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

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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. First the analysis provides a detailed evaluation of the locational marginal price (LMP) impact of increasing quantities of offshore wind capital stock it is possible to quantify the incremental benefits for a single year and to estimate the present value of the benefits over the expected lifetime of the assets. Second, the analysis tracks and presents the reductions in air emissions the 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, though 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 (over land based 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 carbon (GHG) emissions.

The discussions of off-shore wind both pro and con have focused on the cost to construct

[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] Vittrup, C. (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

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($/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.[5]

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. While the problem can be broken for parallel processing, few organizations can maintain dedicated processors running the complex SCUC and SCED software such as GE MAPS, GRIDVIEW or Ventyx PROMOD. The result has been an inability to do multiple scenarios or multiple year investment analyses prevented by both hardware and time limitations.

pCloudAnalytics™[6]

This study has been designed around our ability to utilize a state-of–the-art cloud based modeling system, *pCloudAnalytics*™ (*pCA*) the electric power market analytics environment that is implemented in the Amazon and Windows Azure commercial clouds. The analytic engine of *pCA* is Power System Optimizer (PSO) that provides chronological simulations of security constrained unit commitment, security constrained economic dispatch, and provision of ancillary services.[7] The PSO engine accurately captures the full topology of the transmission network, accounts for contingency events and models operational constraints of generating units and demand response resources. PSO is based on the same mathematical logic and technology used by

[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] Bakewell, S. (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] 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 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

[6] http://www.newton-energy.com/pcloudanalytics

[7] www.psopt.com

the market engines of MISO, PJM and ISO NE.

As implement here, we have been able, using *pCloudAnalytics™ to* calculate and report hourly Locational Marginal Prices for each of the load areas and the 359 large generator nodes (generators less than 200MW 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. 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.

In addition to the PSO market engine, *pCA* provides vetted, proprietary data and a sophisticated data handling structure permitting both the loading and retrieval of data from the cloud in a flexible format that can readily be combined and analyzed with standard pivot tables MS Excel™. The result for this study is that we have been able to evaluate a base load case and the impact of five offshore wind development projects at a single location ranging in size from 100MW to 1200MW. The actual computational time would normally have been measured in days while with the use of the cloud-based technology we have been able run the full set of scenarios in under an hour utilizing in excess of 60 virtual machines on the cloud and therefore a total of 60+ machine hours of cost plus data handling. The output could be verified, corrections in input data made and new results produced in multiple rounds on a given research day compared with completing one cycle of the 5 scenarios in what would have probably taken 5 days without access to the cloud.

ISO NE Data

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 CELT Report.[8] Generation data was adjusted to 2015 for additions and retirements based upon SNL Financial reports as well as reporting in the energy press.

Wind Regime

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.[9] 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.

Fuel Costs

All fossil fuel costs are based on SNL Financials reporting of actual forward prices for these fuels for 2015.[10] Non-fossil fuel costs as shown in Table 1 below are derived from independently published sources.

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[8] 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
[9] It should be noted that while the data of figure 1 are monthly averages, the data used in the modeling analyses are hourly.
[10] SNL Financial Futures, as of February 2014.

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: 2015 Natural Gas and Petroleum product monthly fuel prices by month

	High	Low	Average
Liquefied Petroleum Gas	**21.50**	**21.04**	**19.61**
No. 6 Fuel Oil 3% Sulfur	**13.30**	**12.48**	**12.83**
No. 6 Fuel Oil 10% Sulfur	**12.15**	**11.40**	**11.72**
No. 2 Fuel Oil	**20.49**	**19.23**	**19.77**
Natural Gas Algonquin	**4.84**	**3.83**	**3.83**
Natural Gas Tennessee at Dracut ME	**16.07**	**3.77**	**7.08**
Natural Gas Transco Z6 CT	**10.21**	**3.77**	**7.08**
Natural Gas Transco Z6 MA	**10.21**	**2.42**	**4.48**

