# ASSESSMENT OF THE ESTIMATED COSTS OF WIND ENERGY IN BRITISH COLUMBIA

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# REVISION HISTORY

| Issue | Issue date | Summary |
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| A | 16 May 2012 | Original draft issue. |
| B | 16 May 2012 | Minor edits, draft issue. |
| C | 24 May 2012 | Final edits, refined O&M cost assumptions. |

# CONTENTS

# EXECUTIVE SUMMARY

In March 2012, the Canadian Wind Energy Association (CanWEA) commissioned GL Garrad Hassan Canada, Inc. (GL GH) to carry out an independent, high-level assessment of the expected levelized cost of energy associated with the 121 onshore wind energy sites listed in BC Hydro's Resource Options Database (RODAT). The results of the work are reported here.

A high-level energy production assessment has been performed by GL GH to generate annual energy yield and capacity factor values for each of the 121 wind energy sites. For this high-level assessment, the annual mean wind speeds reported by DNV Global Energy Concepts Inc. in April 2009 and September 2009 for the 121 sites have been assumed as inputs. Similarly, the project capacities assumed in this assessment for the 121 sites are based on the capacities reported by DNV GEC. Four wind turbine models were selected by CanWEA for use in this study and have been assigned to projects whose annual mean wind speeds fall into specific wind speed ranges.

The range of capacity factors calculated for sites within each of the five regions assessed is summarized as follows:

| **Region** | **Net Capacity Factor** | |
|---|---|---|
| | **Minimum** | **Maximum** |
| Vancouver Island | 32% | 41% |
| North Coast – Cariboo | 30% | 36% |
| Peace | 30% | 41% |
| Southern Interior | 29% | 36% |
| Rest of BC | 24% | 37% |

It should be noted that these results should be considered indicative high-level estimates of energy production only, and caution is recommended when applying the results.

The net capacity factors calculated for each site were used as inputs to GL GH's cost model. The resulting range of unit energy costs for each region is presented in the table below, for Base and High cost calculation cases:

| **Region** | **Levelized Cost of Energy [$/MWh]** | | | |
|---|---|---|---|---|
| | **Base Cost** | | **High Cost** | |
| | **Minimum** | **Maximum** | **Minimum** | **Maximum** |
| Vancouver Island | 83 | 122 | 116 | 187 |
| North Coast – Cariboo | 88 | 110 | 121 | 158 |
| Peace | 80 | 129 | 111 | 195 |
| Southern Interior | 89 | 124 | 124 | 184 |
| Rest of BC | 96 | 155 | 133 | 235 |

It should be noted that the cost ranges presented are based on a high-level assessment of energy production and costs for the 121 wind projects considered in this study, and should be treated as <u>indicative only</u> pending a more detailed review of the sites considered.

# 1 INTRODUCTION AND BACKGROUND

Wind energy in British Columbia is a developing industry, with commercial wind farms currently operating, under construction and in development in the province. Electricity Purchase Agreements have been signed with BC Hydro for several future wind farms, and anticipated increases in electricity demand are expected to accelerate the growth of British Columbia's wind energy industry.

BC Hydro is currently developing its Integrated Resource Plan (IRP) for completion in November 2012. The IRP will guide the utility's acquisition of new generation resources to "reliably and cost-effectively meet customers' anticipated future electricity needs." [1] A major component of the IRP is BC Hydro's 2010 Resource Options Report [2] which details the potential resource options available to supply electricity in the province, and includes an assessment of the project capacity, annual energy production, and unit energy cost for 121 onshore wind energy sites distributed throughout five regions of British Columbia. This information is presented in the Resource Options Database (RODAT) [3], which is an Appendix to the Resource Options Report.

The information regarding onshore wind energy sites in the RODAT is based on the results of two studies completed by DNV Global Energy Concepts Inc. (DNV GEC) in April 2009 and September 2009 respectively [4, 5]. These studies identified potential wind energy sites in British Columbia based on a number of criteria outlined in the reports, and presented project capacities and capacity factors for the 121 onshore wind energy sites considered in the BC Hydro RODAT.

