operational for 25 years, while the wind turbine generators have a precautionary design life of 26.5 years and similarly the foundations have a design life of 27.4 years.

The Project has a total grid connection capacity of approximately 247MW.

The WTGs and OSS are designed according to Federal Maritime and Hydrographic Agency of Germany ("BSH") requirements (namely, BSH Standard 7005, Design of Offshore Structures), and in accordance with the Eurocode package supplemented by German - Deutsches Institut für Normung (DIN) - and European standards.

Asset Information

The project includes the following assets:

- 27 offshore wind turbine generators (or WTGs), (specification: Vestas' V174-9.5 MW) and associated connections
- An offshore substation (OSS) with associated connections incl. internal park cables
- An onshore operations and maintenance (O&M) building on Rügen Island. The O&M building is rented and not in the ownership of Parkwind
- The export cable is owned and operated by 50Hertz Transmission.

Policy context

The Paris Agreement

The Paris Agreement was adopted on 12 December 2015 at Conference of Parties (COP) 21 and entered into force on 4 November 2016 (UNFCC, 2021-a). As of February 2021, it has been signed by 197 countries and ratified by 190, including Germany.

The overarching aim of the agreement is to hold the increase in the global average temperature to well below 2°C, and to pursue efforts to limit the temperature increase to 1.5°C.

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[2] Equator Principles Association, 2020. Guidance Note on climate change risk assessment.

[3] Task Force on Climate-Related Disclosures, Recommendations of the Task Force on Climate-related Financial Disclosures, June 2017, p 6.

It further defines a ‘global goal on adaptation’ which aims to ‘to enhance adaptive capacity and resilience; to reduce vulnerability, with a view to contributing to sustainable development; and, ensuring an adequate adaptation response in the context of the goal of holding average global warming well below 2 degrees C and pursuing efforts to hold it below 1.5 degrees C’ (UNFCC, 2021-b).

Taskforce on climate related financial disclosures (TCFD)

The Taskforce on Climate Related Financial Disclosures (TCFD), established by the Financial Stability Board, is a voluntary disclosures taskforce principally intended to help financial institutions and asset owners assess ‘physical’ and ‘transition’ climate risks on their business, strategy and financial planning (TCFD, 2021). In 2017 the TCFD released recommendations in order to assist in the disclosure of climate-related financial disclosures (TCFD, 2017).

National Adaptation Strategy – Germany

The 2008 framework laid out by the German Federal Cabinet established the need for medium-term, step by step process for adapting to the impacts of climate change in Germany (Climate adapt, 2020). This report focussed on the economic activities and natural environments that would be affected by climate change and acknowledges that ‘Adaptation Strategy’ should follow a ‘transparent and structured approach to stating the needs for action, defining appropriate objectives, identify and resolving conflicts of objectives and developing and implementing potential adaptation measures’.

Literature review

Physical climate risk

Universally accepted definitions of physical and transition climate risk are as follows:

- Climate physical risks are those risks resulting from climate change, which involve event-driven (acute) or longer-term shifts (chronic) in climate patterns. Acute physical risks refer to those that are event-driven, including increased severity of extreme weather events such as cyclones, hurricanes, or floods. Chronic physical risks refer to longer-term shifts in climate patterns (e.g., sustained higher temperatures) that may cause sea level rise or chronic heat waves.
- Climate transition risks are risks which can arise from the process of adjusting to a lower-carbon economy. These include: policy and legal risks, such as policy constraints on emissions, imposition of carbon tax and other applicable policies, water or land use restrictions or incentives; shifts in demand and supply due to technology and market changes; reputation risks reflecting changing customer or community perceptions of an organisation’s impact on the transition to a low carbon and climate-resilient economy.

As such, a physical climate change risk assessment considers both the chronic and acute impacts of climate change and their impacts on a project.

All energy systems are to some extent affected by climate change and changing risks. There are two principal ways in which climate change and intensified disaster risks can affect the wind power sector:

- Wind power generation depends on wind availability and wind speeds. Climate change can affect wind speeds and other variables such as air density, which can have either positive effects (i.e., enhanced energy generation) or negative effects (i.e., disruption to energy generation due to ‘shut down’ periods associated with extreme conditions or reduced energy generation with lower wind speeds or lower air density) on wind power generation.
- Wind turbine plants could be impacted by more pronounced disaster risks such as typhoons, floods, and storm surge exacerbated by chronic sea level rise (particularly in the case of offshore turbines or low-lying substations).

