Price Suppression and Emissions Reductions with Offshore Wind: An Analysis of the Impact of Increased Capacity in New England

Richard D. Tabors, Ph.D.   Lorna Omondi   Aleksandr Rudkevich Ph.D.   Evgeniy Goldis   Kofi Amoako-Gyan
Tabors Caramanis Rudkevich   Newton Energy Group

Abstract

Offshore wind provides multiple benefits both in terms of economic savings to consumers and reduction in environmental residuals. The current paper uses a state-of-of-the-art software system, pCloudAnalytics™ to evaluate multiple scenarios of the incorporation of offshore wind assets in the New England electric power system ranging in size from 100MW to 1200MW. The analysis is focused on the benefits to consumers – the price suppression impacts – of increasing quantities of offshore wind. The analysis provides a detailed evaluation of the locational marginal price (LMP) impact of increasing MW of offshore wind for a single study year, 2015. In addition the analysis tracks and presents the reductions in air emissions that result from incorporation of increased quantities of offshore wind in the New England system.

1. Objective of the paper

The objective of this paper is, through detailed simulation analysis, to evaluate the price suppression benefits and the direct environmental benefits of offshore wind development projects of increasing magnitude operating within one of the Northeast organized markets, in this instance, ISO NE. The second objective is to demonstrate the computational benefits that can be achieved in simulation of Locational Marginal Price (LMP) markets with the advent of more sophisticated and efficient Security Constrained Unit Commitment and Security Constrained Economic Dispatch structures that can take advantage of the availability of massive parallel processing with cloud computing.

2. Background

Offshore wind developments have flourished in the United Kingdom including Scotland and in Denmark. In 2014 the UK is reported to have 3.6 gigawatts of installed offshore wind with an output of roughly 8 terawatt hours. [1] Denmark is reported to have 4.8 gigawatts of installed capacity and 11.1 terawatt hours from offshore wind in 2013.[2] While significant projects have been proposed for the east coast of the US, only two projects have so far gone through the full siting process and been set for construction. These are the Cape Wind project in Nantucket Sound and the Deepwater Wind project off of Block Island in Block Island Sound.

Opposition to offshore wind development has most often focused on the additional cost that offshore entails (relative to onshore wind installations as well gas fired generation). Proponents, on the other hand, argue that the increased cost of offshore relative to onshore is offset by the significant increase in capacity factor and daily wind patterns that better complement the utility's load shape. The argument in favor of wind over natural gas fired generation is focused on greenhouse gas (GHG) or carbon) emissions.

The discussions of off-shore wind both pro and con have focused on the cost to construct ($/MWh) and the required per kWh cost that is paid for the offshore wind generated power. The greatest experience in offshore wind development is in the UK and Scotland and in Denmark. The current levelized cost of energy from current technology offshore wind in the UK is £140/MWh ($210/ MWh). The UK stated goal is to reach £100/MWh ($150/MWh) by 2020.[3] DONG of Denmark reports a current levelized cost of €160/MWh ($210/MWh) in 2013 with a goal of €100/MWh ($130/MWh) in 2020.[4] These cost reductions are seen both in the UK and in Denmark as achievable though relatively ambitious.

In this paper we acknowledge the reality of and uncertainty in offshore wind construction but focus on the positive market impacts of offshore wind in terms of its price suppression and environmental benefits. Offshore wind, like all renewable energy sources integrated in the power sector, suppresses the wholesale energy component of the retail price of electricity. We specifically analyze offshore wind because the benefits are significant and have only rarely been measured or presented in the regulatory debate which has focused more often on the cost of capital or the magnitude of power purchase agreements with incumbent utilities.1

---

[1] It should be noted that the regulatory discussion finally approving the power purchase agreement by National Grid of 18.7 cents per kWh for the energy delivered from the Cape Wind project provided the evidence of the significance of price suppression with offshore wind development on the New England market. See Charles River

Analyzing the impact of the market benefits of investments in the electric power sector has always been a significant challenge given the complexity of both the physical systems and the economics of the restructured markets in the US. The need to be able to simulate the hour by hour (or even more frequent) operations of the system to mimic the Security Constrained Unit Commitment (SCUC) and the Security Constrained Economic Dispatch (SCED) of the real time operation has provided significant challenge.

