Maryland Offshore Wind Development:

Regulatory Environment, Potential Interconnection Points, Investment Model, and Select Conflict Areas

Center for Integrative Environmental Research (CIER)
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Acknowledgements

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Preface

This report summarizes findings from research conducted between November 2009 and September 2010, during which time the various interested and contributing partners have assimilated the results, as they emerged, into their policy and investment decision making. For updates on changes in the technological, economic and regulatory context of off-shore wind that resulted, at least in part, from use of this study in shaping decision making please visit, for example, the following web sites:

www.boemre.gov/offshore/RenewableEnergy/stateactivities.htm#Maryland
www.energy.state.md.us/wind.html
www.dnr.state.md.us/ccp/coastal_resources/oceanplanning

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List of Acronyms and Definitions Used

AC: Alternating Current
AEP: American Electric Power
ASRF: Atmospheric Sciences Research Facility
ATC: Air Traffic Control
COP: Construction and Operations Plan
CPCN: Certificate of Public Convenience and Necessity
DNR: Department of Natural Resources
DPL: Delmarva Power & Light Company
EWEA: European Wind Energy Association
FAA: Federal Aviation Administration
FACSFAC: Fleet Area Control and Surveillance Facility
FDR: Facility Design Report
FERC: Federal Energy Regulatory Commission
GIS: Geographic Information System
HVAC: High-Voltage Alternating Current
HVDC: High-Voltage Direct Current
HVDC VSC: HVDC Voltage Source Converters
HVDC LCC: HVDC Line Commutating Converters
ICSA: Interconnection Construction Service Agreement
ISA: Interconnection Service Agreement
MAPP: Mid-Atlantic Power Pathway
MEA: Maryland Energy Administration
MMS: Mineral Management Service
MOU: Memorandum of Understanding
NASA: National Aeronautics and Space Administration
NAVAIR: U.S. Navy Air Command
NAVSEA: U.S. Navy Sea Command
NAWCAD: Naval Air Warfare Center, Aircraft Division
NOAA: National Oceanic and Atmospheric Administration
NREL: The National Renewable Energy Laboratory
NWS: National Weather Service
OCS: Outer Continental Shelf
PATH: Potomac-Appalachian Transmission Highline
PAX NAS: Patuxent Naval Air Station
PEPCO: Potomac Electric Power Company
PHI: Pepco Holdings, Inc.
RTO: Regional Transmission Organization
POD: Point of Delivery
POI: Point of Interconnection
PPRP: Maryland Department of Natural Resources Power Plant Research Program
PSC: Public Service Commission
RCS: Radar Cross-Section
RECs: Renewable Energy Credits
RF: Radio Frequency

RIR: Range Instrumentation Radars
RLOS: Radar Line of Sight
RPS: Renewable Portfolio Standards
RTEP: Regional Transmission Expansion Plan
SAIC: Science Applications International Corporation
SAP: Site Assessment Plan
SRECs: Solar Renewable Energy Credits
SSPRA: Sensitive Species Project Review Areas
TrAIL: Trans Allegheny Line
US ACE: U.S. Army Corps of Engineers
US DoD: U.S. Department of Defense
US DoE: U.S. Department of Energy
US DoI: U.S. Department of the Interior
VACAPES: Virginia Capes
W-386: Atlantic Warning Area 386
WFF: Wallops Flight Facility

Summary of GIS Files and Metadata

The table below summarizes the 11 .shp (*Shape*) files discussed in this report. Transmission and interconnection files are available online at http://dnr.maryland.gov/ccp/coastalatlas/. In the following section, we provide a general description of each file discussed in this report. Finally, we provide four maps displaying material relevant to this report.

Table 1-Geographic Information System (GIS) Data Files and Chapter of Use

File Name	Source	Year of Most Recent Revision	Chapter Referenced
1. Study Area	CIER*	2009	2, 3 & 4
2. Delmarva Peninsula Substations	Pepco Holdings, Inc.	2009	2 & 3
3. Electricity Transmission System Map	Pepco Holdings, Inc.	2009	2 & 3
4. Bathymetry Data	The Nature Conservancy	2009	2
5. Langley and Victor Corridors	U.S. Department of Defense, Atlantic Test Ranges, Sustainability Office	2009	4
6. NAWCAD Test-track	U.S. Department of Defense, Atlantic Test Ranges, Sustainability Office	2009	4
7. VACAPES W-386	U.S. Department of Defense, Atlantic Test Ranges, Sustainability Office	2009	4
8. Regulated Airspace	NASA, Wallops Flight Facility	2004	4
9. Radar Facilities	NASA, Wallops Flight Facility	2009	4
10. Radar Facilities Buffer	CIER*; NASA Wallops Flight Facility	2009	4
11. Launch Hazard Area	NASA, Wallops Flight Facility	2009	4

* Jeremy Peichel completed all file sources noted as CIER.

1. Study Area: Polygon represents the designated study area for offshore wind considered at this time. The area is defined as extending 64 kilometers from the Maryland Atlantic shoreline.

2. Delmarva Peninsula Substations: The points in this data file represent the locations of substations on the Delmarva Peninsula that have the potential to serve as interconnection points for offshore wind. A letter of the alphabet is used in place of substation name to refer to individual substations. Pepco Holdings, Inc., which provided the data for this layer, has classified this information as critical infrastructure and consequently we are unable to publish both the name and location of each substation. The Federal Energy Regulatory Commission (FERC) refers to the discretion of local utilities on matters pertaining to the classification of critical infrastructure.

3. Electricity Transmission System Map: Lines represent the voltage and location of the transmission grid on the Delmarva Peninsula. Pepco Holdings, Inc. provides the data for this layer with supplementary data pertaining to planned improvements provided by PJM.

4. Bathymetry Data: The Nature Conservancy provides the underlying water depth data found in this section. The depth data is broken into three separate categories based upon the anchoring technologies necessary for operation. The three categories are defined as follows; first, shallow water: less than 30 meters; second, transitional waters: 31 meters to 60 meters; and third, deepwater: anything greater than 60 meters.

5. Langley and Victor Corridors: Represents the airspace used by authorized U.S. Department of Defense personnel as an exit/entrance flight path.

6. NAWCAD Test-track: Represents the airspace used by the National Air Warfare Center, Aircraft Division as a supersonic test-track.

7. VACAPES W-386: Also known as Atlantic Warning Area W-386, this file represents the area used by the U.S. Department of Defense to conduct training exercises, munitions deployment, and flight-testing; operations are sub-surface, surface and airborne. The Langley and Victor Corridor and the NAWCAD Test-track are sub-areas with the VACAPES W-386.

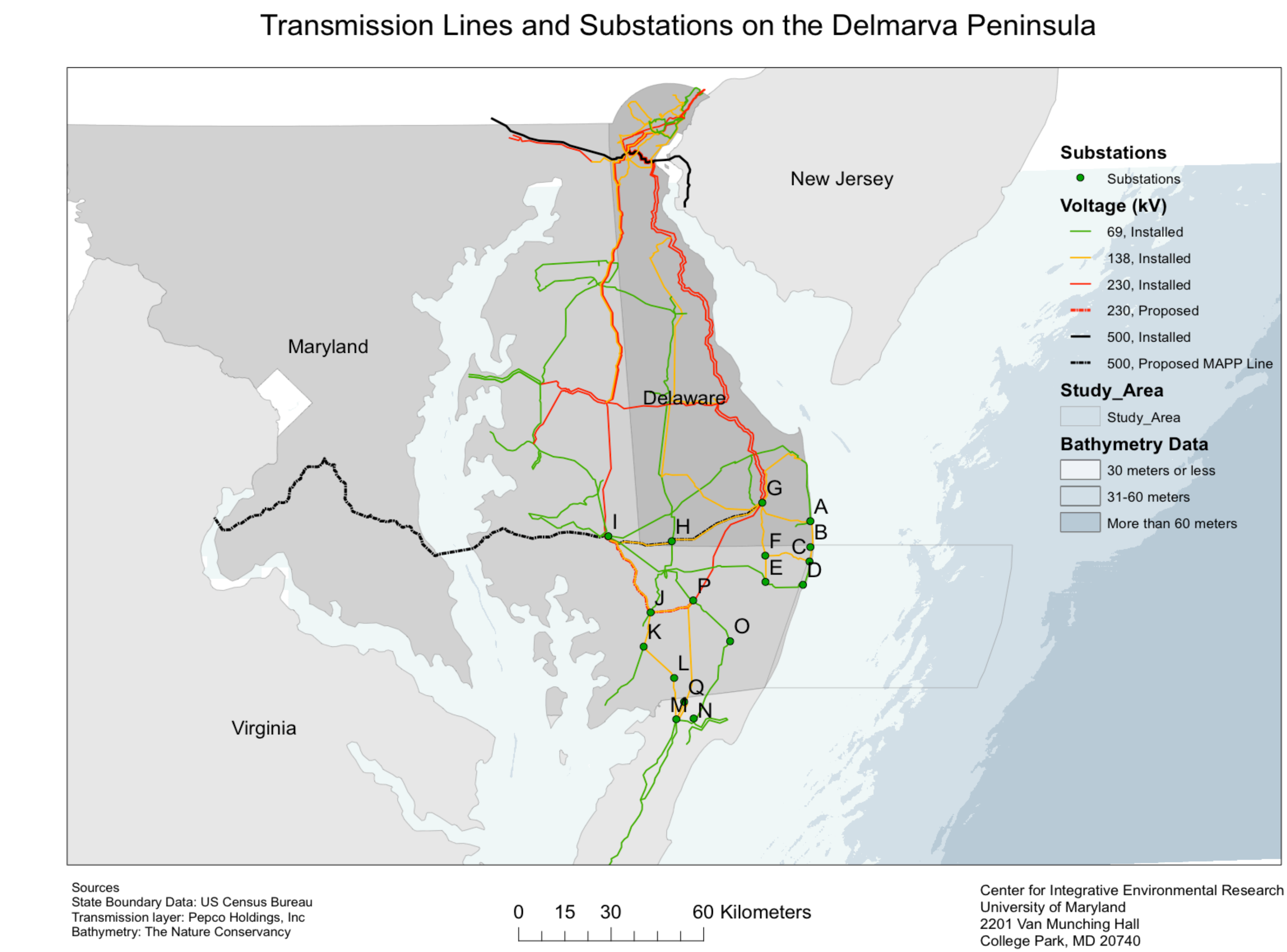
8. Regulated Airspace: Represents R-6604 or regulated airspace adjacent to the NASA Wallops Flight Facility.

9. Radar Facilities: Represents the general area at NASA Wallops Flight Facility where fixed radar facilities are located.

10. Radar Facilities Buffer: Represents radar line-of-sight from the fixed radar of greatest height at NASA Wallops Flight Facility under four scenario wind turbine heights. The four scenarios *assume turbines of height equal to 113, 132, 151 and 182 meters (combined tower and blade) above the surface of the water.*

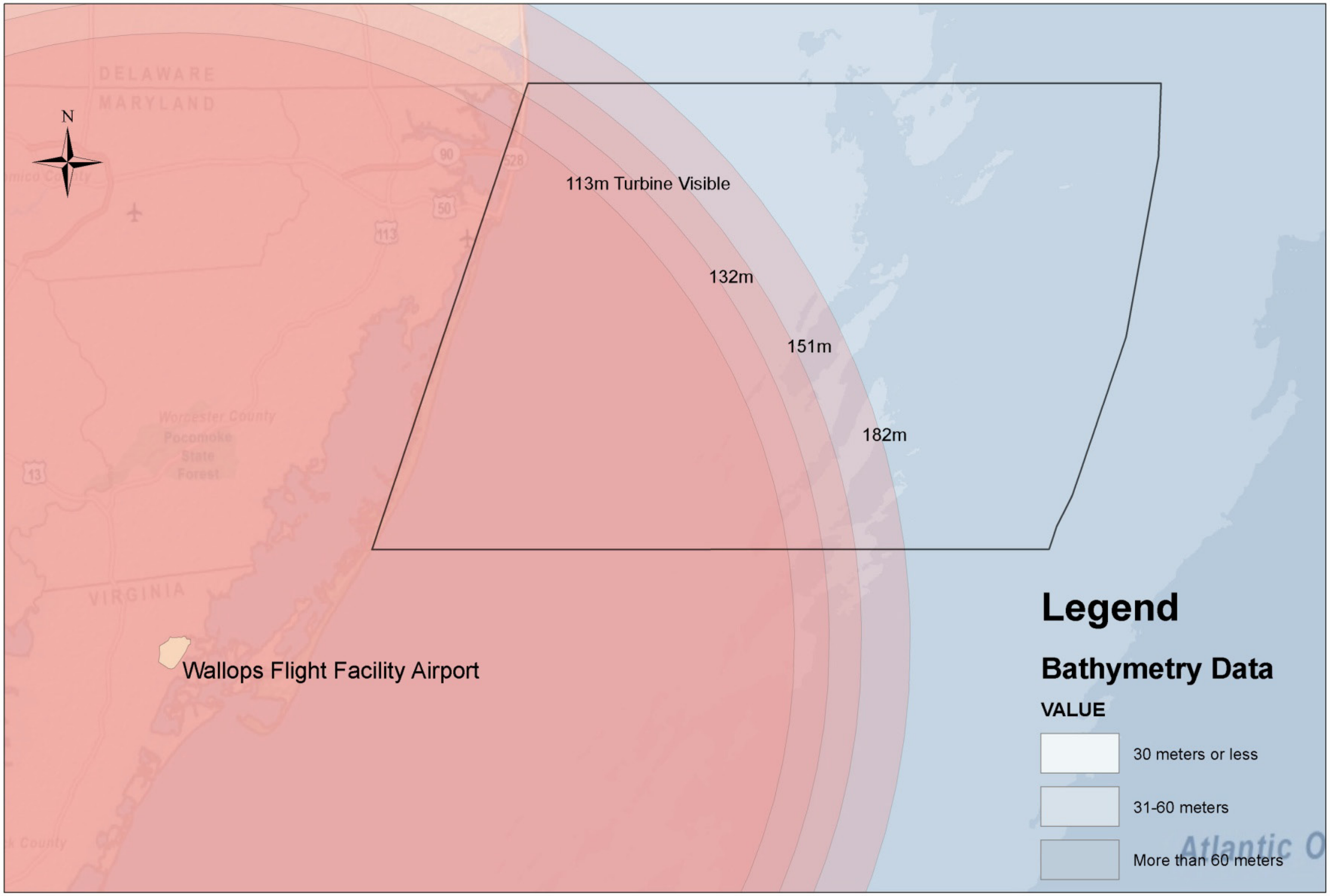
11. Launch Hazard Area: Represents the area where impacts have historically occurred as a result of operations at NASA Wallops Flight Facility (i.e., balloon and rocket launches).

Map 1-Transmission Lines and Substations on the Delmarva Peninsula



Map 2-WFF Radar Line of Sight Radii for 4 Turbine Heights

WFF Radar Line of Sight Radii for 4 Turbine Heights



Sources
Streetmap: ESRI, Tele Atlas North America, Inc.
Radar Horizons: WFF, NASA; CIER
Bathymetry Data: The Nature Conservancy

0 2 4 8 12 16 Kilometers

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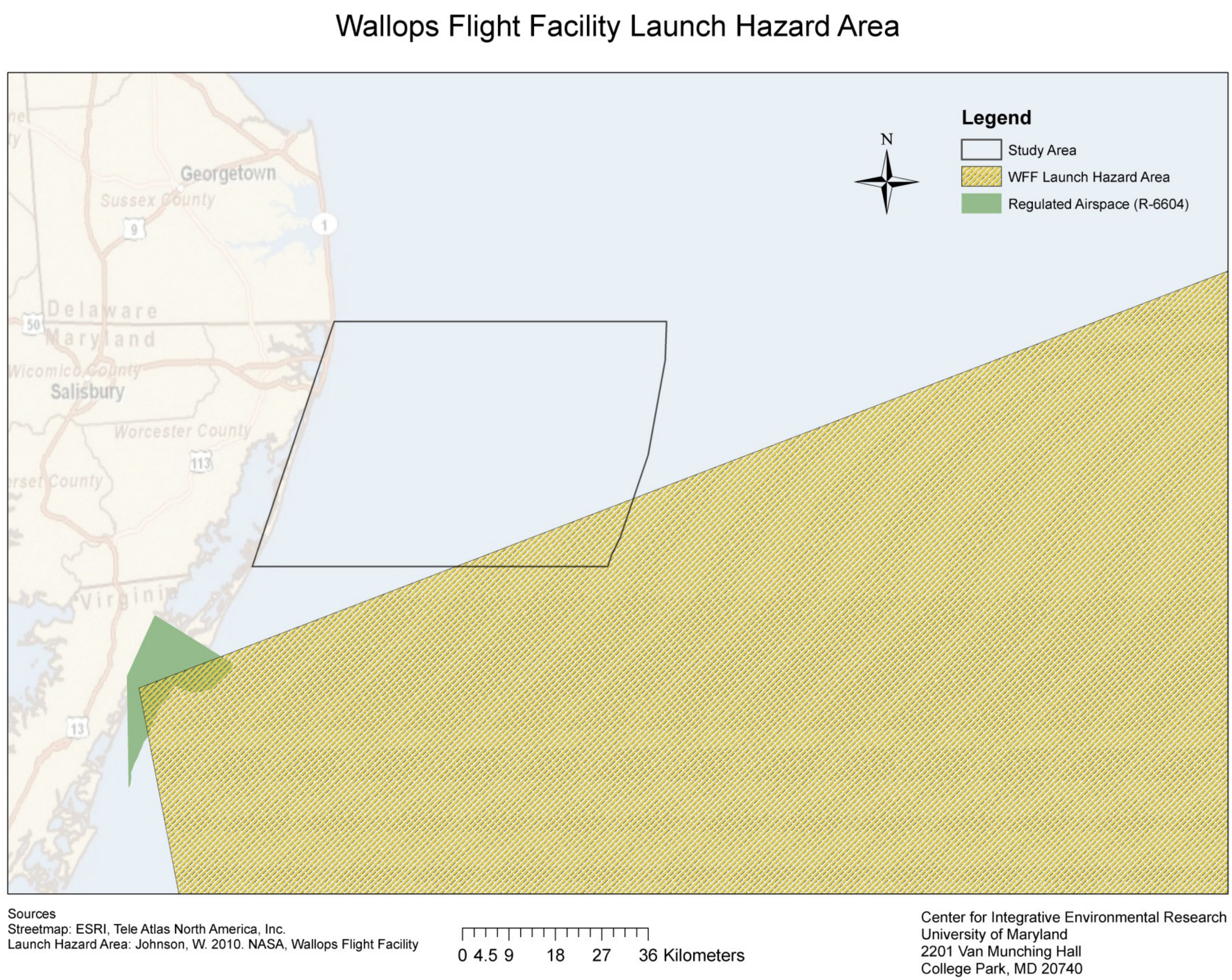
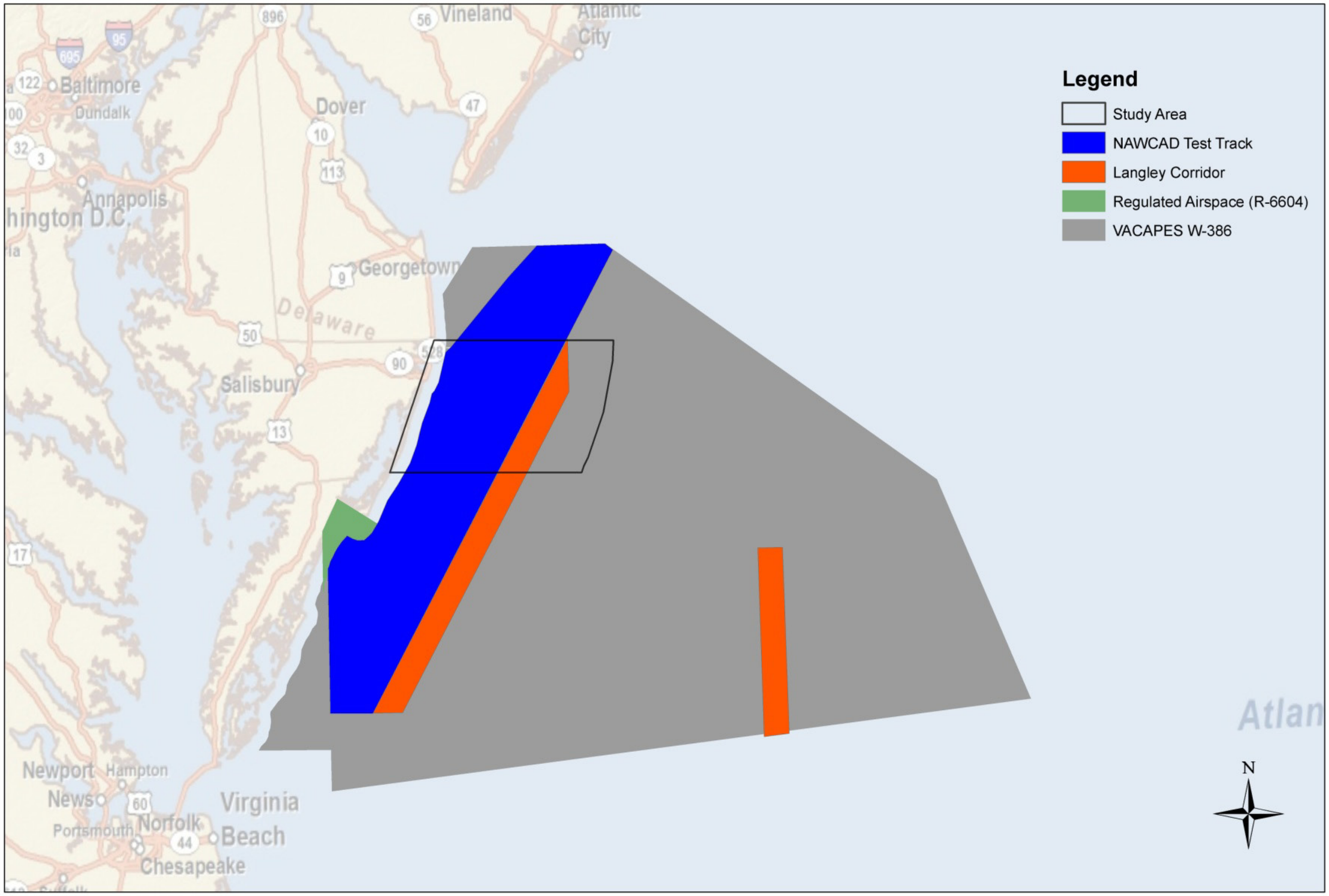
Map 3-Wallops Flight Facility Launch Hazard Area



Map 4-VACAPES W-386

VACAPES W-386



Sources
Streetmap: ESRI, Tele Atlas North America, Inc.
Operations Area: Raymond, S., & Jarboe, C. 2009.
NAVAIR, Ranges Sustainability Office

0 12.5 25 50 75 100 Kilometers

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Executive Summary

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1. Introduction

This study investigates four aspects of developing wind in waters offshore Maryland: (1) the regulatory and policy environment for offshore wind development, (2) optimal interconnection points for bringing offshore power onshore, (3) estimated investment costs, and (4) potential conflicts between research and military activities, and wind farm siting. The Maryland Department of Natural Resources and the Nature Conservancy are investigating other impacts (e.g. biological, physical, and social).

First, we introduce the datasets that will be referenced throughout the chapters. We have compiled information pertaining to existing transmission grid, planned transmission grid improvements, substation locations, bathymetry data, and research and military sites (e.g. bases, operations areas, and other zones of conflicting use) into Geographic Information Systems (GIS) data files. These files are introduced in the table above titled "Geographic Information System (GIS) Data Files and Chapter of Use," which provides a broad outline of the geographic information; additional file details are provided in the chapters that follow. Some of the files described in this report as well as others compiled by the Nature Conservancy and the Maryland Department of Natural Resources can be accessed online at http://dnr.maryland.gov/ccp/coastalatlas/.

In Chapter 1 of the report we explore the policy environment in the State of Maryland, as well as the regulatory environment concerning operations and development of offshore wind resources in federal waters on the outer continental shelf (OCS).

Maryland is interested in exploring offshore wind, as one of a possible suite of renewable energy technologies in order to address the anticipated growth in electricity demand as well as facilitate compliance with the Renewable Portfolio Standards. Offshore wind holds the potential to achieve both of these objectives while also mitigating visual and noise impacts that have been associated with onshore wind farms. However, based on experiences within the U.S. to date, wind farms will more than likely be sited far from shore in federal waters, which will require the involvement of the Minerals Management Service (MMS). The role of MMS, Pennsylvania-New

Jersey-Maryland (PJM) Interconnection, and the Maryland Public Service Commission (PSC) and their processes are explored in Chapter 1.

In Chapter 2, we explore the existing transmission grid on the Delmarva Peninsula, as well as planned improvements. In that chapter we also discuss the best sites for interconnecting offshore wind energy into the existing onshore transmission grid.

Next, in Chapter 3, we build a simplified investment model that explores potential costs of developing offshore wind farms using existing literature, experiential data from previously built and planned wind farms, and consultations with industry experts and vendors. Existing and planned projects feature heavily in our assumptions including the Bluewater Wind and Cape Wind projects in the United States, as well as several European Wind Farms such as Nysted and Horns Rev. The chapter proceeds with the development of the investment model assumptions before then running the model for two case studies, including a 600 MW shallow water wind farm and a 1,000 MW deepwater application.

