NEMS Modeling of East Coast Offshore Wind: Examining the Assumptions

By

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Abstract

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The Energy Information Administration's (EIA) National Energy Modeling System (NEMS) is widely considered a credible source for domestic energy projections, and is frequently used to inform state and federal policy decisions. The model is used to publish the Annual Energy Outlook (AEO). The 2010 AEO publication suggest that offshore wind development along the eastern seaboard is predicted to grow very little over the next 25 years, yet there are currently over 2.5 GW of proposed offshore projects in this area, with interest growing steadily. This project seeks to determine whether NEMS modeling of offshore wind is based on accurate assumptions and on the current state of the industry. Key factors that shape NEMS results are examined. These factors include the shallow water offshore wind resource off the eastern seaboard, the overnight capital costs assumed by the model, and the way in which transmission and reliability costs associated with offshore wind are treated. The assumptions used by the EIA in their modeling were examined for each of these factors. Modeling scenarios were built to test the sensitivity of the results to changes in these assumptions. This method helped to identify which parameters weigh most heavily in how the model determines whether offshore wind will play a role in the near-term future of renewable energy production. Findings indicate that wind resource estimates are out-dated, but that the wind resource is not a constraint on the offshore development. Capital cost assumptions are in line with accepted industry values, and are the largest factor in how much offshore wind capacity is added over the next twenty-five years. This research suggests that capital costs must decrease by as much as 35% before offshore wind can out-compete other forms of renewable generation. Transmission and reliability cost effects are difficult to assess without more access to model data and the calculations it employs. Recommendations for improving the model include more transparency in assumptions and better documentation of model inputs and outputs.

Contents

1 Introduction

Offshore wind energy development has been happening in Europe for twenty years. On September 23rd of 2010, Britain opened the world's largest offshore wind farm. The site will contain up to 341 turbines and represents 300 MW of capacity (The Independent 2010). There are currently 830 wind turbines installed and grid connected, totaling 2,063 MW of capacity in 39 wind farms in nine European countries (EWEA 2010). The US, on the other hand, has no installed offshore wind capacity. However, within the United States there is burgeoning interest in capitalizing on the offshore wind resource available on the east coast. This interest is evidenced by multiple recent studies of the wind resource along the eastern seaboard, as well as a number of project proposals.

It is easy to understand the interest in taking advantage of the wind resource off the coasts of the United States. Foremost among the reasons for this interest is the fact that the resource is abundant and widely dispersed, providing a free and unlimited energy source for much of the coast line. A recent study by Oceana states that conservatively, there is 127 GW of economically available wind resource in shallow water off the east coast of the US. The report suggests that this wind power could supplant 70% of the east coast's fossil-based electricity, and that it would eliminate 335 million metric tons of CO_2 emission (Mahan et al. 2010). Experts at the National Renewable Energy Laboratory (NREL) have stated that there is over 1000 GW of wind resource off the coast of the US (Musial, Butterfield, and Ram, 2006). 28 of the 48 contiguous states have a coastal boundary. The EIA reports that these 28 states use nearly 80% of the nation's electricity (EIA 2006). 22 of these 28 states do not possess the land-based wind resources necessary to supply more than 20% of their electricity demand.

However, if shallow offshore wind is included in the total wind resource, 26 of the 28 states would have the resources required to meet at least 20% of their electricity demand. Some of the states would be able to provide 100% of their electricity needs with wind generation (Musial 2007).

Offshore wind offers benefits additional to availability over other forms of power generation. While the land-based wind industry has experienced robust growth over the last decade, there are considerable challenges involved with maintaining that growth rate. Transmission line access and grid capacity make transport of electricity from windy areas to load centers difficult. Offshore advocates point out that offshore wind generated electricity has the potential to match the contribution of onshore wind in the US because it can compete in densely populated coastal energy markets where onshore wind is generally not available (Mahan et al. 2010). Figure 1 illustrates the point that there are good offshore wind resources near many of the major load centers along the eastern seaboard. This characteristic of offshore wind lessens the concern of long distance power transmission mentioned earlier. In addition, offshore resources tend to be geographically located near regions of the country that already pay higher electricity rates. This makes it easier for offshore wind development to compete with other generation in these areas.

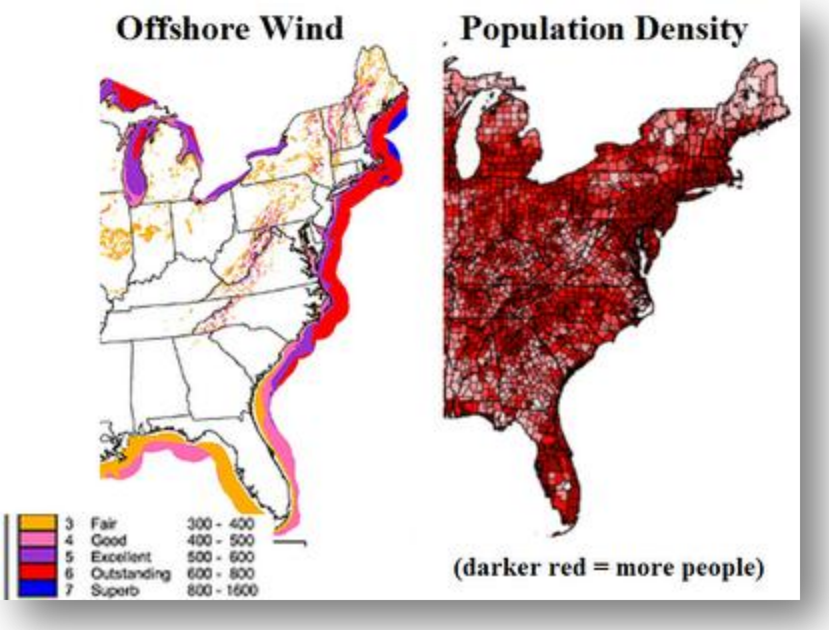

Figure 1. Population density corresponds to highest quality offshore wind resource (Source: NREL).

The proximity to the load centers along the eastern seaboard is a major factor in the current or eventual cost effectiveness of shallow water offshore wind development. This proximity eases issues of transmission congestion in states that require renewable power generation but have little or no land-based renewable resources.

Other factors driving enthusiasm for shallow water offshore wind development include the environmental benefits of having a clean, boundless fuel source. Concerns over global climate change, energy independence, and international competition have helped drive recent increases in renewable power development in the United States. These issues have motivated the legislation and implementation of many state and local policies related to energy generation. Twenty-nine states and the District of Columbia currently have a Renewable Energy Standard (RES) in place which mandates that a certain percentage of electricity generation come from renewable sources. An additional six states have renewable energy goals (DSIRE, 2010). Considering that over half of the states have their own RES or RPS standard, a national RES may be forthcoming. Such a standard could shift the economic balance for renewable energy production. Other motivators include national security, local and regional economic development, and fuel price volatility.

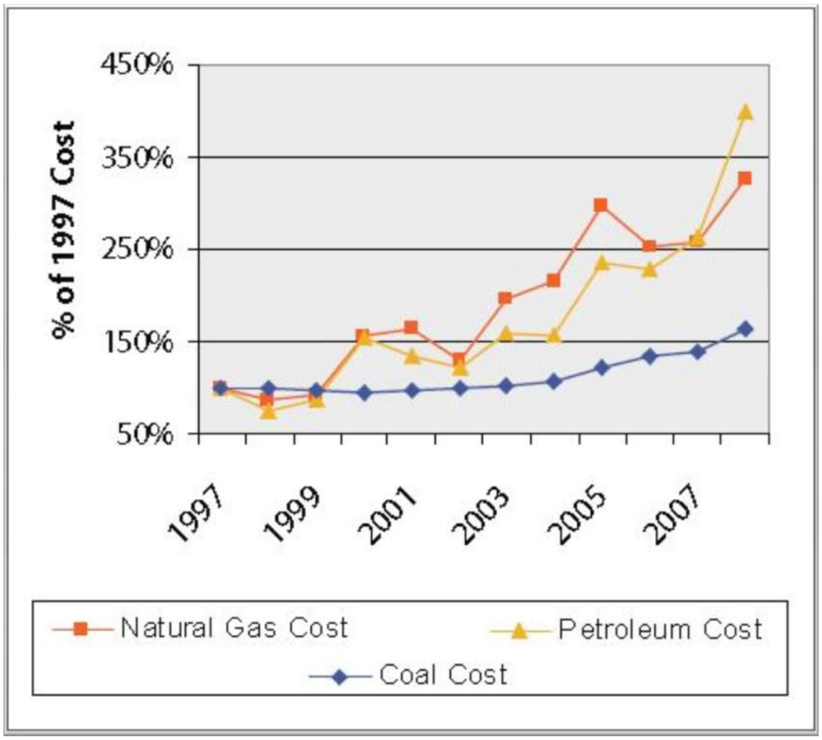

Figure 2. Fuel Costs for Electricity Generation 1998-2008[1]

Figure 2 shows that the major fossil fuels used in energy production have increased in cost dramatically over the last ten years. As demand for electricity continues to rise, price volatility such as this makes it very difficult to plan for how to meet that demand while keeping rates low. It is within the context of these drivers and of the growing interest in harnessing the

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[1] Source: United States Department of Energy (2010, January 21). "Figure ES 4. Fuel Costs for the Electricity Generation," Energy Information Administration. http://www.eia.doe.gov/cneaf/electricity/epa/figes4.html

power of east coast offshore wind that it becomes important to understand the projections of how this industry is expected to evolve. One important source for such projections comes from the National Energy Modeling System, or NEMS.

NEMS is a multi-sectoral, fully integrated macro-economic energy model. It is the primary modeling tool used by the Energy Information Administration (EIA) to create their annual energy report, the *Annual Energy Outlook* (AEO). This yearly report is based upon the state and federal laws in affect at the time the model was run. NEMS was developed and is maintained within the EIA by the Office of Integrated Analysis and Forecasting (OIAF). In addition to developing the projections in AEO, NEMS provides analytical forecasts for the Congress, the Executive Office of the President, other offices within the Department of Energy, and other federal agencies. It is widely used to do sensitivity studies for alternative energy policies. NEMS is considered a credible reference in energy analysis and policy circles (EIA 2010a). This credibility is exactly why the data and assumptions used in the model must be as accurate as possible. However, when it comes to offshore wind there is reason to question the assumptions used by NEMS.

1.1 Reasons to Question NEMS Assumptions Regarding East Coast Offshore Wind

There are two things that suggest the current NEMS characterization of east coast offshore wind may be inaccurate. The first is a difference in expectations for the future expansion of offshore wind capacity. Several wind developers have made it clear they are interested in building new offshore wind capacity along the eastern seaboard. There are currently ten proposed offshore wind projects that, if realized, will add roughly 2.5 GW of generation capacity (OffshoreWind.net. 2010). Contrast this with the AEO 2010 projections regarding future offshore wind development in the United States; AEO 2010 forecasts that offshore wind will provide 0.75 terawatt-hours (TWh) of electricity generation in each year from 2015 through 2035. In 2035, this amount is one tenth of one percent of the total forecasted renewable generation for that year (EIA 2010a). According to the EIA, offshore wind will not play a role in meeting the demand for electricity from renewable sources in the near future. Figure 3, taken from AEO 2010, illustrates this point. NEMS predicts 200MW of offshore wind capacity will be added in 2015, with no additional capacity built through 2035. The difference between 2.5GW and 200MW is a difference of twelve times. This difference represents a significant disparity between what the EIA expects and what some offshore wind investors expect.

