DNV·GL

INTEGRATED RESOURCE PLANNING

Evaluation of Three Renewable Supply Options

Portland General Electric Company

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1 INTRODUCTION

Portland General Electric Company ("PGE" or the "Customer") has requested Garrad Hassan America, Inc., (hereinafter DNV GL), to provide updates to technical and financial information provided in the previous report "Integrated Resource Planning: Evaluation of Five Renewable Energy Supply Options," dated 25 November 2015 ("the 2015 analysis") [1]. PGE has requested that DNV GL provide updates related to three potential renewable electricity generation projects in support of the Customer's Integrated Resource Planning ("IRP" or "Project"). The updated projects are as follows:

- Onshore wind project in Ione, Oregon
- Onshore wind project in Central Montana
- Solar photovoltaic (PV) single-axis tracker project in Christmas Valley, Oregon

Additionally, PGE requested that only specific technical and financial parameters be updated from the 2015 analysis, as reflected in the scope of work executed between DNV GL and PGE.

Where possible and appropriate, DNV GL has kept the assumptions and methodologies similar to the 2015 analysis, such that meaningful conclusions can be drawn from a comparison between the results in the 2015 analysis and this updated report. The information provided in this Technical Note summarizes the updated results of DNV GL's analyses of these three projects along with the methodologies employed and assumptions made. Unless otherwise noted, all previous assumptions made during the 2015 analysis remain.

2 ABBREVIATIONS AND TERMINOLOGY

The following abbreviations are used in this document:

Abbreviation	Meaning
AC	Alternating Current
aMW	Average Megawatts – the total annual production divided by the number of hours per year
BoP	Balance of Plant
DC	Direct Current
EPC	Engineering, Procurement, Construction
GTM	Greentech Media
IEA	International Energy Agency
IRP	Integrated Resource Planning
O&M	Operations and Maintenance
OSEIA	Oregon Solar Energy Industries Association
PGE	Portland General Electric
PTC	Production Tax Credit
PV	Photovoltaic
Wp	Watts Peak – the measure of DC output under full solar radiation

The average capacity of the energy projects discussed herein is given in average megawatts (aMW). This is different than the project's nameplate capacity, which is discussed below in units of megawatts (MW).

The solar industry tends to base its calculations on DC electricity, whereas utilities tend to prefer to work in AC electricity. In order to convert the requested solar parameters into AC units, a DC-to-AC conversion factor of 1.2 was used. This value is commonly seen in the industry; however, for a more accurate value for a given project, a site-specific and technology-specific evaluation is required.

Within this report, solar cost results referenced to watts peak (e.g., $/Wp) are based on DC power, whereas cost results referenced to watts (e.g., $/MW) have been converted to AC power.

3 SUMMARY OF THE WORK

PGE requested that DNV GL update numerical values for the specific technical and financial parameters described in Sections 3.1 and 3.2 below, for three of the renewable energy projects under consideration in its IRP. This section describes the methodology and assumptions DNV GL used to determine these numerical values.

The three renewable energy projects under consideration are as follows:

Project name	Location	Average capacity	Generation technology
Ione Wind	Ione, Oregon	116 aMW	Wind
Central MT Wind	Montana East of Rockies Along Colstrip Line	100 aMW	Wind
Christmas Valley Solar 2	Christmas Valley, Oregon	25 aMW	Solar (single axis tracking)

As noted by PGE, these three projects are not currently under development.

3.1 Technical parameters

3.1.1 Nameplate capacity

3.1.1.1 Results

- Ione Wind: 332 MW
- Central MT Wind: 240 MW
- Christmas Valley Solar 2: 103 MWac

3.1.1.2 Methodology

For all projects, the Nameplate Capacity is calculated by dividing the Average Capacity by the Capacity Factor.

3.1.1.3 Assumptions

Assumes Average Capacities provided by the Customer (see table above).