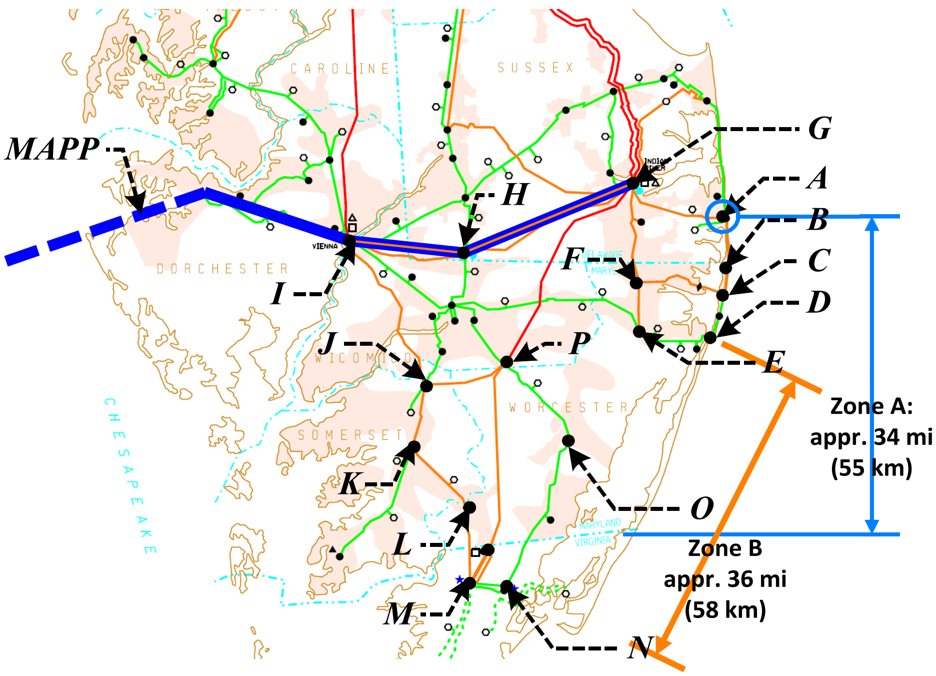
Last, in Chapter 4 we investigate potential conflicts between mid-Atlantic operations (i.e., military or research-based operations) and offshore wind development. The mid-Atlantic region adjacent to Maryland's coastline is used by a number of federal agencies (e.g., NASA, U.S. Department of Defense) and the potential exists for conflict between any offshore wind development and currently existing uses. Of particular focus in this section is the potential impact offshore wind development might have on radar functionality.

2. Major Findings

Upon outlining regulatory and policy procedures in Chapter 1, we begin analysis in Chapter 2 with an investigation of potential interconnection points and find that based upon the limited number of generator interconnection studies undertaken thus far, opportunities on the Delmarva Peninsula are limited for interconnecting offshore wind resources with the transmission grid. Potential options for addressing offshore wind interconnection include an offshore transmission collection system for interconnecting multiple offshore wind projects as well as constructing additional backbone transmission lines. Due to slower than expected load growth over the last few years, the need for backbone transmission lines is being reevaluated by PJM. In this project, we assume the Mid-Atlantic Power Pathway (MAPP) line is constructed to Indian River. Further, we do not investigate the impact of an offshore backbone line.

The transmission grid in the PJM region, especially in the mid-Atlantic, is dynamic with a number of backbone projects proposed or already under construction. Particularly important to this study is the proposed MAPP line, a bidirectional 640 kV High-Voltage Direct Current

(HVDC) cable that would travel under the Chesapeake Bay, connecting Calvert Cliffs with Indian River [1]. We find in our analysis that among the Substations A, B, C, and D, those closest to the Atlantic Coast are optimal substations for the point of interconnection, with the optimal point of delivery (POD) at Substation G (See Figure 1). Substation A, located in Delaware has the unique advantage of being the shortest distance to Substation G, which is the optimal delivery point. In its interconnection proposal, Bluewater Wind proposes to build a new substation in the same area as Substation A. Interconnections further south would likely require a circuitous cabling around Assateague Island National Seashore.



Approximate Distance between Substations		
A ↔ B	5.5 mi	8.9 km
A ↔ G	12.2 mi	19.6 km
B ↔ C	3.0 mi	4.8 km
C ↔ D	5.0 mi	8.0 km
C ↔ F	9.0 mi	14.5 km
D ↔ E	8.0 mi	12.9 km
E ↔ F	5.5 mi	8.9 km
F ↔ G	11.0 mi	17.7 km
G ↔ H	21.4 mi	34.4 km
H ↔ I	14.0 mi	22.5 km
I ↔ J	19.0 mi	30.6 km
I ↔ P	23.0 mi	37.0 km
J ↔ K	7.0 mi	11.3 km
J ↔ P	9.5 mi	15.3 km
K ↔ L	9.0 mi	14.5 km
L ↔ M	9.0 mi	14.5 km
M ↔ N	3.6 mi	5.8 km
M ↔ P	27.0 mi	43.5 km
N ↔ O	19.0 mi	30.6 km
O ↔ P	12.0 mi	19.3 km

Figure 1-PHI Substations and Transmission Lines on the Delmarva Peninsula (Source: PHI, 2009)[2,3]

From our development and exploration of the simplified investment model for offshore wind in Chapter 3, we confirm that offshore wind investments will be dominated by the costs of turbines and foundations, which are likely to make up a large percentage of the overall cost. Second, we find that the much lower cabling cost of an HVDC system, \$2.29 million per kilometer, as compared to a High-Voltage Alternating Current (HVAC) system, \$5.05 million per kilometer,

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[1] More information concerning the MAPP line can be found in Chapter II.
[2] Substations A, H, M and N are outside of Maryland; Transmission lines: Blue=MAPP, Red=230 kV, Orange=138 kV, Green=69 kV
[3] The distances are roughly measured using a ruler when they are not available in PJM, 2009a; PJM, 2009b; PJM, 2009c; PJM, 2009f. The transmission lines are drawn with the connectivity information in the PHI facilities list (PJM, 2009e).

offsets at longer distances the increased costs of HVDC offshore and onshore substations (as confirmed by previous studies). In our 600 MW and 1000 MW scenarios, which investigate not only a difference in the size of the wind farm but also its location (e.g. shallow versus deep water application) and transmission system, we do not see a significant difference in the costs per kW as both projects have an estimated cost of $1,850 per kW.

Regarding mid-Atlantic operations, we find that the potential for diminished radar functionality exists at NASA's Wallops Flight Facility, which is used by multiple parties ranging from the Federal Aviation Administration (FAA) and NASA, to the United States Navy. However, the potential for diminished radar functionality at other mid-Atlantic facilities as a result of wind development is unlikely and depending on siting and other factors, impacts on the Wallops Flight Facility can be mitigated. These findings apply strictly to fixed radar units. Conflict with U.S. military operations occurring in the air or surface space adjacent to Maryland's coastline including flight-testing, training exercises and munitions deployment is very likely. This includes both the potential for physical conflict and radar interference as it applies to mobile radar units (e.g., on aircraft or naval vessels). However, through collaborative work with specific U.S. military and other users of the mid-Atlantic space, the possibility for reconciling these conflicts exists.

3. Limitations

A number of limitations exist to fully understanding the potential conflicts between offshore wind development and mid-Atlantic operations. First, the impact of wind turbines on fixed radar is generally well understood. However, there is a need for additional information regarding the impact of wind turbines and mobile radar units. An examination of mobile radar interference and potential opportunities to mitigate impacts would be valuable to users of radar and wind power companies alike.

Additionally, a lack of detail on military operations in the mid-Atlantic generally and Virginia Capes (VACAPES) W-386 specifically will serve as an impediment to wind development in Atlantic waters adjacent to Maryland. In particular, more information about surface and subsurface operations (including live training exercises) would clarify circumstances that could result in conflict. There are serious national security concerns in disclosing this information, however, and the U.S. Department of Defense must take precautions to maintain security. Upon receiving the information available in this report, potential wind developers should collaboratively discuss knowledge gaps and critical missing information with the U.S. Department of Defense.

Our investigation of optimal interconnection points for offshore wind generation into the onshore transmission grid does not involve an established Pepco Holdings, Inc. (PHI) transmission system model or simulation tool to analyze the impacts on the transmission system and assess the associated cost of reinforcement in the system. As a preliminary analysis, however, we identify optimal interconnection points using a map of the transmission and substation networks on the Delmarva Peninsula. The approximate locations of substations and the distances between substations were collected from PHI, PJM RTEP and PJM T122 Impact Study (PHI, 2009; PJM, 2009c; PJM, 2009f). The transmission lines are drawn with the connectivity information in the PHI facilities list (PJM, 2009e).

In our examination of investment costs for two hypothetical wind farms, a 600 MW and an 1000 MW facility adjacent to Maryland's coastline in the Atlantic Ocean, we depend largely on existing literature, experiential data from wind farms built to date, as well as contacts within the wind industry. However, in our analysis we do not include such factors as transport and erection of wind turbines, foundations, design and project management, and environmental analysis (EWEA, 2009b). Those factors are beyond our consideration because they tend to be site dependent or vary over time (i.e., availability of installation vessels, weather and wave conditions, water depth, soil conditions under water, proximity to ports, etc.).

4. Future Research

For future research we recommend exploring the development or involvement of analytical models and methods (e.g., a simulation optimization methodology) for a study of the operational performance of the PHI transmission system, based on a scenario-driven approach for variability of wind energy penetration into the grid and various N-1 contingency conditions (e.g., power flow, line outage, and stability) on the transmission system. Combined with cost of reinforcement due to the wind generation injection into the system, this study would provide the optimal interconnection point and the optimal allowable injection of capacity without major transmission upgrade or with the lowest impact and upgrade cost. The model that we would use in the study would be a multi-period model, where, for example, a continuous power flow on a transmission line is discretized into hourly or shorter or longer. Also, the variability of wind power would be represented with discrete probability distribution in the model (i.e., discrete scenarios). So the model should be a multi-period stochastic model. To accomplish this work would require additional cooperation with PHI including access to proprietary information regarding power flow diagrams, power transfer limits and thermal limits on each transmission line in the system, generator reactive powers, bus voltages and phases of all substations (Milano et al., 2005; Deuse et al., 2003). PJM is a regional transmission organization, which manages the wholesale electricity market for an interconnected power grid of 13 states and the District of Columbia. We would refer to PJM's offshore wind study, if available, or invite it to our study to raise public confidence and accuracy and to avoid any inefficiency in our approach.

Research efforts concerned with the potential development of offshore wind in Maryland and federal waters are ongoing. An interagency effort by the Maryland Energy Administration (MEA) and the Maryland Department of Natural Resources (DNR), with the assistance of the Nature Conservancy has yielded a comprehensive marine spatial planning tool that offers guidance on the physical, biological and human use characteristics of Maryland's offshore resources, providing information to wind energy developers and coastal stakeholders. This information can be used to further develop our own analysis in an optimization model for best use of offshore marine space (i.e., optimal wind farm layout to minimize investment costs). This model would include estimated wind farm component costs from Chapter 3, radar and military activity information from Chapter 4, as well as information from DNR and Nature Conservancy included in their Coastal Atlas. Further integration of the offshore model with the onshore transmission system model would allow development of an aggregate model capable of determining both an optimal interconnection point and the most desirable wind farm layout in such a way that minimizes investment costs[4].

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PJM. 2009a. *PJM backbone projects.* Available at http://www.pjm.com/planning/rtep-upgrades-status/backbone-status.aspx.

[4] Multi-objective optimization models have been applied to Smart Growth Planning in the State of Maryland and provide a model for potentially addressing this issue. The project considered conflicting interests of various stakeholders involved in land development decisions (e.g., government planners, environmentalists, conservationists, and land developers) (Gabriel, SA et al., 2005).

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I. An Assessment of the Policy and Regulatory Context for Offshore Wind in Maryland

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1. Introduction

In this chapter, we identify the policy and regulatory context for offshore wind development in waters adjacent to Maryland's coastline. Offshore wind holds the potential to help Maryland reach its Renewable Portfolio Standards (RPS) commitments, which require that 20 percent of electricity sold in the state come from renewable resources by 2022. By 2022, Maryland estimates an additional 7,500 GWh of electricity will be needed despite reductions in demand as a result of demand side management programs and growing electricity output from other renewable energy sources (MEA, 2009c). The State of Maryland would like to meet a portion or all of the projected shortfall through development of Maryland's renewable energy resources. Not only would offshore wind development help Maryland meet its RPS goals, but it would also provide ancillary benefits (e.g. jobs, industry development) and further position the state as an environmental first mover.

This chapter is organized into four sections. In Section 2, we discuss Maryland's RPS commitments. Maryland is constrained for space in choosing sites for wind development within its own territorial waters because state waters extend only 5.5 kilometers from the shoreline. However, in 1945, President Truman extended United States territorial rights to cover all natural resources on its continental shelf. In the United States, the Federal Energy Regulatory Commission (FERC) and the Mineral Management Service (MMS) have permitting authority over renewable energy activities in offshore federal waters. MMS has jurisdiction with regard "to the production, transportation, or transmission of energy from non-hydrokinetic renewable energy projects, including wind and solar"(MMS, 2009a). In Section 3, we therefore discuss the role of MMS and pertinent regulations for operation in federal waters.

Next, in Section 4, we discuss the interconnection requirements as put forth in Manual 14a by PJM Interconnection. We provide background information on the steps necessary for interconnection with the onshore transmission grid. The links provided include detailed reports on the generation interconnection requirements, which are available online. Finally, in Section 5, we discuss the role of FERC and PSC in siting transmission and power generation facilities in the state of Maryland.

2. Renewable Portfolio Standards

In May 2004, the Maryland legislature enacted the RPS, which requires electricity suppliers in the state (e.g. utilities, competitive retail suppliers) to meet 20 percent of retail electricity sales from renewable energy sources by 2022 (Tier 1 sources) (see Appendix A)(DSIRE, 2009)[5]. Under the program, any load serving entity, which includes suppliers and utilities that provide standard offer service, must meet annual renewable portfolio standards (PSC, 2009a). In 2007, Maryland created a solar set-aside that requires 2 percent of Maryland's RPS commitments to come from solar sources. This solar set-aside starts in 2008 and requires Maryland load serving entities to purchase solar renewable energy credits (SRECs) from in-state generation equivalent to 0.005 percent of total retail electricity sales (see Appendix A for the implementation schedule) (PSC, 2008). One SREC represents the environmental attributes of one megawatt-hour (MWh) of solar energy generation. At this point in time, a similar wind carve-out does not exist and would require a legislative mandate (PSC, 2009b).

Renewable energy sources are grouped into two tiers, Tier 1 and Tier 2. Tier 1 renewable energy sources include solar, wind, qualifying biomass, methane from the anaerobic decomposition of organic materials in a landfill or wastewater treatment plant, geothermal, poultry-litter incineration facilities, and ocean energy, including energy from waves, tides, currents, and thermal differences, fuel cells powered by methane or biomass, and small hydroelectric plants (systems less than 30 megawatts in capacity and in operation as of January 1, 2004) (PSC, 2008; DSIRE, 2009). Tier 2 resources are comprised of hydropower generation greater than 30 megawatts (MW) (other than pump storage) and waste-to-energy (PSC, 2008).

Beginning in 2006, electricity providers were required to provide 1 percent of their retail sales from renewable energy sources. The percentage of electricity from renewable sources is then gradually increased until 20 percent of retail sales come from Tier 1 renewable energy sources (see Appendix A). Tier 2 resources can account for 2.50 percent of the RPS requirements during the period 2006 to 2018 (PSC, 2008). However, after 2018, Tier 2 resources cannot be used as a means to achieve RPS requirements (PSC, 2008).

[5] Allowable renewable energy sources include solar thermal electric, photovoltaics, landfill gas, wind, biomass, hydroelectric, geothermal electric, municipal solid waste, anaerobic digestion, tidal energy, wave energy, ocean thermal, and fuel cells using renewable fuels (DSIRE, 2009).

To meet its RPS standards, utilities can purchase Renewable Energy Credits (RECs) from states within the PJM region and adjacent to it (PSC, 2008). States are considered adjacent to the PJM region if they share a border with it or if PJM partially overlaps (PSC, 2008). RECs may be purchased from outside the area as defined above as long as the electricity generated flows into the PJM region (PSC, 2008). Maryland can purchase RECs from renewable energy facilities located in the following states: Pennsylvania, New Jersey, Delaware, District of Columbia, Virginia, West Virginia, New York, North Carolina, Tennessee, Kentucky, Ohio, Indiana, Illinois, Michigan, Wisconsin, and Iowa (other states may be eligible if energy is delivered into the PJM region) (PSC, 2008). Beginning in 2011, Maryland H.B. 375 will restrict acceptable RECs to resources within the PJM region or from a control area adjacent to the region (as long as the electricity flows into PJM) (PSC, 2009b).

3. Development in Federal Waters: The Role of the Minerals Management Service

In this section we discuss the powers granted to MMS under the Energy Policy Act of 2005. We will then discuss the rulemaking process to govern the management of MMS Renewable Energy Program. Finally, we discuss the MMS process towards developing offshore wind resource in federal waters (i.e. formation of a state task force, request for expressions of interest from wind developers, etc.).

MMS, within the U.S. Department of the Interior, manages ocean energy and mineral resources on the outer continental shelf (OCS) as well as federal and Indian mineral revenues to enhance public and trust benefits, promote responsible use, and realize fair value. On August 8, 2005, President George W. Bush signed into law the Energy Policy Act of 2005 (the Act), which grants MMS new responsibilities over federal offshore alternative energy deployment and alternate uses of offshore public lands (i.e. OCS). Section 388 of the Act provides an initiative to facilitate increased alternative energy production on the OCS. It gives the Secretary of the Interior the authority to grant a lease, easement or right-of way for activities on the OCS that produce or support production, transportation, or transmission of energy from sources other than oil or gas. It also gives the Department the authority to act as a lead agency for coordinating the permitting process with other federal agencies, and to monitor and regulate those facilities used for alternative energy production and support services.

On April 9, 2009, MMS signed an MOU with FERC to clarify jurisdiction over renewable energy projects on the OCS. Under the agreement, MMS has exclusive jurisdiction over the production, transportation, or transmission of energy from non-hydrokinetic renewable energy projects, including wind and solar. FERC has exclusive jurisdiction to issue licenses for the construction and operation of hydrokinetic projects like wave energy and current energy, but requires applicants to first obtain a lease through MMS (MMS, 2009a).

On April 22, 2009, President Barack Obama announced the completion of the Department of the Interior's Final Renewable Energy Framework or rulemaking process to govern management of the MMS Renewable Energy Program. MMS will continue coordination with stakeholders, including congressional delegations, coastal states, federal agencies, industry, the environmental community and the general public. It will establish task forces with states to facilitate dialogue regarding OCS leasing with state, federal, local, and tribal governments. It will initiate environmental studies, determine leasing priorities, prepare environmental compliance documents, monitor activities and facility inspection, and initiate the commercial leasing process and work with the state task forces to issue requests for interests. Key mandates for the Renewable Energy Program include: safety, protection of the environment, coordination with affected state and local governments and federal agencies, fair return for use of OCS lands, and equitable sharing of revenue with states (MMS, 2009a; MMS, 2009b).

Deployment of power generation facilities requires commercial leases, which will be issued on a competitive basis, unless the Secretary determines after public notice (normally by issuing the Request for Interest) that there is no competitive interest. For competitive commercial lease, there is a competitive process including a call for information, area identification, proposed sale notice, final notice, lease sale (auction), and award (MMS, 2009e). Subsequently, there will be a 6-month preliminary term, a 5-year site assessment term and a 25-year operations term of an award. Within 6 months, the lessee must submit a Site Assessment Plan (SAP) describing planned site characterization activities and including relevant site survey results. MMS conducts required environmental compliance (e.g., National Environmental Policy Act, Coastal Zone Management Act, Magnuson−Stevens Fishery Conservation and Management Act, National Historic Preservation Act, Endangered Species Act) and technical reviews. Within 5 years of SAP approval by MMS, the lessee must submit a Construction and Operations Plan (COP) describing all activities and facilities to be installed and used to gather, transport, transmit, generate, or distribute energy from the lease. MMS conducts additional required environmental compliance and technical reviews. Two more reports are required before constructing and installing facilities under an approved COP. One is a Facility Design Report (FDR), with details of the design of facilities, including cables and pipelines, described in approved plans. The other is a Fabrication and Installation Report, with details on how facilities will be built in accordance with plans and FDR. Without going through a competitive process, applicants for a noncompetitive lease also must go through SAP and COP processes, and leases are contingent on SAP approval (MMS, 2009b; MMS, 2009f)

In the leasing process, task force development is the preferred first step towards coordination of information, which aids in decision-making and ensures effective communication among parties.

The leasing process is established and coordinated by MMS, with participation from elected officers of state, local and tribal governments and relevant federal agencies, such as U.S. Coast Guard, U.S. Environmental Protection Agency, etc. Following the regulatory framework, members can provide input in the implementation of the MMS Renewable Energy Framework, such as recommendations regarding preparation of required MMS notices and announcements, performance of environmental analyses and identification environmental data needs (MMS, 2009c; MMS, 2009d). Task force members have the opportunity to review and comment on draft Requests for Interest by MMS prior to publication in the Federal Register (MMS, 2009g). Currently, MMS has established task forces in several States regarding OCS renewable energy activities, including Maryland (MMS, 2010).

4. PJM Generator Interconnection Process

The PJM transmission system provides the network for delivery of the output from interconnected generators to load centers for end-use customer consumption. Developers requesting interconnection of a generating facility within the PJM regional transmission organization (RTO) must follow PJM's interconnection process (see Figure 2)(PJM, 2009).

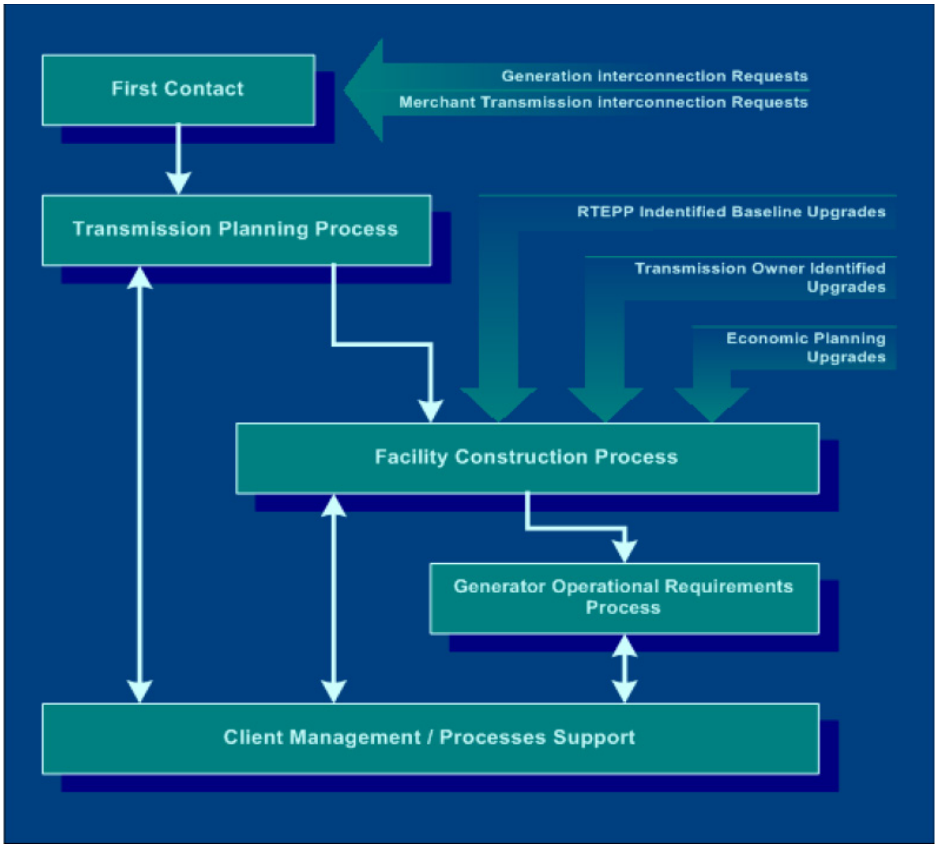

Figure 2-PJM Interconnection Process Overview (Source: PJM, 2009)

A developer must contact PJM to initiate the Interconnection Planning Process and must submit a completed Interconnection Request. This is accomplished by execution of a Feasibility Study Agreement.

After contacting PJM, PJM will assign a project manager. The project manager will be responsible for working with each developer and their respective staff to complete the necessary steps related to interconnection planning. The developer will also be assigned a client manager. Client managers coordinate PJM activities that facilitate each developer's membership and market participation, bridging any concerns or coordination issues with appropriate PJM staff including the PJM project manager (PJM, 2009).

4.1.Generation Interconnection Planning Process

The PJM Operating Agreement and Open Access Transmission Tariff establish the statutory basis for the business rules guiding the interconnection request process. These business rules include three analytical steps or studies: (1) Feasibility Study,(2) System Impact Study, and (3) Interconnection Facilities Study. Each step imposes its own financial obligations and establishes milestone responsibilities. Projects within each time-based queue are evaluated against a baseline benchmark set of studies in order to establish project-specific responsibility for system enhancements; project evaluations are separate from general network upgrades suggested by the results of baseline analyses. Each developer is encouraged to participate in the activities of the Transmission Expansion Advisory Committee and its Regional Transmission Expansion Plan (RTEP) Committee (PJM, 2009).

In the first stage, a developer must submit an Interconnection Request in the form of an executed Generation or Transmission Interconnection Feasibility Study Agreement in addition to a study deposit. The developer could request either of two forms of interconnection service, Capacity Resource or Energy Resource service[6]. The request must include descriptions of the project location, size, equipment configuration, anticipated in-service date, etc. After the request and deposit are received, PJM assigns a system planning senior consultant as the team leader to initiate and direct implementation of the study phases of the Generator and/or Transmission Interconnection Process. During this phase, project location and size are identified (PJM, 2009).

After receipt of the Generation or Transmission Interconnection Feasibility Study results, if the developer decides to proceed, an executed System Impact Study Agreement must be submitted to PJM with the required deposit. The System Impact Study is a comprehensive regional analysis of the impact associated with adding a new generation and/or transmission facility to the system. One essential component of the System Impact Study is an evaluation of the project's impact on deliverability to PJM load with a particular focus on the PJM region where the new generator and/or transmission facility will be sited. This Study identifies the system constraints related to the project and the necessary attachment facilities, local upgrades, and network upgrades to ensure project success (PJM, 2009).

