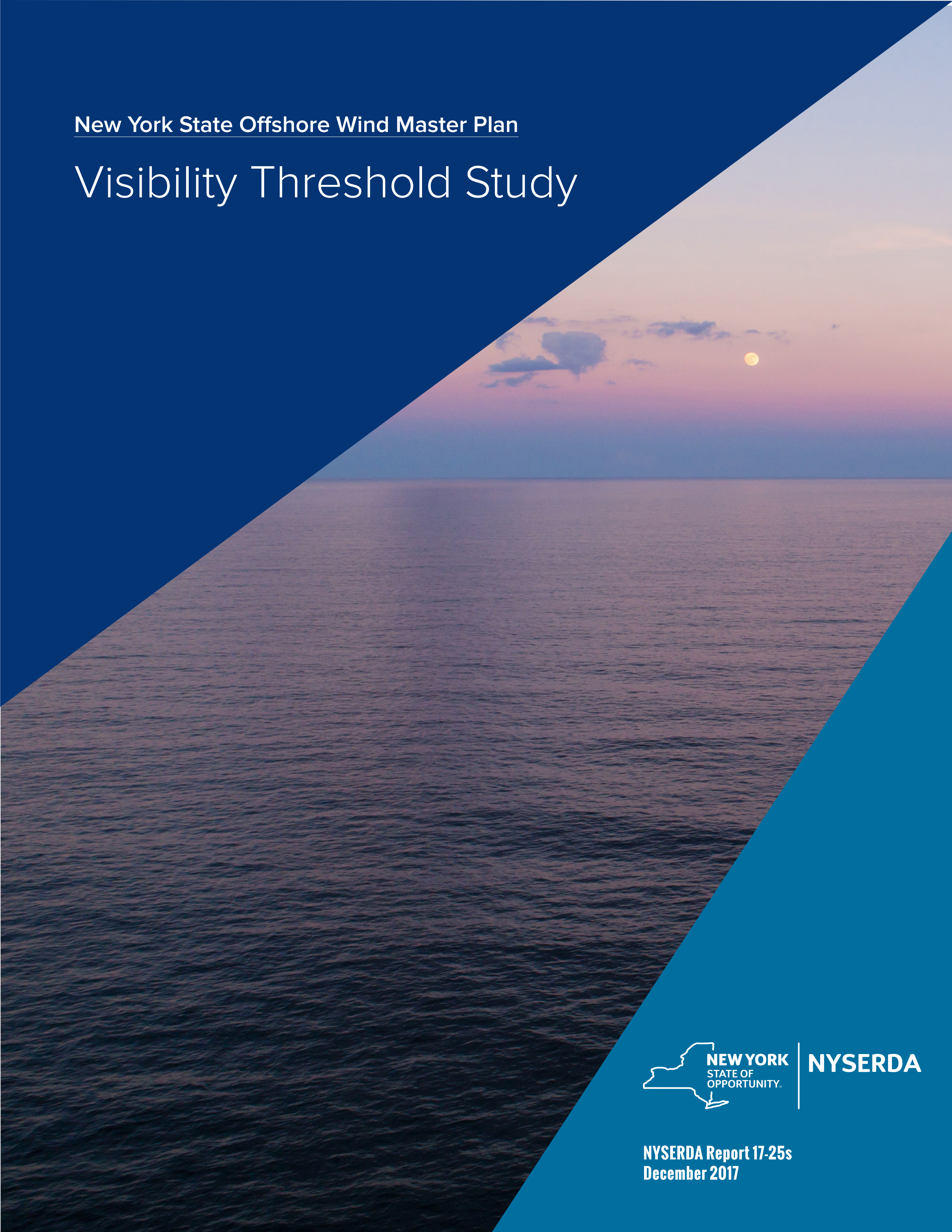
New York State Offshore Wind Master Plan

Visibility Threshold Study



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New York State Offshore Wind Master Plan Visibility Threshold Study

Final Report

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New York State Energy Research and Development Authority

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Notice

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Acronyms and Abbreviations

3D	three dimensional
ADLS	Automatic Detection Lighting Systems
AIS	Automatic Identification System
AoA	Area of Analysis
ASOS	Automated Surface Observing Systems
BKN	broken clouds
BOEM	Bureau of Ocean Energy Management
CLR	clear skies
FAA	Federal Aviation Administration
FEW	few clouds
GPS	global positioning system
JFK	John F. Kennedy International Airport
LI MacArthur	Long Island-MacArthur Airport
Master Plan	New York State Offshore Wind Master Plan
MW	megawatts
NCDC	National Climate Data Center
nm	nautical miles
OCS	Outer Continental Shelf
OVC	overcast
SCT	scattered clouds
Study	Visibility Threshold Study

Executive Summary

The visibility and visual impact of wind energy projects can be an issue of concern to the public. The purpose of this Visibility Threshold Study (Study) is to assess the visibility of a hypothetical typical wind farm at various distances from shore under a variety of meteorological conditions. This information could be used in the planning of future projects off the coast of Long Island, New York, and potentially considered for New York State power procurement mechanisms, which may set distance-from-shore standards.

For this Study, meteorological data were obtained from weather stations at both the John F. Kennedy International Airport and the Long Island-MacArthur Airport for the period of January 1, 2010, through December 31, 2016. These data were examined to determine how frequently various combinations of visibility, cloud cover, and time of day are likely to occur during a typical year. A hypothetical offshore wind project was then evaluated at various distances from the shoreline, under three different sky conditions and at three different times of day, to determine the degree of project visibility under each scenario. Photorealistic visual simulations of a hypothetical wind farm project were developed, and this cumulative information was used to draw conclusions as to visibility of the wind farm during daytime hours at various distances under a variety of conditions. An analysis of the visibility of aircraft warning lights at night determined that, over 99% of the time and at any distance from shore, such lights would not be visible to onshore viewers if Automatic Detection Lighting Systems are employed.

Analysis of weather data indicated that, during daylight hours, clear sky conditions occurred approximately 17% of the time. Partly cloudy conditions had the lowest frequency of occurrence at approximately 6% of daylight hours, while overcast sky conditions were predominant, occurring about 61% of the time. During the remaining 16% of the time, visibility was less than 10 miles, and turbines at any distance being considered for offshore wind energy development in New York would not be visible.

Based on analyses of the meteorological data and evaluation of the visual simulations, it can be concluded that starting at a distance of 20 miles from shore, turbines would become difficult or impossible to see in the majority of conditions. During approximately 77% of the daylight hours in a given year, turbines placed 20 miles from the viewer would be very difficult to discern or invisible due to atmospheric conditions. In the morning, before 10 a.m., with clear skies, when color contrast is highest, offshore turbines are possibly most visible. The data show this condition has the potential to occur only during approximately 8% of the daylight hours of a typical year, and even under such conditions, turbines placed beyond a distance of 20 miles offshore would be substantially screened by the curvature of the Earth and their visibility would be somewhat masked by atmospheric scattering and haze.

At a distance of 25 miles, under even clear or partly cloudy skies, it is likely that a viewer would not notice above-horizon portions of turbines unprompted, but rather would have to know they are there and actively look for them. The exception to this would likely occur under very specific lighting conditions involving a dark cloudy horizon and intense morning or evening sunlight. Additionally, blade movement, although nearly impossible to discern at 25 miles, may draw the viewer's eye under specific particularly clear conditions.

Viewer experience can greatly differ from meteorological visibility prediction. Viewer experience is influenced by visual acuity, viewer activity, and a variety of environmental factors, including direction and intensity of the light source (sun angle and azimuth), and sea spray, as well as the specific attributes of turbines. When all factors are considered, it is likely that visibility models relying on meteorological measurements alone, as employed for this study, may overstate the theoretical visibility of offshore wind turbines.

A comprehensive visual impact assessment study should be performed for any wind farm proposed for construction offshore of New York State. The study should consider the project's specific location, turbines, and other details to better define potential visual impacts on onshore resources. However, it is expected that offshore wind energy projects of typical magnitude would have minimal visual impact at a distance of 20 miles from shore and negligible impact beyond 25 miles. Photographic and personal observations of the constructed Block Island Wind Farm, which is 23 miles from Montauk, New York, support this finding.

1 Introduction

This Visibility Threshold Study (Study) is one of a collection of studies prepared on behalf of New York State in support of the New York State Offshore Wind Master Plan (Master Plan). These studies provide information on a variety of potential environmental, social, economic, regulatory, and infrastructure-related issues associated with the planning for future offshore wind energy development off the coast of the State. When the State embarked on these studies, it began by looking at a study area identified by the New York State Department of State in its two-year Offshore Atlantic Ocean Study (DOS 2013). This study area, referred to as the "offshore study area," is a 16,740-square-mile (43,356-square-kilometer) area of the Atlantic Ocean extending from New York City and the south shore of Long Island to beyond the continental shelf break and slope into oceanic waters to an approximate maximum depth of 2,500 meters (m) (Figure 1). The offshore study area was a starting point for examining where turbines may best be located, and the area potentially impacted. Each of the State's individual studies ultimately focused on a geographic Area of Analysis (AoA) that was unique to that respective study. The AoA for this study is described below in Section 1.2.

