The Vineyard Wind Power Purchase Agreement: Insights for Estimating Costs of U.S. Offshore Wind Projects

Philipp Beiter, Paul Spitsen, Walter Musial, and Eric Lantz

National Renewable Energy Laboratory

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List of Acronyms and Abbreviations

AEP	annual energy production
CapEx	capital expenditures
DOE	U.S. Department of Energy
DOER	Massachusetts Department of Energy Resources
EDCs	electric distribution companies
EF	escalation factor
ITC	investment tax credit
LCOE	levelized cost of energy
LROE	levelized revenue of energy
MW	megawatt
MWh	megawatt-hour
NREL	National Renewable Energy Laboratory
OREC	offshore renewable energy credit
PPA	power purchase agreement
PV	present value
REC	renewable energy credit
UCAP	unforced capacity
WACC	weighted average cost of capital

Executive Summary

This report analyzes the power purchase agreements (PPAs) between Massachusetts electric distribution companies (EDCs) and Vineyard Wind LLC filed on July 31, 2018. The analysis is intended to derive insights for estimating cost of U.S. offshore wind systems and to inform broader cost modeling activities. The documented first-year price for delivery of offshore wind generation and renewable energy certificates under the Vineyard Wind/EDC PPA is $74/megawatt-hour (MWh) (2022$) for facility 1 (400 megawatts [MW]) and $65/MWh (2023$) for facility 2 (400 MW). This first-year PPA price, however, does not reflect the entire 20-year PPA price schedule or the complete set of expected revenue sources and tax benefits available to the Vineyard Wind LLC project. An extensive accounting of the PPA price schedule and expected revenue sources inclusive of those that are exogenous to the reported PPA is conducted in this study to estimate the project's levelized revenue of energy (LROE). This allows for a more equivalent comparison of the reported PPA pricing with bottom-up modeled (unsubsidized) levelized cost of energy (LCOE) estimates. The reader should note that this analysis solely reflects the opinions of the authors and was conducted independently of the ongoing evaluation by the Massachusetts Department of Energy Resources of the PPA between Vineyard Wind LLC and Massachusetts electric distribution companies as filed on July 31, 2018. The analysis and conclusions described herein do not reflect actual cost data, which are confidential to Vineyard Wind and its partners.

The total calculated LROE from the Vineyard LLC/EDC PPA is estimated to be $98/MWh (2018$). This LROE estimate for the first commercial-scale offshore wind project in the United States appears to be within the range of LROE estimated for offshore wind projects recently tendered in Northern Europe with a start of commercial operation by the early 2020s. This suggests that the expected cost and risk premium for the initial set of U.S. offshore wind projects might be less pronounced than anticipated by many industry observers and analysts.

A series of adjustments were made to convert the Vineyard Wind/EDC PPA price point to LROE. The adjustments to Vineyard Wind/EDC's price point account for investment tax credit benefits to the project and expected revenue sources outside of the PPA, such as revenue from the ISO-NE Forward Capacity Market. The report also explores several sensitivity cases and broadly discusses the Vineyard Wind price point in context of other offshore wind cost analyses. The assumptions made in this report about the PPA contract pricing should be further validated as more information about the Vineyard Wind project becomes available. The calculations in this report also reflect a first-order deterministic scenario that does not capture the inherent uncertainty of many of the parameters considered (e.g., future revenue from wholesale and capacity markets).

Table of Contents

Acknowledgments iii
1 Introduction 1
2 Analysis of the Vineyard Wind PPA and Estimated Levelized Revenue of Energy 3
3 Sensitivity Analysis 9
4 Discussion and Conclusions 11
References 14
Appendix A 17
A-1. Levelized Cost of Energy and Levelized Revenue of Energy Equations 17
Levelized Cost of Energy (LCOE) 17
Levelized Revenue of Energy (LROE) 17
Annual Energy Production (AEP) 17
A-2. Financing Assumptions 18
Appendix B 19
B-1. Vineyard Wind/Electric Distribution Companies Power Purchase Agreement Price Schedule 19

List of Figures

Figure 1. Sensitivity analysis of LROE to variations in ITC, capacity payment, WACC, AEP degradation, and 5-year merchant revenue. 10
Figure 2. Adjusted prices from European offshore wind auctions including the Vineyard Wind project. 12

List of Tables

Table 1. Vineyard Wind LLC/EDC PPA Contract Terms and Project Information 3
Table 2. Analysis Steps to Calculate LROE from the Vineyard Wind Power Purchase Agreement ... 7
Table 3. ITC Phase-Down Rate Schedule 8
Table A-1. Financing Assumptions for Weighted Average Cost of Capital under consideration of the ITC election 18
Table A-2. PPA Price Schedule 19

1 Introduction

The pace of offshore wind capacity procurement in the United States accelerated during 2017-2018 with four projects being awarded offshore wind renewable energy certificates (US Wind Maryland project, Deepwater Wind[1] Skipjack project) or a power purchase agreement (PPA) (Deepwater Wind South Fork project) (Beiter et al. 2018b). In Massachusetts, electric distribution companies (EDCs) entered into PPAs[2] for offshore wind generation and renewable energy certificates with Vineyard Wind LLC (hereafter referred to as "Vineyard Wind/EDC PPA") for a total capacity of 800 megawatts (MW) on July 31, 2018. This report provides a first-order assessment of this long-term contract to contextualize the Vineyard Wind/EDC PPA pricing point, interpret it in terms of levelized revenue of energy (LROE), and generate insights and validation for bottom-up cost modeling, including ongoing analysis efforts at the National Renewable Energy Laboratory (NREL).