Changes in wind speed and pattern due to climate change differ significantly from one region to another. Studies suggest changes in global wind speeds could affect regions such as Europe and North America minimally (Urban and Mitchell, 2011).

A range of climatic changes can affect wind energy generation, such as changes in wind speed and direction, air density, land cover / sea ice cover changes, icing, changes in sea levels, sea temperature, salinity content and wave heights. However, studies suggest the wind power sector might not be negatively impacted by climate change, suggesting a net gain in energy yield from more sustained - or higher - wind speeds (Urban and Mitchell, 2011).

Sea level rise (SLR) may have implications for offshore and near-shore wind turbines, with the increased risk of flooding or corrosion of turbines. Another aspect of importance to the foundation(s) of offshore wind turbines is wave height, which is significantly dependent on wind speeds (Urban and Mitchell, 2011).

To proactively adapt to changing wind speeds, SLR and changing disaster risks, turbines and associated infrastructure that is able to operate and which can physically withstand extreme high wind speeds, rising seas and storms is advisable (Urban and Mitchell, 2011).

The impact of waves is considered more important than changing currents or chronic increasing water levels for operation because of potential access and servicing issues. A change in the tidal range may affect tidal currents, which could in turn exacerbate scour on the structure or on undersea cables causing them to become exposed; however, it is worth noting that there is little precedent for damage to foundations due to their piled nature and the safety factors involved in their design.

Table 1: Effects of climate change and changing disaster risks on wind energy generation

Change in meteorological variable	**Impact on wind energy plant/resources**	**Impact on electricity generation**
Temperature increase	Indirect impact on air density and wind patterns; extreme heat could impact operating conditions and lead to shut down of turbines	Either increased or decreased electricity generation possible
Increase in average precipitation	Increase wear of the turbines – edge erosion	None
Decrease in average precipitation	None	None
Drought	None	None
Glacier melt	None, unless flooding occurs. If flooding occurs risk of damage to equipment	None if no flooding occurs. If flooding occurs, disrupted / decreased electricity generation
Flood	Risk of damage to equipment through inundation, weathering	Risk of disrupted / decreased electricity generation
Increased frequency and/or strength of storms/cyclones	Risk of damage to equipment and increased periods of shut down	Decreased electricity generation if wind turbines / equipment is damaged
Increased wind speed	Better wind conditions; wind speeds that exceed the cut-out	Increased electricity generation, unless a storm occurs (see above) in which case decreased energy generation from shutdowns
Decreased wind speed	Worse wind conditions	Decreased electricity generation
Changes in wind patterns	Changes in air density, wind direction, wind variability	Either increased or decreased electricity generation
Changes in wave patterns	Potential access and servicing issues	Either the same or decreased energy generation
Changes in the tidal range	Increased scour potentially causing undersea cables to become exposed	Risk of disrupted / decreased electricity generation although increasing the level of scour

Change in meteorological variable	Impact on wind energy plant/resources	Impact on electricity generation
		protection is often relatively straightforward
Oceanic acidification	Increased corrosion of the structures	Risk of disrupted / decreased electricity generation

Source: Urban & Mitchell (2011) adapted by Mott MacDonald (2020)

Generally speaking, adaptation to climate change and changing disaster risks are issues which have not been traditionally or adequately captured in the energy sector thus far. The focus has been more so on mitigation by reducing emissions from energy systems – 'transitioning' – than finding solutions for adapting these transition-enabling technologies to chronic climatic changes and extreme events.

Global best practice points to the following high-level mitigating aspects for wind farm projects:

- Enhance resilience to climate change by carefully assessing siting procedures, feasibility studies and EIAs (or similar) for new power plants, which need to account for existing disaster risks and adaption strategies to climate change,
- Design more robust infrastructure based on reasonable worst-case scenarios in terms of the above,
- Establish disaster risk systems, whereby clear procedures are in place for early warning systems to enable evacuation of staff and to secure electricity infrastructure where possible before an extreme weather event,
- Establish clear recovery and contingency plans during and following acute climate events like flood,
- Long-term insurance schemes for power yields and damage from storms could also be considered.

Baseline climate

To understand the impacts of climate change, the baseline or present day climate must be understood. Climate scenarios including baseline conditions are based on observed data averaged over a ~30 year time period. For this assessment, the baseline climate is generally considered the average for the period between 1970 and 2000.

