NYSERDA: Offshore Wind Climate Adaptation and Resilience Study

Final Report | Report Number 21-04 | February 2021

NYSERDA’s Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Our Vision:

New York is a global climate leader building a healthier future with thriving communities; homes and businesses powered by clean energy; and economic opportunities accessible to all New Yorkers.

Our Mission:

Advance clean energy innovation and investments to combat climate change, improving the health, resiliency, and prosperity of New Yorkers and delivering benefits equitably to all.

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NYSERDA: Offshore Wind Climate Adaptation and Resiliency Study

Final Report

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Abstract

New York State will increasingly face challenges from a rapidly changing climate in the years ahead and is undertaking comprehensive climate action to mitigate the impacts of and increase resiliency to climate change. Offshore wind (OSW) represents a critical component in achieving the State objective of achieving a 100% clean electricity portfolio by 2040.

While OSW farms are already designed to withstand many climate hazards, climate change has the potential to stretch design and operational limits, exposing equipment to potentially harsher and more variable conditions than anticipated under conventional design paradigms.

Work accomplished under this NYSERDA project aggregated, refined, and distilled climate adaptation and resiliency considerations that pertain to offshore wind for New York State and in the broader North Eastern Atlantic region of the United States. The report identifies climate factors that are meaningful to OSW operations and reliability and examines the range of options to build resilience to climate change, including revisions to planning and design processes, technology solutions, and improvements to operational strategies.

Keywords

offshore wind resilience, wind turbine resilience, OSW, offshore wind resilience, climate change

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

ABS	American Bureau of Shipping
ACPARS	Atlantic Coast Port Access Route Study
AEP	Annual Energy Production
AWEA	American Wind Energy Association
BOEM	Bureau of Ocean Energy Management
CLCPA	Climate Leadership and Community Protection Act
CMIP5	Coupled Model Intercomparison Project
DLC	Design Load Cases
DOE	Department of Energy
EERE	Energy Efficiency & Renewable Energy
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
GCM	Global Climate Model
GHG	greenhouse gas
HVAC	high voltage alternating current
HVDC	high voltage direct current
IEC	International Electrical Commission
IPC	individual pitch control
IPCC	Intergovernmental Panel on Climate Change
LEE	leading edge erosion
LIDAR	Light Detection and Ranging
MARIPARS	Massachusetts and Rhode Island Port Access Route Study
NCA4	Fourth National Climate Assessment
NEPA	National Environmental Policy Act
NNBF	natural and nature-based features

NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NWS	National Weather Service
NYC	New York City
NYS	New York State
NYSERDA	The New York State Energy Research and Development Authority
OEM	original equipment manufacturers
OREC	Offshore Wind Renewable Energy Certificate
OSW	offshore Wind
PARS	Port Access Route Studies
RCP	Representative Concentration Pathways
SCADA	supervisory control and data acquisition
SME	subject matter expert
USCG	U.S. Coast Guard

Executive Summary

The purpose of this study is to aggregate, build knowledge of, and distill climate adaptation and resiliency considerations that pertain to offshore wind (OSW) for New York State and to identify resilient design strategies that the New York State Energy Research and Development Authority (NYSERDA) can implement to support meeting its OSW development objectives. Published in support of NYSERDA's goals under its 2020–2023 Strategic Outlook: Toward a Clean Energy Future, this study aims to build awareness and drive resilient outcomes to implement the goals outlined in the New York State Climate Leadership and Community Protection Act (CLCPA) as well as to ensure a just transition, bringing energy efficiency, community resilience, and clean energy jobs to our State. This study represents a first industry sector in depth investigation into the topic of resiliency and serves as a harbinger of more concentrated action from NYSERDA in the months ahead on this strategic focus area.

Given that New York State's OSW resource is situated in federal waters spanning the coast from New England through southern New Jersey, resiliency considerations for the State may also be relevant for the broader Northeastern Atlantic Region. For the purposes of this study, we consider resilience as the planning, design, operational, and financial considerations that facilitate meeting performance objectives under a broad range of conditions today as well as in the future. There are several performance objectives for OSW, including project economics (e.g., energy generated, operations, and maintenance costs), technical performance criteria (e.g., mechanical availability), climate change mitigation (e.g., avoided tons of carbon), and the consideration of these objectives differs depending on a given stakeholder.

New York State will face challenges from a rapidly changing climate in the years ahead. In response, the State is undertaking comprehensive climate action at an unprecedented rate in our nation to deliver a range of projects and initiatives to decarbonize our economy, mitigate impacts and increase resiliency to climate change. The CLCPA seeks to mitigate climate change impacts by requiring NYS to have a net zero carbon economy by 2050, including a 100% clean electricity portfolio by 2040. Offshore wind represents a critical component to meet this mandate and improve climate resiliency in the State. Accordingly, NYS is supporting the development of at least 9 gigawatts (GW) of OSW energy by 2035 as a crucial step on the pathway to a carbon-neutral economy and an integral part in achieving the Clean Energy Standard, whereby 70% electricity will come from renewable sources by 2030.

While OSW developments are already designed to withstand many climate hazards, including extreme winds and storm surge,[1] climate change has the potential to stretch design and operational limits, exposing equipment to potentially harsher and more variable conditions than anticipated under conventional design paradigms. For example, climate change may exacerbate strong storms and sea level rise, as well as drive changes in wind patterns and velocity that could affect reliability or the extent to which the system provides output and avoids periods of temporary disruption. However, while climate change is an acknowledged reality in New York State and around the globe, the extent and severity of impacts related to climate change remains to be seen.

Mainland ports are also integral in the transport and staging of material used for construction of OSW systems. Port infrastructure, such as warehouses, wharves, piers, cranes, and container storage yards, as well as port operations, are potentially vulnerable to several of the climate factors described in this report. Additionally, potential threats to resilience such as hacking, vandalism, and terrorism are considered, though the strong remote monitoring software and challenge of physically accessing offshore turbines mitigate the vulnerability to such attacks.

Since 2010 over much of North America, Europe, and Asia, global wind speeds have increased, yielding an estimated 17% increase in potential wind energy for the average wind turbine (Zeng et al. 2019). Looking forward, changes to wind velocity, frequency, and variation due to climate change and corresponding impacts to offshore wind performance and reliability in the Northeastern United States remain uncertain. Projections regarding hurricanes indicate that by 2050, the frequency of hurricanes will likely be similar to today, although the frequency of strong hurricanes is projected to increase. Stronger hurricanes produce stronger winds, ocean waves and storm surge that could be detrimental to offshore wind developments and coastal infrastructure.

All forms of energy generation have the potential to impact wildlife and communities. However, the impact on wildlife and ecologies is far less significant from wind power generation than traditional forms of energy production based on fossil fuels, because wind power does not require the same level of resource extraction in manufacturing and construction or promote large-scale ecosystem pollution and emissions during their up to 25-year operational lives (Carini, 2018; American Bird Conservancy, 2017). Due to the uncertain nature of several likely future changes—such as changes in biodiversity patterns and future species redistribution—some impacts noted in this review are neither positive or negative, but rather trends that NYSERDA is aware of and will seek to understand potential technical and design adaptations to promote sensitivity to a changing climate in its efforts to support the responsible and cost-effective advancement of this industry and projects supplying New York State with clean energy.

The common potential community impacts associated with offshore wind development—particularly sound impacts experienced by nearby communities and coastal impacts such as turbine visibility—will be significantly mitigated by the wind farm's location more than 14 miles offshore (see Figure A-1) and will not likely be significantly influenced by changes in climate (NYSERDA, 2013a). Conversely, significant direct and indirect benefits to coastal communities in the State are anticipated through offshore wind, including the responsible transition away from dirtier "peaker plants" (power plants used to balance the fluctuating power requirements of the grid) to provide local energy while meaningfully improving air quality in more vulnerable communities; investment in grid hardening and resource diversity; port infrastructure investment that will enable maritime industries; and the creation of 10,000 jobs by 2035. Where the CLCPA squarely recognizes the frontline experience of disadvantaged communities[2] in the fight against climate change, this study's identified resiliency considerations should be furthermore considered as a starting point to think of how users could best intersect these initiatives with the delivery of benefits including workforce development, training, jobs creation, and economic development broadly to disadvantaged communities, and the critical partnerships to do so.

Current OSW design practices already consider a range of climate factors in OSW project site assessments and characterizations. Indeed, these components are fundamentally designed to be subjected to harsh conditions, and international OSW design standards account for storms and extreme weather in the region of interest. However, under climate change, these factors will only grow in importance. Recognizing the important new investments in technology to help support New York State's electricity grid that offshore wind will bring, NYSERDA recognizes the opportunity to employ best efforts to ensure that the infrastructure built today is also cost-effective and responsible for tomorrow.

This study identifies a range of options to build resilience into OSW systems. For example, wind turbines can be made more robust with heavier or stiffer blades, or new radical designs such as split pitch and two-bladed turbine layouts may enable turbines to more efficiently withstand extreme weather events without damage (NREL, 2016; Kim et al, 2015). Turbines can incorporate technology that actively adjusts the blades to either improve performance in low-wind conditions or reduce loading in high-wind conditions. Smart technologies can optimize operation in changing wind conditions by using lasers that allow the turbine to register the wind approaching the turbine rotor, allowing the turbine to optimize operation in changing wind conditions. This type of technology is becoming more commonplace in the wind industry but is currently only offered as standard with wind turbines by one major turbine original equipment manufacturer (OEM). Future scenarios of sea level rise can be incorporated into OSW system planning through the design of the turbine foundations. Additionally, future climate conditions, such as sea level rise and extreme weather, can be factored into the structural composition of and operations at mainland ports that are associated with the OSW developments. In contemplating the anticipated changes to the climate in the Northeast Atlantic and the various design or operational enhancements that are emerging in the industry, NYSERDA and its selected OSW projects have the ability to make considered decisions to support the incorporation of resilient design strategies into the development of 9 GW of OSW by 2035, along with the associated mainland port infrastructure.

1 Introduction: Climate Considerations for Offshore Wind Systems

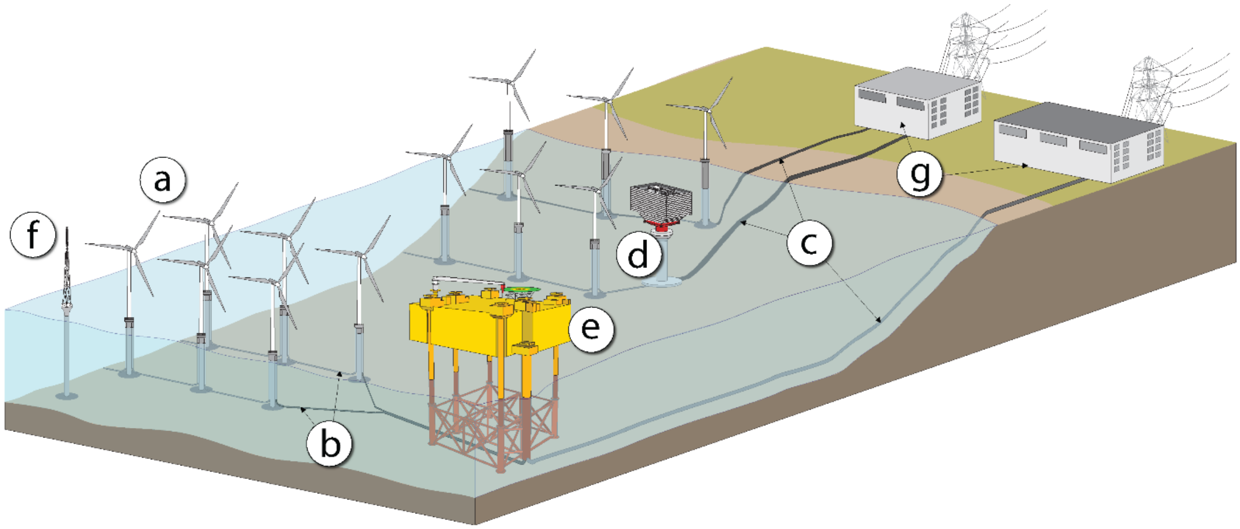
Offshore wind infrastructure includes ocean-based and land-based assets as well as supporting assets such as coastal ports and their associated supply chains. There are several climate factors that are meaningful to offshore wind (OSW) operations. Some factors such as wind velocity, shear, turbulence, consistency of direction, and geographic distribution affect the performance of OSW systems or their ability to deliver the expected output of energy over their useful lives. Other climate factors such as high wind speeds, storms, and waves may affect reliability or the extent to which the system provides output and avoids periods of temporary disruption as a result of climatic conditions outside of the normal operating range. This section covers those climate factors and describes the ways in which those factors impact OSW reliability and performance. In addition, the section covers human factors such as hacking and terrorism and the potential impact on offshore wind systems. Finally, the research team discusses how climate change may impact project financing and the associated due diligence[3] required.

1.1 Offshore Wind Systems

Offshore wind systems include ocean-based and land-based assets. Figure 1 shows a representative offshore wind system. Ocean-based assets include (a) wind turbine generator, and its foundations, which generates electricity from the wind, (b) collection or inter-array cables that electrically connect together, (c) export cables which transmit the electricity to shore and include the cable landings where ocean-based cable systems transition to underground land-based systems, (d) transformer stations which increase the voltage of the electricity for transmission to shore, (e) converter stations that, in some installations, convert the alternating current output of the wind turbines to direct current for transmission to shore, and (f) meteorological masts which contain weather sensors. Land-based assets include (g) onshore stations which receive the transmitted electricity and provide connection to the energy grid. At the OSW system level, resilience is reflected in the fact that the output of the system is distributed across numerous wind turbine generators, and the undersea electrical grid can be designed via a combination of series and parallel connections to provide redundancy to allow continued output despite failures in the electrical cables and substations.

Figure 1. Offshore Wind System

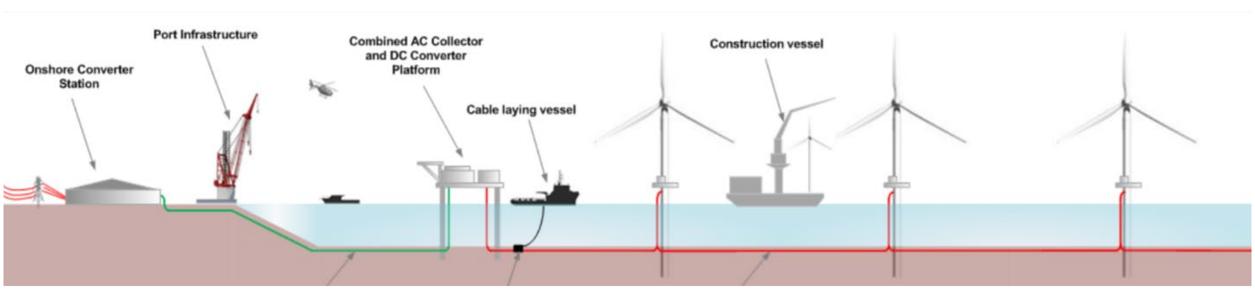
From Rodriguez et al., 2016.



OSW systems also include support infrastructure, such as ports, that facilitate construction and maintenance of wind farms. Ports are strategic elements in the OSW supply chain because manufacturing, staging, and assembly rely upon these facilities as the enormous size of OSW components generally prohibit inland transportation and logistics. Figure 2 shows port infrastructure as it relates to the components of offshore wind systems.

Figure 2. Offshore Wind Port and Port Infrastructure Example

From Baring-Gould, 2014.



OSW systems also represent vast complex financial transactions where the initial due diligence in financing, underwriting of capital investments, and security of product delivery (energy, capacity, and environmental attributes) play a major role in the design and operational phases of these long-term projects. New York State's ratepayers are insulated from the financial risks of a project by virtue of the use of Offshore Wind Renewable Energy Certificate (OREC) contracts that represent an all-in price for the life of the contract, ensuring that such concerns are borne exclusively by the developer of an OSW project. However, financial risks nevertheless bear consideration as part of the project's original design and risk premiums that may be built into the original project price.

The consideration of OSW systems in this report refers to the state of built and operational infrastructure. The study does not consider climate factors and adaptations that specifically treat the construction phases of offshore wind.

The development of at least 9 gigawatts (GW) of OSW by 2035 per the CLCPA's mandate will be built through billions of dollars of transformative private investments to the New York State grid. It is important that the State work with the private sector to ensure that these investments, across each of the OSW system components described above, support robust designs not only for current conditions but further offer responsible, cost-effective designs for potential future conditions.

1.2 Offshore Wind and Climate Considerations

This section provides an overview of the basics of wind turbine operation and the climate factors relevant to offshore wind ocean-based and land-based assets. It covers key factors considered in standard design practices for both performance and reliability of these assets. "Performance," used in this report, is meant to convey the ability of the system to deliver the expected output of energy over its useful life. "Reliability," for the purposes of this report, captures the extent to which the system provides output and avoids periods of temporary disruption as a result of climatic conditions that are outside of the normal operating range.

1.2.1 Overview of Key Relevant Climate Factors

The primary climate variables impacting the performance of offshore wind developments include wind speed, direction, turbulence, and geographic distribution as well as shear, temperature, and moisture. These wind variables may have independent or compounding effects on a wind turbine's performance. The effectiveness of an offshore wind project will depend in part on the optimal confluence of these variables.

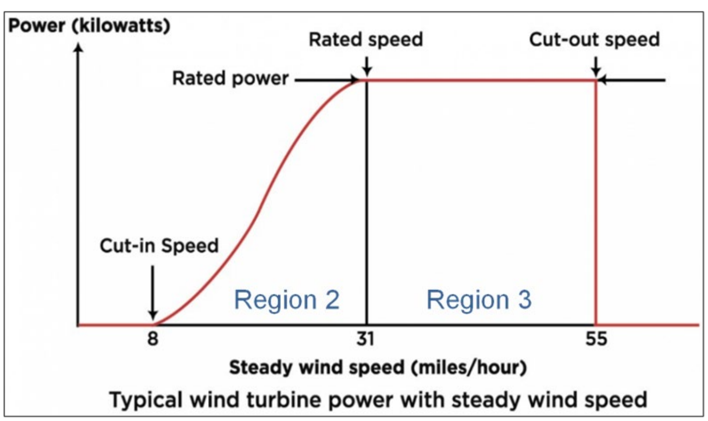
Equally important to consider are the climate variables that may impact reliability and cause disruption to offshore wind systems. While offshore wind systems are designed to withstand harsh environments, extreme weather such as high or low windspeeds ("wind droughts"), ocean waves, precipitation (especially in the form of rain and ice), and sea level changes can potentially have a detrimental impact on wind energy production and OSW system assets. All these factors are accounted for in international design standards, such as the International Electrical Commission (IEC) 61400-3 standard, which outlines the minimum design requirements for offshore wind turbines, including such considerations as acute maximum loads and long-term fatigue performance. Offshore wind systems are designed to maximize performance and minimize disruptions to power production.

1.2.2 Basics of Wind Turbine Operation

A wind turbine creates electrical power from the wind. As wind speed increases, turbine power output increases. In fact, wind energy density and consequently, turbine power, has a cubic relationship with wind speed such that turbine power increases with the cube of wind speed ($P = \frac{1}{2} pAC_PU^3$, where P = wind power [W], p = air density [kg/m^3], A = swept rotor area [m^2], C_P = rotor efficiency, also known as coefficient of power, and U = wind speed at hub height [m/s]). Airflow over the turbine blades creates a low-pressure suction on the top of the blade. This low-pressure suction along the blade, also known as lift, acts to rotate the turbine rotor. The turbine rotor consists of the blades and hub assembly. This rotational energy is converted into electrical power by the turbine generator.

Figure 3. Turbine Wind Power Curve

From DOE EERE, 2017.



The turbine controller, essentially the "brain" of the turbine, constantly monitors the operational health of the turbine and adjusts the turbine blades or turbine orientation based on the incoming wind. The designed operational plan for the turbine is prescribed by the turbine's "power curve," an example of which is shown in Figure 3. At any given point in time, the speed of wind into the turbine rotor determines the turbine's "operation point," or the location on the power curve.

As the wind speed increases above zero, it reaches the wind turbine's "cut in" wind speed, defined as the minimum wind speed at which the turbine can produce power (see Figure 3). At this point the wind turbine pitches, or rotates, the blades such that the airflow over the blades produces a rotational force that spins the rotor and ultimately creates power. As the wind speed continues to increase, the turbine operating point climbs up the power curve slope (DOE EERE, 2017). This part of the power curve, with continuously increasing power production with increasing wind speed, is known as "Region 2" in the power curve. At rated wind speed the turbine can produce rated "nameplate power." Nameplate power is the as-designed rated power of a turbine. For example, the nameplate power of a 3-megawatt (MW) machine is 3 MW. The part of the power curve where the turbine can produce rated nameplate power is known as the "knee of the power curve" and represents the highest loading the turbine will experience during normal operation. As the wind speed increases above the knee of the curve, the blades are pitched into the wind such that the overall loading on the blades is reduced to maintain rated nameplate power and to ensure loads respect the turbine design limits. This area of the power curve with constant rated power production is known as "Region 3." Wind turbines operate at highest efficiency in Region 3. As the wind speed continues to increase, it will reach the maximum wind speed design limit of the turbine at the cut-out wind speed. Beyond this speed, the turbine exceeds its design operational load limit. To prevent damage, the wind turbine will pitch the blades into the wind for wind speeds above cut-out, also known as "feathering," which results in no lift on the blades and ceases power production. The turbine will remain in an idle configuration until the wind speed drops to below the cut-out speed (DOE EERE, 2017). This idle configuration allows the rotor to slowly turn as needed without producing power and to reduce overall loading on the turbine to "ride out" gusts or sustained heavy winds such as those experienced under storm conditions. Once the wind speed returns to prevailing conditions (i.e., below cut-out speed) the wind turbine will change the blade pitch to start producing power again.

1.2.3 International Wind Turbine Design Standards

IEC 61400-1 and IEC 61400-3

There are a number of international design standards that give guidance on the design of wind turbines, and all wind turbines sold internationally are certified to have been designed per these international design standards. Two of the most common and widely used standards are the IEC 61400-1, which outlines the design of onshore wind turbines, and the IEC 61400-3, which outlines the design of offshore wind turbines. Both design standards set a list of Design Load Cases (DLC) which simulate various loading conditions a wind turbine may experience. In order to achieve international certification, a wind turbine design must meet or exceed all DLC requirements.

