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DOCKETS UE-17____/UG-17____
2017 PSE GENERAL RATE CASE
WITNESS: RONALD J. ROBERTS

BEFORE THE
WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, **Complainant,** **v.** **PUGET SOUND ENERGY,** **Respondent.**	**Docket UE-17____** **Docket UG-17____**

TWENTY-SIXTH EXHIBIT (NONCONFIDENTIAL) TO THE PREFILED DIRECT TESTIMONY OF

RONALD J. ROBERTS

ON BEHALF OF PUGET SOUND ENERGY

JANUARY 13, 2017

DNV·GL

LOWER SNAKE RIVER

Operations and Maintenance Cost Benchmark and Forecast Study

PUGET SOUND ENERGY

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DNV GL - Energy
Advisory Americas
1400 Ravello Dr.,
Katy, TX 77449
Tel: 832-409-7711
Enterprise No.: 26-2535197

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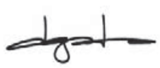
Prepared by:	Verified by:	Approved by:
		
Darrell Stovall Principal Engineer	Chris Walford Principal Engineer	Katy Briggs Head of Section

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1 INTRODUCTION

Puget Sound Energy ("PSE") retained DNV KEMA Renewables, Inc. ("DNV GL") to provide operations and maintenance (O&M) cost benchmarking and O&M cost forecast for the Lower Snake River (LSR) project (the "Project"). LSR is located in Southeast Washington near Pomeroy, in Garfield County, and consists of 149 Siemens SWT-2.3-101 wind turbines producing up to 343 MW. The Project achieved commercial operation in 2012 and end of warranty (EOW) is February 2017. This report presents the results of DNV GL's analysis.

1.1 Objective and scope of review

The objective of the analysis presented in this report is to provide O&M cost benchmarking and O&M cost forecast for selected turbines. The following approaches have been used to achieve this objective:

- DNV GL maintains a database of 15 GW of actual O&M costs across North America; this database has been employed to provide typical O&M cost ranges covering a range of turbine models and regions defined in Section 2.
- DNV GL has a probabilistic O&M cost model which is validated by the above database and allows for detailed O&M cost forecasts for various project locations and turbine configuration. This O&M cost model has been used to forecast turbine-specific turbine O&M costs for the Project (through year 20 of operations). The O&M cost ranges provided include scheduled and unscheduled turbine and balance of plant (BoP) costs.

2 O&M COST BENCHMARKING

2.1 Benchmark: Methodology

The first step in providing a range of typical costs for operating wind projects is to extract data from the DNV GL O&M Cost Benchmarking database. This database contains O&M cost information for over 15 GW of operating projects, ranging in age from 1 to over 15 years of operation. The distribution of turbine suppliers represented in the database is as follows: 35% GE; 25% Vestas; 7% Siemens; 6% Gamesa; and 26% other including Suzlon, MHI, Clipper, Nordex, Enercon, and other models.

The data were queried to assess the O&M cost variation with a number of parameters. Specifically, the costs were evaluated by:

- Year: 2010, 2011, 2012, 2013, and 2014
- O&M service strategy: Full Service Agreement/Long Term Service Agreement (FSA/LTSA), i.e., Full Wrap by original equipment manufacturer (OEM), self-manage, self-perform for post-warranty projects
- Turbine rated capacity: Less than 1.5 MW, 1.5 MW to 2.0 MW, greater than 2.0 MW
- Projects using SWT-2.3 MW turbines, presented as $/MW as well as $/turbine
- Project age:
    - Years 1-5, 6-10, 11+
    - Years 2-3, 4-5, 6-7, 8-9, 10-11, 12+ … Filtered for wind farms with at least 8 years of data

The results are provided in various resolutions as follows:

- Total Operating Expenses, i.e., all costs included in Table 2-1; and
- Total Turbine O&M costs, including turbine scheduled and unscheduled maintenance (BOP costs are not included).

All costs presented have been adjusted for inflation and are presented in 2015 U.S. Dollars.

Table 2-1 DNV GL detailed O&M cost categories

DNV GL cost category	Description
Turbine scheduled O&M	Turbine fees, turbine labor, scheduled maintenance, tools and equipment; personnel costs such as travel and meals.
Turbine unscheduled repairs	Unscheduled maintenance parts costs, spare parts and consumables.
Total Turbine O&M	Total turbine O&M costs included in the two categories above. ("All-in" costs including material, labor and subcontract associated with turbine maintenance) Note: • SCADA monitoring is typically included in Total Turbine O&M; if maintenance is not performed by OEM, post warranty SCADA support would typically be included in the Project admin/contract fees category or BoP maintenance • If maintenance is performed by OEM, remote monitoring and diagnostics would typically be included in Total Turbine O&M; post warranty remote monitoring and diagnostics may be included in the Project admin/contract fees category
BoP maintenance	O&M conducted on site to components including collection system, substation,

DNV GL cost category	Description
	roads and fences; spare parts and consumables; vehicles. Waste management, security, O&M building rent, office supplies.
Utilities	Energy usage, facility utilities, telecom expenses, information technology (IT) costs.
Project admin/contract fees	Project administration and management fees, 3rd party provider contract fees, inventory fees.
Generation charges	Charges related to system operator/transmission.
Land leases/Royalties	Lease payments or royalties payable to third party land owners.
Insurance	Insurance premiums and/or deductibles with regard to the wind farm site.
Property tax	Property tax due with respect to the wind farm site.
Outside professional & advisory	Environmental expense; consultant fees including audit, independent engineer (IE), legal, tax services; meteorological data analysis, regulatory compliance.
Other general & administration	Production shortfall penalties, generation charges, fuel, co-tenancy fee, bank/guarantee fees, community involvement, license, permits and fees, sales & marketing costs, miscellaneous expenses, contingency.
Total expenses	Total of all of the above categories.