The Baltic Sea Region (BSR) has a large geographical extent covering two climatic zones. While a humid, sub-polar climate predominates in the north and northeast, the south and southwest have an oceanic, temperate climate. The AO1 offshore wind farm is located within the south of the Baltic Sea Region.

In relation to the nearby onshore O&M building in Sassnitz the climate is classified as temperate oceanic climate ('Cfb') according to Köppen and Geiger. This climate is warm and temperate with significant rainfall - including in the (drier) summer months of the year.

Temperature

Germany experiences a temperate oceanic climate characterised by relatively moderate mean annual temperatures. Monthly average temperatures are uniform across north-eastern Germany and range in temperature from 1.6°C – 4.3°C in the winter months (December to March) and from 14.4°C – 18.5°C in the summer months (June to September). Maximum hot temperatures have reached 31 °C, while minimum cold temperatures have reached -8 °C.

More specifically, on Rügen island, the closest landmass to the offshore site, the average annual onshore temperature is 9.0°C with temperature peaks and troughs reflective of the temperate climate in which it is located, with average highs in summer of 17.7°C and average winter lows of 1.4°C (ERA5, 2020).

Precipitation

Annual mean precipitation across Germany varies by region, with north east Germany receiving average annual rainfall of approximately 800mm (Britannica, 2021).

On Rügen island annual average monthly precipitation is ~60mm, slightly higher than the country average, with peaks in the summer months, 73mm in August, and winter months receiving less than average rainfall.

Snow, hail and frost

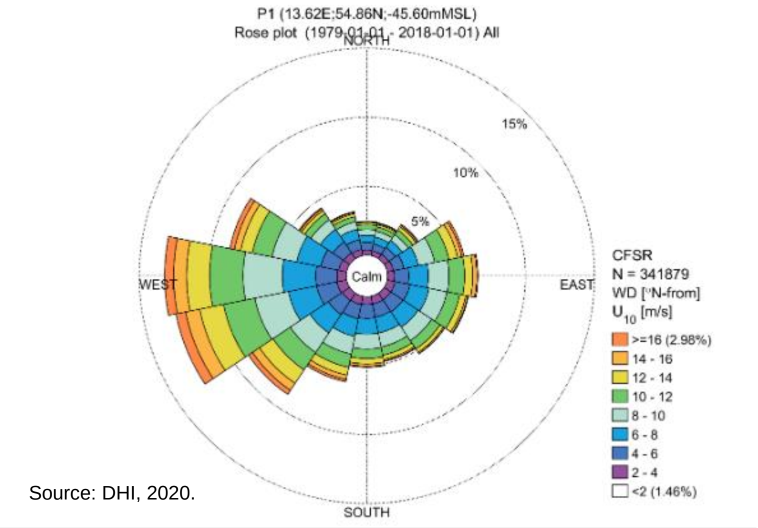
Data on snow cover has been compiled from the German Deutscher Wetterdienst (DWD), weather and climate authority. Historical data on annual average snowfall in Germany show that there has been an overall decline in snowfall over the past 30 years.

The onshore study area shows an overall decline in snow depth from roughly 2-21 cm in 1990 to an average depth of 0-8 cm in 2020.

Wind

Offshore wind levels are typically higher and more consistent than onshore due to the lack of obstructions, i.e. flat sea surface as opposed to built-up areas. Normal wind conditions, using data collected between 1979 and 2017, indicates that the prevailing wind direction at the WTG/OSS site is west with a mean wind speed of 8.6m/s.

The wind rose plot in Figure 1 shows the prevailing wind direction with the fasted wind speed from the west and a uniform wind speed between 2 and 14m/s from other directions (DHI, 2020).



Source: DHI, 2020.

Figure 1: Wind rose plot of modelled CFSR wind speed and direction at 10m MSL

Waves

Analyses of the normal wave conditions were performed on data available for a 39-year period from 1979 to 2017 (DHI, 2020). The predominant wave direction was from the west, with secondary wave directions coming from north-east and east. The mean wave height (Hm0) during the same study period was 0.86m.

Sea levels

Mean sea level (MSL) is a crucial factor for a wind farm. Any elements under the water level will be subjected to higher levels of corrosion, understanding the MSL will inform any maintenance plans. An extreme water level analysis has been undertaken for the baseline climate as part of the Met Ocean study undertaken by DHI (2020). The extreme value analysis used observed and modelled data to generate water levels for a range of return periods, the Met Ocean report provides water levels up to the 100-year event, this represents a 1% annual exceedance probability. Extreme high-water levels for this return period reach 1.53m MSL.