Both IEC wind turbine standards categorize the operational environments for which a wind turbine should be designed. Table 1 contains the IEC wind classes, as defined in IEC 61400-1.

Table 1. The IEC 61400-1 Ed 4 Wind Turbine Classes

Source: Liu et al, 2018.

Wind Turbine Class		I	II	III	S
V_{ave}	(m/s)	10	8.5	7.5	Values specified by the designer
V_{ref}	(m/s)	50	42.5	37.5	
	Tropical (m/s) $V_{ref,T}$	57	57	57	
A+	I_{ref} (-)	0.18			
A	I_{ref} (-)	0.16			
B	I_{ref} (-)	0.14			
C	I_{ref} (-)	0.12			

The parameter values apply at hub height:

V_{ave} is the annual average wind speed

V_{ref} is the reference wind speed average over 10 min

$V_{ref,T}$ is the reference wind speed average over 10 min applicable for areas subject to tropical cyclones

I_{ref} is a reference value of the turbulence intensity

A+ designates the category for very high turbulence characteristics

A designates the category for higher turbulence characteristics

B designates the category for medium turbulence characteristics

C designates the category for lower turbulence characteristics

The IEC 61400-3 combines the above table with wave and current loading as well as sea level to develop a full-offshore design load case set for the design of offshore wind turbines.

The reader should note the S class on the top right of Table 1. The S stands for "site specific." In the early days of the wind industry, wind turbines were generally designed for a specific wind class per the IEC, such as IA or IIIB, which defines the average and reference wind speeds as well as the turbulence level. Since wind farm designers would select the next higher wind class for their project site, the result was that turbine designs would include a level of margin by virtue of these discrete classes. However, it is becoming increasingly common for modern wind turbines to be designed for S-class or site-specific wind, which is unique for each wind farm location. This means smaller wind speed, load, and design margins resulting in turbines operating closer to their ultimate design limits than older models. Accordingly, there may be less additional design margin to absorb an increase in loads that may occur due to climate change, requiring designers to better understand the impact of climate change to site-specific loading conditions.

The international design standards provide design guidance for the development of onshore and offshore wind turbine systems to withstand all reasonably expected loading, including extreme weather events. Given the potential for climate change to affect the severity and probability of occurrence of extreme weather, there is a potential for increased damage and/or reduced productive life due to extreme weather loading. Accordingly, the wind industry continues to research solutions to improve resilience in extreme weather.

1.2.4 Climate Factors Impacting Offshore Wind Performance

1.2.4.1 Wind: Velocity, Shear, Turbulence, Direction, Geographic Distribution, Temperature, and Moisture

The following sections discuss factors that are common inputs to site assessments, characterizations, and yield estimates for wind turbines. With climate change, these factors will continue to be important and may change wind turbine calculations and performance.

Offshore wind site conditions are particularly optimal for wind energy production with less turbulent and more consistent wind flow conditions and higher overall energy levels than those onshore. As such, offshore wind farms exhibit great potential to power much of future electrical demand in coastal regions, particularly those close to highly populated areas with high-electrical demand.

1.2.4.2 Wind Velocity (Including Frequency Distribution and Variation)

Wind velocity, which accounts for wind speed and direction, has the most significant impact on wind turbine performance. Site assessments typically consider annualized mean wind speed, wind speed frequency distributions, and seasonal as well as diurnal variations in velocity.

As mentioned previously, wind energy density is directly proportional to the cube of wind speed ($E = ½ pU^3$, where E = energy density [W/m^2], p = air density [kg/m^3], and U = wind speed at hub height [m/s]). As such, small changes in average wind speed will significantly impact turbine power production (Pryor and Barthelmie, 2010). If average wind speed increases, there will be more total energy in the wind and the average operating point for the turbine will shift to the right on the power curve. It is typical for a turbine to operate in Region 2 for most of its life. In this case, an increase in average wind speed will shift the operating point to the right on the power curve, climbing up Region 2. The wind turbine will operate at maximum power output capacity if the shift is sufficient to push the turbine to rated wind speed and into Region 3. Conversely, decreasing average wind speed may shift the turbine average operating point out of Region 3 and into Region 2, or, at extremely low-wind speeds, below cut-in speed, decreasing overall power production.

The "capacity factor" of a wind turbine is a measure of the amount of electricity the turbine produces over a given period relative to its nameplate power level (American Wind Energy Association). A turbine's capacity factor depends on the quality of the wind at a given site in addition to its intended operating level and design criteria. Capacity factor is important to the overall economics of a wind turbine and wind farm as the main characterization of a project's net energy production over a period of time. For a project to be profitable, the value of the net energy produced must exceed all costs by an amount equal to or greater than the desired rate of return for the project. Annualization means wind speed has a direct impact on turbine capacity factor.

Annual Energy Production (AEP) for a turbine or a wind project will be estimated based on knowledge of meteorological conditions specific to the project site, taking into account typical variances in daily and seasonal winds. For instance, if average wind speed increases or if high winds become more frequent, the wind speed may be more likely to exceed a turbine's designed cut-out speed, necessitating shutdown (Pryor and Barthelmie, 2010). Prolonged periods of turbine shutdown could result in an overall decline in AEP. Where climate change has the potential to alter common wind patterns, it is important to consider how such changes could alter AEP.

The frequency distribution of wind speeds is important for planning offshore wind farms because short-term wind speeds impact power output, extreme wind loading, and fatigue loading of the structural elements. The frequency distribution of wind speeds is typically approximated by a Weibull Distribution,[4] the parameters of which are determined according to wind speed measurements taken during site assessments.

Wind speed also exhibits variation over longer time periods. Wind farms often experience a diurnal wind effect, or consistent but different daytime and nighttime wind trends. This effect is accounted for when planning the development and operation of future wind farms in terms of annual energy production and expected downtime. The diurnal wind effect also impacts the timing and relationship between energy production and energy consumption. Wind speeds off New York City show a peak during the late afternoon and early evening hours (NYSERDA 2010). Seasonal wind variation is also considered in the planning process. The strongest winds off New York City normally occur during the winter, while the weakest winds occur during the summer.

1.2.4.3 Wind Direction

The directional distribution of wind is an important consideration when planning a wind project. Consistency in wind direction is key for optimal turbine power production and longevity as it reduces overall turbine wear and tear because the wind turbine yaw system—which rotates the turbine hub horizontally to match the prevailing wind direction—needs to rotate less to track the wind and, as such, suffers less wear and tear over the life of the project.

Consistent wind direction also allows for a more efficient wind farm layout with turbine placement optimized for the prevailing wind direction. It likewise allows turbines to be located closer to each other within wind farms, because wake effects[5] can be better predicted and accounted for in the layout design. Offshore sites often have more consistent winds than onshore sites (DOE EERE, N.d. B). Wind consistency also has a direct relationship with wind turbine capacity factor.

Site assessments use directional wind plots (wind roses) to indicate the frequency of occurrence and percentage of total energy from each direction sector. The resulting information is used to support the site analysis and farm layout design.

1.2.4.4 Turbulence Intensity

Turbulence intensity conveys the fluctuations in the wind speed, recorded by instrumentation, in each recording time interval as a fraction of the average speed (NYSERDA, 2010). Turbulence intensity can have a negative effect on turbine performance and power production. As air flows over the turbine blades, the blade shape creates a low-pressure suction that “lifts” the blade and causes the rotor to rotate, in similar fashion to the way airplane wings lift the airplane for flight. Smooth, or “laminar,” air flow over the turbine blades is required to properly create this lift for rotation and power production. If air is “turbulent,” air flow may separate prematurely over the turbine blade and result in a loss of low pressure and lift, reducing power production and increasing loads due to increased drag on the blade. In general, smooth air flow is optimal to efficiently extract energy and produce power from the wind.

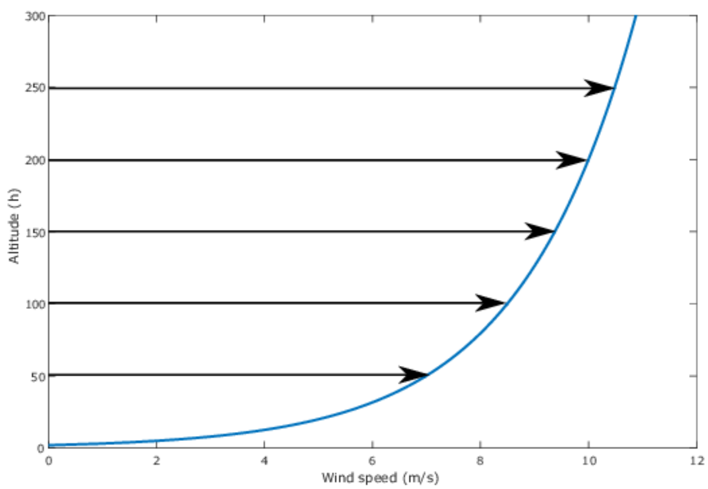
More frequent or intense events of high-wind turbulence will increase turbulent flow of wind over turbine blades, diminishing turbine power production.

1.2.4.5 Wind Shear

Changes in wind speed and direction can be described in terms of “wind shear,” a measure that indicates the amount of change in wind speed or direction over a given distance (Sanchez and Lundquist, 2020). There are two main types of wind shear that affect wind turbines: vertical and horizontal. Vertical wind shear is the variation of wind speed with elevation. Horizontal wind shear is a change in wind velocity or direction as one moves laterally. Vertical shear is influenced by thermal differences within the air column and by surface roughness interactions near the ground or water level. Horizontal shear is typically most influenced by weather fronts and is similar between onshore and offshore locations. Vertical wind shear has a much larger impact on overall wind turbine design than horizontal shear.

Figure 4. Graphical Profile of Vertical Wind Shear

From Salazar et al, 2016.



Typically, wind speed increases with elevation due to decreasing effects of wind shear because the wind profile is affected by friction with the surface which produces drag, reducing wind speed. For this reason, turbine original equipment manufacturers (OEM) design turbines with towers and hub heights high enough to minimize the impact of vertical wind shear. Accordingly, taller towers are used onshore due to the increased onshore vertical shear impact. For offshore, surface roughness values over the ocean are quite small (~ 0.001) as compared to over land (0.1-1). Because of this, offshore turbine towers can be shorter because of the decreased offshore vertical wind shear impact. In fact, the current industry standard for the lowest blade tip elevation is approximately 20 m above the ambient sea level. The ocean surface frictional effects are predominantly caused by interaction with waves and swells. Water surface variations have been shown to cause distortions in vertical wind profiles up to 100 m above the water surface (Kalvig et al, 2014). Where climate change has the potential to increase water surface turbulence due to changing wave or current patterns, the impact of such changes on wind shear and consequently turbine performance needs to be considered.

The extent of horizontal shear is similar between onshore and offshore locations and the impact is less than vertical shear. Current design standards for wind turbines already account for moderate levels of horizontal shear. Horizontal shear produces imbalanced loading on the turbine rotor. Mitigation of horizontal shear loading is normally done through the turbine controller dynamically adjusting the blade pitch and yaw of the turbine based on real-time information about rotor load imbalances. Turbine design also includes a prescribed amount of margin in the design limits to account for rotor imbalance loads as part of the international industry design standards, such as IEC 61400-3.

1.2.4.6 Wind Geographic Distribution

Large scale changes in the geographic distribution of wind could have significant negative impacts on overall energy production for existing wind farms (Pryor, S. C., and R. J. Barthelmie. 2010). Energy production will diminish if turbines are designed for wind patterns and speeds divergent from those actually experienced by the wind turbines. Predictable and consistent wind patterns for a given geographic area are required to accurately plan for and finance wind farm development, both onshore and offshore.

1.2.4.7 Air Temperature

As discussed previously, wind energy and, consequently, wind turbine output, is directly proportional to air density and air density is itself inversely proportional to air temperature. Thus, increases in air temperature lead to slight declines in air density and wind turbine power output. At mean sea-level pressure, an increase in air temperature of 5 degrees C would result in a decrease in air density of 1–2% with a similar, marginal change in wind energy (Pryor, S. C., and R. J. Barthelmie. 2010).

1.2.4.8 Air Moisture

Moisture in the air has the potential to impact the functionality of blades and will cause blade leading edge erosion over time. Where turbine blades are designed for air flow to separate at specific areas of the blade surface to ensure optimal lift and drag at all locations along the blade span, if air flow is disrupted such that it separates from the blade prematurely, the resulting flow becomes turbulent. Erosion along the front of a turbine blade, known as “leading edge erosion” (LEE), is one of the main causes of suboptimal turbine blade performance (Liersch and Michael, 2014). LEE creates a rough surface along the front of the blade which causes laminar airflow to detach prematurely and transition to turbulent airflow. Turbulent airflow reduces lift and increases drag, ultimately reducing turbine power production (Corrigan and Demiglio, 1985). Recent studies have shown that leading edge erosion is more likely to occur due to a high volume of small mass impacts (e.g., mist or dirt) than to a low volume of high-mass impacts (i.e., rain or bugs/Eisenberg et al., 2018). While offshore wind blades are designed with sacrificial layers of coatings to combat the effects of LEE, offshore turbines are nevertheless susceptible to leading edge erosion due to the wetter environment in which they operate. Operations and maintenance commonly include efforts to inspect, prevent, and repair leading edge erosion.

1.2.5 Climate Factors Impacting Offshore Wind System Reliability

1.2.5.1 High Winds above Operating Limits

Wind turbines generate rated power at wind speeds in Region 3 (see Figure 3). Turbines are designed to optimize power production efficiency and to minimize structural damage in this operating region. If, in a given geographic location, the average wind velocities shift higher or high-wind events become more frequent, turbines in that location may experience more frequent shutdowns, decreasing overall power output.

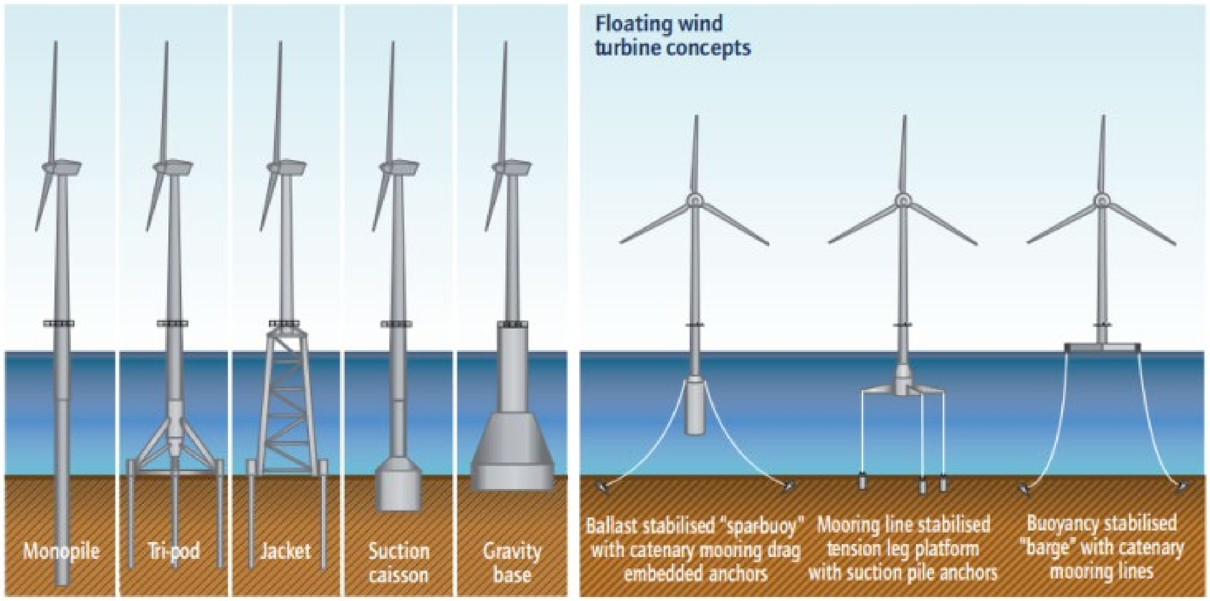
1.2.5.2 Ocean Waves

Ocean waves can affect OSW foundations, inter-array and export cables, and cable landings. Figure 5 shows the various types of offshore wind foundations that can be used for turbines, substations, and converter stations. Ocean waves directly impact and influence foundation and tower loading for both fixed and floating wind turbine, substation, and convertor station foundations (Kalvig et al., 2014). Wave loading is accounted for in the design of offshore wind turbines and is combined with ocean current as well as wind loads. Any increase in wave or current loading needs to be accounted for in the turbine design to ensure that such loading does not exceed design limits. Severe wave loading increases may exceed the foundation design load limits and result in turbine tower bottom and/or foundation damage or failure.

Wave loading frequency can potentially match a tower's first fundamental modes[6] (side-side and fore-aft). This includes a phenomenon called "ringing," which occurs when choppy waves strike marine structures. If these frequencies overlap, a resonance condition can occur where energy is continuously loaded into those tower modes. In this configuration, waves will cause a sympathetic motion response in the tower with tower and foundation displacement exceeding design limits.

Figure *5*. Offshore Wind Foundations

Source: IPCC 2011.



Mooring lines for offshore wind infrastructure are also sensitive to changes in wave loading. Wave motion causes the touchdown point of mooring lines on the ocean floor to change, moving back and forth and side to side as waves pass on the surface. Changes in wave loading, either in amplitude or frequency, have the potential to affect the fatigue life of mooring lines along the sections near and at the touchdown point. There is potential for increased fatigue damage or rate of fatigue damage if wave loading changes sufficiently.

Additionally, if changing global climate patterns result in increased wave activity around turbines, accessing the turbines to perform time-sensitive maintenance could become more challenging.

OSW cable systems include inter-array cables that make electrical connections between wind turbine generators and export cables that transmit the electricity to shore. Most of the cable system is buried beneath the ocean floor. However, for floating foundation systems, a portion of the cable system is exposed to ocean currents as it transitions from the foundation to the ocean floor. Standard design practices consider wave motion by incorporating bend stiffeners that provide strength against flexion, buoyancy modules that help maintain cable shape and reduce tension loads, and touchdown protection that reduces the risk of damage where the cable transitions to a buried configuration. However, changes in wave loading, either in amplitude or frequency, have the potential to affect the fatigue life of these parts of the cable systems.

Inter-array, export cables, and cable landings can be impacted by waves through scour—erosion that is caused by the turbulence from waves. Scour can wash away the underlying seabed, exposing buried cables, allowing ocean currents to move the cables, potentially increasing the amount of stress on the cables.

1.2.5.3 Precipitation

In general, precipitation tends to improve turbine performance by regularly cleaning the turbine blades. This cleaning removes bugs and dirt that collect over time and improves blade performance and overall turbine power production. However, extreme precipitation such as more energetic and/or more frequent thunderstorms or torrential rainstorms, with a high level of water particles continuously striking the turbine blades, increases the risk of blade leading edge erosion (Eisenberg et al., 2018). This happens particularly with offshore turbines operating for frequent, extended periods of time in fog, mist, high humidity, or rainy conditions. As previously described, leading edge erosion increases blade surface roughness, which in turn, disrupts the airflow over the blade and causes premature flow separation. This results in a loss in blade lift and ultimately reduced turbine power production. If precipitation levels or events become increasingly extreme or frequent, accessing the turbine to perform operations and maintenance could also become more challenging.

1.2.5.4 Sea Level Rise

Sea level rise is the gradual increase in the static level of the sea as opposed to storm surge which is abnormal rise in seawater level during a storm. Sea level rise alone may threaten infrastructure and that threat can be compounded by storm surge. Sea level rise has the potential to impact both fixed foundation and floating foundation offshore turbines by increasing water damage and corrosion of non-resistant components. For floating turbines, the impact would be less noticeable and would likely only show up on mooring line length and tension. The mooring line or tether tension limits for floating turbines may be exceeded due to the increase in elevation from sea level rise.

Sea level rise may also affect the corrosion rate of the offshore turbine foundations. If the sea level is higher than expected, it may exceed the height of the corrosion-resistant section of the foundation and come into contact with more sensitive parts of the structure. Sea level rise may also cause higher than anticipated sea spray onto the underside of foundation top or at the tower base connection which could also result in unwanted corrosion to these parts.

The offshore wind profile may also be affected by sea level rise and result in increased wear and tear on turbines. As referenced earlier, water surface variations have been shown to cause distortions in vertical wind profiles up to 100 m above the water surface (Kalvig et al, 2014). In this way, sea level rise could distort or change the vertical wind profile and affect the shear loading into the offshore turbine. The shear loading into the turbine directly affects the wear and tear rate on the pitch and yaw systems. Turbines dynamically maintain loading balance using Individual Pitch Control (IPC). A change in the shear loading could cause increased pitch activity and result in faster wear of the pitch bearings.

1.2.5.5 Ice and Frozen Precipitation

Ice and other frozen precipitation can pose risks to turbine health and performance. Ice can build up on the blades and disrupt the airflow over the blades and cause weight imbalances in the rotor that will trigger shutoff of an affected turbine, reducing project performance. Sea ice, while less likely to be a risk off the coast of New York State, can damage foundations and tower bottoms. Hail or sleet, if severe, can damage blades. If climate change causes a shift to colder weather patterns, there is an increased risk of damage or under performance due to ice. Shifting weather patterns may cause increased operations and maintenance (O&M) expense due to the need to retrofit existing turbines to prevent ice buildup.

1.2.5.6 Extreme Storms

Although extreme weather events are accounted for in the international design standards for wind turbines, such as IEC 61400-1 (onshore) and IEC 61400-3 (offshore), standards do not account for all possible levels of storms. Extreme storms have damaged turbines, caused failures, and resulted in decreased output both during events and as a result of extended repair times.

If high-wind speeds increase due to an increase in the intensity and/or frequency of extreme weather events, such as storm fronts, hurricanes, or typhoons, this may heighten the risk of turbine damage or failure when they occur (Worsnop et al., 2017; Rose et al., 2012).