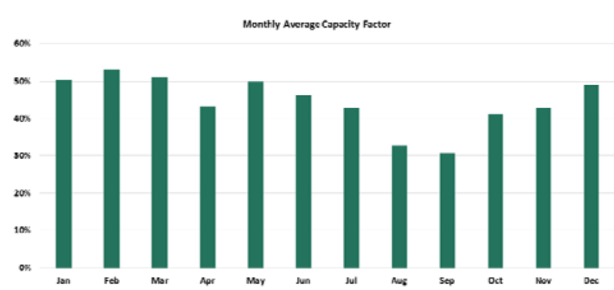

Figure 1: Monthly Wind Capacity Factor Block Island, RI

3. 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 White Paper are for a single future year, 2015 and all results are reported relative to the base case (Figure 2) in which there is a limited percent of onshore wind generation (2.7%). Table 3 and Figure 2 show the generation and fuel mix for the base case. The addition of 100MW of offshore wind increases the percentage of energy delivered by wind to 3%; 200MW to 3.4%; 300MW to 3.7%; 600MW to 4.6% and 1200MW to 6.4%. Figure 3 (1200MW of offshore wind) shows a decrease of 6.5% in consumption of natural gas (49.5% to 46.3%) and a decrease of 5.6% in coal consumption (7.1% to 6.7%). Figure 3 shows the fuel mix with 1200MW of offshore wind.

Critically, there is a significant reduction in air emissions with the addition of the offshore wind. As shown in Figure 4, CO_2 emissions are reduced by 288 thousand short tons in the case of addition of 100MW of offshore wind and 3.24 million tons in the case of 1200MW of offshore wind. In parallel, 100MW of offshore wind reduces SO_2 in the 100MW case by 357 tons or 1% and 2,859 tons or roughly 8% in the 1200MW case. The reduction in NO_x is 127 tons in the 100MW case or 0.75% and 1,121 tons or 6.5% in the 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.

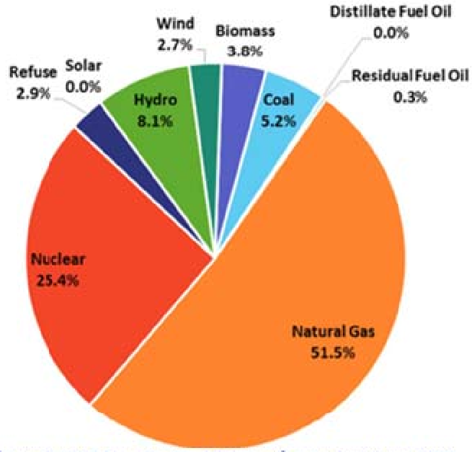

Figure 2: 2015 New England Generation by fuel type: 1200 MW of Additional offshore wind

Table 3: Base Case Generation 2015

Fuel	Sum of Generation (MWH)	% of Total
Biomass	4,770,674	3.78%
Coal	8,903,062	7.06%
Distillate Fuel Oil	53,676	0.04%
Residual Fuel Oil	415,474	0.33%
Natural Gas	62,522,839	49.55%
Nuclear	32,063,952	25.41%
Refuse	3,695,107	2.93%
Solar	3,504	0.00%
Hydro	10,303,819	8.17%
Wind	3,455,952	2.74%

