Charting the Wind:

Quantifying the Ratepayer, Climate, and Public Health Benefits of Offshore Wind in New England

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EXECUTIVE SUMMARY

Offshore wind is a critical resource for achieving New England's climate goals and protecting New Englanders from energy price shocks, and it does so cost-effectively under a range of future gas prices. Massachusetts, Connecticut, and Rhode Island are collectively targeting development of approximately 9,000 megawatts (MW) offshore wind by 2030. For this report, we analyzed the economic, climate, and public health impacts that building 9,000 MW of offshore wind by 2030 would deliver based on recent actual offshore wind contract prices in the region. We conclude that in 2030, 9,000 MW of offshore wind would:

- Reduce New England electricity customers' bills by approximately $630 million annually under a mid-range gas price scenario but reaching $1.7 billion annually in a high gas price scenario. This translates to reduced customer bills of $2.79/month for an average residential customer under mid-case future natural gas prices, and $4.61/month under a high gas price scenario, or $33.48 to $55.32 annually.
- Reduce ISO New England's carbon dioxide (CO_2) emissions from electricity generation by 14 million short tons annually. This equates to a 42% reduction in annual CO_2 from the grid.
- Halve the amount of money New England spends on natural gas for power generation, which currently averages $3 billion annually. Under a mid-case gas price, New England would retain approximately $1.57 billion that would have otherwise flowed out of the region for natural gas fuel.
- Provide $362 million in annual public health benefits by avoiding 3,700 short tons of NO_X emissions, 824 tons of SO_2 emissions, and 641 tons of $PM_{2.5}$ emissions each year.
- Improve energy security by reducing the region's reliance on natural gas pipelines. During winter cold snaps these pipelines often reach their maximum capacities. Adding more offshore wind would ease pressure on these pipelines.

While recent economic and supply chain hurdles have slowed the region's first steps toward integrating offshore wind energy into the electric grid, New England states remain well-positioned to take advantage of offshore wind as a key energy source. Currently, New England's heavy reliance on imported natural gas leaves the region vulnerable to fluctuations in natural gas fuel prices, which can in turn cause electricity prices to spike.

Adding renewable resources such as offshore wind to New England's generation mix can both reduce the cost of electricity in the region, lowering customer bills, and act as a hedge against future natural gas price fluctuations, potentially resulting in even greater savings.

1. Introduction

Offshore wind has the potential to provide vast amounts of clean, reliable, and locally-sourced electricity to the New England grid. Recent project cancellations due to inflation and supply chain issues and the higher costs of recent contracts have raised questions about the benefits of offshore wind to New England, and prompted consideration of further increasing the region's reliance on natural gas for power generation.

At the request of Sierra Club, Synapse Energy Economics, Inc. (Synapse) studied the impacts that states' targeted levels of offshore wind procurement would have on New England's electricity grid based on recent actual contract prices from the region. Our analysis zeroed in on two areas: how offshore wind would affect the region's outsized dependence on electricity from natural-gas-fired power plants and how offshore wind deployment would impact electricity prices, and by extension, customers' electric bills.

2. New England's Increasing Exposure to Natural Gas Price Volatility

As New England's electricity sector phases out its older coal- and oil-fired resources, New England has become increasingly reliant on natural gas power plants to provide electricity. In the winter when natural gas demand for heating surges, natural gas power plants must compete with residential and commercial customers to obtain fuel. This causes prices to rise and leaves the region vulnerable to natural gas price swings. These swings in turn produce electricity price volatility and negatively impact the regional economy. At the same time, continued use of natural gas and other fossil fuels for electricity generation also poses risks to the environment and health of the region's residents.

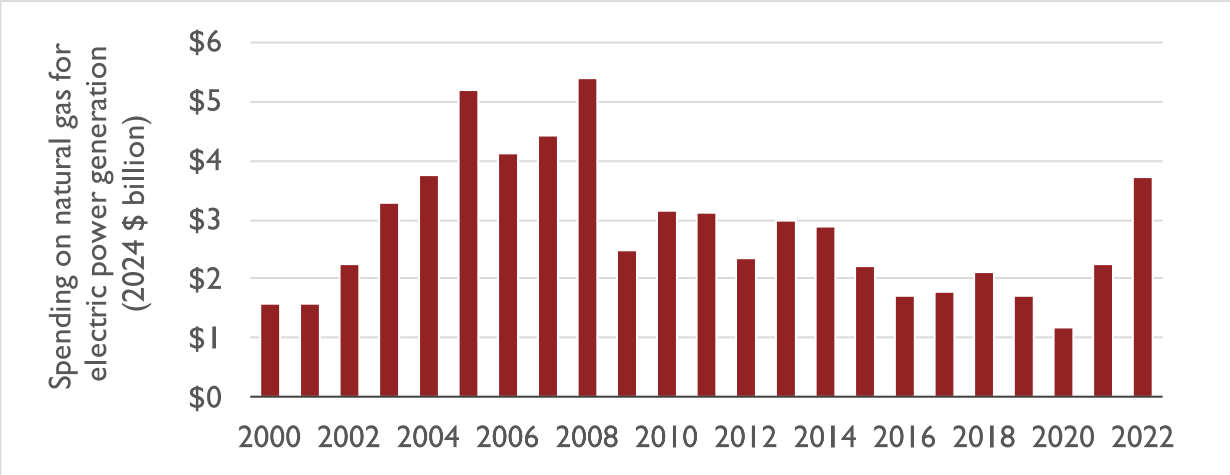
2.1. Natural gas expenditures for electricity generation

In 2023, more than half of the electricity produced in New England came from power plants burning natural gas.[1] Between 2000 and 2022, cumulative spending on natural gas for electricity generation in New England totaled $65 billion. This equates to an average of $3 billion flowing out of the regional economy each year. In some years, regional electric sector expenditures on natural gas surpassed $5 billion due to spikes in natural gas prices.[2]

[1] ISO New England. *Key Grid and Market Stats*. Accessed April 2024. Available at https://www.iso-ne.com/about/key-stats/markets.