After reviewing the results of the study, the developer must decide whether or not to proceed with a Generation or Transmission Interconnection Facilities Study. If the developer decides to proceed with the project, the results of the System Impact Study are integrated into the RTEP process for development; the RTEP will subsequently be submitted to PJM's Board of Managers for approval. The developer will execute and return the Generation and/or Transmission Interconnection Facilities Study Agreement and the required deposit. When completed, the study will document the engineering design work necessary to begin construction (PJM, 2009).

4.2. Generation and Transmission Interconnection Facility Construction

Upon completion of the Interconnection Facility Study, PJM will furnish an Interconnection Service Agreement (ISA) to be executed by the developer and any affected Interconnected

[6] A capacity resource requires that energy be deliverable while an energy resource does not need to meet the same requirement (DNR, 2010b).

Transmission Owners. The ISA defines the obligation of the developer with regards to cost responsibility for any required system upgrades. The ISA also confers the rights associated with the interconnection of a generator as a capacity resource and any operational restrictions or other limitations on which those rights depend.

Construction of new Interconnection Facilities expected to interconnect a generator or transmission project with the PJM Transmission Grid shall be performed in accordance with the Standard Terms and Conditions as specified in an Interconnection Construction Service Agreement (ICSA), which is executed jointly among the developer, PJM and the affected Interconnected Transmission Owner(s). The ICSA specifies the developer's option to build and the general project timeline (PJM, 2008).

The complexities associated with the ISA/ICSA Implementation Phase of the Generator Interconnection Projects warrant a project management model approach and an effective tool for managing the activities and deliverables associated with the projects is a work breakdown structure (PJM, 2008).

4.3. Markets and Operations

The Generator Markets and Operations phase is initiated during the ISA and ICSA implementation phase of the generator interconnection process. The Interconnection Coordination Project Manager coordinates the activities of PJM Internal Coordination (Operations Planning, System Operations, CR&T, PJMnet, EMS) and the developer to complete the Generator Markets and Operations activities during this phase (PJM, 2010).

For more information on the PJM Generation and Transmission Interconnection Process See PJM Manual 14a available at http://www.pjm.com/documents/manuals.aspx.

5. Role of the Federal Energy Regulatory Commission and Maryland Public Service Commission in Offshore Wind Transmission

This section explores the respective roles of FERC and the Maryland PSC with regard to the challenge of connecting offshore generation to the onshore grid, with a particular focus on Maryland waters.

FERC regulates the PJM Regional Transmission Organization and most utilities within the PJM region (municipal power systems are excluded) (FERC, 2010). One of FERC's primary roles is to oversee the sale of wholesale electricity and ensure competition and non-discrimination of utilities. Over the past two decades, FERC has been instrumental in ensuring competitive electricity sales through open access transmission tariffs and the subsequent formation of RTOs and breakdown of traditional vertical integration (FERC, 2009; PHI, 2010a). Additional regulatory responsibilities for FERC consist of overseeing mergers and certifying cogeneration plants. FERC does not regulate the physical siting of electricity generation, transmission or distribution facilities except under specific circumstances (FERC, 2010). Moreover, under Section 1221 of the Energy Act of 2005, FERC has the authority to issue transmission construction permits for facilities located in corridors designated as a "national interest electricity transmission corridor," by the U.S. Department of Energy[7]. The exact role FERC will play in the siting of transmission lines within the mid-Atlantic region depends on whether siting occurs in a national interest electricity transmission corridor.

The PSC is likely to play an active role in the siting process within Maryland waters, but the nature of this role is presently unclear. The PSC has several responsibilities within the State's power sector, including siting of generating facilities and overhead transmission lines as well as supporting competitive retail electricity markets (PSC, 2009c; PHI, 2010a)[8]. PSC does not have explicit authority to site underwater transmission cables at this time, but legislation in the Maryland General Assembly may clarify the role (MDNR, 2010b).Within Maryland, construction of a power plant or transmission line greater than 69 kV requires a Certificate of Public Convenience and Necessity (CPCN) (PPRP, 2007). The Maryland Power Plant Research Program (PPRP), within the Maryland DNR, is involved in the certification process by helping to inform the PSC CPCN evaluation process through reviews of environmental, engineering, and cost issues in addition to providing a set of licensing recommendations (PPRP, 2007).

The traditional protocol for large new transmission lines (e.g., backbones) requires that prior to any application for a CPCN with the PSC, PJM Interconnection must establish a need for new transmission. This is evident in the recent suspension of the PSC permitting process of the Mid-Atlantic Power Pathway (MAPP) line. It is expected that PJM Interconnection will re-evaluate and confirm the need for the MAPP line before the PSC permitting process proceeds (PHI, 2010b). Whether a similar order of operations will be necessary for offshore interconnection and transmission siting within Maryland remains to be seen.

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[7] The Atlantic coastal area from metropolitan New York southward through Northern Virginia is classified as critical congestion areas, including most of Maryland's Eastern Shore (U.S. DOE, 2006; U.S. DOE, 2007).

[8] The PSC does not have sole responsibility over transmission siting and approval and cannot unilaterally expedite the process (PSC, 2009c).

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7. Appendices

Appendix A: Renewable Portfolio Standard Implementation Schedule

Compliance Year	Previous RPS Requirement			2009 RPS Requirement		
	Tier 1	Tier 1 Solar	Tier 2	Tier 1	Tier 1 Solar	Tier 2
2007	1.0%	NA	2.50%			
2008	2.005%	0.005%	2.50%	2.005%	0.005%	2.50%
2009	2.010%	0.010%	2.50%	2.010%	0.010%	2.50%
2010	3.025%	0.025%	2.50%	3.025%	0.025%	2.50%
2011	3.040%	0.040%	2.50%	5.000%	0.040%	2.50%
2012	4.060%	0.040%	2.50%	6.500%	0.040%	2.50%
2013	4.100%	0.100%	2.50%	8.200%	0.100%	2.50%
2014	5.150%	0.150%	2.50%	10.300%	0.150%	2.50%
2015	5.250%	0.250%	2.50%	10.500%	0.250%	2.50%
2016	6.350%	0.350%	2.50%	12.700%	0.350%	2.50%
2017	6.550%	0.550%	2.50%	13.100%	0.550%	2.50%
2018	7.900%	0.900%	2.50%	15.800%	0.900%	2.50%
2019	8.700%	1.200%	0.00%	17.400%	1.200%	0.00%
2020	9.000%	1.500%	0.00%	18.000%	1.500%	0.00%
2021	9.350%	1.850%	0.00%	18.700%	1.850%	0.00%
2022	9.500%	2.000%	0.00%	20.000%	2.000%	0.00%
2023 +	9.500%	2.000%	0.00%	20.000%	2.000%	0.00%

(Source: PSC, 2009a)

II. An Assessment of Potential Interconnection Points for Offshore Wind

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1. Introduction

This chapter identifies potential interconnection points for offshore wind development adjacent to Maryland's coast. First, in Section 2, we discuss the transmission system in the region operated by PJM Interconnection, focusing on proposed improvements including the MAPP line and other upgrades planned on the Delmarva Peninsula. For each of these projects, we include a brief synopsis of proposed routes or locations as well as their development [9]. In Section 3, we consider the case of Bluewater Wind and its proposals to interconnect a proposed offshore wind facility to the transmission grid in Maryland and Delaware. That proposed project currently provides the closest reference point to assess potential offshore wind generation in Maryland. The impact and facilities studies undertaken for the Bluewater Wind project illustrate the variation in the ability of the transmission system to interconnect with offshore wind. Finally, in Section 4, we apply the lessons learned from the Bluewater Wind case study and discuss optimal interconnection points.

2. Delmarva Peninsula Transmission Grid: Planned System Upgrades and Status

This section details planned transmission upgrades in PJM and corresponds to a Geographic Information System data file (See Map 1) that includes the transmission network on the Delmarva Peninsula (e.g., existing and planned transmission upgrades, line voltages, and substation locations). In this section, we discuss the proposed backbone facilities before detailing the proposed MAPP line, which would directly impact electricity transmission on the

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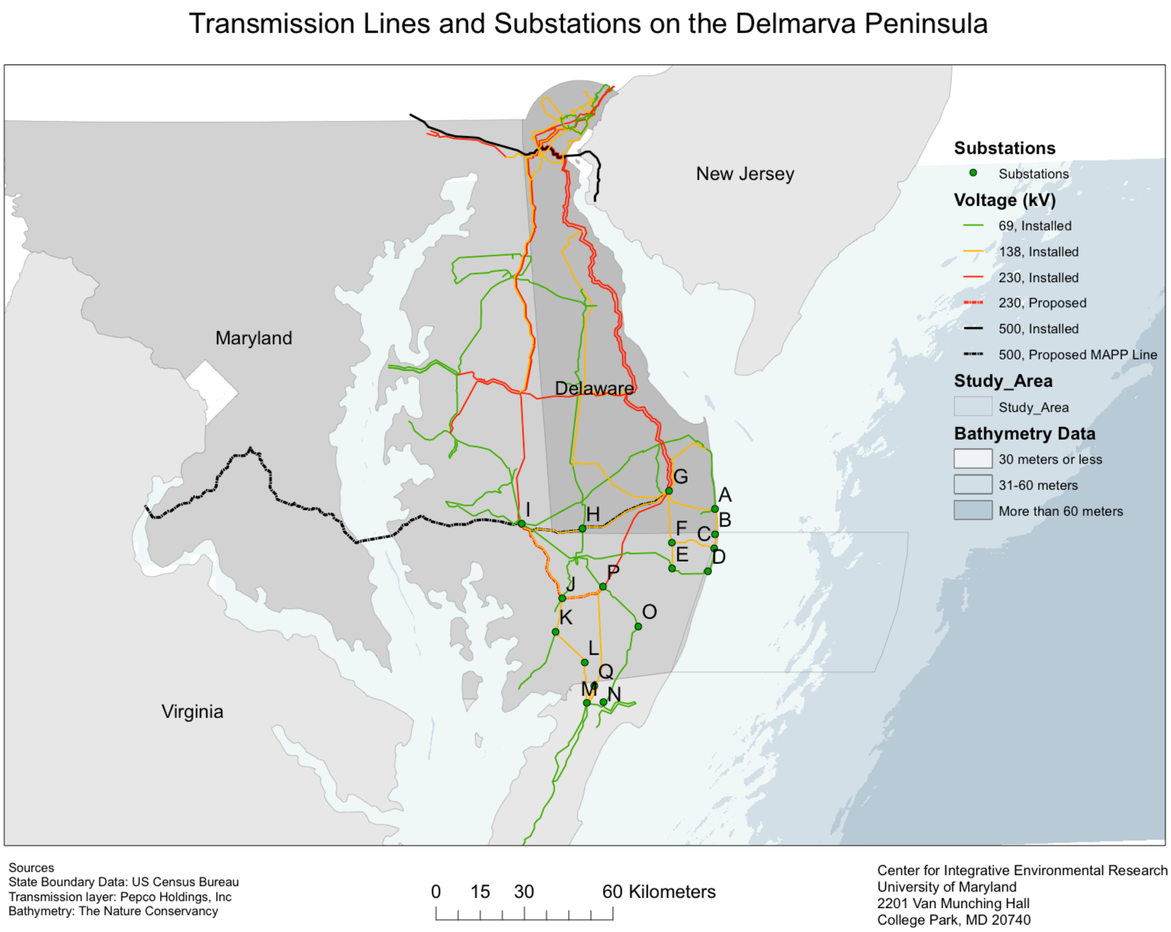
[9] The transmission system (e.g. current transmission grid, including line voltages, planned expansions to the system, substations) is available as a geographic information system data file online at http://dnr.maryland.gov/ccp/coastalatlas/,.

Delmarva Peninsula. Next, we discuss the proposed transmission upgrades, not considered as backbone projects, on the Delmarva Peninsula.

Map 5-Transmission Lines and Substations on the Delmarva Peninsula



2.1.Proposed PJM Backbone Projects

PJM Interconnection coordinates the movement of wholesale electricity in Maryland and all or parts of 12 other states, as well as the District of Columbia. In order to resolve reliability criteria violations, PJM implements baseline upgrade projects; some projects are designated as “backbone projects” due to their high degree of visibility within the stakeholder community. Backbone upgrades are on the Extra High Voltage System and typically resolve a wide range of reliability criteria violations and market congestion issues (PJM, 2009a).

There are currently six backbone projects in the PJM queue (PJM, 2008c). In 2006, two projects were proposed: 500 kV Trans Allegheny Line (TrAIL) and Carson-Suffolk 500 kV transmission line. In 2007, four more backbone projects were proposed including a 500 kV Mid-Atlantic

Power Pathway (MAPP), a 765 kV Potomac-Appalachian Transmission Highline (PATH),the Susquehanna-Roseland 500 k V transmission line and the Branchburg-Roseland-Hudson 500 kV transmission line (see Figure 3 and Table 2).

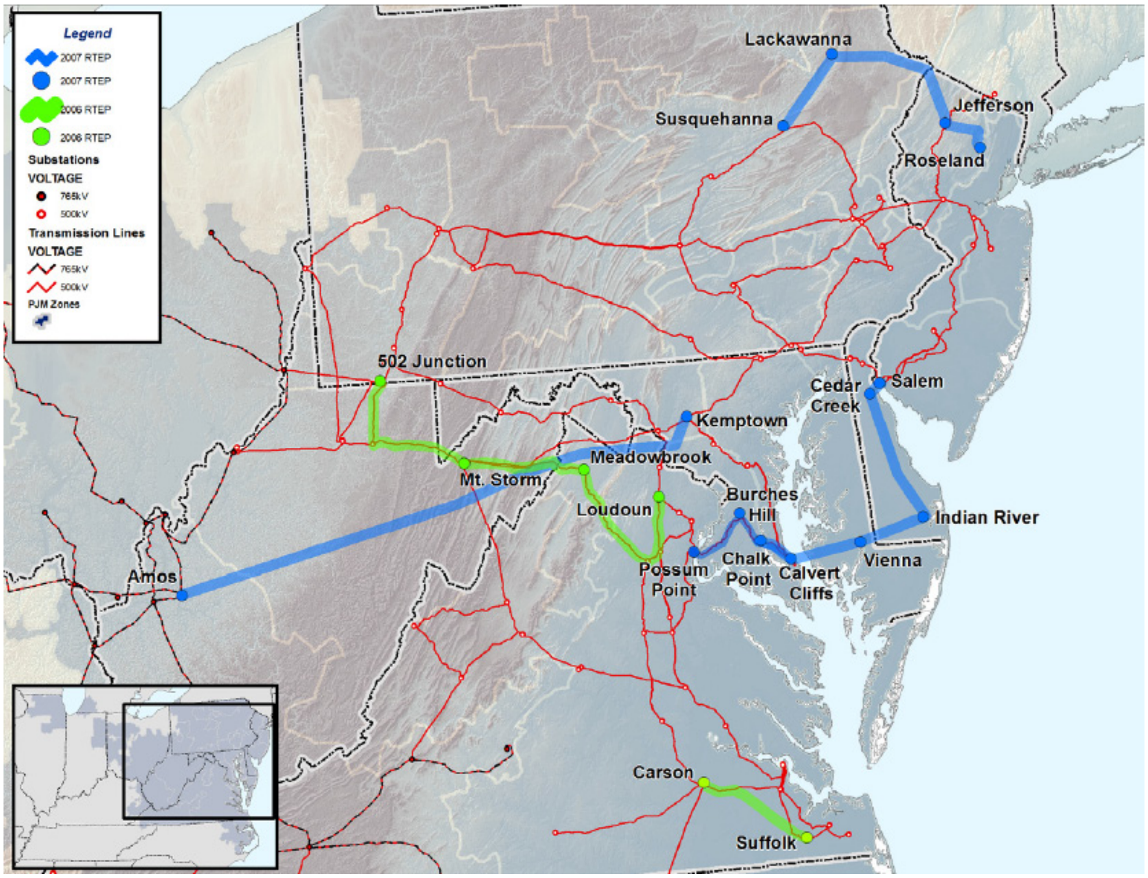


Figure 3-PJM Proposed Backbone projects (Source: PJM, 2009a)

The MAPP project is a 241km transmission line that would serve Maryland, Delaware, and the District of Columbia, and significantly increase the region's ability to import and export power. One part of the line will be a 116km long 500 kV HVAC power line that travels through Charles, Prince George’s, and Calvert Counties in Maryland, from Possum Point, VA through Burches Hill, Chalk Point, to Calvert Cliffs[10]. The other portion of the line is a proposed 640 kV HVDC power line crossing the Chesapeake Bay onto the Delmarva Peninsula, from Calvert Cliffs through Salisbury to Indian River in Sussex County, DE. While the 500 kV HVAC power line will mostly use existing transmission towers and is estimated to be completed in 2012, the 640 kV HVDC power line is estimated to be completed in 2014 because it will include a new line

[10] The high voltage backbone MAPP is scheduled to be in service by June 1, 2014; the project schedule and current status of MAPP is summarized in Chapter II.

whose route has not yet been decided. Currently, permit application, land acquisition and design are all in progress for MAPP (PHI, 2009a).

Table 2-PJM Proposed Backbone Projects (Source: PHI, 2009a; AEP et al., 2009; PPL, 2008; PSE&G, 2009; PJM, 2009a; Allegheny Energy, 2009; Dominion, 2008)

Name	Voltage (kV)	Length (km)	Status	Completion Date	Est. Cost (Billion dollars)
MAPP	500/640	241	See below	2012/2014	1.2
PATH	765	443	Waiting for permission	June 1, 2014	1.8
Susquehanna -Roseland	500	N/A	Waiting for permission	June 1, 2012	
Branchburg-Roseland-Hudson	500		Proposed by PJM	June 1, 2013	1.088
TrAIL	500	N/A	In construction	June 2011	0.82[11]
Carson -Suffolk	500 230	96 34.6		June 1, 2011	

In January 2010, Pepco Holdings, Inc. was granted approval to suspend its procedural permitting schedule (e.g., CPCN) for the MAPP line, which is coordinated by the PSC (PHI, 2010). PJM is currently re-evaluating the need for the MAPP line, which, under the current order of operations, will likely occur before the PSC resumes its CPCN process (PHI, 2010).

The MAPP line is proposed as two separate HVDC cables with parallel circuits capable of transmitting a maximum 1,000 MW each. The lines are bidirectional so that the power (2,000 MW in total) can flow either from Calvert Cliffs to the Delmarva Peninsula or back across. The benefits of an HVDC bidirectional system would be twofold: (a) allowing renewable energy (or energy more broadly) to flow into or out of the Delmarva Peninsula; and (b) providing the necessary control to accommodate the variability of wind generation (due to variable wind speed) in order to maintain system reliability (Gausman, 2009).

[11] An estimate of TrAILCo's portion of the project.

2.2.RTEP Upgrades on the Delmarva Peninsula (Proposed)

Table 3 provides an account of the newly approved transmission upgrades on the Delmarva Peninsula, which are greater than $5 million (PJM, 2008c).

Table 3-Transmission Expansion Plans on the Delmarva Peninsula (Source: PJM, 2008c)

ID	Description	Location	Due date	Status	Est. Cost (Millions)
b0725	Add a 3rd 230/138 kV transformer	Steele	06/01/2013	Engineering /Planning	8.00
b0733	Add a 2nd 230/138 kV transformer	Harmony	06/01/2013	Engineering /Planning	7.50
b0737	Build a new 138 kV line	Indian River – Bishop	06/01/2013	Engineering /Planning	18.00
b0750	Convert 138 kV Line to 230 kV Add a 230/138 kV transformer	Vienna-Loretto-Piney-Grove Loretto	06/01/2013	Engineering /Planning	40.00
b0754	16km line to bring 298 MVA normal rating to 333 MVA emergency rating	Glasgow – Mt. Pleasant	06/01/2013	Engineering /Planning	5.70
b0792	Reconfigure Sub into 230 and 138 kV ring buses, add a 230/138 kV transformer, operate the 34 kV bus normally open	Cecil	06/01/2013	Engineering /Planning	6.00

3. Interconnecting to the Onshore Transmission Grid

In this section, we investigate the feasibility/optimality of various interconnection points for potential Maryland offshore wind generation and identify the basic requirements to deliver wind energy. Bluewater Wind proposals, designated in the PJM queue as T122 and R36, will provide a case study from which it is possible to review impacts on the transmission system, and the associated cost of reinforcement in the system that might be incurred by the interconnection. Under the scope of this analysis, however, this study does not involve a PHI transmission system modeling and simulation for contingency analysis to determine the effect of various types of abnormal disturbances on the system performance[12]. Modeling work would require proprietary information from PHI, including power flow diagrams, information regarding power transfer limits and thermal limits on each transmission line in the system, generator reactive powers, bus voltages and phases of all substations (Milano et al., 2005; Deuse et al., 2003). Instead, for this analysis, we use a transmission map to make a preliminary birds-eye view determination of feasible interconnection points.

Two geographic information system data layers, Transmission and Substation layers, accompany this section of the report. These files contain approximate substation locations as well as transmission lines, voltages and locations, and the distance between each substation. It should be noted that in this report we do not reveal substation names because of their classification by Pepco Holdings, Inc. as critical infrastructure. The transmission and substation data files can be accessed online at http://dnr.maryland.gov/ccp/coastalatlas/.

3.1. Case Study: Bluewater Wind–Potential Impacts on the Transmission System and Network Reinforcement

Integration of offshore wind energy into the onshore transmission grid requires consideration of interconnection points that minimize network impacts so as to prevent contingent overloads on the grid. For example, the impact study for project T122 in the queue analyzed the network impacts and necessary upgrades to the PHI transmission system resulting from the integration of 600 MW of offshore wind generation[13]. T122 plans proposed a 138 kV transmission system from offshore wind farm facilities to Substation B (see Figure 4). However, the total cost of reinforcing all necessary 69 kV, 138 kV, and 230 kV transmission cables, as well as the breakers in local or remote substations coupled with Substation B is estimated to cost in excess of $200 million. In Figure 4 we illustrate the local substations cascaded with Substation B.

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[12] Examples of abnormal disturbances considered by PHI are shown in the PEPCO transmission and interconnection reliability standards (PHI, 2009d).

[13] Queue T122, located approximately 20.9 - 24.1 km off of Ocean City, MD was proposed by Bluewater Wind Maryland, LCC to interconnect an offshore wind energy of 600 MW to PHI's transmission grid on the Delmarva Peninsula. The offshore wind farm consisted of two hundred 3 MW wind turbine generators.

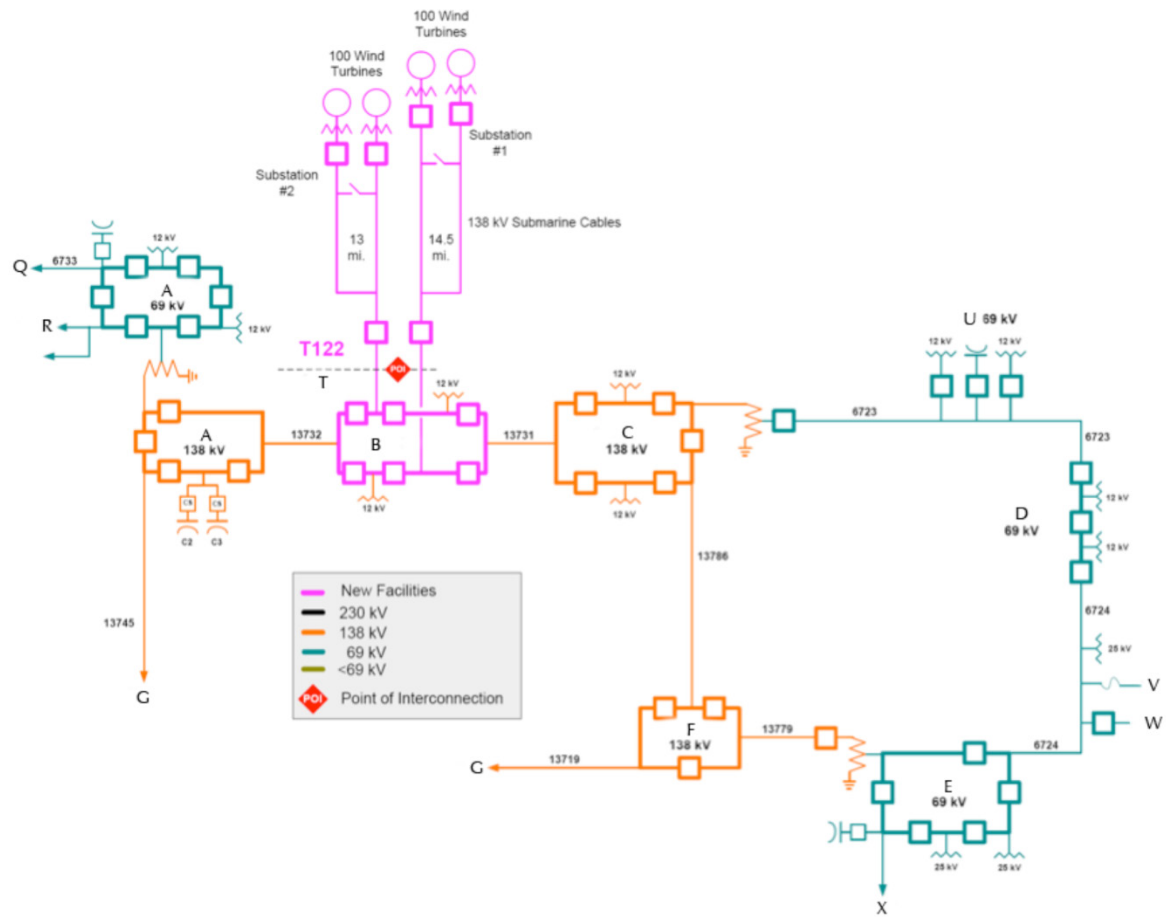


Figure 4-Diagram of Direct Connection in PJM Queue T122 (Source: PJM, 2009f)

As shown in Figure 5, approximately 94 percent of the reinforcement cost was allocated to replacing and re-tensioning existing AC transmission lines to accommodate the contingency overloads.