The first-year PPA price for delivery of offshore wind generation and renewable energy certificates for the Vineyard Wind LLC project is $74/megawatt-hours (MWh) ($2022)[3] for facility 1 (400 MW) and $65/MWh ($2023) for facility 2 (400 MW). The PPA (and first-year PPA price), however, does not reflect the entire 20-year price schedule or the complete set of expected revenue sources and tax benefits available to the Vineyard Wind LLC project. An extensive accounting of the 20-year price schedule and expected revenue sources and tax benefits inclusive of those that are exogenous to the PPA is conducted in this study to estimate the project's LROE. This metric allows for a more accurate comparison with (unsubsidized) bottom-up levelized cost of energy (LCOE) estimates than comparing with the PPA price alone. The reader should note that this analysis solely reflects the opinions of the authors and was conducted independently of the ongoing evaluation by the Massachusetts Department of Energy Resources (DOER) of the PPA between Vineyard Wind LLC and Massachusetts electric distribution companies as filed on July 31, 2018. As such, the analysis and conclusions described herein do not in any way reflect actual cost data, which are confidential to Vineyard Wind LLC and its partners.

The long-term contractual agreement between Vineyard Wind LLC and Massachusetts EDCs was made against the backdrop of declining pricing in recent European offshore wind tenders and past offshore wind awards that were made in the United States. The first PPA in the United States was signed in 2010 for the 30-MW Block Island Wind Farm between Deepwater Wind and National Grid. The contract duration is 20 years, with a starting price of $244/MWh and a 3.5% annual escalation factor. Subsequent commercial projects include the 90-MW South Fork project (reported PPA price of $160/MWh with the Long Island Power Authority), the 120-MW Skipjack project (Maryland offshore renewable energy credit [OREC] of $132/MWh), and the

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[1] Deepwater Wind was acquired by Ørsted on October 8, 2018.

[2] Separate (but identical in its content) PPAs for facility 1 and facility 2 were filed for approval by the Massachusetts Department of Public Utilities pursuant to Section 83C of an Act Relative to Green Communities between Vineyard Wind LLC and NSTAR Electricity Company (d/b/a Eversource Energy), Massachusetts Electric Company and Nantucket Electric Company (d/b/a National Grid), and Fitchburg Gas and Electric Light Company (d/b/a Unitil) (D.P.U. docket number 18-76/18-77/18-78).

[3] All dollars are reported in $2018, unless indicated otherwise.

248-MW US Wind project (Maryland OREC of $132/MWh).[4] European tender strike prices for large-scale commercial projects commencing commercial operation in the early- to mid-2020s fall between $76/MWh and $88/MWh, after adding export-system transmission costs and adjusting for the same contract length. LCOE estimates for projects in the northeastern United States commencing operations in the same period ranged from approximately $120/MWh to $160/MWh (see e.g., Beiter et al. 2017; Kempton, McClellan, and Ozkan 2016; Harries 2018; NREL 2018).

Section 2 provides context for the PPA between Vineyard Wind LLC and Massachusetts EDCs and estimates the project's LROE. Section 3 presents a limited set of sensitivities. Section 4 provides conclusions and discusses the Vineyard Wind project price point in the context of offshore wind cost reduction estimates.

[4] Note that any of these projects may capitalize on the federal investment tax credit if they can commence physical work of a significant nature on the facility or by incurring at least 5% of the total cost of the facility under the timeline prescribed by the ITC (see Section 2 for further discussion).

2 Analysis of the Vineyard Wind PPA and Estimated Levelized Revenue of Energy

As required by Chapter 188 of the Acts of 2016 "Section 83C Offshore Wind Generation," the DOER issued a competitive solicitation for offshore wind generation on June 29, 2017 (DOER 2017). Vineyard Wind LLC was selected by DOER to enter into negotiations with Massachusetts EDCs for a long-term generation contract on May 23, 2018. On July 31, 2018, Vineyard Wind LLC and the Massachusetts EDCs submitted a 20-year PPA for 800 MW of offshore wind generation and renewable energy certificates to the Massachusetts Department of Public Utilities for review and approval. The Vineyard Wind/EDC PPA establishes a contract for procurement of electricity from two 400-MW facilities that enter commercial operation in 2022 (facility 1) and 2023 (facility 2), respectively, at a specified pricing schedule (Massachusetts Department of Public Utilities 2018a, 2018b).

Key parameters of the Vineyard Wind/EDC PPA, including the first-year PPA price, and project filings from Vineyard Wind's Draft Environmental Impact Assessment (Vineyard Wind 2018a), construction operation plan (Vineyard Wind 2018b), and the independent evaluator report (Peregrine Energy 2018) are shown in Table 1.