In anticipation of the release of BC Hydro's draft Integrated Resource Plan (IRP) for public comment in May 2012, the Canadian Wind Energy Association (CanWEA) has retained GL Garrad Hassan Canada, Inc. (GL GH) to carry out an independent, high-level assessment of the expected levelized cost of energy (LCOE) associated with the 121 onshore wind energy sites listed in BC Hydro's RODAT. As the wind industry is continually evolving, the purpose of the assessment is to provide a robust high-level assessment of the LCOE associated with the onshore wind energy RODAT projects, considering recent increases in wind turbine efficiencies at low to moderate wind speed sites, and employing the most current cost data available. CanWEA has also formed an Advisory Board to provide input on several assumptions made in this assessment, including turbine model selection and BC-specific cost considerations.

Section 2 of this report describes the inputs, methodology and results of a high-level energy production assessment carried out by GL GH for the 121 onshore wind energy sites.

Section 3 summarizes the energy cost assessment, including the assumptions used as inputs in the cost modeling and the results of the assessment.

Section 4 provides a summary of the main conclusions of the assessment.

# 2 HIGH-LEVEL ENERGY PRODUCTION ASSESSMENT

The local wind resource is of fundamental importance for the viability of wind projects. In a typical pre-construction energy production assessment, wind data from one or multiple meteorological masts are analyzed to gain an understanding of a proposed wind farm's local wind regime. This involves a rigorous analysis of the wind data, correlations with sources of longer-term reference wind data to predict the long-term wind regime, prediction of the site air density, wind flow modelling to establish wind speed variations across the site, wake modelling to establish array losses, and a review of other sources of energy production loss.

GL GH has undertaken a high-level energy production assessment for the 121 RODAT wind energy sites using the same principles employed in standard wind energy production assessments, but with several assumptions defined to accommodate the limited scope and timescale required for this study.

## 2.1 Inputs and Assumptions

The high-level energy production assessment was carried out based on the assumptions and calculated parameters defined below.