Extreme weather events are also likely to result in an increase in offshore wave loading. As discussed above, a change in wave loading may dramatically affect the overall fatigue life of electrical cable systems for offshore wind systems and mooring lines for floating system designs. Increased wave loading may also increase the amount of scour (see discussion on ocean waves), which can uncover buried cable systems. Standard practice includes assessing touchdown points and laydown shapes of all underwater lines against the expected wave loading.

1.2.6 Onshore Electrical Infrastructure

Onshore electrical infrastructure includes onshore stations which receive the electricity from OSW export cables and provide connection to the energy grid. The receiving station is typically a transmission substation with operating voltages of 69 kilovolts (KV) or higher that is part of the larger energy grid and transfers power from several sources including transmission feeders from other substations, conventional generation, and renewable generation. These substations may be located near-shore but more often are located inland. Transmission substations located near-shore may be vulnerable to both sea level rise and storm surge while transmission substations inland may be vulnerable to inland flooding from heavy precipitation events, particularly in areas of dense build-up. The vulnerability of transmission substations is typically part of the operating utility's considerations of climate change vulnerability across its broad portfolio of assets rather than the scope of an OSW system design, but nevertheless bears mention.

1.2.7 Coastal Infrastructure and Ports

Due to the size of OSW components, ports are integral in the transport and staging of material used for construction of OSW systems. Port infrastructure, such as warehouses, wharves, piers, cranes, and container storage yards, as well as port operations, are potentially vulnerable to several of the climate factors described above. Such climate factors include sea level rise, heavy precipitation, and storm surge from coastal storms, and high winds and icing from hurricanes and nor'easters.

Sea level rise allows storm surge to travel further inland, compounding potential water damage to ports infrastructure. Increased seawater flooding can increase metal corrosion of port equipment. Higher sea levels also increase the risk that drainage systems could be overwhelmed by heavy precipitation, leading to surface flooding. Flooding, from either ocean sources or from inland flooding due to heavy precipitation, can damage shipping containers and their contents, as well as terminal buildings and other port infrastructure. Flooding can also impact operations by limiting access to roads and disrupting movement of cargo into and out of the port.

Storms can cause damage to marine port services by impairing visibility, disrupting the power and communications networks, washing away channel buoys, and submerging debris in ship channels. Channels may require more frequent, and more costly, dredging of debris and silt build-up following severe storms. Waves can cause structural damage to wharves and piers and as well as vessels and their cargo.

High wind speeds from storms can also damage port facilities and impact operations. High winds can damage or destroy piers, wharves, cranes, and berths. Wind can also result in loss of markers, making navigation channels temporarily inoperable.

1.2.8 Human Stressors

In addition to the climate factors described in earlier sections, there are several human factors that are relevant to OSW systems and their resilience. Since OSW systems are remotely located and operate "unmanned," they require supervisory control and data acquisition (SCADA) systems to allow operators to receive operating information about the system and to make control adjustments when necessary. This dependence of OSW on SCADA systems creates a vulnerability to hacking. The remote location of OSW systems makes it challenging to monitor the individual turbines and associated equipment, making such systems vulnerable to vandalism and physical attack.

1.2.8.1 Hacking

Researchers from the University of Tulsa have demonstrated the ability to hack wind turbine control systems after gaining physical access to an individual turbine. They were able to impact the power output for the turbine they accessed as well as for other turbines in the wind farm. They also simulated actions that would have been able to damage turbines (Greenberg, 2017). The researchers also built software tools to demonstrate several concepts. One tool repeatedly engaged the turbine brakes to cause damage; another tool demonstrated the ability for malware to spread from turbine to turbine, while a third tool allowed hackers to hide the cyber-attack from plant operators. Researchers also examined the ability to remotely hack into wind turbine systems. They found that the encryption used between operations centers and wind farms was effective at limiting a hacker's ability to remotely access wind turbine controls.

This successful attack by researchers required physical access to and breach of a wind turbine's structure. The current practice for security measures for wind farms include basic physical protection such as locks as well as physical intrusion detection and alarm systems. Offshore wind systems have the added protection of being relatively difficult to access because of their location and the need for ocean transport to reach them.

A cyberattack on a renewable energy company in Utah resulted in a loss of communication between the energy provider control center and wind turbine farms, denying operators the ability to control around 500 megawatts of wind and solar generation, although the attack did not result in the loss of generation to the grid (Sobczak, 2019). This attack was not aimed at the wind turbines directly but was a denial-of-service attack,[7] which flooded energy providers' computers with fake traffic, eventually crashing the devices. Denial-of-service attacks do not only affect energy generation systems but are an increasing problem across many industries. The federal government as well as private industries continue to be focused on this issue and continue to develop solutions.

1.2.8.2 Vandalism and Terrorism

Energy infrastructure assets have been the target of terrorist attacks in the past. One notable example was the 2013 attack on the Pacific Gas & Electric Metcalf substation that damaged 17 transformers (Behr, 2016). Vandals have also targeted transmission lines by shooting at insulators and even toppling transmission towers. Transmission substations and transmission lines are targeted because they are likely to be transfer points for significant amounts of power and are often remotely located and minimally staffed. Offshore wind farms are also remotely located and minimally staffed. However, even a wind farm with significant amounts of total generation is composed of individual turbines distributed across a large area. Since the output of any single turbine is small relative to the farm's total output, the value of physically sabotaging any one unit is correspondingly small. In addition, as mentioned previously, the electrical connections for OSW systems incorporate series and parallel connections to implement a level of redundancy and allow continued operations despite failures of some components. Coupled with the challenge in reaching the offshore site and the inability to access the transmission lines which are under water, offshore wind sites do not appear to be an inviting target for terrorist attack.

1.2.9 Project Financing

As the energy industry continues to transition away from fossil fuels, investors are seeing increasing value in renewable investment opportunities such as offshore wind. Offshore wind investments offer significant certainty and transparency because much of the deployment is tied to government incentives. In addition, relative to fossil fuel investments that have risk increases with the continued transition to a low-carbon economy, the risk profile for OSW decreases as more projects come online and underscore the ability for OSW to provide carbon free energy. These factors, as well as offshore wind's value to mitigate the effects of climate change, support estimates of over $200 billion in investment by 2025 (Lassen and Evans, 2020).

In addition to considering transition risks,[8] the project finance and due diligence processes consider both chronic and acute physical risks. Chronic physical risks refer to longer-term shifts in climate such as sea level rise while acute risks are those that are event-driven like extreme storms. Due diligence relating to chronic physical risks caused by gradual climate shifts focuses on the potential for those risks to negatively impact the long-term performance of OSW systems. Due diligence for event-driven physical risks examines the likelihood of extreme weather events that cause damage to infrastructure that either reduces its lifespan or results in catastrophic failure. Both chronic and acute physical risks have the potential to affect the financial viability of projects by reducing revenues and increasing expenses over the lifetime of a project.

The potential impact of climate change on project finances is based on the difference between the actual future conditions (i.e., annualized mean wind speed, wind direction, sea level, storm frequency) and that assumed in financial models. Project due diligence considers the potential financial impact on several areas including revenues, expenditures, asset value, capital, and financing.

Revenues can be impacted by chronic physical risks such as lower than expected annualized wind speed resulting in lower energy output from OSW facilities. Revenues can also be impacted by acute physical risks such as storms that result in periods of time during which wind assets are unavailable.

Expenditures can be impacted by chronic physical risks such as greater horizontal wind shear, requiring more frequent yaw adjustments, which increase maintenance costs, or icing, which could require more frequent blade maintenance. Acute risks such as storms can require significant expenditures to repair facilities that have been damaged. Higher expenses related to repair, and normalization of infrastructure may also increase insurance fees.

Once in service, the asset value of OSW infrastructure may be impacted by the potential for chronic and acute physical risks to shorten asset life and hence increase depreciation rates. The process of accounting for the potential for climate change to impact OSW projects may increase forecasts for capital expenses, costs of supplies and materials, and maintenance, all with potential implications to liabilities.

Climate-related physical risks have implications to rates of return and the cost of capital as well as to long-term debt. Physical risks from climate change may be reflected in higher expected rates of return from investors and higher costs of capital to developers to account for those risks, making it more challenging to finance projects. Climate-driven increases in capital and operational expenses may, over the life of a project, require an increase in debt, particularly if physical climate risks reduce cashflows or increase expenses. In addition, the ability to raise or refinance debt may be affected by climate-related physical risks by reducing project valuation which lowers attractiveness, increasing the difficulty in raising capital.

The perception of climate risk is already reflected in the pressure coming from private equity firms, banks, and their underwriters. For example, The Network for Greening the Financial System, a group of central banks and financial supervisors, has expressed concern that financial risks related to climate change are not fully reflected in the valuation of assets and has called for increased monitoring (NGFS 2019). The uncertainty around climate risk is also echoed in the pricing of offshore wind renewable energy certificates (ORECs)[9] in the form of risk premiums where developers are submitting lower bids to mirror this uncertainty. The extent to which underwriters and developers will acknowledge the potential for climate adaptations in OSW design to reduce risk is an evolving area in need of further evaluation.

2 Projected Changes to Climate Factors and Potential Impacts

New York State will face challenges from a rapidly changing climate in the years ahead. In response, NYS is undertaking a range of projects and initiatives to mitigate impacts and increase resiliency to climate change. The recent landmark CLCPA seeks to mitigate climate change impacts by requiring NYS to have a net zero carbon economy by 2050, including a portfolio of 70% renewable energy by 2030. Offshore wind represents a critical component to meet these mandates and improve climate resiliency in the State. To this end, the New York State Energy Research and Development Authority (NYSERDA) has adopted a strategy to incorporate resilience considerations into planning and programs to ensure that clean energy investments and infrastructure are protected and resilient against future climate impacts over the long term.

Climate change has the potential to impact multiple aspects of offshore wind performance, functionality, and reliability, encompassing both offshore development and coastal infrastructure. Global Climate Models (GCM) provide numerical representations of the climate system (Hayhoe et al. 2017) and are the primary tools to understand future climate change. Models are driven by changes in greenhouse gas concentrations known as Representative Concentration Pathways (RCP), which consider both unabated and mitigated greenhouse gas emissions through time and in response to different anthropogenic actions such as business-as-usual emissions as well as social and political pathways to support aggressive global decarbonization (IPCC, 2013). A standard set of GCMs and RCPs were developed for the most recent Intergovernmental Panel on Climate Change Assessment (IPCC), which underpin our understanding of future climate change and corresponding impacts (IPCC, 2013). The information provided in this report largely draws on this existing body of research.

While offshore wind developments are already designed to withstand many climate hazards including extreme winds and storm surge, climate change has the potential to stretch design and operational limits. For example, climate change may exacerbate strong storms and sea level rise, as well as drive changes in wind patterns and velocity. This section provides an overview of potential changes to climate factors relevant to offshore wind performance and reliability because of climate change. Ultimately, the overview aims to strengthen offshore wind developments to provide clean and resilient energy generation in NYS.

2.1 Projected Climate Factor Changes

2.1.1 Wind Velocity, Frequency, and Variation

The potential for offshore wind production in the northeastern United States, from the New Jersey coast to the Gulf of Maine, is among the greatest in the country (e.g., Figure 6). Overall, average windspeeds in the region range from 8.0 to nearly 10.0 m/s (approximately 18 to 22 mph) [Figure 6]. A range of processes drive regional wind velocity, frequency, and variation, including the prevailing westerlies, storm systems, and local sea breeze. A change to any of these drivers produces a corresponding impact on regional windspeeds and, in turn, offshore wind performance.

Impacts to offshore wind performance from changes in windspeed depends, in part, on the sensitivity of the wind turbine power curve (Figure 3). Wind turbines are designed to operate optimally under specific wind conditions and turbines typically have small design margins. This means that small changes in windspeed can result in reduced power production (Pryor and Barthelmie, 2010).

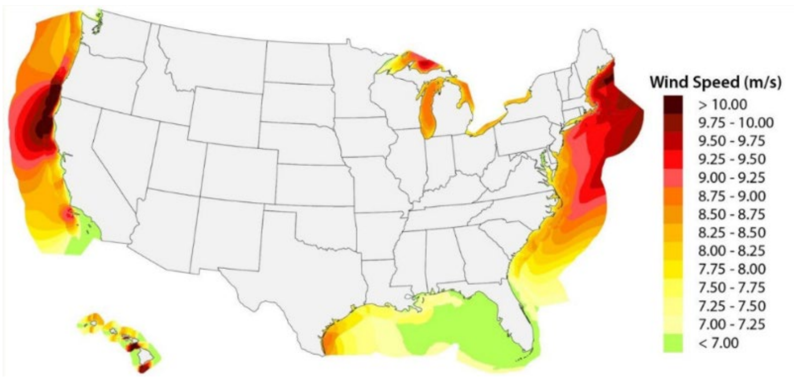
Looking forward, changes to wind velocity, frequency, and variation due to climate change and corresponding impacts to offshore wind performance and reliability in the northeastern United States remain uncertain (McInnes et al., 2011; NYSERDA, 2014a). Despite these unknowns, historical observations help characterize future change, and new research provides insights into plausible future conditions.

Variability in global windspeeds has impacted wind power generation in the past. Historical observations show surface windspeeds declined after the 1970's, during a period referred to as "global stilling" (Vautard et al. 2010; Azorin-Molina et al. 2017). This trend reversed in 2010 over much of North America, Europe and Asia. Since then, global wind speeds have increased from about 3.1 to 3.3 m/s translating to a 17% increase in potential wind energy for the average wind turbine (Zeng et al. 2019). At a global scale, natural climate variability such as changing ocean and atmosphere temperatures can trigger decadal scale windspeed changes as observed in the past (Zeng et al. 2019; Harvey, 2019). While the recent speed up could persist for several decades, natural variability may also yield future declines (Zeng et al. 2019).

Figure 6. U.S. Wind Energy Potential Based on Average Wind Speeds at 300 Feet

Three hundred feet is the height of most turbines. The northeastern U.S. and Northern California coasts (in red) have the greatest potential.

DOE EERE, 2016.



In addition to global influences, sea breezes exert a local control on windspeeds over diurnal and seasonal timescales and can represent an important wind source for offshore wind production. Temperatures are projected to increase between 3.0–5.5 °F in New York State through mid-century based on a range of GCMs and greenhouse gas concentration scenarios (NYSERDA, 2014a), which could invigorate the sea breeze in the northeastern United States. However, a stronger onshore sea breeze circulation can also cause wind patterns to move inland, potentially limiting their influence on offshore wind production.

2.1.2 Wind Shear and Geographic Distribution

Reduced wind shear improves wind turbine performance and reliability. In general, offshore winds are abundant and frequent because frictional forces and vertical shear are small over the ocean compared to over land. While ocean waves can distort vertical wind profiles and disrupt generation efficiency, it is unclear how climate change impacts sea surface roughness over the long term (Lange et al. 2004). In turn, higher and more intense windspeeds provide more reliable power production.

Stable wind patterns are essential to predictable and consistent offshore wind generation. Changes in the geographic distribution of wind patterns, such as to the location of the jet stream or historical storm tracks, would result in significant changes to offshore wind production. Ultimately, the long-term outlook for offshore northeastern United States remains promising, and abrupt shifts are unlikely through 2050.

2.1.3 Extreme Weather and Wind Turbulence

Extreme weather presents outsized impact potential to offshore performance and reliability. In particular, hurricanes and nor'easters drive a range of hazards relevant to offshore wind, including extreme and turbulent winds, waves, storm surge, and icing. In addition, these storms can also impact coastal infrastructure, including ports used to support offshore developments and transmission cables.

Elevated windspeeds and wave heights during storms can be particularly detrimental to offshore wind infrastructure. Strong storms can produce winds causing physical damage, but also above cut-out and operating limit speeds that curtail production (Pryor and Barthelmie, 2010). Storm-driven winds can be turbulent and chaotic, which can cause turbines to rotate and yaw beyond design levels, affecting their functionality or damaging them (Worsnop et al. 2017). Furthermore, wave activity can impact foundation and tower loads and worsen blade functionality and leading edge erosion (Pryor and Barthelmie, 2010).

The sections below describe potential future changes in the frequency and intensity of these storms and their associated hazards offshore the northeastern United States through the mid-century.

2.1.4 Hurricanes

Hurricanes are rapidly rotating low-pressure systems that produce extreme winds, waves, precipitation, and storm surge. Since about 1980, hurricanes in the North Atlantic have increased in intensity, frequency and duration, potentially in response to warming sea surface temperatures (Walsh et al. 2014). While storm activity has increased overall, fewer storms have made landfall in recent decades, and prevailing westerly winds generally steer hurricanes away from the coast as storms approach the northeastern United States. As a result, locations further from shore are slightly more likely to experience strong storms than nearshore locations. Regional changes in hurricane intensity and frequency depend on coincident changes across a range of factors including sea surface temperatures and atmospheric conditions.

In the fall of 2020, Tropical Storm Isaias tracked up the Eastern Seaboard on a path which centered approximately 100 miles from NYSERDA's pair of offshore wind floating lidar buoys in the New York Bight. Launched in September 2019, the buoys have been collecting data from prospective wind energy development areas, the BOEM Hudson North and Hudson South Call Areas. As Isaias made its way, wind speeds were tracked to show an average of 50 miles per hour (22.3 m/s), and a maximum of 93 miles per hour (41.5 m/s), well within the Class I design conditions (see Table 1). Where offshore wind turbines are classed to survive maximum gusts of up to 155 miles per hour (70 m/s) gusts for three-seconds, the in-situ data offers encouraging insights into the relative design standards anticipated in the region's eventual construction.[10]

Looking forward, climate model projections show that warming atmospheric and ocean conditions will likely increase hurricane intensity, wind turbulence and the frequency of the strongest storms, including Category 4 and 5 hurricanes, in the North Atlantic relative to historical conditions (Knutson et al. 2013, IPCC, 2013). At the same time, models project that overall hurricane activity in the North Atlantic will most likely remain the same or slightly diminish over the coming century (Knutson et al. 2013), although other research projects marked increases globally (Emanuel, 2013) and more northward trajectories in the Atlantic (Kossin et al. 2014; Baldini et al. 2016). Projections also show future hurricane tracks could move offshore at the latitude of New York City, which could result in more direct impacts to offshore wind developments in the New York Bight and offshore New England (Garner et al. 2017).

Overall, projections suggest that mid-century hurricane frequencies will likely be similar to today, but an anticipated increase in the number of very strong hurricanes. Stronger hurricanes produce stronger winds, ocean waves and storm surge detrimental to offshore wind developments and coastal infrastructure.

2.1.5 Nor'easters

Nor'easters differ from hurricanes in that they do not form in the tropics and most commonly occur between November and April due to the convergence of cold polar air and warm air over the Atlantic Ocean. These storms often track along the boundary of these air masses and drive a range of hazards including hurricane-force winds, ocean waves, and storm surge. Nor'easters also produce a range of precipitation types, including freezing rain and icing, depending on air temperatures at the time of the storm.

While the future behavior of nor'easters is still largely unknown, some regional climate models provide insights into the direction and magnitude of future change (Colle et al. 2015). Model simulations reveal a potential 10% to 40% increase in the frequency of very strong storms and the density of storms along the Atlantic Coast by end of the century (Colle et al. 2013). These results suggest a possible increase in extreme winds and ocean waves with the potential to impact OSW.

2.1.6 Precipitation

Precipitation is both beneficial and detrimental to offshore wind turbines. Normal rainfall helps clean turbine blades of dirt and other debris, which can increase turbine performance. In contrast, excessive or long duration precipitation can increase the risk of leading edge erosion, as described in Section 1.2.5.3. Similarly, ice accretion can disrupt airflow around the turbine and decrease performance.

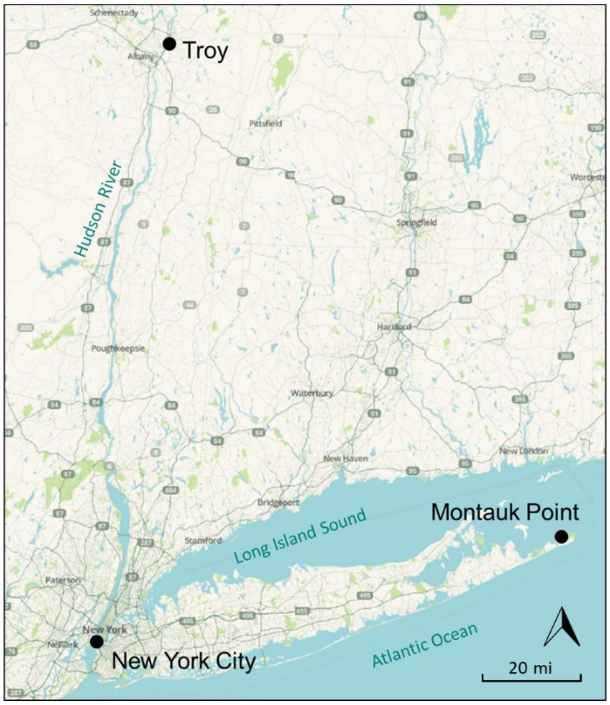
Climate change is expected to increase heavy precipitation events because a warmer atmosphere holds more water vapor and drives stronger storms. Climate projections show large increases in the frequency and magnitude of heavy precipitation in the northeastern United States. For example, the amount of precipitation than falling during the heaviest events is projected to increase from 20% to 40% by the late twenty-first century (Hayhoe et al. 2018). Similarly, both hurricanes and nor'easters are projected to produce more precipitation during the previous century (e.g., Knutson et al., 2013).

Ice and other frozen precipitation can pose a risk to turbine health and performance. Climate model projections show a decrease in the frequency of frozen precipitation over the twenty-first century (Zarzycki, 2018), which will likely decrease the impact of icing on offshore wind turbines. However, projected decreases are smaller for the larger storms, meaning that strong storms in the future may produce more ice than present-day if atmospheric conditions are cold enough.

2.1.7 Sea Level Rise

Sea level rise is an important planning and design consideration for resilient infrastructure. In particular, sea levels present potentially outsized impacts to coastal infrastructure through both long-term, chronic tidal flooding and short-term, acute storm surge events.