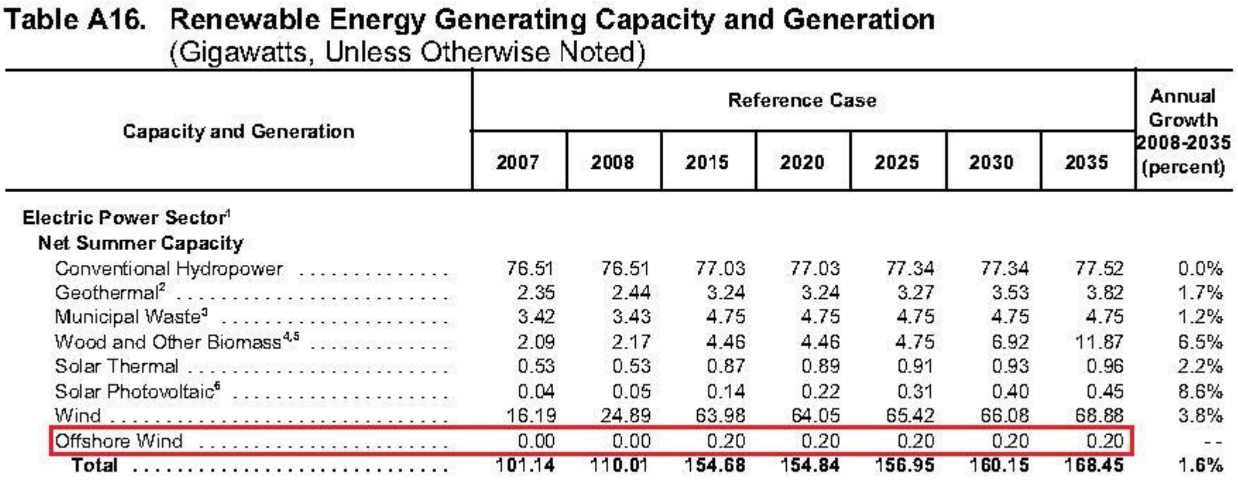

Table A16. Renewable Energy Generating Capacity and Generation
(Gigawatts, Unless Otherwise Noted)

Capacity and Generation	Reference Case							Annual Growth 2008-2035 (percent)
	2007	2008	2015	2020	2025	2030	2035	
Electric Power Sector[1]								
Net Summer Capacity								
Conventional Hydropower	76.51	76.51	77.03	77.03	77.34	77.34	77.52	0.0%
Geothermal[2]	2.35	2.44	3.24	3.24	3.27	3.53	3.82	1.7%
Municipal Waste[3]	3.42	3.43	4.75	4.75	4.75	4.75	4.75	1.2%
Wood and Other Biomass[4,5]	2.09	2.17	4.46	4.46	4.75	6.92	11.87	6.5%
Solar Thermal	0.53	0.53	0.87	0.89	0.91	0.93	0.96	2.2%
Solar Photovoltaic[6]	0.04	0.05	0.14	0.22	0.31	0.40	0.45	8.6%
Wind	16.19	24.89	63.98	64.05	65.42	66.08	68.88	3.8%
Offshore Wind	0.00	0.00	0.20	0.20	0.20	0.20	0.20	- -
Total	**101.14**	**110.01**	**154.68**	**154.84**	**156.95**	**160.15**	**168.45**	**1.6%**

Figure 3. AEO 2010 Projection of offshore wind capacity over the next 25 years.

The second reason to question how NEMS forecasts offshore wind along the east coast comes from a recent study of renewable energy resources in the Southern US. "Renewable Energy in the South" (Brown et al. 2010), a recent study released by researchers at Duke University and Georgia Institute of Technology, suggests that current assessments of the

Southern wind resource base by the EIA are outdated. This assertion is driven by the fact that NEMS uses available windy land assumptions based upon 50m turbine hub heights (Brown et al. 2010). Current industry standard hub heights are 80m or more in height. They argue that these estimates result in EIA forecasts that underestimate the economic potential of onshore wind, and that there are large wind resources in the South. The fact that EIA assumptions about the Southern land-based wind resource are outdated provides justification for questioning their assumptions about offshore wind.

These two issues provide a foundation for the goals of this study. The purpose of this study is to examine whether the EIA's modeling of offshore wind development off the east coast of the United States is based upon assumptions consistent with the current state of offshore wind development and the current technologies used to estimate the quality of the wind resource. This project focuses on four key factors that affect the extent to which east coast offshore wind is selected by NEMS as being cost competitive with other sources of generation. Specifically, the following modeling assumptions are examined: the availability of the wind resource in the region, the overnight capital costs of offshore wind, and the offshore wind costs associated with transmission and reliability, relative to those of land-based wind. For each of these assumptions, the value used in the model must be compared with what is currently accepted in the industry. To explore the extent to which each assumption affects the forecast, the NEMS model was updated to run a set of scenarios that varied in their inputs. The scenario results provided insights into the influence of each assumption in the offshore wind forecast.

This report is organized into four sections. The first section provides an introduction to the project and arguments for examining NEMS assumptions, as well as an overview of the current state of the offshore wind industry in the United States. The second section is devoted to an explanation of the methods undertaken in the study. Section three describes the findings of the study, and the final section provides a discussion of the results and their implications. The final section also offers some recommendations about the NEMS model.

1.2 Barriers to Offshore Development

While offshore wind holds the promise of a free, renewable source of energy, and while it provides the benefits of lessened problems with congested transmission from remote locations and proximity to urban load centers, there are considerable obstacles to large-scale offshore power development. The most significant of these barriers is the technological requirements of the substructures necessary to support the large wind turbines. As water depths increase, so do the challenges associated with these structures.

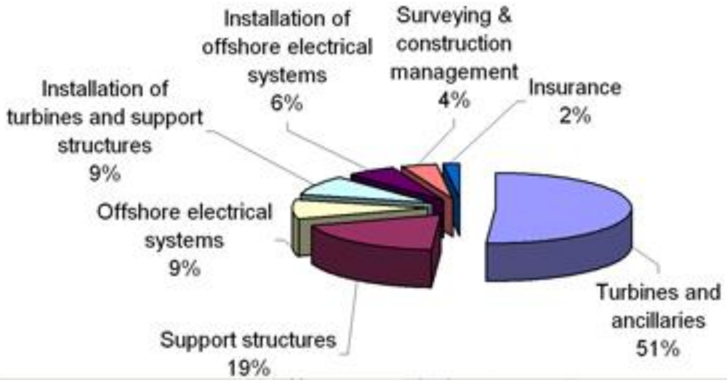

Figure 4. Capital Cost Breakdown for Typical Offshore Wind Farm (Source: http://www.wind-energy-the-facts.org/en/part-i-technology/chapter-5-offshore/wind-farm-design-offshore/)

Figure 4 shows that support structures make up nearly a fifth of the total capital cost of a typical offshore wind farm.

Another consideration for offshore wind development is adapting current onshore wind technology for use on the open ocean. The turbines must essentially be reengineered with factors relevant to the operating conditions of the ocean and the challenges inherent in working in that environment in mind. Musial et al. (2006) indicates that to address this need for adaptation, investment, research and development must be concentrated in the following areas:

- Establishing a design basis for offshore turbines
- Develop offshore design codes and models
- Minimize work at sea
- Develop low cost anchors and moorings
- Conduct offshore wind-wave measurements
- Offshore turbine weight reduction
- Electric grid and systems integration
- Investigate potential for ultra-large turbines

The Offshore Wind Technology portion of the US DOE's Wind and Water Program has been put in place to promote collaboration and research initiatives designed to focus on issues such as those listed here, in an effort to reduce the costs of offshore development (DOE 2010). Technological hurdles are not the only obstacle for offshore wind energy. Environmental and regulatory barriers exist that pose risks for would-be developers of offshore wind resources. Though Europe has two decades of experience with offshore wind development, the US did not have its first project proposal until 2001[2], and no federal policies addressing the issue until 2005. It was in August of that year that the Energy Policy Act of 2005[3] was signed into law. This

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[2] Cape Wind Associates proposed Cape Wind for Nantucket Sound, Massachusetts

[3] EPAct 2005, PL 109-58

bill granted control over renewable energy projects off the coast of the US to the Minerals Management Service (MMS), within the Department of the Interior. The MMS has since been renamed the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE). The BOEMRE has extensive experience regulating the offshore oil and gas industry on the Outer Continental Shelf (OCS). Given this experience, the BOEMRE is well equipped to oversee siting and managing activities on the OCS. However, the BOEMRE has no practical experience with the wind energy industry.

In addition to the BOEMRE, the Army Corps of Engineers (ACE), the Federal Energy Regulatory Commission (FERC), and the National Ocean and Atmospheric Administration (NOAA) all have some jurisdiction over activities related to offshore wind development on the OCS. There are myriad other federal and state agencies that have some responsibility for use and management of the oceans, and that have input into the approval process for offshore wind energy development (Musial et al. 2006). Until some experience with offshore wind projects has been gained, it is easy to see how the current regulatory structure may impede the growth of the industry.

No less important than the technical and regulatory barriers are the issues of a limited supply chain and an installation bottleneck for offshore wind equipment. Currently, there are only three offshore turbine manufacturers in the marketplace. Most of the manufacturing is taking place in Europe, where there is high demand for the turbines. The result is a scarcity of available equipment and labor, and high prices.

There are also environmental and social impacts of offshore wind development that are not yet well understood. Examples can be cited from European wind farms, but for the most part these projects have been relatively small and had few scientifically credible studies conducted before being built (Musial et al. 2006). However, the growth rate for offshore wind in Europe is high, and as such there will be more data about the environmental and socio-economic impacts available relatively soon.

1.3 Offshore Industry in the Near Term

There are numerous projects in development along the east coast of the US. Just as it has with onshore wind, growth in the offshore industry could spur economic development through job creation in manufacturing and construction. In June of this year, Secretary of the Interior Ken Salazar and the governors of ten East Coast states signed a Memorandum of Understanding, establishing an Atlantic Offshore Wind Energy Consortium in order to promote the development of wind resources on the Outer Continental Shelf. The ten states are Maine, New Hampshire, Massachusetts, Rhode Island, New York, New Jersey, Delaware, Maryland, Virginia, and North Carolina. The consortium will work to encourage federal-state cooperation to promote Outer Continental Shelf wind development. Upon signing the MOU, Salazar said that “Appropriate development of Outer Continental Shelf wind power will enhance regional and national energy security and create American jobs through the development of energy markets and investments in renewable energy technologies” (US Department of Interior, 2010, p.1).

Federal agencies are not the only entities interested in exploring the potential of offshore wind in the US. On August 19th of 2010, New Jersey enacted the “Offshore Wind Economic Development Act”. It is modeled from the law that propelled New Jersey close to the top of US rankings for solar installations. The bill mandates a percentage of its electricity be supplied by offshore wind, and directs state utilities to buy offshore renewable credits from approved wind farms. The hope is the program will help to ease the concerns of developers that may feel offshore wind is too costly an investment. Opponents of the bill contend that it will cause rates to increase in a State that pays the seventh highest electricity rates in the nation. New Jersey Governor Chris Christie touted the bill as an instrument of economic development (Marshall 2010).

The State of Delaware is pursuing what is likely the only option for meeting its state Renewable Energy Standard from power generated in Delaware – offshore wind power. In July of 2008, NRG Bluewater Wind signed a power purchase agreement (PPA) with Delmarva Power of Delaware to provide stable priced electricity for 25 years. Bluewater Wind plans to build an offshore wind project with nameplate capacity of 450 MW. The wind park will be 13 miles offshore, and will provide enough electricity to power 100,000 Delaware households. Bluewater Wind expects the entire process to take two years from planning to completion. The project was commissioned by the Delaware General Assembly in response to volatile energy prices in a deregulated market, and the state's Renewable Energy Standard. For Delaware and most other coastal states, offshore wind resources are the only indigenous energy source capable of making a significant energy contribution. In addition to Delaware, NRG Bluewater has offshore projects in New York, New Jersey, and Maryland (NRG Bluewater Wind 2010).

The University of Delaware is working with NREL to develop a commercial offshore wind turbine test facility off the Delaware coast. NREL and UD will design test procedures specifically focused on the effects of the area's harsh offshore environment. They hope to create methods for predicting offshore wind energy costs in the US, as well as provide valuable training resources for future wind energy professionals (NREL 2010).

Cape Wind is undoubtedly the offshore project with the highest profile. It is also furthest along in the process of being realized. Cape Wind will be a 454 MW offshore wind farm on the Horseshoe Shoal in Nantucket Sound, off the coast of Massachusetts. In May of 2010, the project received the final federal approvals required, allowing the project to move to the construction phase. The farm will cover roughly 25 square miles of ocean, and be made up of 130 turbines with hub heights approximately 80 meters above the water and blade diameters of 110 meters. The turbines will be sited between 4 and 11 miles offshore. Cape Wind is expected to eventually produce enough electricity to power 420,000 homes. It was conceived and is being developed by private developer Cape Wind Associates, at an estimated cost of $1-2 billion (Cape Wind 2010). The concept has been vigorously opposed for nearly ten years by community groups and fishermen, as well as some prominent figures such as Ted Kennedy, John Kerry, and Mitt Romney. The Alliance to Protect Nantucket Sound was formed in 2001 to fight the proposed wind farm. They argued that Nantucket Sound is unmatched in its natural beauty, and should be protected from development. They also contend that Cape Wind would endanger migratory birds and other wildlife (Alliance to Protect Nantucket Sound, 2010).

In 2007, Southern Company and the Georgia Institute of Technology released a report on the wind power generation potential off the coast of Georgia. A recent request by the North Carolina General Assembly prompted the University of North Carolina at Chapel Hill to conduct a study to assess the feasibility of wind power generation off the coast of North Carolina. These are but a few of the ongoing research initiatives aimed at providing a more complete picture of the resource potential and whether it can be economically leveraged.

Musial (2004) suggests that there are 64 GW of offshore wind resource off the coast of the Mid-Atlantic alone. The flourish of activity in the offshore wind industry along the Atlantic coast implies that some in the energy industry think there is economically viable offshore wind potential that will be realized in the relatively near term.