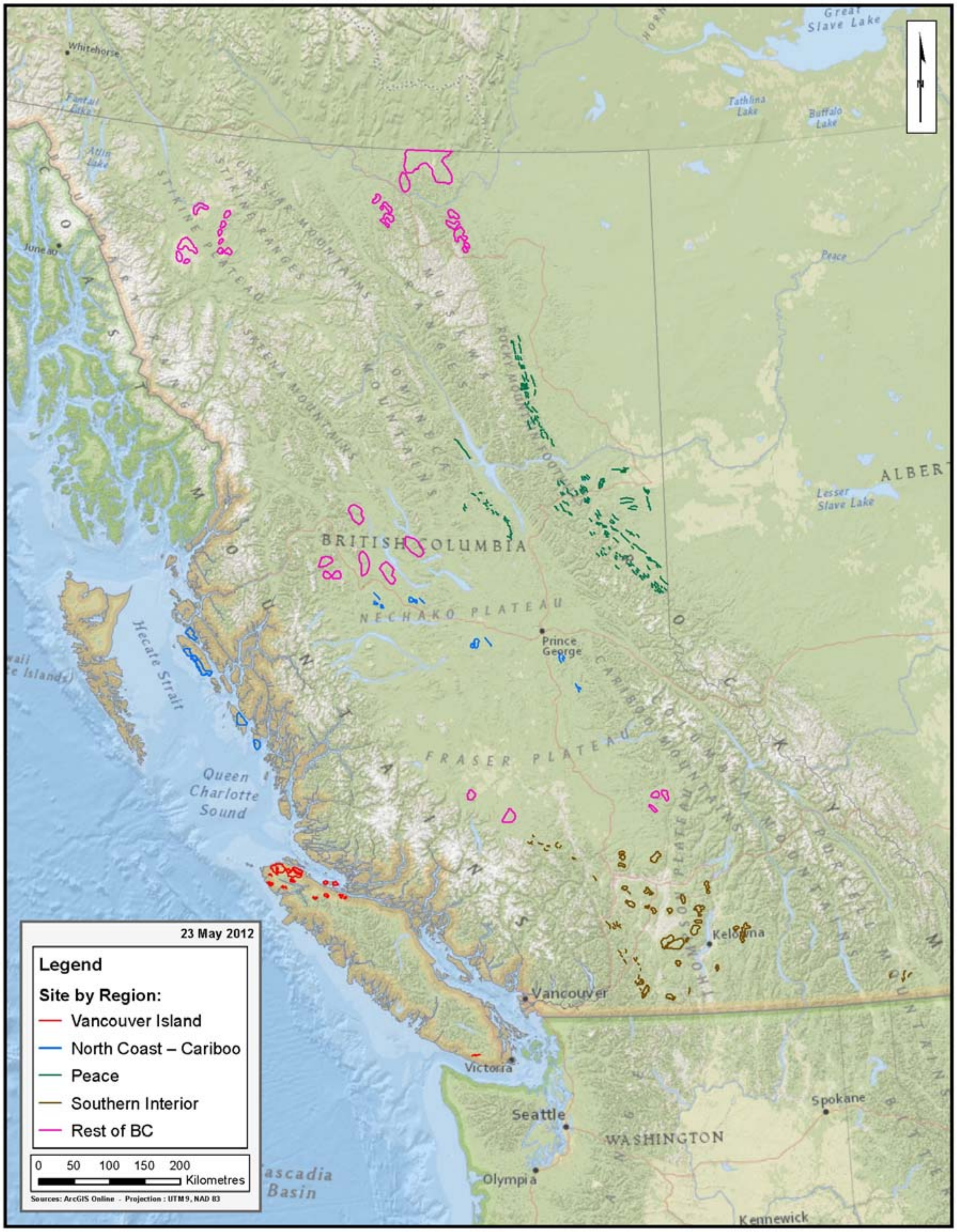
### 2.1.1 Wind Farm Locations

The 121 onshore wind energy sites included in BC Hydro's RODAT are classified into five regions of the province:

- Vancouver Island;
- the North Coast – Cariboo region;
- the Peace region;
- the Southern Interior; and
- the rest of British Columbia.

Sites in the first four of these regions were identified in DNV GEC's April 2009 report, and sites in the rest of British Columbia were identified in DNV GEC's September 2009 update report. The 121 site locations are shown in Figure 2-1, classified by region.

**Figure 2-1: Locations of 121 onshore wind energy sites considered in BC Hydro RODAT**



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### 2.1.2 Wind Farm Rated Capacities

The project rated capacity in megawatts (MW) for each of the 121 sites was obtained from the RODAT Summary Sheets [3]. These rated capacities are based primarily on the DNV GEC 2009 studies [4, 5].

In [4] and [5], installed capacities for each site were calculated by DNV GEC based on a set of turbine spacing assumptions. Turbine spacing was assumed to be approximately 4 rotor diameters between turbines along a ridge or within a row, and approximately 15 turbine diameters between rows.

As described in Section 2.1.5, several of the turbine models assumed in this assessment differ in rotor size and capacity from those used in the DNV GEC studies. GL GH has analyzed the turbine spacing that would result from use of the installed capacities calculated by DNV GEC with the turbine models selected for this assessment. For each layout type and turbine model, GL GH considers the calculated turbine spacing to be reasonable for the anticipated wind regime. Therefore, the project installed capacities calculated by DNV GEC for each site were used in this assessment. For projects where the turbine rated capacity used in this assessment differed from that of DNV GEC's study, the site installed capacity was adjusted slightly to represent the nearest whole number of turbines.

It should be noted that GL GH has not reviewed the suitability of the project installed capacities in relation to the available area, topography and other siting constraints associated with each site.

### 2.1.3 Wind Farm Annual Mean Wind Speeds

The long-term mean wind speed at a wind farm site is the most important parameter influencing the viability of the resource associated with an individual project. A significant portion of a typical energy production assessment is focused on accurately predicting the long-term mean wind speeds at hub height at individual turbine locations.

Given the limited scope and timescale associated with this high-level assessment, GL GH has assumed the same average annual mean wind speeds for each of the 121 onshore wind energy sites as calculated in previous studies completed by DNV GEC [4, 5], which also formed the basis of the BC Hydro RODAT. These mean wind speeds were assumed to be the average for all project turbines at a hub height of 80 m.

It should be noted that GL GH has not assessed the accuracy of the wind speed predictions from the previous DNV GEC studies.