[2] U.S. Energy Information Administration. *State Energy Data System (SEDS)*. Available at: https://www.eia.gov/state/seds/seds-data-fuel.php?sid=US#DataFiles

Figure 1. Annual New England natural gas expenditures for electricity generation



Source: U.S. Energy Information Administration. State Energy Data System (SEDS). *Available at:* *https://www.eia.gov/state/seds/seds-data-fuel.php?sid=US#DataFiles*

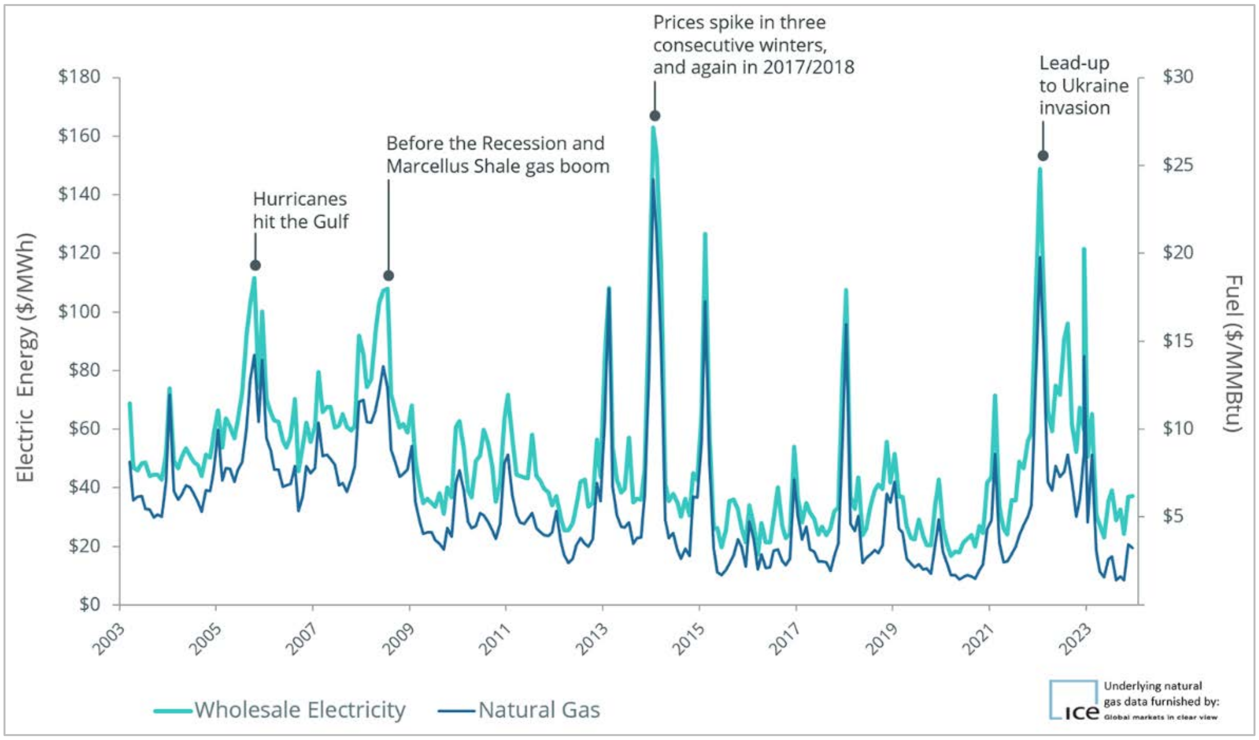
2.2. Natural gas makes New England vulnerable to price spikes

The region's reliance on natural gas for electricity generation leaves it particularly prone to fluctuations in natural gas fuel prices, which in turn causes electricity prices to spike. In New England, electricity prices are set in wholesale markets based on the marginal cost of the most expensive generator needed to meet demand. Natural-gas-fired power plants are usually the marginal generator, meaning that they typically set the market clearing price at which all electricity is purchased. Because of this, the price of electricity in the wholesale market is closely tied to the cost of the natural gas fuel used to generate electricity.

When prices in the natural gas market increase due to extreme weather or geopolitical events, the price of electricity closely follows. Figure 2 below shows an analysis by the regional grid operator, ISO New England, illustrating how wholesale electricity prices (in dollars per megawatt-hour) closely follow natural gas fuel costs (in dollars per million British thermal units (MMBtu)). [3] The figure highlights the sensitivity of natural gas fuel costs, and thus electricity prices, to weather events (including hurricanes and extended cold spells) and geopolitical events (such as the Russian invasion of Ukraine).