Sea ice

Sea ice has existed at the site in 14% of the past 57 winters. The dominant ice type is drifting ice. The 50- and 100-year level ice thicknesses were estimated to be 35 cm and 41 cm. It has been noted that there were extremely sever ice winters during the 1940s, however, these are not considered to happen anymore due to climate change. Based on the historical ice ridge occurrences, ice ridges are important to be taken into account in ultimate load design in 50-year return period. The 50- and 100-year thicknesses of consolidated layers were 55 cm and 75 cm (COWI, 2020).

Lightning

The UK Met Office operates a long-range lightning detection network, whereby the average annual flash density for most of Europe including Germany was between 0.5 and 3.0 flashes per km^{-2} y^{-1} between 2008 and 2017 (Stone and Enno, 2019).

Extreme events

Parkwind contracted a comprehensive Met Ocean Study for the Detailed Design. The study produced by the DHI Group entails a collection of extreme events data (e.g. storm, heatwaves, flooding) obtained by technical specialists looking at the site location for the WTGs and OSS.

Climate change

Introduction

This section presents observed and future projected (modelled) scenarios for climate change in the project area.

The German strategy for adaptation to climate change (2011 - as amended) states that climate change is already evident in Germany. Rising temperatures, wetter winters and more frequent weather extremes are increasingly having an impact on German society. Observed 'headline' climate change over the past century in Germany includes:

- Mean temperature increase of 1.3°C recorded over the last century.
- An increase in heatwaves lasting 7 days or more
- No apparent change in precipitation volumes over the past century
- A seasonal discrepancy of precipitation patterns signalling increasingly wetter winters and increasingly drier summers season is observed.
- Mean SLR has been occurring at 1.7mm/annum.

Global climate models project the warming of the Baltic Sea Region to be higher than what global mean warming will be. The climatic variety will most likely be increased (Climate-ADAPT, 2021). The region's high vulnerability to climate change is presented in the sections further below.

Climate change projections

Due to the resolution of the Global Climate Models (GCMs) used, the spatial scope of this climate change assessment focuses on data for the North and Central Europe Region, for Germany and the Baltic Sea Region as appropriate. GCM model outputs for North and Central Europe Region have been extracted from the Climatic Research Unit (CRU) of the University of East Anglia (UK). This data has been used in conjunction with outputs from GERICS, European Environment Agency, World Resources Institute, Copernicus and Climate-ADAPT.

The temporal scope is focused on current observations and projection timeframes up to the 2050s to align with the investment period for the infrastructure.

Climate change scenarios

The IPCC's Fifth Assessment Working Group I Report (IPCC AR5), published in 2013, provides global scale climate projections from the latest generation of climate models forced using emission scenarios provided by the Representative Concentration Pathways (RCPs)[4]:

- RCP 2.6 assumes that emissions peak between 2010-2020, declining substantially thereafter.
- RCP 4.5 assumes emissions peak around 2040, then decline.
- RCP 6.0 assumes emissions peak around 2080, then decline.
- RCP 8.5 assumes emissions continue to rise throughout the 21st century.

In line with the precautionary principle, a cornerstone of resilience preparation is planning for a 'reasonable worst-case scenario', in parallel with taking actions to reduce the likelihood of that scenario becoming reality. The assessment is therefore primarily based on the more extreme RCD 6.0 and RCP 8.5 scenarios. However, it should be noted that this differences between the scenarios in the 2050s are relatively small as all represent the inherent impacts of climate change already in the Earth's systems.

Qualitative outcome of future climate change to mid-century for the study site

In summary, in line with the IPCC's guidance note on likelihood scales (IPCC, 2010) and the CCRA method described hereinafter the range of climate observations and projections for Germany and the BSR determine:

- A virtually certain increase in average and extreme surface temperature
- A virtually certain increase in sea surface temperatures
- An uncertain (possible) net increase in annual precipitation
- A very likely increase in precipitation intensity (specifically falling as rain)
- An unlikely net increase in snow, hail and frost occurrence and extent
- A virtually certain increase in mean sea level
- An uncertain (possible) increase in annual mean and extreme wind speeds
- An uncertain (possible) increase in extreme water levels and wave heights
- An unlikely increase in sea-ice extent and thickness
- An uncertain (possible) net increase in lightning occurrence.

