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2017 PSE Integrated Resource Plan

Washington
Wind and Solar Costs

The attached report developed for PSE by DNV GL provides capital cost industry benchmarks for wind power and solar power project construction specific to the eastern Washington region.

Contents

Washington State Wind and Solar Power Project Capital Cost Benchmarks

Puget Sound Energy, Inc.

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Provide capital cost industry benchmarks for wind power project and solar power project construction specific to the eastern Washington region.

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1 INTRODUCTION

Puget Sound Energy, Inc. ("PSE" or the "Customer") has requested DNV KEMA Renewables, Inc (DNV GL) provide capital cost industry benchmarks related to both a theoretical wind power plant and a theoretical solar power plant constructed in eastern Washington State. These benchmarks will allow the Customer to make informed investment decisions regarding future wind and solar power plant acquisition or development. In addition to the onshore wind power plant benchmarks, this document also includes comments regarding the increase in capital costs to be expected when considering an offshore wind power plant.

2 WIND POWER PLANT BENCHMARKS

This section presents high-level estimates for capital costs representative of a theoretical utility-size wind power project constructed in eastern Washington State (the "Theoretical Wind Project").

2.1 Project and Site Assumptions – Onshore Wind

DNV GL used the following assumptions to define the Theoretical Wind Project and determine the numerical values for each cost category:

- Located in eastern Washington State;
- Total capacity of 100 MW;
- Land-use and zoning compatible with wind project development;
- Non-complex terrain (slopes and constraints);
- Reasonable access (not remote; accessible by State highways and County roads);
- Normal geotechnical conditions; and
- Equipped with modern size wind turbines. (i.e. 1.5 MW–3 MW)

All cost estimates presented herein are in 2017 dollars. The "low" and "high" cost estimates are meant to represent the expected range of costs for the Theoretical Wind Project and do not consider outliers (i.e., either extremely high or low data points) DNV GL has observed in its review of existing wind projects.

2.2 Methodology – Onshore Wind

DNV GL has used several sources to identify and estimate capital costs, excluding development costs, namely its proprietary cost database which includes actual and estimated component cost data for 399 wind energy projects located through the United States and Canada. For some cost categories, namely balance of plant (BoP) items, the database has been filtered to include projects constructed in the last 7 years and projects that are similar to the Theoretical Wind Project (i.e. Northwest US, modern turbines used, etc.).

It is noted that capital costs were observed to vary substantially from one project to another. For instance, turbine cost depends on model and options selected, and BoP costs are influenced by local material prices, labor rates, and equipment rental rates. Additionally, BoP costs can vary significantly from project to project, specifically civil costs (i.e., roads, foundations, crane pads) and electrical costs (i.e. collection system and interconnection), depending on location, site access considerations, and terrain.

The capital cost categories cover a broad range of EPC activities including:

- *Wind turbine generators.* This category includes the cost of all heavy crane work and labor necessary for procuring the wind turbines, including transport to the Theoretical Wind Project site, unloading, erection, wiring, and mechanical completion and turbine commissioning. DNV GL's project cost database indicates that turbine costs vary relatively little by region. However, turbine costs are dependent on options selected from the manufacturer such as control packages, monitoring services, warranty periods and other commercial terms.
- *Civil Balance of Plant.* This category includes costs related to the Theoretical Wind Project's civil BoP aspects including:
    - *Roads.* This category includes the costs, including material, equipment and labor, of new roads or road improvements, either public or private, and access roads to turbines. DNV GL has assumed that soils at the Theoretical Wind Project are appropriate for road building.
    - *Foundations.* This category includes costs of wind turbine and transformer foundations. DNV GL has assumed that soils at the Theoretical Wind Project are appropriate for foundation construction and a typical foundation design will be used.
    - *Crane pads.* This category includes costs of crane pads necessary for turbine erection. DNV GL has assumed that soils at the Theoretical Wind Project are appropriate for crane pad construction.
    - *O&M building.* This category covers the buildings and other infrastructure associated with operations and maintenance of the Theoretical Wind Project including any on-site staff offices, storage for spare parts and equipment, and shop space. Given the size of the Theoretical Wind Project, a separate O&M building may not be needed, and may depend on the turbine manufacturer's requirements and local operating staff presence. For the low end estimate, DNV GL has assumed that no O&M building would be built. For the high end estimate, DNV GL has assumed there would be one O&M building on site with between 1,000 and 3,000 square feet.
- *Electric Balance of Plant.* This category includes costs related to the Theoretical Wind Project's electrical BoP including:
    - *Collection system and pad-mount transformers*. This category includes costs associated with underground and overhead electrical collection systems, pad-mount transformers, and SCADA (including fiber network) installation. This category covers all of the electrical wiring and junction boxes required to transmit and regulate the flow of electricity throughout the Theoretical Wind Project, and the fiber optic cables necessary for communication. This cost is dependent on turbine density (i.e. turbine spacing).
    - *Substation and interconnection.* This category includes costs associated with the substation and interconnection (switchyard). Substations generally have switching, protection and control