2.2 Background information

2.2.1 O&M strategies and their effect on operating costs

When considering the data set for Turbine Scheduled and Unscheduled Maintenance (Total Turbine O&M), the choice of O&M strategy can have a notable effect on the cost of operations. In recent years there has been an increase in the variety of options for Turbine O&M available to wind project owners as the number of wind farms have increased and created a competitive market particularly in locations where there are significant populations of wind projects in close proximity. Turbine O&M may be performed by the OEM, a third party, an owner self-performing (Owner/Operator), or a combination of these options. Three general operating strategies are discussed in this report including:

- Full Service Agreement/Long Term Service Agreement (FSA/LTSA): In this strategy, full-wrap contracts are in place, which have a fixed price for both scheduled and unscheduled maintenance. This strategy is often provided by the OEM.
- Self-Manage: In this approach, both fixed and time and materials O&M service provisions or contracts are in place with the OEM or other service providers.
- Self-Perform: In this strategy, the wind farm owner utilizes internal staff for most of the O&M functions.

2.2.2 Turbine scheduled O&M

The initial agreements during the warranty period are typically for a fixed service fee and the scope of work generally follows the turbine manufacturer's operating manual.

Post warranty O&M strategies can be various combinations of OEM, Owner/Operator, or third-party O&M providers. Some experienced Owners of multiple wind projects prefer to self-perform O&M activities, taking advantage of lower costs and economies of scale with regard to labor, owner purchased equipment, in-house repair shops, and supplier discounts. Owners new to the industry, or with a remote or smaller capacity wind project, tend to prefer an OEM or third-party O&M provider, thus taking advantage of service providers that are already present and experienced in a particular region. The cost effectiveness of self operating does, however, need to be weighed against the lack of performance warranty and increased exposure to cost variability that might have otherwise been mitigated by a third-party fixed fee with performance guarantees.

It should be noted that as a wind project transitions out of warranty during an operational year, the Turbine Scheduled O&M costs will be a combination of OEM and the post warranty O&M provider fees; and in most cases there will be additional lump sum costs for spare parts inventory and possibly also end-of-warranty inspections.

2.2.3 Turbine unscheduled repairs

During the warranty period the Unscheduled Turbine Repairs and Replacement costs for major components are covered by the OEM and include the cost of labor, cranes, and equipment. The cost of the equipment warranty is generally included in the price of the turbines under the Turbine Supply Agreement (TSA), but there are instances of OEMs charging a fixed fee during the operating warranty period which represents the cost of the warranty. To avoid skewing the data, warranty fees are excluded from the reported data in this study. Aside from maintenance activities which may not be covered by the OEM scope of work, there will be no charge to the wind project operating costs for unscheduled maintenance during the warranty period.

Parts-only warranties allow owners to self-operate the project from the commercial operations date but retain a warranty only on the equipment, provided that they follow the manufacturer's operating procedures. Thus the cost of the parts is covered by the OEM warranty; however, the labor costs associated with the parts change out is payable by the owner and is variable dependent on the nature of the work.

When a project emerges out of the warranty phase, unscheduled maintenance costs become the most variable operating cost due to the uncertainties in the long-term component lifetimes which make accurate estimations of maintenance costs difficult. In recent years, there has been an increase of extended service and maintenance agreements or 'Full Wrap' offered by OEMs. These agreements typically cover scheduled and unscheduled turbine maintenance at a fixed rate, providing a level annual cost over the term of the service contract with the aim to reduce or eliminate cost variability. That being said, the owners do bear some risk of additional costs with repairs or replacements due to extraordinary wear and tear or out-of-scope work, although under a full service agreement such costs will be relatively minor. The location and site conditions, for example high turbulence or high capacity factor, can create more risk of additional extraordinary maintenance costs. Therefore the owner should carefully consider the definition of such terms during the negotiation of a Full Wrap agreement.

2.3 Benchmark: Results and Observations

The O&M cost ranges from DNV GL's benchmark database are presented below on a cost-per-megawatt ($/MW) basis normalized to 2015 dollars; the one exception is Figure 2-6, which presents cost Total Turbine O&M costs for Siemens SWT-2.3 MW turbines in both $/MW (shown in Blue) and $/turbine (Green). Total Operating Expenses, as presented in Figure 2-2, are shown in Orange. Table 2-1 illustrates how to interpret the percentiles from the cost benchmark figures. All cost projections are in 2015 dollars.