3.1.2 Capacity factor

3.1.2.1 Results

- Ione Wind: 35%
- Central MT Wind: 42%
- Christmas Valley Solar 2: 23.3%

3.1.2.2 Methodology

- Wind projects: Gross energy is based on the power curve noted below and assumed mean wind speed (see assumptions below). Net energy includes typical energy loss factors and model-specific availability assumptions.
- Solar projects: DNV GL notes that there is a slight decrease in capacity factor from the 2015 analysis. This was due to using a different source of meteorological data from the 2015 analysis. DNV GL analyzed 5-8 publicly available and SolarAnywhere Clean Power Research sources of meteorological data, with a special focus on global horizontal irradiance (GHI). Using our latest approach, we eliminate any sources that show anomalous trends in GHI, diffuse horizontal irradiance (DHI), temperature, or wind speed and selected the source closest to median. This is the approach that DNV GL believes results in the lowest uncertainty data being used in the energy assessment. The PVsyst software was used to calculate net energy, assuming spacing and loss factors considered reasonable for the region and type of technology. The DC net capacity factor was calculated as the ratio of the net energy to the product of the Average Capacity and 8760 hour per year. The reported AC net Capacity Factor was calculated by applying a DC/AC ratio of 1.2, which is considered reasonable for this region.

3.1.2.3 Other assumptions

- Ione Wind: Mean wind speed of approximately 6.6 m/s, which is based on extensive wind resource analysis and experience in the region
- Central MT Wind: Mean wind speed of approximately 8.2 m/s, which is based on extensive wind resource analysis and experience in the region
- Christmas Valley Solar 2: Result given in AC based on DC capacity factor of 19.4% with DC/AC ratio of 1.2. Assumed horizontal single axis tracking oriented due south, normalized by DC capacity, assumed Performance Ratio of 80.0%, solar resource based on regional irradiation data, includes loss factor for inverter clipping.

3.1.3 Power curve

3.1.3.1 Results

The Vestas V110 – 2.0 MW turbine was identified as representative of the type of technology utilized in projects with this wind regime.

3.1.3.2 Methodology

Identified example of turbine currently available in the market and representative of a potentially appropriate turbine to be utilized in these regions and wind conditions.

3.1.4 8760s

3.1.4.1 Wind

The predicted 8760 of energy production at both the Ione Wind and Central MT Wind sites has been derived from hourly wind speeds from DNV GL Virtual Met Data (VMD) and hourly temperature and pressure data from MERRA-2. The long-term average seasonal and diurnal variation in air density was developed from temperature and pressure records from the MERRA-2 data and scaled to the site-predicted long-term annual site air density. The VMD simulated wind speeds at a hub height of 80 m were adjusted to reflect the predicted long-term mean wind speed and monthly profile at each site, as described in Section 3.1.2.

A simulated time series of production data was calculated using the time series of air density, wind direction, and VMD wind speeds. Energy loss factors were applied appropriately to the resulting production time series.

The resulting expected energy production at 80 m at the Ione Wind and Central MT Wind sites are presented in the accompanying Excel numerical results in the form of an 8760 time series. It is noted that the uncertainty associated with the prediction of any given month or hour of day is significantly greater than that associated with the prediction of the annual energy production. It is also noted that the results presented are inclusive of all losses.

3.1.4.2 Solar PV

DNV GL simulated the solar PV project using internal tools and the PVsyst simulation software, the most commonly used simulation tool in the industry. DNV GL currently uses version 6.52 and independently quality-checks new releases prior to adopting them. DNV GL included assumed losses for the energy simulation and assumed two annual module washes. Losses occurring after the inverter (i.e., AC ohmic, transformer, station loads, and unavailability) are calculated in a post-processing tool. DNV GL presents the expected energy production in the accompanying excel numerical results in the form of an 8760 time series.

3.2 Financial parameters

The financial parameters below were requested by the Customer. All cost figures presented herein are in 2016 dollars.

3.2.1 Total overnight capital cost, including EPC and owner's costs

3.2.1.1 Results

- Ione Wind: $M ($1,491/kW)
- Central MT Wind: $M ($1,508/kW)
- Christmas Valley Solar 2: $176M ($1,710/kWac)

3.2.1.2 Methodology

The total overnight capital cost is the cost to instantaneously develop and construct a project. Financing costs are excluded.

For the wind projects, DNV GL reviewed capital cost information for over 50 U.S. wind power projects constructed in 2015, 2016, and 2017. These projects were constructed with a variety of wind turbine technology (that is, the capital cost estimates are original equipment manufacturer (OEM)-agnostic). DNV GL has observed that BoP EPC costs vary from region to region; however, the number of Northwest U.S. wind projects constructed from 2013 to the present is limited. To better understand how Northwest U.S.

wind project BoP EPC costs compare to nation-wide costs, DNV GL analyzed BoP EPC costs in the Northwest from 2008 through 2012 (when significant wind construction was undertaken in the Northwest) and scaled those findings against nation-wide costs to develop a Northwest-specific projection. The values presented are median values.