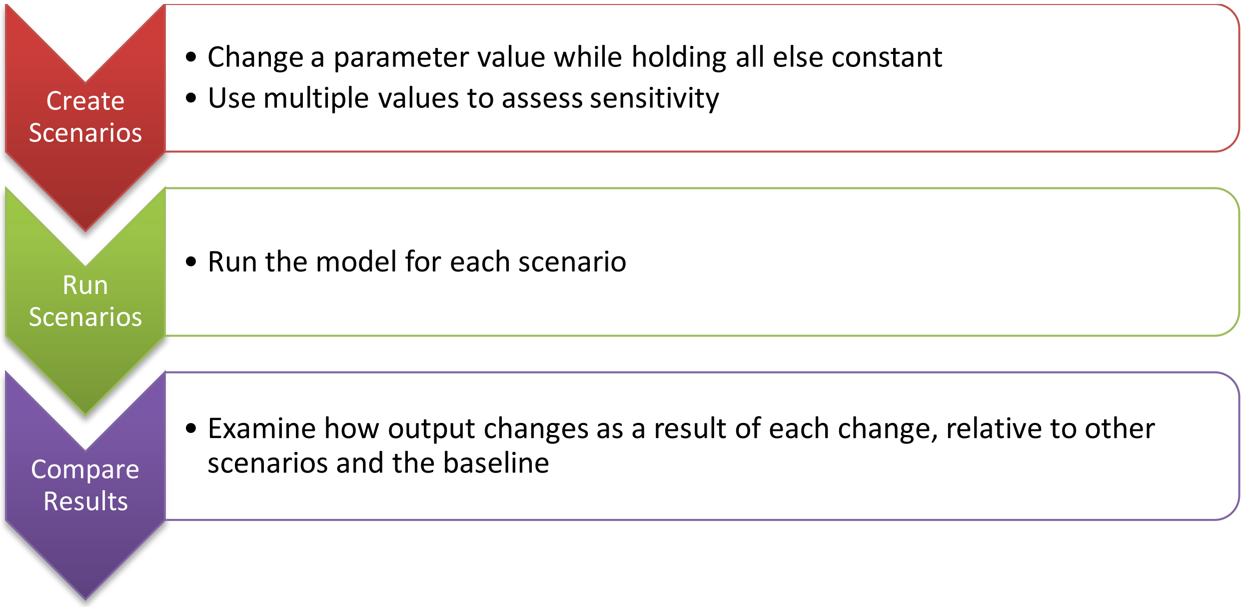
2 Methods

To understand whether NEMS modeling assumptions about offshore wind are correct, and the degree to which each assumption impacts the forecast, a scenario modeling approach was used. Scenarios were built to examine each of the four key assumptions being studied. These assumptions are outlined in Table 1.

	Assumption/Parameter	Importance to Offshore Wind Forecast
1	Offshore Wind Resource	Key to viability of offshore wind development
2	Overnight Capital Cost	May restrict what is cost effective
3	Relative Transmission Cost	Benefits of proximity to load considered?
4	Relative Reliability Cost	Effect on system reliability considered?

Table 1. Key assumptions affecting east coast offshore wind development

For each assumption being studied, model scenarios were constructed to reveal the importance assigned by the model to each parameter.



- Change a parameter value while holding all else constant
- Use multiple values to assess sensitivity

- Run the model for each scenario

- Examine how output changes as a result of each change, relative to other scenarios and the baseline

Figure 5. Overview of modeling methodology

Figure 5 above illustrates at a high level the general methodology undertaken. Before describing in detail how these scenarios are built using NEMS, a bit of background on the model is in order.

2.1 NEMS

NEMS uses a market based approach to create energy projections. For each fuel and consuming sector, NEMS balances supply and demand while accounting for competition between fuel sources and technologies. NEMS is built in a modular fashion. The modules represent each of the supply markets, conversion sectors, and end-use consumption sectors (Figure 6). There is also a macroeconomic and international module. NEMS runs each supply, conversion, and demand module in sequence until there is convergence between the delivered prices of energy and the quantities demanded in that consumption sector. This process of solving is done for each year in the time horizon (EIA 2010a).

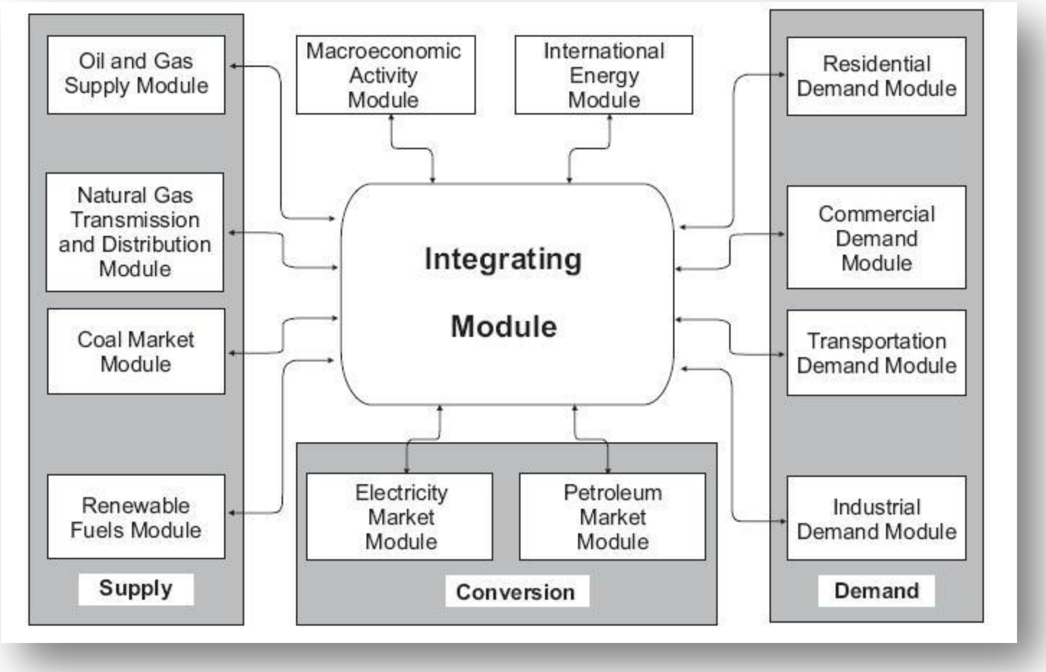


Figure 6. NEMS Organizational Structure (Source: EIA, http://www.eia.doe.gov/oiaf/aeo/overview/)

2.2 SNUG-NEMS

For this study, I used an instance of NEMS called SNUG-NEMS, which stands for Southeastern NEMS User Group. Duke University has installed and calibrated SNUG-NEMS to match the AEO 2010 version of NEMS released by EIA. This version of NEMS reflects the current legislation and environmental regulations as of October 31st, 2009. References to "NEMS" in this report are used when discussing generic attributes of EIA's model. The SNUG-NEMS instance of the model used for this study incorporates changes to the initial assumptions regarding offshore wind, and is executed on Duke University systems.

2.3 National RES Scenario

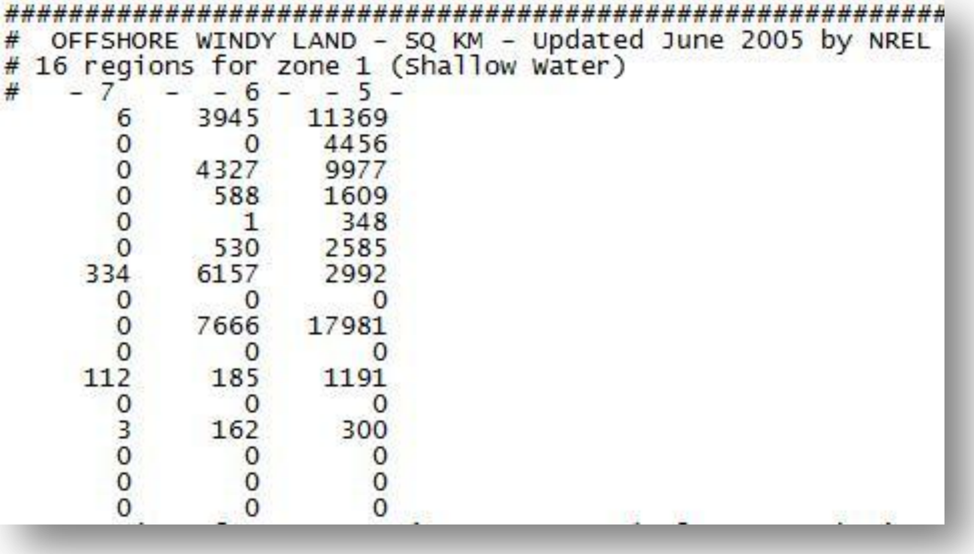
Congress has been debating the adoption of a national renewable standard for years. In response to a request from Chairman Edward Markey, in 2009 the EIA released a report on the effect of a 25% national RES. The report, entitled "Impacts of a 25-Percent Renewable Electricity Standard as Proposed in the American Clean Energy and Security Act Discussion Draft", summarized the modeling done by the EIA using an RES scenario (EIA 2009). The scenario requires 25% of electricity be provided by renewable sources by 2025. It also exempts small retailers from the mandate, and excludes hydroelectric power and municipal waste from the baseline (EIA 2009). Given the active debate on the subject, and the fact that more than half the states have an RES or RPS, it is reasonable to assume that a future in which offshore wind contributes to the overall electricity generation mix in a significant way will also be one in which there is a national RES. As such, this study focuses on the future of offshore wind within the context of a national RES.

To model differing assumptions about offshore wind and how an RES may influence them, a national RES scenario for SNUG-NEMS was developed using the same code used by the EIA to produce their report. This scenario is referred to as "RES scenario" or "Baseline". Running this baseline scenario produces a forecast that includes no additional offshore wind generation relative to the AEO 2010 scenario created by the EIA. In other words, according to the EIA, having a national RES in place does not encourage offshore wind development. Each of the modeling scenarios described in this report are built on top of this baseline.

2.4 Examining Offshore Wind Resource Assumption

The Renewable Fuels Module (RFM) of NEMS requires as input “available windy land area” estimates in units of square kilometers for each of the 13 NERC regions (EIA 2010b). “Available windy land area” is the term used by the NEMS documentation and the relevant input file to describe the extent of the available wind resource, both onshore and offshore. The RFM uses the available windy land area and an assumed power density to determine what amount of wind generating capacity is theoretically possible for a region. The model uses the same input format for offshore wind; available windy land area in square kilometers. In the case of onshore wind, these values are assumed to exclude areas that are unlikely to be used for wind energy development, such as wilderness areas, parks, urban areas and water features (EIA 2010b). The RFM documentation does not explicitly address the assumptions made about exclusions for offshore windy land area.

The “available windy land area” data is read in by the model from the SNUG-NEMS input file wesarea.txt. For offshore wind, the input file breaks the land area availability into groups, based upon both water depth and wind class. There are three water depths characterized in wesarea.txt: zone 1: Shallow Water – 30 meters or less, zone 2: Transitional Water – 30 to 60 meters, and zone 3: Deep Water (includes Great Lakes) – greater than 60 meters (C. Namovicz, personal communication, September 2, 2010). A screen capture of the relevant portion of the input file is provided in Figure 7.