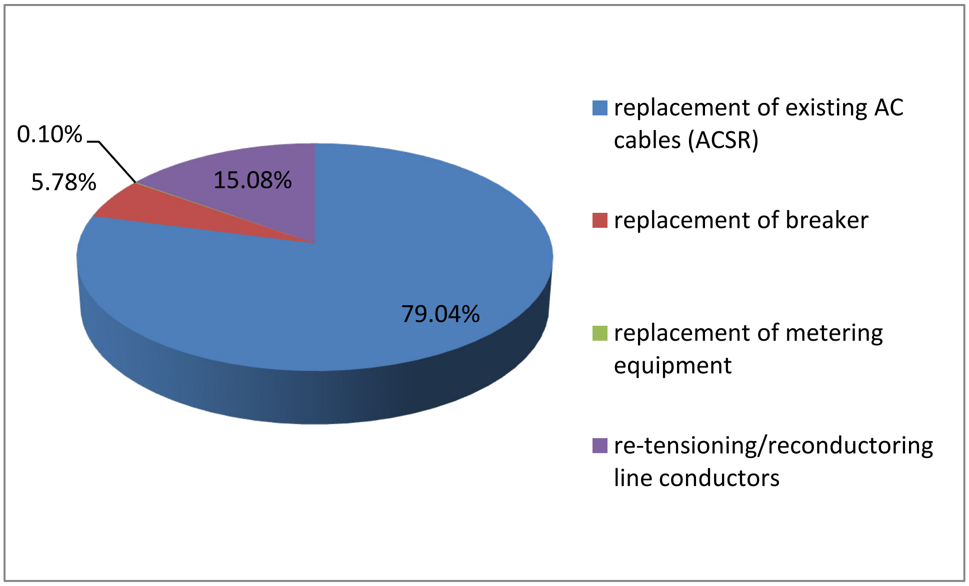


Figure 5-PJM Queue T122 System Upgrade – Cost Distribution (Source: PJM, 2009f)

As a result of the expected costs of interconnection, project T122 was replaced in the PJM queue by project R36, which changed the interconnection point and transmission system voltage. The total interconnection cost for the new project is reduced to approximately 10 percent ($21 million) of the former[14]. The R36 project moves the point of interconnection (POI) to the vicinity of Bethany Beach, DE and proposes a higher transmission voltage onshore to the POI, which would then be transmitted to substation G (POD). Subsequently, the R36 proposal requires fewer transmission system upgrades than project T122 (PJM, 2009d; Gausman, 2009).

For a direct connection between the POI and POD, a 230 kV onshore substation would be constructed near Substation A. In addition, approximately 19 kilometers of new 230 kV transmission line would be installed between the new onshore substation and Substation G. The R36 project originally proposed a direct connection from Bluewater Wind DPL Substation to Substation G with a new 138 kV transmission line (19.6 kilometers in length). However, it would have incurred over $50 million of transmission system upgrade costs to enable delivery of the full wind energy output of 600 MW (Gausman, 2009)[15].

[14] Project R36 reduced the size of the wind farm from 600 MW to 450 MW and reduced the number of 3 MW wind turbines from 200 to 150.

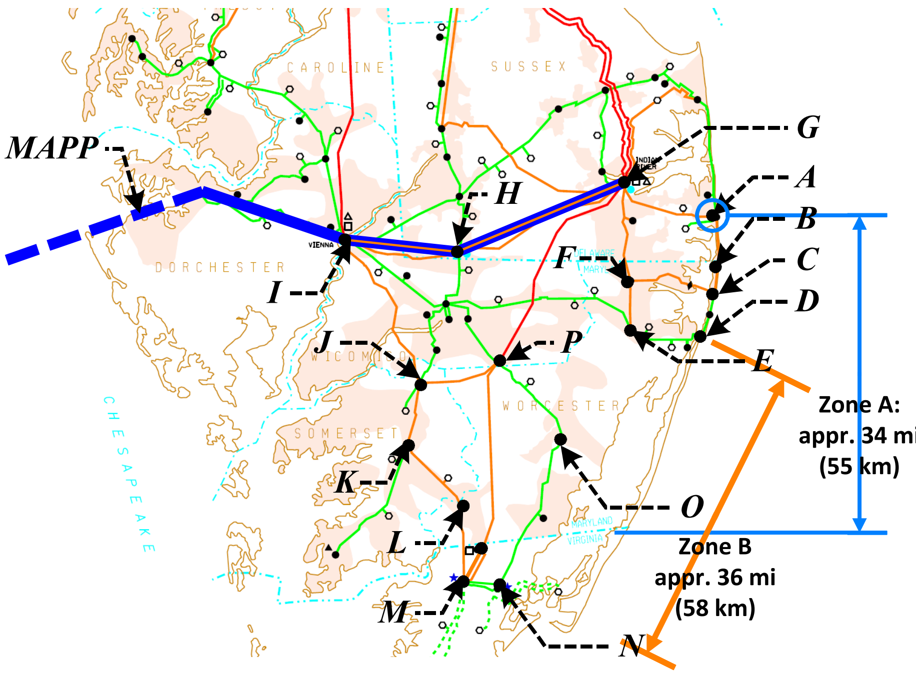
[15] The direct transmission line from Bluewater Wind DPL Substation to Substation G is an open right-of-way which would allow PHI to build an additional line on the existing right-of-way over 138 kV transmission line between the two stations with new steel pole H-frame structures (PHI, 2009c). The existing transmission corridor between Bethany and Indian River Substations is approximately 19.3 kilometers long and is 150 feet wide.

The impact study undertaken for project T122 in the PJM queue suggested that the injection of 600 MW of offshore wind energy into the PHI transmission system at Substation B would result in thermal congestion on various 138 kV and 230 kV lines (PJM, 2007b). In other words, the current PHI transmission system appears to be unable to accommodate the significant offshore wind resource available (MEA, 2009a; MEA, 2009b). However, because of the high transmission capacity (up to 2,000 MW), the proposed MAPP line could help to address the issue by handling the contingent overflow. Moreover, controllability of DC flow in the lines would enable absorption and delivery of offshore power across Maryland without congestion.

4. Optimal Interconnection Points

The costs, projected in the impact and facilities studies of projects T122 and R36 in the PJM queue, as well as the proposed introduction of the MAPP HVDC transmission backbone in the Delmarva Peninsula, present two rules for choosing an optimal interconnection point in the area: (a) wind energy needs to be transmitted via a high transmission voltage (i.e., 230 kV or more) to reduce network impacts and the associated cost of transmission system upgrade, and (b) the closer the 230 kV (or higher voltage) substation at POD is to an HVDC transmission line, the higher the reliability and deliverability of the transmission system. With these two rules we can predict that optimal POI and POD for an offshore wind farm adjacent to Maryland's Atlantic coast.

Figure 6 shows two offshore zones in the Atlantic Ocean: Zone A is a 55 km region from Substation A to the boundary of Maryland and Virginia. Zone A covers most of the ocean east of Maryland; Zone B represents the offshore area along the Assateague Island National Seashore, which is designated a Sensitive Species Project Review Areas (SSPRA) by the Maryland Department of Natural Resources (DNR, 2003).



Approximate Distance between Substations		
A ↔ B	5.5 mi	8.9 km
A ↔ G	12.2 mi	19.6 km
B ↔ C	3.0 mi	4.8 km
C ↔ D	5.0 mi	8.0 km
C ↔ F	9.0 mi	14.5 km
D ↔ E	8.0 mi	12.9 km
E ↔ F	5.5 mi	8.9 km
F ↔ G	11.0 mi	17.7 km
G ↔ H	21.4 mi	34.4 km
H ↔ I	14.0 mi	22.5 km
I ↔ J	19.0 mi	30.6 km
I ↔ P	23.0 mi	37.0 km
J ↔ K	7.0 mi	11.3 km
J ↔ P	9.5 mi	15.3 km
K ↔ L	9.0 mi	14.5 km
L ↔ M	9.0 mi	14.5 km
M ↔ N	3.6 mi	5.8 km
M ↔ P	27.0 mi	43.5 km
N ↔ O	19.0 mi	30.6 km
O ↔ P	12.0 mi	19.3 km

Figure 6-PHI Substations and Transmission Lines on the Delmarva Peninsula (Source: Pepco Holding, Inc., 2009c)[16]

Assuming that (a) paths along with the transmission lines in Figure 6 are right-of-ways, (b) new transmission lines can be installed on the pole (e.g., 19.6 kilometers direct connection in (PJM, 2009d)) or underground, and (c) there are no major regulatory or environmental impacts along the transmission lines, we propose that the optimal POI for offshore wind be located within Zone A (i.e., Substations A through D) because of the proximity to the coast. As substations A through C are 138 kV substations and Substation D is 69 kV, an additional higher voltage (i.e., 230 kV) switching substation such as Bluewater Wind DPL Substation would need to be built within the right-of-way of the existing substation (PJM, 2009d).

Substation A, located in Delaware, has the unique advantage of the shortest distance to Substation G where the MAPP Line is proposed to pass. Further the path from A to G is an open right-of-way, so there is no additional cost from land acquisition. If the offshore wind farm is located within 50 km of substations B or C then the shortest path to substation G is B-A-G or C-B-A-G.

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[16] The black dots represent substations while the blue line represents the proposed route of the 640 kV High Voltage Direct Current MAPP Line. The distances are approximated when they are not available from PJM sources (PJM, 2009a; PJM, 2009b; PJM, 2009c; PJM, 2009f). The transmission lines are drawn with the connectivity information in the PHI facilities list (PJM, 2009e).

As shown in the R36 Facilities Study, the procurement of cables (over 19.3 kilometers in length) and necessary equipment for cabling work accounts for the largest portion of the total cost estimate (i.e., $9.56 million of the projected total cost of $21 million) and implies that the interconnection cost will increase with the distance between two onshore substations (PJM, 2009d). Thus minimizing the interconnection cost requires finding the shortest path from POI to POD (e.g., shortest path problems in network models) (Winston and Venkataramanan, 2003).

However,in Zone B there are significant barriers to interconnection between any offshore wind facilities and the onshore transmission grid. A lack of substations located near the coast would likely require land acquisition costs for a new substation on the coast and a right-of-way to Substations N and O. Additionally, Assateague Island National Seashore prevents a direct connection to Substations N and O, resulting in a circuitous route around the Seashore[17].This indirect routing would be necessary if an additional high voltage substation could not be constructed on Assateague Island due to possible impact on the environmental resource area. In this case, Substation N in Virginia would be the first option for a POI, but it would require approximately 76.6 kilometers of cabling (on the shortest path N-M-L-K-J-I) in order to deliver offshore wind energy to Substation I.

For the given configuration of substations and transmission lines on the Delmarva Peninsula, and considering our assumptions, we propose that Substations A to D provide for the optimal POIs and Substation G for optimal POD.

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III. An Investment Model: Collection and Transmission Systems for Offshore Wind Power

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1. Introduction

In this chapter, we examine investment costs for two hypothetical wind farms adjacent to Maryland's coastline. In our scenario analysis, we consider the influence of water depth and its implications on foundation technology choices, transmission and collection systems, cable length, and wind potential for the area on total investment cost for a 600 MW and 1,000 MW facility. The organization of the chapter is as follows. We first explore the underlying assumptions within our simplified investment model, then perform the model analysis and discuss the results. In this study, we rely heavily on existing literature, experiential data from wind farms built to date, planning documents for wind farms yet to be constructed, as well as information from contacts within the wind industry.

In Section 2, we discuss offshore wind projects in Europe and proposed projects in the United States. We use the experiences in Europe and the United States to estimate component costs, technology choice, wind farm configuration and interconnection costs associated with developing offshore wind. Wind farm component costs are compiled from a variety of sources including existing literature on offshore wind energy development in Europe as well as planned projects in the United States, such as the planned 468 MW Cape Wind project in Nantucket Sound, Massachusetts and the 450 MW Bluewater Wind project proposed offshore of Bethany Beach, Delaware.

Section 3 focuses on bathymetry and wind data for areas off of Maryland's shores. Water depth will be a critical factor in determining the appropriate foundation system for a project and, according to a study of European wind farms, foundation costs accounted for approximately 24 percent of total costs (DUWIND, 2001). In our first scenario, we assume that offshore wind will be sited in shallow water (less than 30 meters) for two reasons: first, only two projects have been built in water depths greater than 30 meters; and second, shallow water predominates off the coast of Maryland (within 64 kilometers of shore) (see Section 3.1)[18]. In the second scenario, a 1,000 MW facility, we assume a deep-water application. It is likely that offshore wind in deepwater applications will rely heavily on existing oil and natural gas platform technologies.

Section 4 discusses existing collection and transmission system technologies, as well as reviews existing wind farm configurations. The choice of transmission system will depend on a number of factors including the distance from the point of interconnection, as well as the capacity constraints to receive input at those points.

In Section 5, we specify the underlying assumptions for a simplified investment model using our review of literature before discussing the results from our model. The investment cost is estimated for a wind farm layout given input parameters such as the number of wind turbines, wind turbine size, wind turbine array and spacing, and length of collection and transmission cables.

2. Offshore Wind-Europe and the United States

In this section, we explore lessons learned from offshore wind in Europe before turning our attention to proposed offshore wind projects in the United States. Europe has significantly more offshore wind projects installed, while the United States has a number of projects in development. Two projects in the United States -- Cape Wind and Bluewater Wind -- are particularly important for informing assumptions within the investment model detailed in Section 5.

Offshore wind energy has many advantages over its onshore counterpart including greater and less intermittent wind speed, space, aesthetic advantages, and proximity to population centers. However, offshore wind is still about 50 percent more expensive than onshore wind (EWEA, 2009b).

First, stronger, steadier winds offshore can produce more wind energy, which offsets a portion of the higher installation and operation costs. Weather models have shown a sharp increase in wind speed as the distance from shore increases (Musial et al., 2006). The National Renewable Energy Laboratory (NREL) estimates an offshore wind resource potential of 907 gigawatts (GW) for the zone of 9.6-92 kilometers off the coast of United States – Class 5 and 6 and some Class 7 winds

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[18] The Beatrice Project is a demonstration project off the coast of Scotland that operates in water depths of 45 meters. The Hywind Project is a demonstration project off the coast of Norway operated by StatoilHydro. The project consists of a floating wind turbine and is located in over water depths of approximately 220 meters (Statoil, 2009).

are available in this zone (Musial and Butterfield, 2004). About 10 percent or 98 GW of the wind energy potential is found in shallow water; mid-Atlantic states have a wind energy potential of 82 GW in shallow water and 178.5 GW in deep water. Of the contiguous 48 states, 28 with coastal boundaries use 78 percent of the nation's electricity; shallow water offshore potential (less than 30m in depth) in 26 of 28 states would meet at least 20 percent of their electricity needs (US DOE EERE, 2009).

Second, siting wind farms further from shore can mitigate some of the public acceptance issues related to visual and noise impacts of the wind turbines (Musial et al., 2006)[19]. Third, building wind farms offshore offers a larger area for installation, which allows for installation of larger turbines (Breton and Moe, 2009). Finally, adequate wind sites close to major urban load centers can allow for shorter transmission lines.

There are many challenges in developing offshore wind energy as described in Breton and Moe (2009). Higher investment costs for installing wind turbine towers and substructures and underwater cabling between wind turbines are required, which is 1.5-2 times more expensive than onshore (Breton and Moe, 2009). According to the European Wind Energy Association, in both offshore and onshore applications, turbines account for the largest share of total costs, or 49 percent of total investment costs for offshore applications and 76 percent for onshore applications (2009b) (see Table 4). However, offshore wind farms require significant investments in foundation and transmission systems, which can account for approximately 37 percent of the total investment cost per MW. Meanwhile, similar costs for an onshore application (i.e., land rent, grid connection, foundation, road construction) accounts for only 20 percent of the total investment cost (EWEA, 2009b). The European Wind Energy Association projects that investment costs for a new offshore wind farm (near shore in shallow water) is currently in the range of 2.0-2.2 million Euro/MW on average (2009b)[20]. The average cost is expected to decrease approximately 15 percent (1.81 million Euro/MW or $2.5 million) by 2015.

[19] Visual and noise impacts do not represent the entire set of issues related to offshore wind farms. The College of Marine Studies, University of Delaware identified other impacts from a survey of Cape Cod, MA residents including impacts on marine life, aesthetics, fishing impacts, and boating and yachting safety, etc. (Firestone and Kempton, 2006).

[20] Given the current exchange rate of 1 euro equal to about $1.41, range of investment is on the order of $2.8 million to $3.1 million (XE, 2010).

Table 4-Average Investment Cost per MW: Offshore Wind Farms Horns Rev and Nysted (Source: EWEA, 2009; DEA, 2009)

	Investments (1,000 Euro/MW)[21]	**Cost Share %**
Turbines, including transport and erection	815	49
Transformer station and main cable to coast	270	16
Internal grid among turbines	85	5
Foundations	350	21
Design and project management	100	6
Environmental analysis	50	3
Miscellaneous	10	< 1
TOTAL	1,680	~100

2.1.European Experiences with Offshore Wind

Offshore wind development in Europe has largely been confined to shallow water (less than 30 meters), where the established monopile foundation technologies can be utilized without further significant research and development effort[22]. European wind farms have varied in terms of capacity, as well as number and the size of turbines (see Table 5). Turbine size has ranged

[21] Investment totals are in 2006 Euros.
[22] Exceptions include the Beatrice and Hywind projects mentioned previously, however, these projects are demonstration projects and to date no commercial wind farms are operating in these depths.

between 2 MW and 3.6 MW with more recent wind farms utilizing larger turbine sizes[23]. There has been large variability in overall wind farm capacities, from 23 MW to 180 MW[24]. Investment costs in Europe have varied significantly from a low of 1.175 million Euros per MW to 2.7 million Euros per MW (see Table 5).

Table 5-European Offshore Wind Farms (2001-2008) (Source: EWEA, 2009b)

	First Year in Operation	Number of Turbines	Turbine Size (MW)	Capacity (MW)	Investment Costs (M Euro)	Investment Costs (M Euro/MW)
Middelgrunden (DK)	2001	20	2	40	47	1.175
Horns Rev I (DK)	2002	80	2	160	272	1.700
Samsø (DK)	2003	10	2.3	23	30	1.304
North Hoyle (UK)	2003	30	2	60	121	2.017
Nysted (DK)	2004	72	2.3	165	248	1.503
Scroby Sands (UK)	2004	30	2	60	121	2.017
Kentish Flats (UK)	2005	30	3	90	159	1.767
Barrows (UK)	2006	30	3	90	-	
Burbo Bank (UK)	2007	24	3.6	90	181	2.011
Lillgrunden (S)	2007	48	2.3	110	197	1.791

[23] Offshore wind turbines manufactured range from 2.5 MW to 6 MW: 2.5 MW by Nordex; 3 MW by Vestas; 3.6 MW by Siemens; 5 MW by BARD Engineering, Multibrid, and REpower; and 6 MW by REpower (See Appendix B for more information) (EWEA, 2009a).

[24] A more detailed description of each project including wind farm location, developer, water depths, distance to shore, turbine manufacture and rated power is available in Appendix A.

Robin Rigg (UK)	2008	60	3	180	492	2.733

2.2. Planned Offshore Wind Projects in the United States

In the United States, offshore wind projects have been announced however, at this time, none are in service. Three proposed projects that are examined further are the Cape Wind project offshore Cape Cod, Massachusetts; Bluewater Wind project offshore of Bethany Beach, Delaware; and the New York City offshore wind project located off of the Rockaway peninsula. Each of these projects is detailed below, including proposed layouts that can be found in Figures [7, 8, 9]. Table 6 lists the proposed offshore wind facilities in the United States.

Table 6-Proposed US Commercial Offshore Wind Projects (Source: MMS, 2009a; American Wind Energy Association, 2010)

Project	State	Capacity (MW)	Federal or State Waters
Cape Wind	MA	468	Federal
Hull Municipal	MA	15	State
Rhode Island (OER)	RI	400	Federal
Block Island Wind Farm	RI	TBD	TBD
New Jersey (BPU)	NJ	350	Federal
Bluewater Wind	NJ	TBD	TBD
Garden State Offshore Energy	NJ	TBD	TBD
NC Coastal Wind Demonstration Project	NC	TBD	TBD
Bluewater Wind	DE	350	Federal
Southern Company	GA	10	Federal
W.E.S.T.	TX	150	State
Cuyahoga County	OH	20	State
Total		2,068	

2.2.1. Cape Wind – Cape Cod, Massachusetts

The proposed Cape Wind project consists of 130, 3.6 MW wind turbines spread over an area of 62 square kilometers with a designed maximum capacity of 454 MW (MMS, 2009b)[25]. With an average wind speed of 8.8 m/s, the net energy production delivered to the regional transmission grid (NSTAR) is expected to be approximately 1.6 GWh per year (MMS, 2007). The wind farm's proposed location is in federal waters 7.6 kilometers offshore Cape Cod, Massachusetts,

[25] The capacity is based on design wind velocities of between 13.4 m/s (30 mph) and 24.6 m/s (55 mph) (MMS, 2009b)

on Horseshoe Shoal in Nantucket Sound (see Figure 7). According to the project timeline, the permitting process was to be completed in 2009 while turbine manufacturing and construction would begin in 2010 (Cape Wind Associates, 2009). In April 2010, the Cape Wind project was approved by the Secretary of the Department of the Interior (USDOI, 2010).

2.2.2.Bluewater Wind - Bethany Beach, Delaware

The Bluewater Wind site is proposed 21 – 24 kilometers off of the coast of Delaware near Bethany Beach (Figure 8). The project proposes to employ 150, 3 MW wind turbines and has been evaluated as an energy resource for its nameplate capacity of 450 MW (PJM, 2009d). Bluewater wind has a power purchase agreement in place for 200 MW. The project has an estimated in-service date of late 2013 or early 2014 (PJM, 2009d).

2.2.3.New York City/Long Island Offshore Wind – Rockaway Peninsula, New York

The Long Island, New York City Offshore Wind project is proposed for an area approximately 24 kilometers off of the Rockaway Peninsula in the Atlantic Ocean (Figure 9). The project has a designed generation capacity of 350 MW. In April 2009, an application was submitted to the New York Independent System Operator to interconnect the offshore wind project to the state's power grid by 2015 (LINY Offshore Wind Collaborative, 2009).

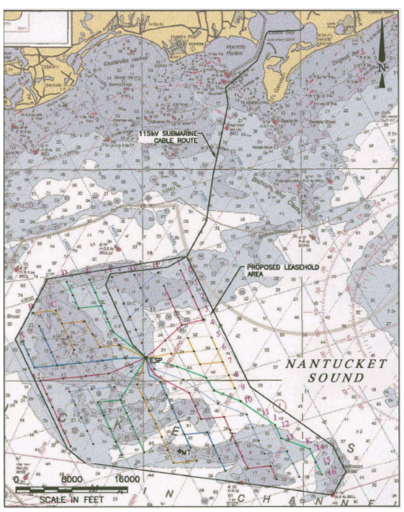

Figure 7-Cape Wind Project, MA (Source: MMS, 2009b)

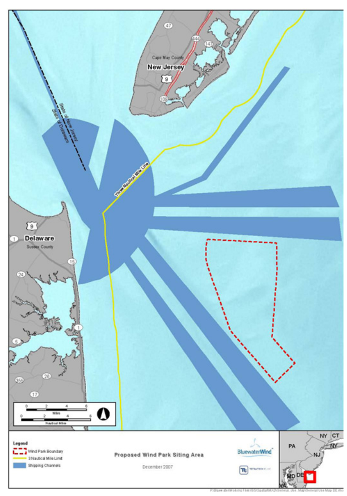

Figure 8-Bluewater Wind Project, DE (Source: DPL, 2009)

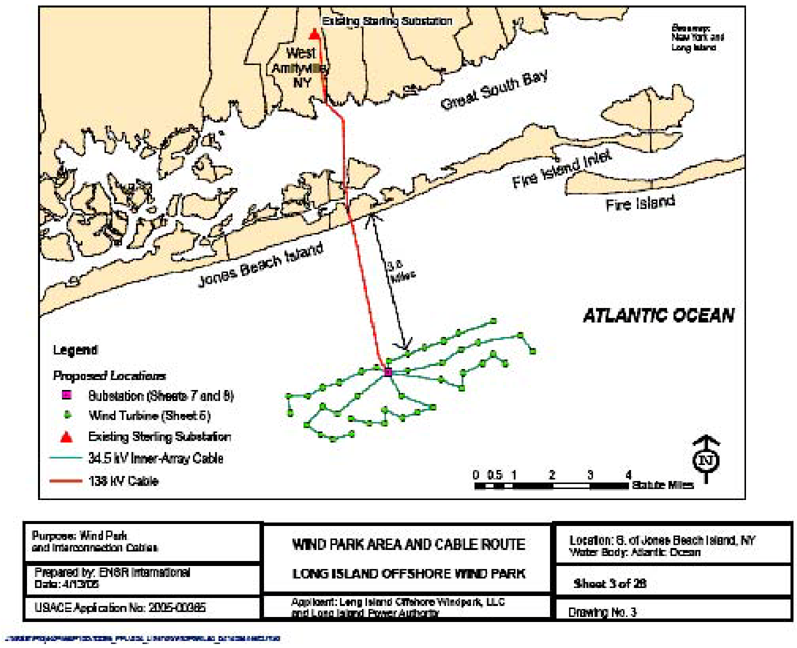

Figure 9-Long Island, New York City Offshore Wind Park Project (Source: Long Island Offshore Wind Park, 2005)

3. Bathymetry Data Analysis: Capabilities and Limitations of Offshore Wind Foundation Technologies

A number of factors will determine the location and deployment of offshore wind farms. In this section, we investigate the impact of water depth on the choice of anchoring technology and explore bathymetry data for the area adjacent to Maryland's coastline.