Figure 7. Tide Gauge Locations and Regional Settings



Since 1900, sea levels along the New York State coastline have been rising by an average of 1.2 inches per decade and this rate is expected to increase in the future due to climate change (NYSERDA, 2014a). Sea level rise is driven by a range of factors, including ocean thermal expansion and ice sheet mass loss. New York State sea level rise projections are evaluated probabilistically to consider uncertainties in these and other contributions under varying increases of greenhouse gas concentrations.

Based on these projections, New York City and the Long Island coastline could experience up to 30 inches of sea level rise by the 2050s (Table 2). The Hudson River is also susceptible, with the Capitol Region projected to experience up to 27 inches of sea level rise by the 2050s (Table 2). Importantly, these sea level rise projections refer to coastal locations where tide gauge records help constrain present and future sea level changes. The Gulf Stream also influences sea level off the Northeast coastline, with warming or weakening of the Gulf Stream driving faster rates of sea level rise relative to the global average (Yin et al., 2009 and 2010).

Table 2. NYSERDA ClimAID Sea Level Rise Projections for New York State

The projections correspond to the locations shown in Figure 7. Percentiles represent in inches a low estimate (10th percentile), middle range (25th to 75th percentiles), and high estimate (90th percentile) of the model projection distribution. Projections are based on 24 global climate models and both representative concentration pathways, 8.5 and 4.5. Sea level rise projections are relative to the 2000–2004 base period.

Tide Gauge	Montauk Point				New York City				Troy			
	Percentile											
Time Interval	10th	25th	75th	90th	10th	25th	75th	90th	10th	25th	75th	90th
2020s	2	4	8	10	2	4	8	10	1	3	7	9
2050s	8	11	21	30	8	11	21	30	5	9	19	27
2080s	13	18	39	58	13	18	39	58	10	14	36	54
2100	15	21	47	72	15	22	50	75	11	18	46	71

2.1.8 Storm Surge

Coastal flooding depends on both rising sea levels and storm surge, both of which are influenced by climate change. Rising sea levels are projected to increase storm surge associated with coastal storms relative to present-day conditions. For example, the return period associated with a seven-foot flood in New York City are projected to increase from approximately 25 years between 1970–2005 to approximately five years by 2030–2045 (Garner et al. 2017). Similarly, models also show small increases in storm surge levels associated with nor'easters as a result of climate change in the northeastern United States (Lin et al. 2019). Ultimately, storm surge severity depends on storm trajectory, intensity, and timing relative to high tide. Within the northeastern United States, coastal locations along the Atlantic Ocean are most exposed to storm surge compared to inland locations, such as those along the Hudson River.

Climate change may also drive changes to future storm tracks and coastal regions exposed to storm surge. Models reveal that hurricane storm tracks are projected to shift farther offshore of the northeastern United States, which would partly offset increases in coastal storm surge within the New York City metropolitan area (Garner et al. 2017). However, new storm tracks could potentially drive more direct impacts to offshore wind developments situated in the mid continental shelf and other coastal regions such as New England. More work is needed to confirm these potential impacts.

3 Impacts of Climate Change on Wildlife and Communities from Offshore Wind

The process for developing OSW projects includes assessing potential impacts on wildlife and nearby communities. This section reviews how those impacts may be affected by climate change.

Each state that borders the Atlantic Ocean or Pacific Ocean has jurisdiction over submerged lands out to a distance of three nautical miles offshore.[11] Beyond three nautical miles, the jurisdiction to grant leases, rights-of-way and easements lies with the federal Bureau of Ocean Energy Management (BOEM). The OSW development process considers the potential impacts on wildlife and communities through the Environmental Impact Assessment (EIA) process administered by BOEM pursuant to the federal National Environmental Policy Act (NEPA) process.[12]

All forms of energy generation have the potential to impact wildlife and communities. However, the impact on wildlife is far less significant from wind power generation than traditional forms of energy production, such as those based on fossil fuels (Saidur et al., 2011; Sovacool, 2012). The relatively low impact of OSW on surrounding wildlife is due to a range of factors, including the fact that wind power does not require the same level of resource extraction, or promote large-scale ecosystem and noise pollution as compared to traditional power generation projects (Jarvis, 2005). Additionally, many of the potential adverse impacts to wildlife, including noise pollution and increased vessel traffic, are significantly worse during the construction phase of offshore wind development, and will taper off during operations (BOEM, 2020). Due to the uncertain nature of several likely future changes—such as changes in biodiversity patterns and future species redistribution—some impacts noted in this review are neither positive or negative, but rather trends that NYSERDA is aware of, is working with stakeholders—notably through New York State's Technical Working Groups—to support active research to better monitor and understand environmental changes and the intersections with this evolving industry, and will prepare for to the extent possible.[13]

Offshore wind also has the potential to influence waves and currents and therefore may in turn affect how waves and currents impact coastal processes and consequently the shoreline. However, the proposed locations of New York's OSW developments, which are far from the coast and not closer than 14 miles (see Figure A-1) from any New York State coastline, helps ameliorate many of the potential coastal and community impacts discussed in the sections below and may even offer beneficial uses for wildlife in addition to the anticipated benefits to humans through this new resource.

Where understanding the potential impacts and benefits of offshore wind are of continuous focus for New York, Table 3 details NYSERDA's current activities pertaining to environmental research and offshore wind. (For more information on specific activities, see Appendix B. NYSERDA Environmental Research Offshore Wind Activities.)

Table 3. NYSERDA's Current Environmental Research Offshore Wind Activities and Associated Categories

NYSERDA Environmental Research OSW Activities	Cumulative Impacts	Fishing	Environmental	Navigation	Outreach	Predevelopment
Regional Wildlife Science Coordinating						
State of the Science Workshops						
Wind Resource Assessment						
Monitoring Protocols for Bird and Bat Nanotag Studies						
Understanding Ecosystem Dynamics						
Bird and Bat Research Framework						
Regional Monitoring						
Fishing and Environmental Mitigation Plans						
State OSW Fisheries Manager and Recreational Fishing Liaison						

3.1 Wildlife

3.1.1 Offshore Wind Impacts on Wildlife

The primary risks to wildlife associated with OSW farms are avian impacts and habitat alteration and temporary noise in the marine environment. The primary avian impacts from Northeast U.S. OSW are likely to be fatalities of birds and bats. Compared in terms of gigawatt-hours (GWh) of power generated, avian fatalities per GWh associated with wind power generation are, on average, less than 3% of the avian fatalities per GWh associated with fossil fuel power generation (Sovacool, 2012). Research indicates that impacts to marine wildlife are largely temporary and localized, and for the most part can be mitigated or avoided with proper pre-construction planning and considered operations and maintenance protocols (Mahan et al., 2010).

NYSERDA has developed a wind siting and biodiversity evaluation tool[14] that may be valuable to weigh potential impacts to wildlife and communities alongside energy generation capacity at different OSW sites under consideration (NYSERDA, 2014b). NYSERDA may also draw on regional habitat information from habitat mapping analyses (e.g., Guida et al., 2017) as part of this effort. Further, NYSERDA will conduct offshore wind development in compliance with the national and sub-national regulatory framework governing wildlife and coastal protection (NYSERDA, 2017a). This framework involves federal laws and regulations, state laws and regulations, and policies by state and regional councils and commissions (NYSERDA, 2017a; DOE, 2012).

3.1.1.1 Avian Wildlife: Bird and Bat Fatalities

When compared with risks that other forms of energy generation pose to avian wildlife, fatalities associated with wind turbines are significantly lower than those associated with other energy sources (Sovacool, 2012). A comparison of fatalities per gigawatt-hour (GWh) of electricity generated found that wind farms resulted in approximately 0.27 avian fatalities per GWh, compared to 0.6 fatalities per GWh for nuclear power plants and 9.4 fatalities per GWh for fossil fuel power stations (Sovacool, 2012). At the California Altamont Pass wind farm, for example, where recorded avian mortality rates appeared high, cost-benefit calculations that also included the benefits to avian populations of reduced pollution associated with wind generation found the wind farm not only reduced avian mortality but also benefited human health (Sovacool, 2012).

In general, a greater density of birds and bats around turbine sites is associated with higher mortality rates. Additional research on bats' offshore activities and how bats may interact with distant offshore wind turbines is an area recognized by the offshore wind industry as warranting increased study. A recent study reviewing existing research found that a variety of migrating and non-migrating bat species may venture to offshore wind farms and predicted that the phenomenon of bats colliding with onshore turbines could translate into an offshore phenomenon (Pelletier et al., 2013). However, in New York State's anticipated OSW environment, at greater than 14 miles offshore, the density of birds and bats is low.

Both turbine design and siting and climate factors may influence avian risks. Similar turbine height and elevation of local or migrating species' flight zones, and turbines' proximity to regions with high avian concentration (e.g., migratory routes or along coastlines), are associated with higher fatality rates onshore; locating turbines more than 14 miles offshore may therefore mitigate fatality risks (FWS, 2018). For example, higher turbine height is correlated with greater numbers of bat fatalities due to flying patterns (Barclay et al., 2017).

Climate factors that alter avian activity may also influence rates of avian mortality due to interaction with OSW turbines. Specifically, warming temperatures may drive higher fatality rates on wind farms. A study on bat activity on an onshore wind farm in the Mediterranean found avian fatality rates were positively correlated with temperatures and relative humidity—authors theorized this was due to increased insect activity driving increased bat activity in warmer temperatures—while fatalities were negatively correlated with wind speed (Amorim et al., 2012).

Acoustic monitoring of avian calls—in particular, nocturnal flight calls—has been used to study avian activity with the goal of assessing potential for avian fatalities at a given location, though there are recognized limitations to this method (NYSERDA, 2012b).

3.1.1.2 Marine Wildlife: Underwater Sound and/or Habitat Alteration

Offshore wind impacts on marine wildlife, such as habitat alteration or displacement, addition of underwater noise and vibration, and in some cases wildlife mortality, are concerns that NYSERDA is considering in development of its offshore wind program.

Sounds associated with construction necessary for farm scoping and turbine installation may be detrimental to marine fish and mammals, and other marine wildlife (Thomsen et al., 2006; Matuschek and Betke, 2009). Techniques such as wildlife warning signals and "bubble curtains" can be used to reduce noise levels and increase the distance of wildlife from the noise during the period of construction (Mahan et al., 2010). Previous studies have also found that marine wildlife migrates away from farm sites during construction when noise becomes significant, even without warning signals (Leonhard et al., 2013). The main climate factor that affects how and where sound disperses underwater is water temperature (NOAA, 2019).

Once built, wind farms may alter marine ecosystems and habitats through changes to local ecosystems and/or development of "artificial reefs," where underwater turbine structures attract mussels and fish (ten Brink and Dalton, 2018). These "reefs" may lead to temporary fish aggregation, particularly of reef fishes. Some studies have found that they do not significantly alter fishing opportunities in the area (ten Brink and Dalton, 2018; Leonhard et al., 2013), while others have found local habitat and biodiversity could be improved by the "reefs" (NYSERDA, 2017a).

3.1.1.3 Climate Change and Impacts of Offshore Wind on Wildlife

Climate change can modulate the relationship between OSW turbines and coastal wildlife. In particular, climate change can cause ocean and atmospheric warming, corresponding changes in species distribution and ecosystem function, and increased species endangerment and extinction. This section provides information regarding these potential changes.

Climate change already drives global redistribution of species and alteration of migration patterns due to changing environmental conditions such as air and water temperature, as well as shifts in ecosystem function and resource availability (Pecl et al., 2017; Sugden, 2017; Horton et al., 2020; Dupigny-Giroux et al., 2018). Climate change is also already causing faster endangerment and extinction of species and is likely to continue to do so at an increasing rate in the future (Román-Palacios and Wiens, 2020). Together, these climate stressors may intensify caution around risks to wildlife, including those associated with OSW. Looking forward, the exact location and extent of future species endangerment and redistribution, and potential associated changes in protection, are not known. The degree to which these changes will be relevant to energy generation projects including OSW development are site-specific as well as dependent on environmental and societal shifts.

Additionally, in relatively shallow ocean areas such as the middle continental shelf, changes in water depth and density, acoustic properties of the sea floor, and wind and wave action due to climate change may affect sound transmission (Lynch et al., 2018). Given the extent to which shallow water regions vary, the resulting effect in a specific area will depend on local conditions proximal to wind turbines.

3.2 Community Impacts

The common potential community impacts associated with offshore wind development—particularly noise and coastal impacts—will be significantly mitigated by the location of the wind farm being more than 14 miles offshore with visibility limited to clear conditions and representing the equivalent size on the horizon of the quarter of your thumbnail when visible at all. Impacts of localized vertical air mixing (Armstrong et al., 2016; Roy and Traiteur, 2010) on coastal communities are unlikely to be significantly altered by climate change. Because sound attenuation with distance is only weakly linked to ambient temperature, future increases in atmospheric temperature are unlikely to impact OSW sound levels for nearby communities (NYSERDA, 2013a). Likewise, average turbine visibility is unlikely to be significantly influenced by changes in climate.

Coastal communities in New York State are some of the most vulnerable to certain effects of climate change by nature of their location. For example, flooding from sea level rise and the increased severity and frequency of storms impact coastal communities the most. As Figure 8 depicts, coastal areas are also host to many environmental justice areas (i.e., primarily low income and minority communities). As such, in many areas these coastal communities bear dual burdens of greatest risk of impacts due to their location and greatest vulnerability if exposed (e.g., lacking resources to quickly or fully recover). This environmental justice issue is already visible, exemplified by the effects of storms like the 2012 Super Storm Sandy, which incurred over $65 billion in damages to the United States[15] with impacts particularly notable in New York State and New Jersey, and for which future flooding mitigation solutions are being proposed.

Figure 8. Potential Environmental Justice Areas

Department of Enviornmental Conservation, 2020.

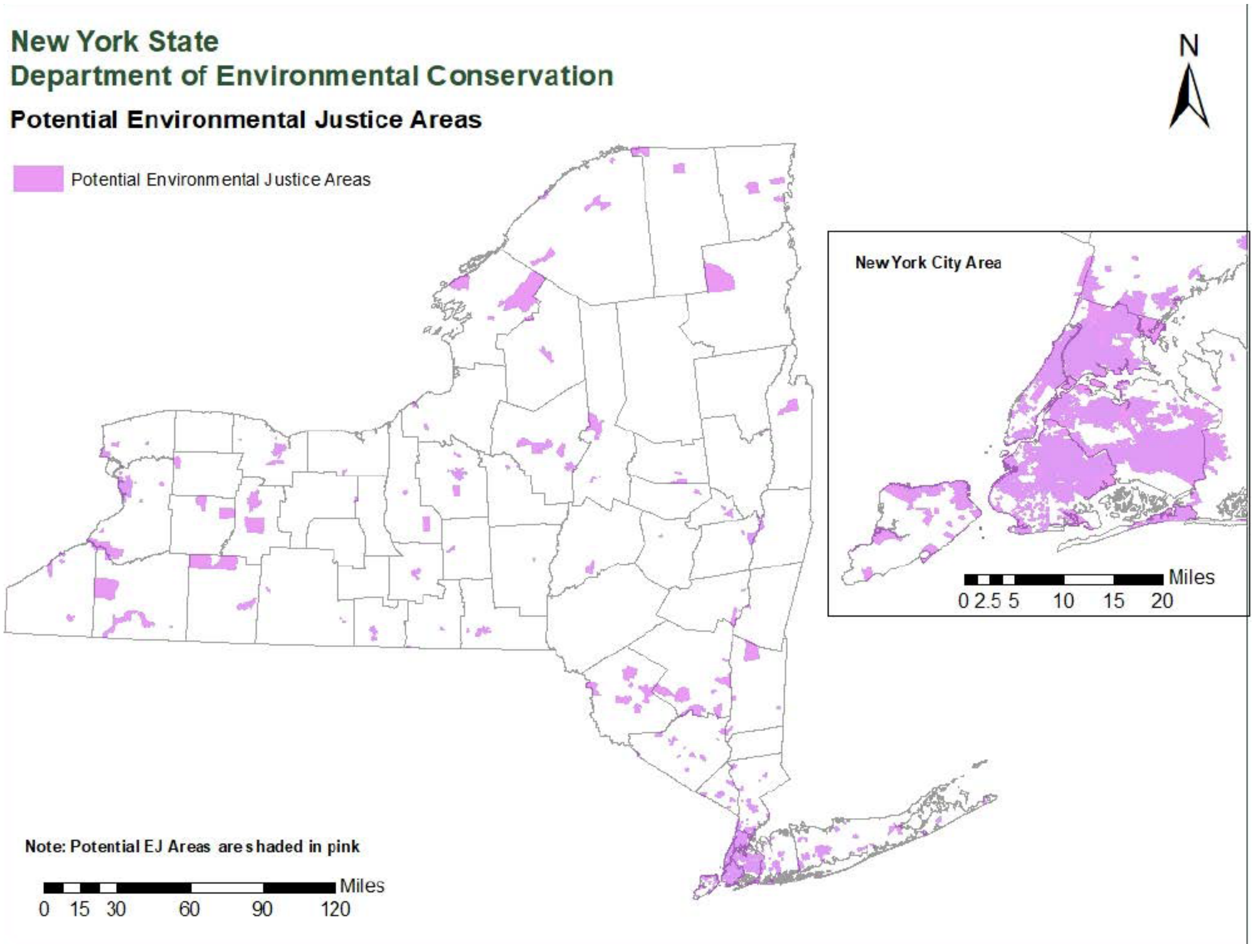


Figure 9. Map of New York City Flooding from Hurricane Sandy, October 29, 2012

Dotted red lines show proposed future storm barriers.

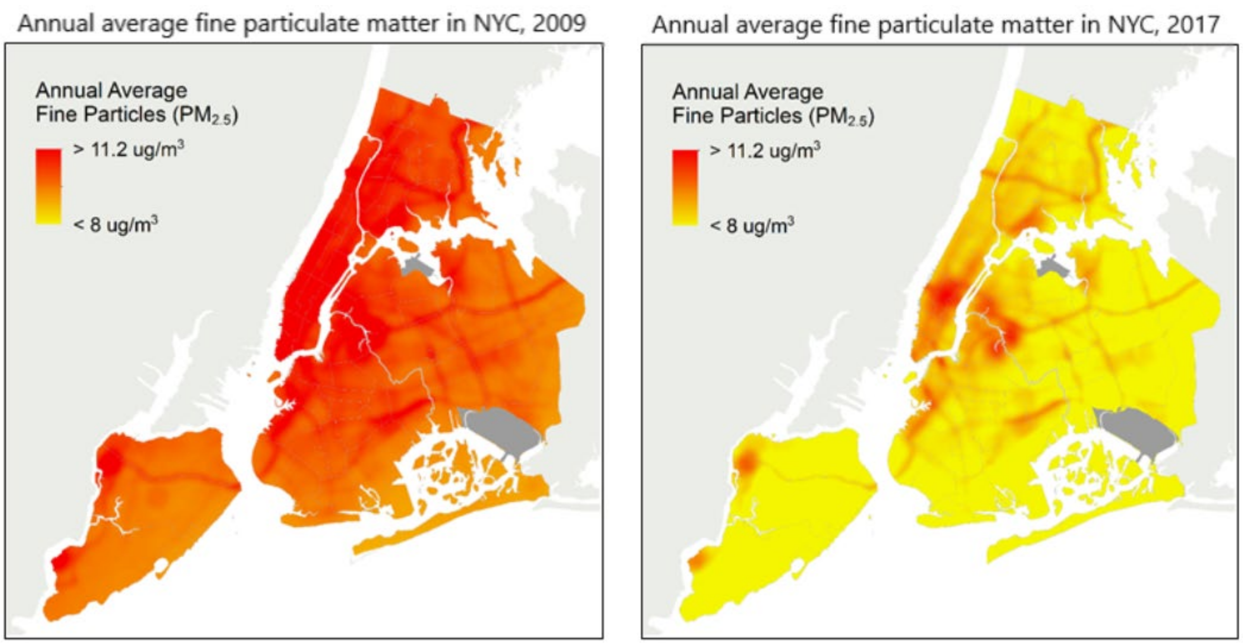
Federal Emergency Management Agency, National Institute for Coastal & Harbor Infrastructure.

Moreover, many of these communities, notably in the New York City metropolitan area, also experience higher concentrations of fine particulate matter (PM2.5) and ozone, which can lead to health impacts including respiratory and cardiovascular disease. These high pollutant levels are estimated to be associated with more than 2,000 premature deaths, 4,800 emergency department visits for asthma, and 1,500 hospitalizations (NYSERDA, 2018). Further, most of the emissions from peaker plants occur during the summer season, when pollution from ozone is already high, and urban heat island effects compound the risks to health-vulnerable populations.

As an example, two Bronx communities that host older peaker plants (Mott Haven and Melrose) have three times the citywide rate of asthma-related emergency room visits by children between the ages of five and 17.[16] The novel coronavirus (COVID-19) pandemic has exacerbated and further shined a light on these injustices. The costs imposed on the health of adjacent communities is also significant because these plants are often sited near highways where emissions from the plant compounds the effects of traffic-related pollutants.

Figure 10. Air Quality in New York State Metropolitan Area

NYC Department of Health, 2019.



Environment justice factors stemming from pollution from peaker plants and the risks caused by climate change vulnerability to flooding highlight the severity of impacts against which coastal communities will need to build resilience. These risks offer important context for the policies that inform New York State's approach to its OSW goal of delivering 9 GW by 2035. Significant direct and indirect benefits to coastal communities in the State are anticipated from the development of offshore wind, including the responsible transition away from dirty peaker plants to provide local energy while meaningfully improving air quality in those more vulnerable communities; investment in grid hardening and resource diversity; port infrastructure investment that will enable maritime industries and support coastal community logistical needs; and the creation of thousands of jobs by 2035.

3.2.1 Turbine Sound and Human Perception

Turbine sound affecting coastal communities can be mitigated through a range of factors, such as compliance with local, federal, and international wind turbine sound limit guidelines, and siting turbines far from the coast (NYSERDA, 2013a). The distance that turbine sound travels is affected by a range of turbine-related (e.g., size, condition, and number of turbines) and climate-related (e.g., wind speed and direction, air temperature, atmospheric conditions) factors (NYSERDA, 2013a). The significant offshore distance associated with the planned developments likely means their impact on adjacent coastal communities will be negligible. For example, several studies found that sound levels were between 20 and 50 dBA[17] at distances ranging from 0.30 to 0.40 miles from turbines, which are similar to levels ranging from a whisper to typical sound levels inside a home (NYSERDA, 2013a). At 10 miles or greater, turbine sound will be imperceptible to coastal communities.