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############################################################
#   OFFSHORE WINDY LAND - SQ KM - Updated June 2005 by NREL
# 16 regions for zone 1 (shallow water)
#    - 7   -   - 6 -   - 5 -
       6    3945   11369
       0       0    4456
       0    4327    9977
       0     588    1609
       0       1     348
       0     530    2585
     334    6157    2992
       0       0       0
       0    7666   17981
       0       0       0
     112     185    1191
       0       0       0
       3     162     300
       0       0       0
       0       0       0
       0       0       0
```

Figure 7. Screen capture of NEMS input file wesarea.txt. This file contains the available windy "land" (km^2) used by the model to plan offshore wind development. The data is organized into three columns, representing wind power classes 7,6, and 5, and 16 rows representing the NERC regions. This portion of the file shows the data for zone 1, shallow water, which is water of depth 30m or less.

The image shows that available land area is also broken into wind classes 5, 6, and 7. For a given height, these classes correspond to wind speeds and power densities. Table 2 illustrates this relationship at a height of 50 meters.

	50 meters		
Wind Power Class	Power Density (W/m2)	Wind Speed m/s	Wind Speed mph
1	0	0	0
	200	5.6	12.5
2	200	5.6	12.5
	300	6.4	14.3
3	300	6.4	14.3
	400	7	15.7
4	400	7	15.7
	500	7.5	16.8
5	500	7.5	16.8
	600	8	17.9
6	600	8	17.9
	800	8.8	19.7
7	800	8.8	19.7
	2000	11.9	26.6

Table 2. NREL Wind Power Classes (Source: NREL http://www.nrel.gov/gis/wind.html)

The "Renewable Energy in the South" report written by Duke and Georgia Tech describes how NEMS uses values for available windy land area based upon wind speeds necessary to make wind turbines with 50 meter hub heights economically viable[4]. The researchers updated the inputs to the model to reflect the land area that could be developed using 80 meter turbines. At this elevation, average wind speeds are higher and more consistent, meaning that many areas that were not suitable for wind development at 50 meters would now be accessible. A similar update of the offshore wind resource data was done for this project, to reflect the current industry standard of 80 meter hub height. To update the model inputs, data from NREL's Eastern Wind Integration and Transmission Study (EWITS) was used, along with some data published by the Southern Alliance for Clean Energy (SACE).

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[4] Brown et al., section 3.4.2, pg 28

2.4.1 EWITS

NREL's EWITS dataset is a collection of three years worth of modeled time-series wind speed and power output data, spanning 2004 to 2006. It simulates both onshore and offshore wind sites for much of the Eastern US (Figure 8). NREL and the US Department of Energy (DOE) created the dataset as part of a study conducted to examine the operational impact of 20-30% penetration of wind power on the Eastern Interconnect power system of the US. The point of the study was to help to address the unanswered questions about wind energy and the transmission system of utilities and other interest groups associated with the electric power industry in the east (EWITS 2010).

The EWITS dataset represents the best and most up-to-date collection of offshore wind resource information for the eastern seaboard. This data provides information regarding how much surface area of ocean, in square kilometers, experiences wind speeds high enough to support economically viable wind energy development. This is what the RFM within SNUG-NEMS needs to compute the contribution of offshore wind generation for each year of the modeled time horizon.

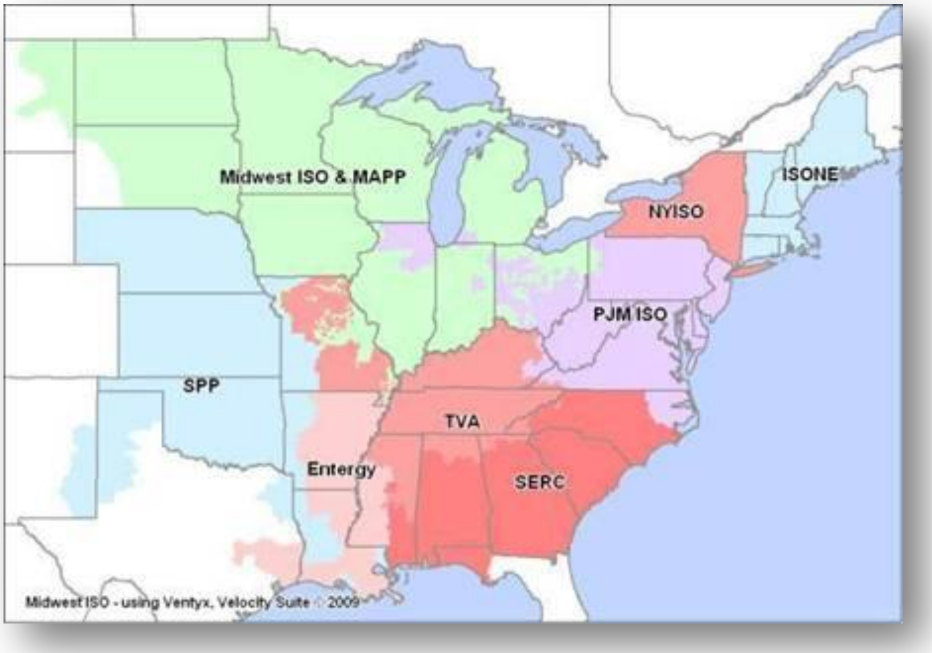

Figure 8. EWITS Study Area (Source: NREL - http://www.nrel.gov/wind/systemsintegration/ewits.html)

Figure 8 illustrates that EWITS does not include offshore wind data for Florida. At the time of this writing, more recent estimates than those used by EIA and NEMS of offshore wind resources for Florida were not available. As such, the baseline SNUG-NEMS assumption for available windy area suitable for offshore wind development for Florida was not changed for this analysis. To model an Updated Offshore Wind scenario, the EWITS dataset was used to determine how much available windy land area is represented by the offshore wind resource along the eastern coastline. From this point forward in the study this modeling scenario, in which the offshore wind resource base has been updated, will be referred to as the "Updated Offshore Wind" scenario.

NREL provides free access to the EWITS dataset via free download from this location: http://www.nrel.gov/wind/integrationdatasets/eastern/data.html. The file

OFFSHORE_selected_sites.csv was downloaded from this site, and contains the set of all offshore sites simulated by the study, each of which is represented by a record in the file. The simulated sites represent wind speeds at 80 meters in height. There are a total of 4,948 offshore sites chosen along the Atlantic coast, from Maine to North Carolina and in the Great Lakes. Each site represents a single meso-scale grid cell 4 km^2 in area, and is assumed to be capable of supporting 20MW of capacity. This equates to a mean power density of $5MW/km^2$. SNUG-NEMS also assumes a power density of $5MW/km^2$. This means that no adjustment to the windy land area values from EWITS need be made. The sites simulated by EWITS are constrained to waters 30 meters or shallower. This means that all of the windy land area represented in the EWITS data can be attributed to zone 1 in the wesarea.txt input file. The sites are organized in the file by unique site ID number, but each site record also contains the state associated with that area of water[5]. Because each site represents 4 km^2 of area, the data was easily filtered to determine how much offshore available windy land area there is for each east coast state represented in the data. For example, there are 121 sites listed in the OFFSHORE_selected_sites.csv file for the State of Delaware. This means that there are 484 km^2 of available windy area in shallow water for Delaware. The power law was used to categorize each east coast site into one of the power classes used by SNUG-NEMS.

The wind profile power law, also known as the 1/7th power law, can be used to do an extrapolation of wind speeds from one height to another. The wind profile power law relationship is:

$$u/u_r = (z/z_r)^{\propto}$$

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[5] See screenshot of OFFSHORE_selected_sites.csv in Appendix A for detail of data format

where u is the wind speed (in meters per second) at height z (in meters), and u_r is the known wind speed at a reference height z_r. The exponent (α) is an empirically derived coefficient that varies dependent upon the stability of the atmosphere. For neutral stability conditions, α is approximately 1/7, or 0.143 (Elliot et al. 1986). However, according to Hsu et al. (1994), when over open water, a more accurate exponent of 0.11 should be used. This exponent was used with the power law to determine into which power class the EWITS provided windy area should fall. Table 2 shows the range of wind speeds for each wind class.

80 meters	
Wind Power Class	Wind Speed m/s
1	0.0 5.9
2	5.9 6.7
3	6.7 7.4
4	7.4 7.9
5	7.9 8.4
6	8.4 9.3
7	9.3 12.5

Table 3. Wind class and speed at 80m height

Each site in the dataset was classified by wind class according to the wind speeds depicted in Table 3. The majority of sites were categorized as a class 6 wind resource. Table 4 illustrates the breakdown of sites into classes, by NERC region and state.

		CLASS 5 (7.9 to 8.3 m/s)			CLASS 6 (8.4 to 9.2 m/s)			CLASS 7 (9.3+ m/s)		
State	NERC	# Sites	Estimated Capacity (MW)	Region Area (km^2)	# Sites	Estimated Capacity (MW)	Region Area (km^2)	# Sites	Estimated Capacity (MW)	Region Area (km^2)
ME	7	15	300	60	48	960	192	0	0	0
NH	7	1	20	4	0	0	0	0	0	0
MA	7	0	0	0	0	0	0	501	10020	2004
RI	7	0	0	0	45	900	180	6	120	24
CT	7	49	980	196	0	0	0	0	0	0
Total				**260**			**372**			**2028**
NY	6	48	960	192	353	7060	1412	0	0	0
Total				**192**			**1412**			**0**
NJ	3	0	0	0	801	16020	3204	0	0	0
DE	3	0	0	0	121	2420	484	0	0	0
MD	3	0	0	0	401	8020	1604	0	0	0
Total				**0**			**5292**			**0**
VA	9	217	4340	868	784	15680	3136	0	0	0
NC	9	0	0	0	1001	20020	4004	0	0	0
Total				**868**			**7140**			**0**

Table 4. Breakdown of EWITS sites by wind class. The total area for each region is calculated by multiplying the number of sites per state by 20MW of capacity per site, then dividing by 5MW/km^2. The total per region is the sum of the totals of each state in the region.

NERC Regions

- 9: Southeastern Electric Reliability Council (SERC)
- 7: New England (NE)
- 6: New York (NY)
- 3: Mid-Atlantic Area Council (MAAC)

Table 4 shows, for each wind class and NERC region, how much area is available. Though the EWITS dataset is considered the most up-to-date source of offshore wind data, it is not complete. The EWITS dataset does not contain sites for states south of North Carolina. As such, estimates reported by the Southern Alliance for Clean Energy in their report *Yes We Can: Southern Solutions for a National Renewable Energy Standard* (2009) of potential offshore capacity for South Carolina and Georgia were used to supplement the EWITS data.

According to SACE (2009), South Carolina has off its coast the potential for 43,360 MW of wind capacity. They estimate that Georgia has 17,180 MW of potential wind capacity that could feasibly be realized. Only 60% of these estimates are assumed to be from class 6 wind. Based upon a power density of 5MW/km^2, this capacity equates to 7,265 km^2 of additional class 6 windy area in the SERC region. The wesarea.txt input file was updated based upon the combination of the area calculated from the EWITS data and the SACE estimates.

Table 5 below shows how the wesarea.txt input file was updated. The numbers shown in blue represent figures that were increased, while red numbers have been reduced in the file. Overall, there was a reduction in available windy area, mostly in Class 5.

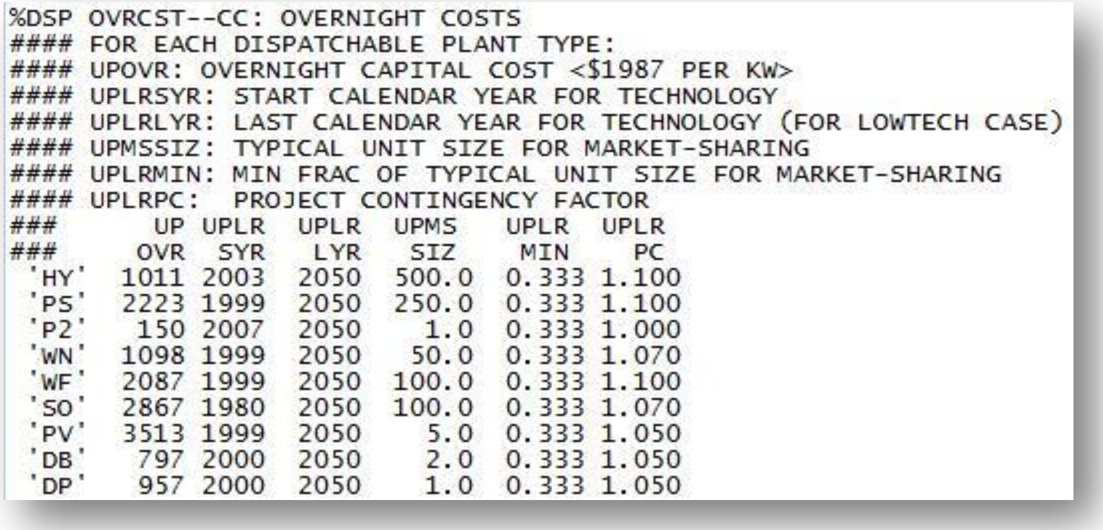
NERC Region	Class 7	Class 6	Class 5
1	6	3945	11369
2	0	0	4456
3	0	5292	0
4	0	588	1609
5	0	1	348
6	0	1412	192
7	2028	372	260
8	0	0	0
9	0	14405	868
10	0	0	0
11	112	185	1191
12	0	0	0
13	3	162	300

Table 5. Updated wesarea.txt input file. The three wind classes considered by SNUG-NEMS are represented by cols labeled Class 7, Class 6, and Class 5. Each row corresponds to a NERC region. The data values in blue represent "land" area totals in km^2 that were increased from the default input, while those in red were decreased.

2.5 Examining Capital Cost Assumptions

In addition to exploring the validity of the offshore wind resource assumptions used by NEMS, this study examined whether the overnight capital cost estimates used by the model for offshore wind development are consistent with the current state of the industry. The literature cited suggests that capital costs are the biggest obstacle limiting offshore wind development. Black & Veatch (2007) propose that a reasonable estimate for overnight capital costs for offshore wind is $2520/kW ($2006). This is 40% higher than the overnight capital cost of onshore wind assumed by NEMS. The Union of Concerned Scientists estimates capital costs at 70% above those of onshore wind (Cleetus et al. 2009). However, some wind developers have backed off plans for projects due to cost estimates escalating to twice that of onshore projects. Given this range of estimates, cost scenarios were developed to gauge the sensitivity of offshore wind development to overnight capital costs. These cost scenarios were used to estimate at what level of cost reduction offshore wind becomes cost competitive with other electricity generation options.

Overnight capital costs are provided to SNUG-NEMS exogenously through the ecpdat.txt input file. A cost value is given for each power plant type for a specified starting year. This cost is adjusted via a cost multiplier in each of the following years in the modeled time horizon. Figure 9 is a screen capture of the relevant portion of the ecpdat.txt input file. The offshore wind plant type is denoted by ‘WF’, and the cost is represented by the UPOVR variable.