To date, most offshore wind development has been in shallow waters between five and eighteen meters, with two notable exceptions, the Beatrice Project located off the coast of Scotland is in 45 meter water depths and the Hywind Project located off the coast of Norway is in 220 meter water depths (Talisman, n.d.; IEA, 2005; Musial et al., 2006). The Beatrice project achieved a number of firsts including being the first offshore wind project to deploy in transitional technology water depths (which require more advanced foundation types) as well as the first to use the 5MW turbines (Musial et al., 2006). The Hywind project utilizes a 2.3 MW wind turbine located on a floating platform (Statoil, 2009).

Offshore wind farms today tend to be marinized versions of onshore wind farms, which can be operated in waters of up to 30 meters depth and are largely dependent on monopile technology (e.g., Horns Rev, Denmark) and gravity-based structures (e.g., Nysted, Denmark)(Musial et al., 2006). However, as turbine size increases and the industry migrates into deeper waters, jackets/tripods (up to 50-60 meters) or floating structures (over 60 meters) will be required. The costs of offshore foundations will likely increase due to the complexity and resources needed below the waterline as water depth increases. At depths of over 25 meters, the foundation costs increase dramatically (See Appendix D for more information) (Musial et al., 2006).

3.1. Bathymetry Data Analysis[26]

This section of the report corresponds with the bathymetry data layer, which is available online at http://dnr.maryland.gov/ccp/coastalatlas/.

Figure 10 illustrates water depth data for our study area. The three colors represent the three types of foundation technology classifications necessary to operate in these areas; shallow, transitional, and deepwater. Shallow water technologies are those technologies that are capable of operating in water depths up to 30 meters and represent all existing commercial wind farms. The next subgroup includes transitional technologies that are capable of operating in the 30 meter to 60 meter water depths. Currently only the Beatrice demonstration project is employing such technologies. Finally, deepwater technologies are those wind farms deployed in water depths greater than 60 meters.

Maryland has a significant proportion of shallow water in the study area. In Figure 10, we have broken the offshore area into a grid made up of 3.2 kilometer by 3.2 kilometer cells [27]. The yellow areas represent those squares that meet two conditions; (1), water depths less than 30 meters and (2), distance greater than 19.3 kilometers from the coastline[28].

In Zone 1, 0-32.2 kilometers offshore, shallow water or water with depth less than 30 meters predominates. In Zone 2, 32.2-49.9 kilometers offshore, there is a mix between shallow (less than 30 meters) and transitional depths (30 to 60 meters). Shallow waters account for approximately 756 square kilometers of Zone 2, which is twelve times as large as the Cape Wind project area (62 square kilometers). Assuming the same wind farm configuration deployed in the area as the Cape Wind project, by a rough calculation, the shallow water area of 756 km^2 corresponds to approximately 5,500 MW of wind energy potential[29]. In Zone 3, over 49.9

[26] The Nature Conservancy (2009) provided the bathymetry data utilized in this section.
[27] The arrows and curves respectively portray the distance from the shore and boundaries of equal distance from a point on the shore.
[28] After consultations with Bluewater Wind we were able to arrive at a distance from shore of 19.3 kilometers. Experiences with the Cape Wind project have illustrated the contentiousness of the debate surrounding any potential visual impacts of wind farms. As a result of this and other factors, Bluewater has chosen to pursue their project off of Delaware at this distance such that the visual impact of wind farms on onshore communities and/or tourist destinations is minimized (though not fully mitigated).
[29] We assume 130, 3.6 MW wind turbines installed in 62 km^2; $5500 \approx 130 \times 3.6$ MW $\times$ 292/24, where 3.5 MW is 97 percent of 3.6 MW, taking into account the 3 percent loss at each wind turbine.

kilometers from the coastline, water depths are a mix between transitional (30-60 meters) and deepwater anchoring technologies (greater than 60 meters).

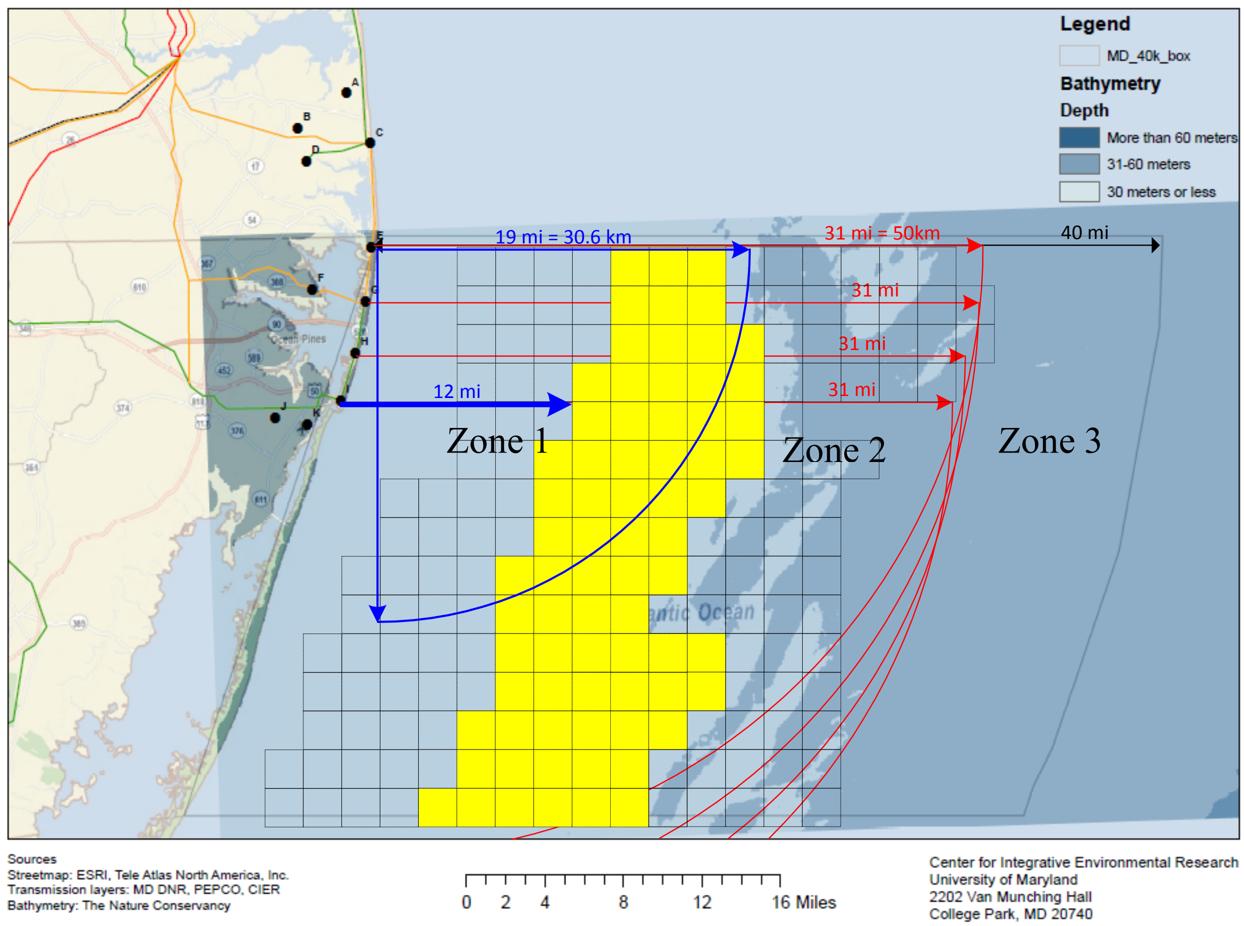

Figure 10-Bathymetric Map: Water Depths of the Atlantic Ocean adjacent to Maryland[30]

4. Offshore Wind Farm Component Costs: Wind turbines, foundations, transmission and collection systems

In this section we examine component costs of an offshore wind farm, including wind turbines, local wind turbine grid, collection system, and transmission system (from the offshore grid to the

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[30] In Figure 10, black dots correspond with the location of onshore substations. Due to classification as critical infrastructure by PHI, we are unable to publish their names and instead label each with a letter of the alphabet for future reference.

onshore grid through the point of interconnection (POI). The information compiled in this section was arrived at through a variety of means including conversations with industry experts, a review of literature, and experiential data from existing wind farms.

4.1. Wind Turbines and Foundations

Table 7 summarizes the cost of wind farm components, as well as technical specifications from DUWIND (2001), Bresesti et al. (2007), and Musial and Butterfield (2004)[31]. Because wind turbine costs for the sizes between 2.5 MW and 5 MW are not available in our survey, we estimate them using price data from DUWIND (2001) for 0.89-2.5 MW and cost estimates for 5 MW from Musial and Butterfield (2004). The green diamonds in Figure 11 represent the costs of wind turbines with respect to the rated power, gathered from the two literatures. Using this data, we fit the discrete pair of data (X,Y), where X = the rated power of wind turbine and Y = wind turbine cost, with the hyperbolic tangent (an S-shaped curve). The equation of the curve is given as:

$$Y=3\tanh(X)$$

X=0.526×rated power of wind turbine
Y=wind turbine cost in $M

The foundation cost for a 3 MW wind turbine was approximated by multiplying a scale factor of 3/5 by the 5 MW foundation costs (utilizing 5 MW foundation costs from Musial and Butterfield (2004)).

Table 7-Component Costs: Turbines and Foundations

Component	Unit Cost	Data Source
Wind Turbine	0.8893 [M[32] Euro/MW] for a constant speed turbine	Bresesti et al., 2007
	0.95 [M Euro/MW] for a variable speed turbine	Bresesti et al., 2007

[31] DUWIND (2001) provided an extensive survey of costs of wind turbines with 52 m diameter or longer (the rated powers range from 0.8 MW to 2.5 MW) (See Appendix D). Musial and Butterfield (2004) provide the cost prediction for 5 MW wind turbine with 90 m diameter.
[32] M = Million.

	3.08244 [$M] for a 5 MW turbine[33]	Musial and Butterfield, 2004
	2.75531 [$M] for a 3 MW WT	Modeled data; see Figure 6.11
Transformer at Turbine	0.505 [$M] (690/34 kV; 3.16 MVA rating)	Green et al., 2007
Steel Monopile Foundation	87.296 [$M] for a shallow water application with 100 units of 5 MW WT	Musial and Butterfield, 2004
	52.3776 [$M]=$87.296M×(3 MW/5 MW) for a shallow water application with 100 units of 3 MW WT	Modeled data
Mean Floating Platform	384.580 [$M] for a deep water application with 100 units of 5 MW WT	Musial and Butterfield, 2004

[33] 5 MW Turbine; rotor diameter=128 m; hub height=80 m; for both shallow and deep water application

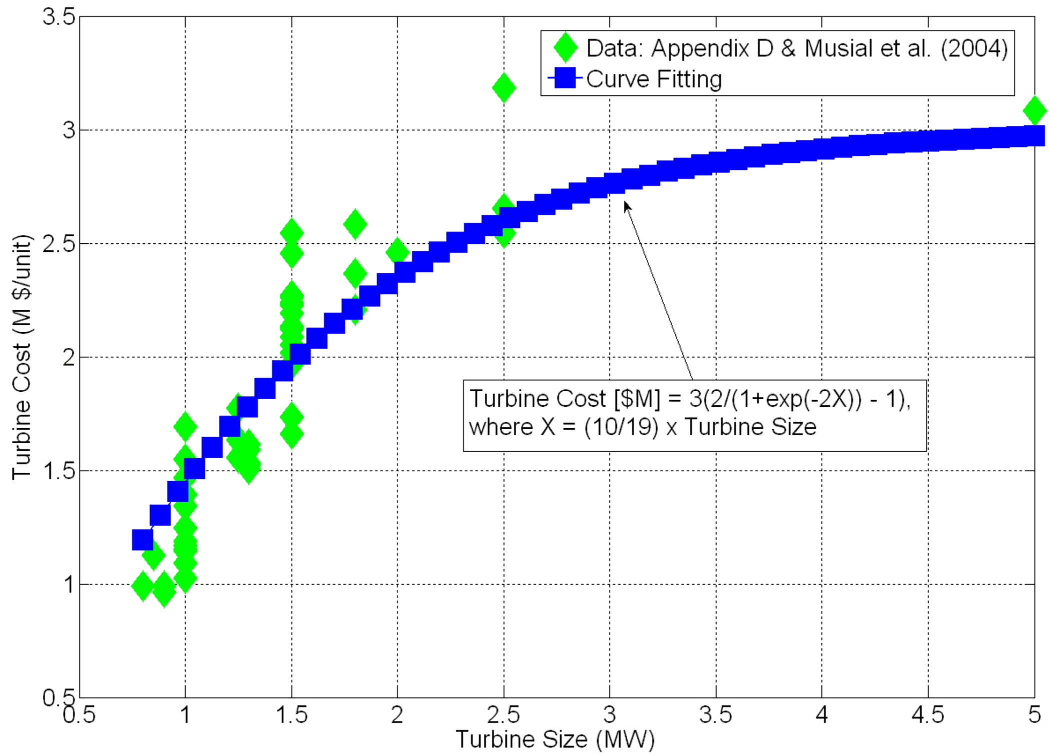

Figure 11-Curve Fitting for WT Cost ($ million per unit) with respect to Wind Turbine Size (MW)

4.2.Collection and Transmission System

In this section, we investigate potential transmission technologies. We consider three transmission technologies: HVAC (High Voltage Alternating Current), HVDC LCC (HVDC Line Commutating Converters), and HVDC VSC (HVDC Voltage Source Converters). With a brief overview of the features of these transmission solutions, the cost of each component along with the assumptions made will be presented.

4.3.Collection System

Wind turbines generate power as an alternating current (AC) with a typical voltage of 33 kV. The power generated by the wind turbine generators is collected by submarine cables buried in the seabed. Wind turbines within a wind farm grid are interconnected at 33 kV to an offshore substation located within the grid, where the low voltage is transformed (or stepped-up) to higher voltage to match the voltage of the existing onshore utility transmission lines (e.g. 138 kV or 230 kV of Delmarva Power).

The collection system consists of transformers at wind turbines and medium-voltage submarine cables. The transformer at each wind turbine steps up the low generation voltage (e.g. 690 V) to a medium voltage (34 kV). The submarine cables, typically buried 1-2 m deep in the seabed, connect wind turbines with an offshore substation. We assume that the generator voltage is 690 V, which is then stepped up to 34 kV by the transformer of a 3.16 MVA rated power. Both costs of collection cables for specific conductor sizes and transformer unit cost are provided in Green et al. (2007). Table 8 summarizes the unit costs for different conductor sizes of cables collected from the reference.

Table 8-Cost of AC Collection Cables

Component	Unit Cost	Data Source
AC Collection Cable	\$152/m (XLPE[34]; 95 mm^2)	Green et al., 2007
	\$228/m (XLPE; 150 mm^2)	Green et al., 2007
	\$381/m (XLPE; 400 mm^2)	Green et al., 2007
	\$571/m (XLPE; 630 mm^2)	Green et al., 2007
	\$600/m (XLPE; 800 mm^2)	Green et al., 2007

4.4.Analysis of characteristics and costs of three transmission systems

European wind projects have proven HVAC as a feasible solution for bringing offshore wind power onshore. Offshore wind projects in the United States, including the Cape Wind and the Bluewater Wind projects, have also chosen the HVAC technology for interconnecting offshore wind farms to the onshore transmission grids (i.e., NSTAR, Delmarva Power & Light). However, HVAC cables become increasingly expensive beyond distances of 40 km owing to the need for

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[34] XLPE: Cross Linked Polyethylene Insulation

reactive power compensation (EASAC, 2009). HVDC has emerged as an attractive solution for interconnections with longer transmission distances (above 50 km) owing to lower power losses during transmission as well as lower costs of cables than HVAC (Green et al., 2007; Wright et al., 2002). However, the disadvantage of HVDC is that the capital costs of AC-to-DC converter stations (for both offshore and onshore) are higher than the corresponding substations in HVAC transmission[35]. In subsequent sections, we provide a brief description of each of the three transmission systems and the costs of components of each system for a better understanding of the relative characteristics of the capital costs of HVAC and HVDC transmission systems.

4.5.HVAC Transmission System

The main components of HVAC transmission system are: (a) offshore and onshore substations including transformers and reactive compensators; and (b) three-core XLPE HVAC cables. AC cable generates considerable reactive current, which decreases active power transmitted through the cable. Bresesti et al. (2007) find that typical reactive powers are in the range of 100-150 kVAR per km for 33 kV XLPE cables, 1,000 kVAR/km for 132 kV XLPE cables, and 1,000 kVAR per km for 400 kV XLPE cables. Thus the longer the AC cable, the more reactive power (kVAR) is generated. For a long transmission (e.g., 10~40 km) reactive compensators are installed at both offshore and onshore substations to compensate the reactive power loss along the transmission line. Table 9 summarizes costs and characteristics of transformers, reactive power compensators, switch gears and HVAC transmission cables with installation costs acquired from Green et al. (2007) and Lazaridis (2005). Costs of 500 kV submarine AC cables are obtained from a MAPP project description (PJM, 2008a).

Table 9-Component Cost: HVAC Transmission System

Component	Unit Cost	Data Source
Transformer	Cost [M Euro] = $0.03327P^{(0.7513)}$, where P is the rated power in MVA and $40 \le P \le 800$	Lazaridis, 2005
	2.618 [$M] for offshore substation(34/138 kV; 187 MVA)	Green et al., 2007
	5.6 [$M] for onshore substation (138/345 kV;	Green et al., 2007

[35] The distinct characteristics of HVAC and HVDC transmission systems, in the context of submarine transmission, are well described in Wright et al. (2002) and Negra et al. (2006).

	560 MVA)	
Reactive Power Compensator	See Table 6.6 in Lazaridis (2005)	Lazaridis, 2005
Switching Gear	Cost = 0.00066874V+0.035891 [M Euro], where V is the rated voltage in kV and $33 \leq V \leq 400$	Lazaridis, 2005
Offshore Substation	40.52 [$M] (500 MW)	Green et al., 2007
Onshore Substation	29.37 [$M] (500 MW)	Green et al., 2007
HVAC Cable	1.6 [M Euro/km] (3-core TKVA; 132 kV; 1,055 A; 1,000 mm^2)	Lazaridis, 2005
	1.65 [M Euro/km] (3-core TKVA; 220 kV; 1,055 A; 1,000 mm^2)	Lazaridis, 2005
	1.95 [M Euro/km] (3-core XPLE; 400 kV; 1,323 A; 1,200 mm^2)	Lazaridis, 2005
	755 [$/m] (XLPE; 630 mm^2)	Green et al., 2007
	131.5 [$M] for 19kilometer cable (3-core XLPE; 500 kV)	MAPP – Cost Comparison AC vs. DC Bay Crossing, 2008
Cable Installation	1.5 [$M] for marine route survey & engineering (East Coast)	Green et al., 2007
	$58/m for cable transport via freighter from Europe to East Coast	Green et al., 2007
	5.0 [$M] for mobilization/demobilization	Green et al., 2007
	$94/m for cable laying operations	Green et al., 2007

4.5.1. HVDC LCC Transmission System

HVDC LCC is one of the basic types of HVDC transmission link, which has been extensively used worldwide (60 GW installed by the end of 2004), operating up to 6 GW and 800 kV(EWEA, 2009a). The system consists of (a) AC and DC filters, absorbing harmonic currents or voltage caused by the electrical switching in AC-to-DC conversion, (b) converter transformer, (c) thyristor valves; (d) smoothing reactors, exhausting the faulty current induced by resonances in the DC circuit or interferences from other power lines; (e) capacitor banks (or STATCOMs), controlling reactive power needed to operate the thyristor valves, and (f) HVDC cables. Table 10 shows costs and characteristics of converter stations and high-voltage DC cables (mass impregnated), including the installation cost of DC cables –cost data was collected from Lazaridis (2005). HVDC LCC is not suitable for offshore applications because of the significant space required by the offshore substation, which would be several times the size of a HVAC substation (Bresesti et al., 2007; Wright et al., 2002).

Table 10-Component Cost: HVDC LCC Transmission System

Component	Unit Cost	Data Source
Converter	40 [M Euro] for two 500 MVA converter station	Lazaridis, 2005
Cable Purchase and Installation	Cost = 1.148P+156.1 [M Euro], where P is the rated power in MVA and $440 \le P \le 600$	Lazaridis, 2005

4.5.2. HVDC VSC Transmission System

The relative compactness of HVDC VSC (half the size of HVDC LCC) is favored over HVDC LCC to minimize environmental impact and construction costs. Its controllability of active and reactive power enables it to connect to both strong and weak onshore grids, not to mention the long transmission capability of up to 600 km with low line losses (EWEA, 2009a).There are two HVDC VSC technologies: HVDC Light by ABB and HVDC Plus by Siemens. According to Pan et al. (2008), the NORD E.ON project will utilize HVDC Light to interconnect the 400 MW offshore wind farm in Germany by 2009 over 200 km long sub-sea and underground cable system to the onshore transmission grid. HVDC Plus will transmit up to 400 MW at 200 kV DC between San Francisco's City Center electric power grid and a Pacific Gas & Electric substation near Pittsburg, California with a 85.2 kilometer undersea transmission in 2010. This is the first order for Siemens using its HVDC Plus technology (Siemens, 2007). The main components of HVDC VSC are (a) converter stations (both offshore and onshore) and (b) HVDC cable pair (polymeric extruded cables) (Lazaridis, 2005). Table 11 shows costs of converters (both ABB and Siemens) and submarine DC cables with installation cost. Some of the costs are acquired from the Cape Wind offshore wind project and the MAPP project.

Table 11-Component Cost: HVDC VSC Transmission System

Component	Unit Cost	Data Source
Converter	62 [$M]Siemens; excludes 33 kV switchgear and platform structure; equipment installation is included; assuming 500 MW	USACE, 2003
	Cost = 0.11P [Euro/VA], where P is the rated power in MW	Lazaridis, 2005
	141.3 [$M] for a 1,000 MW Converter Station plus site preparation	MAPP – Cost Comparison AC vs. DC Bay Crossing, 2008
	137.3 [$M] for a 1,000 MW Converter Station (640 kV→230 kV) without site preparation	MAPP – Cost Comparison AC vs. DC Bay Crossing, 2008
	139.6 [$M] for a 1,000 MW HVDC Light Converter (640 kV→500 kV) with site preparation	MAPP – Cost Comparison AC vs. DC Bay Crossing, 2008
HVDC Cable	0.47 [$M/km] (ABB ±150 kV DC submarine cable; 4 1-core 630 mm^2; landfall 500 ft HDD included)	USACE, 2003
	Cost = (0.00067746P+0.14893)×L [M Euro], where P is the rated power in MW and L is the cable length in km	Lazaridis, 2005
	128/12 [$M/mile] (3 parallel 640 kV cables (total of 6); 3,000 kcmil);	MAPP – Cost Comparison AC vs. DC Bay Crossing, 2008
Cable Installation	0.23 [$M/km] (ABB ±150 kV DC submarine cable; 4 1-core 630 mm^2; landfall 500 ft HDD included)	USACE, 2003
	Cost = 0.2×L [M Euro], where L is the cable length in km	Lazaridis, 2005

5. Scenario Analysis of Costs

In this section, we calculate the energy transmission cost for two (hypothetical) wind farms: a 600 MW facility and a 1,000 MW facility with different types of transmission solutions (HVAC or HVDC VSC) at different water depths (shallow or deep). We first define the layout of an offshore wind farm for 600 MW or 1,000 MW. Then for each layout we define the components of the corresponding wind farm. Wind farm parameters considered in the cost estimation include wind turbine size, the number of wind turbines, wind turbine dimensions, water depth, offshore grid configuration and spacing, and transmission distance to shore. Transmission cost is defined as the sum of the costs of the components and their installation divided by the energy production of the wind farm (i.e., maximum net output in MW). We use cost data previously presented in Tables 6 to 10.

Our intent in this section is to provide a transmission cost model utilizing the extensive cost data set developed in the previous section, taking into account wind turbine cost and foundation cost (or floating platform for deep water application) and the AC or DC option in the transmission system depending on the distance from shore. As pointed out in Lundberg (2003), transmission cost is used to determine which layout is preferred for a given set of boundary conditions (transmission length, rated power, average wind speed, etc.). Previous studies have suggested that the operational range of AC transmission system is less than 50 km and for distances greater than 80 km, a DC transmission system is better suited. The bathymetric map (See Figure 10 in Section 3.1) shows that areas off the coast within 32.2 kilometers tend to be shallow water (30 m or less); and between 32 and 50 kilometers are of mixed shallow and transitional waters (depth of 30-60 m). We assume then that shallow water areas utilize an AC transmission system. Areas beyond 50 kilometers from shore may be suitable for DC transmission system. To examine the question of how these transmission options affect the transmission cost of wind energy, we consider two scenarios as follows:

Scenario 1: 600 MW wind farm in shallow water with HVAC transmission system

Scenario 2: 1,000 MW wind farm in deep water with HVDC transmission system[36]

<u>The assumptions underlying the scenarios are as follows:</u>

[36] We choose to model a deep water wind application because the 80.5 kilometers distance works well as a break-even distance for transmission options. Beyond this distance HVDC is more economical than HVAC (Wright et al., 2002; Negra et al., 2006).

- Onshore transmission grid is 230 kV; transmission voltage between the offshore and onshore substations is 230 kV; all transformers at wind turbines are 34 kV.
- Collection cables are operated at 34 kV – no intermediate voltages between transformers at wind turbines and the offshore substation.
- Total power loss of each wind farm is 3%: maximum net output is 582 MW for 600 MW wind farm and 970 MW for 1,000 MW wind farm[37].
- Transmission distance for 600 MW wind farms is 27 km from POI; 80 km for 1,000 MW wind farm and assumes a deep-water application[38].
- Wind farm layout is rectangular with the same distance between row and column wind turbines.
- We do not consider losses in the transmission line and the energy unavailability of the transmission system[39], as proposed in Lazaridis (2005) and Lundberg (2003), because we lack data regarding power loss in each component in Tables 7 to 11.

5.1. Scenario 1: 600 MW Wind Farm in Shallow Water with HVAC Transmission System

Figure 12 and Table 12 respectively present the layout of 600 MW wind farm and parameters. The number of turbines per row is ten; the collection cables are radial from the offshore substation. Necessary components and their quantity and unit cost are tabularized in Table13.