Table 1. Vineyard Wind LLC/EDC PPA Contract Terms and Project Information

Vineyard Wind LLC/EDC PPA Contract Terms[5]				
	PPA 1	**PPA 2**	**Notes**	**Source**
Capacity (MW)	400	400	N/A	a, b
Commercial operation date	January 15, 2022	January 15, 2023	N/A	a, b
Delivered product	Energy and RECs		N/A	a, b
First-year PPA price ($\$_{nominal}$/MWh)	74 $\$_{2022}$/MWh	65 $\$_{2023}$/MWh	N/A	a, b
PPA duration (years)	20		N/A	a, b
Escalation factor (%)	2.5		N/A	a, b
Vineyard Wind LLC Project Filings				
Wind speed (meters per second)	9.3		Simple average of the entire Vineyard Wind lease area	c
Net capacity factor (%)	45		Average capacity factor reported by Vineyard Winds; assumed to be net capacity factor (not clear from Peregrine Energy [2018])	d
Average water depth (meters [m])	42		The construction and operation plan indicates water depths in the northern half of the lease area range from 35 m to 49 m; 42 m is the simple average	d
Substructure type	Monopiles		Vineyard Wind has indicated that it prefers to use monopiles but could deploy jackets for up to 400 MW of capacity depending on seafloor conditions	d

[5] These terms are derived from the PPA contract between NSTAR ELECTRIC COMPANY d/b/a EVERSOURCE ENERGY and Vineyard Wind LLC; similar contract terms apply to the other EDC parties that have separate contracts with Vineyard Wind LLC.

Vineyard Wind LLC Project Filings				
Turbine rating (MW)	8		Turbine rating will range between 8 MW and 10 MW[6]	d
Export cable length (kilometers) [km]	69.2		Generator lead line proposal selected by Buyer (Vineyard Wind LLC procures all cables from turbine to point of interconnection); point of cable landfall: New Hampshire Ave	e
Onshore cable length (km)	9.65		Generator lead line proposal selected by Buyer (Vineyard Wind LLC procures all cables from turbine to point of interconnection); interconnection point: Barnstable	e
Operation and maintenance port distance (km)	60		Operation and maintenance port: Vineyard Haven	d
Installation port distance (km)	92		Installation port: New Bedford Commerce Terminal	d
Investment tax credit (ITC) (%)	18	18	Assumes safe harbor provision through expense of 5% of the overall project cost by the end of 2018; according to National Grid, Vineyard Wind LLC "intends to qualify all 800 MW for the 18% ITC […] by treat[ing] all 800 MW as a single project." (Peregrine Energy 2018)	f
Note: "Buyer" refers to Massachusetts EDCs; "seller" refers to Vineyard Wind LLC.				

[a] Massachusetts Department of Public Utilities (2018a)
[b] Massachusetts Department of Public Utilities (2018b)
[c] Musial et al. (2017)
[d] Vineyard Wind (2018b)
[e] Vineyard Wind (2018a)
[f] Peregrine Energy (2018).

In this analysis, Vineyard Wind LLC's estimated LROE is used as a proxy metric for the project's levelized cost of energy LCOE (see Appendix A for general equations) because cost data from the company are not publicly available. In previous offshore wind cost analyses conducted by NREL (e.g., Beiter et al. 2017, 2016; Musial et al. 2016), LCOE was estimated without consideration for tax incentives such as the investment tax credit (ITC) or the production tax credit (PTC) but inclusive of benefits from accelerated depreciation (e.g., the Modified Accelerated Cost Recovery System [MACRS]). The LROE represents an estimate of the discounted revenue of a project during its lifetime, presented in levelized ($/MWh) terms.[7] In a perfectly competitive electricity market, the LROE can be expected to approximate the LCOE because the sum of project revenues (i.e., the LROE) needs to meet total project expenditures

[6] Note that on November 27, 2018, Vineyard Wind LLC named MHI Vestas as the preferred turbine supplier with the intent to procure the V164-9.5 MW turbine (MHI Vestas 2018).
[7] The LCOE also can be thought of in revenue terms. The LCOE is the *revenue required per unit of energy* to cover all expenditures and to meet a rate of return on investment. Conversely, LROE captures the *revenue available per unit of energy* (e.g., under a contract regime and market structure). In this analysis, LROE also includes the value from tax benefits (such as the ITC, for example) for comparison with unsubsidized LCOE.

(i.e., the LCOE) (both inclusive of a rate of return) over the lifetime of the project.[8] To enable direct comparison with (unsubsidized) LCOE estimates, an extensive first-order accounting of revenue sources and financial adjustments was conducted. Beyond the compensation for provision of energy and renewable energy certificates (RECs) as documented in the Massachusetts Department of Public Utilities (2018a and 2018b), the project is expected to generate value and revenue from tax benefits and the ISO-NE Forward-Capacity market. These value and revenue sources are exogenous to the documented PPA price. The value from accelerated depreciation (e.g., under the MACRS schedule) is not considered for estimating the LROE in this analysis because it is commonly already accounted for in the LCOE (Beiter et al. 2016; Musial et al. 2016).

To estimate LROE for the Vineyard Wind LLC project, the following steps were implemented in a simplified cash-flow model[9] (Table 2):

- **Step 0 ("*First-year PPA price*")** represents the negotiated Vineyard Wind LLC/EDC first-year PPA price for facility 1 (400 MW) and facility 2 (400 MW) from the PPA price schedule (Massachusetts Department of Public Utilities 2018a, 2018b).