Climate change risk assessment

The following qualitative calculation method is used to determine the level of risk associated with current and future climate change impacts to the project to understand its risks:

Likelihood of impact (occurrence) x Severity/consequence of impact = Risk

Likelihood

The likelihood of impacts to the infrastructure is rated based on a uniform scale and has been adapted from the IPCC's guidance on likelihood scales and consistent treatment of uncertainty. Scores have been determined based on a combination of expert judgement and review of available evidence and literature.

Severity

The potential severity of the climate impact is rated based on a uniform scale determined based on a combination of expert judgement and review of available evidence and literature. In addition, severities have been classified through consultations with engineers and project designers when workshopping potential outcomes.

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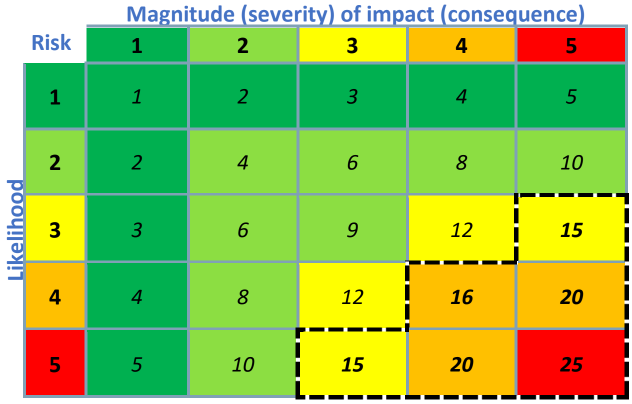
[4] RCP: Representative Concentration Pathways. RCPs are the new definition used by the IPCC in their latest climate projections, and are based on the projected concentration of greenhouse gases in the atmosphere in 2100, so e.g. RCP 8.5 models a radiative forcing of 8.5 in 2100. These replace the previous Low, Medium and High scenarios. There are 4 RCPs in UKCP18 (2.6, 4.5, 6.0 and 8.5), and they do not directly map onto the Low, Medium, High scenarios used previously. However, RCP 2.6 is the lowest emissions scenario, and RCP 8.5 the highest.

Risk

The physical climate change risks assessment has been conducted to cover the operational lifetime of the Project which is stated as 25 years in the Technical Due Diligence Report. It is noted that the WTG design life is 25 years although an assumption of life extension beyond 25 years has become relatively commonplace in offshore wind. Figure 2 summarises the potential impacts of climate hazards on the vulnerability of project components.

The risk to the assets of the Project is scored using the risk matrix shown in Figure 2, which categorises the level of risk as insignificant, low, moderate, high or extreme as per Table 2.



		Magnitude (severity) of impact (consequence)				
Likelihood	**Risk**	**1**	**2**	**3**	**4**	**5**
	1	*1*	*2*	*3*	*4*	*5*
	2	*2*	*4*	*6*	*8*	*10*
	3	*3*	*6*	*9*	*12*	***15***
	4	*4*	*8*	*12*	***16***	***20***
	5	*5*	*10*	***15***	***20***	***25***

Figure 2: Risk scoring matrix

Note: The area indicating the priority risk score (a risk score >12) is indicated by a black dashed line

Source: Mott MacDonald (2021)

Table 2: Risk category

Score	Associated risk rating	Consequence on water services element
1-5	Insignificant	No, or negligible, vulnerability to specific climate risk(s). Remedial action not required.
6-10	Low	A low level of vulnerability to specific climate risk(s). Remedial action or adaptation may be required but is not a priority. Maintain a watching brief.
11-15	Moderate	A moderate level of vulnerability to specific climate risk(s). Mitigating action or adaptation could improve resilience, although an appropriate level of resilience is provided. If not a priority, maintain a watching brief.
16-20	High	A significant level of vulnerability to specific climate risk(s). Mitigating action or adaptation is recommended.
21-25	Extreme	An extreme level of vulnerability to specific climate risk(s). Mitigating action or adaptation is highly recommended.

Source: Mott MacDonald (2021)

CCRA matrices

The CCRA matrices have been categorised into the following four groups:

- WTG and OSS Infrastructure
- Inter-array and export cables including electrical design
- Onshore Assets (Operation Phase) - O&M Building, CTV Quay and Associated Assets
- Onshore and Offshore (Construction, Operation, Decommissioning Phases) - Staff and Contractors

Due to reasons of confidentiality, project specific measures, design elements and potential mitigating actions referring to the design and operation of the wind farm are not provided in this summary.