3.2.2 Coastal Dynamics

Dynamic processes such as tides, waves, and currents influence coastal sediment transport through longshore drift[18] and erosion. OSW developments have the potential to influence waves and currents and therefore may in turn affect how waves and currents impact coastal processes. An OSW project's Environmental Impact Assessment may include modeling of the potential impacts and revisions to design parameters affecting ocean water transport such as the diameter of monopile foundations (ESTU, 2002).

Construction of different types of turbine foundations—such as monopile, gravity, tripod, and floating—will have different impacts (ESTU, 2002) that can be considered in the project design phase. One study investigating turbine foundations in the U.K. validated the ability to model coastal impacts and did not find significant wave impacts or impacts on sediment transport processes, at large spatial scales, for projects after completion (Lambkin et al., 2009). Design guidelines and environmental impact assessments can incorporate the latest understanding of climate change driven changes in waves and currents into coastal impact models.

With marine transportation offering an increasingly low-carbon alternative for coastal commerce and logistics, investments in port capital infrastructure that will buttress these facilities against dynamic coastal processes will not only enable supply chain activities related to offshore wind but also have the potential to offer benefits to other industries and to service coastal community needs.

3.3 Maritime Commerce

3.3.1 Shipping

Wind farms and turbines are typically placed outside of main shipping routes to avoid infrastructure damages such as transmission or mooring lines being snagged by passing vessels.

Though global shipping routes are projected to see significant changes due to climate change and Arctic melt, the study team did not identify research linking these changes to the areas of the U.S. East Coast under consideration for OSW development.

Conversations between government agencies and industry stakeholders on the interaction between OSW farms and maritime shipping and navigation are currently underway. A 2017 NYSERDA study on potential shipping and navigation risks to offshore wind farm development identified the primary concern as proximity to shipping and traffic routes, particularly high-traffic or high-convergence routes (NYSERDA, 2017b). The U.S. Bureau of Ocean Energy Management (BOEM) and Coast Guard (USCG) are in discussion around how OSW energy and maritime industries such as fishing and shipping can coexist well (BOEM, 2018). With this goal in mind, Port Access Route Studies (PARS) such as the ACPARS and MARIPARS have been developed (e.g., ACPARS, 2015; Coast Guard, 2020); regulations and guidelines around development and land management are under consideration; and at a recent workshop, representatives from the responsible agencies as well as industry stakeholders discussed their respective needs and roles, with the aim of continuing discussion (BOEM, 2018).

3.3.2 Commercial and Recreational Fisheries

Investment in renewable offshore wind energy has the potential to mitigate the release of greenhouse gas emissions associated with nonrenewable energy sources and, in turn, mitigate species redistribution caused by climate change (NYSERDA, 2017a).

Under ocean warming conditions associated with climate change, many fish are projected to move away from their traditional habitats in seeking the same water temperatures they are used to. On the Northeast coast of the United States, this will translate into fish moving north as Atlantic waters warm (Goldfarb, 2017). There remains uncertainty around exactly when and where different species will move (Pecl et al., 2017; Sugden, 2017), and as such it is unclear exactly how this redistribution may enhance or stress fisheries near the potential offshore wind developments.

Ocean waters off the northeastern United States are home to a range of fish species and, in turn, recreational and commercial fisheries (NYSERDA, 2017a). An evaluation of the potential adverse impacts to fish and fisheries that could be introduced by the development of an offshore wind farm include (NYSERDA, 2017a) impacts pre-construction, during construction, and during operation/following construction. Pre-construction, the primary impacts to fish, which may include seafloor disturbance noise generated by survey equipment, could temporarily hamper local fishing activities. During construction, impacts such as changes in water turbidity and suspended sediments, disruption of habitat, and increased noise levels could temporarily displace local fish populations and hamper local fishing activities. Local fisheries could be restricted during construction due to safety concerns. Finally, after construction is complete and turbines are in operation, there may be a variety of direct impacts to fisheries and indirect impacts to fisheries through impacts to fish populations. Direct impacts to local fishing practices may include increased potential for damage to fishing gear and vessels through contact; financial risk associated with increased risks to fishing materials, increased complexity in fishing around the wind farms and increased competition in surrounding areas, and changes in availability and species of local fish; and navigational challenges. Impacts to fish, which may affect local fish stocks and fishing practices, may include sensory disturbances, development of new reef-like habitats in what was previously open water, and shifts in fish availability and inter-species competition.

Offshore wind developments and management are engaging in a range of initiatives to mitigate potential risks and ensure vital fisheries in the future. For example, NOAA Fisheries is working in conjunction with BOEM and developers of offshore wind projects to ensure that the needs of marine habitats and fisheries are involved in project development and partnering with regional and international fisheries management councils (NOAA Fisheries, 2020).

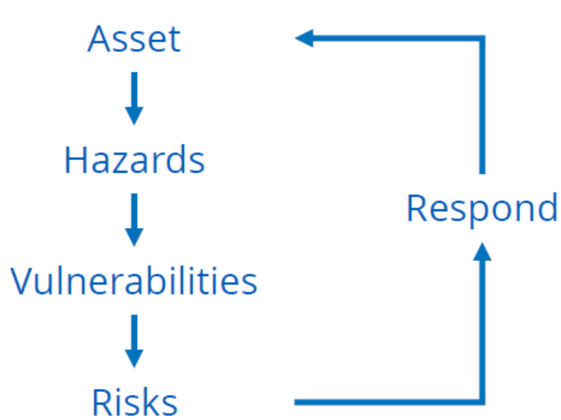
4 Evolving Opportunities for Offshore Wind Resilience

This section examines a range of evolving design opportunities to build resilience of OSW for the climate factors identified in section 1 of this report, and with the anticipated projected changes as discussed in section 2. Design and material options for turbines are included as are technology options related to wind turbine operations to improve performance in low-wind conditions or reduce loads and potential damage in high-wind conditions. Resilience options for coastal ports and onshore electrical infrastructure are explored as are options to build resilience against human stressors. Finally, we discuss some strategies to mitigate climate risk for project financing.

This report identifies several ways in which climate change may impact OSW, such as reducing revenues and increasing lifecycle costs. Some adaptations, such as revising foundation elevations to address sea level rise, are likely to be relatively incremental while others like building robustness against extreme storms are likely to require more investment and increase project costs. The incremental costs of adaptations to climate change are best viewed in terms of the value they can provide to support meeting a project's performance objectives.[19] The additional cost of adaptation can offer a favorable return on investment by reducing risk such that lower financing rates and improved underwriting are available to a project. Indeed, the potential for climate change to impact OSW dictates that there is a cost to *not* incorporating adaptations. This is an area where state leadership can support growth by helping the industry to more effectively value these options.

Figure 11. Resiliency Risk Analysis Framework

RWDI, 2020.



The approach taken by an offshore wind project and by the State in considering potential resiliency adaptations should follow a form of recursive risk analysis that considers the detailed context of the subject and its specific exposure, vulnerabilities, and risks to support an appropriate design response (Figure 11). Where this study does not prescribe the adoption of any specific adaptations, it initiates a dialogue with the industry and with stakeholders to promote awareness of resiliency approaches as a first step to NYSERDA's strategic focus on resiliency in keeping with NYSERDA's Strategic Plan, Toward a Clean Energy Future: A Strategic Outlook 2020–2023.

Where the CLCPA squarely recognizes the front-line experience of Disadvantaged Communities in the fight against climate change, the opportunities for offshore wind resiliency listed in this section should be furthermore considered as an opportunity to consider how these adaptations can best intersect with the delivery of benefits including workforce development, training, jobs creation, and economic development broadly to Disadvantaged Communities, and the critical partnerships to advance such important benefits.

4.1.1 Wind Speed

As discussed in section 2, since 2010 global wind speeds have increased from about 3.1 to 3.3 m/s translating to a 17% increase in potential wind energy for the average wind turbine (Zeng et al. 2019). However, while the recent speed up could persist for several decades, natural variability may also yield future declines (Zeng et al. 2019) and when considering the resiliency of OSW projects, planners should acknowledge this uncertainty and potential impacts of natural climate variability on future windspeeds.

Recognizing the impact of wind speed on a turbine's performance is discussed earlier in this report, several things can be done to mitigate the impact of an increase or decrease of wind speed on overall turbine power production and performance. In general, a decrease in wind speed results in reduced power production and increased idle time while an increase in wind speed can result not only in reduced power production but also in potential component damage or turbine system failure.

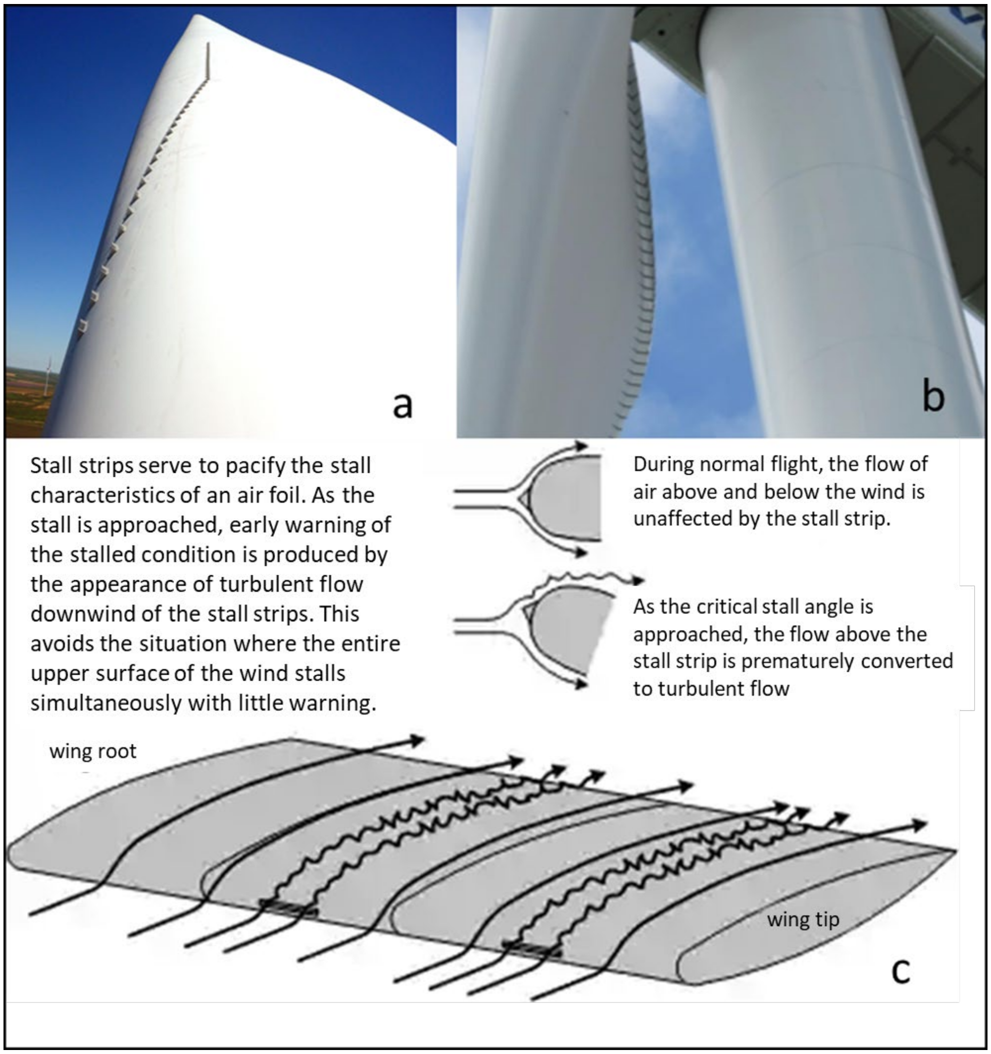
A variety of design options are available to mitigate the impact of wind speed on a turbine's performance. These lift modification devices use technologies that can be active (i.e., requiring dynamic activation and/or electrical mechanisms) or passive to either improve performance in low-wind conditions or reduce loads in high-wind conditions.

Passive technologies are used to “design in” changes in turbine performance based on operating conditions. These technologies, such as vortex generators, gurney flaps, and stall strips, all work to improve turbine performance in low-wind conditions. The following three images show how these technologies are deployed on wind turbine blades (Figure 12). Gurney flaps act as chord extenders on the inboard span of a blade and work to improve the aerodynamic performance of this section of the blade (Giguère, Lemay and Dumas, 2012; Saenz-Aguirre, 2019; Nikoueeyan et al., 2015). Vortex generators are installed on the suction side of blades and help to maintain laminar air flow over the blade, thus improving the aerodynamic performance of the blade (Martinez et al., 2016; Hu et al., 2016), and particularly to boost power production in low-wind conditions. Vortex generators can improve the efficiency of turbines and increase annual energy production by 2–3% (Sharpley, 2015). Stall strips are lift-modifying devices that are typically installed on the leading edge of portions of wind turbine blades to modify the air flow around the airfoil shape so that stalling effects are adjusted, improving performance-reducing loads in high-wind conditions (Tee et al., 2017).

Figure 12. Close-Ups of Lift Modification Devices

(a) Vortex generators, (b) gurney flaps, and (c) stall strips.

Source: CFI Notebook, Smart Blade, Vestas.



Active technologies typically need to be installed during manufacturing as they require power for actuation and tend to be installed in the outer span of the blade which is inaccessible after manufacture. Once the blade is manufactured, most retrofit add-ons can only be installed on the external surface of the blade or the accessible inner span sections of the blade interior that are limited by blade size. Some examples of active technologies include microtabs and flaps on wind turbine blades and LIDAR for the turbine system (van Dam et al., 2008). Microtabs are actuated dynamically during operation to adjust and/or disrupt the airflow over the blades. Flaps can be used to adjust the camber or curvature of the blade airfoil, in much the same way as they do on airplane wings (van Dam et al., 2008). Some turbine OEMs offer high wind speed derating control beyond cut-out, where the turbine gradually reduces power production above cut-out rather than completely stopping production (Vestas, 2019).

A unique technology that bridges the gap between design and operation is LIDAR. A LIDAR system (Light Detection and Ranging) allows the turbine to scan in the upwind direction to predict the wind that is approaching the turbine rotor. The turbine can then pitch the blades and/or reposition the rotor by proactively turning the wind turbine towards the incoming wind (Aitken et al., 2012; Mikkelsen et al., 2010). LIDAR systems can be ground- or turbine-mounted (Morris, 2011) and can be forward- or upward-looking, depending on installation. LIDAR has become more commonplace within the wind industry and allows the turbine to better optimize operation in changing wind conditions, including both improved power performance in low-wind as well as load mitigation in high-wind (Dunne et al., 2011; Mikkelsen et al., 2010). LIDAR systems can be installed during initial turbine erection or at a later time as an add-on to the system.

Another option to build resilience is to develop a wind turbine that uses a more robust design than is typically used in the current wind industry, where wind turbines are generally designed to closely match the loads expected for a specific site in accordance with the IEC 61400-1 and -3 guidelines. Such a design should operate well in a variety of wind conditions as compared to a focused design that is optimal in a limited wind regime only (Cognet et al., 2017). The use of wind regime in this context is to define the overall wind loading and annual/seasonal variation for a given site. This design would result in additional design margin in the overall turbine. The wind industry has started to investigate a shift to this type of robust design philosophy in current offshore wind turbines. For example, the current large-scale offerings from GE and Siemens both use more robust, over-sized direct drive generators.

Operational measures to address wind speed impacts on turbines include using the active technologies discussed above to make active load control reductions. Active load control involves the wind turbine controller making dynamic changes to the turbine positioning such that an overall loading level into the turbine system is maintained. This may involve the use of independent or collective pitch controls (van Dam et al., 2008), derating or curtailment at higher wind speeds before cut-out (Aho et al., 2012), or use of very fine pitch settings to increase power production at lower wind speeds below rated.

Increased maintenance efforts can be used to help reduce the impact of changing wind speed on wind turbines. This can include increased turbine and component inspections to catch damage more quickly (Kuiler et al., 2018). Improved remote monitoring of the turbine health to more quickly and accurately detect problems or issues can also help mitigate the impact of variable wind speed and loads.

4.1.2 Wind Consistency and Geographic Distribution

4.1.2.1 Directional Consistency and Predictability

As described in section 2, the impact of wind directional consistency and predictability on a turbine's performance is an important consideration. In summary, less consistent, more variable wind can lead to reduced power production; a change in wind direction requires the turbine to adjust the rotor heading to "chase" the prevailing wind direction; and an increase in the variability of wind direction will require an increase in the frequency of the turbine repositioning the rotor. Greater frequency of rotor repositioning will increase the wear and tear on the turbine yaw system components, potentially resulting in reduced component life and/or more frequent maintenance requirements. Mitigating the effects of changing directional consistency and predictability on overall turbine power production and performance continues to represent an area of significant focus in wind turbine design and manufacturing.

As described in the preceding section, one design option is to create a wind turbine blade design that is optimal for a large range of incoming wind angles. Such a design should operate well in a variety of wind directionalities as compared to current industry designs that are optimal in a narrow section of operating wind environments.

Another design option currently in use in the wind industry is to utilize pitch and yaw systems that are more powerful, robust, and can handle higher loading. These systems would potentially allow the turbine to respond more quickly, smoothly, and consistently to wind direction changes without affecting power production, particularly at high or extreme wind speeds. Additionally, use of a LIDAR system to scan the upstream air conditions before they impact the rotor can improve the turbine performance, particularly in turbulent and/or chaotic wind conditions. The combined use of a LIDAR system with more robust pitch and yaw systems can help mitigate the impacts of changing wind directionality. These designs are becoming more common in the wind industry, particularly for offshore wind turbines. An example of this design option is Enercon's Storm Control controller feature, which slows the wind turbine down so that it can continue to operate at high wind speeds. This is essentially a high wind speed curtailment used during storm events (ENERCON, N.d.).

Increased maintenance efforts can be used to help reduce the impact of lower wind direction consistency and predictability on wind turbines. This can include increased turbine and component inspections to catch damage more quickly as well as remote sensing for pitch and yaw lubrication degradation rates. Improved remote monitoring of the turbine health to more quickly and accurately detect problems or issues can also help mitigate the impact of variable wind speed and loads.

The wind industry has been shifting from gearbox generators to direct-drive generators for the very large offshore wind turbines currently in development, prototyping, and commercial sale. Although these direct-drive generators are more expensive than gearbox generators, because of fewer moving parts, they have lower inspection and maintenance costs.

4.1.2.2 Geographic Distribution

The initial project siting analyses and optimization has the greatest potential to address changes in the geographic distribution of wind for OSW developments. A geographically diverse portfolio of projects also serves to provide resilience to changes in geographic distribution of wind. The NYS OSW lease areas in the New York Bight span a distance of over 120 nautical miles, providing a measure of geographic diversity.

4.1.3 Wind Shear

Increasing the turbine hub height using taller towers would help to mitigate the impact of increasing vertical shear in offshore wind turbines. Horizontal shear results in a loading imbalance on wind turbine rotors which requires active turbine yaw and pitch response that over time increases component wear and tear and reduces useful lifespan and may reduce power output. For horizontal shear, mitigating design options include the use of LIDAR systems to scan the upstream incoming wind before it gets to the rotor to enable proactive actions to minimize loading imbalance and its impact to component wear and power production, in addition to the use of more robust pitch and yaw systems. Combining LIDAR with robust pitch and yaw systems would enable the wind turbine to handle increased rotor load imbalances due to horizontal shear.

A decrease in both vertical and horizontal wind shear should have minimal impact on turbine performance and loading. Any turbine properly selected and installed in a given site should already be able to withstand the expected wind loading during its lifetime. Any reduction in wind shear should have little impact on turbine performance, as it would represent the wind becoming more optimal for power production.

Increased maintenance efforts can be used to help reduce the impact that increased wind shear would have on wind turbines. This can include increased turbine and component inspections, specifically for blades, drivetrains, and gearboxes, to catch damage more quickly and enact repairs.

4.1.4 Sea Level Rise

The New York State Community Risk and Resiliency Act requires certain State expenditures and projects to consider climate risks, including sea level rise projections. Current OSW system design practices for foundations provide resilience beyond the maximum projected increases in sea level of around 1 meter by 2050 as shown in see Table 2. This is because, as per international design standards, the "air gap," the distance from the sea level to the tower/foundation connection, must be at least 20% of the length of the "50-year significant wave height" (DNV GL, 2018). For example, assuming a 50-year significant wave height of approximately 50 ft, (NOAA, 1972) the air gap requirement is 10 feet, which is more than triple the expected sea level rise projection. Given that Table 2 shows a less than 1-meter sea level rise, the current requirement for the air gap of an offshore wind turbine should already be sufficient to handle sea level rise due to climate change.

In order to address further projected sea level rise, the design elevations of future fixed foundations for OSW components (wind turbines, substations or converter stations) can reflect sea level projections to avoid water damage and corrosion of nonresistant components. For floating turbines, the design lengths and tensions of mooring lines can similarly incorporate projections to be sufficiently resilient.

4.1.5 Extreme Weather

Extreme weather drives the limits of wind turbine design, often the cause of the highest loading a turbine will see in its lifetime (Rose et al, 2012). If climate change causes an increase in the frequency or intensity of extreme storms, there would be an increased likelihood of wind turbine damage and output disruptions. An increase in extreme weather, specifically wind and wave loading, may push the turbine outside of its design margin and could cause component damage or system failure. Wind turbines do not typically operate during extreme weather events (Worsnop et al., 2017; Rose et al., 2012). Any such increases need to be accounted for in the turbine and wind farm design phases to ensure the design load envelope anticipates these needs to the extent practicable (Rose et al., 2012). There are several options available to improve a turbine's resiliency to extreme weather and changes in extreme weather.