[3] The price is shown as a volume-weighted average of trades at four natural gas delivery points in Massachusetts, including two Algonquin points, the Tennessee Gas Pipeline, and the Dracut Interconnect.

Figure 2. New England monthly average natural gas fuel costs and wholesale electricity prices



Source: ISO New England, Key Grid and Market Stats*, April 2024. Available at* ***https://www.iso-ne.com/about/key-stats/markets****.*

Constraints on the natural gas pipeline system serving New England, failure of many New England gas-fired power plants to secure firm natural gas supplies, and increasing overseas demand for liquified natural gas (LNG) exports will continue to exacerbate the regional natural gas price volatility risk. While natural-gas-fired generating capacity has increased considerably since 2000, the natural gas supply infrastructure serving New England during the same period has seen only incremental changes. On cold winter days, New England pipeline capacity is running close to, or at, its maximum capacity. Most of this natural gas is under contract to serve heating demand rather than power plants.[4] The majority of the natural gas purchased by generators in New England is purchased through the spot market, rather than through expensive long-term contracts, since generators do not know when they will be called to run.[5] This means that natural gas power plants may not be able to obtain fuel for generating electricity when natural gas demand for heating is also high.

When natural gas generators are unable to procure the fuel they need due to pipeline constraints, more expensive and polluting generators, particularly oil-fired power plants, are dispatched to meet electricity

[4] ISO New England. *Natural Gas Infrastructure Constraints*. Accessed April 2024. Available at https://www.iso-ne.com/about/what-we-do/in-depth/natural-gas-infrastructure-constraints.

[5] EIA Form 923 Schedule 5.

demand. This has further contributed to the high electricity prices seen in recent winters, as well as the emissions from power plants during these periods.

3. OFFSHORE WIND LOWERS ELECTRICITY BILLS

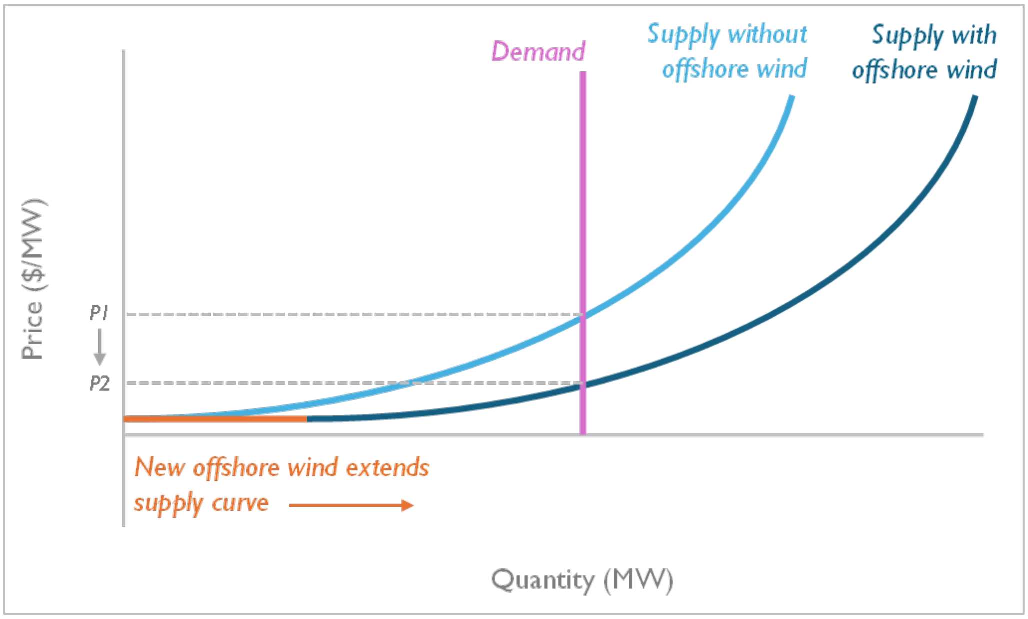
Adding renewable resources such as offshore wind to New England's generation mix can reduce the market clearing price of electricity and act as a hedge against natural gas price fluctuations. This helps to reduce the cost of electricity in the region, and in turn, lower customer bills. We project that offshore wind's ability to lower electricity costs for New Englanders will continue, even accounting for recent increases in offshore wind development costs. This section describes how offshore wind reduces electricity prices through the interaction of supply and demand in the wholesale energy market.

3.1. How offshore wind can lower electricity prices

In the wholesale energy market, owners of electric generators place bids to provide electricity based on their resources' variable costs of operation. For fossil fuel generators, the bid is largely based on the cost of fuel. Because offshore wind plants have no fuel costs, these resources are typically bid in at a price near zero. Generators with lower variable operating costs (like wind resources) are dispatched by the regional grid operator ahead of natural-gas-fired generators with higher variable natural gas costs. The wholesale market clearing price that all generators receive is based upon the last-dispatched (or marginal) unit. Over time, offshore wind generation will reduce the frequency and quantity of dispatch from higher variable cost natural-gas-fired generators, lowering the wholesale electricity market clearing price. In effect, offshore wind extends the wholesale market supply curve, exerting downward pressure on power system operating costs and reducing electricity costs for households and businesses across New England. This is referred to as market price suppression.