Offshore Assets (Operation Phase)

WTG and OSS Infrastructure

Climate change impact (per variable)	**Likelihood of occurrence (score)**	**Direct impact of climate change - hazard**	**Potential consequence of direct impact**	**Severity of consequences (score)**	**Physical risk (Score)**
Increase in average and extreme surface temperature	While likelihood of a ~3 °C average annual increase in air temperature is almost certain to 2050 (5), the likelihood of exceedance of temperature outside the design envelope of -15°C to 35°C is unlikely (2).	Heating / overheating and expansion	• Exacerbated temperature extremes and/or sustained high temperatures may inhibit power infrastructure performance and export • Increased temperatures could lead to the failure of electrical equipment and gear boxes (possibility of fire) • Degradation of turbines • Exacerbated temperature extremes and/or sustained high temperatures may inhibit power infrastructure performance and export.	3	6 (Low)
Increase in sea surface temperatures	5	Heating / overheating and expansion; Humidity and corrosion	• Corrosion of structures, e.g. monopiles. • Warmer waters may encourage sea life growth including algae (which may cause additional water resistance and therefore loading on the structure).	2	10 (Low)
Net increase in annual precipitation	3	Impact force; fluctuating salinity	• The damage due to raindrops has an erosive and a fatigue contribution due to the impact force. Moreover, it was seen that the rain drops are sensitive to the blade flow field, (Fujiwara et al, 2015) • Impacts can propagate further to and through resins and fibres. A deterioration in blade surface condition can lead to a substantial increase in drag along with a decrease in lift coefficient, resulting in a significant reduction in annual energy production, (Macdonald et al, 2015).	1	3 (Insignificant)
Increase in precipitation intensity (specifically falling as rain)	4	Flood and inundation	• n/a	-	-
Net increase in snow, hail and	2	Cold weather events/anomalies affecting the	• Cold weather events/anomalies can affect the efficiency and performance of turbines.	4	8

Climate change impact (per variable)	**Likelihood of occurrence (score)**	**Direct impact of climate change - hazard**	**Potential consequence of direct impact**	**Severity of consequences** **(score)**	**Physical risk** **(Score)**
frost occurrence and extent		efficiency and performance of turbines, e.g. impact force; weathering, loading, ice build-up and accretion	• Hailstones have been found to collide on nearly every portion of the blade section along their trajectory due to insensitivity of hail stones to the blade flow field. Damaged surface areas have however been found to be small when compared to the overall impingement surface. Most delamination damage is typically expected to be localised on the blade leading edge and to outboard sections.(Fujiwara et al, 2015) • Impacts can propagate further to and through resins and fibres. A deterioration in blade surface condition can lead to a substantial increase in drag along with a decrease in lift coefficient, resulting in a significant reduction in annual energy production (Macdonald et al, 2015). • Damaged/broken blades can create imbalances and bending of shafts. • Brackets can come loose.		(Low)
Increase in mean sea level	5	Additional loading/drag	• Structural stress; additional corrosion and/or scour.	2	10 (Low)
Increase in annual mean and extreme wind speeds	3	Changing wind patterns so that average wind speed falls outside of the optimal range	• Project reports suggest the risk of damage to infrastructure from increased wind force is considered low with negligible increase or decrease in power production expected over time. • However, possibility of the following should be noted: - Infrastructure damage and impact to power yields: - Damaged/broken blades can create imbalances and bending of shafts. - Brackets can come loose.	2	6 (Low)
Increase in extreme water levels and wave heights	3	Additional loading, scour	• Project reports suggest the risk of damage to infrastructure from increased wave force is considered low with negligible increase or decrease in power production expected over time. • However, possibility of the following should be noted:	3	9 (Low)

Climate change impact (per variable)	**Likelihood of occurrence (score)**	**Direct impact of climate change - hazard**	**Potential consequence of direct impact**	**Severity of consequences (score)**	**Physical risk (Score)**
			- Infrastructure damage and impact to power yields: - Damaged/broken blades can create imbalances and bending of shafts. - Brackets can come loose. • The UK Climate Change Risks Assessment has been estimated that extreme weather conditions have caused about 80% of all North Sea offshore turbines to sustain failing grouted connections, causing some turbines to tip and no longer stand vertically. This has primarily been in monopile turbines, which can experience bending movement in the bolted/grouted joints between the monopile and the transition piece, resulting in the need for urgent repairs. • Moreover, dissolved or cracked grouting has caused turbines to shift on their foundations. (Diamond, 2012).		
Increase in sea-ice extent and thickness	2	Ice accretion to structures, e.g. monopiles	• While project reports conclude that this is a decreasing risk over time – a continuation of the trend observed in the past century, drag is still a risk, as well as wear and tear; weathering	3	6 (Low)
Net increase in lightning occurrence	3	Shock and damage to systems	• n/a	-	-