```
%DSP OVRCST--CC: OVERNIGHT COSTS
#### FOR EACH DISPATCHABLE PLANT TYPE:
#### UPOVR: OVERNIGHT CAPITAL COST <$1987 PER KW>
#### UPLRSYR: START CALENDAR YEAR FOR TECHNOLOGY
#### UPLRLYR: LAST CALENDAR YEAR FOR TECHNOLOGY (FOR LOWTECH CASE)
#### UPMSSIZ: TYPICAL UNIT SIZE FOR MARKET-SHARING
#### UPLRMIN: MIN FRAC OF TYPICAL UNIT SIZE FOR MARKET-SHARING
#### UPLRPC:  PROJECT CONTINGENCY FACTOR
###        UP UPLR  UPLR  UPMS   UPLR  UPLR
###       OVR  SYR   LYR   SIZ    MIN    PC
  'HY'   1011 2003  2050  500.0  0.333 1.100
  'PS'   2223 1999  2050  250.0  0.333 1.100
  'P2'    150 2007  2050    1.0  0.333 1.000
  'WN'   1098 1999  2050   50.0  0.333 1.070
  'WF'   2087 1999  2050  100.0  0.333 1.100
  'SO'   2867 1980  2050  100.0  0.333 1.070
  'PV'   3513 1999  2050    5.0  0.333 1.050
  'DB'    797 2000  2050    2.0  0.333 1.050
  'DP'    957 2000  2050    1.0  0.333 1.050
```

Figure 9. SNUG-NEMS input file ecpdat.txt showing overnight capital costs

There were six model runs done to examine the effect of overnight capital cost reductions to offshore wind development, as shown in Table 6.

Scenario Description	Reduction %	Model Input Value ($/kWh $1987)
Overnight capital cost at 70% above onshore	11%	1867
Overnight capital cost at 40% above onshore	26%	1537
Overnight capital cost at 24% above onshore	35%	1357
Overnight capital cost at 14% above onshore	40%	1252
Overnight capital cost at 5% above onshore	45%	1148
Overnight capital cost = that of onshore	50%	1044

Table 6. Offshore Wind Cost Reduction Scenarios

2.6 Relative Transmission and Reliability Costs

Transmission constraints are a serious and complex barrier to the integration of land-based wind throughout the United States. One of the key benefits of offshore wind on the eastern seaboard is the fact that the resource is close to the load centers. And yet, even under a national RES scenario the technological and economic factors considered by NEMS do not suggest that development of offshore wind on the eastern seaboard is cost effective. This report considers whether the benefit of having wind generation close to the load is taken into account by the NEMS model.

In addition to cost concerns related to transmission, wind power can incur reliability costs on the system. The intermittent nature of wind power often requires additional measures be taken to ensure system reliability when the wind generation is integrated into the broader electric power system. Ancillary services may need to be provided to balance the ups and downs of wind power generation. The costs associated with these reliability measures are an important factor in the economic viability of wind generation, whether it be land-based or offshore (Parsons, Milligan. 2006). This project attempts to determine whether the NEMS model accurately characterizes these costs.

Each of these tasks is done by comparing how much overall transmission and reliability costs increase when there is an increase in total onshore and offshore wind generation. To do this, model scenarios were built that force the model to individually increase both onshore and offshore wind by the same amount with respect to the baseline. For instance, if 300 TWh of offshore generation were added to the baseline while no new onshore generation was added, the added transmission or reliability cost should be entirely due to the new offshore capacity. If another scenario is constructed in which 300 TWh of onshore was added and no offshore added, the difference in transmission or reliability cost here is attributable to the additional onshore capacity. If the model assumes offshore costs are lower than onshore, the difference should show up when comparing these scenarios.

3 Results

3.1 Updated Offshore Wind Resource Assumption

To determine the extent to which the original NEMS forecast for east coast offshore wind may have been affected by poor wind resource assumptions, the Updated Offshore Wind scenario was run using SNUG-NEMS. The results of this model run were compared to the baseline scenario. The result was that updating the wind resource data had zero effect on the forecast for offshore wind development. Table 7 illustrates these findings.

Affect of Updated Offshore Wind Assumptions in 2035

Scenario	National Capacity (GW)	National Generation (TWh)
Baseline RES	0.2	0.75
Updated Offshore Wind	0.2	0.75

Table 7. Affect of Updated Wind Assumptions

In an effort to gain a better understanding of how much the wind resource is a factor in the model, a sensitivity analysis was done on the availability of the wind resource offshore. If the amount of offshore wind development along the coast is being limited by the wind resource itself, adjusting the assumptions about the resource in the model should impact development over the modeled time horizon. Two model runs were done in which the amount of available windy area was quadrupled. In the first run, the area available in the Southeastern Electric Reliability Council (SERC) region for wind class 6, shallow water was changed from 7,666 km^2 to 30,664 km^2. In the second model run, the available area for wind class 6, shallow water was quadrupled for the following NERC regions, which constitute nearly the entire east coast:

- NE (New England)
- NY (New York)
- MACC (Mid-Atlantic Area Council)
- SERC (Southeastern Electric Reliability Council)