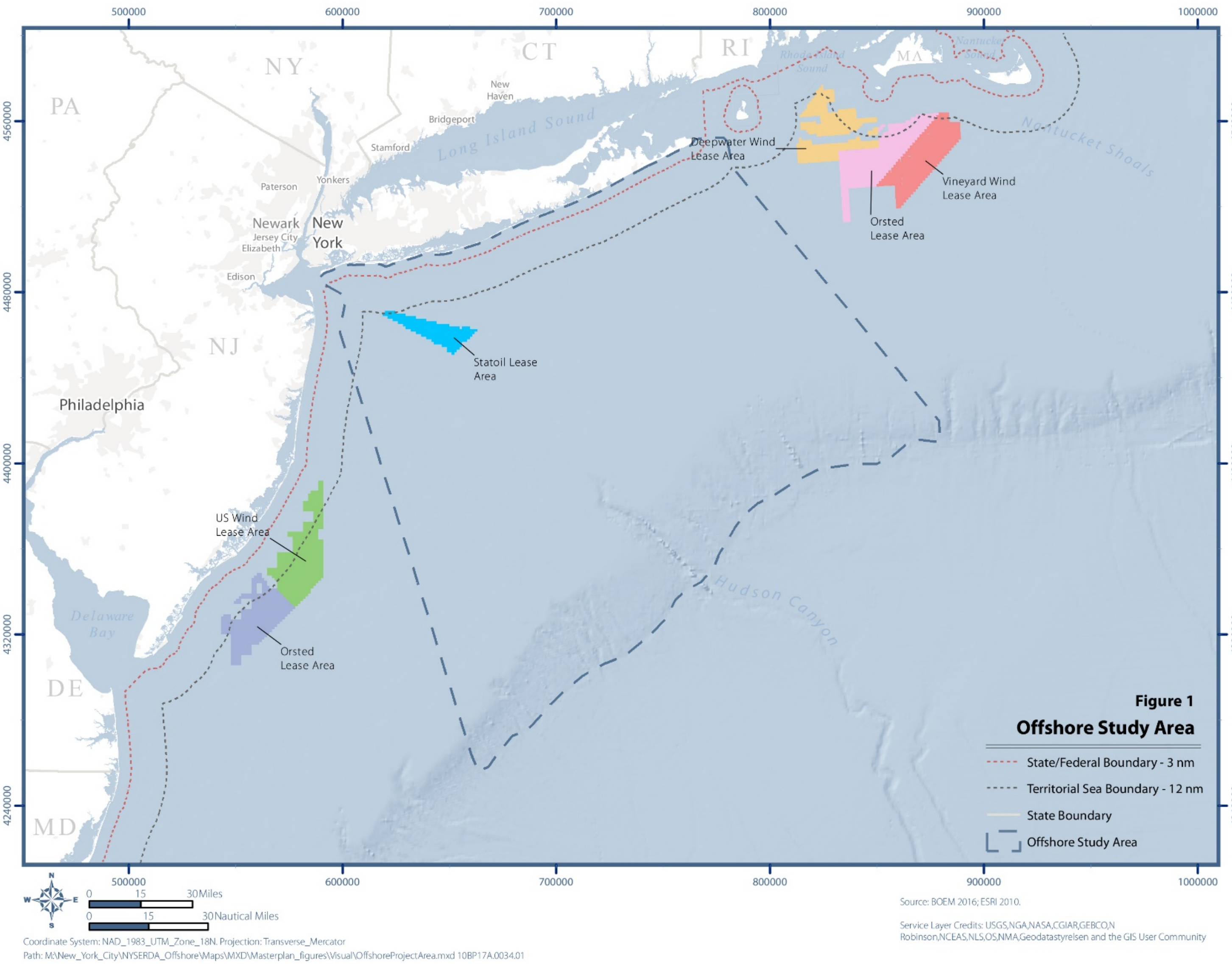
The State envisions that its collection of studies will form a knowledge base for the area off the coast of New York that will serve a number of purposes, including (1) informing the preliminary identification of an area for the potential locating of offshore wind energy areas that was submitted to the Bureau of Ocean Energy Management (BOEM) on October 2, 2017, for consideration and further analysis; (2) providing current information about potential environmental and social sensitivities, economic and practical considerations, and regulatory requirements associated with any future offshore wind energy development; (3) identifying measures that could be considered or implemented with offshore wind projects to avoid or mitigate potential risks involving other uses and/or resources; and (4) informing the preparation of a Master Plan to articulate New York State's vision of future offshore wind development. The Master Plan identifies the potential future wind energy areas that have been submitted for BOEM's consideration, discusses the State's goal of encouraging the development of 2,400 megawatts (MW) of wind energy off the New York coast by 2030, and sets forth suggested guidelines and best management practices that the State will encourage to be incorporated into future offshore wind energy development.

Each of the studies was prepared in support of the larger effort and was shared for comment with federal and State agencies, indigenous nations, and relevant stakeholders, including nongovernmental organizations and commercial entities, as appropriate. The State addressed comments and incorporated feedback received into the studies. Feedback from these entities helped to strengthen the quality of the studies, and also helped to ensure that these work products will be of assistance to developers of proposed offshore wind projects in the future. A summary of the comments and issues identified by these external parties is included in the Outreach Engagement Summary, which is appended to the Master Plan.

The Energy Policy Act of 2005 amended Section 8 of the Outer Continental Shelf Lands Act to give BOEM the authority to identify offshore wind development sites within the Outer Continental Shelf (OCS) and to issue leases on the OCS for activities that are not otherwise authorized by the Outer Continental Shelf Lands Act, including wind farms. The State recognizes that all development in the OCS is subject to review processes and decision-making by BOEM and other federal and State agencies. Neither this collection of studies nor the State’s Master Plan commit the State or any other agency or entity to any specific course of action with respect to offshore wind energy development. Rather, the State’s intent is to facilitate the principled planning of future offshore development off the New York coast, provide a resource for the various stakeholders, and encourage the achievement of the State’s offshore wind energy goals.

Figure 1. Offshore Study Area

Source: BOEM 2016; ESRI 2010



1.1 Statement of Purpose

The visibility and visual impact of wind energy projects has been an issue of concern to the public. Concern about the perceived impacts to scenic landscapes has resulted in the delay or denial of approvals for several projects, both on land and offshore.

The purpose of this Study is to assess the visibility of a hypothetical typical wind farm at various distances from shore under a variety of meteorological conditions. This information could be used in the planning of projects proposed off the coast of Long Island and potentially considered for New York State power procurement mechanisms, which may set standards for distance-from-shore. This Study used weather data and computer-assisted visual simulations based on a variety of hypothetical project parameters to evaluate the potential visual impact of offshore wind energy development in New York under a variety of distance and sky conditions. For several reasons, this analysis was not designed to provide visual representations of what a specific project might look like from a particular on-shore location. The analysis relied on reasonable assumptions concerning the size and design of turbines and standard turbine separation distances. It did not consider benthic habitat, underwater archeological resources, water depth, or other factors that may influence the actual location of a wind farm and distribution and placement of offshore turbines. Visual simulations of a hypothetical wind farm at various distances from shore were therefore used to reach general conclusions about visibility but are not provided herein as project mock-ups. It is anticipated that site-specific visual analyses would be prepared for specific projects as they are proposed, and these analyses would provide more definitive information about the projects' visual effects.

1.2 Scope of Study

The visibility of wind energy projects to a particular viewer is influenced by a variety of factors, including

- Number of turbines
- Size of turbines
- Arrangement of turbines
- Distance from the viewer (such as curvature of the earth and atmospheric diminishment)
- Weather/sky conditions
- Viewer sensitivity
- Landscape/seascape character and sensitivity
- Time of day/sun angle

Some of these variables can be easily quantified (e.g., distance), while others cannot (e.g., viewer sensitivity). It is therefore difficult, if not impossible, to define a specific set of conditions under which visual impacts would always be considered acceptable to every viewer, short of siting the turbines far enough from the shoreline that they would be fully obscured by the curvature of the earth. This distance is variable, depending on the size of the turbines and the elevation of the viewer, but utilizing current technology, turbines would have to be placed a minimum of 35 miles offshore to physically screen them from viewers at water level, and further for viewers at an elevated position. This distance threshold may not be a realistic/practical siting criterion or warranted to avoid all but infrequent minimal visual impacts. Therefore, this Study employs reasonable parameters of analysis regarding the physical characteristics of a hypothetical wind project and the environmental variables that affect visual impacts. For the purpose of this Study, the following parameters of analysis were applied:

- The most significant environmental variables that affect potential daytime visual impact at the distances under consideration are visibility (less than 10 miles, or greater than 10 miles), background sky conditions (clear, partly cloudy, or overcast), and time of day/sun angle (morning, midday, or afternoon).
- Based on previous studies and field observations of constructed projects, the range of distances at which a project's visibility and visual impact could become negligible is somewhere between 13 and 30 miles offshore.
- An 800 MW wind energy project consisting of one hundred 8 MW turbines arranged in a grid pattern is the largest single project likely to be located off the coast of New York.

This AoA for this Study was the Atlantic shoreline of Long Island, New York and off-shore views roughly perpendicular to that shoreline. Weather data from Long Island was examined to determine how frequently each combination of visibility, background sky conditions, and time of day is likely to occur during a typical year. A hypothetical project was then evaluated at various distances from the shoreline, under three different sky conditions and at three different times of day, to determine the degree of project visibility under each scenario. This cumulative information was used to draw conclusions as to how often and under what conditions turbine visibility and visual impact are likely to be considered minimal and/or negligible. Photorealistic visual simulations were developed as supporting documentation to aid in this assessment. A sample simulation is appended to this report to illustrate the methodology. Details regarding the methodology and results of this Study are presented below.