This study has been designed around our ability to utilize a state-of–the-art cloud based simulation environment implement on the Amazon EC2 commercial cloud. pCloudAnalytics™ (pCA) has been developed by Newton Energy Group. The pCA environment employs the Power System Optimizer Model ("PSO") analytic engine developed by Polaris Systems Optimizations, Inc.[5] PSO is a detailed, Mixed Integer Programming (MIP) based, unit commitment and economic dispatch model that simulates the operation of the electric power system. PSO determines the security-constrained commitment and dispatch of each modeled generating unit, the loading of each element of the transmission system, and the locational marginal price (LMP) for each generator and load area. PSO support both hourly and sub hourly timescales.

As implemented for this research paper, PSO models a rolling horizon next day unit commitment with 72-hour look-ahead window in simulating hourly schedules of the dispatch of the ISO NE grid. In the commitment process, generating units in a region are dispatched or kept running in order for the system to have enough generating capacity available to meet the expected peak load and required operating reserves in the region for the next day. PSO schedules the dispatch of committed units in the system on an hourly real-time basis, whereby committed units throughout the modeled footprint are operated between their minimum and maximum operating points to minimize total production costs. The unit commitment in PSO is formulated as a mixed integer linear programming optimization problem which is solved to the true optima using the commercial Gurobi Solver Engine. [6]

The key inputs for the PSO model, as used in the ISO-NE model, are summarized below. All inputs and outputs are in December 31, 2012 real dollars. The study period for this project is the calendar year 2015. The study calculated the hourly LMPs for each of the load areas and the 359 large generator nodes (wind and hydro generators less than 20 MW are aggregated in the analysis) in New England. The LMP values represent the marginal cost of the next unit of energy consumed or produced at that nodal point in the ISO NE grid. From the perspective of the generator, these values are what is paid on a generator bus by generator bus basis to suppliers of energy. From the perspective of consumers the LMP represents the wholesale, load bus by load bus price of energy in NE. On the load side, knowing the hourly LMP at each bus and the hourly quantity delivered to the bus it is possible to calculate the total, LMP-based, wholesale cost of energy supplied to load.

Using the *pCA* simulation environment we have been able to evaluate a base case and the impact of five offshore wind development projects at a single location ranging in size from 100MW to 1200MW. pCA provides a time efficient and data efficient environment within which to undertake analysis of the multiple scenarios. While acknowledging that analytic time is not the only consideration, it is important to note that using 60 virtual machines on the cloud allowed the analyses to be completed in a single hour. As a result, the output could be verified, corrections in input data made and new results produced in multiple rounds on a given research day.

3. ISO NE Data Sources

The analyses are based on simulating the hour by hour Security Constrained Unit Commitment and Security Constrained Economic Dispatch operation of ISO NE for 2015 based upon the generating mix reported in the 2014 NE ISO CELT Report. [7] Generation data were adjusted to 2015 for additions and retirements based upon SNL Financial reports as well as reporting in the energy press. Operating characteristics of thermal units such as full load heat rates, planned and forced outages rates were derived from SNL financial where plant specific data were not available from published sources. Variable O&M costs were estimated from public data of similar units in other of the Northeast markets. The analysis schedules the New England system against a known hourly wind regime and therefore does not incorporate the impact of the variability in the availability of wind on the reserve requirements as is discussed by Gan and Litvanov [8] and Zheng and Litvanov [9].

All fossil fuel costs are based on SNL Financials reporting of actual forward prices for these fuels for

---

Associates, "Analysis of the Impact of Cape Wind on New England Energy Prices," February 8, 2010 prepared for Cape Wind Associates, LLC. http://www.crai.com/uploadedFiles/Publications/analysis-of-the-impact-of-cape-wind-on-new-england-energy-prices.pdf?n=944

2015.[2] Non-fossil fuel costs as shown in Table 1 below are derived from independently published sources.