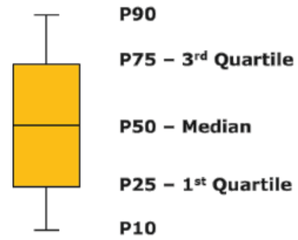

Figure 2-1 Legend

2.3.1 Operating costs by year

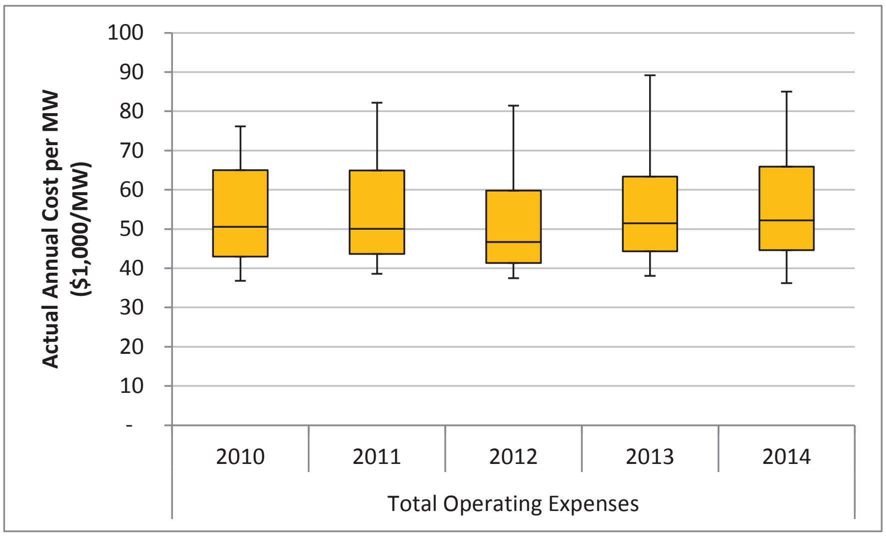

Figure 2-2 Total Operating Expenses by year: 2010, 2011, 2012, 2013 and 2014

Figure 2-2 presents benchmark costs for all projects in DNV GL's database. Although the median value for Total Operating Expenses has remained stable over the last five years, the range of costs within any given year reflects the variability in cost categories from site to site.

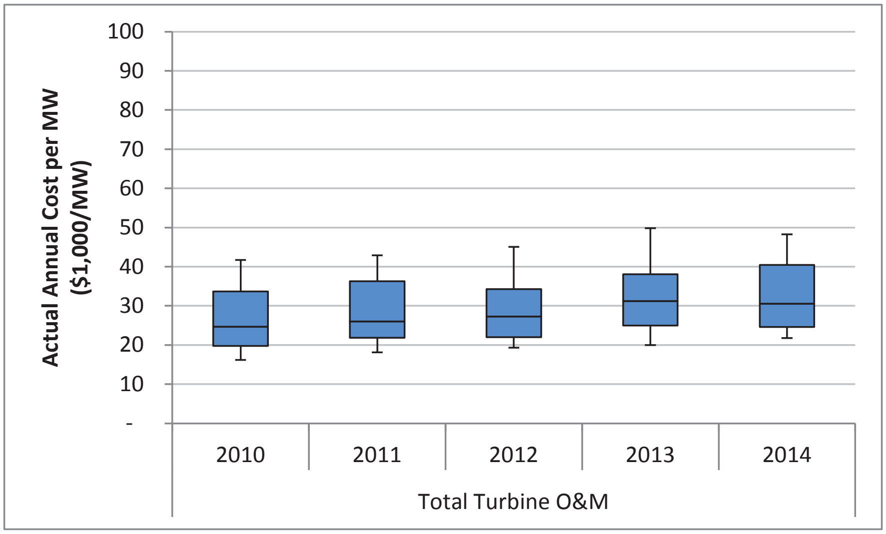

Figure 2-3 Total Turbine O&M cost by year: 2010, 2011, 2012, 2013 and 2014

In general, the benchmark plots show that the median Total Turbine O&M costs may have risen to varying degrees from 2010 to 2014.