equipment and one main power transformer and are used to interconnect the a wind project to the electric grid. Interconnection involves the infrastructure needed to link up the substation to the electric grid, including the cost of any new transmission lines or required network upgrades. The costs in this category are highly influenced by the interconnection voltage, the distance to point of interconnection, and the any grid upgrades required.

The following aspects of construction are included in equal proportions within the civil and electric BoP costs described above:

- *Permanent measurement towers.* Permanent measurement towers are used to monitor the wind regime for project operations and to monitor project performance. DNV GL has included cost estimates for zero (low end) to one 80 m, IEC-compliant measurement tower (high end).
- *Detailed engineering.* This category represents the work related to the mechanical design, electrical design, civil design, geotechnical engineering and foundation design, as well as preliminary submittal packages, issued-for-construction (IFC) drawings, and as-built drawings.
- *Construction management.* Management is required to organize and oversee the construction-related tasks involved with building a wind energy project, including cost-control, scheduling, site supervision, and environmental and safety compliance monitoring. Construction management can be performed in-house, by a third-party representative such as an independent engineer, or by the BoP EPC contractor.
- *Other costs*. This category covers BoP costs incurred by the Theoretical Wind Project that do not necessarily fit into of the categories above, such as reactive power compensation equipment.

It is important to note that the following costs are not included in this cost estimates provided: Owner's engineering, capital spares, contingency, financing or major grid upgrades.

2.3 Results – Onshore Wind

DNV GL estimates a total capital cost for the Theoretical Wind Project to range between M$1.14/MW at the low end and M$2.19/MW at the high end, as further detailed in Table 2-1 below.

Table 2-1 Capital cost estimates for the Theoretical Wind Project

Capital Costs[1]	**Low ($/kW)**	**Average ($/kW)**	**High ($/kW)**
Wind turbine generators	860	1,080	1,510
Civil Balance of Plant	166	224	322
Electrical Balance of Plant	111	185	358
Total	**1,137**	**1,489**	**2,191**

1. Does not include owner's engineering, capital spares, contingency, financing or major grid upgrade costs.

3 SOLAR POWER PLANT BENCHMARKS

This section presents high-level estimates for capital costs representative of a theoretical utility-size solar power project constructed in eastern Washington State (the "Theoretical Solar Project").

3.1 Project and Site Assumptions – Solar

DNV GL used the following assumptions to define the Theoretical Solar Project and determine the numerical values for each cost category:

- Located in eastern Washington State;
- Total capacity of 20 MWac / 25 MWdc;
- Land-use and zoning compatible with solar project development;
- Non-complex terrain (slopes and constraints);
- Reasonable access (not remote; accessible by State highways and County roads);
- Normal geotechnical conditions; and
- Equipped with polycrystalline modules, central inverter, and typical single-axis tracker.

All cost estimates presented herein are in 2017 dollars.

3.2 Methodology - Solar

DNV GL has used several sources to identify and estimate capital costs, excluding development costs, including its solar project database which includes actual component cost data for solar projects located through the United States, and Greentech Media (GTM) Research Reports[1].

Capital costs can vary significantly by project, depending on items including, but not limited to: interconnection requirements, grid availability, transmission upgrades, land costs, environmental / permitting requirements, site access considerations, soil conditions, and terrain. Interconnection costs can vary based on the size of the facility. For example, a 10-20 MW distribution facility will require a Federal Energy Regulatory Commission (FERC) Small Generator interconnection process (IP) and will most likely have significantly lower costs, and less extensive distribution upgrade requirements, if any, compared to a Large Generator IP. BoP costs can vary from project to project, specifically civil costs (i.e., roads, foundations (i.e. frost heave and pile refusal considerations), and hydrology requirements) and electrical costs (i.e. AC collection system, dc/ac ratio).