Additional background on capital costs can be found in the U.S. Department of Energy's 2016 Capital Cost Estimates for Utility Scale Electricity Generating Plants Report [1] and for solar projects, in GTM Research's Executive Briefing Solar Data – Q3 2016 [4].

3.2.1.3 Other assumptions

- Ione Wind: Based on the following breakdown:
  - $897/kW turbine
  - $367/kW EPC
  - $227/kW development/contingency/etc.
- Central MT Wind: Based on the following breakdown:
  - $897/kW turbine
  - $384/kW EPC
  - $227/kW development/contingency/etc.
- Christmas Valley Solar 2: Cost includes turnkey construction costs and reflects single-axis tracking technologies and regional larger utility-scale PV projects that often require financing.
- These estimates do not include the cost of capital, taxes, or other financing costs.
- These estimates do not include financial impacts associated with any tax credits (e.g., the Production Tax Credit, Investment Tax Credit, etc.), or potential impacts from other revenue sources.
- The "development/contingency/etc." cost estimates provided above cover a nominal level of development spending and typical contingency above the price of the construction contract and are included here to reflect more complete project costs. These values are inherently project specific.

3.2.2 Range of costs from average total overnight capital cost

3.2.2.1 Results

- Wind projects: expected range $+2.6 to $-1.3M/MW
- Christmas Valley Solar 2: Expected range: $+1.5M to $-2.0M/MWac

3.2.2.2 Methodology

- Onshore wind project: These expected values and a range of costs were determined based on a review of over 50 U.S. wind power projects constructed in 2015, 2016, and 2017.

- Solar projects: range of ±15% based on recent project costs using similar technologies in Idaho and Colorado [6].

3.2.3 Escalation rate for capital costs over next 20 years, if different from inflation

3.2.3.1 Results

The following table and plot show DNV GL's projection for the percentage decrease in overnight capital cost for onshore wind and solar PV tracker projects. These results were informed from the 2015 analysis [1] and updated by using GTM Research's Executive Briefing Solar Data – Q3 2016 [4], and DNV GL's Wind and Solar Due Diligence Project Databases [6]. DNV GL compiled historical overnight values and correlated these to key historical market indicators, commodity prices, demographic information, and other metrics. Statistical multivariable regressions were performed until significant outcomes were obtained and a model was developed and applied to generate the projected values.

No ongoing capital costs are assumed for a given project after it achieves commercial operation.

Table 3-1 Percentage of 2017 Overnight Cost (based on $2017)

Year	Onshore Wind	PV
2017	100%	100%
2018	99%	93%
2019	97%	89%
2020	96%	84%
2021	95%	81%
2022	93%	80%
2023	92%	78%
2024	91%	77%
2025	91%	76%
2026	89%	74%
2027	89%	73%
2028	88%	72%
2029	87%	70%
2030	87%	69%
2031	86%	68%
2032	85%	66%
2033	85%	65%
2034	84%	64%
2035	84%	62%
2036	83%	61%
2037	82%	60%