Figure 3 presents a stylized representation of the price suppression effect for a hypothetical hour. In this graph, the solid purple line represents the demand curve, while the blue curves represent generation resources with increasingly expensive bid prices. The intersection of the supply and demand curves is the market clearing price. In this example, the addition of a substantial quantity of offshore wind (shown in orange) adds additional low cost energy bids, and therefore extends the supply curve to the right, resulting in a price reduction.

Figure 3. Hypothetical market dynamics, with and without offshore wind



Importantly, this price suppression effect impacts the price for *all* electricity purchased in the wholesale market when wind is generating, not only for the amount of electricity produced by wind resources. Because the impact is felt over the total quantity of energy purchased in the wholesale market, even a small change in wholesale price can result in substantial reductions in retail costs for customers.

3.2. Methodology for modeling offshore wind benefits

With the addition of considerable new offshore wind generation in the coming years, we can expect significant reductions in wholesale electricity market clearing prices due to price suppression effects. Massachusetts, Connecticut, and Rhode Island have set offshore wind procurement targets totaling between 8,630 and 9,030 MW by 2030.[6] In addition, Maine recently set a target of 3,000 MW by 2040, with the first request for proposals to be issued by January 2026.[7] If these targets are met, New England could have more than 9,000 MW of offshore wind capacity by the end of the decade.

To estimate the price suppression effect of new offshore wind, we developed a model to simulate the impact of adding 9,000 MW of offshore wind by 2030. The wholesale market clearing price is primarily a function of electricity demand and the natural gas fuel prices used by power plants (since natural gas power plants are usually the marginal unit in New England). Adding a renewable resource to the supply curve can therefore be modeled as a reduction in the demand curve – the result is the same. This allows us to leverage the relationship between electricity prices and demand to forecast the price impact of

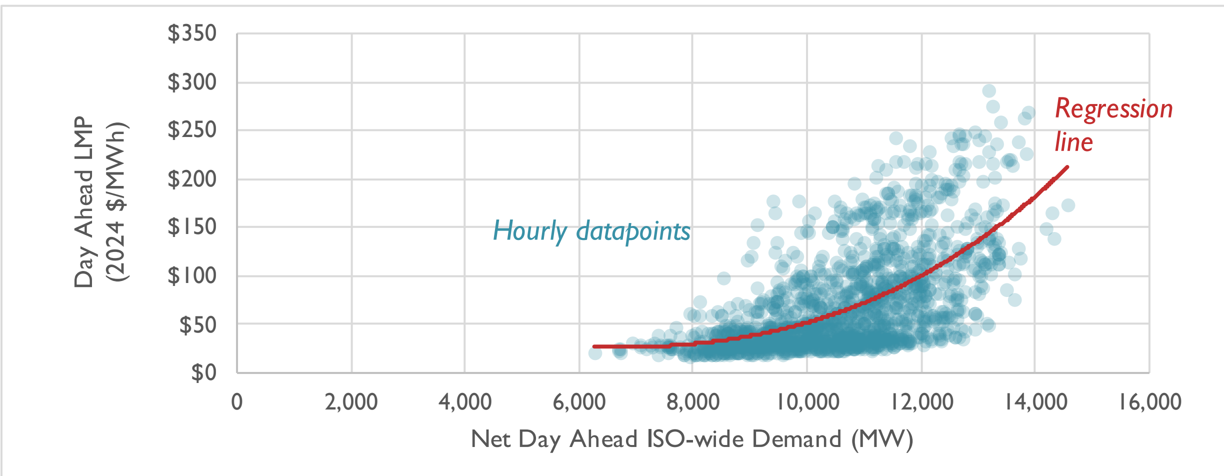
[6] Connecticut's Public Act 19-71 calls for the procurement of 2,000 MW of offshore wind; Massachusetts' bill H. 5060 requires the procurement of 5,600 MW of offshore wind, and Rhode Island's S 2583 increases required procurements by an additional 600 MW to a total of 1,030 MW.

[7] Maine LD 1895.

offshore wind for each hour. In New England, the spot price of natural gas fuel is primarily a function of temperature, since cold weather increases the demand for heating.[8] To capture this relationship, we conducted regression analyses to derive a relationship between daily average temperatures and expected spot prices for natural gas.

Next, we conducted regression analyses using historical data to determine the relationship between natural gas prices, electricity demand, and resulting electricity prices. The regression analysis produces an equation that captures the impact that changes in electricity prices and natural gas prices have on electricity market clearing prices. Figure 4 illustrates actual wholesale market electricity prices (in blue) as a function of electricity demand. The red line shows the predicted prices derived from our regression equation for one illustrative region.[9]

Figure 4. Illustration of the relationship between electricity demand and electricity prices



Source: Reproduced from figure 55 in Synapse's AESC 2024 Study, available at https://www.synapse-energy.com/sites/default/files/inline-images/AESC%202024.pdf.
Note: "Day Ahead LMP" refers to the hourly locational marginal price as it is determined in ISO New England's day-ahead wholesale energy market.

Since weather (particularly temperature) can vary year to year, we relied on weather data published by ISO New England for 23 historical data years to capture a wide range of potential natural gas market prices and forecasted electricity market clearing prices.