2 Methods

2.1 Weather Conditions Summary - Data Collection and Processing

Airport meteorological data were assessed to analyze the frequency of occurrence of various weather/sky conditions on a daily, seasonal, and annual basis. Airports use Automated Surface Observing Systems (ASOS), made up of various automated sensor units, to meet meteorological and aviation observation needs. Because these systems are critical to aviation safety, there are more than 900 ASOS sites in the U.S. (NOAA 2017a). ASOS is used as the primary climatological observation network in the U.S. Meteorological data were obtained from the National Climatic Data Center (NCDC) for the ASOS stations at both the John F. Kennedy International Airport (JFK) and the Long Island-MacArthur Airport (LI MacArthur) for the period of January 1, 2010, through December 31, 2016 (NCDC 2017). The NCDC provides climate data as part of a global surface hourly database, known as DS3505. DS3505 datasets are publicly available in tabular format and provide a synopsis of climate variables for each weather station. Climate variables include hourly, daily, and monthly measurements of precipitation, temperature, dew point, humidity, winds, sky conditions, visibility, weather type, and more. Hourly recording times are in local standard (24-hour) time and do not account for daylight savings (NOAA 1998).

As shown in Table 1, the raw 2010 to 2016 DS3505 data included 101,038 records from JFK and 81,471 records from LI MacArthur. Those data included various report types, including hourly reports, special reports, daily and monthly summaries, and various other weather reports. To maintain consistency, duplicate records, special reports, and daily and monthly summary records were removed from the data, leaving only the standard automated hourly recordings.

Furthermore, only daylight records were required for the visibility assessment. According to the Federal Aviation Administration (FAA) Code of Federal Regulations (2017), "Night means the time between the end of evening civil twilight and the beginning of morning civil twilight, as published in the Air Almanac, converted to local time." Daily local civil twilight tabular data are available on a yearly basis through the Air Almanac (Department of Defense 2017). Yearly Air Almanac data from 2010 to 2016 were obtained for each airport location. Seasonal morning and evening civil twilight was determined by averaging daily recordings within the date range assigned to each season.

Once civil twilight hours were determined by season, nighttime hours (i.e., before and after the civil twilight hours) were removed from the DS3505 datasets. After non-automated and nighttime reports were removed, the total records validated at JFK were 38,452 and the total records validated at LI MacArthur were 38,471.

The resulting daylight hour records were then sorted by visibility distance and were not further subdivided in the datasets. Records reflecting visibility of less than 10 miles were removed. The final data analysis included 31,602 records from JFK and 31,644 records from LI MacArthur (Table 1).

Table 1. Meteorological Station Record Validation and Processing

Station	Total Initial Records	Records Retained for Daylight hours	Records Retained for 10 Miles or Greater Visibility
JFK	101,038	38,452	31,602
LI MacArthur	81,706	38,471	31,644

The purpose of the weather conditions analysis was to determine the following:

- How often during the course of a typical year does daytime visibility exceed 10 miles?
- On days with visibility over 10 miles, what is the frequency of occurrence of different weather/sky conditions (i.e., clear, partly cloudy, or overcast)?
- How do the weather/sky conditions observed during the days identified in item 2, above, break down by time of day (i.e., morning, midday, and afternoon)?

By answering these questions, a frequency of occurrence could be assigned to each of the nine time-of-day/weather condition scenarios described in Section 3.3 and illustrated in the simulations.

To conduct this analysis, the three different times of day under consideration in this Study were defined by their starting and ending time, as follows:

- Morning = civil twilight[1] to 1000
- Midday = 1000 to 1400
- Afternoon = 1400 to civil twilight

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1 The U.S. Naval Observatory, Astronomical Applications Department, defines "civil twilight" as follows: *Civil twilight is defined to begin in the morning, and to end in the evening when the center of the sun is geometrically 6 degrees below the horizon. This is the limit at which twilight illumination is sufficient, under good weather conditions, for terrestrial objects to be clearly distinguished; at the beginning of morning civil twilight, or end of evening civil twilight, the horizon is clearly defined and the brightest stars are visible under good atmospheric conditions in the absence of moonlight or other illumination. In the morning before the beginning of civil twilight and in the evening after the end of civil twilight, artificial illumination is normally required to carry on ordinary outdoor activities* (U.S. Naval Observatory 2011).

Because daylight hours vary by time of year, it was determined that daylight hours and time of day would need to be organized by season. Seasons are often described as meteorological or astronomical (NOAA 2017b). Meteorological and astronomical seasons do not begin and end at the same time. Meteorological seasons are based on temperature cycles, whereas astronomical seasons are based on the position of the earth in relation to the sun. Astronomical seasons are marked by solstices and equinoxes, which are based on the sun's alignment over the equator. Because the data analysis is based on daylight conditions, it was determined that seasons would follow the astronomical definition. Therefore, the seasons were defined as follows:

- Summer = June 22 to September 22
- Spring = March 20 to June 21
- Fall = September 23 to December 21
- Winter = December 22 to March 19

Sky conditions, generally described as clear, partly cloudy, and overcast, do not express the full range of sky conditions described by the hourly meteorological data available from the NCDC (2015). These data record cloud coverage on a scale of 00 to 08. The FAA defines cloud coverage as clear (CLR, 00), few clouds (FEW, 01 to 02), scattered clouds (SCT, 03 to 04), broken clouds (BKN, 05 to 07), and overcast (OVC, 08). In addition, hourly sky conditions are coded in the following format: CCC:11-XXX where:

- CCC is the three-letter cloud coverage acronym
- 11 is cloud coverage on the scale of 00 to 08
- XXX is the cloud base height above the ground at the lowest point of each layer, given in hundreds of feet (e.g., 20 = 2,000 feet)

Hourly records report these data for up to three cloud layers. Therefore, one hourly report may provide cloud cover at various heights. The following is an example hourly reading:

FEW:02 27 BKN: 07 55 OVC:08 100

This report would indicate few clouds (02 coverage) at a height of 2,700 feet, broken clouds (07 coverage) at a height of 5,500 feet, and overcast skies (08 coverage) at 10,000 feet. Because hourly records frequently had multiple codes, and to simplify the codes into the three categories mentioned above, the data were converted to one of the three categories. In cases with multiple codes, the code with the greatest cloud cover was selected as the prevailing condition in each record. In the example of hourly sky conditions shown above, the record would be simplified to overcast conditions. For example, if OVC appeared in an hourly report, “overcast” was chosen as the overruling condition regardless of elevation. The rationale for this assumption is that, unlike an observer in a plane, a viewer on the ground would perceive the greatest cloud cover as the prevailing condition.

For the purpose of this analysis, sky conditions were organized into three groups, as indicated below.

- Clear = CLR and FEW
- Partly Cloudy = SCT
- Overcast = BKN and OVC

Because this data source is designed for pilots travelling through the air, it is important to translate it to apply to the perspective of a ground-level viewer. The clear condition would seemingly only occur when there are no clouds in the sky. However, the term FEW means that a maximum of one quarter of the sky is occupied by clouds, suggesting otherwise clear blue skies. Therefore, the FEW category of cloud cover was combined with the clear condition.

Similarly, BKN indicates a mostly cloudy sky with potential breaks showing blue sky, but cloudy is the dominant condition; thus, BKN is combined with the overcast condition.

2.2 Field Photography

The State collected the data necessary to prepare visual simulations of the various scenarios used in this Study. On July 20, 2017, two technicians obtained photographs from a beach on the south shore of Long Island, for subsequent use in the development of the visual simulations. The crew arrived on site and initiated fieldwork at approximately 0700 hours. They took photographs with a Canon EOS 5D Mark IV full frame digital SLR camera leveled on an anchored tripod, using a fixed aperture and variable shutter speed to maintain even focus throughout the view and proper exposure of the photographs. The camera captured images at approximately 30-second intervals, from the early morning (0712 hours) through early evening (2049 hours). The camera was affixed to an anchored tripod throughout the day to ensure that field of view, camera height, and viewing angle remained consistent for all photographs.

The crew used a global positioning system (GPS) unit with reported sub-meter accuracy to document the precise location of the camera, as well as a locational reference (the GPS itself, captured in the photographs) centered on the precise bearing of the centroid of the hypothetical offshore wind farm. In addition, the location of ships visible in the photographs at different times throughout the day was determined by consulting the Automatic Identification System (AIS) provided by Marine Traffic, Global Ship Tracking Intelligence, AIS Marine Traffic. These locational reference points were used to ensure accurate camera alignment during the simulation process.

2.3 Visual Simulations

To illustrate the appearance of the hypothetical wind project at different distances from the shoreline, high-resolution three-dimensional (3D) image processing was used to create realistic photographic simulations of the hypothetical project from a single vantage point.

The photographic simulations were developed by constructing a 3D computer model of the proposed 8 MW turbine and a 100-turbine layout. The turbine was assumed to be a Siemens SWT 8.0-154 or similar model, with a hub height of 110 m (361 feet), a rotor diameter of 154 m (505 feet), and a total maximum height of 187 m (614 feet) above the water's surface. The dimensions and appearance of the modeled turbines are shown in Figure 2. The hypothetical project was assumed to be located on a bearing of approximately 160 degrees (south southeast), roughly perpendicular to much of the Long Island shoreline. The most likely turbine layout was assumed to be a grid pattern with a turbine spacing of eight rotor diameters (1,232 m).[2] This layout, at different distances from the Long Island shoreline, is illustrated in Figure 3.

The visual simulations were used to reach general conclusions about visibility and do not represent what a particular project would look like from a particular on-shore location. It is anticipated that such site-specific visual analyses would be prepared for specific projects as they are proposed, and these analyses would provide more definitive information about the projects' visual effects.

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2 At the request of the New York State Energy Research and Development Authority, an alternative using 15 MW turbines was also simulated to account for the possibility of larger turbines in the future..