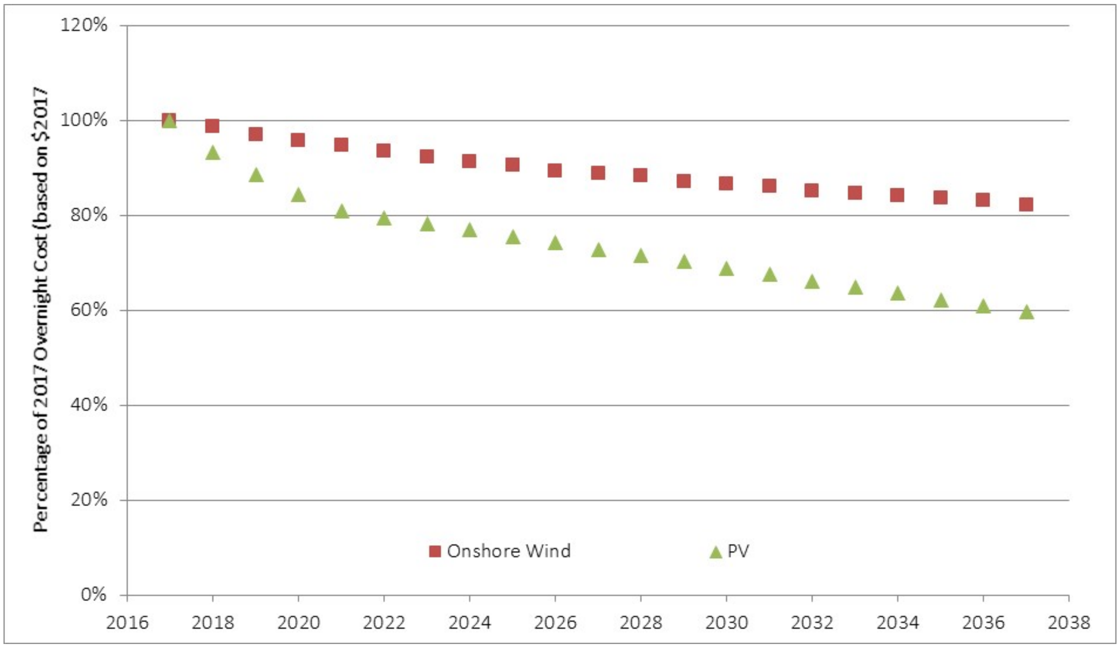

Figure 3-1 Percentage of 2017 Overnight Cost (based on $2017)

has presented values for year one; a 1% to 3% yearly escalator is common and typically negotiated as part of the O&M agreement for years thereafter.

Nominal environmental costs (such as bat and bird monitoring) have been included. Note that these costs may be present only in the first few years of a project's operation, and are inherently project specific. DNV GL has assumed no significant environmental monitoring requirements.

3.2.4 Breakdown of fixed O&M costs including, but not limited to, service contracts and warranty costs, royalty payments, and labor

3.2.4.1 Results

- Ione Wind:
  - Scheduled Turbine O&M: $17,000/MW
  - BoP O&M: $2,000-4,000/MW
  - Utilities/Consumption: $1,500/MW
  - Project Management Administration: $3,000/MW
  - Generation Charges: $1,000/MW
  - Land Lease: $5,500/MW
  - Insurance: $3,000/MW

- Property Taxes: $5,500/MW
- Professional Advisory: $3,000/MW
- Other G&A: $1,500/MW

- Central MT Wind:
  - Scheduled Turbine O&M: $17,000/MW
  - BoP O&M: $2,000-4,000/MW
  - Utilities: $1,500/MW
  - Project Management Administration: $3,000/MW
  - Generation Charges: $1,000/MW
  - Land Lease: $5,500/MW
  - Insurance: $3,000/MW
  - Property Taxes: $5,500/MW
  - Professional Advisory: $3,000/MW
  - Other G&A: $1,500/MW
- Christmas Valley Solar 2:
  - Module Cleaning: $2,400/MWac
  - Other: $6,000/MWac

3.2.4.2 Methodology

- Wind Projects: The above wind estimates are based on typical costs from projects using similar technologies at similar locations in the U.S. [6] and industry publications [7].

  Additional information on some of these charges is provided below:

  - Scheduled Turbine O&M: annual or semi-annual service
  - BoP O&M: maintenance of the physical plant
  - Utilities: electricity, water, sewer, etc. needed to operate the project facilities
  - Project Management Administration: on-site and off-site project and asset management
  - Generation Charges: interconnection charges
  - Professional Advisory: outside services such as engineering, tax, and legal services
  - Other G&A: general and administrative costs not captured above, including nominal environmental costs
- Solar Projects:
  - DNV GL's estimate is based on two module washings per year.

- The above solar estimate is based on a scope that commonly includes periodic inspection of major equipment, 24/7 monitoring, inventory management, occasional medium voltage and inverter work, preventive maintenance and monthly reporting. For sites in Oregon periodic vegetation control is common. DNV GL would expect a +25 MWac installation to have either on-site staff, or guaranteed response times. [6]

3.2.4.3 Other assumptions

- Wind projects: Based on DNV GL database and publicized industry data [7].
- Solar projects: Based on DNV GL database. Cost does not include insurance, taxes, utility fees, land lease, and other similar costs. These values are typically excluded from the technical documents reviewed by DNV GL. As such, DNV GL has too few data points to provide a meaningful estimate of non-technical costs.