[8] See, for example, U.S. Energy Information Administration. *Northeast natural gas spot prices particularly sensitive to temperature swings*. August 11, 2014. Available at: https://www.eia.gov/todayinenergy/detail.php?id=17491.

[9] For the purposes of this figure, the natural gas price is held constant.

After modeling hourly market clearing prices for all 23 historical weather years without offshore wind, we modeled the impact of adding 9,000 MW of offshore wind to the supply stack.[10] Using the weather year 2022, we find that 9,000 MW of offshore wind interconnecting to the New England grid would generate 38,000 GWh,[11] roughly 30 percent of current annual New England electric demand.[12]

Our analysis leveraged forecasts of hourly offshore wind electricity generation produced for ISO New England by the consulting firm DNV-GL.[13] This data set models hourly generation for future offshore wind plants in the Bureau of Ocean Energy Management lease area (off the coast of Massachusetts and Rhode Island). The model assumes wind turbine hub heights ranging from 119 meters to 150 meters and uses offshore wind power curves coupled with historical weather data (for the years 2000 to 2022) to model the hourly electricity that would be produced at each site.[14]

The modeled offshore wind data show that the capacity factor for offshore wind is highest during the coldest months, with an average capacity factor between 55 percent and 60 percent during the winter.[15] Figure 5 shows how the monthly average capacity factor varies across weather years. The blue bars show the range of average monthly offshore wind capacity factors for modeled weather years 2000 to 2022, with the diamond indicating the average across all modeled years. As shown in the figure, average monthly offshore wind capacity factors exceed 45 percent in all winter months modeled, at times even exceeding 70 percent. This means that offshore wind is well-positioned to provide electricity to the grid when natural gas supply constraints are greatest.

[10] For the purposes of this analysis, we focused only on the impacts that offshore wind would have on recent historical years, and did not account for future changes to electricity demand, resource additions (such as new solar resources), or resource retirements.

[11] One gigawatt-hour (GWh) of electricity can power about one million homes for one hour. This assumes a typical household consumes around 10,000 kilowatt-hours (kWh) of electricity per year, so a GWh is equal to one million kWh. A 1 GW offshore wind project could power approximately 876,000 households for one year if they collectively consume 10,000 kWh each.

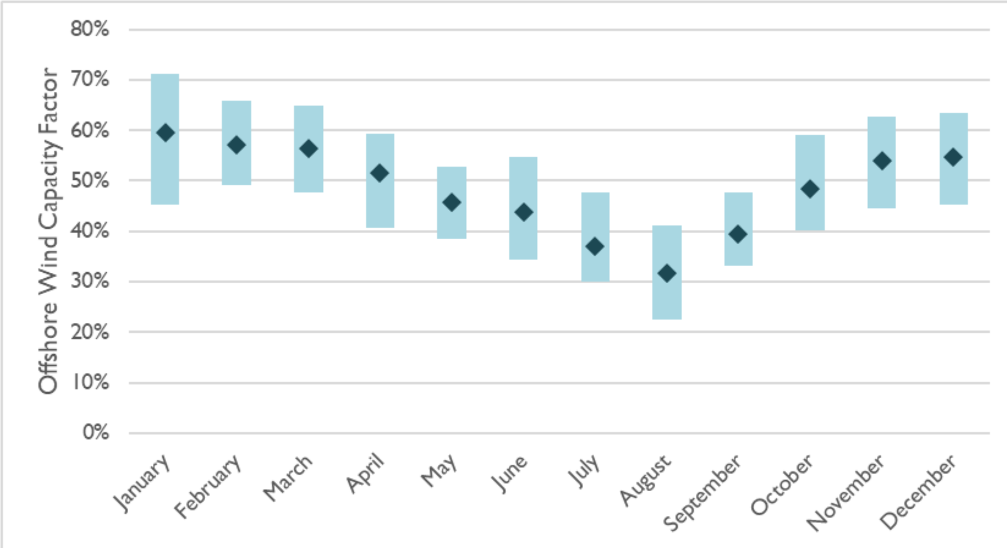
[12] For comparison, in 2023, natural gas-fired generation produced 55,579 GWh of electricity to serve load in New England consuming 387 billion cubic feet of natural gas in the process.

[13] ISO New England. Variable Energy Resource (VER) Data for weather years 2000-2022. https://www.iso-ne.com/system-planning/planning-models-and-data/variable-energy-resource-data

[14] DNV-GL modeled a total of 12,124 MW of offshore wind generation in the Bureau of Ocean Energy Management (BOEM) lease area. The analysis assumed minimum turbine spacing of 1 nautical mile and hub heights ranging from 119 meters to 150 meters and confidential power curves coupled with historical weather data adjusted using LiDAR measurements from the BOEM lease area. The power model captures turbine and wind plant wake interactions. DNV-GL. *Wind and Power Time Series Modeling of ISO-NE Wind Plants: Methodology and Analysis of Results*. Planning Advisory Committee. February 20, 2020. Available at https://www.iso-ne.com/static-assets/documents/2020/02/a7b_wind_power_time_series_dnvgl.pdf

[15] ISO-New England. Variable Energy Resource (VER) Data for weather years 2000-2022. https://www.iso-ne.com/system-planning/planning-models-and-data/variable-energy-resource-data