Figure 2. 3D Model of Wind Turbine

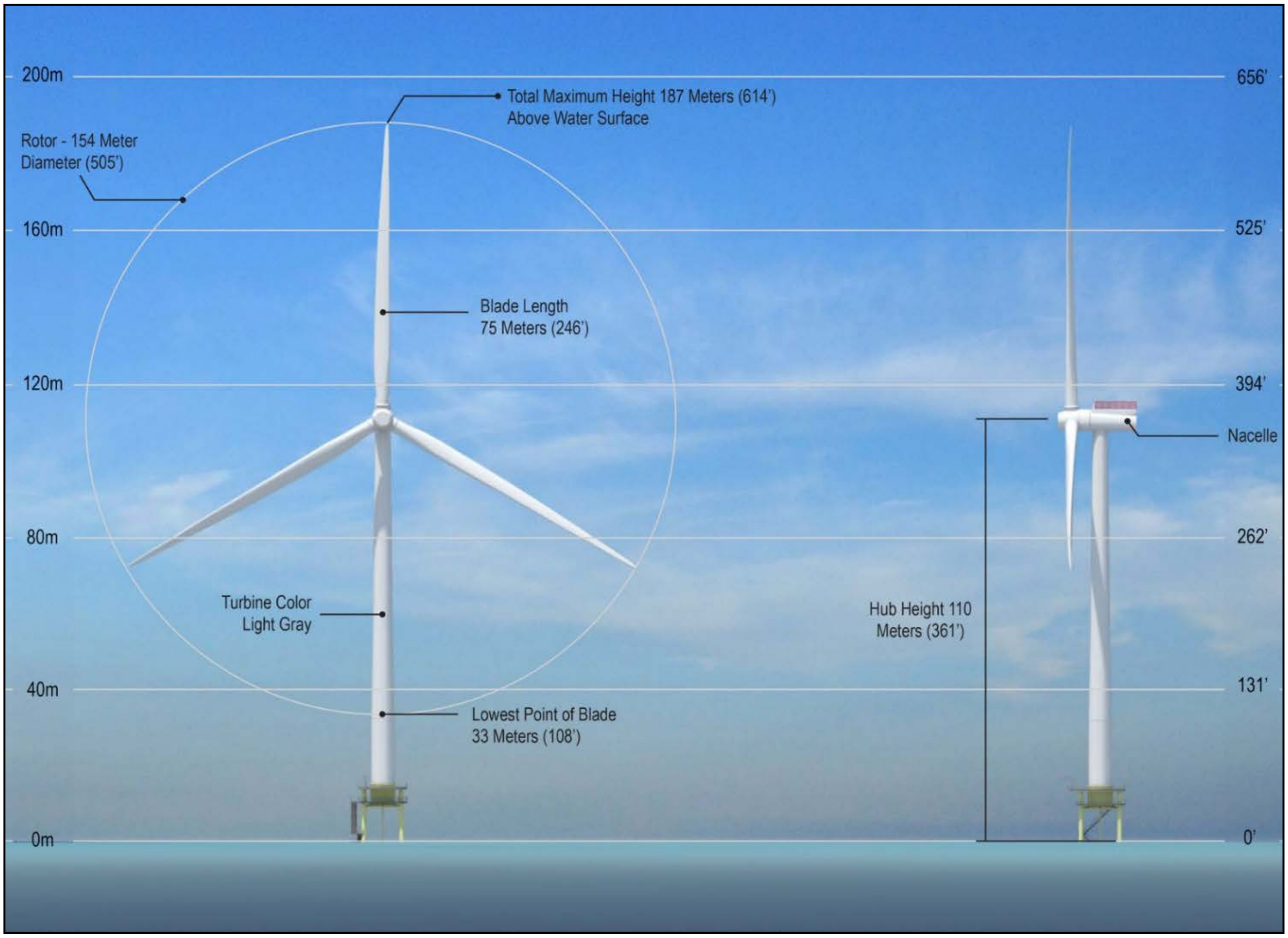
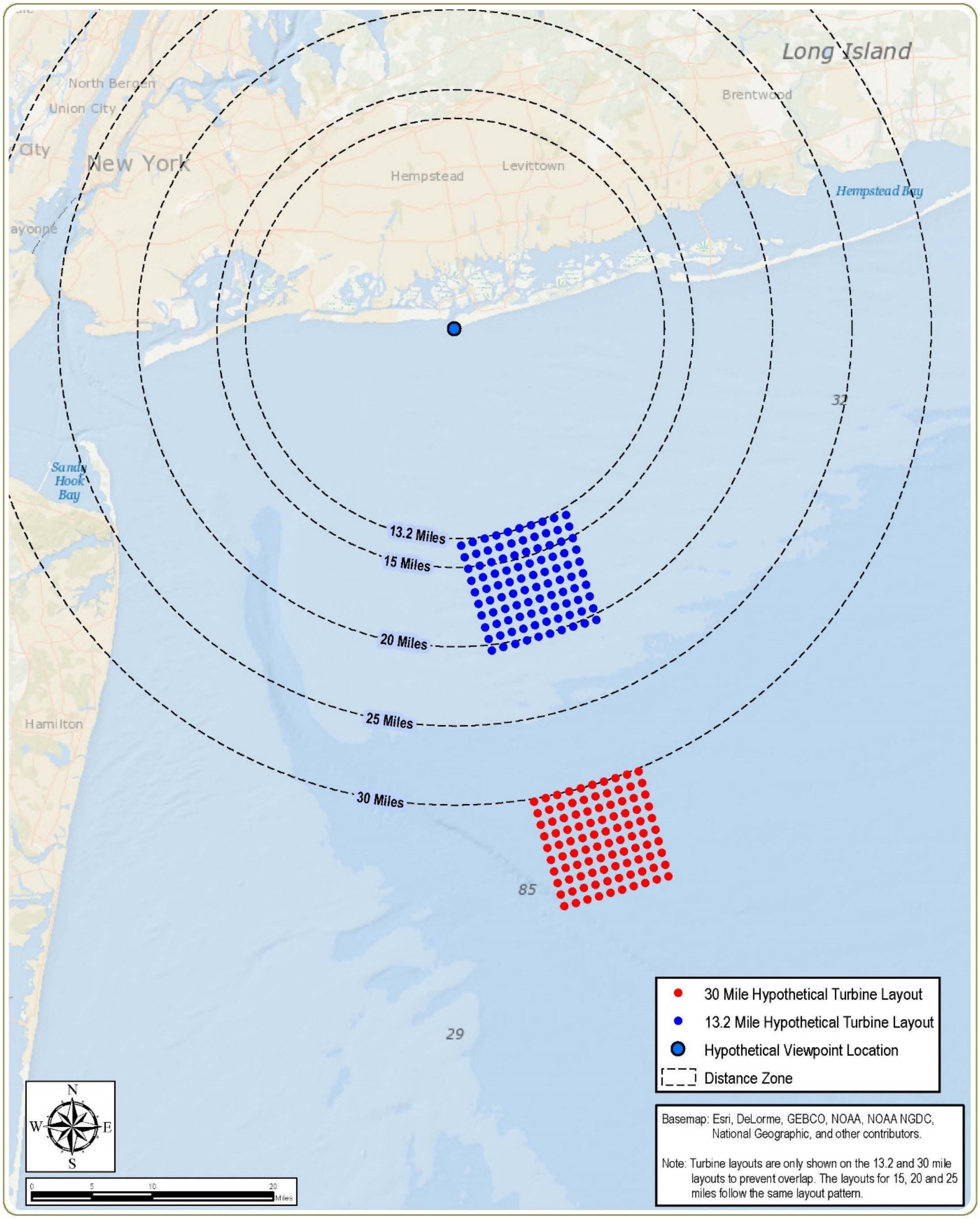


Figure 3. Hypothetical Wind Farm Layouts



Simulations were created by aligning the photographic viewpoint with the computer model of the proposed turbines at five different distances (13.2,[3] 15, 20, 25, and 30 miles) and superimposing the models on the photographs. To determine the effects of the curvature of the earth and refraction, the turbine layouts representing the five distances from the viewer were plotted in a geographic information system (GIS) workspace. Then, utilizing the latitude and longitude of each turbine, the Haversine Formula[4] adjusted for atmospheric refraction was used to determine how much of each turbine would appear behind the horizon based on its position relative to the viewer (Figure 4). The locational information was entered into a database that performed calculations and automatically provided a turbine position with a corrected Z value. For example, if the bottom 100 feet of a turbine would be screened, the turbine is automatically placed at 100 feet below mean sea level.

The next step involved utilizing aerial photographs and GPS data collected in the field to create an AutoCAD Civil 3D drawing. The two-dimensional AutoCAD data were imported into Autodesk 3ds MAX and 3D components (cameras, modeled turbines, etc.) added. These data were then superimposed over photographs representing three different times of day (morning, midday, and afternoon) and aligned with all known reference points within the view. This process ensures that project elements are shown in proportion, perspective, and proper relation to the existing landscape elements in the view. Consequently, the alignment, elevations, dimensions, and locations of the proposed turbines are accurate and true in their relationship to other landscape features in the photo.