3.2.5 Non-fuel variable O&M

3.2.5.1 Results

- Ione Wind: Not applicable
- Central MT Wind: Not applicable
- Christmas Valley Solar 2: Not applicable

3.2.5.2 Methodology

Consistent with the 2015 analysis and based on discussion with PGE, project O&M costs are considered to be covered under either “Fixed O&M” or “Ongoing expected Capital Additions or maintenance accrual”. As such, no costs are expected in this category.

3.2.5.3 Other assumptions

None.

3.2.6 Ongoing expected Capital Additions or maintenance accrual

DNV GL notes that in this Report and at the request of the Customer, the term “ongoing capital additions” is synonymous with the term “unscheduled maintenance,” which is more commonly used in the solar and wind industries.

3.2.6.1 Results

- Ione Wind: $12,500/MW/year
- Central MT Wind: $13,500/MW/year
- Christmas Valley Solar 2: $4,800/MWac/year

3.2.6.2 Methodology

Costs in this section are associated with the replacement or repair of major components. These are typically considered to be unscheduled costs [3].

3.2.6.3 Other assumptions

The values in this section are based on typical values seen within the wind and solar industries. The values presented here are averages over the economic life of the project.

- Ione Wind: Based on DNV GL database, 20-year average value, does not include unscheduled BOP maintenance.
- Central MT Wind: Based on DNV GL database, 20-year average value, does not include unscheduled BoP maintenance.
- Christmas Valley Solar 2:
  - 20-year average value
  - Depending on how the fixed-cost O&M contract is structured and whom it's with, a typical range is $3,600 – 6,000/MWac/year; and includes an inverter reserve and other on-site O&M costs, plus monitoring. On-site costs exclude insurance, taxes, utility fees, and similar, which are typically considered as separate line items in project budgets.
  - DNV GL notes that the cost of non-fixed O&M has increased from the 2015 analysis due to scope shifting from fixed O&M costs to non-fixed O&M costs. This shift has been driven by the competitive solar landscape. As a result of this price pressure, a less rigorous fixed O&M scope has become more common (e.g. less preventative maintenance) – which results in more issues being resolved via the non-fixed O&M budget.

3.2.7 Decommissioning accrual

3.2.7.1 Results

- Ione Wind: $0.00
- Central MT Wind: $0.00
- Christmas Valley Solar 2: $0.00

3.2.7.2 Methodology

For wind projects, decommissioning cost may be fully offset by salvage value or resale of used components in certain conditions. The five items listed below will have the largest impact on the net cost. Projects for which the below items are true are those most likely to have a net decommissioning cost of $0 or a small gain.

- Access roads do not need to be removed
- Transmission lines do not need to be removed

- Collection system does not need to be removed. Note that overhead collection system removal is significantly more expensive than underground collection system removal
- Major components aged 5 years or less can typically be re-sold for a percentage of their purchase price. This typically helps reduce net costs more than simply scrapping the metal found in the components
- Current scrap metal prices (primarily steel, iron and copper) at the time of decommissioning are at current prices or higher

Final cost may vary depending on the specific configuration of the site, as well as local, county, state, or other ordinances. A bond may be required to accumulate funds, although this is uncommon for onshore wind projects.

For the Christmas Valley 2 solar projects, decommissioning cost is assumed to be offset by salvage value of used components. A bond may be required to accumulate funds. DNV GL notes that the future cost to dispose of any waste that may in the future be deemed hazardous was not considered (e.g. lead solder).

3.2.7.3 Other assumptions

None.

4 REFERENCES

[1] DNV GL, 703337-USPO-T-01-C PGE renewables IRP support, dated 25 November 2015.

[2] U.S. Department of Energy, Capital Cost Estimates for Utility Scale Electricity Generating Plants Report, dated November 2016.

[3] DNV GL, Turbine O&M costs, 10054020, *Confidential*, dated 05 July 2017.

[4] GTM Research, Executive Briefing Solar Data – Q3 2016, dated October 2016.

[5] OSEIA & Green Energy Institute, Oregon Solar Business Plan Project Update, Dated 21 December 2016.

[6] DNV GL, Wind and Solar Due Diligence Project Databases, dated 31 May 2017.

[7] MAKE Global Wind Turbine, O&M Costs, dated 22 November 2016.