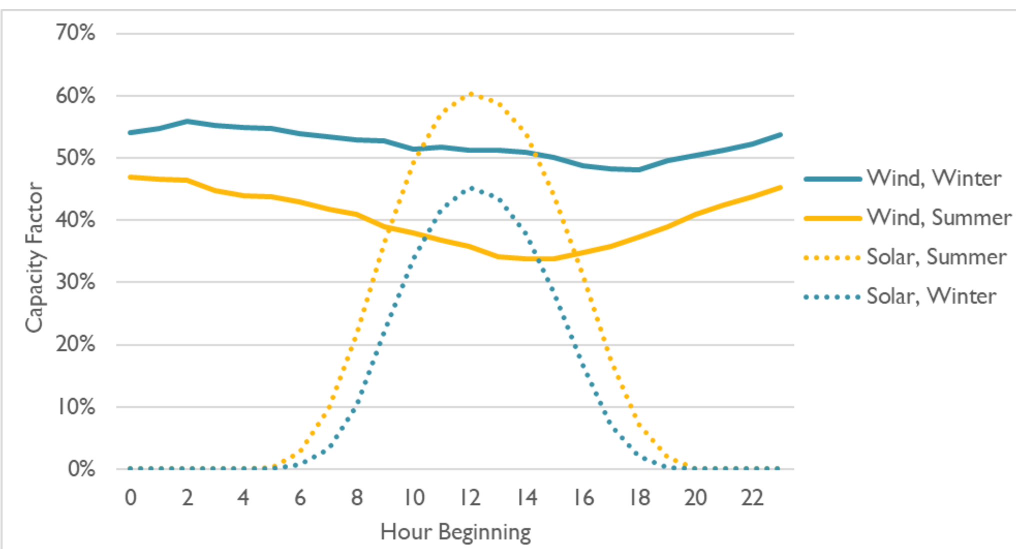
Figure 5. Range of monthly offshore wind capacity factors for New England



Source: ISO-New England Variable Energy Resource dataset for weather years 2000-2022.

Furthermore, the times of day that offshore wind generation is typically highest are complementary to the generation profile of solar resources. Figure 6 shows how offshore wind output is often higher in the evenings and early mornings, making this resource well-suited to provide energy in hours when solar generation is low.[16]

Figure 6. Hourly offshore wind and solar capacity factors for New England by season



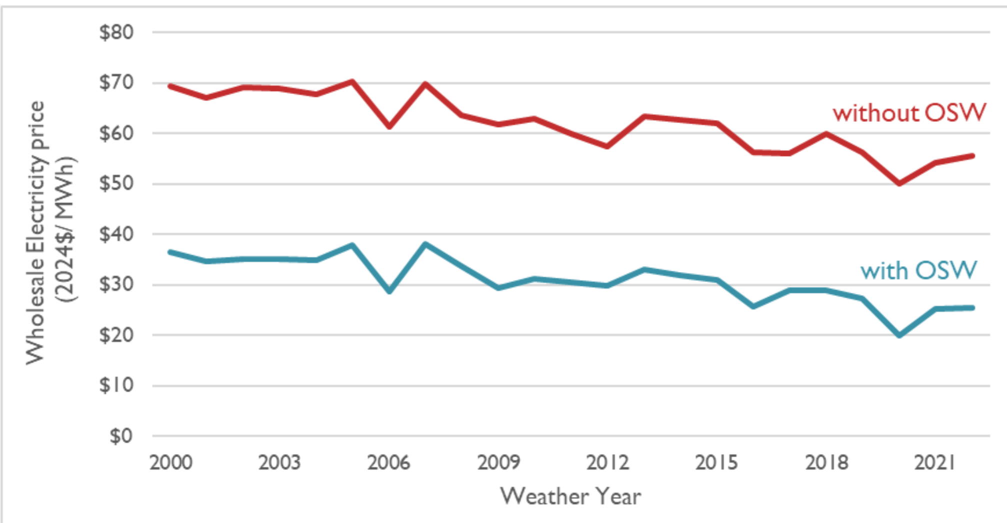
Source: ISO-New England Variable Energy Resource dataset for weather years 2000-2022.

[16] ISO-New England Variable Energy Resource dataset. Offshore wind values are modeled for historical weather years 2000-2022, while solar values are based on a stochastic time series analysis.

3.3. Customer bill impacts

The results of our modeling indicate that adding 9,000 MW of offshore wind by 2030 will substantially shift the electricity market supply curve. Figure 7 shows how this amount of offshore wind would reduce market clearing prices by an average of $31 per MWh, or about 50 percent in 2030, assuming the Annual Energy Outlook's Reference case natural gas prices.[17] The magnitude of the price reductions varies based on the underlying weather patterns assumed by the model. Over the 23 historical weather years used in this analysis, the annual weighted average reduction in wholesale electricity market prices ranges from 45 percent to 60 percent.