In both cases, there was zero effect on the modeled forecast of offshore wind capacity. These results make the case that the wind resource is not a constraint on development, at least on the east coast of the US. Despite the fact that updating the modeling assumptions of offshore wind resource availability had no effect on results, it is informative to understand whether the EIA forecast is based upon valid assumptions, regardless of whether these assumptions affect the result. As such, the updated picture of the wind resource was used in the other scenarios described in this report.

3.2 Capital Cost Assumption Analysis

In the national RES baseline scenario, the EIA assumes that offshore wind has an overnight capital cost 95% higher than that of onshore wind. The literature suggests that offshore overnight capital costs may be as low as 40% above onshore development costs. Six overnight capital cost reduction scenarios were constructed to analyze the effect of costs on offshore wind development along the eastern seaboard. Each of these scenarios builds upon the national RES scenario. The results presented here show how offshore wind development is affected, in terms of total generation and whether offshore wind displaces onshore and/or biomass generation. These results are given for each of the NERC regions represented by states along the eastern seaboard.

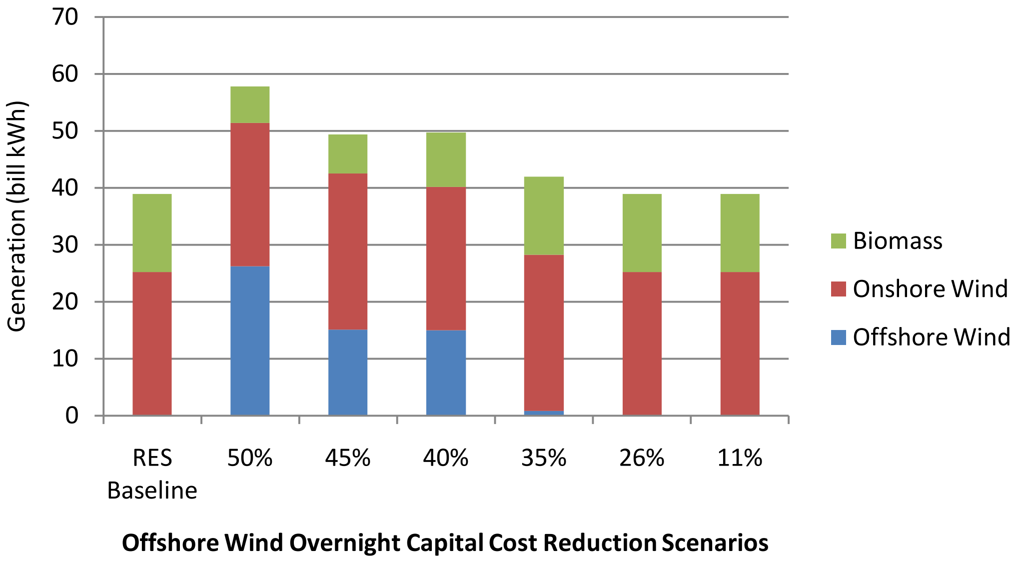


Figure 10. New England (7) Generation in 2035

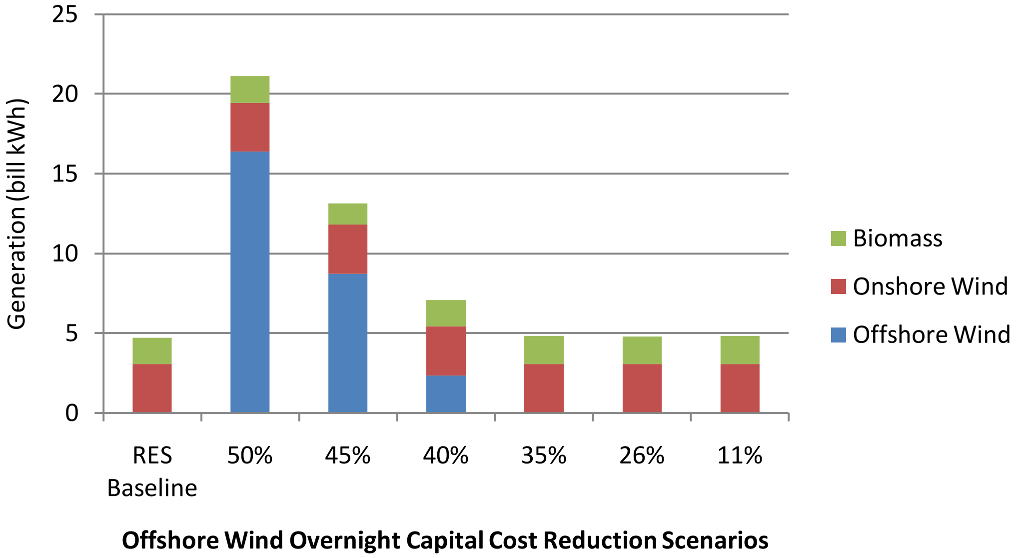


Figure 11. New York (6) Generation in 2035

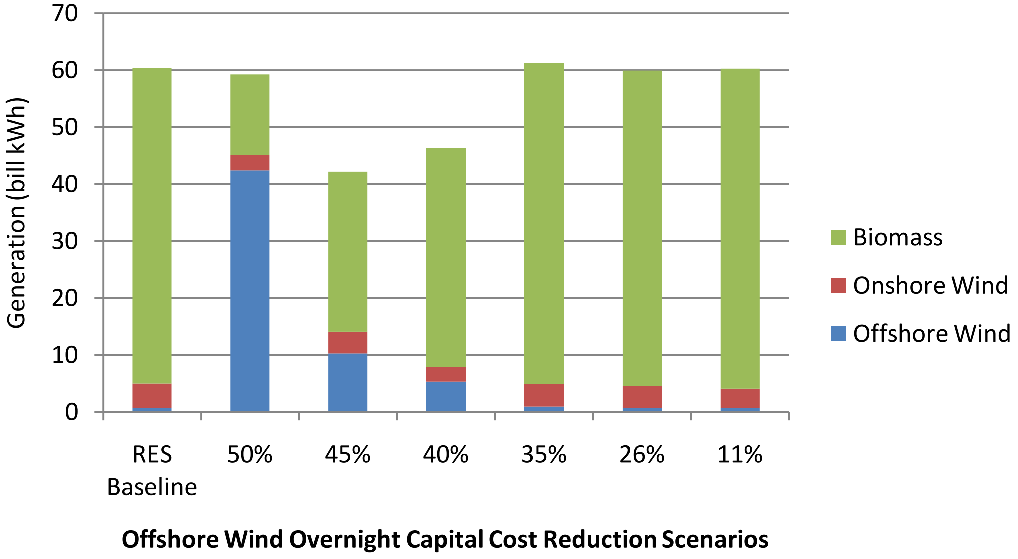


Figure 12. MAAC (3) Generation in 2035

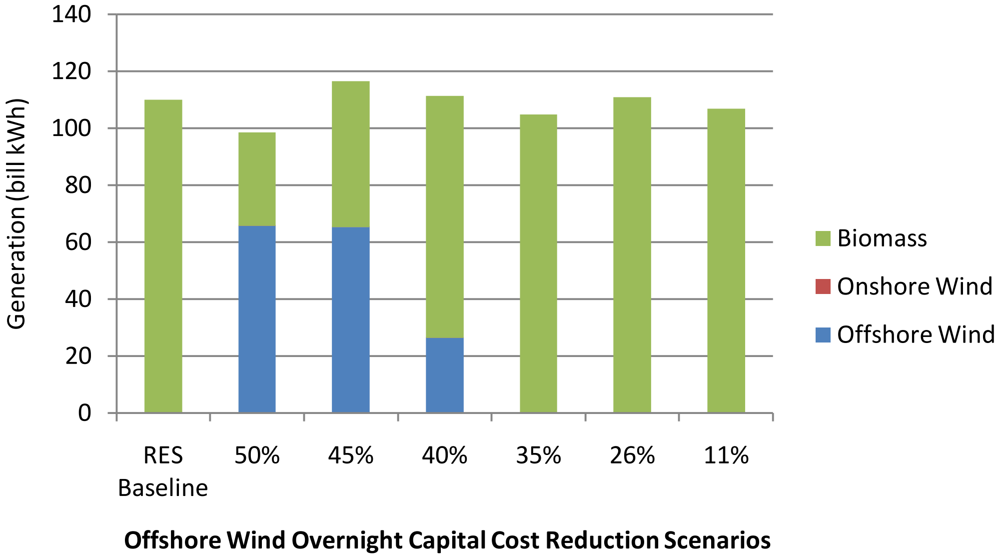


Figure 13. SERC (9) Generation in 2035

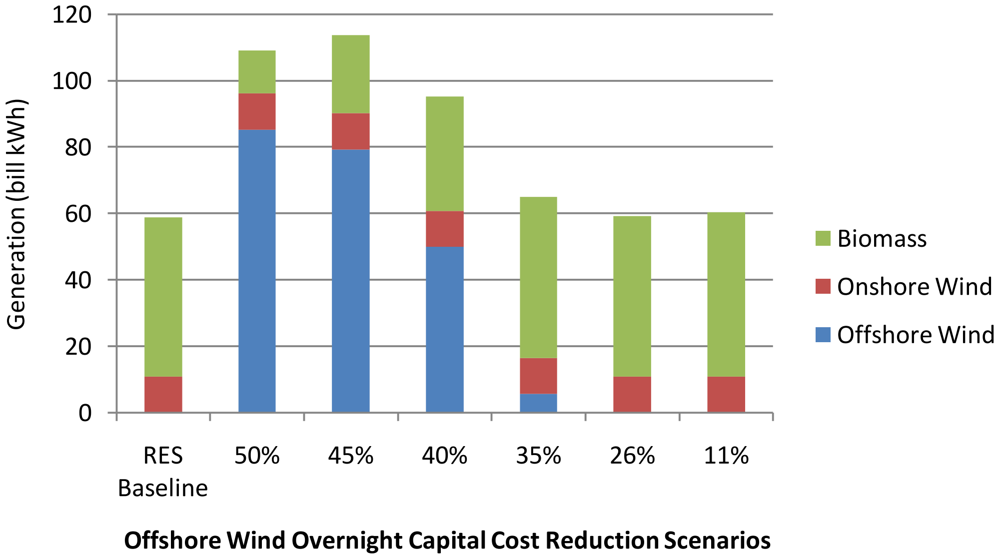


Figure 14. Florida (8) Generation in 2035

Figures 10-14 show that offshore wind can be competitive with other forms of generation, but only when overnight capital costs are greatly reduced from the value assumed in the baseline scenario. The 11% and 26% reduction scenarios respectively correspond to overnight capital costs 70% and 40% above those assumed for onshore wind by the model. In none of the east coast NERC regions is offshore wind cost effective at either of these levels. Only at a 35% reduction is offshore wind viable in any region, and even then the generation reaches only 5.6 terawatt-hours. It is also worth noting that in the scenarios in which offshore wind generation is greatly increased, only the amount of biomass generation is affected. Offshore wind does not compete with onshore wind. These relationships are not surprising when the overnight capital costs assumed by the model for renewable plants are compared (Table 8).

Baseline Expected Renewable Plant Costs in 2013

Plant Type	Overnight Capital Cost (real $/kW)
Wood and Other Biomass	$ 4,045
Geothermal	$ 5,593
Conventional Hydropower	$ 2,435
Municipal Waste	$ 2,762
Solar Photovoltaic	$ 6,372
Solar Thermal	$ 5,140
Wind	$ 2,089
Offshore Wind	$ 4,125

Table 8. Overnight Capital Costs of Renewable Plants (real $/kW)

See Appendix B for a set of charts showing, for each cost reduction scenario, the percentage of total renewable generation provided by each of the three generation types.

3.3 Quantifying Offshore Wind Transmission Benefits

Proponents of east coast offshore wind suggest that one of the most fundamental reasons for developing the resource is the fact that it is very close many of the nation’s largest load centers (Mahan et al. 2010). This is in contrast to most of the land-based renewable resources available to the US. Given this advantage of proximity, it stands to reason that the transmission costs associated with a given amount of additional offshore wind capacity would be less than those costs associated with the same amount of additional onshore wind capacity. Modeling scenarios were created to force the model to choose a similar amount of new capacity and generation for both onshore and offshore wind in the year 2035. This was done by creating two model runs, each of which reduced the capital cost of one form of wind generation by 50%. Table 9 shows how national capacity and generation totals were similarly affected by the two model runs, relative to the RES baseline.

Change in Generation and Capacity in 2035

Wind Type	Generation in Baseline (TWh)	Generation in Forced Scen. (TWh)	Net Increased Generation (TWh)	Capacity in Baseline (GW)	Capacity in Forced Scen. (GW)	Net Increased Capacity (GW)
Offshore	0	310	**310**	0	83	**83**
Onshore	241	508	**267**	77	163	**86**

Table 9. Results of contrived cost scenarios to force wind development

These two model scenarios facilitate a comparison of onshore and offshore wind transmission costs. Figure 14 shows that throughout the modeled time horizon, onshore transmission costs exceed those of offshore wind. These results indicate that the NEMS model does account for the benefit associated with proximity to load afforded by offshore wind.

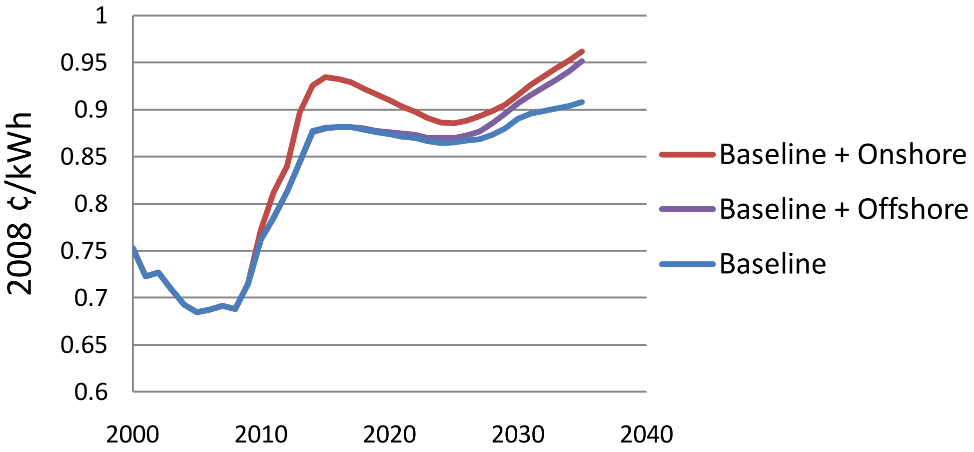


Figure 15. Transmission Costs for Wind Generation

3.4 Considering Offshore Wind Reliability Costs

The use of wind power has expanded significantly over the past several years. Due to the intermittent nature of wind, the integration of these generation resources incurs a cost to the system in the form of increased need for ancillary services. Using the same two scenarios described in the section above and in Table 8, the incremental reliability cost incurred by adding both onshore and offshore wind capacity was examined. Figure 16 shows that reliability costs actually decrease when adding a given amount of onshore wind. Adding the same amount of offshore wind to the system has the opposite effect – reliability costs increase.

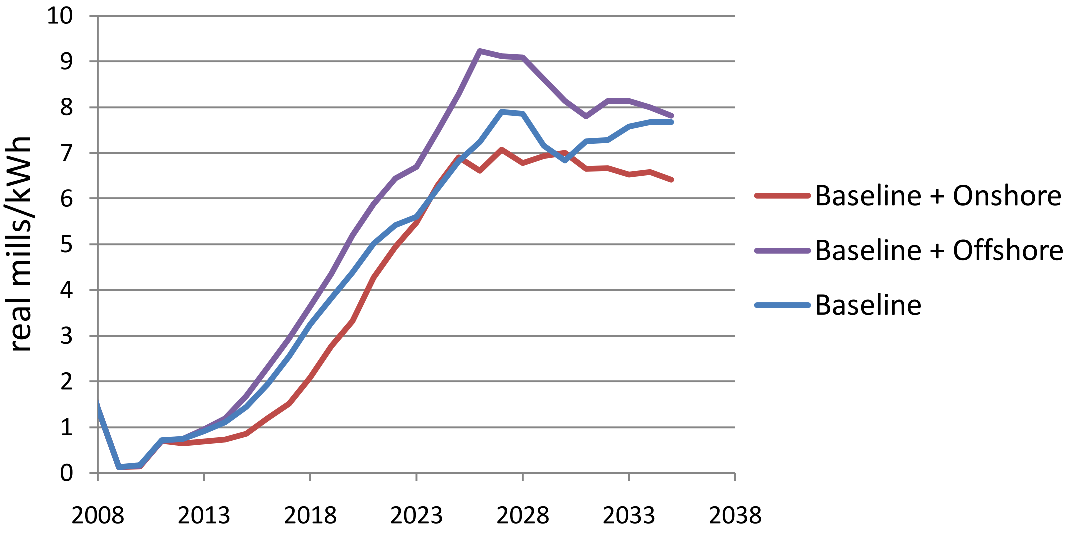