2.3.2 Cost by O&M service strategy (Post Warranty)

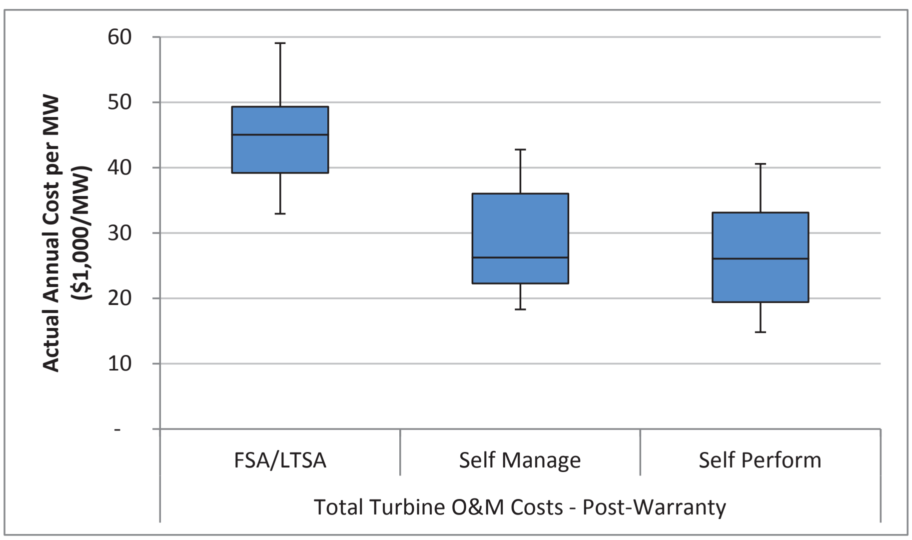

Figure 2-4 Post-Warranty Total Turbine O&M Cost by O&M service strategy

Figure 2-4 presents benchmark costs for all projects in DNV GL's database. The post-warranty Total Turbine O&M cost are the highest for the FSA/LTSA strategy which have a fixed price for both scheduled and unscheduled turbine costs. The Self-manage and Self-perform costs are lower and include some variable time-and-materials costs. This difference in cost is notable and primarily attributed to a “risk-premium” being applied to FSA/LTSA agreements. The Self-manage and Self-perform costs are lower on average, but the wind farm owner is exposed to more cost variability and the potential for higher costs.

2.3.3 Cost by turbine rated capacity

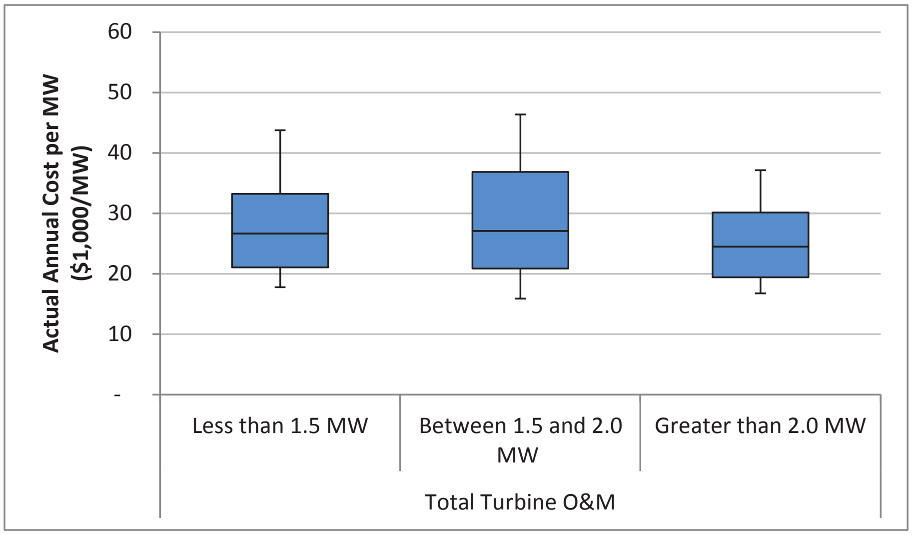

Figure 2-5 Total Turbine O&M Cost by turbine rated capacity: < 1.5 MW, 1.5 MW to 2.0 MW, > 2.0 MW

Figure 2-5 presents benchmark costs for all projects in DNV GL’s database. Comparing the Total Turbine O&M cost per MW of installed capacity by the turbine rated capacity indicates no significant difference in the median. One might expect lower cost per MW for the “Greater than 2.0 MW” category because much of the maintenance costs are the same regardless of the turbine rated capacity. However, the differences by turbine size may be driven by other factors such as the turbine models in each grouping or the data sample. For example, about 20% of the data falls into the “Greater than 2.0 MW” category so this category is more sensitive to the individual attributes of these data in the sample.

2.3.4 Cost for Siemens SWT-2.3 MW Wind Farms

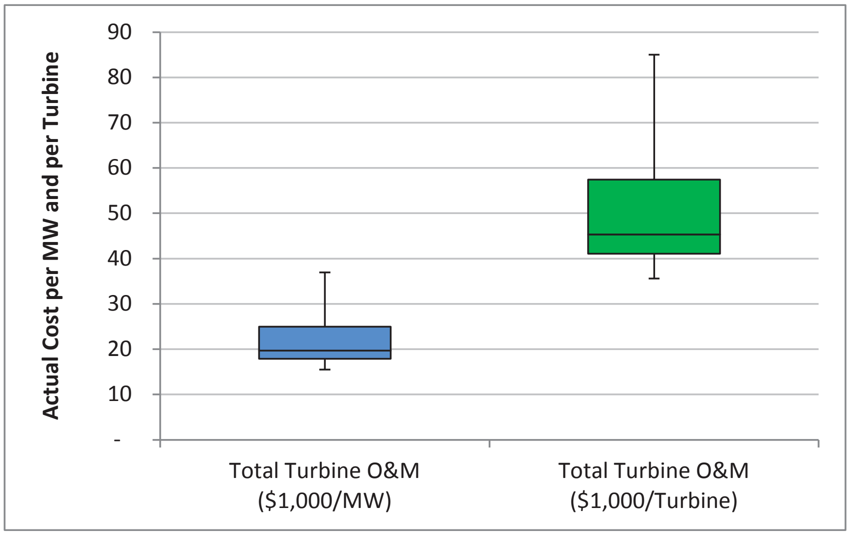

Figure 2-6 Total Turbine O&M Cost for Siemens SWT-2.3 MW

Total Turbine O&M Costs for the subset of wind farms with Siemen SWT-2.3 MW turbines are shown in Figure 2-6 on a cost per MW and a cost per Turbine basis. The results are derived from 9 wind farms and a total of 33 annual cost values from these sites.