Figure 7. Annual modeled wholesale electricity prices for New England with and without 9 GW of offshore wind (OSW)



Because offshore wind is purchased outside of the electricity market (typically through long-term power purchase agreements, or PPAs), the cost of these contracts must be factored into the analysis to estimate the net impact on electricity customer bills.[18] In recent years, the cost of these contracts has increased significantly from pre-pandemic levels due to supply chain disruptions, commodity price increases, and inflation, although these pressures are expected to ease by 2026.[19] To estimate the cost of procuring 9,000 MW of offshore wind by 2030, we took a weighted average of existing New England

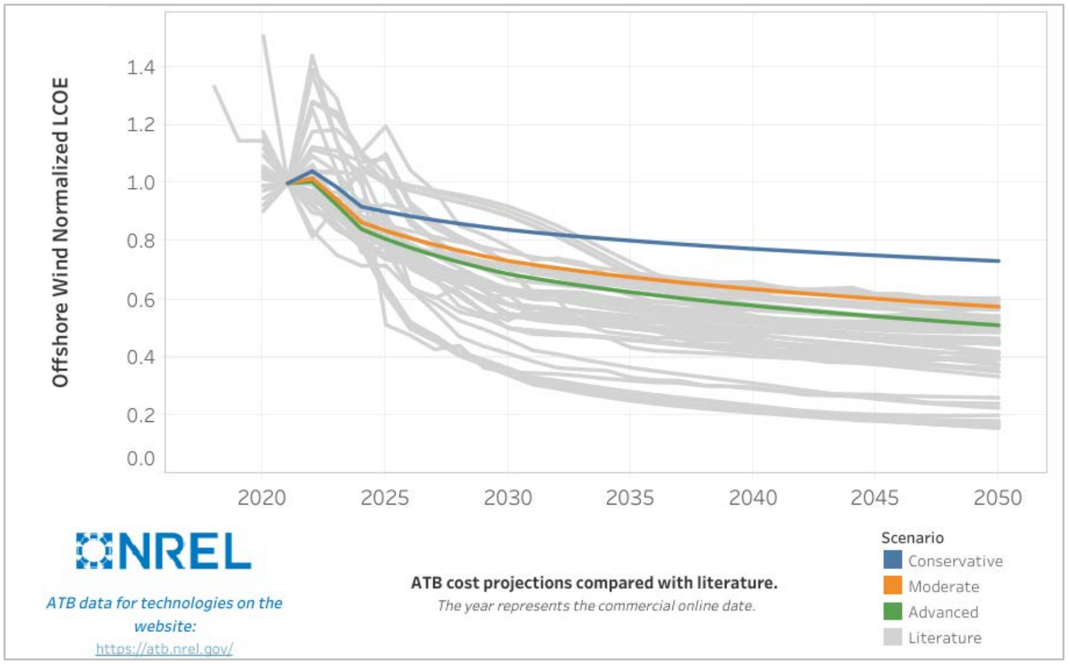
[17] U.S. Energy Information Administration. *Annual Energy Outlook.* 2023. Available at: https://www.eia.gov/outlooks/aeo/

[18] We accounted for the estimated value of the renewable energy certificates (RECs) when calculating the net costs of these contracts, as the PPAs include the rights to the RECs, which reduces the need to purchase these RECs elsewhere. We assumed a REC cost of $19 per MWh (2024 dollars), based on REC costs calculated in Synapse's 2024 Avoided Energy Supply Costs study for New England, available at: https://www.synapse-energy.com/aesc-2024-materials.

[19] DiGangi, Diana. *Wind turbine market improves, but higher costs may linger in 2024: BNEF*. Utility Dive. December 21, 2023. Available at: https://www.utilitydive.com/news/offshore-wind-turbine-market-cost-developers-china/703256/

offshore wind contracts[20] and newly-announced offshore wind contracts in New York.[21] To be conservative, we assumed that the cost of additional offshore wind procurements will reflect the more recent, higher contract costs of $150.15 per MWh, even though industry experts expect that offshore wind costs will decline in the future,[22] as shown in the figure below.[23]

Figure 8. Range of projected offshore wind costs



Source: National Renewable Energy Laboratory. 2023 Annual Technology Baseline, July 15, 2023.

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[20] Electricity from Revolution Wind (704 MW) is contracted to be sold to Connecticut and Rhode Island at fixed nominal prices of $99.50 and $98.43 per MWh. Crowley, Brendan. *Revolution Wind Wins Approval for 100 Turbines Off Rhode Island*. CT Examiner. July 18, 2023. Available at https://ctexaminer.com/2023/07/18/revolution-wind-wins-approval-for-100-turbines-off-rhode-island/. For 2030, this translates into costs of $87.05 and $86.12 in real 2024 dollars, assuming an annual inflation rate of 2.5 percent.

Prices for Vineyard Wind Facility 1 (400 MW) and Facility 2 (400 MW) were obtained from Hines, Eric and Barbara Kates-Garnick. (2022). U.S. Offshore Wind Prices (2018-2021). OSPRE-2022-01. Tufts University. https://doi.org/10.60965/wf48-tb73. Vineyard Wind PPA prices contain an annual escalation factor. The 2030 nominal prices for Facility 1 and Facility 2 are $75.38 to $87.96/MWh, respectively. For 2030, these prices translate to $65.95 and $76.96 in real 2024 dollars assuming an annual inflation rate of 2.5 percent.