- **Step 1 (*"Revenue from electricity and REC sales"*)** calculates the present value (PV) (in 2021 and 2022) of the products delivered under the PPA, electricity, and RECs using the PPA price schedule (Appendix B) and a simplified cash-flow model representation with a discount rate of 7%, equal to the estimated weighted average cost of capital (WACC) (see Appendix A-2 for "mid" case WACC assumptions):

$$PV\ of\ PPA\ revenue\ \left(\frac{\$}{MWh}\right) = \left(\sum_{t=1}^{T=20} \frac{(Electricity\ Price_t + REC\ price_t) \times AEP}{(1+WACC)^t}\right) \times \frac{1}{\sum_{t=1}^{T=20} \frac{AEP}{(1+WACC)^t}} \quad (1)$$

where

$Electricity\ Price_t$: *According to PPA pricing schedule*
$REC\ Price_t$: *According to PPA pricing schedule*
$WACC\ (nominal) = 7.0\%$
$Annual\ energy\ production = 8{,}760h \times 45\% \times 400\ MW$ (see Table 1)

This step yields a starting LROE of $89/MWh ($2021) for facility 1 and $79/MWh ($2022) for facility 2.

- **Step 2 (*"Value of the ITC"*)** accounts for the project's reported intent to utilize the 18% federal ITC.[10] This ITC rate could be leveraged by the project if it commences "physical

[8] Note that the negotiated price schedule in the Vineyard Wind PPA provides revenue certainty to the project, which has become less common among recently tendered offshore wind projects in Europe, which increasingly face higher merchant price risk (Beiter et al. 2018).
[9] For simplification purposes, end-of-year cash flows were assumed in this study (versus e.g., mid-year cash flows).
[10] Election of the ITC requires a reduction of the eligible (depreciable) cost basis for the MACRS equal to 50% of the value of the tax credit (Schwabe et al. 2017). Given the broader monetization uncertainties analyzed in this report, the impact from a reduction in the MACRS cost basis was not considered.

work of a significant nature" on the facility or by incurring at least 5% of the total cost of the facility before January 1, 2019 (Deloitte 2017). The value of the ITC for the Vineyard Wind LLC/EDC PPA at t=0 is calculated by:

$$ITC\ value\ \left(\frac{\$}{MWh}\right)_{t=0} = \frac{ITC\ rate \times CapEx \times Capacity}{\sum_{t=1}^{T=20} \frac{AEP}{(1+WACC)^t}} \tag{2}$$

where
$ITC = 18\%$ (see Table 1)
$Capital\ expenditures = \$3{,}500/kW$
$Capacity = 400\ MW$
$AEP = 8{,}760h\ \times\ 45\% \times\ 400\ MW$ (see Table 1)
$WACC = 7\%$

The capital expenditures (CapEx) of $3,500/kilowatt (kW) was sourced from Bloomberg New Energy Finance (2018) for the prevailing average CapEx for offshore wind projects in Europe.[11] A nominal WACC of 7% was assumed as the discount rate, which reflects current offshore wind financing conditions and a debt-to-equity ratio that is amendable to leveraging tax incentives (i.e., the ITC) (Appendix A-2, Table A-1). The incremental value of the ITC was estimated to be approximately $15/MWh.

- **Step 3 (*"Revenue from the sale of capacity"*)** adds potential project revenue from participation of the Vineyard Wind LLC project in ISO-New England's Forward Capacity Market. The sale of capacity rights for the project's own account without revenue crediting to Massachusetts EDCs is permitted under the PPA (Massachusetts Department of Public Utilities 2018a, 2018b) (i.e., revenue is exogenous to the PPA price schedule). Revenue from the sale of capacity was estimated by:

$$PV\ of\ capacity\ revenue\ \left(\frac{\$}{MWh}\right) = \sum_{t=1}^{T=20} \frac{Capacity\ payment_t \times (1+EF)^t \times UCAP\ \times Capacity}{(1+WACC)^t} \tag{3}$$

where
$Capacity\ payment = \$5/kW - month = \$60{,}000/MW - year$
$Escalation\ factor\ (EF) = 2.5\%$ (consistent with Vineyard Wind/EDC PPA escalation factor)
$WACC = 7\%$
$Unforced\ capacity\ (UCAP) = 38\%$
$Capacity\ =\ 400\ MW$

The capacity payment over the 20-year project life was determined by estimating the simple capacity price average from ISO-New England's 2010/2011 to 2020/2021 Forward Capacity Market. To account for the facility's credited firm capacity delivery, an unforced capacity (UCAP) percentage of 38% was assumed. This UCAP value for offshore wind is derived from New York Independent System Operator (2018). An escalation factor (EF) of 2.5% is assumed, consistent with the EF for the PPA revenue from the sale of electricity and RECs.

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[11] Note that for land-based wind projects, approximately 95% of the project installed costs are generally eligible as "cost basis" for the ITC (Bolinger 2014). Given the broader monetization uncertainties (e.g., with the assumed CapEx value), it is assumed that 100% of the project installed cost (i.e., $3,500/kW) is eligible for the ITC.

The incremental revenue from the sale of capacity was estimated with approximately \$7/MWh.