Design options to improve wind turbine resiliency to increases in extreme weather strength or frequency can involve improving the robustness of the turbine system. Heavier or stiffer blades can endure higher extreme loading (NREL, 2016). Stronger or additional pitch and yaw motors allow the wind turbine to respond and change orientation under extreme weather. Other more radical designs such as split pitch and two-bladed turbine layouts enable turbines to more efficiently "ride out" extreme weather events without damage. Split pitch moves the pitching mechanisms out along the blade length, reducing the load needed to pitch the blades. Two-bladed turbines can orient the blades tip-on into the wind to reduce loading (Kim et al, 2015). These more radical designs are often designed to withstand hurricane and/or typhoon loading, sometimes called "typhoon proof" in commercial materials (SME, 2020).

In addition, there are operational adjustments that can be made to improve the resiliency of offshore wind turbines in extreme weather events. As mentioned before, wind turbines do not typically operate in extreme weather. The turbine goes into an idle configuration, where blades are feathered into the wind, the rotor is allowed to slow-roll, as needed, and power is not produced (DOE EERE, N.d. A). Depending on the type of extreme weather, wind turbines can be programmed to adjust the turbine orientation to minimize the extreme loading into the turbine system. For most traditional three-bladed turbine machines, maintaining rotor orientation into the prevailing wind with blades feathered will maintain the minimum possible loading given the environmental conditions. However, some turbines designed for extreme offshore weather such as typhoons and hurricanes, can orient their rotors sideways, edge-on to the wind to reduce overall loading. Other more radical turbine designs, such as down-wind turbines, allow the rotors to "wind vane" with the wind to find the minimum loading condition. The term "wind vane" means to allow the wind loading to adjust the yaw orientation of the turbine rotor passively. This enables down-wind turbines to passively have optimal rotor positioning. All these operational options enable the turbine system to withstand extreme loading conditions such as extreme weather without sustaining damage.

Maintenance options to improve offshore turbine resiliency consist predominantly of increased and improved inspections and monitoring. This can include increased turbine and component inspections to catch damage more quickly as well as remote sensing for pitch and yaw lubrication degradation rates. Improved remote monitoring of the turbine health to more quickly and accurately detect problems or issues can also help mitigate the impact of variable wind speed and loads.

4.1.6 Waves

The impact of waves on offshore wind turbines is discussed in previous sections of this report. As with a reduction in wind, a reduction in waves should have little to no effect on offshore wind turbines. An increase in wave loading can impact foundation and tower bottom loads in addition to loading into transmission and structural cabling (Kalvig et al., 2014).

Fixed foundations will be more susceptible to wave loading. Robust design options can be used to improve offshore turbine resiliency to increases in wave loading. Heavier and more massive foundations, larger tower bottoms, and larger and/or more numerous foundation bolts can be used to increase the amount of wave loading a turbine can withstand (Bhattacharya, 2014).

Floating offshore foundations can potentially “ride” the wave amplitude loading better than fixed alternatives. However, the frequency of the waves may impact the fatigue life of both types of foundations, depending if the fundamental modes of the foundations are close to the frequency of wave loading. Also, the structural cabling used to maintain general positioning of the floating turbine may experience reduced fatigue life if the frequency of waves impacting the turbine system increases. This potential reduction in fatigue life can be addressed in the design phase of the project. Operations and maintenance actions have minimal ability to provide resilience; however, increased inspection frequency and remote monitoring can be used to minimize damage caused by waves.

4.1.7 Precipitation

4.1.7.1 Rain, Water, and Ice

The impact of ice on offshore wind turbines is discussed in previous sections of this report. The following paragraphs discuss options to improve offshore turbine resiliency to ice.

Wind turbine OEMs already offer several optional design additions for blades to address issues with ice accumulation. These include hydrophobic blade coatings that diminish and/or prevent ice collection as well as heating systems, both electrical and fluid-driven, to reduce or eliminate ice along the blades. Typically, these are suggested for use in cold weather climates.

Real-time health monitoring of wind turbines can be used to monitor rotor imbalance as well as power production. This can be used to determine when there is sufficient ice build-up on the blades to create a mass imbalance and/or negatively affect power production. When such ice build-up occurs, the turbine can deice the system by using heaters or pumping hot air or liquid throughout the at-risk components.

Increased maintenance efforts as well as the use of blade heating devices in areas that experience frequent icing conditions can be used to help reduce the impact that ice has on wind turbines. This can include increased turbine and component inspections, specifically for blades, to catch damage more quickly and enact repairs. Remote visual inspections using drones may also help with increased turbine monitoring and inspection.

4.2 Coastal Infrastructure and Ports

The extent to which port operators consider climate change impacts and adaptation in their planning varies across the globe. A 2018 survey done by the United Nations Conference on Trade and Development found that although 70% of ports had emergency response measures in place for extreme events, 40% of respondents reported not having or planning relevant vulnerability assessments and the same percentage had not yet carried out any work to identify and evaluate potential adaptation measures (Asariotis, et al., 2018).

Resilience options for flooding due to sea level rise and storm surge include elevating port infrastructure, using storm-resilient pier and wharf designs and building sea walls. Natural and nature-based features (NNBF) (e.g., engineered wetlands, oyster reefs) can often provide flood protection and resilience for coastal infrastructure while also providing additional benefits such as wildlife habitat and reduced coastal erosion. Additional options are targeted protection of electrical and mechanical systems within buildings, such as elevated platforms or waterproof rooms to house critical infrastructure. For flooding due to heavy precipitation, drainage systems can be installed where needed and existing systems can be expanded to accommodate the expected increase in water flow. Paved areas such as parking lots can be designed with porous surface technologies that can absorb water and reduce flooding. Green infrastructure can help minimize industrial runoff by collecting and managing rainwater and preventing it from entering local sewer systems. This supports local water quality and reduces the burden on combined sewer systems which is important for workforce and community resilience. Operational measures include clearly defined protocols for moving materials out of harm's way or temporarily offsite when storms are anticipated. Maintenance actions may include more frequent dredging of channels to keep them clear of debris and silt build-up following severe storms.[20]

Because of the significant land area occupied by ports, they provide an opportunity to help reduce the urban heat island effect.[21] Strategies for mitigating urban heat islands include increasing tree and vegetation cover, green roofs, cool (mainly reflective) roofs and cool pavements. Tree and vegetation cover lowers both surface and air temperatures by providing shade. Green roofs include a vegetative layer to reduce roof temperatures which reduces nearby surface temperatures. Cool roofs are made of materials or coatings that reflect sunlight and heat away from buildings. Cool pavements use materials that remain cooler than conventional pavements by reflecting more solar energy and enhancing water evaporation.

For high-wind events, the initial design of permanent structures such as piers, berths, and buildings can include consideration of high winds. Existing structures, to a practical extent, can be upgraded to withstand the expected winds over the life of the infrastructure. Operational measures such as lowering and securing cranes and other equipment may also be used to reduce risk during high-wind events.

Ports have the potential to impact air pollution and greenhouse gases (GHG) in the areas in which they are located. The U.S. Environmental Protection Agency (EPA) has developed a Ports Initiative[22] to reduce air pollution and GHGs, to achieve environmental sustainability for ports, and improve air quality for near-port communities. The initiative addresses emissions from major sources including ocean going vessels, harbor craft, rail, cargo handling equipment and regional trucking. Emissions reduction strategies include fuel economy improvements, low sulfur as well as hydrogen fuels, electrification, and emission control technologies.

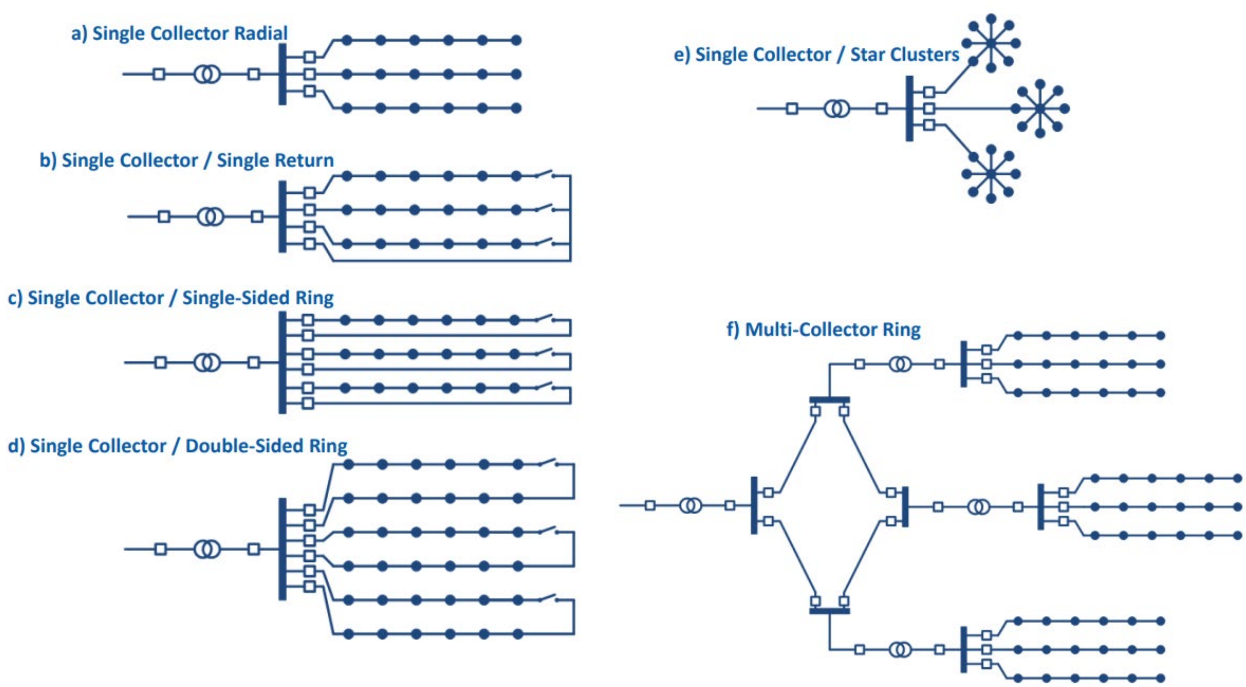
4.3 Electrical Infrastructure

4.3.1 Ocean-Based Electrical Infrastructure

Offshore wind collection or inter-array cables and export cables as well as cable landings can be impacted by extreme storms through scour and erosion. A first set of options for resilience includes the design of the inter-array cable configuration. Figure 13 shows a range of cable configurations for OSW inter-array cables with power generally flowing from right to left in the diagram. The single collector radial configuration is the simplest and lowest cost configuration. However, it is more susceptible to reductions in output due to cable failures than the other designs because there is a single path for power to flow back to the collector bus. Alternate designs that incorporate redundancy features such as additional return lines and ring topologies have the potential to provide higher reliability although at higher cost because of the additional cabling and other infrastructure such as circuit breakers.

Figure 13. Offshore Inter-Array Cable Configurations

Source: NREL Offshore Wind Electrical Systems.



There are several resilience considerations for the OSW export cable system. For large transmission capacities, as will be required for the transmission of 9 gigawatts of power, multiple systems and cables must be used because the capacity of a single cable is typically no higher than 600 to 700 megawatts. The use of multiple systems and cables provides redundancy and reduces the impact of the failure of any single component. Another consideration is the choice of whether to use high voltage alternating current (HVAC) or high voltage direct current (HVDC) transmission. The choice between HVAC and HVDC depends on the amount of power to be transmitted, the voltage level and the distance to the connection point in the transmission grid. The higher the amount of power to be transmitted and the greater the distance to the interconnection point, the more HVDC is economical. For HVDC systems, the choice of configuration can provide additional resilience against cable damage caused by extreme storms. The simplest HVDC configuration is a monopole design which uses a single cable as one side of the electrical circuit and the earth as the other side. A symmetric monopole configuration uses two conductors, one with positive polarity and one with negative polarity, and allows for double the capacity of a traditional monopole link. Both monopolar configurations have no redundancy to operate if one of the cables is damaged and out of service until a repair is made. In a bipolar configuration, there are two conductors, one operating with positive polarity and one with negative polarity which allows for double the capacity of a traditional monopole link. There is also a ground conductor which allows the system to operate at one-half capacity in the event either of the two main conductors are damaged, thus providing an added level of resilience to the export cable system.

Most of an OSW cable system is buried beneath the ocean floor, but floating foundation systems have a portion of the cable system exposed to ocean currents as it transitions from the foundation to the ocean floor. Standard design practices consider wave motion by incorporating bend stiffeners, which provide strength against flexion; buoyancy modules that help maintain cable shape and reduce tension loads; and touchdown protection that reduces the risk of damage where the cable transitions to a buried configuration. The OSW cable industry offers “resilience cables” for harsh environments that are designed to withstand more frequent and severe flexion over their lifetimes.

Even buried sections of OSW inter-array and export cables may be susceptible to wave caused scour, the erosion of the ocean bottom that may expose the cables and increase the risk of movement and subsequent damage. The OSW industry has developed several methods to minimize the potential for scour. A typical method is the use of a subsea mattress that sits on the sea floor and prevents ocean currents from interacting with and eroding the seabed. Mattresses can be made of concrete, engineered plastics and even repurposed vehicle tires and through surface chemistry and design can be enhanced to promote the cultivation of NNBF and beneficial ecosystems via habitat creation that serve to improve adherence to the seafloor further reducing the effects of scour (Perkol-Finkel and Sella, 2015).

Offshore wind transformer stations which increase the voltage of the electricity for transmission to shore, and converter stations, which, in some installations, convert the alternating current output of the wind turbines to direct current for transmission to shore, can be impacted by severe storms. Resilience options for these stations include heavier and more massive foundations, larger tower bottoms, and larger and/or more numerous foundation bolts which can be used to increase the amount of wave loading a structure can withstand (Bhattacharya, 2014).

4.3.2 Onshore Electrical Infrastructure

Onshore substations, which receive the electricity from OSW export cables and provide connection to the energy grid, can be vulnerable to sea level rise and storm surge if they are located near the shore. Industry practices for hardening substations against flooding involves a defense-in-depth strategy which calls for "multiple layers of protection that provide redundancy in the event that one or more of the measures fails" (Con Ed, 2013). The outer layer of protection is typically provided by a floodwall designed to withstand storm surge. An inner layer of protection is provided by elevating or installing moats around critical equipment, sealing penetrations of electrical conduits, using flood doors in some locations and installing high-capacity flood pumps to address any water that breaches initial protection layers (Con Ed, 2013). These stations are also marginally susceptible to the impact of high winds during extreme storms and ice from ice storms. Utilities are increasingly conducting climate change vulnerability studies across their asset portfolios, including transmission substations (DOE, OEPS, 2016).

4.4 Human Stressors

4.4.1 Hacking, Vandalism, and Terrorism

As described in Section 1.2, the successful cyber attack on wind turbines by researchers at the University of Tulsa required physical access to and breach of the wind turbines structure. Wind turbine designers have the options of making access to and breach of wind turbine structures more difficult by incorporating more robust physical protection such as the burglary protection door shown in Figure 14.

Figure 14. Wind Turbine Burglary Protection Door

The ability to track and control the number of available master keys to wind turbine access doors presents a challenge to physical security. The use of electronic locks with access codes that can be granted or rescinded remotely can help address the vulnerability posed by physical keys. In addition, electronic access systems can allow medical staff or firefighters to enter without losing valuable time.

Offshore wind operators can also employ tracking technology to monitor vessels in the vicinity of wind farms. Recent systems use radar, thermal imaging, and long-range acoustic devices to provide an integrated view of vessel movement near wind farms (ISJ, 2020).

Since the threat space is continually expanding for attacks on critical infrastructure, OSW companies are focused on preventing such attacks from impacting their operations. The energy industry has initiatives focused on protecting the grid and is partnering with federal agencies to improve resilience to cyber threats. The Department of Energy's Idaho National Laboratory is leading several research efforts to explore ways in which to improve the cybersecurity resilience of wind farms (DOE, WETO 2020).

Other organizations involved in such collaborations include the National Institute of Standards and Technology, the North American Electric Reliability Corporation, and federal intelligence and law enforcement agencies.

Because of the remote location of OSW farms and the fact that the output of any single turbine is relatively small relative to the total farm output, the value of physically sabotaging any one unit is correspondingly small. Coupled with the challenge in reaching the offshore site and the inability to access the transmission lines that are underwater, offshore wind sites do not appear to be an inviting target for terrorist attack.

4.5 Project Financing

Investors are broadening the scope of due diligence processes to include climate risk by identifying the potential for chronic and acute physical climate risk to impact project revenues, expenditures, assets, capital, and financing. The financial industry is increasingly recognizing and working to understand and value climate risk to investments. Climate risk may be reflected in higher expected rates of return from investors and higher costs of capital to developers to account for those risks, making it more challenging to finance projects. The ability to raise or refinance debt may be affected by climate-related physical risks by reducing project valuation which lowers attractiveness, increasing the difficulty in raising capital. This report has outlined a range of options to help reduce climate risk to OSW projects in order to make them more attractive to investors and lower the cost of capital to developers.

Two primary elements support reducing OSW project risk: understanding projected changes to climate factors for the region in which the project is located and evaluating the adaptation options to address projected climate risk. Section 2 of this report provides an overview of potential changes to climate factors relevant to offshore wind for the Northeast. Updating the view of these changes as new information and projections become available will support understanding the risk profile for OSW. The options to build resilience to climate change, covered in this section of the report, demonstrate the range of levers available to reduce the risk to both performance and reliability of OSW. Systematically, evaluating the relative benefits of these resilience options and selecting those options that are suitable, as an early part of the project planning process, will help reduce project climate risk and provide more favorable project finance options.

5 Conclusions

This report aggregated, refined, and distilled climate adaptation and resiliency considerations that pertain to offshore wind (OSW) for New York State and in the broader Northeastern Atlantic Region of the United States. The report identified climate factors that are meaningful to OSW operations and reliability and examined the range of options to build resilience to climate change. Table 4 summarizes the relative risks that different hazards associated with climate change may pose to the OSW systems evaluated. It quantitatively characterizes risk as a combination of vulnerability to the given climate stressor and the resilience options available to address that vulnerability.

Table 4. Summary of Relative Risk of Factors Associated with Climate Change to NYSERDA Offshore Wind Development

Climate Stressor		Wind Turbine Generators	Foundations*	Cables**	Onshore stations	Ports
Wind	Low velocity					
	High velocity					
	Turbulence					
	Shear					
	Geographic distribution					
Air	Temperature					
	Moisture					
Ocean	Waves					
	Sea level rise					
Precipitation	Rain					
	Ice / frozen					
Extreme storms	Extreme wind					
	Storm surge					
Human stressors	Hacking					
	Vandalism					

	Low risk
	Medium risk
	High risk

*Includes foundations for wind turbine generators, transformer stations and converter stations

** Includes inter-array and export cables

6 References

Aho, J., Buckspan, A., Laks, J., Jeong, Y., Dunne, F., and Pao, L. 2012. "Tutorial of Wind Turbine Control for Supporting Grid Frequency through Active Power Control: Preprint," 14. Montreal, Canada. https://www.nrel.gov/docs/fy12osti/54605.pdf

Aitken, M. L., Rhodes, M., and Lundquist, J. 2012. "Performance of a Wind-Profiling Lidar in the Region of Wind Turbine Rotor Disks." Journal of Atmospheric and Oceanic Technology 29, no. 3 (January 9, 2012): 347–55. https://doi.org/10.1175/JTECH-D-11-00033.1

American Bird Conservancy. 2017. "Wind Energy and Birds FAQ Part 1: Understanding the Threats." https://abcbirds.org/wind-energy-threatens-birds/

Prepared by American Bureau of Shipping (ABS) and Submitted to the U.S. Department of the Interior. 2011. "Design Standards for Offshore Wind Farms." U.S. Department of the Interior, Bureau of Ocean Energy Management, Regulation and Enforcement. https://www.bsee.gov/sites/bsee.gov/files/tap-technical-assessment-program/670aa.pdf

American Wind Energy Association (AWEA). N.d. "U.S. Offshore Wind Industry." Awea.Org. https://www.awea.org/policy-and-issues/u-s-offshore-wind

American Wind Energy Associate (AWEA). N.d. "Basics of Wind Energy." Awea.org. https://www.awea.org/wind-101/basics-of-wind-energy

Amorim, Francisco, Hugo Rebelo, and Luísa Rodrigues. 2012. "Factors Influencing Bat Activity and Mortality at a Wind Farm in the Mediterranean Region." Acta Chiropterologica 14 (2). https://doi.org/info:doi/10.3161/150811012X661756

Armstrong, Alona, Ralph R Burton, Susan E Lee, Stephen Mobbs, Nicholas Ostle, Victoria Smith, Susan Waldron, and Jeanette Whitaker. 2016. "Ground-Level Climate at a Peatland Wind Farm in Scotland Is Affected by Wind Turbine Operation." Environmental Research Letters 11 (4): 044024. https://doi.org/10.1088/1748-9326/11/4/044024

Asariotis, Regina & Benamara, Hassiba & Mohos Naray, Viktoria. 2018. Port Industry Survey on Climate Change Impacts and Adaptation. 10.13140/RG.2.2.28176.66569

Atlantic Coast Port Access Route Study (ACPARS) Workgroup. 2015. "Atlantic Coast Port Access Route Study: Final Report." Docket Number USCG-2011-0351. https://navcen.uscg.gov/pdf/PARS/ACPARS_Final_Report_08Jul2015_Combined_Appendix_Enclosures_Final_After_LMI_Review.pdf Azorin-Molina, Cesar, Sergio M. Vicente-Serrano, Tim R. McVicar, Jesus Revuelto, Sonia Jerez, and Juan-I. López-Moreno. 2017. "Assessing the Impact of Measurement Time Interval When Calculating Wind Speed Means and Trends under the Stilling Phenomenon." International Journal of Climatology 37 (1): 480–92. https://doi.org/10.1002/joc.4720

Baldini, Lisa M., James U. L. Baldini, Jim N. McElwaine, Amy Benoit Frappier, Yemane Asmerom, Kam-biu Liu, Keith M. Prufer, et al. 2016. “Persistent Northward North Atlantic Tropical Cyclone Track Migration over the Past Five Centuries.” Scientific Reports 6 (1): 1–8. https://doi.org/10.1038/srep37522

Barclay, Robert M.R., E.F. Baerwald, and J.C. Gruver. 2007. “Variation in Bat and Bird Fatalities at Wind Energy Facilities: Assessing the Effects of Rotor Size and Tower Height.” Canadian Journal of Zoology 85 (3): 381–87. https://doi.org/10.1139/Z07-011

Baring-Gould, Ian. 2014. “Offshore Wind Plant Electrical Systems.” Presented at the BOEM Offshore Renewable Energy Workshop, July 29-30, 2014. https://www.boem.gov/sites/default/files/about-boem/BOEM-Regions/Pacific-Region/Renewable-Energy/6-Ian-Baring-Gould---BOEM-Offshore-Wind-Plant-Electrical-Systems-CA.pdf

Behr, Peter. 2016. “Substation Attack Is New Evidence of Grid Vulnerability.” E&E News. https://www.eenews.net/stories/1060043920

Bhattacharya, S. 2014. “Challenges in Design of Foundations for Offshore Wind Turbines.” Engineering & Technology Reference. https://doi.org/10.1049/etr.2014.0041

Bureau of Ocean Energy Management (BOEM). 2020. “Vineyard Wind 1 Offshore Wind Energy Project.” https://www.boem.gov/sites/default/files/documents/renewable-energy/Vineyard-Wind-1-Supplement-to-EIS.pdf

Bureau of Ocean Energy Management (BOEM). 2018. “Summary Report: Bureau of Ocean Energy Management’s Offshore Wind and Maritime Industry Knowledge Exchange.” https://www.boem.gov/sites/default/files/renewable-energy-program/BOEM-Maritime-Meeting-Summary-FINAL-%281%29.PDF

Carini, F. 2018. “Stop the Spin: Turbines Less Deadly Than Fossil Fuels.” Eco RI News. https://www.ecori.org/renewable-energy/2018/1/22/stop-the-spin-wind-turbines-kill-less-birds-than-fossil-fuels

Center for Hearing and Communication (CHC). N.d. “Common Environmental Noise Levels.” Center for Hearing and Communication. https://chchearing.org/noise/common-environmental-noise-levels/

CFI Notebook. N.d. “Graphics – Aerodynamics and Performance: Stall Strips.” https://www.cfinotebook.net/graphics/aerodynamics-and-performance/stall-strips.webp

Coast Guard, Department of Homeland Security (DHS). 2020. “Port Access Route Study: The Areas Offshore of Massachusetts and Rhode Island” (MARIPARS). https://www.federalregister.gov/documents/2020/01/29/2020-01522/port-access-route-study-the-areas-offshore-of-massachusetts-and-rhode-island

Cognet, V., Courrech du Pont, S., Dobrev, I., Massouh, F., and Thiria, B. 2017. “Bioinspired Turbine Blades Offer New Perspectives for Wind Energy.” Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences 473, no. 2198 (February 28, 2017): 20160726. https://doi.org/10.1098/rspa.2016.0726

Colle, B.A., Zhang, Z., Lombardo, K. A., Change, E., Liu, P., & Zhang, M. 2013. Historical evaluation and future prediction of Eastern North American and Western Atlantic extratropical cyclones in the CMIP5 models during the cool season. *Journal of Climate*, 26, 6882-6903.