Table 2-2 (below) presents costs for SWT-2.3 MW turbines on a $/MW and $/turbine basis along with the benchmark costs multiplied by 149 turbines to represent the total wind farm costs for that size site. The median, 1st Quartile and 3rd Quartile is presented. It is noted that this results are derived from a smaller data set which can be affected by individual attributes in the data sample.

Table 2-2 Siemens SWT-2.3 MW Total Turbine O&M Cost per MW; per turbine and for LSR Project by Percentile

Total Turbine O&M Cost vs. Percentile	$/MW	#/turbine (SWT-2.3 MW)	$ for Project (149 x SWT-2.3 MW)
1st Quartile	$17,850	$41,055	$6,117,195
Median	$19,700	$45,310	$6,751,190
3rd Quartile	$24,975	$57,443	$8,558,933
Annual Total Turbine DNV GL Benchmark O&M Costs in 2015 Dollars			

2.3.5 Cost by project age

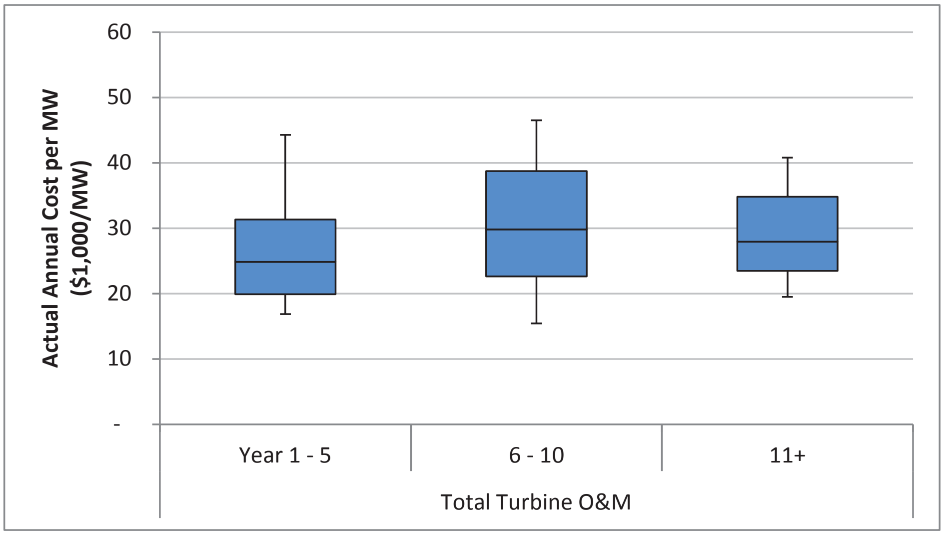

Figure 2-7 Total Turbine O&M Cost by project age

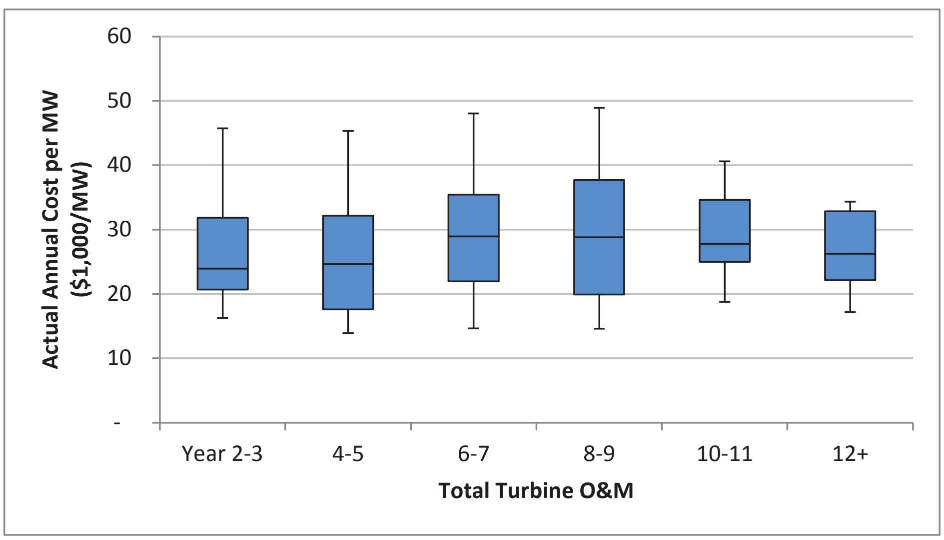

Figure 2-8 Total Turbine O&M Cost by Project Age – Filtered for wind farms with at least 8 years of data

Figure 2-7 and Figure 2-8 both present wind turbine O&M costs by project age for different age groupings and with different data filters applied. There is an increase in costs as projects age. However, it is noted that the data sample in each age range is different, which has an effect on the apparent trend. For example there is a different combination of turbine models and O&M strategies between the earlier and the later years. In order to reduce the impact of the different data samples skewing the results, the data have been filtered to only include projects that have at least three years of data reported for Figure 2-7 and at least eight years of data for Figure 2-8. Even with these filters applied, the costs in the later years are affected by differences in the data samples, resulting in the appearance of a decrease in cost after year 10. However, applying other data filters, generally illustrates a larger and continuing increase in cost as wind farms age than are observed in the above figures.