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[37] Bluewater Wind project considered the 3% power loss (PJM, 2009f; PJM, 2009d).

[38] The 27.3 kilometers distance was used in Musial and Butterfield (2004); the 80.5 kilometers distance was set as the least distance to the shore for HVDC transmission.

[39] In Lazaridis (2005), energy unavailability is defined as the percentage of the energy produced by the wind farm that could not be transmitted as a result of failures in the transmission system (forced outages). Maintenance (scheduled outages) is another factor that contributes to the energy availability of a transmission system.

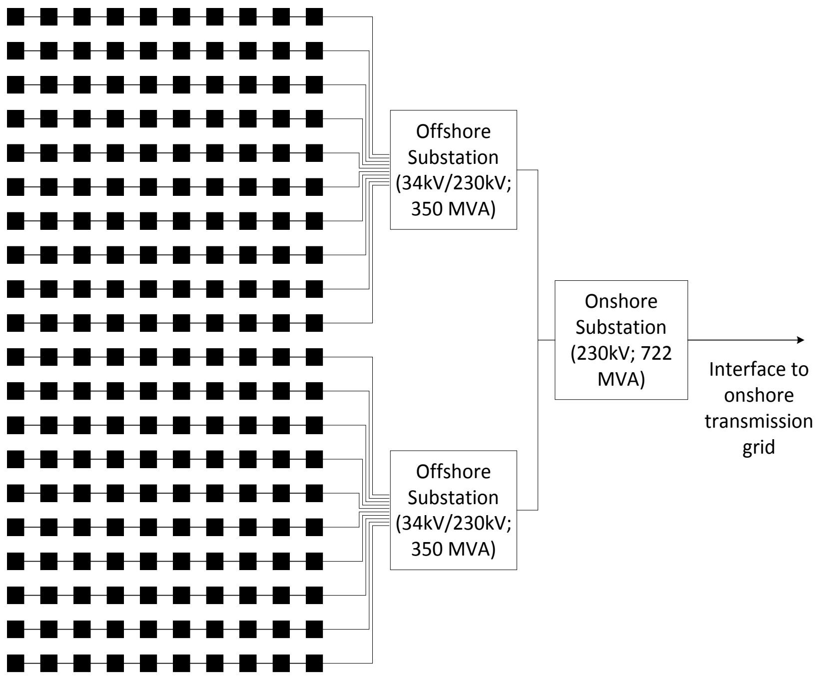

Figure 12-600 MW Wind Farm Layout with 3 MW Wind Turbines

Table 12-600 MW Wind Farm Parameters

Wind Turbine Rating	3 MW
Number of Wind Turbines	200
Rotor Diameter	90 m
Water Depth	20 m
Distance between Turbines	7×90 m= 630 m
Distance between Rows	630 m
Cable Length between Turbines	830 m
Distance between Wind Farm Grid to Offshore Substation	7 km in average
Substation Distance to Shore	27.36 km

Table 13-Cost for a 600 MW Offshore Wind Farm

Component	**Quantity**	**Unit Cost***	**Total Cost ($M)****
Wind Turbine (WT)	200 units	2.75531 [$M]	551.062
Transformer at WT	200 units	0.0505 [$M]	10.83
Switching Gear at WT	200 units	0.00066874×34 +0.035891 [M Euro]	16.69
Steel Monopile Foundation	2	52.3776 [$M] for 100 Turbines	123.07
AC Collection Cable	(2×9×10)×830 + 2×10×7,000 m	$381 per meter	118.23
AC Collection Cable Shipping & Installation	(2×9×10)×830 + 2×10×7,000 m	($58+$94) per meter	47.169
Transformer at Offshore Substation	2 units	$0.003327\times(350)^{0.7513}$	7.7228
Reactive Compensator at Offshore Substation	2 units	0.52425 [$M]	1.0485
Switching Gear at Offshore Substation	2 units	0.00066874×230 +0.035891 [M Euro]	0.5397
HVAC Cable	2×27.36 km	1.6597 [M Euro/km]	129.26
HVAC Cable Shipping & Installation	2×27.36 km	($58+$94) per meter	8.9188
Transformer at Onshore Substation	1 unit	$0.003327\times(722)^{(0.7513)}$	6.6528
Reactive Compensator at Onshore Substation	2 units	0.52425 [$M]	1.0485

Switching Gear at Onshore Substation	1 units	0.00066874×230 +0.035891 [M Euro]	0.26985
Total Transmission Cost			\$1,022.5 M \$1,756.9/kW*** (=\$1,022.5 M/582 MW)
*: The unit cost is shown in Table 7, Table 8, and Table 9. **: The total cost (2009 \$) is measured with unit cost times quantity, where the unit cost is adjusted with inflation and foreign exchange rates (i.e., Euro to US dollar). ***: The costs for offshore and onshore substations, respectively \$ 9.311 M and \$ 7.97115 M, are much less than the corresponding prices of \$40.52 M and \$ 29.37 for the 500 MW rated power in (Green et al., 2007). If we change the costs for the two substations components with those higher prices, then the transmission cost increases to \$1,847.3/kW.			

5.2. Scenario 2: 1,000 MW Wind Farm in Deep Water with HVDC Transmission System

Figure 13 and Table 14 respectively show the layout of 1,000 MW wind farm and parameters. Wind turbines are arranged in the same way as the 600 MW wind farm. The number of turbines per row is ten; the collection cables are radial from the offshore substation. Table 15 gives necessary components and their quantity and unit cost.

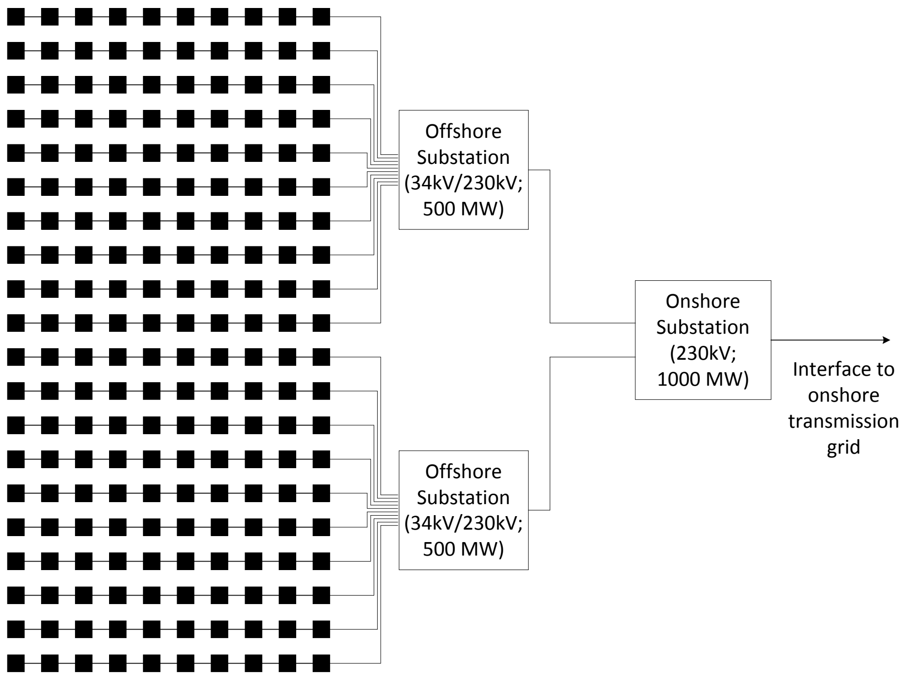

Figure 13-1,000 MW Wind Farm Layout with 5 MW Wind Turbines

Table 14-1,000 MW Wind Farm Parameters

Wind Turbine Rating	5 MW
Number of Wind Turbines	200
Rotor Diameter	128 m
Water Depth	600 ft = 182.88 m
Distance between Turbines	7×128 m= 896 m
Distance between Rows	896 m
Cable Length between Turbines	1 km
Distance between Wind Farm Grid to Offshore Substation	7 km in average
Substation Distance to Shore	80 km

Table 15-Cost for a 1,000 MW Offshore Wind Farm

Component	Quantity	Unit Cost*	Total Cost ($ M)**
Wind Turbine (WT)	200 units	3.08244 [$M]	616.488
Transformer at WT	200 units	0.0505 [$M]	22.482
Switching Gear at WT	200 units	0.00066874×34 +0.035891 [M Euro]	16.69
Mean Floating Platform	1	384.580 [$M] for 200 WTs	451.83
AC Collection Cable	(2×9×10)×1,000 + 2×10×7,000 m	$381 per meter	143.24
AC Collection Cable Shipping & Installation	(2×9×10)×1000 + 2×10×7,000 m	($58+$94) per meter	57.146
Offshore Converter Station	2 units	0.11×500 [M Euro]	156.58
HVDC Cable	2×80 km	(0.00067746×500+0.14893) [M Euro/km]	138.61
HVDC Cable Installation	2×80 km	0.2 [M Euro/km]	45.55
Onshore Converter Station	1 unit	141.3 [$M]	141.87
Total Transmission Cost			$1,790.5M $1,845.9/kW (=$1,790.5 M / 970 MW)
*: The unit cost is shown in Table 7, Table 8, and Table 11. **: The total cost (2009 $) is measured with unit cost times quantity, where the unit cost is adjusted with inflation and foreign exchange rates (i.e., Euro to US dollar).			

5.3.Findings: Cost Comparison of Scenarios 1 & 2

Figures 14 and 15 present the cost distributions for the two scenarios. The results are summarized as follows:

For both scenarios, the costs of the wind turbines and foundation systems (or floating platform) account for more than 59% of total costs; collection systems (i.e. transformers and switching gears at wind turbines, AC collection cables) represent the second largest portion of total costs.

For the HVAC transmission system, the cable cost ($138.2 M) requires a much larger investment than offshore and onshore substations ($17.3 million altogether); for the HVDC transmission system the offshore and onshore substations cost more than 1.5 times as much as DC cables.

The HVDC cables cost $2.29 million/km, which is much smaller than the HVAC cable cost of $5.05 million/km. We find that the greater cost of the HVDC offshore and onshore substations at both ends of transmission line can be offset by lower cabling costs. However, the difference in cabling costs alone does not compensate for the higher substation costs of an HVDC transmission system. Thus, as has been confirmed in previous studies, HVDC may not be an appropriate transmission option for shallow water applications close to shore.

In our 600 MW case study, we determine a cost estimate of $1,858.0 per kW, which is significantly lower than the estimates produced by Green et al., 2007. We believe this is due to differences in cost estimates of offshore and onshore substations. In our revised calculations utilizing Green et al., 2007, transmission costs of an HVAC transmission system increase from $1,756.9 per kW to $1,847.3 per kW, which is $1.4 per kW more than $1,845.9 per kW of the transmission cost for the 1,000 MW wind farm.

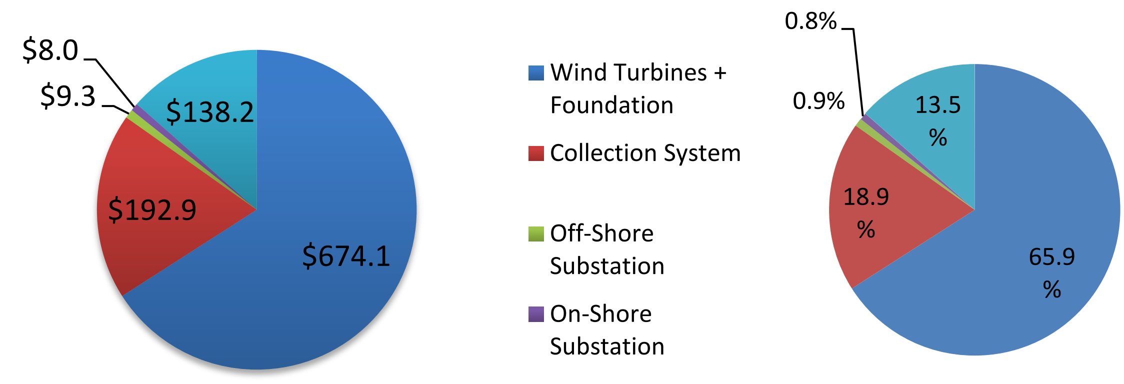

Figure 14-Cost Distribution for 600 MW Wind Farm Scenario[40]

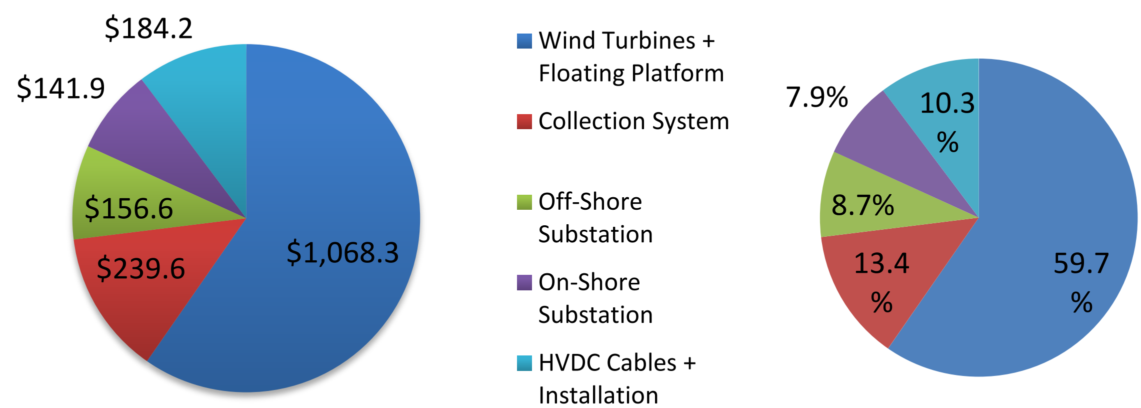

Figure 15-Cost Distribution for 1,000 MW Wind Farm Scenario[41]

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[40] All costs are in millions of dollars
[41] All costs are in millions of dollars

6. References

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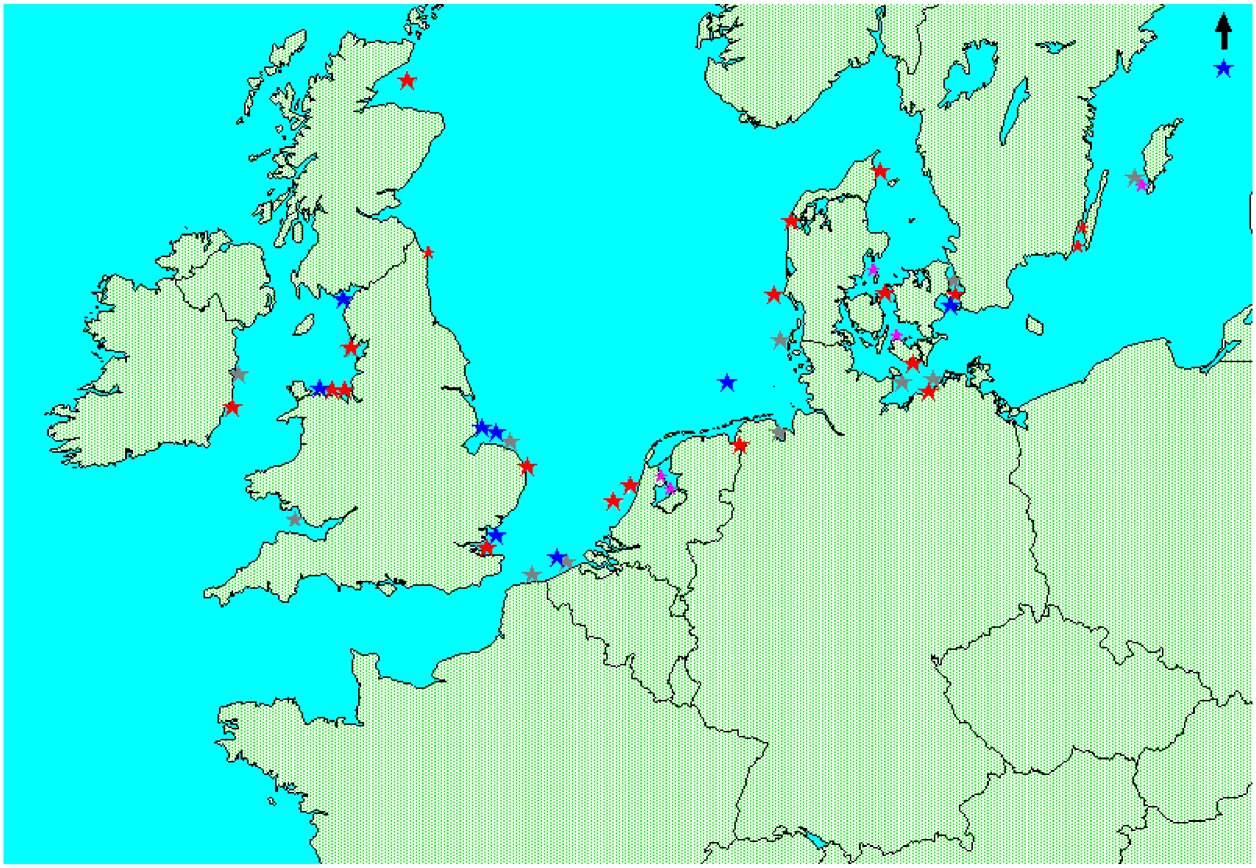
7. Appendices

Appendix A: Existing and Planned Wind Farms in North West Europe, June 2007



Red=built large turbines; purple=built small turbines; blue=under construction; gray=planned

(Source: Offshore Wind Energy, http://www.offshorewindenergy.org)

Appendix B: Wind farms in North West Europe – Detailed Information

Name/location	Developer	Manufacturer	Turbines × rating (MW)	Depth (m)	Dist. to shore (km)
Built					
Beatrice/UK	Talisman energy Inc., Scottish and southern energy	REpower	2 × 5	45	25
Blyth/UK	AMEC/Shell/Nuon/powergen	Vestas	2 × 2	6–11	0.8
Barrow-in-Furness/UK	Barrow offshore wind Ltd	Vestas	30 × 3	21–23	7
Burbo/UK	DONG energy A/S	Siemens windpower	25 × 3.6	1–8	6.4
North Hoyle/UK	National windpower	Vestas	30 × 2	10–20	6
Scroby sands/UK	E.ON UK	Vestas	30 × 2	4–8	2.3
Kentish flats/UK	Elsam	Vestas	30 × 3	5	8.5
Arklow bank/Ireland	Airtricity	GE Wind	7 × 3.6	2–5	10
Q7-WP/Netherlands	Econcern, energy investments holding, ENECO energy	Vestas	60 × 2	20–24	23
Egmond ann Zee/Netherlands	Noordzee wind (Shell, NUON)	Vestas	36 × 3	19–22	10
Lely/Netherlands	ENW	Nedwind	4 × 0.5	5–10	0.75
Irene Vorrink/Netherlands	NUON*	NordTank	28 × 0.6	5	0.02
Ems-Enden/Germany	Enova	Enercon	1 × 4.5	3	0.04
Breitling/Germany	WIND-projekt GmbH	Nordex	1 × 2.5	2	0.5
Nysted/Denmark	Elsam/Elkraft/Energy E2	Bonus	72 × 2.3	5–9.5	10
Samso/Denmark	Samso Havvind A/S*	Bonus	10 × 2.3	20	3.5
Frederikshavan/Denmark	Elsam	Vestas, Bonus, Nordex	1 × 3 + 2 × 2.3	4	0.2
Ronland/Denmark	Two local cooperatives	Bonus/Vestas	4 × 2.3 + 4 × 2	1*	0.2*
Horns Rev/Denmark	Dong energy*	Vestas	80 × 2	6–12	14–20
Middelgrunden/Denmark	Kobenhavns Energi*	Bonus	20 × 2	3–6	3
Vindeby/Denmark	Dong energy*	Bonus	11 × 0.45	3–5	1.5
Tuno/Knob/Denmark	Dong energy*	Vestas	10 × 0.5	3–5	6
Yttre Stengrund/Sweden	Vindkompaniet	NEG-Micon	5 × 2	6–10	5
Utgrunden/Sweden	GE wind energy	GE wind energy	7 × 1.425	7–10	8
Bockstigen-Valor/Sweden		Windworld	5 × 0.5	6	3
Under construction					
Robin Rigg/UK	E.ON UK	Vestas*	60 × 3	3–21	9
Inner Dowsing/UK	Centrica	Siemens	27 × 3.6	10*	5
Lynn/UK	Centrica	Siemens	27 × 3.6	6–13	5
Alpha Ventus/Germany	E.ON Energy, EWE, Vattenval	Multibird-RePower	12 × 5	30	43–50
Lillgrund Bank/Sweden	Vattenvall AB, Nordic Generation	Siemens	48 × 2.3	4–8	7
Kemi, Ajos/Finland	PVO innopower Oy	WinWind	8 × 3		0.05–1
Planned					
Kish Bank/Ireland	Powergen Renewables/Saorgus/ESB		50 MW total*		
Rhy1Flats/UK	RWE npower	Siemens	25 × 3.6		8
Scarweather Sands/UK	E.ON UK/eEnergy E2		30 × 3		5–10
Gunfleet Sands/UK	GE Gunfleet Ltd.	GE	30 × 3.6	8*	7
Cromer/UK	Norfolk Offshore Wind		30 × 4	23*	7
Breedit-Mardyck Bench/Erance	Nord-Pas-de-Calais/Shell/TFE/Jeumont	Jeumont	8 MW total		
Vlakte van Raan/Belgium	Seanergy		20 MW total		
Thornton/Bank/Belgium	C-power	GE wind energy	60 × 5*	12–27.5	27–30
Jade/Germany	Winkra-Energie GmbH	Enercon	1 × 4.5	5	0.55
Butendiek/Germany	OSB/Bürger-windpark	Vestas	80 × 3	20	34
Sky 2000/Germany	GEO		100 MW total	−20*	17*
Mecklenburg-Vorpommern/ Germany	Neptun		40 MW total		
Skabbrevet/Sweden	Renewable energy/Cynergy global power		54 MW total		
Klasarder/Sweden	NEG-micon	NEG-micon	16 × 2.75*	7–11*	1.5*

(Source: Breton and Moe, 2009)

Appendix C: Offshore Wind Turbine Manufacturers

Manufacturer	Power Output	Record
Siemens	3.6 MW	Siemens Wind Power has stated that it is prepared to reserve up to one third of its production capacity for offshore wind turbines. In offshore development, Siemens has taken a lead position, with the SWT3.6 107. This position was further strengthened in 2008, when the company signed an agreement with Denmark's DONG Energy for the supply of up to 500 offshore turbines. Bonus – now Siemens Wind Power - pioneered the offshore installation of wind turbines with the world's first offshore wind farm at Vindeby, Denmark, installed in 1991. Since then, its track record includes Nysted Havmøllepark, Burbo Offshore Wind Farm and Greater Gabbard. Siemens Energy will supply 175 of its SWT-3.6-107 (3.6 MW) wind turbines to the 1 GW London Array offshore windfarm owned by DONG Energy, E.ON and Masdar. Siemens is currently developing its next generation of offshore turbines, and testing 3.6 MW direct drive concept, suitable for offshore applications, with the aim to improve reliability and reduce costs.
Vestas	3 MW	Vestas is one of the few players that has experience in the offshore sector. In late 2008 the company won a large order of 300 MW for Warwick Energy's Thanet project in the UK. Vestas will increase its total production capacity (onshore and offshore) to 10 GW in 2010. No reservation of capacity has been announced for offshore. The offshore turbine supply will rely on the developments of the onshore market.
Nordex	2.5 MW	The N90 offshore is an adaptation of the onshore design. This turbine is designed for offshore use.
Repower	5 and 6 MW	REpower manufactures some of the largest wind turbines in the world suitable for offshore use, the 5M (5 MW) and the 6M (6 MW). REPower will install six 5M in 2009 at the test project Alpha

		Ventus. The 5Mserial production begun in autumn 2008 in a new construction hall in Bremerhaven. In the beginning of 2009, the first three 6M turbines were erected close to the Danish-German border, where they are to be tested for offshore operation and where they will be subjected to a type certification. REpower is participating in the "Beatrice Demonstrator Project" to test the performance of the 5 MW turbine on the open sea 25 km off the east coast of Scotland and at a water depth of over 40m. REpower recently signed an agreement with Vattenfall to supply 150 MW to the Ormonde wind farm. Delivery is scheduled to start in 2010
BARD Engineering	5 MW	BARD has developed a specific offshore design. Their development focuses on the Deutsche Bucht. In the first phase BARD has planned three wind farms each with 80 turbines of 5 MW. The permit for the project "Bard Offshore 1" has already been obtained.
Multibrid	5 MW	Multibrid developed a specific offshore design based on a 5 MW permanent magnet generator and a single stage planetary transmission, currently being tested at Alpha Ventus. Multibrid will supply 80 M5000 turbines for the offshore Global Tech 1 wind farm (400 MW). Global Tech 1 is located 90 kilometers from the coast in the German North Sea. Delivery is scheduled for 2011-2012.