Inter-array and Export Cables including Electrical Design

Climate change impact (per variable)	**Likelihood of occurrence (score)**	**Direct impact of climate change - hazard**	**Potential consequence of direct impact**	**Severity of consequences (score)**	**Physical risk (Score)**
Increase in average and extreme surface temperature	5	Heating; expansion	• Corrosion; power loss	2	10 (Low)
Increase in sea surface temperatures	5			2	10 (Low)
Net increase in annual precipitation	3	n/a	n/a	-	-
Increase in precipitation intensity	4	n/a	n/a	-	-
Net increase in snow, hail and frost occurrence and extent	2	Cold weather events/ anomalies affecting the efficiency and performance of turbines, e.g. loading, ice accretion and weathering	• Scour could cause failure at a cable joint; Subsidence and scour impacts on WTGs and inter array cables.	2	4 (Insignificant)
Increase in mean sea level	5	n/a	• n/a	-	-
Increase in annual mean and extreme wind speeds	3	Weathering; ice accretion	• Scour could cause failure at a cable joint; Subsidence and scour impacts on WTGs and inter array cables. • While Project reports conclude that sea ice is a decreasing risk over time – a continuation of the trend observed in the past century - drag is still a risk, as well as wear and tear; weathering.	1	3 (Insignificant)
Increase in extreme water levels and wave heights	3			2	6
Increase in sea-ice extent and thickness	2			2	4 (Insignificant)

Onshore Assets (Operation Phase) - O&M Building, CTV Quay and Associated Assets

Climate change impact (per variable)	**Likelihood of occurrence (score)**	**Direct impact of climate change - hazard**	**Potential consequence of direct impact**	**Severity of consequences (score)**	**Physical risk (Score)**
Increase in average and extreme surface temperature	5	Heatwave; overheating	• Increased temperatures could lead to the failure of electrical equipment	1	5 (Insignificant)
Increase in sea surface temperatures	5	n/a	• n/a	-	-
Net increase in annual precipitation	3	Flood; Inundation,	• Damage to structures, movable assets, critical equipment; disruption to operations	1	3 (Insignificant)
Increase in precipitation intensity (specifically falling as rain)	4			1	4 (Insignificant)
Net increase in snow, hail and frost occurrence and extent	2	Cold weather events/anomalies causing loading, ice accretion and slippery conditions		1	2 (Insignificant)
Increase in MSL	5	n/a	• n/a	-	-
Increase in annual mean and extreme wind speeds	3	Weathering; coastal spray/flood/inundation	• Physical damage from extreme wind loads/forces; • Coastal spray and/or potential flood from overtopping of harbour wall	1	3 (Insignificant)
Increase in extreme water levels and wave heights	3			1	3 (Insignificant)
Increase in sea-ice extent and thickness	2	Ice accretion	• Freeze conditions/ice at quay and CTV (suspended inspections/maintenance services)	2	4 (Insignificant)
Net increase in lightning occurrence.	3	n/a	• n/a	-	-

Onshore and Offshore (Construction, Operation, Decommissioning Phases) - Staff and Contractors