- **Step 4 (*"Deflation to \$2018"*)** converts the estimated LROE of \$112/MWh (\$2022) (facility 1) and \$101/MWh (\$2023) (facility 2) to 2018 nominal dollars, yielding \$104/MWh (\$2018) for facility 1 and \$91/MWh (\$2018) for facility 2. A deflation factor of 2.5% is assumed for this conversion, consistent with the reported escalation factor of 2.5% in the Vineyard Wind/EDC PPA pricing schedule.

- **Step 5 (*"Calculating the average between facility 1 and 2"*)** calculates the LROE average between facility 1 (400 MW) and facility 2 (400 MW) for simplification purposes, adjusting the LROE by ± \$6/MWh for these two facilities.

In sum, these analysis steps yield a net adjustment of approximately +24 \$/MWh (facility 1) and + \$33/MWh (facility 2) compared to the first-year PPA price, producing an **LROE of \$98/MWh** (\$2018) for the combined facilities (800 MW) of the Vineyard Wind LLC project.

Table 2. Analysis Steps to Calculate LROE from the Vineyard Wind Power Purchase Agreement

Step	Description	Estimate	Method	Source
0	First-year PPA price ($\$_{nominal}$/MWh)	74 $\$_{2022}$/MWh for facility 1 65 $\$_{2023}$/MWh for facility 2	Reported	a, b
1	Revenue from electricity and REC sales ($\$_{nominal}$/MWh)	89 $\$_{2021}$/MWh for facility 1 79 $\$_{2022}$/MWh for facility 2	Present value of future cash flow	a, b
2	Value of ITC ($\$_{nominal}$/MWh)	105 $\$_{2021}$/MWh for facility 1 94 $\$_{2022}$/MWh for facility 2	Value of ITC in t=0	a, b
3	Revenue from sale of capacity ($\$_{nominal}$/MWh)	112 $\$_{2021}$/MWh for facility 1 101 $\$_{2022}$/MWh for facility 2	Present value of future cash flow	a, b
4	Deflation to \$2018 (\$2018/MWh)	104 \$/MWh for facility 1 92 \$/MWh for facility 2	Discounting	N/A
5	Average between facility 1 and 2 (\$/MWh)	**\$98/MWh**	Averaging	N/A

[a] Massachusetts Department of Public Utilities (2018a)
[b] Massachusetts Department of Public Utilities (2018b)

Table 3. ITC Phase-Down Rate Schedule

Construction Start Before	Applicable ITC Rate
1/1/2017	30%
1/1/2018	24%
1/1/2019	18%
1/1/2020	12%
On or after 1/1/2020	0%

Source: Re-printed from Deloitte (2017)

3 Sensitivity Analysis

The LROE estimated in Section 2 is the result of a deterministic, single-scenario assessment. Some parameters applied in this study are very uncertain and require further validation. To understand how variation in individual parameters influences the estimated LROE while holding all other parameters constant, Figure 1 depicts the results of a limited set of sensitivity cases. A sensitivity case was performed for the valuation of the ITC, which varies by ± $2/MWh if CapEx is changed by ± $500/kW from the baseline of $3,500/kW. Project CapEx seems particularly prone to some modeling uncertainty as detailed project information on the export system cable configuration is not yet available. The impact of changing the sales revenue from the ISO-New England from $5/kW-month (simple average of 2010/11-2020/21 clearing prices) to $3/kW-month ($25^{th}$ percentile of 2010/11-2020/21 clearing prices) and $6/kW-month ($75^{th}$ percentile of 2010/11-2020/21 clearing prices), is approximately -$2/MWh and $2/MWh, respectively. The impact from a change of the baseline WACC (which serves as the discount rate in this analysis) of 7.0% was estimated to be -$0.03/MWh (6.7% WACC) and +$0.8/MWh (8.5% WACC).[12] An annual degradation factor of -0.5% (lower performance than expected) and +0.5% (higher performance than expected) was considered for the AEP as part of this sensitivity study with an effect of approximately $0.5/MWh. Lastly, the potential revenue from the sale of energy after the expiration of the Vineyard Wind/EDC PPA (after 20 years of operation) but before the termination of the federal lease (after 25 years of operation [BOEM 2015]) was considered. This opportunity for merchant revenue (after expiration of the PPA) for a 5-year duration (project years 20-25) was considered under a low (75%) and high (125%) wholesale electricity price sensitivity in comparison to the price schedule trajectory for years 1-20 established in the PPA. The impact is ± $0.6/MWh compared to the baseline of $98/MWh. Although there is some uncertainty whether revenue after expiration of the initial PPA enters the project owner's calculus for the negotiated PPA price, it is included here as an illustration of the potential impact.

[12] See e.g., Green Giraffe (2018) for an overview of financing conditions for recent European offshore wind projects.