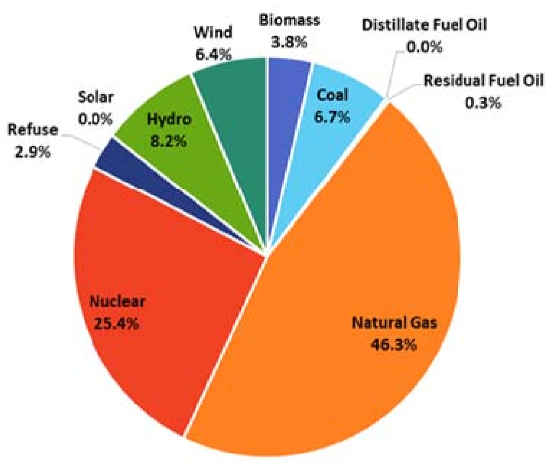

Figure 3: 2015 New England Generation by Fuel Type Base Cost

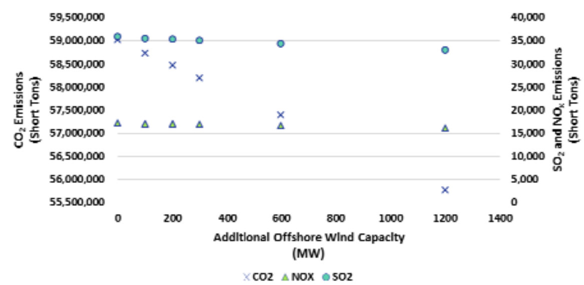

Figure 4: Environmental Emissions Reductions CO2, NOx and SO

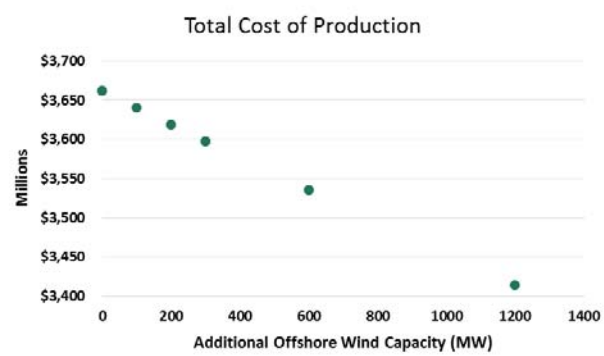

Figure 5: Cost of Production

Figure 5 shows the reduction in the operating costs (fuel and variable O&M) in the New England region with the addition of the offshore wind by size of installation. It is important to note that this is the expenditure for fuel and O&M cost 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 nor the cost paid by consumers in an LMP market.

4. Results: New England Region

As described above, using *pCA* we have calculated the reduction in average price to load with increased implementation of offshore wind (Figure 5). As stated above, the simulation analysis undertaken has focused on an evaluation of an increasingly large installation of offshore wind.[11] The analysis has calculated the resultant wholesale, bus by bus energy price to load in New England. Adding the first 100MW reduces the wholesale cost to load by 1%; adding 300MW reduces the cost to load by 1.5%, adding 600MW reduces the cost to load by 3% and adding 1200MW reduces the cost to load in ISO NE by over 5.3% from the base case value.

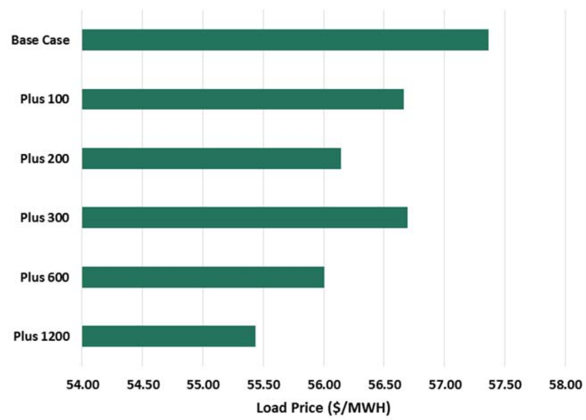

Figure 5: Load Wholesale Cost Reduction with Increased Offshore Wind

To provide a perspective on the calculated average price to load values, the average retail price in New England to all consuming sectors in 2012 was $140.2/MWH and $144.8/MWh in 2013.[12] Assuming that 2015 will be roughly equivalent to 2013 in retail cost, the wholesale price to load without the offshore wind would represent 38% of the final average retail price. The added cost to retail customers covers the costs of the transmission and distribution systems, administrative costs, and any added programatic costs required by the public service commission. Based on a retail cost of $144.8/MWh, the price suppression on retail rates with the addition of 1200MW of offshore wind would be roughly 2% or a reducton to $ 2.93/MWh. The same calculation for the addition of 100MW of offshore wind would result in a reduction of $0.52/MWh.