[1] *PV Balance of Systems 2015: Technology Trends and Markets in the U.S. and Abroad,* dated August 2015, by GTM Research and *Q2 2016 Solar Executive Briefing*, dated July 2016, by GTM Research.

3.3 Results - Solar

DNV GL estimates a total capital cost for the Theoretical Solar Project to range between \$1.35/Wac at the low end and \$1.79/Wac at the high end, as further detailed in Table 3-1 below.

Table 3-1 Capital cost estimates for the Theoretical Solar Project

Capital Costs[1]	**Low ($/kWac)**	**Average ($/kWac)**	**High ($/kWac)**
Modules	500	590	680
Inverter and Skid	60	85	110
Structural BoP	180	215	250
DC Electrical BoP	60	70	80
AC Subsystem	50	55	60
Design, Engineering, Permit, Installation, Other	555	555	610
Total	**1,350**	**1,570**	**1,790**

1. Does not include owner's engineering, capital spares, contingency, financing, substation, O&M building, interconnection or major grid upgrade costs.

For a fixed-tilt system, overall costs will decrease by approximately 10-15%. The major differences are due to decreased structural costs, labor and AC wiring.

4 OFFSHORE CAPITAL COST EXPECTATIONS

Given water depths and bathymetry in the Pacific Northwest, DNV GL expects any near-term offshore wind power project would most likely utilize floating structures to support turbines. Relative to onshore wind, floating offshore wind has significantly higher capital and operating costs but could allow for access to stronger and more consistent wind resources. Cost differences are driven by the following factors:

- *Wind turbine generators* – offshore wind turbines are generally similar to onshore wind turbines in overall architecture, but are typically much larger and designed for operations in a marine environment. While offshore wind turbine's cost per kW is closing in on onshore turbine cost, the cost of the first floating offshore wind turbines are high.
- *Substructure and mooring and anchoring system* – Floating offshore wind turbines are supported by floating support structures that are typically made of steel or concrete. Multiple design concepts are in various stages of development but generally fall into one of three design types: semi-submersibles, spars, or tension-leg platforms (TLPs). These support structures are moored to the seabed to maintain position of the unit.
- *Electrical BoP* – For large scale offshore wind farms, the turbines are typically connected to an offshore substation via a collector system consisting of array cables linking the turbine arrays to the substation. Power from the offshore project is then delivered to shore and to the grid via an export

cable. In comparison to a bottom fixed offshore project, the substation for a floating project will also need to be floating, and the infield cables will need to be dynamic.

- *Installation* – Offshore installation requires specialized equipment and workers trained for working in a marine environment. The offshore environment presents a range of hazards and risks that are not present onshore or are more easily managed. These conditions result in installation costs that are significantly greater for offshore wind projects relative to onshore wind projects.

4.1 Project and Site Assumptions – Offshore Wind

DNV GL used the following assumptions to define a theoretical utility-size offshore wind power project constructed offshore of Washington State (the "Theoretical Offshore Wind Project"):

- Located offshore of Washington State;
- Total capacity of 20-30 MW;
- Wind turbines are supported by floating support structures;
- No offshore substation is assumed due to the small size of the windfarm;
- Equipped with modern size offshore wind turbines. (i.e. 6 MW–8 MW)

All cost estimates presented herein are in 2017 dollars.

4.2 Results – Offshore Wind

Given the lack of any operating floating offshore wind projects in the United States and the limited experience with floating offshore wind globally, the cost estimates presented here are subject to a high level of uncertainty. The costs shown here are for a first of a kind pilot project with a relatively small number of turbines. Significant cost reduction can be achieved from the costs shown here with larger scale projects and the application of lessons learned after further advancement of the offshore industry in the United States.

Table 4-1 Capital cost estimates for the Theoretical Offshore Wind Project

Capital costs	Low ($/kW)	Average ($/kW)	High ($/kW)
Wind turbine generators	2,100	2,200	2,600
Floating substructure and anchoring	1,500	2,300	3,800
Electrical Balance of plant	300	700	900
Installation	1,100	2,000	3,200
Other	500	1,100	2,700
Total	**5,500**	**8,300**	**13,200**