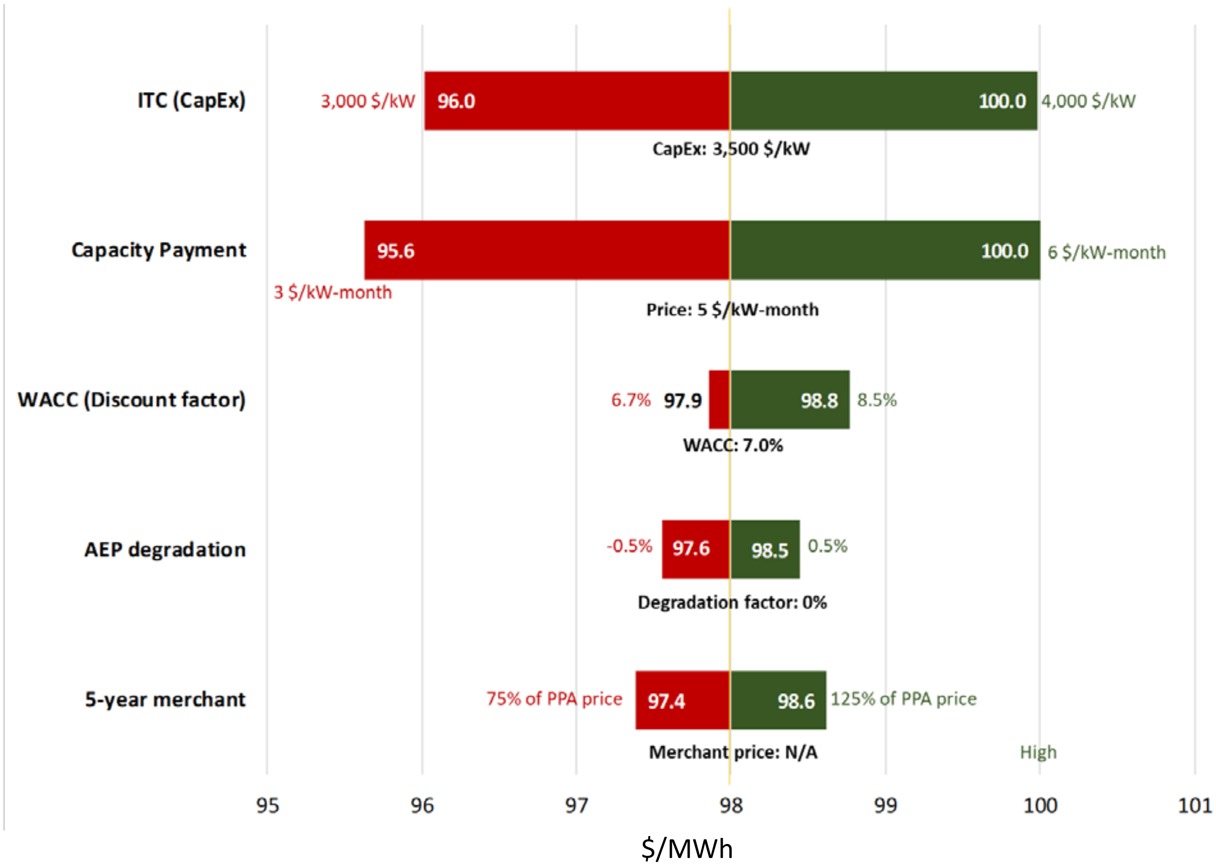

Figure 1. Sensitivity analysis of LROE to variations in ITC, capacity payment, WACC, AEP degradation, and 5-year merchant revenue

Note: The base scenario (resulting in $98/MWh) is consistent with the assumptions documented in Table 2. The ITC sensitivity is derived by varying the assumed CapEx value. The WACC sensitivity was derived by varying the assumed discount factor for deriving net present value of expenditures and energy production.

4 Discussion and Conclusions

Starting with the reported first-year PPA price of $74/MWh ($2022) and $65/MWh ($2023) for Vineyard Wind facilities 1 and 2, this analysis made a set of adjustments to represent the PPA price in $2018 terms and to account for revenue streams outside of the PPA and tax benefits to derive an LROE of $98/MWh ($2018). This LROE can serve as an initial reference for bottom-up cost modeling but should be validated further as more information from the Vineyard Wind LLC/EDC PPA and broader industry and supply chain development in the United States become available. The assumptions made herein about the PPA contract pricing have not been validated extensively and reflect a first-order deterministic scenario that does not capture the inherent uncertainty of many of the parameters considered. Limitations and caveats to this analysis include the following:

- There is inherent uncertainty associated with the parameters considered in this analysis. For instance, the monetized ITC value depends on the CapEx of the project (which was estimated from global averages but was not explicitly known to the authors) and the ITC rate the project will qualify for; similarly, there is inherent uncertainty with any merchant revenue considered in this analysis (e.g., from capacity markets).
- Corporate portfolio considerations (e.g., corporate financing conditions, such as balance sheet financing) and strategic bidding behavior (e.g., to gain an advantage as a first mover/market entrant) are not considered in this study but might have impacted the Vineyard Wind LLC/EDC PPA price.
- In this analysis, the election of the 18% ITC rate rests on the assumption that the project is able to raise sufficient tax equity financing (of up to $600 million)[13] and can adhere to the assumed ITC schedule.
- The calculations of this first-order assessment represent simplifications of the contractual agreements and market structures.
- It is not clear if all the revenue sources have been identified (e.g., local incentives, sales tax abatements).
- Some contractual arrangements in the Vineyard Wind LLC/EDC PPA were not considered in this study, such as the risk allocation of negative prices.