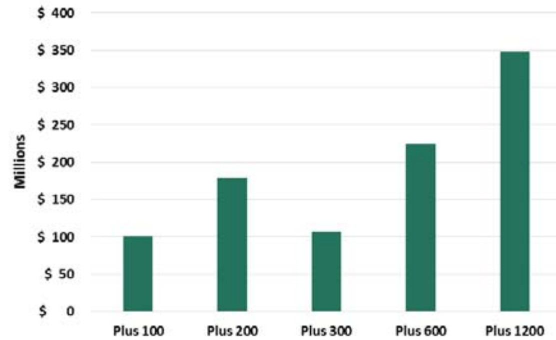

Figure 6: Total Value of Savings to New England Load[13]

Focusing on the single year, Figure 6 shows the total value of the savings to load in the ISO NE service area for the single year of 2015. Offshore wind reduces load costs from a base case value of $8,522 million to $8,421 million (a cost reduction of $101.34 Million) with the addition of 100MW of offshore wind; a reduction of $106.79 million with the addition of 300MW of offshore wind and a reduction of $348 million with the addition of 1200MW of offshore wind.

As indicated, the detailed analyses were undertaken for 2015. In an effort to evaluate the present value of the price suppression impact over the lifetime of the investment, on a total and a per megawatt basis, we have looked out 30 years with the assumption that the annual benefits will remain constant, i.e., that the annual impact will not diminish over

[11] The wholesale cost paid by the load is equal to the hourly LMP at each load bus($/MWh) times the load at the bus; summed over the region.

[12] Energy Information Administration. (2014, February). Electric Power Monthly, Table 5.6.B. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, Year-to-Date through December 2013 and 2012. http://www.eia.gov/electricity/monthly/current_year/february2014.pdf

[13] See the appendix to this paper for a discussion of the cause of the increased cost with the addition of 200MW of offshore capacity relative to 100MW and 300MW of incremental capacity.

the anticipated 30 year life of the investment. The justification for this assumption is that with the development of the offshore wind investment, the inherent structure of the underlying fossil and renewable generation mix of the region will adjust to an optimal mix that incorporates this calculated operating cost reduction into the decision process for all future investments.

Figures 7 and 8 show the present value of the price suppression impacts of the offshore wind projects using a 6% and a 10% discount rate reflecting a higher and lower evaluation of the social and commercial benefit of the renewable investment. Focusing only on the 100MW and the 1200MW scenarios, at a discount rate of 10% the present value of price suppression of the 100MW scenario is \$0.96 billion and \$1.4 billion at 6%. The corresponding figures for the 1200MW scenario are \$3.3 billion at 10% and 4.85 billion at 6%.

Dividing through by the project size it is easily possible to calculate the per megawatt present value of the price suppression impact on load. Adding the first 100MW of offshore wind provides a benefit of between \$9.6 and \$14.1 million.[14] The per megawatt present value of the price suppression impact of adding 1200MW ranges between \$2.8 and \$4.0 million.

5. 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 69% of the reduction while the average off-peak reduction is 31% as shown in figure 9.

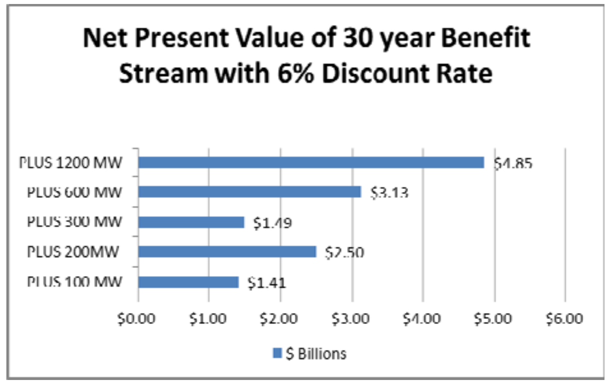

Figure 7: Net present value of price suppression to load at 6% discount rate over 30 years