Figure 16. Reliability Costs for Wind Generation

4 Discussion and Recommendations

Though the offshore wind resource data used by the EIA looks to be a poor estimate of the true resource, the amount of wind assumed by the model does not matter in terms of the build-out of offshore wind capacity. Even when using highly inflated windy area values, there was no effect on forecasted offshore capacity or generation. The overnight capital cost assumption used by NEMS – 95% above cost of land-based wind – is in the range of what the industry suggests are current development costs. Assuming other factors considered by the model such as transmission costs are accurate, it seems current capital costs are simply too high for any significant investment in shallow water offshore wind over the next 25 years. The only way to increase the forecast of offshore wind generation in NEMS is by lowering the penalty in capital costs relative to other forms of generation. Offshore wind development will have to become more cost competitive. The results of modeling cost reduction scenarios suggests that under a national RES, only when costs are reduced by at least 35% does offshore wind become competitive with other generation options. Even at this level of cost reduction, by 2035 there is only marginal growth in offshore wind in some regions along the coastline. An overnight capital cost reduction of 50% brings about large investment in shallow offshore development all along the eastern seaboard. There is no evidence, however, that such a decrease in costs is a reasonable near term expectation.

Transmission costs per kilowatt-hour associated with offshore development are lower than those of onshore development. The difference is most likely due to the advantage offshore wind has in terms of proximity to load. However, it is not clear whether this benefit is fully realized by the model. There is very little difference in the costs associated with transmission for each type of wind. More transparency in the data and calculations used to determine transmission costs is needed to fully assess whether these costs are accurately represented. Even though shallow offshore wind development requires less investment in transmission infrastructure than does onshore wind, it remains too costly for any significant growth in the overall installed capacity over the next 25 years. If the transmission assumptions are invalid, it could have a significant impact on the model's assessment of the cost-competitiveness of offshore wind.

The results of the reliability testing are not conclusive. The model suggests that adding land-based or offshore wind capacity to the system reduces overall reliability costs. It also predicts that offshore wind incurs a higher cost in terms of reliability than does onshore wind. Both of these conclusions are suspect. Bonneville Power Authority has instituted a charge for each kilowatt-hour of wind generation, called the Wind Integration – Within-Hour Balancing Service charge. This charge of $0.68/kW is meant to cover the costs incurred as a result of the variability of wind power generation (BPA. 2008). Other electricity providers and balancing authorities are considering similar charges (Parsons, Milligan. 2006). Therefore, it seems very unlikely that the addition of wind capacity could lower system reliability costs. In addition, the costs associated with reliability are likely to be lower for integrating offshore wind than for land-based wind generation. In a study conducted for the New York Independent System Operator (ISO) in 2005, GE Energy and the New York State Energy Research and Development Authority (NYSERDA) determined that for calculating total system capacity, wind capacity must be heavily de-rated. They concluded that the capacity credit value for land-based wind should be 9% of rated capacity, and the capacity credit for offshore wind should be 36% of rated capacity (GE Energy. 2005). This relationship implies that offshore wind is a more reliable resource, and therefore should incur lower integration costs.

It is not clear from the NEMS documentation how reliability costs for offshore wind are calculated, and how they may differ from the calculations for onshore wind. If the model is inaccurately characterizing the reliability costs attributable to offshore wind generation, this may be further restricting the forecast for future capacity.

This study provides evidence that the shallow water offshore wind modeling done by the EIA in the AEO 2010 is based, at least in part, on valid assumptions. The model factors tested indicate that overnight capital costs for shallow water offshore wind development along the eastern seaboard are prohibitively high, even in a scenario where there is a nationwide mandate for renewable electricity generation. Nonetheless, there is strong evidence that sufficient resources exist to make offshore wind development a reality. The question remains – why are there such differing expectations about the future of east coast offshore wind development? It is important to note that none of the proposed projects along the eastern seaboard have begun construction. Perhaps, just as the model predicts, offshore wind development will prove too costly for the near future. Many, if not all of the project proposals were presented when it seemed there could soon be federal carbon legislation in place. This possibility seems distant at the moment. It could be that as a result of the current political environment, offshore wind will remain too expensive to be viable over the next twenty-five years. The NEMS scenario presented by the AEO 2010 does not consider carbon legislation. Perhaps these factors explain, at least in part, the disparity discussed in this paper. It seems it may take more than state or federal level RES laws to bring about the birth of offshore wind development in the United States. Perhaps some of the benefits outlined in this report, such as national security, environmental well being, or economic development will eventually provide the incentive needed to spur on this nascent industry.