[21] NYSERDA reports that the weighted average strike price for NYSERDA's fourth offshore wind solicitation was $150.15/MWh (nominal). NYSERDA. New York State Offshore Wind: Fourth Solicitation Award and Program Update. March 19, 2024. Available at https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Programs/Offshore-Wind/2024-03-19-NYSERDA-NY4-Awards-Public-Webinar.pdf

[22] U.S. Department of Energy. Offshore Wind Market Report: 2023 Edition. May 31, 2023. Available at: https://www.energy.gov/sites/default/files/2023-09/doe-offshore-wind-market-report-2023-edition.pdf; National Renewable Energy Laboratory. 2023 Annual Technology Baseline for offshore wind costs. Updated July 15, 2023. Available at: https://atb.nrel.gov/electricity/2023/offshore_wind.

[23] National Renewable Energy Laboratory. 2023 Annual Technology Baseline for offshore wind costs. Updated July 15, 2023. Available at: https://atb.nrel.gov/electricity/2023/offshore_wind.

After factoring in the costs of offshore wind contracts, our modeling results show net annual electricity cost savings for the region averaging $630 million, with net savings in some years surpassing $1.3 billion under a mid-case natural gas price. If natural gas prices increase, the savings would also increase. In addition, we observe net benefits in 19 of the 23 weather years modeled, suggesting that offshore wind can provide bill savings in every four out of five years, on average.

Using a high natural gas price forecast for 2030 (based on the gas price in the 2023 Annual Energy Outlook's Low oil and gas supply case), we estimate that the average annual savings to electricity customers would exceed $1 billion, with savings in some years exceeding $1.7 billion. Under the high gas price case, we find that positive net benefits in all but one of the 23 weather years analyzed.

These results equate to average monthly residential bill reductions of approximately $2.79 under a reference-case gas scenario, and approximately $4.61 per month under a high gas price scenario.[24]

In addition to these customer bill reductions, integrating 9,000 MW of offshore wind into the New England grid would reduce expenditures on natural gas for electricity generation by half. Specifically, under a mid-case gas price, New England would retain approximately $1.57 billion that would have otherwise flowed out of the region for natural gas fuel.

It is important to highlight that, under the long-term contracts being pursued by New England states, the costs to construct offshore wind projects are covered by the wind project developers and recovered through the contract price only after the wind project begins delivering energy to the grid. The contract price typically also includes the cost for the wind energy to be delivered to an agreed-upon location on the grid. This means that customers do not pay additional costs for transporting the energy from the wind farm to the grid, and there is no impact on customer bills until the wind projects begin generating energy. In addition, once offshore wind begins generating and offering its generation into the wholesale energy market, the market price suppression benefit occurs immediately. Thus, the timing of the benefits and costs of wind contracts are well-aligned.

4. Benefits from Avoided Emissions

Adding 9,000 MW of offshore wind would have substantial benefits for the environment and New England residents' health. The electricity from the new offshore wind would avoid 238 trillion Btu of natural gas burn in 2030, equivalent to all the natural gas delivered to natural gas-fired power plants operating in Connecticut and Massachusetts in an average year. The environmental benefits would be substantial: in both 2021 and 2022, as the New England power grid emitted roughly 33 million short tons of CO_2 and by avoiding 238 trillion Btu of natural gas burn, 9 GW of offshore wind would avoid 14

[24] According to the most recent EIA 861 data, residential customers in New England consume approximately 581 kWh per month.

million short tons of CO_2 emissions annually. Using a 2 percent discount rate, this represents a social cost of carbon value of $3.5 billion.[25]

In addition, offshore wind reduces the emission of criteria pollutants, which pose public health risks. We used the U.S. Environmental Protection Agency's (EPA) AVoided Emissions and geneRation Tool (AVERT) to model reductions in various emissions from changes in electricity power plant dispatch patterns.[26] We found that adding 9,000 MW of additional offshore wind would result in avoided emissions from the New England power grid of 2,300 tons of NO_X, 824 tons of SO_2, and 641 tons of $PM_{2.5}$ emissions each year. We then quantified the value of these avoided emissions in terms of regional health benefits using EPA's Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA).[27] COBRA uses county-level inputs on changes in criteria pollutants to estimate impacts on public health, including morbidity and monetized health effects. These reductions in criteria pollutants represent an annual public health benefit of approximately $362 million.

5. CONCLUSIONS

Our modeling indicates that offshore wind can provide substantial customer, environmental, climate, and public health benefits to New England while also acting as a hedge against natural gas price volatility. Reductions in regional wholesale market prices and avoided purchases of renewable energy certificates more than offset the cost of recent wind contracts under current gas price forecasts, and those benefits are even larger when a higher gas price sensitivity is considered. Further, unlike increased investments in gas and gas pipeline infrastructure, offshore wind helps to comply with the region's climate mandates and provides myriad public health benefits by reducing emissions from the combustion of natural gas, oil, and other fossil fuels for electricity.

[25] The U.S. Environmental Protection Agency's 2023 social cost of CO_2 using a 2% discount rate is approximately $200 per metric ton. *See: Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances*. November 2023. Available at https://www.epa.gov/environmental-economics/scghg.

[26] AVERT's uses hourly data from U.S. EPA's Air Markets Program Data (AMPD) and National Emissions Inventory to perform statistical analysis on actual behavior of past generation, heat input $PM_{2.5}$, SO_2, NO_x, CO_2, VOCs, and NH_3 emissions data given various regional demand levels. AVERT is available at https://www.epa.gov/avert.

[27] U.S. EPA's COBRA tool is available at https://cobra.epa.gov/.