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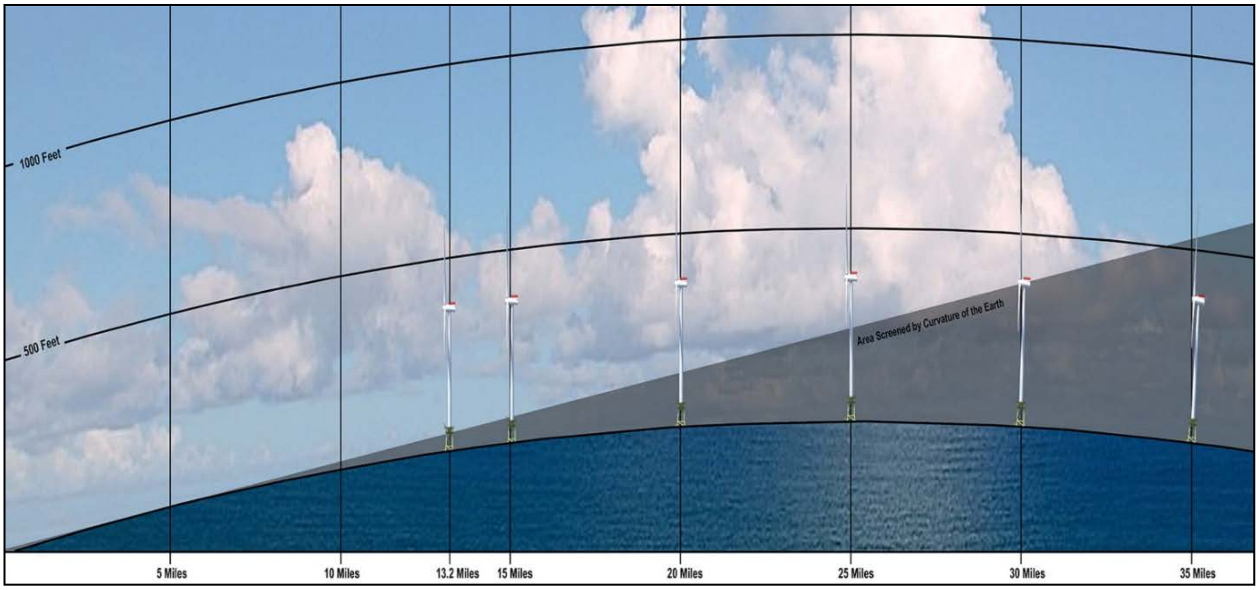
[3] 13.2 miles represents the minimum distance from the existing New York Lease Area (BOEM Lease OCS-A 0512) to the New York shoreline.

[4] The Haversine Formula is used to calculate the geodesic distance between two points using latitude and longitude coordinates. This formula is also used to determine the distance to the visible horizon. The results allow calculation of the angular distance from the visible horizon to the turbine position, thus allowing the determination of an elevation behind the horizon.

Figure 4. Effect of Curvature of the Earth on Turbine Visibility



With the alignment complete, a “wire frame” model of the hypothetical facility and known reference points were displayed over each of the photographs. A typical exterior color/finish of the turbines was then added to the model and the appropriate sun angle simulated based on the specific date, time and location (latitude and longitude) to replicate the desired condition. This information allows the computer to accurately illustrate highlights, shading, and shadows for each individual turbine shown in the view. All simulations show the turbines with rotors oriented toward the viewer, which provides for maximum turbine visibility.

To simulate various sky conditions (clear, partly cloudy, and overcast), the original photographs were digitally altered/enhanced as necessary, utilizing PhotoShop. The techniques used to represent the various weather conditions included the replacement of the sky with the desired conditions, and adjustments to the hue/saturation of the water, sand, and foreground shadows to evoke the lighting conditions associated with each of the specific weather and time of day scenarios.

For each distance represented, a total of nine visual simulations were produced to represent common sky/weather conditions and typical times of day for viewing. Consequently, a total of 45 individual simulations were prepared (see Table 2). The sample simulation provided in Appendix A demonstrates the most frequent sky condition, with a viewing point at a distance of 20 miles from the turbines.

Table 2. Simulated Conditions

Time of Day	Distance from Viewer (Miles)				
	13.2	**15**	**20**	**25**	**30**
Morning	Clear	Clear	Clear	Clear	Clear
	Partly Cloudy	Partly Cloudy	Partly Cloudy	Partly Cloudy	Partly Cloudy
	Overcast	Overcast	Overcast	Overcast	Overcast
Mid-day	Clear	Clear	Clear	Clear	Clear
	Partly Cloudy	Partly Cloudy	Partly Cloudy	Partly Cloudy	Partly Cloudy
	Overcast	Overcast	Overcast	Overcast	Overcast
Afternoon	Clear	Clear	Clear	Clear	Clear
	Partly Cloudy	Partly Cloudy	Partly Cloudy	Partly Cloudy	Partly Cloudy
	Overcast	Overcast	Overcast	Overcast	Overcast

Although a nighttime visibility assessment is not included in this Study, a separate aviation and radar study calculated the potential frequency of aircraft warning light activation when utilizing Automatic Detection Lighting Systems (ADLS). This system activates the FAA lights based on the presence of aircraft, detected using on-site radar. The results of this study are briefly analyzed in the context of potential onshore visibility, described in Section 4.3.

3 Results

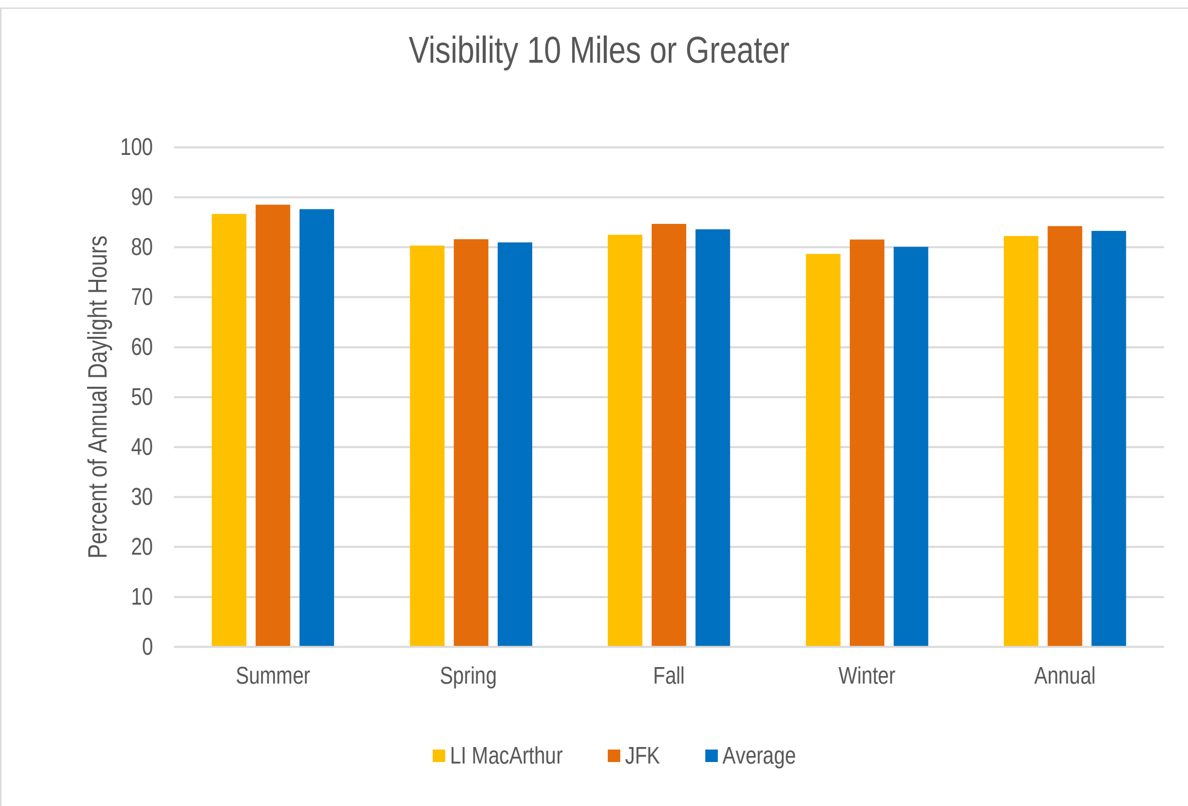
3.1 Weather Data

Analysis of NCDC weather data for the six-year period from January 1, 2010, to December 31, 2016, indicated that visibility was 10 miles or greater during daylight hours, approximately 84% of the year (see Table 3 and Figure 5). Visibility was highest in the summer, with 88% of daylight hours having visibility over 10 miles. Visibility was the lowest in winter, with around 81% of daylight hours having visibility greater than 10 miles. During a typical year, approximate 16% of daylight hours have visibility less than 10 miles.