In Figure 2, prices from recent European offshore wind tenders were adjusted for contract length, as well as grid and development costs to represent “all-in” prices.[14] The estimated LROE of the Vineyard Wind project seems to fall within a price range similar to that of commercial-scale projects in Northern Europe with an expected start of commercial operation in the same period (Figure 2).

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[13] Deepwater Wind (2018)

[14] These adjustments were made to allow for a more direct comparison. However, they may not fully account for the entire set of differences in procurement mechanisms, available revenue streams, and policy among the offshore tenders depicted in Figure 2, which require further analysis. In addition, Figure 2 does not depict some of the uncertainty that is associated with any single price point (e.g., if they are exposed to merchant price risk). Any conclusions from Figure 2 should therefore be made with these caveats.

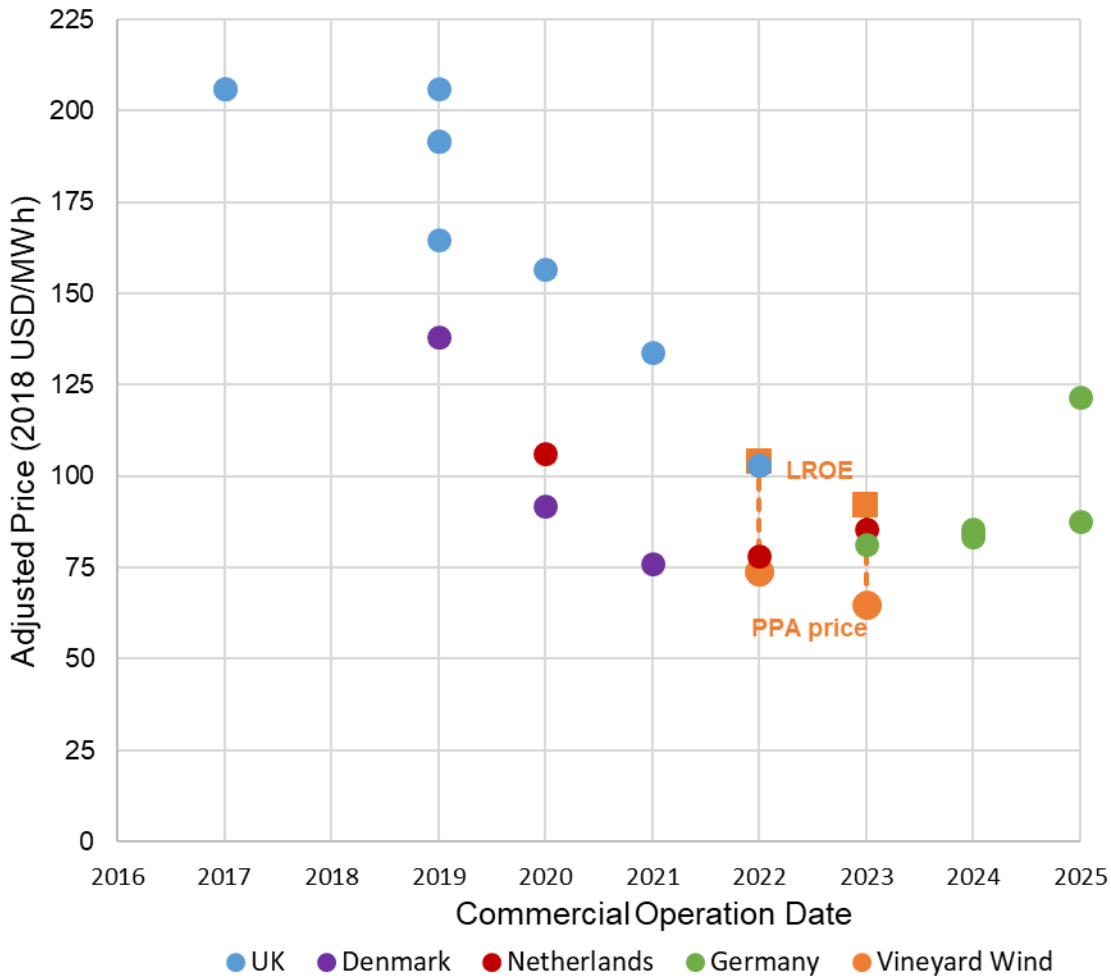

Figure 2. Adjusted prices from European offshore wind auctions including the Vineyard Wind project

Note: Re-printed from Beiter et al. (2018) with the Vineyard Wind project added. European strike prices were adjusted for differences in contract length, grid, and development costs to represent "all-in" prices. The Vineyard Wind data points reflect the signed PPA price (bottom) and the estimated LROE (top) for the two Vineyard Wind facilities. The dashed line represents the difference between the Vineyard Wind LLC signed PPA price and the LROE estimated in this analysis.