3 O&M COST FORECAST

3.1 Forecast: Methodology

The long-term cost estimates presented herein as well are a product of DNV GL's proprietary O&M Cost Forecasting Model (the "DNV GL Model"). Considering that the turbine designs are typically evolved and improved variants of earlier designs, it is not appropriate to apply directly derived historical statistical reliability metrics for the basis of projecting the reliability of the major components. Therefore, while the DNV GL Model is informed by historical failure rate data, DNV GL's experience and technical knowledge of the considered turbine model design, together with historical information provided by PSE, are also used as inputs.

The DNV GL Model evaluates a range of costs based on different failure rate assumptions for various turbine components. These can be modified to accommodate different turbine architectures. The modeling is carried out as follows:

- Lifetime failure rates for major components are, in most cases, described as Weibull distributions. These failures are distributed from year to year across a project's life using a two-parameter Weibull curve. Some failure types; however, are assumed to occur randomly because of uncontrollable circumstances such as lightning strikes, manufacturer defects, operational errors, or servicing omissions and errors. These are represented by a constant failure rate.
- To account for uncertainties related to component failure rates over its operating life, both the Weibull scale parameter and constant failure rate parameter are allowed to vary according to a normal distribution.
- Additional probability distributions are assigned to parts, labor, and crane costs as well as per-event downtime assumptions. These are nominally normally distributed. All distributions in the O&M Cost Model are parameterized using project-specific data where possible.
- A probabilistic representation of the total O&M costs is developed by running DNV GL's in-house model through Monte-Carlo simulations with each parameter changed randomly and independently to describe the distribution of potential costs and downtime. The individual results are combined to generate a distribution of project costs and downtime at several probability levels (P-values).
- Also included in the model are scheduled turbine costs. The scheduled turbine O&M includes fixed costs for parts and supplies required for scheduled service, as opposed to repairs, including consumables such as lubricants, filters, and cooling fluids as well as periodic turbine maintenance events such as inspections (every five years), gear oil changes (every three years with synthetic oil) and blade refinishing ($5000 per turbine every ten years).

3.2 Forecast: Details

For unscheduled maintenance, expenses tend to increase in real dollars over the life of the project because major component failures increase in frequency with age. DNV GL has developed an approach to this forecasting challenge by considering a specific failure distribution over time for each of the major component failure events listed in Table 3-1 below.

Table 3-1 Major unscheduled maintenance event categories

Major component	Event type	Brief description
Gearbox	Replace/Refurbish	Complete replacement of the gearbox with a new or refurbished gearbox; requires a crane; it is expected that replaced gearbox will recover significant core value. This is accounted for in Parts Cost.
	Up-tower repair	Gearbox repair that can be performed up-tower, such as high-speed (HS) bearing replacement.
Generator	Replace/Refurbish	Replace generator with a new or refurbished generator; it is expected that replaced generator will recover significant core value. This is accounted for in Parts Cost.
	Up-tower repair	Work performed up-tower, e.g., generator bearings.
Blades	Replace/Structural Repair	Full replacement or significant repair performed on site; requires a crane.
	Non-structural repair	Minor repair; performed up-tower with rope access technique or a man-basket.
Main bearing	Replace	Complete replacement; may require refurbishment of main shaft, requires a crane.
Transformer	Replace/Refurbish	Parts and labor only for pad mounted transformers.
Pitch	Replace/Refurbish	Includes crane, labor, and parts cost. Project refurbishes gears and drives but pitch bearings are purchased new.
Yaw	Replace/Refurbish	Full replacement or significant repair of slew ring performed on site; requires a crane.
	Minor Repair	Yaw drive repairs;-crane not required
Power converter	Repair/Replace	IGBT (“Delta”) modules

For each of the events in the table above, DNV GL has assumed an event cost and an event frequency distribution. The event cost considers parts (including transport to site), labor, and crane charge. Event frequency distributions are a combination of either a two-parameter Weibull function or a constant failure rate (depending on the event type) and an assumed infant mortality curve. Project failure rates are calculated using the appropriate frequency distribution under the assumption that components are replaced with new or refurbished parts. DNV GL maintains default assumptions for the Weibull parameters and infant mortality curves which are specific to each turbine model; for certain components the default values are adjusted based on site-specific conditions.

3.3 Forecast: Assumptions

The following assumptions have been used to estimate scheduled and unscheduled maintenance costs:

- Adverse conditions, such as “winded-out” days where a crane will be idling on standby unable to perform the work due to site wind speeds exceeding safe working limits, will occasionally occur, while some other repairs will be completed in a shorter timeframe. All costs presented are based on average event duration over a 20-year project life, such that a single event cost could be above or below presented numbers.