Table 3. Visibility Ranges

Visibility	Summer	Spring	Fall	Winter	Annual
Less than 10 miles (percent)	12.3	18.6	16.2	19.1	16.3
10 miles or greater (percent)	87.7	81.4	83.8	80.9	83.7

Figure 5. Seasonal and Annual Visibility 10 miles or Greater from Both JFK and LI MacArthur Airports

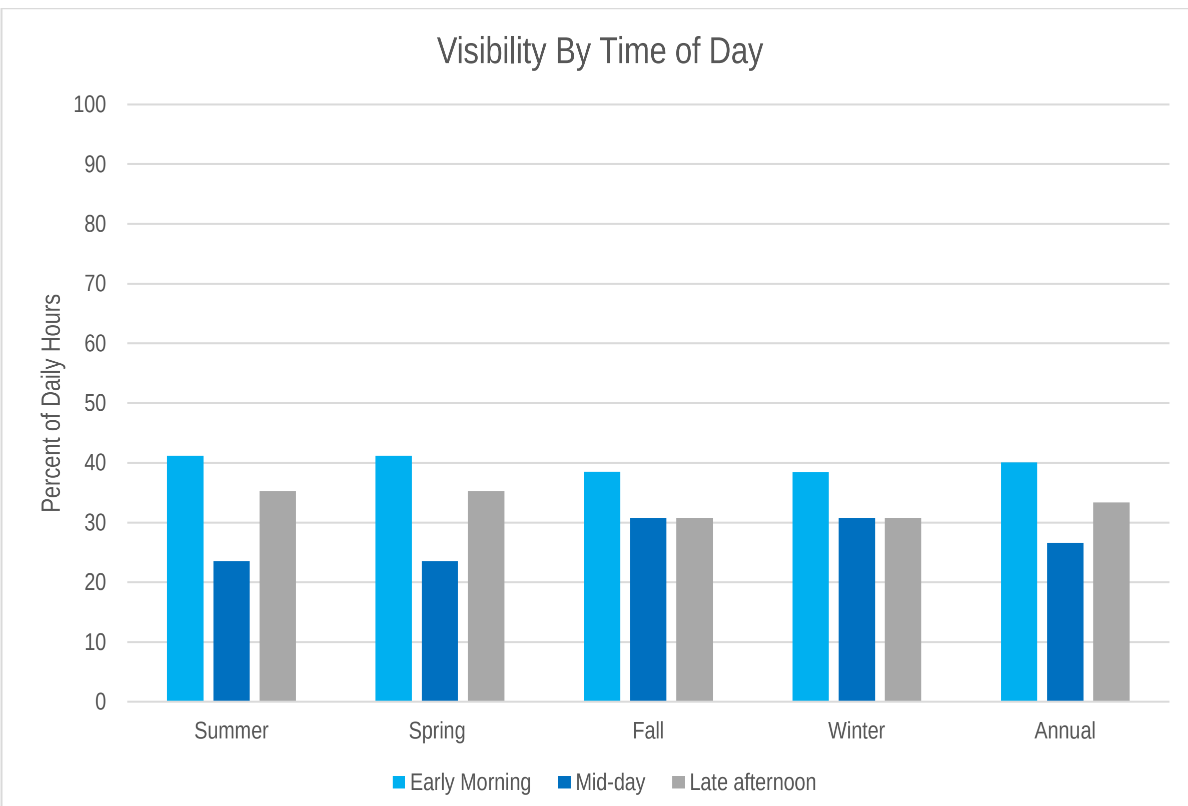


To gain a better understanding of predominant conditions by season and time of day, only records with visibility greater than 10 miles were analyzed initially, since only under this condition would turbines be visible at the distances under consideration. Generally, 40% of the daylight hours when visibility was greater than 10 miles occurred during the morning. Approximately 33% of those hours occurred during the afternoon, and 27% of those hours occurred at midday (see Table 4 and Figure 6).

Table 4. Visibility 10 Miles or Greater by Time of Day

Time of Day	Percentage of Daylight Hours				
	Summer	**Spring**	**Fall**	**Winter**	**Annual**
Morning	41.2	41.2	38.5	38.4	40.0
Midday	23.5	23.5	30.8	30.8	26.6
Afternoon	35.3	35.3	30.8	30.8	33.4
Total Daylight Hours with Visibility >10 Miles	100	100	100	100	100

Figure 6. Visibility Greater than 10 Miles by Time of Day



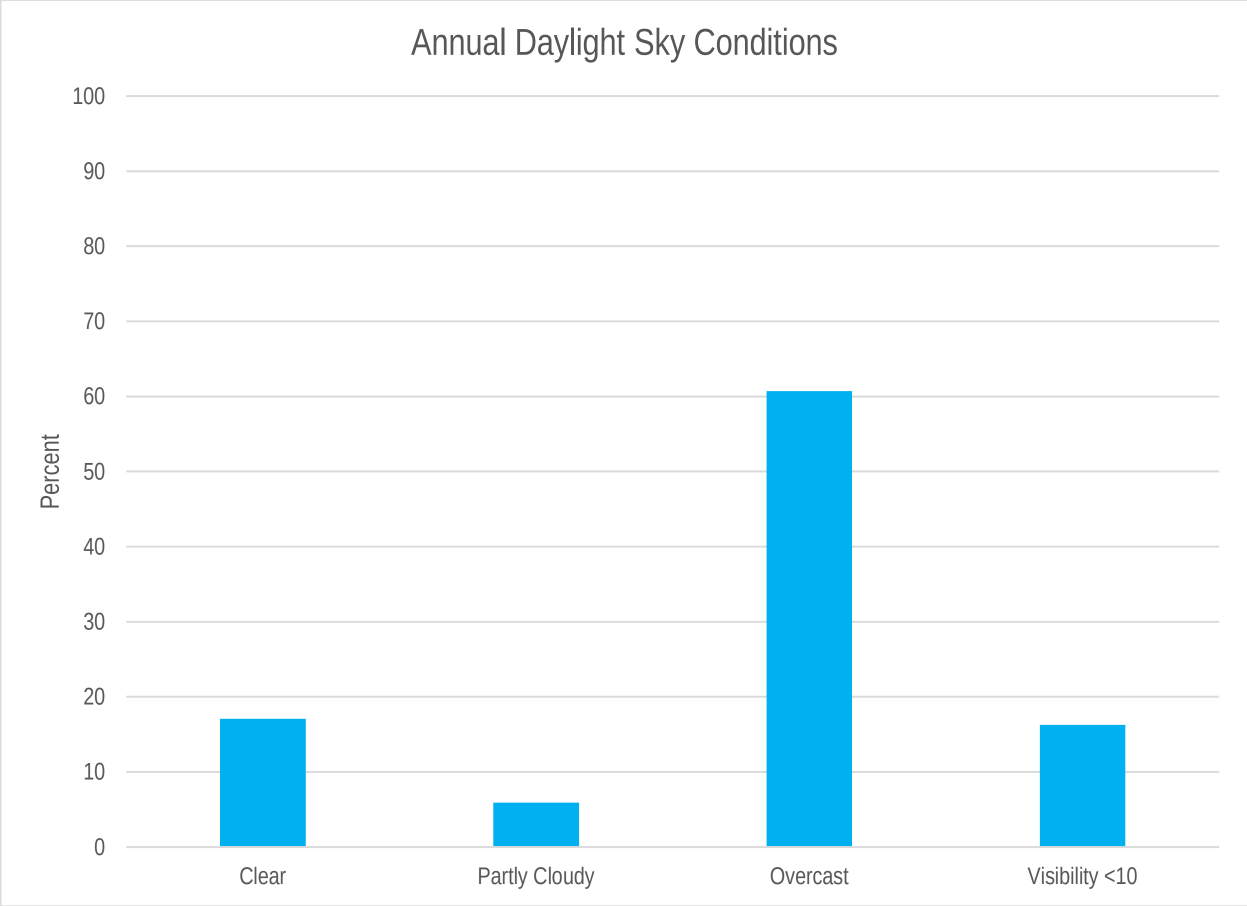
To analyze turbine visibility during all available daylight hours, visibility less than 10 miles was reintroduced to the dataset as a “condition.” Any number of actual weather conditions could compose this portion of the dataset, but the important fact is that, at the distances under consideration (13.2 to 30 miles), the turbines would not be seen since they would be located beyond the theoretical limit of visibility (10 miles).

During daylight hours, clear sky conditions (i.e., 00–02 cloud cover) occurred approximately 17% of the time. Partly cloudy conditions (i.e., 03–04 cloud cover) had the lowest frequency of occurrence at approximately 6% of the daylight hours, while overcast sky conditions (i.e., 05–08 cloud cover) were predominant, occurring about 61% of the time. Conditions under which visibility was less than 10 miles occurred during the remaining 16 percent of all daylight hours (see Table 5 and Figure 7).

Table 5. Frequent of Occurrence of Various Sky Conditions

Cloud Cover	Percentage of Daylight Hours				
	Summer	Spring	Fall	Winter	Annual
Clear	17.4	15.6	18.1	17.4	17.1
Partly Cloudy	6.8	6.1	5.5	4.9	5.9
Overcast	63.5	59.7	60.2	58.6	60.7
Visibility < 10 miles	12.3	18.6	16.2	19.1	16.3
Total	100	100	100	100	100

Figure 7. Frequency of Occurrence of Various Sky Conditions



To put the results of the visual simulation evaluation in context, the anticipated frequency of the combination of conditions represented by each simulation was determined. The likelihood of occurrence of the 12 different time of day/weather condition scenarios evaluated in this study is summarized in Table 6 and Figure 8[5].