This could suggest that the generally anticipated price (and cost) premium for the nascent U.S. offshore wind industry in comparison to offshore wind projects in the established European markets might be much less pronounced than has widely been expected by many analysts (see e.g., Beiter et al. 2017; Musial et al. 2016; Maness, Maples, and Smith 2017; Kempton, McClellan and Ozkan 2016). Recent cost analyses have estimated an LCOE of between \$160/MWh and \$120/MWh for a commercial-scale offshore wind project built in the northeastern United States in the early 2020s. These estimates seem overly conservative in light of the LROE of \$98/MWh, even under consideration of the sensitivity cases presented in Section 3 of this report. The ability for technology transfer and the import of major technology components from Europe and Asia, rapid technological innovation, larger project sizes, higher turbine capacity, a relatively predictable revenue stream, and intensified competition within the global and U.S. supply chain and among bidders, seem to have extended the European cost reduction trajectory to the Vineyard Wind project. It is possible, however, that the Vineyard Wind LLC/EDC PPA price retrospectively could be classified as an outlier among early U.S. commercial-scale projects. The project might have benefited from one-time effects, such as strategic bidding behavior among market entrants to gain first-mover advantages for subsequent U.S. offshore wind tenders. The PPA price was also negotiated in a macroeconomic environment that provides historically low financing rates. Finally, the underlying Massachusetts legislation mandating the procurement of 1.6 gigawatt of offshore wind capacity by 2027 requires future offshore wind procurement under this scheme to produce a price below the Vineyard Wind LLC/EDC PPA contract price. This will require further cost reductions amid a tax environment that is expected to become less favorable with the ITC phase-out underway (Table 3). Future research is needed to validate and refine the project, price, and contractual assumptions made in this analysis, so that this first U.S. price point for a commercial-scale offshore wind project can serve as a robust reference point for bottom-up cost modeling.

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Appendix A

A-1. Levelized Cost of Energy and Levelized Revenue of Energy Equations

Levelized Cost of Energy (LCOE)

$$LCOE\ (\frac{\$}{MWh}) = \frac{\sum_{t=1}^{T} \frac{CapEx_t + O\&M_t + F_t}{(1+DR)^t}}{\sum_{t=1}^{T} \frac{AEP_t}{(1+DR)^t}} \tag{A-1}$$

where

$CapEx_t$ (\$/kilowatt [kW]): capital expenditures in t

$O\&M_t$ (\$/kW per year): annual operation and maintenance costs in t

F_t (\$/kW): annual fuel costs in t

DR (%): discount rate

AEP_t (megawatt-hour [MWh]): annual energy production in t

Levelized Revenue of Energy (LROE)

$$LROE\ (\frac{\$}{MWh}) = \frac{\sum_{t=1}^{T} \frac{\sum_{i}^{I} PPA\ price_t + Ex\text{−}PPA\ price_{i,t}}{(1+DR)^t}}{\sum_{t=1}^{T} \frac{AEP_t}{(1+DR)^t}} \tag{A-2}$$

where

Power purchase agreement (PPA) $price_t$ (\$/MWh): price set for PPA products in t

Ex-PPA $price_{i,t}$ (\$/MWh): price or valuation for product i in t that is exogenous to the PPA and compensated in applicable market

Annual Energy Production (AEP)

$$AEP\ (MWh) = 8760h\ \times NCF\ \times\ Capacity \tag{A-3}$$

A-2. Financing Assumptions

Table A-1. Financing Assumptions for Weighted Average Cost of Capital Under Consideration of the ITC Election

	Low	Mid	High
Debt Interest Rate		4.4%	
After-Tax Equity Rate (Nominal)	9%	9.5%	12%
Debt Share	40%	40%	40%
Effective Tax Rate (Federal and State)		26%	
Weighted Average Cost of Capital (Nominal)	6.7%	7.0%	8.5%

Appendix B

B-1. Vineyard Wind/Electric Distribution Companies Power Purchase Agreement Price Schedule

Table A-2. Power Purchase Agreement Price Schedule

	Facility 1			**Facility 2**		
Year	Price ($/MWh)	Energy Price ($/MWh)	REC* Price ($/REC)	Price ($/MWh)	Energy Price ($/MWh)	REC Price ($/REC)
2022	74.00	70.55	3.45	*N/A*	*N/A*	*N/A*
2023	75.85	72.31	3.54	65.00	61.55	3.45
2024	77.75	74.13	3.62	66.63	63.09	3.54
2025	79.69	75.97	3.72	68.29	64.67	3.62
2026	81.68	77.87	3.81	70.00	66.28	3.72
2027	83.72	79.82	3.90	71.75	67.94	3.81
2028	85.82	81.82	4.00	73.54	69.64	3.90
2029	87.96	83.86	4.10	75.38	71.38	4.00
2030	90.16	85.96	4.20	77.26	73.16	4.10
2031	92.42	88.11	4.31	79.20	75.00	4.20
2032	94.73	90.31	4.42	81.18	76.87	4.31
2033	97.09	92.56	4.53	83.21	78.79	4.42
2034	99.52	94.88	4.64	85.29	80.76	4.53
2035	102.01	97.25	4.76	87.42	82.78	4.64
2036	104.56	99.69	4.87	89.60	84.84	4.76
2037	107.17	102.17	5.00	91.84	86.97	4.87
2038	109.85	104.73	5.12	94.14	89.14	5.00
2039	112.60	107.35	5.25	96.49	91.37	5.12
2040	115.41	110.03	5.38	98.91	93.66	5.25
2041	118.30	112.78	5.52	101.38	96.00	5.38
2042	*N/A*	*N/A*	*N/A*	103.91	98.39	5.52

*Renewable energy credit (REC)

Source: Re-printed from Massachusetts Department of Public Utilities (2018a and 2018b, Exhibit D).