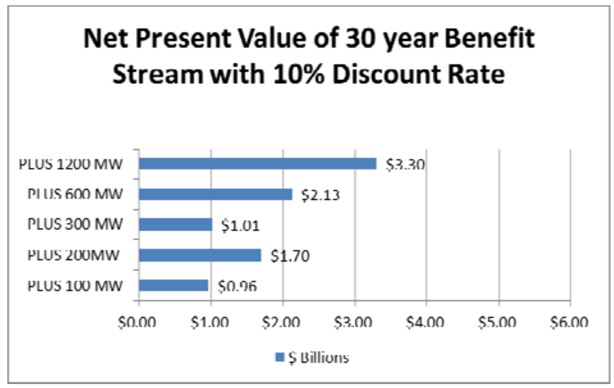

Figure 8: Net present value of price suppression to load at 10% discount rate over 30 years

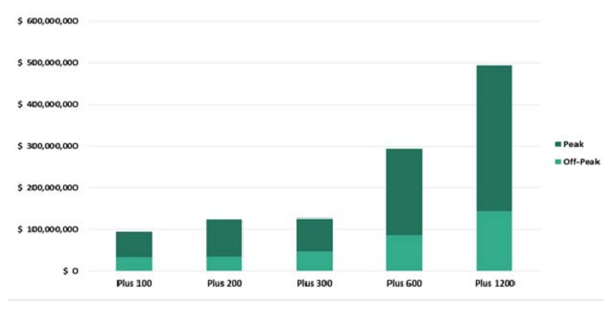

Figure 9: Price suppression peak and off peak

Finally, it is informative to look at the individual states / regions in New England to see where the benefits are the greatest. As Figure 10 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.

[14] It is important to note that the values presented are per MW and not per MWh and therefore are not comparable with the levelized cost of electricity values described in the background section of this paper.

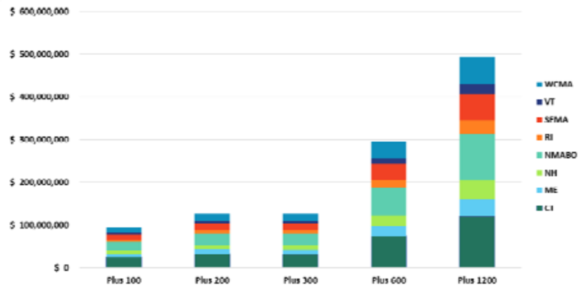

Figure 10: Price suppression benefits by load area

6. 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 1% and that the installation of 1200MW would reduce the wholesale cost to load by 5.3%. These values account for a total dollar savings to load of $101 million annually with an incorporation of 100MW and $348 million annually with the incorporation of 1200MW. Assuming that the flow of benefits is constant for an installation of 100 megawatts for the 30 year life of the assets, the net present value per megawatt of offshore capacity would, at 6% discount rate, be equivalent to a savings of $14.1 million over the life of the assets. For an installation of 1200MW the present value per megawatt of offshore capacity would, again at 6% discount rate be $4.0 million. The total present value of benefits to load in New England for the two installations would be $1.4 billion and $4.85 billion respectively.

Air emissions are reduced substantially. CO_2 emissions are reduced by 288 thousand short tons in the case of addition of 100MW of offshore wind and 3.24 million tons in the case of 1200MW of offshore wind. In parallel, 100MW of offshore wind reduces SO_2 in the 100MW case by 357 tons or 1% and 2,859 tons or roughly 8% in the 1200MW case. The reduction in NO_x is 127 tons in the 100MW case or 0.75% and 1,121 tons or 6.5% in the 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.

7. Appendix

The analysis of increased the economic and environmental benefits of increased investment in offshore wind in New England has demonstrated an important point in the physical operation of this or any region's non-wind or non-renewable generating capacity. While it was expected that there would be a smooth pattern of benefits to load with increased offshore capacity, that smooth transition was not seen as demonstrated in figures 5 through 10 where the 300MW scenario was less economically beneficial to load than was the 200MW scenario.