Colle, B. A., Booth, J. F., & Chang, E. K. M. 2015. A review of historical and future changes of extratropical cyclones and associated impacts along the US East Coast. *Current Climate Change Reports*. 1(3). 125-143.

Consolidated Edison (Con Ed). 2013. "Post Sandy Enhancement Plan." https://www.coned.com/-/media/files/coned/documents/services-outages/post_sandy_enhancement_plan.pdf

Dam, C.P. van, Berg, D. E., and Johnson, S. J. 2008. "Active Load Control Techniques for Wind Turbines." Sandia National Laboratories. https://doi.org/10.2172/943932

Department of Trade and Industry Energy Technology Support Unit (ESTU). 2002. "Potential Effects of Offshore Wind Developments on Coastal Processes." https://tethys.pnnl.gov/sites/default/files/publications/Potential_Effects_of_Offshore_Wind_Developments_on_Coastal_Processes.pdf

DNV GL. 2018. "Support Structures for Wind Turbines: Standards." https://rules.dnvgl.com/docs/pdf/DNVGL/ST/2018-07/DNVGL-ST-0126.pdf

Dunne, F., Simley, E., and Pao, L.Y. 2011. "LIDAR Wind Speed Measurement Analysis and Feed-Forward Blade Pitch Control for Load Mitigation in Wind Turbines: January 2010--January 2011." https://doi.org/10.2172/1028529

Dupigny-Giroux, L.A., E.L. Mecray, M.D. Lemcke-Stampone, G.A. Hodgkins, E.E. Lentz, K.E. Mills, E.D. Lane, R. Miller, D.Y. Hollinger, W.D. Solecki, G.A. Wellenius, P.E. Sheffield, A.B. MacDonald, and C. Caldwell. 2018. Northeast. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 669–742. Hellodoi: 10.7930/NCA4.2018.CH18

Eichelberger, S., Bart Nijssen, James Mccaa, and A. W. Wood. 2008. "Climate Change Effects on Wind Speed." North American Windpower. https://www.researchgate.net/publication/281611243_Climate_change_effects_on_wind_speed

Eisenberg, Drew, Steffen Laustsen, and Jason Stege. 2016. "Leading Edge Protection Lifetime Prediction Model Creation and Validation." Presented at WindEurope Summit 2016, Hamburg, Germany

Eisenberg, Drew, Steffen Laustsen, and Jason Stege. 2018. "Wind Turbine Blade Coating Leading Edge Rain Erosion Model: Development and Validation." Wind Energy 21 (10): 942–51. https://doi.org/10.1002/we.2200

ENERCON. N.d. "WEC Features - Configuration Specific to Site." https://www.enercon.de/en/technology/wec-features/

Fox, A., and Petersen, I. 2019. “Offshore Wind Farms and Their Effects on Birds.”

Garner, Andra J., Michael E. Mann, Kerry A. Emanuel, Robert E. Kopp, Ning Lin, Richard B. Alley, Benjamin P. Horton, Robert M. DeConto, Jeffrey P. Donnelly, and David Pollard. 2017. “Impact of Climate Change on New York City’s Coastal Flood Hazard: Increasing Flood Heights from the Preindustrial to 2300 CE.” PNAS 114 (45). https://www.pnas.org/content/114/45/11861

Giguere, P., Lemay, J., and Dumas, G. 2012. “Gurney Flap Effects and Scaling for Low-Speed Airfoils.” In 13th Applied Aerodynamics Conference. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.1995-1881

Glegg, Stewart. N.d. “The Impact of Offshore Wind Turbines on Underwater Ambient Noise Levels.” Florida Atlantic University Center for Acoustics and Vibration. https://vtechworks.lib.vt.edu/bitstream/handle/10919/54723/Glegg.pdf?sequence=1&isAllowed=y

Goldfarb, Ben. 2017. “Feeling the Heat: How Fish Are Migrating from Warming Waters.” Yale E360. https://e360.yale.edu/features/feeling-the-heat-warming-oceans-drive-fish-into-cooler-waters

Greenberg, Andy. 2017. “Researchers Found They Could Hack Entire Wind Farms.” WIRED. https://www.wired.com/story/wind-turbine-hack/

Guida, V., A. Drohan, H. Welch, J. McHenry, D. Johnson, V. Kentner, J. Brink, D. Timmons, E. Estela-Gomez. 2017. Habitat Mapping and Assessment of Northeast Wind Energy Areas. Sterling, VA: US Department of the Interior, Bureau of Ocean Energy Management (BOEM). OCS Study BOEM 2017-088. 312 p. https://espis.boem.gov/final%20reports/5647.pdf

Haney, J. C., Jodice, P., Montevecchi, W., and Evers, D. C. 2017. “Challenges to Oil Spill Assessment for Seabirds in the Deep Ocean.” Archives of Environmental Contamination and Toxicology 73, no. 1: 33–39. https://doi.org/10.1007/s00244-016-0355-8

Harvey, Chelsea. 2019. “The World’s Winds Are Speeding Up.” Scientific American. November 19, 2019. https://www.scientificamerican.com/article/the-worlds-winds-are-speeding-up/

Hasager, C., F. Vejen, J. I. Bech, W. R. Skrzypiński, A. -M. Tilg, and M. Nielsen. 2020. “Assessment of the Rain and Wind Climate with Focus on Wind Turbine Blade Leading Edge Erosion Rate and Expected Lifetime in Danish Seas.” Renewable Energy 149 (April): 91–102. https://doi.org/10.1016/j.renene.2019.12.043

Hayhoe, K., J. Edmonds, R.E. Kopp, A.N. LeGrande, B.M. Sanderson, M.F. Wehner, and D.J. Wuebbles. 2017. “Climate models, scenarios, and projections.” In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 133-160, doi: 10.7930/J0WH2N54

Hayhoe, K., D.J. Wuebbles, D.R. Easterling, D.W. Fahey, S. Doherty, J. Kossin, W. Sweet, R. Vose, and M. Wehner. 2018. "Our Changing Climate." In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 72–144. doi: 10.7930/NCA4.2018.CH2

Hoen, Ben, Jason P Brown, Thomas Jackson, Ryan Wiser, Mark Thayer, and Peter Cappers. 2013. "A Spatial Hedonic Analysis of the Effects of Wind Energy Facilities on Surrounding Property Values in the United States." 58.

Horton, Kyle G., Frank A. La Sorte, Daniel Sheldon, Tsung-Yu Lin, Kevin Winner, Garrett Bernstein, Subhransu Maji, Wesley M. Hochachka, and Andrew Farnsworth. 2020. "Phenology of Nocturnal Avian Migration Has Shifted at the Continental Scale." Nature Climate Change 10 (1): 63–68. https://doi.org/10.1038/s41558-019-0648-9

Horton, Radley, Christopher Little, Vivien Gornitz, Daniel Bader, and Michael Oppenheimer. 2015. "New York City Panel on Climate Change 2015 Report Chapter 2: Sea Level Rise and Coastal Storms." Annals of the New York Academy of Sciences 1336 (1): 36–44. https://doi.org/10.1111/nyas.12593

Hu, H., Li, X., and Gu, B. 2016. "Flow Characteristics Study of Wind Turbine Blade with Vortex Generators." International Journal of Aerospace Engineering (May 12, 2016): e6531694. https://doi.org/10.1155/2016/6531694

Hubbard, Harvey H. Shepherd. 2009. "Wind Turbine Acoustics." https://ntrs.nasa.gov/search.jsp?R=20090026531

Intergovernmental Panel on Climate Change (IPCC). 2013. Summary for Policymakers, Technical Summary and Frequently Asked Questions. In: Climate Change 2013: The Physical Science Basis. [T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. Midgley (Eds.)]. Cambridge, United Kingdom: Cambridge University Press, pp. 3–29.

Intergovernmental Panel on Climate Change (IPCC). 2011. Renewable Energy Sources and Climate Change Mitigation. [Ottmar Edenhofer, Ramón Pichs-Madruga, Youba Sokona, Kristin Seyboth, Patrick Matschoss, Susanne Kadner, Timm Zwickel, Patrick Eickemeier, Gerrit Hansen, Steffen Schloemer, Christoph von Stechow (Eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 535-608.

International Security Journal (ISJ). 2020. "RadarWatch protects Korean wind farm." https://internationalsecurityjournal.com/cambridge-pixels-radarwatch-and-target-tracking-technology-protect-korean-offshore-wind-farm/

Jarvis, Christina M. 2005. "An Evaluation of the Wildlife Impacts of Offshore Wind Development Relative to Fossil Fuel Power Production." University of Delaware Graduate College of Marine Studies. http://www.seaturtle.org/PDF/JarvisCM_2005_MSc.pdf

Kalvig, Siri, Eirik Manger, Bjørn H. Hjertager, and Jasna B. Jakobsen. 2014. "Wave Influenced Wind and the Effect on Offshore Wind Turbine Performance." Energy Procedia, EERA DeepWind' 2014, 11th Deep Sea Offshore Wind R&D Conference, 53 (January): 202–13. https://doi.org/10.1016/j.egypro.2014.07.229

Kanki, Barbara G., Jean-Francois Clervoy, and Gro Sandal. 2017. Space Safety and Human Performance. Butterworth-Heinemann.

Kim, T., Larsen, T. J., and Yde, A. 2015. "Investigation of potential extreme load reduction for a two-bladed upwind turbine with partial pitch." Wind Energy, 18: 1403– 1419. doi: 10.1002/we.1766

Kolundzic, Daniel. 2016. "Exploring the Impact of the Proposed Galloo Island Energy Project," 31.

Kuiler, I., Adonis, M., and Raji, A. 2018. "Preventive Maintenance and Fault Detection for Wind Turbine Generators Using a Statistical Model." Fault Detection and Diagnosis, November 5, 2018. https://doi.org/10.5772/intechopen.80071

Ernest Orlando Lawrence Berkeley National Laboratory (LBNL). 2013. "A Spatial Hedonic Analysis of the Effects of Wind Energy Facilities on Surrounding Property Values in the United States," 58.

Lambkin, D.O., Harris, J.M., Cooper, W.S., Coates, T. 2009. "Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment: Best Practice Guide."

Lange, Bernhard, Søren Larsen, Jørgen Højstrup, and Rebecca Barthelmie. 2004. "Importance of Thermal Effects and Sea Surface Roughness for Offshore Wind Resource Assessment." Journal of Wind Engineering and Industrial Aerodynamics 92 (11): 959–88. https://doi.org/10.1016/j.jweia.2004.05.005

Lassen, Søren, and Mhairidh Evans. 2020. "Why Offshore Wind Will Attract More than US$211 Billion between 2020 and 2025." Wood Mackenzie. https://www.woodmac.com/news/opinion/why-offshore-wind-will-attract-more-than-us$211-billion-between-2020-and-2025/

Leonhard, S. B., Stenberg, C., Støttrup, J., Deurs, M. V., Christensen, A., & Pedersen, J. 2013. Fish benefits from offshore wind farm development. In Danish offshore wind - key environmental issues – a follow-up (pp. 31- 45). Danish Energy Agency. https://backend.orbit.dtu.dk/ws/portalfiles/portal/55080896/Havvindm_llebog.pdf

Letson, Frederick, Rebecca J. Barthelmie, and Sara C. Pryor. 2019. "RADAR-Derived Precipitation Climatology for Wind Turbine BladeLeading Edge Erosion." Preprint. Design methods, reliability and uncertainty modelling. https://doi.org/10.5194/wes-2019-43

Liersch, J, and J Michael. 2014. "Investigation of the Impact of Rain and Particle Erosion on Rotor Blade Aerodynamics with an Erosion Test Facility to Enhancing the Rotor Blade Performance and Durability." Journal of Physics: Conference Series 524 (June): 012023. https://doi.org/10.1088/1742-6596/524/1/012023

Lin, N., Marsooli, R. & Colle, B.A. 2019. Storm surge return levels induced by mid-to-late-twenty-first-century extratropical cyclones in the Northeastern United States. Climatic Change 154, 143–158. https://doi.org/10.1007/s10584-019-02431-8

Lindeboom, H. J., H. J. Kouwenhoven, M. J. N. Bergman, S. Bouma, S. Brasseur, R. Daan, R. C. Fijn, et al. 2011. "Short-Term Ecological Effects of an Offshore Wind Farm in the Dutch Coastal Zone; a Compilation." Environmental Research Letters 6 (3): 035101. https://doi.org/10.1088/1748-9326/6/3/035101

Liu, J-H, Chen, J-C, Lai, W-J, Su, W-N. 2018. "Extreme Load Analysis of a 5MW Offshore Wind Turbine under Tropical Cyclone Wind Conditions. Research Gate." https://www.researchgate.net/profile/Jui_Hung_Liu/publication/334494246_Extreme_Load_Analysis_of_a_5MW_Offshore_Wind_Turbine_under_Tropical_Cyclone_Wind_Conditions/links/5d2e035792851cf4408a179b/Extreme-Load-Analysis-of-a-5MW-Offshore-Wind-Turbine-under-Tropical-Cyclone-Wind-Conditions.pdf?origin=publication_detail

Lutzeyer, Sanja, Daniel J. Phaneuf, and Laura O. Taylor. 2017. "The Amenity Costs of Offshore Wind Farms: Evidence from a Choice Experiment." Energy Economics 72: 621–39. https://doi.org/10.1016/j.eneco.2018.03.020

Lynch, J.F., G.G. Gawarkiewicz, Y.-T. Lin, T.F. Duda, and A.E. Newhall. 2018. Impacts of ocean warming on acoustic propagation over continental shelf and slope regions. Oceanography 31(2):174–181. https://doi.org/10.5670/oceanog.2018.219

Mahan, Simon, Isaac Pearlman, and Jacqueline Savitz. 2010. "Untapped Wealth: Offshore Wind Can Deliver Cleaner, More Affordable Energy and More Jobs than Offshore Oil."

Martinez, J., Flaszynski, P., Doerffer, P., and Szulc, O. 2016. "Improvement of Wind Turbine Blade Performance by Means of Rod Vortex Generators." In MARE-WINT: New Materials and Reliability in Offshore Wind Turbine Technology, edited by Wiesław Ostachowicz, Malcolm McGugan, Jens-Uwe Schröder-Hinrichs, and Marcin Luczak, 81–102. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-39095-6_6

Matko, Maruša, Mojca Golobič, and Branko Kontić. 2016. "Integration of Extreme Weather Event Risk Assessment into Spatial Planning of Electric Power Infrastructure." Urbani Izziv 27 (1): 95–112.

Matuschek, R, and K. Betke. 2009. "Measurements of Construction Noise During Pile Driving of Offshore Research Platforms and Wind Farms," 4.

McInnes, Kathleen L., Timothy A. Erwin, and Janice M. Bathols. 2011. "Global Climate Model Projected Changes in 10 m Wind Speed and Direction Due to Anthropogenic Climate Change." Atmospheric Science Letters 12 (4): 325–33. https://doi.org/10.1002/asl.341

Mikkelsen, T., Hansen, K., Angelou, N., Sjöholm, M., Harris, M., Hadley, P., Scullion, R., Ellis, G., and Vives, G. 2010. "Lidar Wind Speed Measurements from a Rotating Spinner." EWEC 2010 Proceedings Online, 9.

Miller, G.E. 1995. "Comparative Performance Tests on the Mod-2, 2.5-MW Wind Turbine With and Without Vortex Generators." In DASCON Engineering, Collected Papers on Wind Turbine Technology. 67-77.

Morris, L. 2011. "Second-Generation LIDAR Boosts Wind Power." Power Engineering. https://www.power-eng.com/2011/02/01/second-generation-lidar-boosts-wind-power/

Musial, W, D Elliott, J Fields, Z Parker, G Scott, and C Draxl. 2013. "Assessment of Offshore Wind Energy Leasing Areas for the BOEM New Jersey Wind Energy Area." National Renewable Energy Laboratory (NREL).

National Oceanic and Atmospheric Administration (NOAA) Environmental Data Service. 1972. "Environmental Guide for Seven U.S. Ports and Harbor Approaches." https://books.google.com/books?id=oz8aAQAAMAAJ&lpg=PA44&dq=50%20yr%20significant%20wave%20height%20for%20new%20york%20coast&pg=PP5#v=onepage&q&f=false

National Oceanic and Atmospheric Administration (NOAA) Fisheries. 2020. "Offshore Wind Energy Development in New England/Mid-Atlantic Waters. https://www.fisheries.noaa.gov/content/offshore-wind-energy-development-new-england-mid-atlantic-waters

National Oceanic and Atmospheric Administration (NOAA) National Ocean Service. 2019. "How Far Does Sound Travel in the Ocean?" National Ocean Service Website. https://oceanservice.noaa.gov/facts/sound.html

National Renewable Energy Laboratory (NREL). 2016. "Hurricane Resilient Wind Plant Concept Study Final Report."

National Weather Service (NWS). N.d. "Turbulence." https://www.weather.gov/source/zhu/ZHU_Training_Page/turbulence_stuff/turbulence/turbulence.htm

Network for Greening the Financial System (NGFS). 2019. "A Call for Action. Climate Change as a Source of Financial Risk." Paris.

New York State Energy Research and Development Authority (NYSERDA). 2010. "Pre-Development Assessment of Meteorological and Oceanographic Conditions for the Proposed Long Island – New York City Offshore Wind Project Area. https://www.nyserda.ny.gov/-/media/Files/EIBD/Research/LI-NYC-offshore-wind-climatology.pdf

New York State Energy Research and Development Authority (NYSERDA). 2012a. "An Evaluation of the Potential for Using Acoustic Monitoring to Remotely Assess Aerial Vertebrate Collision at Industrial Wind Energy Facilities." 12–26.

New York State Energy Research and Development Authority (NYSERDA). 2012b. "Avian Acoustic Monitoring Study at the Maple Ridge Wind Project: 2007-2008." 12–23.

New York State Energy Research and Development Authority (NYSERDA). 2013a. "Wind Turbine-Related Noise and Community Response." 13–03b.

New York State Energy Research and Development Authority (NYSERDA). 2013b. "Wind Turbine-Related Noise: Current Knowledge and Research Needs." 13–14.