4.1 Recommendations

If NEMS is ever going to be used by researchers on a broad scale, it needs to be given much more transparency in the form of comprehensive documentation. Clearly documenting data sources, data flows across modules, and calculations would go a long way in making the model accessible to a larger audience. However, the EIA is clear in that it is not interested in supporting the use of NEMS outside the DOE. It is for this reason that such desired support is not provided, and is not likely to be forthcoming. Having said this, the government may benefit from providing resources and access to the data and the model. In doing so, the Department of Energy could get the input of researchers across the nation. Innumerable theses and dissertations could contribute to the understanding of what matters in terms of assumptions and model structure. Providing access and support for the model would result in many alternative runs that could be analyzed. The US government invests a lot of money on analysis. It would require little funding to employ a small team tasked with comprehensive model documentation. Similarly, it would be inexpensive to provide the resources necessary to implement a moderated discussion board for registered researchers. I contend that the US government would realize a greater return on analysis dollars through a modest increase in that investment.

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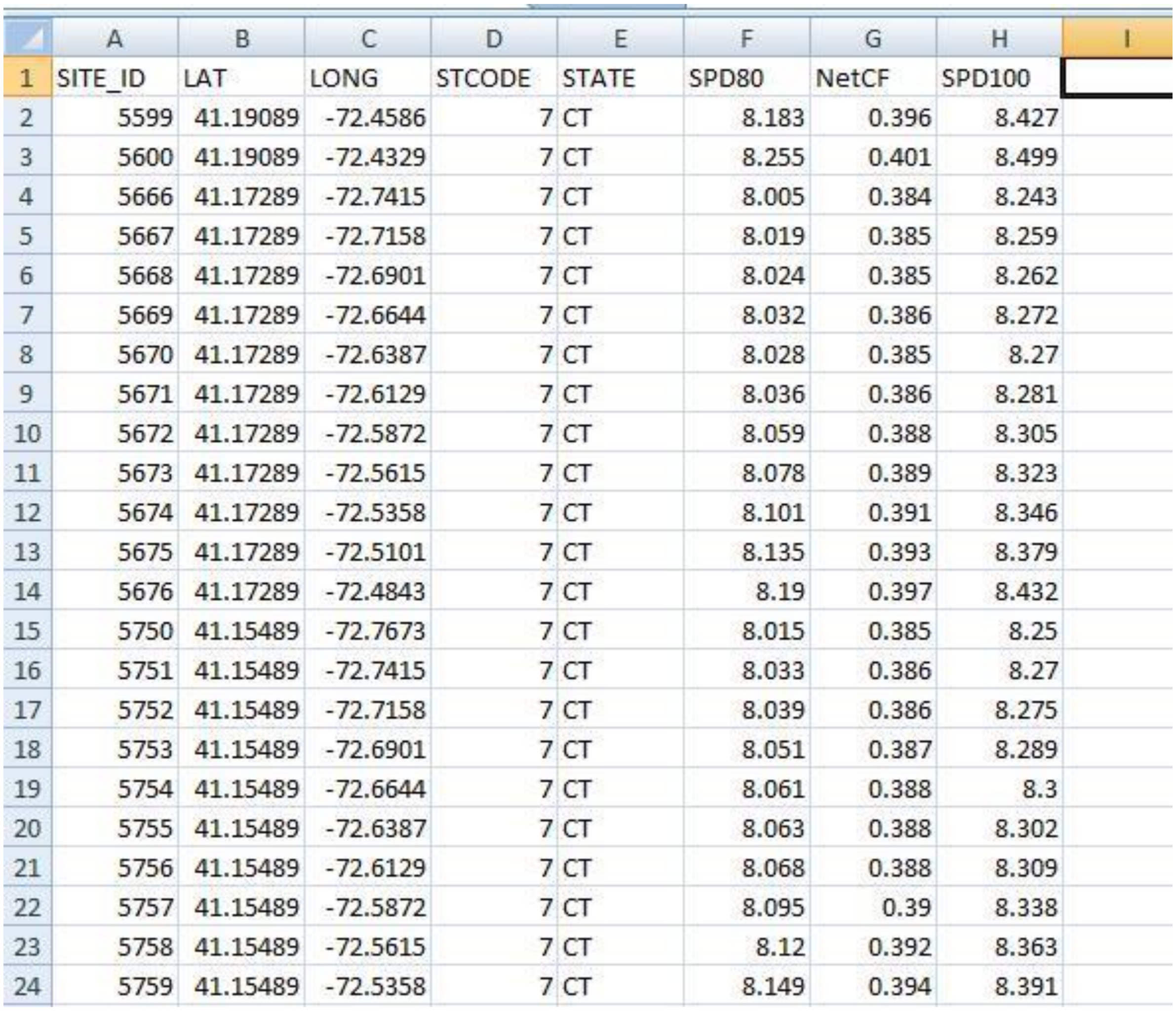
6 Appendix A

Figure 17 below shows a screen capture of the EWITS data file used to summarize the available windy area.



	A	B	C	D	E	F	G	H	I
1	SITE_ID	LAT	LONG	STCODE	STATE	SPD80	NetCF	SPD100	
2	5599	41.19089	-72.4586	7	CT	8.183	0.396	8.427	
3	5600	41.19089	-72.4329	7	CT	8.255	0.401	8.499	
4	5666	41.17289	-72.7415	7	CT	8.005	0.384	8.243	
5	5667	41.17289	-72.7158	7	CT	8.019	0.385	8.259	
6	5668	41.17289	-72.6901	7	CT	8.024	0.385	8.262	
7	5669	41.17289	-72.6644	7	CT	8.032	0.386	8.272	
8	5670	41.17289	-72.6387	7	CT	8.028	0.385	8.27	
9	5671	41.17289	-72.6129	7	CT	8.036	0.386	8.281	
10	5672	41.17289	-72.5872	7	CT	8.059	0.388	8.305	
11	5673	41.17289	-72.5615	7	CT	8.078	0.389	8.323	
12	5674	41.17289	-72.5358	7	CT	8.101	0.391	8.346	
13	5675	41.17289	-72.5101	7	CT	8.135	0.393	8.379	
14	5676	41.17289	-72.4843	7	CT	8.19	0.397	8.432	
15	5750	41.15489	-72.7673	7	CT	8.015	0.385	8.25	
16	5751	41.15489	-72.7415	7	CT	8.033	0.386	8.27	
17	5752	41.15489	-72.7158	7	CT	8.039	0.386	8.275	
18	5753	41.15489	-72.6901	7	CT	8.051	0.387	8.289	
19	5754	41.15489	-72.6644	7	CT	8.061	0.388	8.3	
20	5755	41.15489	-72.6387	7	CT	8.063	0.388	8.302	
21	5756	41.15489	-72.6129	7	CT	8.068	0.388	8.309	
22	5757	41.15489	-72.5872	7	CT	8.095	0.39	8.338	
23	5758	41.15489	-72.5615	7	CT	8.12	0.392	8.363	
24	5759	41.15489	-72.5358	7	CT	8.149	0.394	8.391	

Figure 17. EWITS Simulated Sites (excerpt from OFFSHORE_selected_sites.cvs)

7 Appendix B

The charts in this appendix show the relationship between the electricity generation supplied by land-based and offshore wind, and biomass nationally and in each of the NERC regions represented on the east coast of the US. Each chart shows the percentage of total renewable generation that each generation source provides in the year 2035, under the six offshore wind capital cost reduction scenarios (see Section 2.5).

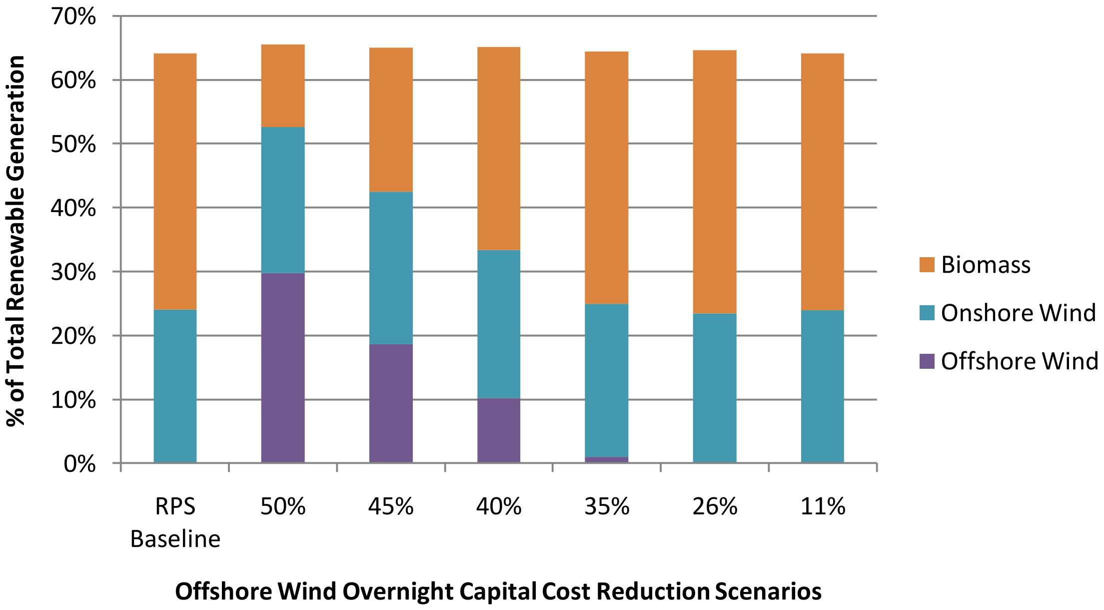


Figure 18. National Offshore Wind Generation in 2035, by cost reduction scenario. Chart shows Biomass, Onshore, and Offshore Wind generation as a percentage of total renewable generation in 2035.

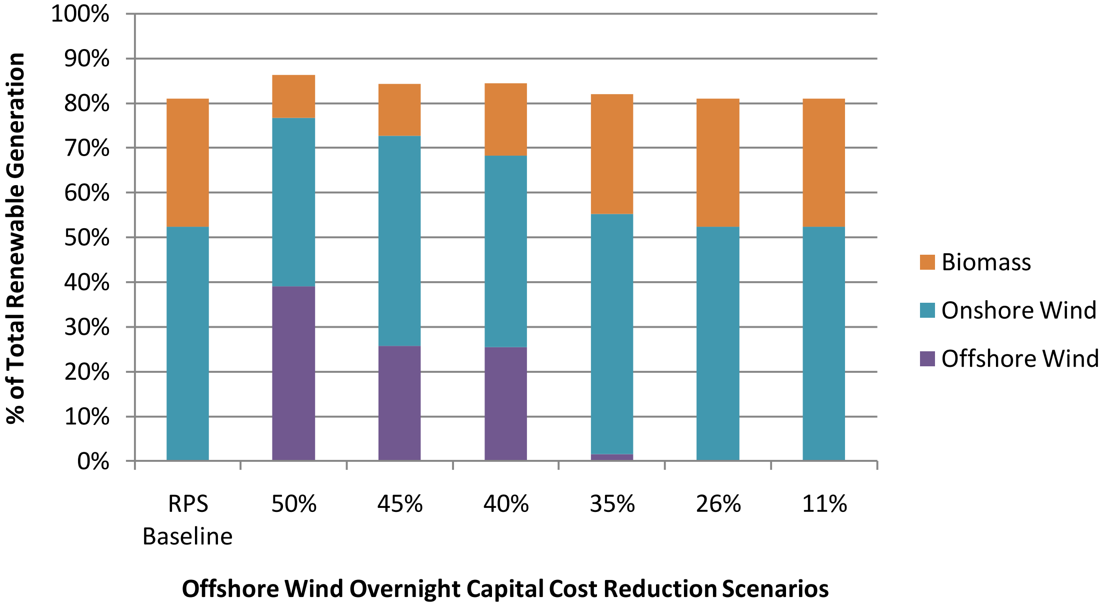


Figure 19. New England (NERC 7) Offshore Wind Generation in 2035, by cost reduction scenario. Chart shows Biomass, Onshore, and Offshore Wind generation as a percentage of total renewable generation in 2035.

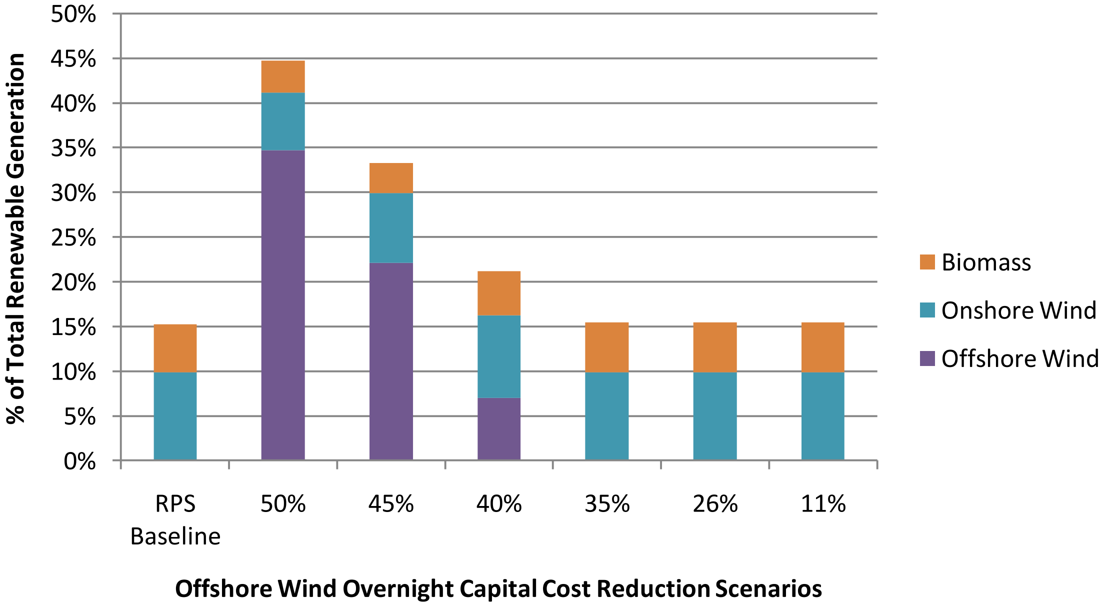


Figure 20. New York (NERC 6) Offshore Wind Generation in 2035, by cost reduction scenario. Chart shows Biomass, Onshore, and Offshore Wind generation as a percentage of total renewable generation in 2035.

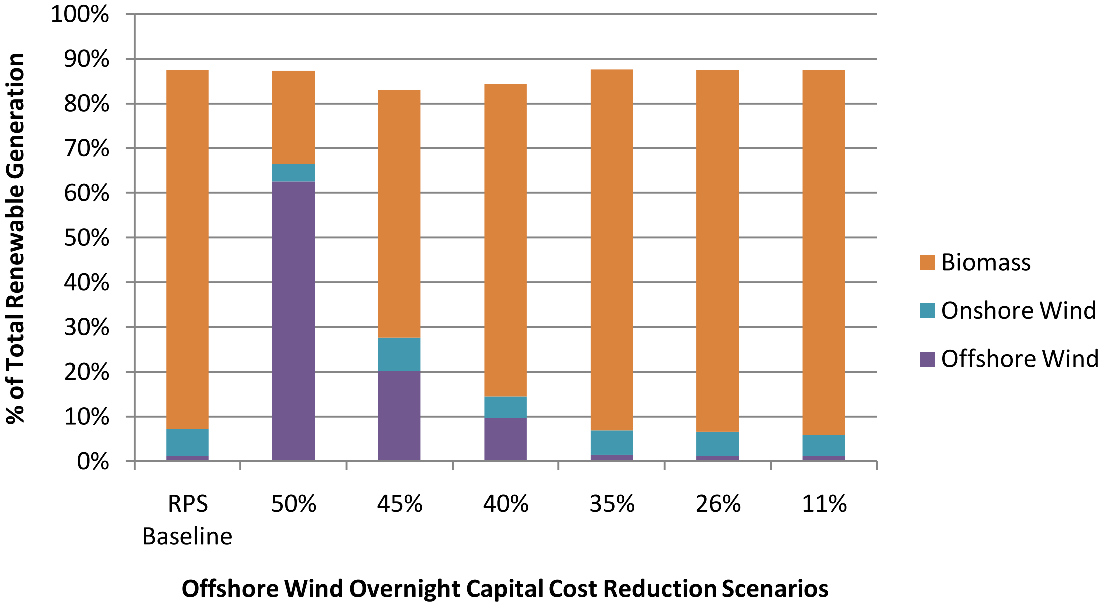


Figure 21. Mid-Atlantic (NERC 3) Offshore Wind Generation in 2035, by cost reduction scenario. Chart shows Biomass, Onshore, and Offshore Wind generation as a percentage of total renewable generation in 2035.

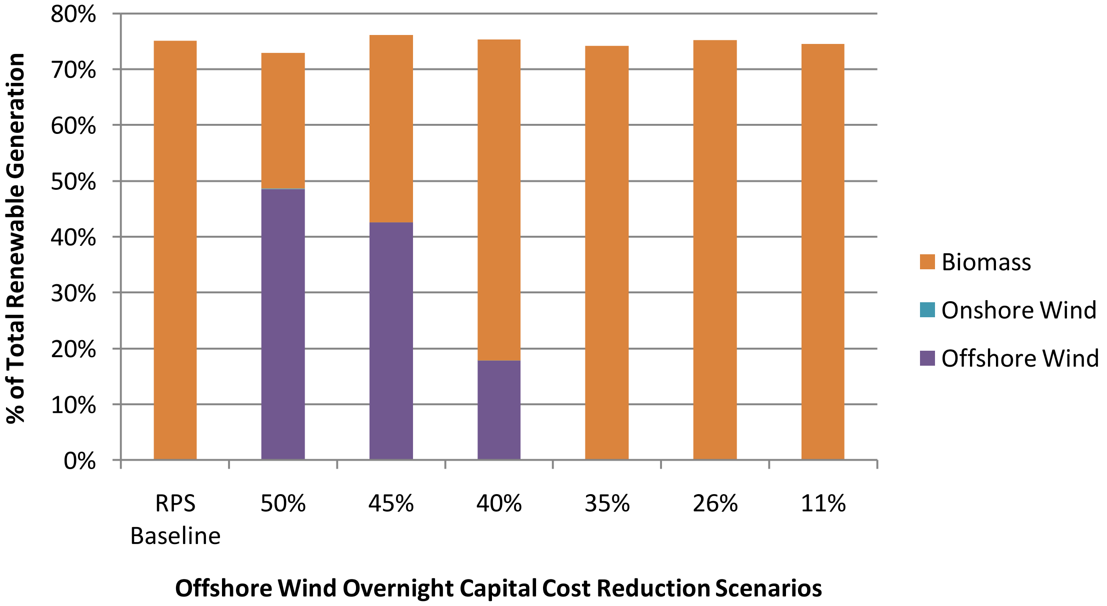


Figure 22. South-east (NERC 9) Offshore Wind Generation in 2035, by cost reduction scenario. Chart shows Biomass, Onshore, and Offshore Wind generation as a percentage of total renewable generation in 2035.

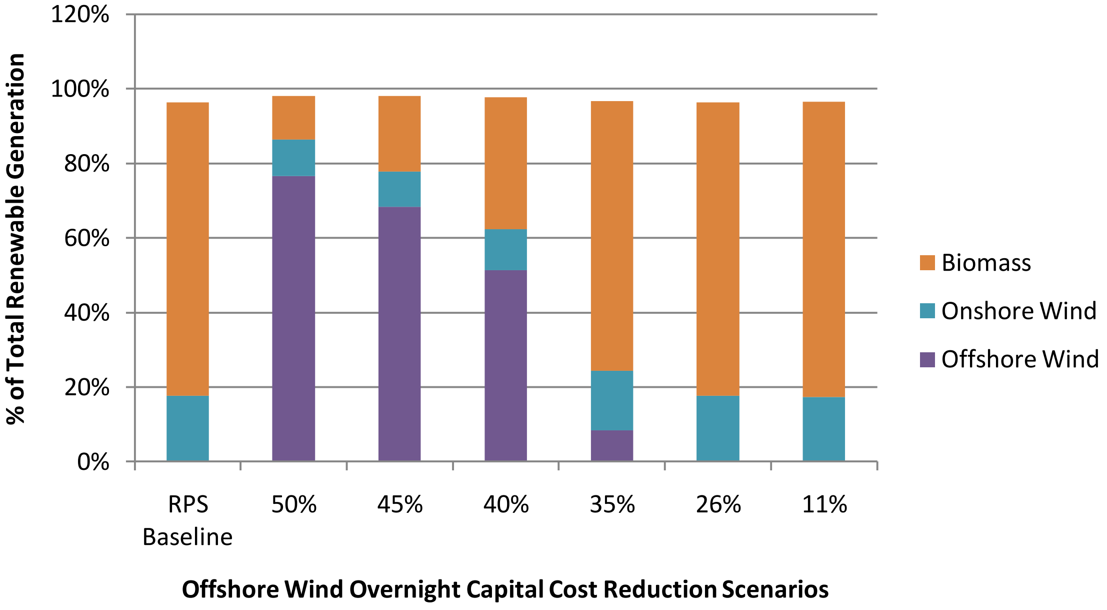


Figure 23. Florida (NERC 8) Offshore Wind Generation in 2035, by cost reduction scenario. Chart shows Biomass, Onshore, and Offshore Wind generation as a percentage of total renewable generation in 2035.

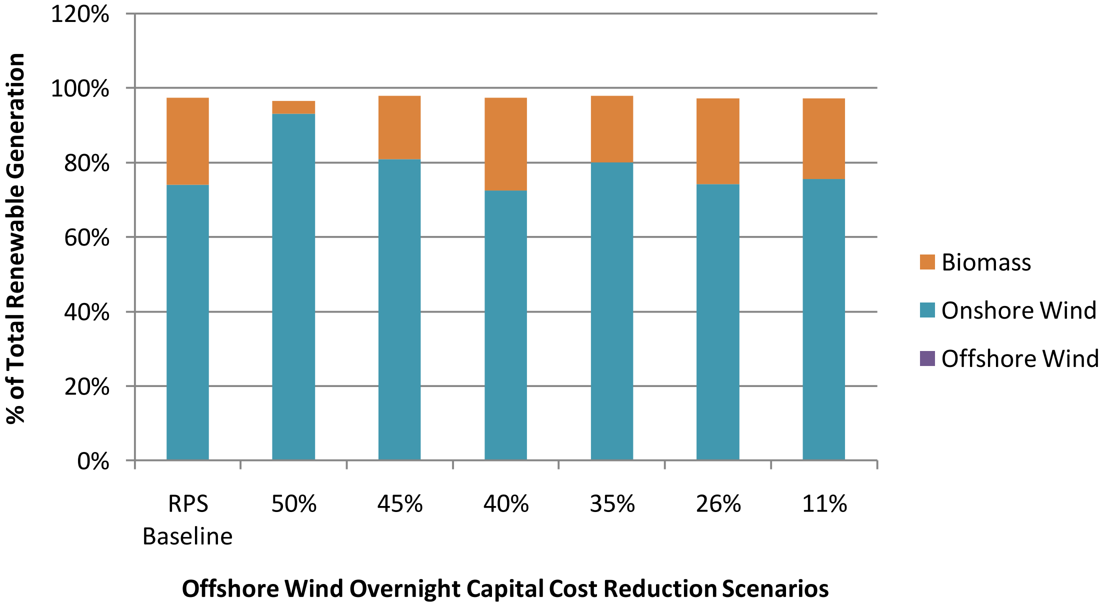


Figure 24. Texas (NERC 2) Offshore Wind Generation in 2035, by cost reduction scenario. Chart shows Biomass, Onshore, and Offshore Wind generation as a percentage of total renewable generation in 2035.