Given the mix of non-wind generating assets in New England and most specifically the operating characteristics and constraints of those units, the generating mix *at the margin* was significantly different when integrating 300MW as opposed to 200MW. That difference was seen, at the margin, in the dispatch of predominantly older, FO2 fired older peaking units (both gas turbine and diesel) with short start-up but quite high cost. Under most circumstances these units were not used in the dispatch of the model or used only sparingly, thus seldom setting the marginal price (LMP). However, as shown in figure A-1 through A-3 for only three specific days, these generators were dispatched in the 300MW case but either not at all or at a far lower level in the other four cases.

The immediate question is whether this is a likely fault of the modeling structure or is a realistic outcome of the operational structure and constraints of the generation mix. Our detailed analysis indicates that it is that latter not the former. All scenarios face the same wind regime. All scenarios face the same generation mix. The 300MW scenario places a demand on the non-wind generation that is inherently different from that of the 200MW or the 600MW scenarios. We see the need to bring on expensive but flexible generation that sets the LMP for a greater number of hours. The sum of the difference in costs of even a relatively small number of hours with both large loads and a high differential between the most expensive and the next most expensive generating sources is more than sufficient to give what appear as counter intuitive results.

The results are model based and for a single year, 2015. Even with this small analytic sample it is possible to see that there are or will be two economic and policy forces at work. The first is one that works to maintain the existing generation mix because there is no need for additional capacity. The second will, more realistically, push for added capacity that allows for a more optimal mix to handle both the variability of the added resources as well as the increased penetration of those resources in the system.

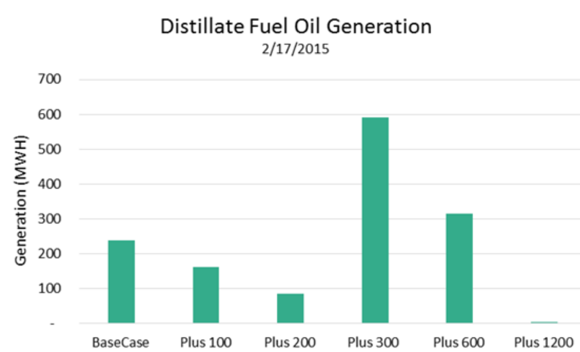

Figure A- 1: Distillate Generation 2/17/2015

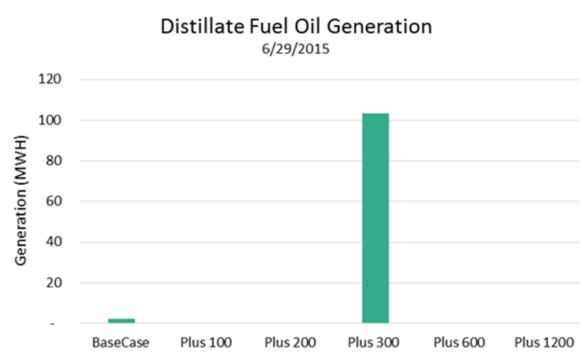

Figure A- 2: Distillate Generation 6/29/2015

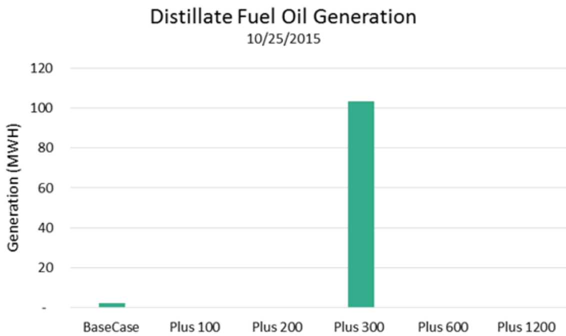

Figure A- 3: Distillate Generation 10/25/2015