The physical location of all modeled transmission network resources has been structured using substation and node mapping. The transmission topology is based on the 2012 FERC 715 powerflow fillings for summer peak 2016.[3] The power flow was compared to the ISO-NE queue to assure that all essential projects are represented. All generators are mapped to bus nodes (eNode).

Buses are mapped to substations and substations are in turn mapped to Load Zones (LZs). The bus mapping to LZs allows PSO to allocate area load forecasts to load busses in proportion to the initial state from the powerflow. The use of both buses and enodes allow PSO users to distinguish between electrical and physical connections. The powerflow model was solved to develop an initial state for injections and flows.

The analysis includes all major ISO-NE interfaces and frequently binding constraints, as reported by ISO-NE. Limits for interfaces are taken from the ISO-NE state of the market report and all line ratings are taken directly from the powerflow.

Table 1: 2015 Fuel prices for fuels with fixed annual value

Fuel Type	$ 2012/MMBTU
Biomass	1.00
Coal at Brayton Point	3.37
Coal at Bridgeport Harbor	2.74
Coal at Mead	3.46
Coal at Merrimack	4.60
Coal at Mt Tom	4.41
Coal at Salem Harbor	2.96
Coal at Schiller	4.11
Uranium	0.80
Refuse	1.00

Table 2:Natural Gas and Petroleum product prices: monthly high, low and average

$2012/MMBTU	High	Low	Average
liquified Petroleum Gas	21.50	21.04	21.27
No. 6 Fuel Oil 3% Sulfur	13.00	13.00	13.00
No. 6 Fuel Oil 10% Sulfur	12.15	11.40	11.78
No. 2 Fuel Oil	20.49	19.23	19.86
Natural Gas Algonquin	20.06	3.84	11.95
Natural Gas Tennessee at Dracut	19.45	4.09	11.77
Natural Gas Tennessee Z6	14.87	2.88	8.88

The load is modeled as an hourly load shape for each simulated time frame and area. Load shapes have been constructed for each area from the template of hourly load profiles and the monthly energy and peak forecasts available for the study period.

Wind data was derived from NREL reported data (2006) for Block Island, Rhode Island as the closest reporting site to the hypothesized offshore wind location in Block Island Sound, Long Island Sound roughly due south of the current Brayton Point power generation station. Figure 1 shows the monthly wind pattern that results in a 44.45% annual capacity factor.[4] The analysis utilized the same wind regime for each of the 5 scenarios evaluated. The simulation assumes that the wind energy is delivered to the Brayton Point substation.

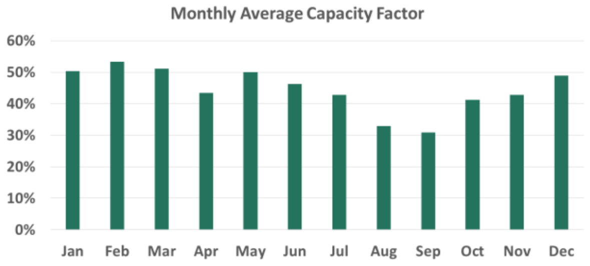

Figure 1: Monthly Wind Capacity Factor Block Island, RI

4. The New England Electric Market

To provide a clear picture of both the price impacts and environmental impacts as well as the flexibility of the pCloudAnalytics™ technology, the results reported in this paper are for a single future year, 2015 and all results are reported relative to the base case in which there is a limited percent of onshore wind generation (2.7%). Table 3 shows the generation and fuel mix for the base case. The addition of 100MW of offshore wind

---

[2] SNL Financial Futures, as of February 2014.

[3] Newton Energy Group is a permitted acquirer of the FERC 715 data. The information in this paper utilizes that knowledge but provides no means by which the underlying data can be accessed or derived.

[4] It should be noted that while the data shown in figure 1 are monthly averages, the data used in the modeling analyses are hourly.

increases the percentage of energy delivered by wind to 3%; and 1200MW to 6.4%. With an increase to 1200MW of offshore wind there is a decrease of roughly 6 % in consumption of natural gas and a decrease of roughly 5% in coal consumption.