Climate change impact (per variable)	Likelihood of occurrence (score)	Direct impact of climate change - hazard	Potential consequence of direct impact	Severity of consequences (score)	Physical risk (Score)
Increase in average and extreme surface temperature	While likelihood of a ~3 °C average annual increase in air temperature is almost certain to 2050 (5), the likelihood of exceedance of temperature outside the design envelope of -15°C to 35°C is unlikely (2).	Heating / overheating and expansion	• Exacerbated temperature extremes and/or sustained high temperatures may inhibit power infrastructure performance and export • Increased temperatures could lead to the failure of electrical equipment and gear boxes (possibility of fire) • Degradation of turbines • Exacerbated temperature extremes and/or sustained high temperatures may inhibit power infrastructure performance and export.	3	6 (Low)
Increase in sea surface temperatures	5	Heating / overheating and expansion; Humidity and corrosion	• Corrosion of structures, e.g. monopiles. • Warmer waters may encourage sea life growth including algae (which may cause additional water resistance and therefore loading on the structure).	2	10 (Low)
Net increase in annual precipitation	3	Impact force; fluctuating salinity	• The damage due to raindrops has an erosive and a fatigue contribution due to the impact force. Moreover, it was seen that the raindrops are sensitive to the blade flow field, (Fujiwara et al, 2015) • Impacts can propagate further to and through resins and fibres. A deterioration in blade surface condition can lead to a substantial increase in drag along with a decrease in lift coefficient, resulting in a significant reduction in annual energy production, (Macdonald et al, 2015).	1	3 (Insignificant)
Increase in precipitation intensity (specifically falling as rain)	4	Flood and inundation	• n/a	-	-
Net increase in snow, hail and frost occurrence and extent	2	Cold weather events/anomalies affecting the efficiency and performance of turbines, e.g.	• Cold weather events/anomalies can affect the efficiency and performance of turbines. • Hailstones have been found to collide on nearly every portion of the blade section along their trajectory due to insensitivity of hail stones to the blade flow field. Damaged surface areas have however been found to	4	8 (Low)

Climate change impact (per variable)	Likelihood of occurrence (score)	Direct impact of climate change - hazard	Potential consequence of direct impact	Severity of consequences (score)	Physical risk (Score)
		impact force; weathering, loading, ice build-up and accretion	be small when compared to the overall impingement surface. Most delamination damage is typically expected to be localised on the blade leading edge and to outboard sections.(Fujiwara et al, 2015) • Impacts can propagate further to and through resins and fibres. A deterioration in blade surface condition can lead to a substantial increase in drag along with a decrease in lift coefficient, resulting in a significant reduction in annual energy production (Macdonald et al, 2015). • Damaged/broken blades can create imbalances and bending of shafts. • Brackets can come loose.		
Increase in mean sea level	5	Additional loading/drag	• Structural stress; additional corrosion and/or scour.	2	10 (Low)
Increase in annual mean and extreme wind speeds	3	Changing wind patterns so that average wind speed falls outside of the optimal range	• Project reports suggest the risk of damage to infrastructure from increased wind force is considered low with negligible increase or decrease in power production expected over time. • However, possibility of the following should be noted: - Infrastructure damage and impact to power yields: - Damaged/broken blades can create imbalances and bending of shafts. - Brackets can come loose.	2	6 (Low)
Increase in extreme water levels and wave heights	3	Additional loading, scour	• Project reports suggest the risk of damage to infrastructure from increased wave force is considered low with negligible increase or decrease in power production expected over time. • However possibility of the following should be noted: - Infrastructure damage and impact to power yields:	3	9 (Low)

Climate change impact (per variable)	**Likelihood of occurrence (score)**	**Direct impact of climate change - hazard**	**Potential consequence of direct impact**	**Severity of consequences (score)**	**Physical risk (Score)**
			- Damaged/broken blades can create imbalances and bending of shafts. - Brackets can come loose. • The UK Climate Change Risks Assessment has been estimated that extreme weather conditions have caused about 80% of all North Sea offshore turbines to sustain failing grouted connections, causing some turbines to tip and no longer stand vertically. This has primarily been in monopile turbines, which can experience bending movement in the bolted/grouted joints between the monopile and the transition piece, resulting in the need for urgent repairs. • Moreover, dissolved or cracked grouting has caused turbines to shift on their foundations. (Diamond, 2012).		
Increase in sea-ice extent and thickness	2	Ice accretion to structures, e.g. monopiles	• While project reports conclude that this is a decreasing risk over time – a continuation of the trend observed in the past century, drag is still a risk, as well as wear and tear; weathering	3	6 (Low)
Net increase in lightning occurrence	3	Shock and damage to systems	• n/a	-	-

CONCLUSION

The CCRA report concludes that the risk of physical damage, risks to worker safety and interdependent system interruptions with respect to wind energy projects is present irrespective of climate change. The physical risk assessment identified project and asset risks that may be magnified by events attributed to climate change. The existing mitigation allowances for climate stressors and shocks to offshore and onshore assets, coupled with proposed management plans and interventions by the Project Company and project partners has rendered the net classification of these risks as being either low or insignificant.

To this end, no fatal flaws in the form of high or extreme risks to the Project have been identified as a result of projected climate change to the 2050s.

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