New York State Energy Research and Development Authority (NYSERDA). 2014a. "Responding to Climate Change in New York State (ClimAID)." https://www.nyserda.ny.gov/About/Publications/Research%20and%20Development%20Technical%20Reports/Environmental%20Research%20and%20Development%20Technical%20Reports/Response%20to%20Climate%20Change%20in%20New%20York

New York State Energy Research and Development Authority (NYSERDA). 2014b. "Wind Power and Biodiversity in New York: A Tool for Siting Assessment and Scenario Planning at the Landscape Scale." 14–46. https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Environmental/Wind-Power-and-Biodiversity-in-New-York.pdf

New York State Energy Research and Development Authority (NYSERDA). 2016. "Wind Energy Guide, Section 1: Wind Energy Basics." https://www.nyserda.ny.gov/Researchers%20and%20Policymakers/Power%20Generation/Wind/Large%20Wind/New%20York%20Wind%20Energy%20Guide%20Local%20Decision%20Makers

New York State Energy Research and Development Authority (NYSERDA). 2018. "New York State Offshore Wind Master Plan: Charting a Course to 2,400 Megawatts of Offshore Wind Energy." 17–25. https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Biomass-Solar-Wind/Master-Plan/Offshore-Wind-Master-Plan.pdf

New York State Energy Research and Development Authority (NYSERDA). 2017a. "New York State Offshore Wind Master Plan Fish and Fisheries Study." 17–25. https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Biomass-Solar-Wind/Master-Plan/17-25j-Fish-and-Fisheries-Study.pdf

New York State Energy Research and Development Authority (NYSERDA). 2017b. "New York State Offshore Wind Master Plan Shipping and Navigation Study." 17–25. https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Biomass-Solar-Wind/Master-Plan/17-25q-Shipping-and-Navigation.pdf

Nikoueeyan, P., Strike, J., Magstadt, A., Hind, M., and Naughton, J. 2015. "Aerodynamic Response of a Wind Turbine Airfoil to Gurney Flap Deployment." https://doi.org/10.2514/6.2015-0995

Paradis, A., Elkinton, J., Hayhoe, K., & Buonaccorsi, J. 2008. Role of winter temperature and climate change on the survival and future range expansion of the hemlock woolly adelgid (Adelges tsugae) in eastern North America. *Mitigation and Adaptation Strategies for Global Change*, 13(5–6), 541–554. http://dx.doi.org/10.1007/s11027-007-9127-0

Pecl, Gretta T., Miguel B. Araújo, Johann D. Bell, Julia Blanchard, Timothy C. Bonebrake, I.-Ching Chen, Timothy D. Clark, et al. 2017. "Biodiversity Redistribution under Climate Change: Impacts on Ecosystems and Human Well-Being." Science 355 (6332). https://doi.org/10.1126/science.aai9214

Pelletier, Steven K., Kristian S. Omland, Kristen S. Watrous, and Trevor S. Peterson. 2013. “Information Synthesis on the Potential for Bat Interactions with Offshore Wind Facilities.” OCS Study. Herndon, VA: U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM). https://espis.boem.gov/final%20reports/5289.pdf

Perkol-Finek, Shimrit and Ido Sella. 2015. “Harnessing urban coastal infrastructure for ecological enhancement.” Proceedings of the Institution of Civil Engineers. Maritime Engineering 168 September 2015 Issue MA3. Pages 102–110 http://dx.doi.org/10.1680/jmaen.15.00017

Powell, Mark. N.d. “Vertical Wind Profiles in Hurricanes.” NOAA Hurricane Research Division.

Pryor, S. C., and R. J. Barthelmie. 2010. “Climate Change Impacts on Wind Energy: A Review.” Renewable and Sustainable Energy Reviews 14 (1): 430–37. https://doi.org/10.1016/j.rser.2009.07.028

Robinson, Stephen. 2012. “Noise Issues for Offshore Windfarms. Basic Acoustics: What Needs to Be Measured and Why.” National Physical Laboratory (NPL). http://www.ewea.org/events/workshops/wp-content/uploads/2012/12/EWEA-Noise-Workshop-Oxford-2012-5-1-Stephen-Robinson.pdf

Rodrigues, Silvio, Carlos Restrepo, George Katsouris, Rodrigo Pinto, Maryam Soleimanzadeh, Peter Bosman, and P. Bauer. 2016. “A Multi-Objective Optimization Framework for Offshore Wind Farm Layouts and Electric Infrastructures.” Energies 9: 216. https://doi.org/10.3390/en9030216

Román-Palacios, Cristian, and John J. Wiens. 2020. “Recent Responses to Climate Change Reveal the Drivers of Species Extinction and Survival.” Proceedings of the National Academy of Sciences 117 (8): 4211–17. https://doi.org/10.1073/pnas.1913007117

Rose, Stephen, Paulina Jaramillo, Mitchell J. Small, and Jay Apt. 2012. “Quantifying the Hurricane Catastrophe Risk to Offshore Wind Power: Hurricane Catastrophe Risk to Offshore Wind Power.” Carnegie Mellon Electricity Industry Center 33 (12): 2126–41. https://doi.org/10.1111/risa.12085

Roy, Somnath Baidya, and Justin J. Traiteur. 2010. “Impacts of Wind Farms on Surface Air Temperatures.” Proceedings of the National Academy of Sciences 107 (42): 17899–904. https://doi.org/10.1073/pnas.1000493107

Saenz-Aguirre, A., Fernandez-Gamiz, U., Zulueta, E., Ulazia, A., and Martinez-Rico, J. 2019. “Optimal Wind Turbine Operation by Artificial Neural Network-Based Active Gurney Flap Flow Control.” Sustainability 11, no. 10: 2809. https://doi.org/10.3390/su11102809

Saidur, R., N.A. Rahim, M.R. Islam, and K.H. Solangi. 2011. “Environmental Impact of Wind Energy.” Renewable and Sustainable Energy Reviews 15, no. 5: 2423–30. https://doi.org/10.1016/j.rser.2011.02.024

Salcedo, S., F. Monge, F. Palacios, Fernando Gandia-Aguera, Angel Rodriguez-Sevillano, and Miguel Barcala-Montejano. 2006. “Gurney Flaps and Trailing Edge Devices for Wind Turbines” 2: 1180–86.

Sanchez Gomez, Miguel, and Julie K. Lundquist. 2020. "The Effect of Wind Direction Shear on Turbine Performance in a Wind Farm in Central Iowa." Wind Energy Science 5 (1): 125–39. https://doi.org/10.5194/wes-5-125-2020

Sharpley, Nic. "Increasing Wind Turbine Efficiency with Vortex Generators." 2015. Windpower Engineering & Development. https://www.windpowerengineering.com/increasing-wind-turbine-efficiency-with-vortex-generators/

Smart Blade. 2020. "Wind Energy Performance: Vortex Generators." https://www.smart-blade.com/vortex-generators

Sobczak, Blake. 2019. "First-of-a-Kind U.S. Grid Cyberattack Hit Wind, Solar." E&E News. https://www.eenews.net/stories/1061421301

Sovacool, Benjamin K. 2012. "The Avian and Wildlife Costs of Fossil Fuels and Nuclear Power." Journal of Integrative Environmental Sciences 9, no. 4: 255–78. https://doi.org/10.1080/1943815X.2012.746993

Sugden, Andrew M. 2017. "Consequences of Shifting Species Distributions." Science 355, no. 6332: 1386. https://doi.org/10.1126/science.355.6332.1386-j

Sullivan, Robert G., Leslie B. Kirchler, Jackson Cothren, and Snow L. Winters. 2013. "Research Articles: Offshore Wind Turbine Visibility and Visual Impact Threshold Distances." Environmental Practice 15 (1): 33–49. https://doi.org/10.1017/S1466046612000464

Tee, W., Oumer, A.N., Shukrie, A., AbdulAziz, A., and Baheta, A. 2017. "Effect of Stall Strip Position, Size and Geometry on the Lift Coefficient of NACA 001 Aerofoil." Edited by H. Sakidin, M.H. Yusof, N. Sa'ad, D. Ling Chuan Ching, and S.A. Abdul Karim. MATEC Web of Conferences 131: 04011. https://doi.org/10.1051/matecconf/201713104011

Ten Brink, Talya S., and Tracey Dalton. 2018. "Perceptions of Commercial and Recreational Fishers on the Potential Ecological Impacts of the Block Island Wind Farm (US)." Frontiers in Marine Science 5. https://doi.org/10.3389/fmars.2018.00439

Thomsen, Frank, Karin Lüdemann, Rudolf Kafemann, and Werner Piper. 2006. "Effects of Offshore Wind Farm Noise on Marine Mammals and Fish," 62.

U.S. Department of Energy (DOE). 2012. "Final Environmental Impact Statement for the Proposed Cape Wind Energy Project, Nantucket Sound, Massachusetts (Adopted), DOE/EIS-0470." U.S. Department of Energy. https://www.energy.gov/sites/prod/files/DOE-EIS-0470-Cape_Wind_FEIS_2012.pdf

U.S. Department of Energy (DOE) Office of Energy Efficiency & Renewable Energy (EERE). N.d. A "How do Wind Turbines Survive Extreme Storms?" https://www.energy.gov/eere/articles/how-do-wind-turbines-survive-severe-storms

U.S. Department of Energy (DOE) Office of Energy Efficiency & Renewable Energy (EERE). N.d. "Offshore Wind Research and Development." Energy.Gov. https://www.energy.gov/eere/wind/offshore-wind-research-and-development

U.S. Department of Energy (DOE) Office of Energy Efficiency & Renewable Energy (EERE). 2016. "Computing America's Offshore Wind Energy Potential." Energy.Gov. September 9, 2016. https://www.energy.gov/eere/articles/computing-america-s-offshore-wind-energy-potential

U.S. Department of Energy (DOE) Office of Energy Efficiency & Renewable Energy (EERE). 2017. "How Do Wind Turbines Survive Severe Storms?" Energy.Gov. June 20, 2017. https://www.energy.gov/eere/articles/how-do-wind-turbines-survive-severe-storms

U.S. Department of Energy (DOE) Wind Energy Technologies Office (WETO). 2020. "Labs Coordinate to Protect Wind Power from Cyberattacks" Energy.Gov. June 20, 2017. https://www.energy.gov/eere/wind/articles/labs-coordinate-protect-wind-power-cyberattacks

U.S. Department of Energy (DOE) Office of Energy Policy and Systems Analysis (OEPS). 2016. "Review of Climate Change Vulnerability Assessments: Current Practices and Lessons Learned from DOE's Partnership for Energy Sector Climate Resilience" https://www.energy.gov/sites/prod/files/2016/10/f33/A%20Review%20of%20Climate%20Change%20Vulnerability%20Assessments%20Current%20Practices%20and%20Lessons%20Learned%20from%20DOEs%20Partnership%20for%20Energy%20Sector%20Climate%20Resilience.pdf

U.S. Fish & Wildlife Service (FWS) Migratory Bird Program. 2018. "Wind Turbines." April 18, 2018. https://www.fws.gov/birds/bird-enthusiasts/threats-to-birds/collisions/wind-turbines.php

Vautard, Robert, Julien Cattiaux, Pascal Yiou, Jean-Noël Thépaut, and Philippe Ciais. 2010. "Northern Hemisphere Atmospheric Stilling Partly Attributed to an Increase in Surface Roughness." Nature Geoscience 3 (11): 756–61. https://doi.org/10.1038/ngeo979

Vestas. 2019. "Energy Boosting Upgrades and Lifetime Extension." https://wfof.eu/files/2019/D2_R3_W2_FOFW2019_Vestas.pdf

Vestas. 2019. "Vestas High Wind Operation (HWO)." http://nozebra.ipapercms.dk/Vestas/Communication/Productbrochure/vestas-hwo/#/

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville. 2014. "Ch. 2: Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment," J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 19-67. doi:10.7930/J0KW5CXT

Windmanager. 2017. "Customized Burglary Protection for Wind Turbine Generators." https://www.windmanager.de/en/customized-burglary-protection-for-wind-turbine-generators/

Worsnop, Rochelle P., Julie K. Lundquist, George H. Bryan, Rick Damiani, and Walt Musial. 2017. "Gusts and Shear within Hurricane Eyewalls Can Exceed Offshore Wind Turbine Design Standards." Geophysical Research Letters 44 (12): 6413–20. https://doi.org/10.1002/2017GL073537

Yin, Jianjun, Michael E. Schlesinger, and Ronald J. Stouffer. 2009. "Model Projections of Rapid Sea-Level Rise on the Northeast Coast of the United States." Nature Geoscience 2 (4): 262–66. https://doi.org/10.1038/ngeo462

Yin, Jianjun, Stephen M. Griffies, and Ronald J. Stouffer. 2010. "Spatial Variability of Sea Level Rise in Twenty-First Century Projections." Journal of Climate 23 (17): 4585–4607. https://doi.org/10.1175/2010JCLI3533.1

Zeng, Zhenzhong, Alan D. Ziegler, Timothy Searchinger, Long Yang, Anping Chen, Kunlu Ju, Shilong Piao, et al. 2019. "A Reversal in Global Terrestrial Stilling and Its Implications for Wind Energy Production." Nature Climate Change 9 (12): 979–85. https://doi.org/10.1038/s41558-019-0622-6

Zhang, Jun A., Robert F. Rogers, David S. Nolan, and Frank D. Marks. 2011. "On the Characteristic Height Scales of the Hurricane Boundary Layer." Monthly Weather Review 139 (8): 2523–35. https://doi.org/10.1175/MWR-D-10-05017.1

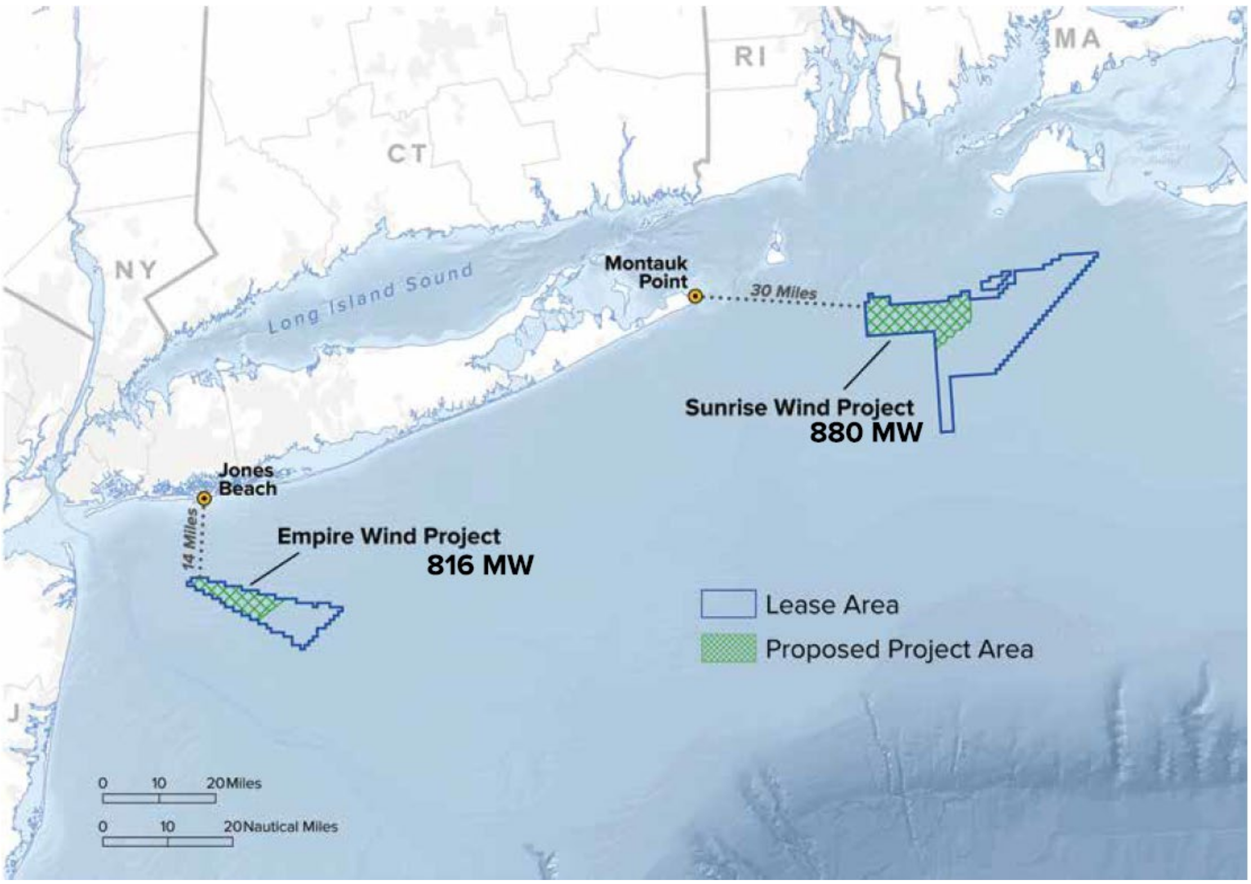
Ziegler, L., Voormeeren, S., Schafhirt, S., & Muskulus, M. 2015. "Sensitivity of Wave Fatigue Loads on Offshore Wind Turbines under Varying Site Conditions." *Energy Procedia*. *80*, 193–200. https://doi.org/10.1016/j.egypro.2015.11.422

Appendix A. Location Maps

Figure A-1 indicates the potential locations under consideration for OSW development for which this report assesses potential impacts of climate change and resilience opportunities.

Figure A-1. Proposed Lease and Project Areas for the Empire Wind and Sunrise Wind Projects

Includes distances from shore at closest point (14 miles and 30 miles, respectively).



Appendix B. NYSERDA Environmental Research Offshore Wind Activities

Regional Wildlife Science Coordinating. In cooperation with the Massachusetts Clean Energy Center and coordination with regional states, federal agencies, developers, and environmental organizations, NYSERDA is leading the development of a regional entity that can support and coordinate environmental research, monitoring and related activities to assure that the scientific and policy value of environmental data collected is maximized.

State of the Science Workshops. Biennial event (2018 and 2020) that brings together stakeholders interested in environmental and wildlife research and offshore wind energy development along the eastern seaboard to share research findings and coordinate on challenging environmental issues relating to offshore wind such as cumulative effects assessments (2020 theme).

Wind Resource Assessment. NYSERDA is sponsoring two metOcean buoys in the New York Bight (Hudson North and South Draft Wind Energy Areas) to develop energy generation estimates and better understand oceanographic conditions in the New York Bight. The buoys are also outfitted with environmental sensors to detect wildlife.

Monitoring Protocols for Bird and Bat Nanotag Studies. NYSERDA is sponsoring the development of standardized guidelines to inform the use of miniature digitally coded VHF transmitters ("nanotags") to monitor birds and bats in relation to offshore wind energy development.

Understanding Ecosystem Dynamics. NYSERDA is sponsoring research to improve our understanding of wildlife distributions through and assessment of multiscale relationships between marine predators and forage fish, and an examination of the relationships between environmental processes, primary productivity, and distribution of species at higher trophic levels.

Bird and Bat Research Framework. Through stakeholder driven processes, NYSERDA is developing a scientific research framework to better understand the impacts of offshore wind energy development on birds and bats. Identify key research questions and generate specific hypotheses for project- and regional-level studies, and generalizable recommendations to monitor and mitigate impacts to birds and bats during construction and operations of offshore wind facilities in the eastern U.S.

Fishing and Environmental Mitigation Plans. NYSERDA was the first and continues to require environmental and fishing mitigation plans as part of the Offshore Wind Solicitation. The documents provide a roadmap of developer activities for discussing with the TWGs, improving transparency. Many other states have followed our lead in this regard.

State Offshore Wind Fisheries Manager and Recreational Fishing Liaison. NYSERDA created of the first and only full-time state dedicated offshore wind fisheries manager with the main responsibility to liaison with the commercial fishing industry. Additionally, NYSERDA has also hired a well-respected and well-known charter boat captain to increase coordination and information sharing for the recreational fishing community.

Regional Monitoring. In the 2020 round of the OSW RFP, NYSERDA is requiring selected developers contribute $10,000/MW of proposed capacity ($8M/800MW project) to support advancing our understanding of how OSW may affect species of concern and key commercial fish stocks. These studies will help inform questions around fishing impacts and cumulative effects.

Endnotes

[1] An abnormal rise in seawater level during a storm.

[2] Disadvantaged Communities are identified in the CLCPA as communities that bear burdens of negative public health effects, environmental pollution, impacts of climate change, and possess certain socioeconomic criteria, or comprise high-concentrations of low- and moderate- income households.

[3] The process of investigating, reviewing and verifying all relevant aspects of a project.

[4] A probability distribution which reflects that most of the time wind speeds will be low to moderate and gales and storms will be infrequent.

[5] Turbine wake is the phenomenon in which wind turbines extract energy from the wind, making downstream wind lower in energy and velocity than upstream wind.

[6] Patterns of motion in which all parts of a system move concurrently, with the same frequency, often with an undesirable result.

[7] A cyberattack that disrupts a "targeted system" by causing thousands or millions of individual computers, often personal computers of unwitting users, to simultaneously and repeatedly request superfluous information from the targeted system.

[8] Risks that arise from the process of transitioning to a lower-carbon economy, such as changes in policy,technology, or investor sentiment.

[9] Market-based instruments that represents the property rights to the environmental, social, and other non-power attributes of offshore wind renewable electricity generation. RECs are issued when one megawatt-hour (MWh) of electricity is generated and delivered to the electricity grid from a renewable energy resource.

[10] DNV GL. Tropical Storm Isaias: What did it mean for the NY Bight? August 18, 2020. https://blogs.dnvgl.com/energy/tropical-storm-isaias-what-did-it-mean-for-the-ny-bight

[11] Submerged Land Act of 1953. Texas, Florida, and Louisiana have jurisdiction over submerged lands in the Gulf of Mexico out to nine nautical miles offshore.

[12] https://www.boem.gov/environment/environmental-assessment/nepa/national-environmental-policy-act-nepa

[13] See further: https://www.nyserda.ny.gov/All-Programs/Programs/Offshore-Wind/Focus-Areas/Ocean-Environment

[14] The New York Natural Heritage Program and The Nature Conservancy recently developed an online mapping tool for NYSERDA to use to weigh biodiversity as part of turbine siting decisions. The tool includes data layers relevant to biodiversity and wind power, as well as a methodology to guide synthesis of that data to identify locations that maximize "energy development and biodiversity conservation" (NYSERDA, 2014b).

[15] NOAA National Hurricane Center.

[16] New York City Health Provider Partnership, Bronx Community Needs Assessment Report, September 25, 2014.

[17] "A-weighted decibels," express the relative loudness of sounds in air as perceived by the human ear.

[18] The displacement of materials such as sand or rocks in the direction of the shoreline, typically by tidal forces.

[19] Objectives include project economics (e.g., energy generated, operations and maintenance costs), technical performance criteria (e.g., mechanical availability) climate change mitigation (e.g., avoided tons of carbon) and the consideration of these objectives differs depending on a given stakeholder.

[20] See the Resilient Industry study (NYC Department of City Planning, 2018).

[21] An urban area or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities.

[22] https://www.epa.gov/ports-initiative/about-epa-ports-initiative

NYSERDA, a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise, and support to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce reliance on fossil fuels. NYSERDA professionals work to protect the environment and create clean-energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York State since 1975.

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