- Parts costs included in the DNV GL Model are DNV GL's best estimates of average part costs over the projects' life. In general, the major part costs assumed in the model are reasonably consistent with quotes provided by PSE.
- Labor costs are based on the estimated average time to perform a task multiplied by the average technician hourly rates, as observed throughout the industry.
- It is assumed that labor costs associated with routine repairs of minor components and replacement of consumables are included in the costs for permanent on-site staff; only part costs are included in the DNV GL Model. While DNV GL recommends that the reader review and verify this with regard to the terms of individual contracts, DNV GL has observed that this is often the case in the industry. While this is a non-negligible assumption, DNV GL does not consider it to be a main driver of the model.
- Each event requiring a crane assumes that the crane will be brought to the site to perform a single replacement. Because crane costs are highly dependent on the regional availability and proximity the depot, DNV GL chose to use crane quotes provided by PSE specific to the Lower Snake River project. Given that a typical event requires 1-3 days of crane work, it is assumed that 55-80% of the crane cost is associated with the mobilization and demobilization of the crane. It should be noted that due to the high cost of cranes and the greater percentage of cost associated with mobilization and demobilization of the crane, it may be possible to achieve significant savings by performing multiple replacements at the same time.
- Proactive maintenance based on continuous condition monitoring of gearbox, generator and main bearing is assumed.
- Proper scheduled maintenance, in accordance with the OEM maintenance manual as well as industry best-practice has been assumed for all turbine components. Improper scheduled maintenance will lead to failure rates higher than those assumed by DNV GL.

3.4 Forecast: Results

As per the scope of work for this study, the DNV GL model has been used to estimate turbine costs for the PSE Lower Snake River site, comprising 149 SWT 2.3-101 wind turbines on 80 meter towers. Table 3-2 lists selected major events and their associated frequency of occurrence and assumed total event cost, including labor, parts and crane. The terms 'low', 'baseline' and 'high' refer to the Monte-Carlo probability simulation results. Note that padmount transformers have been omitted because they are not included PSE's definition of turbine costs.

Table 3-2 Major unscheduled maintenance events

Event Specific Information		# of Failures over 25 yrs			Event Cost	
Component	**Event type**	**Low**	**Baseline**	**High**	**Low**	**High**
Gearbox	Replace	72.9	90.3	122.9	319,300	444,900
	Uptower repair	78.6	92.2	115.0	81,000	117,900
Generator	Replace	61.1	61.1	61.1	156,300	235,900
	Major Repair	66.8	101.8	147.3	15,800	23,900
Main Bearing	Replace	77.4	109.4	153.9	279,800	339,100
Blades	Replace/Structural Repair	10.3	16.8	23.2	294,600	425,300
	Non-structural repair, per blade	34.5	55.8	77.3	15,400	24,900
Transformer	Replace	0.0	0.0	0.0	39,700	66,000
Pitch	Minor repair	68.9	102.8	165.6	6,600	8,600
	Bearing replacement	22.3	40.5	81.1	121,700	138,200
Yaw	Major repair (requires crane)	1.1	1.9	2.6	244,700	280,400
	Minor repair	45.9	74.4	102.9	6,400	10,500
Power Converter	Replace/repair	213.0	260.1	326.1	23,400	38,800

Figure 3-1 through Figure 3-3 depict the projected annual total, scheduled and unscheduled maintenance costs per turbine through year 25. All cost projections are in 2015 dollars. The terms 'low', 'baseline' and 'high' refer to the Monte-Carlo probability simulation results. It is important to note that wind turbines are typically certified to operate for 20 years, and operation beyond this period, while often feasible, will entail increased risk of structural failure. This risk increases with extended operating period beyond 20 years. These cost projections do not include inspection or repair costs associated with structural components, and assume that the structural integrity of the turbines is maintained.