Critically, there is a significant reduction in air emissions with the addition of the offshore wind. As shown in Figure 2, CO_2 emissions are reduced by 143 thousand short tons in the case of addition of 100MW of offshore wind and 2.25 million tons in the case of 1200MW of offshore wind. 100MW of offshore wind reduces SO_2 and NO_x in the 100MW case by less than 1% and by 3 and 4% 1200MW case.

This significant reduction in emissions is brought about primarily by the reduction of 3 gigawatt hours of coal generation and 2000 gigawatt hours of natural gas generation with incorporation of 1200MW of offshore wind into the New England System.

Figure 3 shows the reduction in the operating costs (fuel and variable O&M) in the New England region with the addition of increased MW of offshore wind. It is important to note that this is the actual expenditure for fuel and O&M not the marginal cost and therefore represents the savings on the generation side. It is not directly translatable to either the marginal cost of generation that would represent the earnings (or loss of earnings) to the generators or the cost paid by consumers in an LMP market**.**

Table 3: Base Case Generation 2015

Fuel	Sum of Generation(MWH)	% of Total
Biomass	4,808,117	3.93%
Coal	9,580,233	7.83%
F603	504,177	0.41%
F610	2,357,933	1.93%
FO2	3,498	0.00%
Natural Gas	54,537,790	44.59%
Nuclear	35,355,766	28.90%
Refuse	4,085,236	3.34%
Solar	22,349	0.02%
Hydro	8,072,335	6.60%
Wind	2,990,753	2.45%

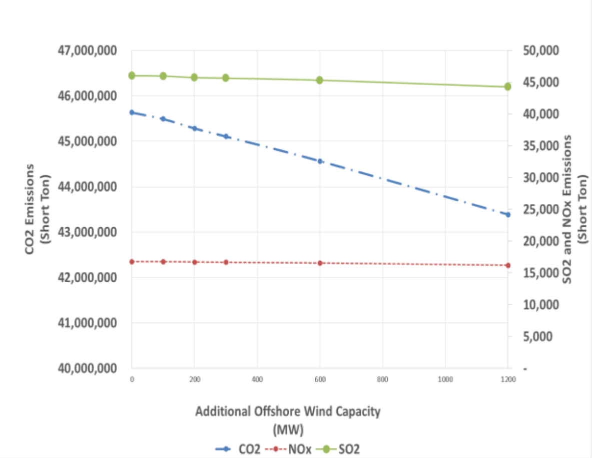

Figure 2: Environmental Emissions Reductions CO2, NOx and SO

5. Results: New England Region

Figure 4 indicates the average wholesale load cost for New England. With the addition of 100MW the wholesale load cost is reduced by 0.2% and with the addition of 1200MW by 2.3%.

Figure 5 shows the total value of the savings to load in the ISO NE service area for 2015. Offshore wind reduces load costs from a base case value of $9,376 million to $9,353 million (a cost reduction of $22.3 Million) with the addition of 100MW of offshore wind; a reduction of $42.6 million with the addition of 300MW of offshore wind and a reduction of $225 million with the addition of 1200MW of offshore wind. It is important to note that because of generation mix in 2015 that the 200MW case shows small negative impact on average wholesale costs reflecting increased operating costs, specifically in the off-peak period, in regions remote from the location of the wind resource. This outcome is reversed in the 300MW and subsequent cases.