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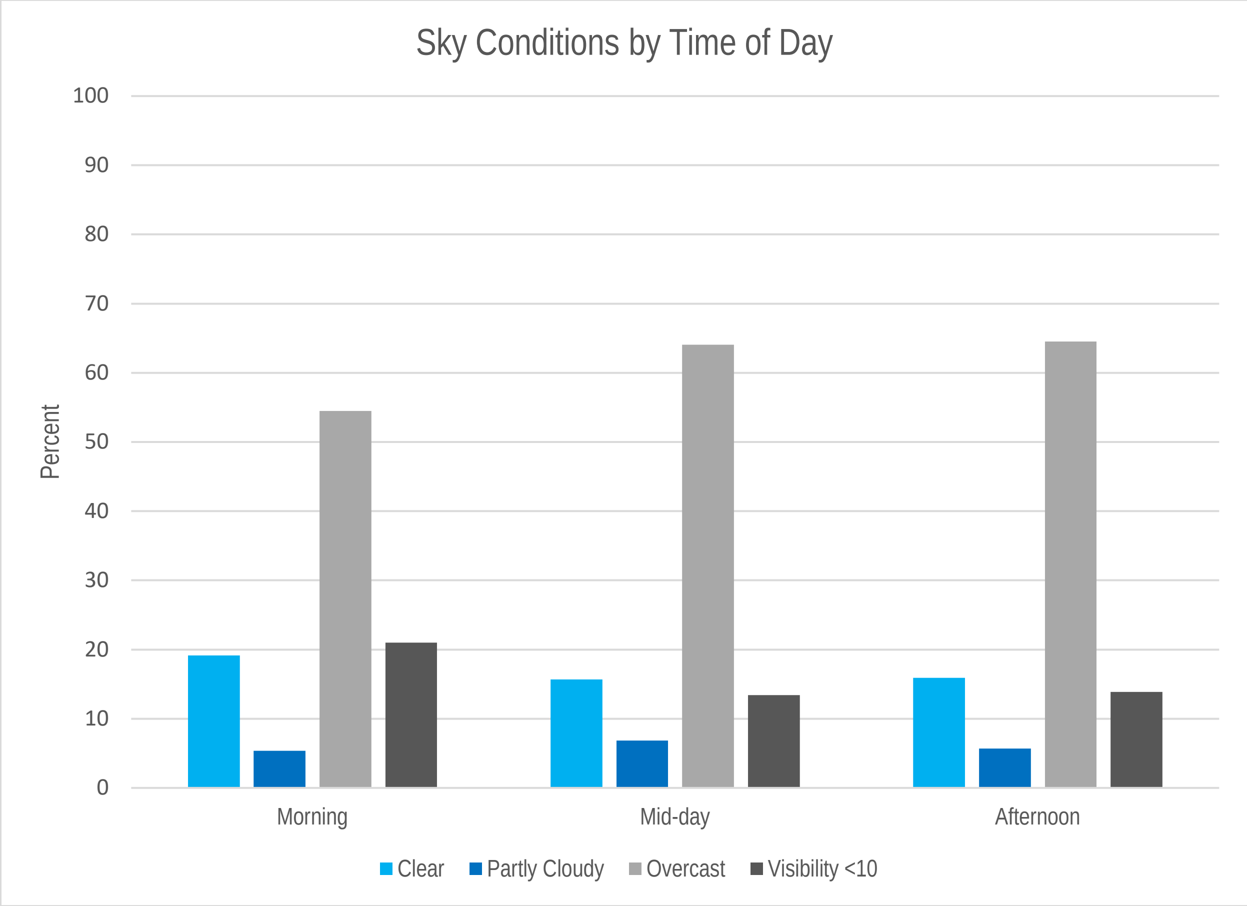
5 Simulations do not include the visibility less than 10 miles condition since they would occur beyond the theoretical limit of visibility.

Figure 8. Breakdown of Sky Conditions by Time of Day



During the morning, midday, and afternoon hours, the most dominant sky condition is overcast (ranging from 54% to 65% of the time). The next most prevalent condition is clear skies. This occurs during 19% of the morning hours, 16% of the midday hours, and 16% of the afternoon hours. Assuming that clear skies generally equate to maximum visibility, this suggests that the greatest visibility likely occurs between 16% and 19% of a given year's total daylight hours. The least frequent condition consists of partly cloudy skies and occurs between 5% and 7% of daylight hours across the three time periods. Complete lack of visibility (visibility less than 10 miles) would occur during approximately 21% of available morning hours, 13% of the midday hours, and approximately 14% of afternoon hours (see Table 6).

Table 6. Breakdown of Sky Conditions by Time of Day

Cloud Cover	Percentage of Daylight Hours/Time of Day		
	Morning	Mid-day	Afternoon
Clear	19.1	15.7	15.9
Partly Cloudy	5.4	6.8	5.7
Overcast	54.5	64.1	64.5
Visibility Less than 10 Miles	21.0	13.4	13.9
Total Daylight Hours	100	100	100

When the combination of sky conditions and time of day are considered together, 12 discrete scenarios are defined. As shown in Table 7, the least frequent condition is partly cloudy skies during the midday hours (1.8% of total daylight hours). The most frequent condition is overcast skies during the morning hours, which occurs during approximately 21.8% of daylight hours, and overcast skies during the afternoon hours, which occurs approximately 21.5% of the time.

Table 7. Frequency of Occurrence of Various Time of Day/Weather Scenarios

Time of Day	Percentage of Daylight Hours
Morning	Clear 7.6
	Partly Cloudy 2.2
	Overcast 21.8
	Visibility<10 miles 8.4
Midday	Clear 4.2
	Partly Cloudy 1.8
	Overcast 17.0
	Visibility<10 miles 3.6
Afternoon	Clear 5.3
	Partly Cloudy 1.9
	Overcast 21.5
	Visibility<10 miles 4.6
Total Daylight Hours (Percentage)	100

3.2 Simulations

The analysis conducted in this Study considered three sky conditions, three times of day, and five different distances from shore. A total of 45 visual simulations were prepared to illustrate the various combinations of these factors, excluding conditions where visibility is less than 10 miles (i.e., when turbines would not be visible at the distances under consideration). A representative visual simulation is presented in Appendix A to illustrate the methodology. Evidence from U.S. and European wind farms suggests that there is a high degree of observed variability in turbine visibility based on multiple factors. Distance from the viewer appears to be the single most influential factor. However, along with distance, contrast of the turbines with the background sky can also have a significant impact on visibility. This contrast is generally greatest under clear sky conditions and low sun angle (early morning and late afternoon).

As indicated by the weather data described above, clear morning and afternoon skies occur during 7.6% and 5.3% of the daylight hours. Visual simulations were used to compare the clear morning and afternoon condition at all five distances. The simulations indicate that the 13.2-mile distance zone would have the greatest visibility and that at a distance of 30 miles the turbines would be nearly indistinguishable regardless of the sky condition, due to the relative size of the turbines and the screening provided by curvature of the earth. When viewing the size and detail in the individual turbines, the 13.2-mile and 15-mile views had very subtle differences. However, when viewing the hypothetical project in its entirety, the differences are more substantial. Due to the proximity of the project, the turbines in the 13.2-mile scenario occupy a larger portion of the horizon than the turbines in the 15-mile scenario. Generally, the portion of the horizon occupied by the turbines decreases as the distance increases, provided the layout and orientation stay the same. When comparing the 15-mile and 20-mile scenarios, the scale differences are even more substantial. At 20 miles distant, the hypothetical project occupies a much smaller portion of the horizon and the most distant turbines in the layout are substantially screened behind the visible horizon (earth curvature screening). At 25 miles, even under the highest contrast viewing condition (clear morning), the turbines, although still discernable on the horizon, become an insignificant factor in the view. It is likely that at this distance, a viewer would have to know the turbines exist or would have to be directed to their presence in order to perceive them on the horizon. Similarly, under the 30-mile scenario, most of the turbines are substantially screened by the curvature of the earth and it is unlikely that a casual viewer would perceive the project.

The partly cloudy simulations present very similar results to the clear conditions. As indicated by the weather data, these conditions can be anticipated in the morning and afternoon, during approximately 2.2% and 1.9% of the daylight hours. Depending on the lighting scenario, the turbines’ contrast with the sky is variable. For example, the morning/partly cloudy condition presents white turbines against a light horizon, which limits their contrast. Conversely, the evening simulation shows the white turbines against a darker horizon, creating a slightly higher contrast than demonstrated in the morning simulation.

Although not illustrated in the simulation prepared for this Study, on occasion this condition can create even greater color contrast, with the turbines appearing bright white against a dark grey sky. Actual observations of offshore wind farms suggest that previously indistinguishable turbines can become visible under this condition, although this would be a highly infrequent occurrence.

The overcast sky condition occurs most frequently (61% of daylight hours) and presents the least amount of color contrast. Under overcast conditions, turbine visibility is limited across all times of day and distances. This is typically due to the strong shadows and lack of direct light under overcast conditions. The cloud cover typically diffuses the sunlight, serving to diminish its effectiveness in producing hard shadows and high color contrast. During overcast conditions, the turbines become very difficult to discern at approximately 20 miles during most times of day, whereas under clear conditions, they become difficult to discern 5 miles further from the viewer (25 miles). Exceptions can occur during the evening hours under overcast conditions. Under this scenario, if the sun breaks through the clouds, it can be low enough in the sky to directly light the turbines against a dark horizon. This short-duration condition tends to extend turbine visibility beyond 20 miles, but again, under typical overcast conditions, and even under this condition, the turbines are barely discernable at the 25-mile distance.

As summarized in Table 8, based on analyses of the meteorological data and evaluation of the visual simulations, the highest color contrast and most visible condition (morning, clear skies) has the potential to occur during approximately 8% of the daylight hours during a typical year. The least visible condition (overcast, all hours) would occur during approximately 61% of the daylight hours. Under the most visible condition (clear, morning) the turbines would be discernable out to a distance of 20 miles, beyond which point they would be substantially screened by the curvature of the earth and their visibility would be somewhat masked by atmospheric scattering and haze. Turbines would be very difficult to see at 20 miles distant under overcast conditions, but easily discernable at the 13.2-mile and 15-mile distances, particularly during afternoon hours (which are overcast approximately 64.5% of the time). At a distance of 25 miles, under clear or partly cloudy skies, it is likely that a viewer would not notice the turbines unprompted, but rather would have to know they are there and actively look for them. The exception to this would likely occur under very specific lighting conditions involving a dark cloudy horizon and intense morning or evening sunlight. Additionally, blade movement, although nearly impossible to discern at 25 miles, may draw the viewer’s eye under specific conditions.