(Source: EWEA, 2009a)

Appendix D: Overview of the Different Types of Substructures

Type of substructure	Brief physical description	Suitable water depths	Advantages	Limitations
Monopile steel	One supporting pillar	10 – 30m	Easy to manufacture, experience gained on previous projects	Piling noise, and competitiveness depending on seabed conditions and turbine weight
Monopile concrete, installed by drilling	One supporting pillar	10 – 40m	Combination of proven methods, Cost effective, less environmental (noise) impact. Industrialization possible	Heavy to transport
Gravity base	Concrete structure, used at Thornton bank	Up to 40m and more	No piling noise, inexpensive	Transportation can be problematic for heavy turbines. It requires a preparation of the seabed. Need heavy equipment to remove it
Suction bucket	Steel cylinder with sealed top pressed into the ocean floor	n.a.	No piling, relatively easy to install, easy to remove	Very sensitive to seabed conditions
Tripod / quadropod	3/4-legged structure	Up to 30m and more	High strength. Adequate for heavy large-scale turbines	Complex to manufacture, heavy to transport
Jacket	Lattice structure	> 40m	Less noise. Adequate for heavy large-scale turbines	Expensive so far. Subject to wave loading and fatiguefailure. Large offshore installation period (first piles, later on placing of structure and grouting) therefore sensitive for weather impact
Floating	Not in contact with seabed	> 50m	Suitable for deep waters, allowing large energy potentials to be harnessed	Weight and cost, stability, low track record for offshore wind
Spar buoy	Floating	120 -	Very deep water, less steel	Expensive at this stage

Hywind being tested	steel cylinder attached to seabed	700m		
Semi submersible	Floating steel cylinder attached to seabed	Blue H Prototype being tested in 113m	Deep water, less steel	Expensive at this stage

(Source: EWEA, 2009a)

Appendix E: Wind Turbines Above 50 m Diameter

TYPE	RATED POWER kW	HUB HEIGHT m	SWEPT AREA m^2	DIA. M	SPEED rpm	TOWER WT kg	NACELLE MASS kg	BLADE WT kg	EURO/ kW	EURO/ m^2	PRICE EURO
Enron EW 1.5s	1500	64.7	3904	70.5	20						
Enron EW 1.5s	1500	80	3904	70.5	20						
Enron EW 1.5s	1500	85	3904	70.5	20						
Enron EW 1.5s	1500	100	3904	70.5	20						
Enron EW 1.5sl	1500	61.4	4657	77	18.3						
Enron EW 1.5sl	1500	80	4657	77	18.3						
Enron EW 1.5sl	1500	85	4657	77	18.3						
Enron EW 1.5sl	1500	100	4657	77	18.3						
Enron Wind 1.5 sl	1,500	61.4	4,657	77	18				1090.8	351.3	1,636,134
Fuhrlander MD 77	1,500	65	4,655	77	17.3	93,000	55,500	5,000	1022.6	329.5	1,533,876
Fuhrlander MD 77	1,500	85	4,655	77	17.3		55,500	5,000	1073.7	346	1,610,569
Fuhrlander MD 70	1,500	65	3,850	70	19	93,000	52,500	5,000	947.6	369.2	1,421,391
Fuhrlander MD 70	1,500	85	3,850	70	19		52,500	5,000	1005.5	391.8	1,508,311
NEG Micon NM 1500/72	1500	98	4,072	72	17.3	89,000	44,000	6,800	1056.7	389.2	1,585,005
NEG Micon NM 1500/72	1500	64	4,072	72	17.3	132,000	44,000	6,800	988.5	364.1	1,482,746
NEG Micon NM 1500/72	1500	80	4,072	72	17.3	201,000	44,000	6,800	1022.6	376.7	1,533,876
NEG Micon NM 1500C-64	1500	68	3217	64	17.3	113,000	43,000	6,000	801	373.5	1,201,536
NEG Micon NM 1500C-64	1500	80	3217	64	17.3	148,000	43,000	6,000	835.1	389.4	1,252,665
PWE 1566 (Pfleiderer)	1,500	65	3,421	66	22	220,000	70,000	3,900			
Sudwind S-70	1,500	65	3,848	70	19	95,000	56,000	6,020	971.5	378.7	1,457,182
Sudwind S-70	1,500	85	3,848	70	19		56,000	6,020	1027.7	400.6	1,541,545
Sudwind S-70	1,500	98.5	3,848	70	19		56,000	6,020			
Sudwind S-70	1,500	114.5	3,848	70	19		56,000	6,020			
Sudwind S-77 = MD77	1,500	61.5	4,657	77	17.3	80,000	56,000	6,020	1022.6	329.4	1,533,876
Sudwind S-77 = MD77	1,500	85	4,657	77	17.3		56,000	6,020	1078.8	347.5	1,618,239
Sudwind S-77 = MD77	1,500	90	4,657	77	17.3		56,000	6,020			
Sudwind S-77 = MD77	1,500	96.5	4,657	77	17.3		56,000	6,020	1094.2	352.4	1,641,247
Sudwind S-77 = MD77	1,500	100	4,657	77	17.3		56,000	6,020	1227.1	395.2	1,840,651
Sudwind S-77 = MD77	1,500	111.5	4,657	77	17.3		56,000	6,020	1182.8	381	1,774,183
Made AE-61	1,320	60	2,922.50	61	18.8	89,500	49,000				
AN Bonus 1.3 MW/62	1300	68	3019	62	19	80,000	50,000		896.7	386.1	1,165,745

TYPE	RATED POWER kW	HUB HEIGHT m	SWEPT AREA m^2	DIA. M	SPEED rpm	TOWER WT kg	NACELLE MASS kg	BLADE WT kg	EURO/ kW	EURO/ m^2	PRICE EURO
Nordex N-60	1300	60	2828	60	19		49,200	4,800			
Nordex N-60	1300	65	2828	60	19		49,200	4,800			
Nordex N-60	1300	69	2828	60	19	98,400	49,200	4,800	837.7	385.1	1,089,052
Nordex N-60	1300	70	2828	60	19				845.6	388.7	1,099,278
Nordex N-60	1300	85	2828	60	19	154,000	49,200	4,800	884.9	406.8	1,150,407
Nordex N-60	1300	120	2828	60	19		49,200	4,800			
Nordex N-62	1300	60	3020	62	19		49,200	4,800			
Nordex N-62	1300	65	3020	62	19		49,200	4,800			
Nordex N-62	1300	69	3020	62	19	98,400	49,200	4,800	853.5	367.4	1,109,503
Nordex N-62	1300	70	3020	62	19						
Nordex N-62	1300	85	3020	62	19	154,000	49,200	4,800			
Nordex N-62	1300	120	3020	62	19		49,200	4,800			
DeWind D6	1250	68	3217	64	24.8	72,000	44,000		944.8	367.1	1,181,000
DeWind D6	1250	91.5	3217	64	24.8	116,000	44,000		1026.4	398.8	1,283,000
DeWind D6	1250	65	3019	62	26.1	72,000	44,000		900	372.6	1,125,000
AN Bonus 1 MW 54	1000	50	2300	54.1	22	54,000	40,000	4,650	828.3	360.1	828,293
AN Bonus 1 MW 54	1000	60	2300	54.1	22	60,000	40,000	4,650	859	373.5	858,970
AN Bonus 1 MW 54	1000	70	2300	54.1	22	90,000	40,000	4,650	899.9	391.2	899,874
DeWind D6	1000	68.5	3019	62	25.2			4,100	1120	371	1,120,000
DeWind D6	1000	91.5	3019	62	25.2			4,100	1222	404.8	1,222,000
Enercon E-58	1000	70	2642	58	24	130,000	82,000	3,400	1060.9	401.6	1,060,931
Fuhrlander 200/1000	1000	70	2180	52.7	22				741.4	340.1	741,373
Fuhrlander FL 1000	1,000	70	2642	58	22	95,000	40,500	4,500			
Fuhrlander FL 1000	1,000	82	2642	58	22	120,000	40,500	4,500			
Fuhrlander FL 1000	1,000	70	2463	56	22	95,000	40,500	4,500			
Fuhrlander FL 1000	1,000	82	2463	56	22	120,000	40,500	4,500			
Fuhrlander FL 1000	1,000	70	2290	54	22	95,000	40,500	4,500	741.4	323.7	741,373
Fuhrlander FL 1000	1,000	82	2290	54	22	120,000	40,500	4,500	833.4	363.9	833,406
MWT 1000 (Mitsubishi)	1,000	60	2,463	56	21	63,000	32,000	4,100			
NEG Micon NM 1000/60	1000	70	2827	60	18	114,000	33,500	5,000	971.5	343.6	971,455
NEG Micon NM 1000/60	1000	80	2827	60	18	114,000	33,500	5,000	1007.2	356.3	1,007,245

TYPE	RATED POWER kW	HUB HEIGHT m	SWEPT AREA m^2	DIA. M	SPEED rpm	TOWER WT kg	NACELLE MASS kg	BLADE WT kg	EURO/ kW	EURO/ m^2	PRICE EURO
Nordex N-54	1000	60	2290	54	22	90,200	50,000	4,200	833.4	363.9	833,406
Nordex N-54	1000	70	2290	54	22	105,000	50,000	4,200	843.6	368.4	843,632
Nordic 1000	1,000	60	2,290	54	25	45,000	29,000	3,600	787.4	343.8	787,389
Enron Wind 900s	900	60	2,206	55	28						
NEG Micon NM 900/52	900	60	2,140	52.2	22	72,000	24,500	4,200	772.6	324.9	695,357
NEG Micon NM 900/52	900	74	2,140	52.2	22	97,000	24,500	4,200	795.3	334.5	715,809
Frisia F 56/850 kW	850	70	2489	56.3	25	74,000	31,000	4,500	956.4	326.6	812,954
Fuhrlander FL 800	800	70	2,180	52.7	22	88,000	40,500	4,500	894.8	328.4	715,809

(Source: DUWIND, 2001)

IV. Offshore Wind Turbines, Radar Functionality and mid-Atlantic Operations

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1. Introduction

This chapter provides background information on Maryland offshore wind development and potential conflict areas and is intended to complement corresponding geographic information system data files. The chapter focuses specifically on two areas of conflict: mid-Atlantic radar functionality and offshore operations (i.e., military or research based operations).

Section 2 provides a general overview of known interactions between wind turbines and radar. Section 3 identifies potential fixed-radar interference in the mid-Atlantic region as the result of wind development. Section 4 describes the methodology and findings of radar-wind interaction specific to fixed-radar facilities at the NASA Wallops Flight Facility. Section 5 transitions to potential physical conflicts between offshore operations and wind development with a particular focus on the U.S. Military.

2. Radar-Wind Turbine Development Interactions

2.1.Background

Radar uses radio frequency (RF) radiation to sense objects in the atmosphere. The radar transmitter emits RF radiation towards a target and a portion is reflected back as a signal to a receiving antenna for processing. The processed signal is interpreted for a presence in the atmosphere including weather or aircraft. The strength and quality of the reflected signal depends on "the power of the transmitter, the distance to the target, atmospheric effects, the radar cross section (RCS) of the target (i.e., reflective surface of the target), presence of intervening objects, and antenna geometry (US DoD, 2006, pg. 10)." Functional, unperturbed radars are able to detect, discern, and quantify among objects of interest (Davis, 2009).

Depending on the circumstances, two characteristics of utility-scale wind turbines can interfere with radar signals when positioned in the radar line-of-sight (RLOS). First, the large size of wind turbines, particularly when clustered together as a farm, can create a large RCS, which can prevent detection of objects beyond or near the turbines. This effect is known as shadowing or static interference. Shadowing will cause targets including aircraft to disappear or intermittently disappear and reappear. Second, the rotation of the blades can create a Doppler frequency shift, which results in the turbine appearing to be a moving object. This effect is known as clutter or dynamic interference. Cluttering makes it difficult to distinguish wind turbines from aircraft, weather systems, or other objects of interest (Davis, 2009).

2.2.Radar Types

Depending on the type of radar and the radar's intended use, the presence of wind turbine interference may be more or less significant. Radar types, which are defined by their use, include air defense, missile early warning, weather observation, and air traffic control. More generally, radars can be categorized as either primary or secondary surveillance radars. Primary radars operate one-way, detecting object range and bearing while secondary radars have the same capabilities as primary radars, but also rely on the presence of transponders on targets (e.g., aircrafts), which conveys additional information including altitude and identity (Solanki, 2009). Finally, radars can be fixed in a single location or mobile (e.g., mounted to a vessel or aircraft).

In 2006, the U.S. Department of Defense (DoD) released a report studying the effects of wind farms on air defense (primary and secondary surveillance radars) and missile early warning radars. Examination of the effects of wind turbines on weather radars and air traffic control radars was relegated to National Oceanic and Atmospheric Administration (NOAA) – National Weather Service (NWS) and the Federal Aviation Administration (FAA), respectively (U.S. DoD, 2006).

Typical air defense radars detect and track larger objects, including aircraft, while missile early warning radars are long-range radars expected to detect and track small objects (i.e., with low-RCS) at "extreme ranges with high confidence and accuracy (U.S. DoD, 2006, pg. 54)." The DoD found that depending on variables such as the size of the wind turbines, the number of turbines, and the distance of the turbines from the radar facility, the primary radar signal may or may not be able to unambiguously detect and track objects of interest. Although a secondary radar signal may enhance detection and tracking, the primary radar signal alone must be able to unambiguously detect and track an object of interest. Therefore, any ambiguous radar signal returns will, "negatively impact the readiness of U.S. forces to perform air defense missions (U.S. DoD, 2006, pg. 4)."

The NWS operates the NEXRAD WSR-88D Doppler radar network to track weather. Wind turbines impact the NEXRAD radars much as they do other radars via shadowing and clutter. As a result, the presence of turbine interference may cause storms to be masked or misinterpreted and false radar returns may lead to costly aircraft re-routing. The NEXRAD network depends on primary radar returns and cannot mitigate turbine interference with secondary radar signal returns (U.S. Department of Commerce - NOAA, 2009).

The FAA controls the National Airspace System with support from air traffic control (ATC) radars. The National Airspace System relies on a network of DoD ATC radars and FAA ATC radars to coordinate air traffic. ATC radars are also calibrated to detect birds, which is a critical factor in preventing bird strikes. Wind turbine interference can prevent ATC radar detection and tracking of both aircraft and birds. However, there tend to be fewer problems tracking aircraft with ATC radars because these radars can rely on both primary and secondary radar signal returns (Haggerty, 2009; U.S. DoD, 2006).

2.3.Interference Variables

The single most important factor in determining whether or not a wind turbine might interfere with radar functionality is radar line-of-sight (RLOS), which is a function of the Earth's curvature, the elevation of the turbine above ground level, and the elevation of the radar antenna above ground level. If a wind farm is not within a RLOS, then the likelihood for interference is very low. If a wind farm is within a RLOS, then the likelihood for and degree of interference increases as the farm is placed closer to the radar facility (U.S. DoD, 2006). RLOS is discussed in more detail in the methodology section below. An additional factor influencing interference is the number of turbines and the amount of space occupied within the RLOS. More occupied space will create more shadowing and probably more clutter. Other relevant factors influencing the likelihood and degree of radar interference include radar frequency (bandwidth) and the heading of the blades relative to the radar. The importance of these two factors is demonstrated in analysis performed by the DoD (See Figure 16). Finally, preliminary research reveals that the composition and surface design of wind turbines may be modified to lessen radar interference (e.g., stealth-like design), however, much work remains in this field and early results are inconclusive (Davis, 2009; Barras, 2009). Radar frequency, blade heading, and turbine composition variables are not accounted for in the data layers developed for this report.

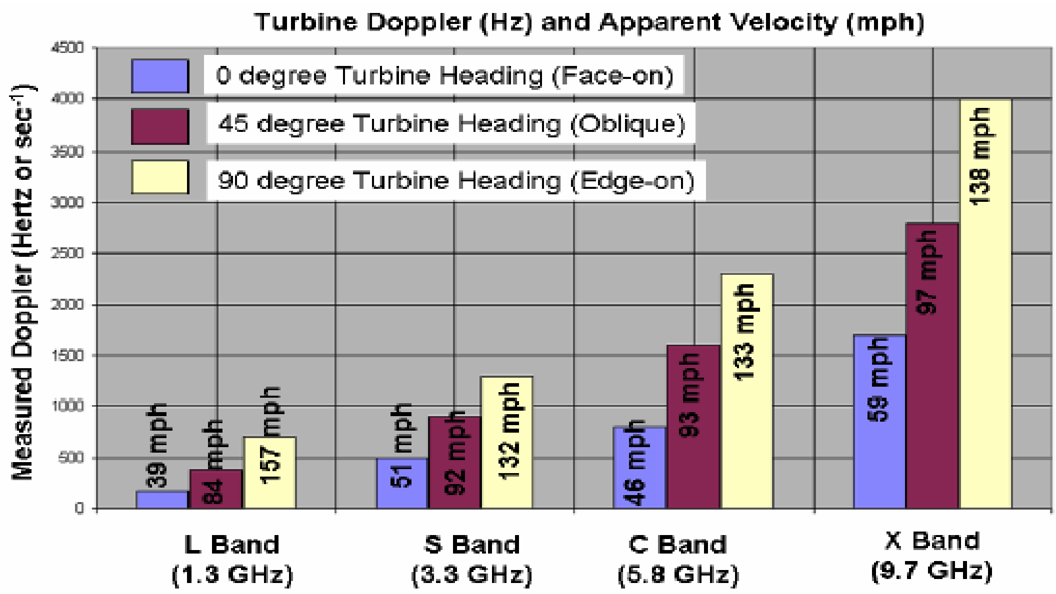


Figure 16-Measured Doppler Effect Caused by Wind Turbines (Source: U.S. DoD, 2006)

2.4.Shepards Flat Wind Farm Case

The Shepards Flat wind farm is a planned 845-megawatt capacity wind farm in north-central Oregon, which serves as an example of wind-radar conflict. In March 2010, the FAA with support from the U.S. Air Force issued a "notice of presumed hazard," over the proposed wind farm citing potential interference with transmissions from radar facilities. The radar facilities, located in Fossil, Oregon, are about 50 miles from the proposed site. The FAA notice stated the wind farms would pose a hazard to air navigation (Eilperin, 2010). In April 2010, the FAA and DoD formally removed the notice of presumed hazard allowing the Shepards Flat wind farm to move forward. The DoD will upgrade the Fossil radar facilities (Wyden, 2010).

3. Mid-Atlantic Fixed Radar Facilities

3.1.Radar Facilities With High Likelihood of Interference

The study area for this research includes the entire Maryland Atlantic Ocean coastline (North to South) out to 64 kilometers (West to East). In part of the study area, fixed radar facilities at the NASA Wallops Flight Facility are likely to be interfered with by wind development.

3.1.1. NASA Wallops Flight Facility

Table 16-NASA Wallops Flight Facility Overview

Location	*Wallops, Virginia*
Latitude	*N 37 Degrees, 57 Minutes*
Longitude	*W 75 Degrees, 28 Minutes*
Ownership/Operation	*NASA*

Wallops, Virginia is home to the NASA Wallops Flight Facility Airport (WFF). The facility, located just south of the Maryland border near Chincoteague Island, specializes in aerospace research, technology, and education. WFF operates 8 fixed radar systems in addition to 5 mobile or transportable radar systems (NASA, 2008). Only the fixed radar systems are analyzed in this research[42]. See Map 6 for the geographic location of the fixed radars at WFF.

Of the 8 fixed radar systems, 3 are range instrumentation radars (RIR), which are most commonly used to track launch vehicles, balloons, and satellites. The remaining 5 fixed radar systems are surveillance radars, used to detect and track targets operating in the Wallops range (NASA, 2008). Of the 5 surveillance radars, the Atmospheric Sciences Research Facility (ASRF) radar (or SPANDAR) has the greatest range and antenna height of any radar at WFF. See Table 17 for a detailed description of fixed radar parameters at WFF.

Table 17-Fixed Radar Systems and Parameters at WFF (Source: NASA, 2008)

Radar Type	**Function**	**Wavelength Band**	**Antenna Height (Meters)**
RIR-706 (Mainland)	Tracking	C	**8.84**
RIR–716	Tracking	C	**3.66**

[42] WFF operates a number of mobile radar units including both land-based and aerial radar units. For example, the AN/APS-143B(V)3[3] is an airborne radar with functionality useful for military training exercises and research.

(Island)			
RIR–716 (Airport)	Tracking	C	**4.88**
ASRF	Surveillance	UHF	**18.29**
ASRF (SPANDAR)	Surveillance	S	**18.29**
ASR–7	Surveillance	S	**5.33**
AN/TPX-42[2]	Surveillance	L	**8.33**
Mariners Pathfinder	Surveillance	X	**3.67**

Users and beneficiaries of the WFF facilities are diverse (NASA, 2008). Stakeholders of radar quality at WFF include:

- NASA
- FAA
- NOAA, which has a field site at WFF designed to collect environmental data via telemetry[43]
- U.S. Department of Defense
    - U.S. Navy (e.g., Surface Combat Systems Center and the Naval Air Command (NAVAIR) out of the Patuxent Naval Air Station)
    - U.S. Coast Guard

3.2.Other Area Radar Facilities

In addition to the facilities at WFF, Dover Air Force Base in Delaware, the Patuxent Naval Air Station (PAX NAS) in Maryland, the Oceana Naval Air Station (Oceana NAS) in Virginia, and the Gibbsboro, New Jersey long range radar facility were studied as mid-Atlantic radar facilities that could potentially be impacted by Maryland offshore wind development. Based on preliminary research, we determine that radar facilities at Dover Air Force Base, PAX NAS, Oceana NAS and Gibbsboro, NJ are unlikely to be impacted by Maryland offshore wind development.

[43] There is potential for wind turbines to interfere with telemetry though the degree to which this might occur is likely less severe than radar interference (Davis, 2009).

Researchers utilized basic analysis tools and pre-existing findings to evaluate potential radar conflicts at both Dover Air Force Base and PAX NAS. The FAA Obstruction Evaluation/ Airport Airspace Analysis (OE/AAA) Office and the DoD Preliminary Screening Tool indicate that RLOS from Dover Air Force Base is unlikely to reach the study area (See Appendix A) (FAA and U.S. DoD, 2009).[44] Analysis of potential radar conflicts at PAX NAS, draws upon work performed by Science Applications International Corporation (SAIC), Inc. (See Appendix B) (Linn, 2009). The SAIC analysis reveals that RLOS from PAX NAS is unlikely to reach the study area.

The long-range radar facilities at Gibbsboro, New Jersey and Ocean NAS, Virginia, were analyzed for potential wind development conflict using basic information on radar height, a maximum turbine height scenario, and an equation that calculates radar line of sight. Appendix C explains in more detail the methodology and data used for estimating the radar line of sight from the Gibbsboro, NJ and Oceana NAS facilities. The methodology employed to evaluate these two radars is nearly identical to Wallop's Flight Facility analysis described in the next section.

4. Approach and Findings

This section pertains specifically to fixed radar operations originating at WFF and demarcation of potential conflict areas off of Maryland's coast.

4.1.Data Layer Methodology

The methodology for developing the WFF radar data layer focused on a criterion of radar line-of-sight (RLOS). If a wind turbine or wind farm is not within RLOS, then the effects of the turbine on the signal will be negligible (U.S. DoD, 2006). RLOS can be represented by an equation that expresses the distance of radar horizontal range (i.e., how far on the horizon the radar will detect an object) given the height of the radar antenna above ground level and the height of the object of interest (e.g., wind turbine) above ground level. The Radar Horizon Range (RHR_k) functions as the radial distance that radar transmission will reach. The equation for RHR_k is as follows:

$$RHR_k = 4.12\ (\sqrt{h} + \sqrt{a})$$

RHR_k = Radar Horizon Range (Km)
h = Antenna height (m)
a = Target altitude or height (m)

[44] The OE/AAA preliminary screening tool represents only the radars catalogued in the national airspace system (NAS) (Kingsmore, 2010).

Four scenario wind turbine heights were adopted to evaluate the possibility for radar conflict. The turbine heights are the summation of the tower height (above the ocean surface) and the blade length. The scenario with the aggregate turbine height (tower and blades) of 151 meters represents the most current technology while the other three scenarios are based on proportional extrapolations of existing technology (Talisman, n.d.).The scenario wind turbine heights are as follows:

- 182 meters based on 100 m tower (above surface) and 82 m blades
- 151 meters based on 88 m tower (above surface) and 63 m blades
- 132 meters based on 77 m tower (above surface) and 55 m blades
- 113 meters based on 66 m tower (above surface) and 47 m blades

4.2.Findings for Wallops Flight Facility

Based on the formula above, the known antenna heights of the eight fixed radars at WFF, and working under four scenarios of variable turbine heights, RLOS radii were developed (See Table 18).

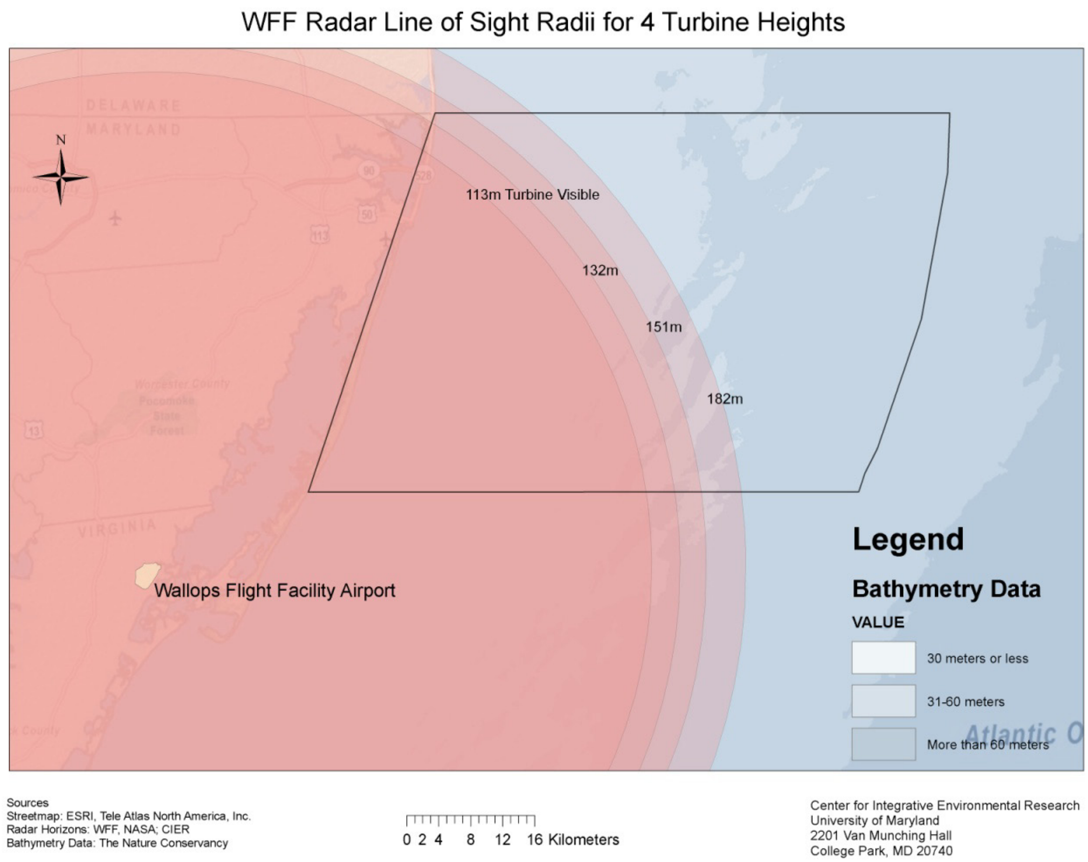
Table 18-WFF Radar Line-of-Sight Radii with Highlight of Tallest Radar Antenna

Specific Radar Unit	**RHR at 182 m turbine height**	**RHR at 151 m turbine height**	**RHR at 132 m turbine height**	**RHR at 113 m turbine height**
RIR-706 (Mainland)	67 km	63 km	60 km	56 km
RIR–716 (Island)	63 km	59 km	55 km	52 km
RIR–716 (Airport)	64 km	60 km	56 km	53 km
ASRF	73 km	68 km	65 km	61 km
ASRF (SPANDAR)	73 km	68 km	65 km	61 km
ASR–7	65 km	60 km	57 km	53 km
AN/TPX-42[2]	67 km	63 km	59 km	56 km
Mariners	63 km	59 km	55 km	52 km

Pathfinder				

The ASRF (SPANDAR) radar unit has the greatest RLOS radius and it encompasses all other RLOS radii at WFF. Because of this fact, visually representing the RLOS radius for the ASRF (SPANDAR) alone sufficiently demonstrates the broad-level possibility for radar interference in the study area. The RLOS radii for the ASRF (SPANDAR) under 4 different turbine height scenarios are represented in Map 6 (see below).