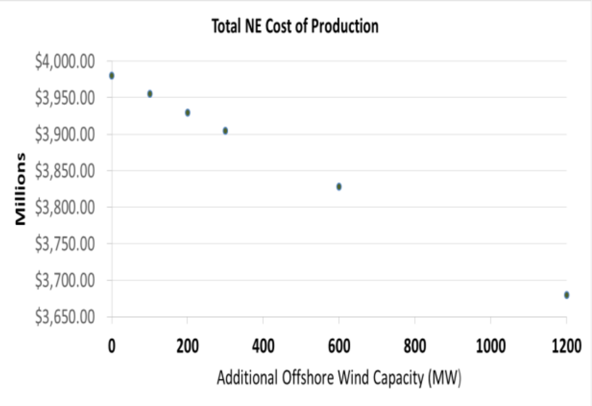

Figure 3: Total New England cost of production

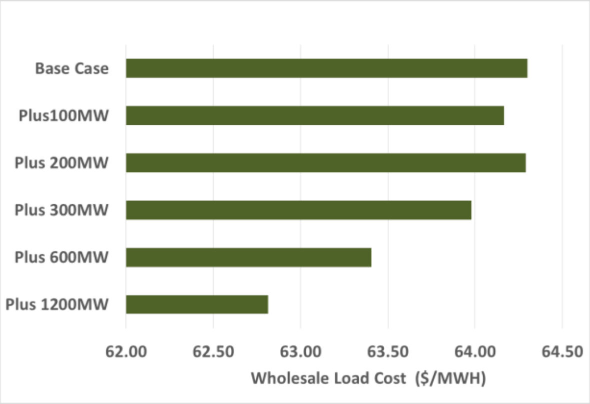

Figure 4: Average Load Wholesale Cost with Increased Offshore Wind ($/MWH)

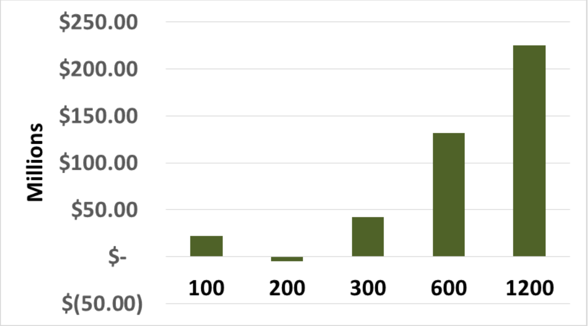

Figure 5: Total Value of Savings to New England Load

6. Results: By location and Peak / Off-Peak

A critical result of the analysis is that the majority of the benefits of offshore wind development is in price suppression in the on-peak time period accounting for 67% of the reduction while the average off-peak reduction is 33% as shown in figure 6. The 200MW case indicates an increase in the cost of supply off-peak and as indicated below, this is primarily in the northeast of the region..

Finally, it is informative to look at the individual states / regions in New England to see where the benefits are the greatest. As Figure 7 indicates, Connecticut is the state that receives the greatest economic benefits to load from the price suppression with the Boston Region receiving the second greatest. Both Maine and New Hampshire show negative benefits for the 200MW case and account for the majority of the negative return indicating that additional cost is required to supply load in these regions under this one case.

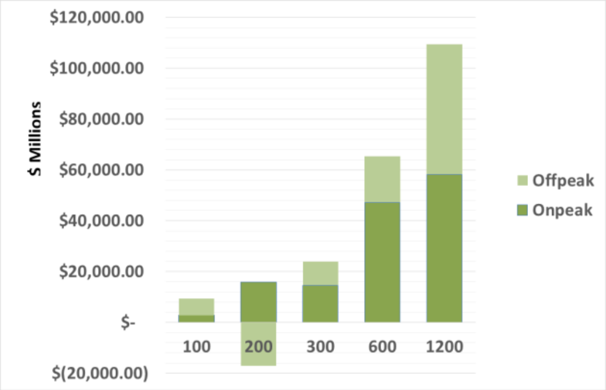

Figure 6: Price suppression peak and off peak

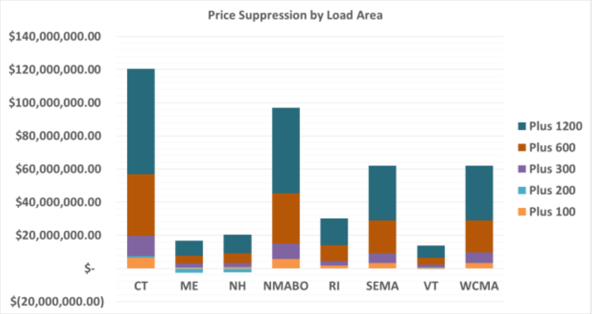

Figure 7: Price suppression benefits by load area

7. Conclusions

Offshore wind development provides significant price suppression benefits to consumers in New England. These benefits are often difficult to calculate and equally difficult to explain to a lay audience. The objective of this paper has been to demonstrate, using state-of-the-art software, *pCloudAnalytics*™, that it is possible, through detailed simulation of the New England power system, to measure the both the economic and the environmental benefits that accrue to increased penetration of offshore wind in the market. We have been able to show that the annual benefit to New England consumers in a single year, 2015 of the incorporation of 100MW of offshore wind would reduce the wholesale cost of electricity to load by 0.2%