Table 8. Frequency and Degree of Visibility by Time of Day/Weather Scenarios

Time of Day	Distance From Viewer (Miles)				
	13.2	15	20	25	30
Morning	Clear 7.6%	Clear 7.6%	Clear 7.6%	Clear 7.6%	Clear 7.6%
	Partly Cloudy 2.2%	Partly Cloudy 2.2%	Partly Cloudy 2.2%	Partly Cloudy 2.2%	Partly Cloudy 2.2%
	Overcast 21.8%	Overcast 21.8%	Overcast 21.8%	Overcast 21.8%	Overcast 21.8%
	Visibility<10mi 8.4%	Visibility<10mi 8.4%	Visibility<10mi 8.4%	Visibility<10mi 8.4%	Visibility<10mi 8.4%
Mid-day	Clear 4.2%	Clear 4.2%	Clear 4.2%	Clear 4.2%	Clear 4.2%
	Partly Cloudy 1.8%	Partly Cloudy 1.8%	Partly Cloudy 1.8%	Partly Cloudy 1.8%	Partly Cloudy 1.8%
	Overcast 17.0%	Overcast 17.0%	Overcast 17.0%	Overcast 17.0%	Overcast 17.0%
	Visibility<10mi 3.6%	Visibility<10mi 3.6%	Visibility<10mi 3.6%	Visibility<10mi 3.6%	Visibility<10mi 3.6%
Afternoon	Clear 5.3%	Clear 5.3%	Clear 5.3%	Clear 5.3%	Clear 5.3%
	Partly Cloudy 1.9%	Partly Cloudy 1.9%	Partly Cloudy 1.9%	Partly Cloudy 1.9%	Partly Cloudy 1.9%
	Overcast 21.5%	Overcast 21.5%	Overcast 21.5%	Overcast 21.5%	Overcast 21.5%
	Visibility<10mi 4.6 %	Visibility<10mi 4.6 %	Visibility<10mi 4.6 %	Visibility<10mi 4.6 %	Visibility<10mi 4.6 %
Total Daylight Hours	100%	100%	100%	100%	100%

Key:

- Visible

- Not Readily Discernable

- Very Difficult to Discern/Not Visible

3.3 Nighttime Federal Aviation Administration Signal Visibility

The *Aviation and Radar Assets Study*, which is appended to the Master Plan, evaluated the potential duration of aircraft warning light activation at night if an ADLS was used on a wind farm offshore of New York. Results of this study suggest that aircraft warning light activation, based on the frequency of flights offshore of New York, would occur during 0.03% to 0.08% of the available annual nighttime hours, or approximately 72 to 201 minutes per year (E&E 2017). This finding suggests that nighttime aircraft warning lighting would not be visible to onshore viewers during the vast majority of nighttime hours if ADLS were employed. This information was not correlated with atmospheric visibility/weather data due the insignificant amount of time the lights would be activated. Additionally, depending on the elevation of the viewer, the lights would likely be screened by the curvature of the earth once beyond 30 miles from shore. In this particular region, if ADLS lighting is utilized, it is unlikely that nighttime aircraft warning lights would have any significant visual impact to onshore resources.

4 Discussion

As indicated in the previous analysis, meteorological data and evaluation of visual simulations indicate that the most visible conditions occur during less than 10% of the daylight hours during a typical year, and that the least visible conditions occur over 75% of the daylight hours. However, viewer experience can greatly differ from meteorological visibility prediction. Viewer experience is a much more complicated metric, as it is influenced by visual acuity, viewer activity, and a variety of environmental factors. Acuity is the physical ability to decipher a subject at a specific distance and level of contrast. Activity relates to where a viewer's attention is focused. Additionally, there are several environmental factors that were not included in the prediction models employed. Possibly the biggest influences on visibility are direction and intensity of the light source (sun angle and azimuth), and sea spray. The sun angle can change the apparent color of turbines against the sky. Flat light, diffused by cloud cover, would reduce the color reflection and hard shadows that can make objects appear in contrast with their backdrop (as discussed in Section 4.2). As mentioned previously, the visibility of turbines can increase under certain overcast conditions with certain sun angles. This occurs primarily during the early morning or late afternoon, when a break in the clouds can allow low-angle sunlight to illuminate white turbines against a dark overcast sky. However, this condition occurs relatively infrequently and lasts for only a short time, and thus would be insignificant in terms of frequency of occurrence throughout a given year. Sea spray can serve to scatter and diffuse light—and therefore visibility—thus reducing the effective visibility range. When all factors are considered, it is likely that visibility models relying on meteorological measurements alone, such as employed in this study, may overstate the theoretical visibility of offshore wind turbines. Photographic and personal observations of the constructed Block Island Wind Farm support the findings of this Study, as discussed and shown in Figures 9 and 10 and discussed below.

Figure 9. 50mm Photograph Showing the Block Island Wind Farm from 23 Miles Away

Figure 10. Detail Area of the Block Island Wind Farm from 23 Miles Away (4x Zoom)

These photographs show the turbines at a distance of 23 miles in overcast conditions. To most observers (informally interviewed on site), the turbines were not readily discernable against the horizon until the observer was guided to the direction and location of the wind farm.

5 Conclusions

Based on analysis of weather conditions, visibility constraints/factors, and visual simulations of a hypothetical wind farm offshore of Long Island, New York, the following conclusions can be drawn regarding potential turbine visibility:

1. During 16% of daylight hours, visibility will be less than 10 miles, meaning that turbines located at the distances under consideration in this study would not be visible.
2. Data regarding sky conditions and daytime visibility showed minimal seasonal variation. The lowest weather-related turbine contrast scenario (overcast conditions) is the most dominant sky condition, accounting for around 59% to 64% of the daylight hours during all four seasons. The highest weather-related contrast scenario would occur during clear and partly cloudy skies. Clear conditions occur between 16% to 18% of total daylight hours, and partly cloudy conditions occur between 5% to 7% of total daylight hours, depending on the season.
3. When broken down by morning, midday, and afternoon hours, the most dominant sky condition is again overcast (ranging from 55% to 65% of the hours during each time of day). Worst case visibility likely would occur during morning and evening hours under clear conditions. The simulations and analysis of the meteorological data conducted as part of this Study suggest that the highest color contrast and most visible condition (morning, clear skies) has the potential to occur during approximately 8% of the daylight hours in a given year. The least visible condition (overcast, morning) would occur during approximately 22% of the daylight hours in a given year.
4. Curvature of the earth becomes a significant factor in turbine visibility beyond 20 miles when viewing from a beach-level position. Calculations using the Haversine Formula suggest that, at 20 miles distant, approximately 142 feet of the lower portion of the turbine would be screened by the curvature of the earth. This is also supported by the photographic example provided in Figure 10, and the simulation in Appendix A. The simulations suggest that the perceived scale of the turbines would be significantly reduced at the 20-, 25-, and 30-mile distances. At 25 miles, only the uppermost portions of the turbines would be visible, and at 30 miles, the nacelle of the turbine would become partially to completely obscured (see Figure 4).
5. The Ecology and Environment, Inc. (2017) study concludes that FAA light activation, based on the frequency of flights over the offshore lease area, would occur during approximately 0.03% to 0.08% of the available annual nighttime hours. Assuming the use of ADLS, the nighttime lighting of offshore wind turbines would be of minimal consequence to onshore resources. Additionally, beyond 25 miles, curvature of the earth may start to screen the FAA lights from view depending on turbine size and viewer elevation.

6. At a distance of 25 miles or greater, during the majority of the year, turbines would generally not be visible to the casual viewer. This is particularly true when viewed under overcast conditions. Under clear and partly cloudy conditions (23% of the total daylight hours during a given year), turbines would likely be somewhat more visible but would still be difficult to discern at a distance of 25 miles or greater. Consequently, it can be reasonably assumed that during the majority of the year, daytime visual impacts would be of negligible significance when turbines are placed at a distance of 25 miles and beyond. However, as previously discussed, this could vary based on a number of factors, primarily the number and size of the turbines, both of which can affect visibility and occupation of the visible horizon.
7. Turbines would be very difficult to see at a distance of 20 miles under overcast conditions, which occur the majority of the time.

A comprehensive visual impact assessment study should be performed for any proposed offshore wind projects in the AoA to better define potential visual impacts to specific onshore resources. However, it can be anticipated that offshore wind energy projects of typical magnitude would have minimal visual impact at a distance of 20 miles and negligible impact beyond 25 miles.

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Appendix A. Representative Visual Simulations of 8 MW Turbines

New York State Offshore Wind Master Plan Visibility Threshold Study

Offshore New York

Appendix A - Visual Simulation: View of Wind Project at 20 Miles (8 MW Turbines)

Simulation Information

Distance to Turbines: 20 Miles

Weather Condition: Overcast

Time of Day: Midday

Camera: Canon EOS 5D Mark IV

Camera Lens: 50mm Fixed

Turbine Information

Model: Siemens SWT-8.0-154

Rotor Diamter: 154 Meters

Hub Height: 110 Meters

Nominal Power: 8 MW

Project Assumptions

Number of Turbines: 100

Generating Capacity: 800MW

Viewer experience may be influenced by many factors including visual acuity, viewer activity, and visual distractions. Additinally, environmental factors such as sea spray, waves, and pollution may reduce the clarity of objects over water. As a result, it is likely that photorealistic visual simulations may over emphasize the visibility of offshore wind turbines.

Viewing Instructions:

Viewers should hold the 11 x 17-inch images approximately 19 inches from the center of the viewer's face to obtain the proper scale and perspective of the simulation.

Sheet 1 of 1

Visual Frequency:

Historic meteorological data suggest that the conditions represented in this simulation would occur during approximately 64.1 percent of available midday daylight hours. During an additional 13.4 percent of midday hours visibility is less than 10 miles so views of the turbines would not be available.

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