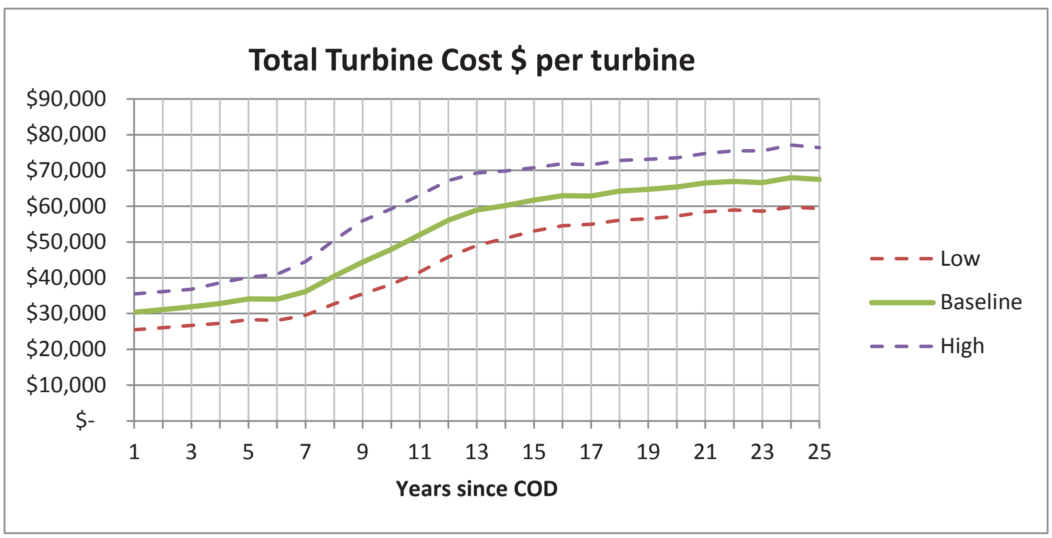

Figure 3-1 Projected total turbine maintenance costs per turbine

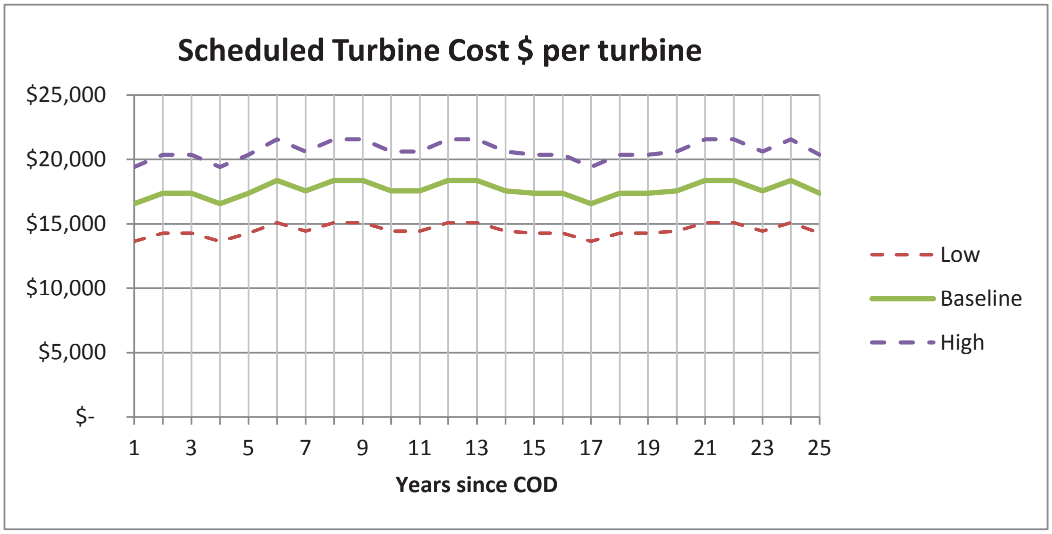

Figure 3-2 Projected scheduled turbine maintenance costs per turbine

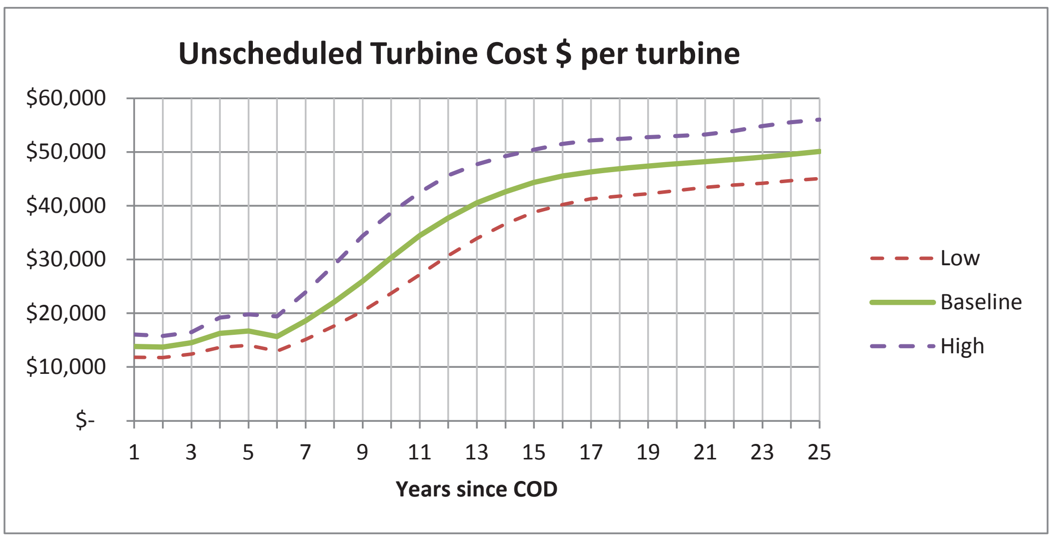

Figure 3-3 Projected unscheduled turbine maintenance costs per turbine

DNV GL notes that care should be taken when comparing operations and maintenance costs calculated by different parties, due to the variety of ways that cost data can be accounted for in operating budgets. The owner capabilities will also directly affect the unscheduled O&M costs: for example, labor costs for specialized repair work may or may not require the use of specialist third party labor, depending on the on-site personnel qualifications. Additionally, DNV GL's projections are cost estimates as opposed to pricing of O&M service. The estimates do not include any margins for profit and risk that may be charged by service providers or OEMs. Therefore, the model results represent the material cost of self-perform O&M strategy. Cost associated with risk is represented by the difference between the High, Low and Baseline estimates.

This deliverable does not include the full detail of the DNV GL O&M cost model, as this is considered proprietary to DNV GL. Further, DNV GL considers its major component cost and failure rates assumptions to be proprietary; therefore all reports will be classified as Commercial in Confidence. A Document Classification of Commercial in Confidence means the Deliverable shall not be distributed outside of PSE's organization.

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