and that the installation of 1200MW would reduce the wholesale cost to load by 2.3%. These values account for a total dollar savings to load of $22 million annually with an incorporation of 100MW and $225 million annually with the incorporation of 1200MW.

A significant information byproduct of the economic analysis of the New England system is the ability using PSO to calculate the air emissions based on the stoichiometric characteristics of the generation stock. Based on the analyses undertaken, the air emissions are reduced substantially with the introduction of large amounts of offshore wind in New England. CO_2 emissions are reduced by 143 thousand short tons in the case of addition of 100MW of offshore wind and 2.25 million tons in the case of 1200MW of offshore wind. 100MW of offshore wind reduces SO_2 and NO_x in the 100MW case by less than 1% and by 3 and 4% 1200MW case.

Price suppression and improvement in air emissions are key values provided by offshore wind that are only infrequently considered in the overall evaluation. Value derives both from the initial impact on savings in traditional operating costs but will continue, we would argue, at level through the lifetime of the project as the optimal structure of the generating mix is adjusted to account for the existence of offshore wind.

8. References

[1] Renewable UK. (2014, January). Offshore Wind: Offshore Wind Energy Figures. Retrieved May, 2014, from http://www.renewableuk.com/en/renewable-energy/wind-energy/offshore-wind/

[2] C. Vittrup, (2014, January). 2013 was a record-setting year for Danish wind power. Retrieved May 1, 2014, from http://energinet.dk/EN/El/Nyheder/Sider/2013-var-et-rekordaar-for-dansk-vindkraft.aspx

[3] Wind Cost Reduction Task Force. (2012, June). Offshore Wind Cost Reduction Task Force Report. UK Government. Retrieved in May, 2014, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66776/5584-offshore-wind-cost-reduction-task-force-report.pdf

[4] S. Bakewell, (2013, January). Dong Targets 40% Cut in Wind Costs to Compete With Gas-Fed Power. Bloomberg News. Retrieved May 1, 2014, from http://www.bloomberg.com/news/2013-03-01/dong-targets-40-cut-in-wind-costs-to-compete-with-gas-fed-power.html

[5] www.psopt.com

[6] www.gurobi.com

[7] ISO New England System Planning. (2013, May). CELT Report: 2013-2022 Forecast Report of Capacity, Energy, Loads and Transmission. ISO New England. Retrieved May 1, 2014, from http://www.iso-ne.com/trans/celt/report/2013/2013_celt_report.pdf

[8] D. Gan and E. Litvinov, “Energy and reserve market designs with explicit consideration to lost opportunity costs,” IEEE Transactions on Power Systems, vol. 18, no. 1, 2003 pp. 53–59.

[9] T. Zheng and E. Litvinov, “Ex post pricing in the co-optimized energy and reserve market,”,IEEE Transactions on, Power Systems vol. 21, no. 4, Nov. 2006, pp. 1528–1538.

[10] A. Keane, M. Milligan, C. J. Dent, B. Hasche, C. D’Annunzio, K. Dragoon, H. Holttinen, N. Samaan, L. Soder, and M. O’Malley, “Capacity value of wind power,” IEEE Transactions on Power Systems, vol. 26, no. 2, May 2011 pp. 564–572.

[11] M. Milligan and K. Porter, “The Capacity Value of Wind in the United States: Methods and Implementation,” The Electricity Journal, Volume 19, Issue 2, March 2006, pp. 91–99.

[12] R. Billington and Y. Gao, “Multistate Wind Energy Conversion System Models for Adequacy of Generating Systems Incorporating Wind Energy,” IEEE Transactions on Energy Conversion, Volume 23, Issue 1 March 2008, pp 163 – 170.