Map 6- WFF Radar Line of Sight Radii for 4 Turbine Heights



5. Mid-Atlantic Operations (Military and Research)

Operations conducted by the U.S. Department of Defense (DoD) and the National Aeronautics and Space Administration (NASA) off of Maryland's coast are significant factors to consider in wind development. The two primary areas of potential conflict are the Fleet Area Control and Surveillance Facility (FACSFAC) Virginia Capes (VACAPES) Operating Area and NASA Wallops Flight Facility Range Hazard Area.

5.1. Areas with High Likelihood for Conflict

5.1.1. VACAPES Operating Area

The FACSFAC VACAPES Operating Area, which consists of air, surface, and subsurface space, is operated by the U.S. Navy and is accessible to the entire U.S. military. The space consists of warning areas, restricted areas, military operating areas, air traffic control assigned airspace, and surface/subsurface operating areas (Stewart, 2009). A number of stakeholders use the VACAPES space including:

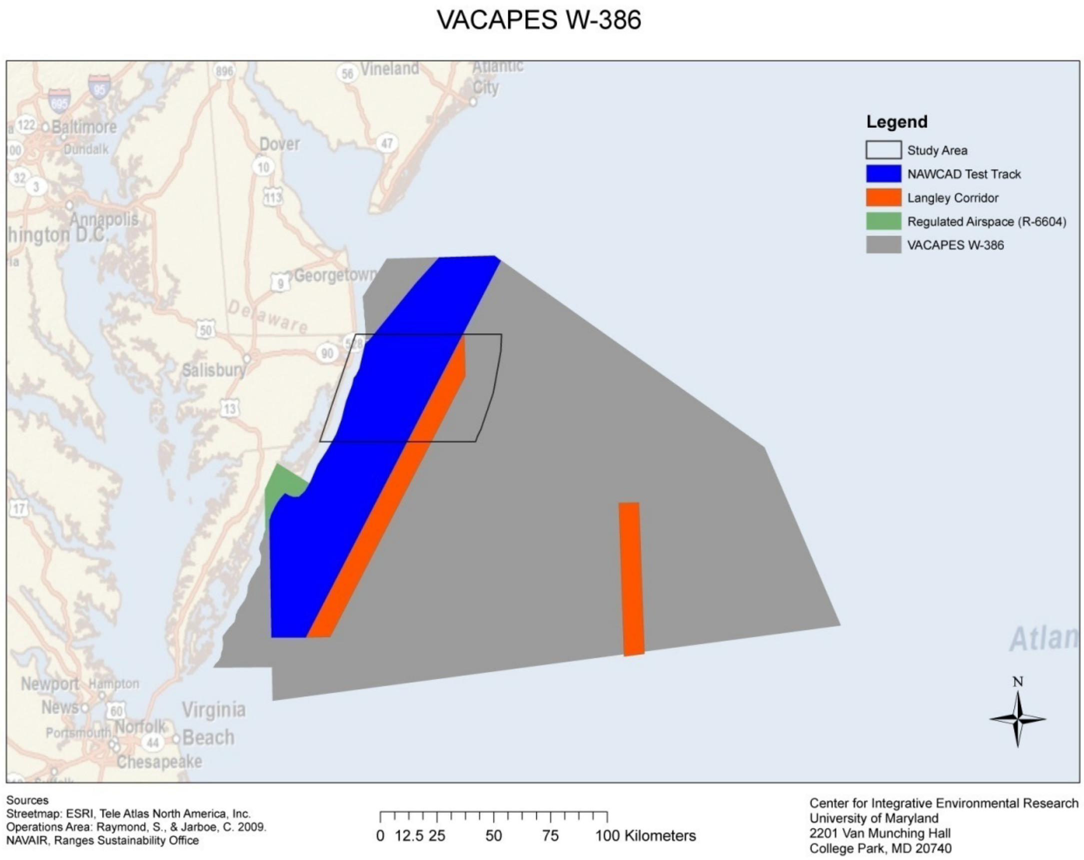
- U.S. Navy [e.g., Tests and Evaluation, Air Command (NAVAIR), Sea Command (NAVSEA)]
- U.S. Air Force
- U.S. Coast Guard
- NASA

The specific space within the VACAPES Operating Area of most relevance to offshore Maryland is Warning Area 386 (W-386). W-386 is special-use airspace located about 5.5 kilometers east of the Maryland Economic Zone. W-386 extends from surface to unlimited altitude, except for the area west of longitude W 75 Degrees, 30 Minutes, which is from surface to 1,999 feet (Global Security, 2005; U.S. DoD, 2001; Owen, 2009). A number of military operations occur within W-386 including flight-testing, munitions deployment, and general training exercises. Primary users of the W-386 include Navy Air Command (NAVAIR) out of PAX NAS and Navy Sea Command (NAVSEA), much of which comes out of Norfolk, Virginia.

For the purpose of understanding potential interactions between mobile radar and wind turbines, it is important to note that military radar can only originate within W-386 (Owen, 2009). However, radar signals do not obey man-made boundaries and signal interference could occur whether turbines are sited within W-386 or not.

Below is a summary of major types of operations that occur within W-386 (See Map 7).

Map 7- VACAPES W-386



5.1.1.1. Flight Testing

Flight-testing, particularly supersonic flight-testing, occurs in the Naval Air Warfare Center, Aircraft Division (NAWCAD) Test Track. Multiple flight tests are conducted on a daily basis and tests are often at very high altitudes (Stewart, 2009). Possible conflicts within the NAWCAD Test Track are physical and radar-based. The potential for physical conflict exists with low-flying aircraft. The potential for radar-based conflict exists with both fixed radar (e.g., WFF) and mobile radar (e.g., aircraft or vessel) experiencing interference from wind-turbines.

In addition to supersonic flight-testing, helicopter operations are frequent in the southern portion of W-386, which links up with air space connecting to the PAX NAS. Helicopters are often low flying in this airspace (Stewart, 2009).

5.1.1.2. Munitions Deployment

Munitions deployment occurs within W-386 including air-to-air, air-to-surface, and surface-to-surface missile, gunnery, and rocket exercises. Much of the munitions deployment is inactive in the sense that explosives are not used. Inactive munitions deployment still involves large objects or missiles that can do damage to personnel or equipment. Hazardous, live-fire exercises are not uncommon (Stewart, 2009).

The likelihood for physical conflict in the study area is high given the deployment of large, potentially damaging weaponry (live or dead). Furthermore, precise radar tracking (fixed or mobile) of weapons could be degraded with the presence of wind turbines.

5.1.1.3. General Training Exercises

Sea-based and air-based training takes place in W-386. Sea based training exercises frequently involve deploying U.S. Navy combat vessels and full crew with the goal of simulating war-like events. For example, common training exercises simulate enemy attack, which might require turning radars to full power to detect objects of interest (Davis, 2009). As a result, wind turbine interference might degrade this simulation experience. Additionally, vessels may cover a significant area during the course of a training exercise. Mobility of vessels could be impaired by the presence of turbines in W-386.

5.1.1.4. Other Operations

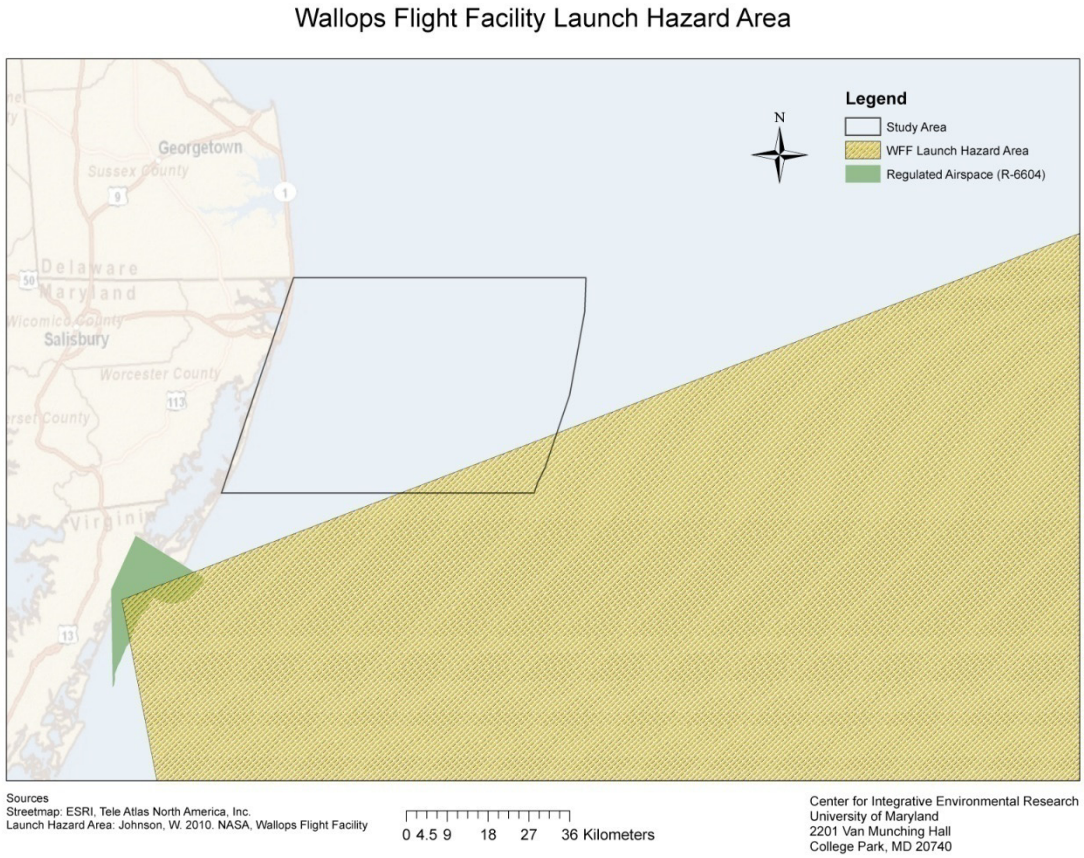
Another specific area within W-386 and the study area is the Langley Corridor, which is used by Langley Air Force Base as an enter/exit route for aircraft. This space is within 64 kilometers of Maryland's coast (Stewart, 2009).

5.1.2. Wallops Flight Facility Launch Hazard Area

NASA's Wallops FFA oversees a Launch Hazard Area, which is an area in the Atlantic Ocean designated for operational impacts (i.e., rockets, balloons). The Launch Hazard Area is fan-shaped beginning at the WFF launch site and extending 305.5 kilometers in a southern and eastern direction. The affected area is roughly 72,000 square nautical kilometers. The Launch Hazard Area overlaps with the VACAPES Operational Area, including W-386 (NASA, 2008).

Map 8 below represents where impacts have historically occurred and is not a specially authorized area. Also, potential impact areas vary from launch to launch, but frequently fall entirely within the Launch Hazard Area (Johnson, 2009).

Map 8- Wallops Flight Facility Launch Hazard Area



5.2.Approach and Findings

The Ranges Sustainability Office at PAX NAS provided the VACAPES data layers accompanying this report, which pertain specifically to W-386 (Sabella and Jarboe, 2009). The VACAPES Operating Area encompasses the entire study area with the exception of Maryland state waters between the coastline and W-386. Of particular relevance to the area off of Maryland's coast are the NAWCAD Test Track and the Langley Corridor, both of which are included in Map 7.

The NASA WFF Facilities Management Branch provided the Launch Hazard Area data layers accompanying this report (Johnson, 2009). A small portion of the NASA WFF Launch Hazard Area overlaps with the study area.. Furthermore, regulated airspace R-6604, which is used and monitored by WFF, is included in Maps 7 and 8 although the airspace is significantly south of the study area and unlikely to conflict directly with wind development (See Map 8).

6. Discussion and Conclusion

Limitations exist to fully understanding the potential for conflicts between offshore wind development and mid-Atlantic operations. A deficit of literature on how mobile radar devices interact with wind turbines is a hurdle to identifying potential conflicts. Additionally, more information about surface and subsurface military operations (including live training exercises) would improve understanding of possible conflict areas and encourage wind developers to further explore the waters adjacent to Maryland.

In conclusion, the potential for diminished radar functionality exists at NASA's Wallops Flight Facility, which would impact many stakeholders. The potential for diminished radar functionality at other mid-Atlantic facilities, is unlikely. These findings apply to fixed radar units only and future field research is needed to truly evaluate conflict potential. U.S. military operations in the air or surface space adjacent to Maryland's coastline are likely to be a source of conflict for wind development, but with more information regarding specific offshore military activities, it may be possible to abate conflict.

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8. Appendices

Appendix A: Maryland state waters and radar line-of-sight, Dover AFB

Disclaimer:

- The DoD Preliminary Screening Tool enables developers to obtain a preliminary review of potential impacts to Long-Range and Weather Radar(s), Military Training Route(s) and Special Airspace(s) prior to official OE/AAA filing. This tool will produce a map relating the structure to any of the DoD/DHS and NOAA resources listed above. The use of this tool is **100 % optional** and will provide a first level of feedback and single points of contact within the DoD/DHS and NOAA to discuss impacts/mitigation efforts on the military training mission and NEXRAD Weather Radars. **The use of this tool does not in any way replace the official FAA processes/procedures.**

Instructions:

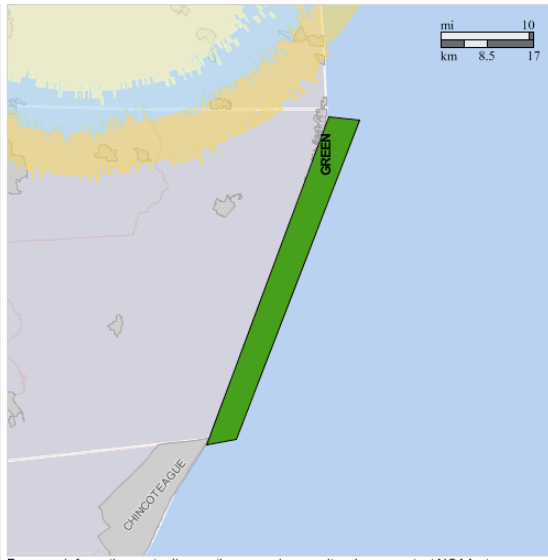
- Select a screening type for your initial evaluation. Currently the system supports pre-screening on:
  -Air Defense and Homeland Security radars(Long Range Radar)
  -Weather Surveillance Radar-1988 Doppler radars(NEXRAD)
  -Military Operations
- Enter either a single point or a polygon and click submit to generate a long range radar analysis map.
- Military Operations is only available for a single point.
- At least three points are required for a polygon, with an optional fourth point.
- The largest polygon allowed has a maximum perimeter of 100 miles.

Screening Type: NEXRAD **Geometry Type:** Polygon

Point	Latitude Deg	Min	Sec	Dir	Longitude Deg	Min	Sec	Dir
1	38	1	12	N	75	14	42	W
2	38	26	30	N	75	2	42	W
3	38	26	13	N	74	59	42	W
4	38	1	36	N	75	11	47	W

Horizontal Datum: NAD83

Submit



For more information, or to discuss the screening results, please contact NOAA at wind.energy.matters@noaa.gov

Map Legend:

- **Green:** Minimal to no impact to Weather Surveillance Radar-1988 Doppler (WSR-88D) weather radar operations. National Telecommunications & Information Administration (NTIA) notification advised.
- **Yellow:** RLOS Coverage At or Below 130m AGL. Impact likely to WSR-88D weather radar operations. Turbines likely in radar line of sight. Impact study required. NTIA notification advised.
- **Blue:** RLOS Coverage At or Below 160m AGL. Impact likely to WSR-88D weather radar operations. Turbines likely in radar line of sight. Impact study required. NTIA notification advised.
- **Gold:** RLOS Coverage At or Below 200m AGL. Impact likely to WSR-88D weather radar operations. Turbines likely in radar line of sight. Impact study required. NTIA notification advised.
- **Red:** Impact highly likely to WSR-88D weather radar operations and wind turbine electronics. Turbines likely in radar line of sight. Aeronautical study required. NTIA notification strongly advised.

Potential NEXRAD WSR-88D radar conflict zone relative to Maryland's 4.8 kilometers economic zone. Nearest NEXRAD WSR-88D radar relative to Maryland coastline is sited at Dover Air Force Base, Delaware.

Disclaimer:

- The DoD Preliminary Screening Tool enables developers to obtain a preliminary review of potential impacts to Long-Range and Weather Radar(s), Military Training Route(s) and Special Airspace(s) prior to official OE/AAA filing. This tool will produce a map relating the structure to any of the DoD/DHS and NOAA resources listed above. The use of this tool is **100 % optional** and will provide a first level of feedback and single points of contact within the DoD/DHS and NOAA to discuss impacts/mitigation efforts on the military training mission and NEXRAD Weather Radars. **The use of this tool does not in any way replace the official FAA processes/procedures.**

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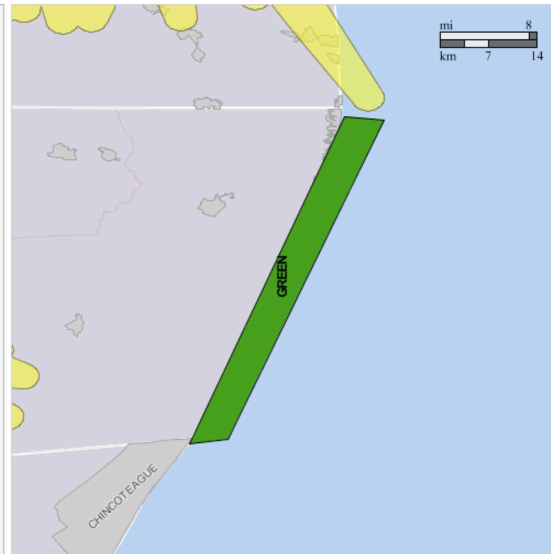
- Select a screening type for your initial evaluation. Currently the system supports pre-screening on:
  -Air Defense and Homeland Security radars(Long Range Radar)
  -Weather Surveillance Radar-1988 Doppler radars(NEXRAD)
  -Military Operations
- Enter either a single point or a polygon and click submit to generate a long range radar analysis map.
- Military Operations is only available for a single point.
- At least three points are required for a polygon, with an optional fourth point.
- The largest polygon allowed has a maximum perimeter of 100 miles.

Screening Type: Long Range Radar **Geometry Type:** Polygon

Point	Latitude Deg	Min	Sec	Dir	Longitude Deg	Min	Sec	Dir
1	38	1	12	N	75	14	42	W
2	38	26	30	N	75	2	42	W
3	38	26	13	N	74	59	42	W
4	38	1	36	N	75	11	47	W

Horizontal Datum: NAD83

Submit



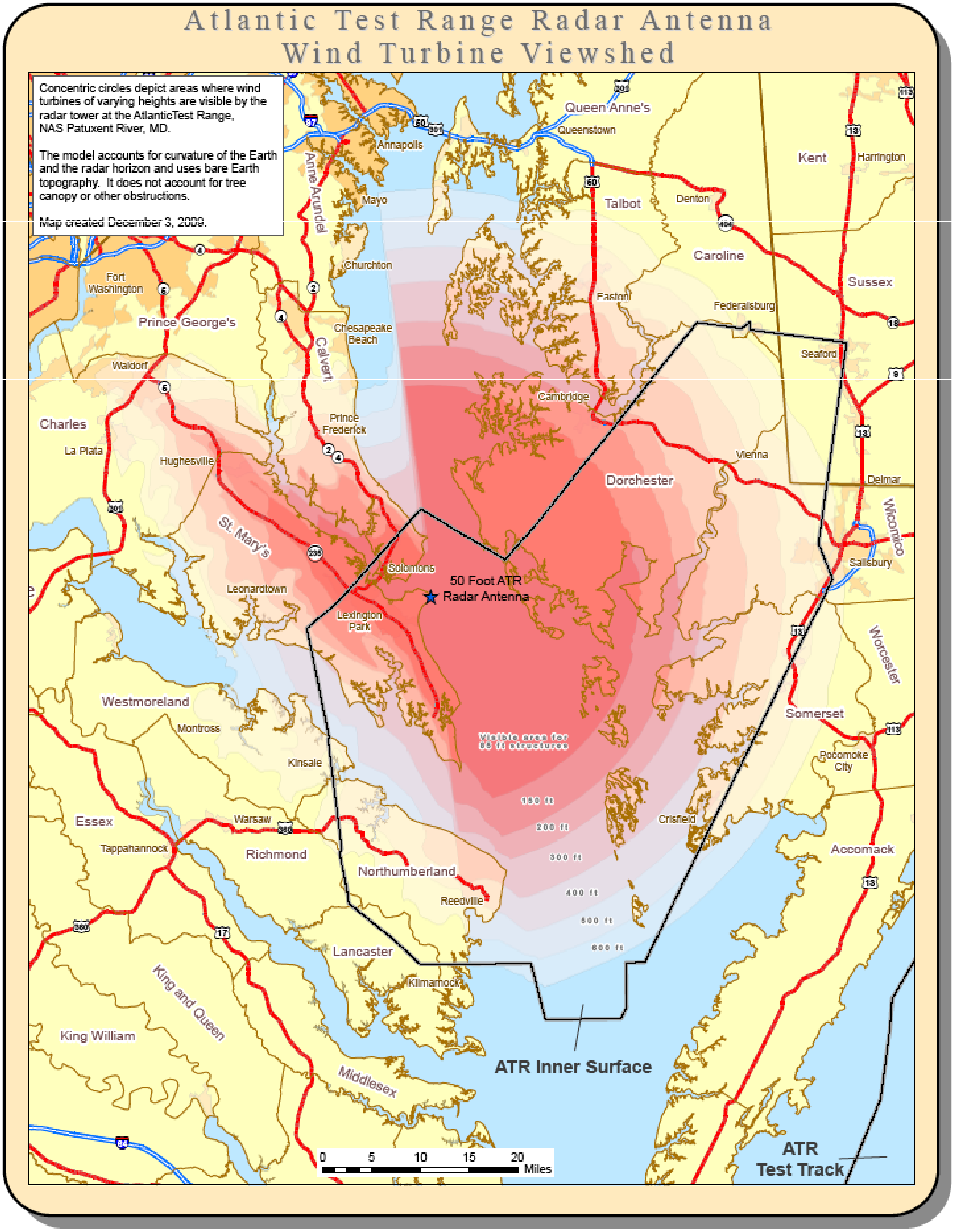
Map Legend:

- **Green:** No anticipated impact to Air Defense and Homeland Security radars. Aeronautical study required.
- **Yellow:** Impact likely to Air Defense and Homeland Security radars. Aeronautical study required.
- **Red:** Impact highly likely to Air Defense and Homeland Security radars. Aeronautical study required.

Potential long-range radar conflict zone relative to Maryland's 4.8 kilometers economic zone. Long-range radars sited at Dover Air Force Base in Delaware and Patuxent Naval Air Station in Maryland.

(Source: FAA-DoD 2009)

Appendix B: Radar line-of-sight, PAX NAS (Source: Linn, 2009)



Appendix C: Methodology for determining potential conflict with long-range radars at Gibbsboro, NJ and Oceana NAS, VA

Specifications: Radar antennae units at both facilities were estimated to be 100 feet in height, or 30.5 meters tall *(h)*. The target height, the wind turbine, is assumed to be a maximum of 182 meters tall *(a)* (tower and blade distance above the surface of the water).

Equation: The equation for RHR_k is as follows:

$$RHR_k = 4.12\ (\sqrt{h} + \sqrt{a})$$

RHR_k = Radar Horizon Range (Km)
h = Antenna height (m)
a = Target altitude or height (m)

Calculation: The Radar Horizon Range is equal to 78 kilometers. In other words, for radar originating from 30.5 meters above the surface of the Earth, a turbine of 182 meters will fall within the radar line of sight out to a distance of 78 kilometers. Beyond 78 kilometers, the turbine will not be detected.

Implications: The long-range radar units at Gibbsboro, NJ and Oceana NAS, VA cannot reach the study area and are therefore unlikely to be impacted by offshore wind development in Maryland (See appendix D below).

Appendix D: Mid-Atlantic Long Range Radar Line of Sight Radii; Gibbsboro, NJ and Oceana NAS, VA (Source: Kingsmore, 2010)