Of the 121 RODAT sites, 95 were located in four defined regions in British Columbia: Vancouver Island, the North Coast, the Peace region, and the Southern Interior. For these 95 sites, annual mean wind speed information from the DNV GEC April 2009 study is available in [4]. The same annual mean wind speeds were assumed for each site in this study.

The 26 RODAT sites found outside the aforementioned four regions of the province were presented in the DNV GEC September 2009 update report [5] without associated annual mean wind speed information. For these sites, annual mean wind speed values were estimated by GL GH based on the parameters presented in [5]:

- Weibull wind speed frequency distribution with shape factor of 2.0;
- Turbine model and air density; and
- Net capacity factor.

No adjustments were applied to these wind speeds by GL GH in this assessment.

### 2.1.4 Wind Speed Frequency Distributions

The site-specific frequency distribution of wind speeds is combined with the power curve to determine the energy production at a given site. Therefore, the shape of the wind speed frequency distribution is another important factor influencing project energy production. As the frequency distributions used by DNV GEC for the 121 sites were not publicly available, GL GH has produced regionally representative frequency distributions based on publicly available wind data and on its experience conducting wind resource assessments in British Columbia.

GL GH has created representative frequency distributions for each of the first four defined regions listed in Section 2.1.1. For the 26 sites found outside these four regions, GL GH has used a Weibull distribution with shape factor of 2.0, as was done in the DNV GEC September 2009 study [5]. For each of the sites within a region, the representative regional frequency distribution was scaled to the annual mean wind speed assumed for the site.

### 2.1.5 Turbine Model Selection

CanWEA and its Advisory Board have selected four turbine models from leading European and North American manufacturers for use in this high-level assessment. The selected turbine models are considered to be modern machines and were selected to cover the broad range of wind conditions at wind farms sites considered in this study. The specific turbine models are not identified in this report.

The nameplate rated capacities of the turbines range from 2.3 MW to 3.0 MW, and a hub height of 80 m was assumed for each model. It should be noted that GL GH has not taken into account the specific hub heights available for each turbine model, but notes that each model considered is currently offered with a hub height at or near the 80 m assumption.

These turbine models were assigned to sites with annual mean wind speeds within a specific range, using the International Electrotechnical Commission (IEC) [6] design classification wind speed ranges as a broad guideline. Table 2-1 presents the annual mean wind speed range for which each turbine model was used in the assessment.

**Table 2-1: Turbine Classification Assumptions**

| Turbine Model | Wind Speed Range | |
|---|---|---|
| | Minimum | Maximum |
| A | 9.0 m/s | >9.0 m/s |
| B | 8.5 m/s | 9.0 m/s |
| C | 7.5 m/s | 8.5 m/s |
| D | <7.5 m/s | 7.5 m/s |

While all of the selected turbines are all currently available to wind energy project developers, it is worth noting that turbines B, C, and D, were not available at the time of the DNV GEC studies in 2009. Turbine model A was available in 2009 and was employed as a turbine in the 2009 DNV GEC studies.

It is noted that turbine model B is certified to IEC design class II, but was assigned to sites at the lower end of Class I average annual mean wind speeds (8.5 m/s to 9.0 m/s). This decision was made at the direction of CanWEA, and is understood to be based on conversations with the Original Equipment Manufacturer (OEM) for turbine model B.

It is also noted that annual mean wind speed is only one site suitability parameter considered in the IEC design standard, and that no formal site suitability review was undertaken by GL GH in assigning specific models to each site. For example, turbulence intensity classes for the selected turbine models were not considered in this high-level assessment. Furthermore, other design suitability parameters such as wind shear, temperature, and extreme wind speeds have not been considered when assigning turbine models to the 121 sites.

Power curves for each of the turbine models selected by CanWEA have been obtained from the turbine manufacturers. Where available, the power curves have been obtained for the regional air densities discussed in Section 2.1.6. Where power curves for these air densities were not available, power curves have been adjusted to these air densities in accordance with the recommendations of the IEC [6].

### 2.1.6 Air Density

In order to select a specific power curve for the calculation of energy production at each site, the site air density must be considered. For this high-level assessment, GL GH calculated a representative air density for all sites within each region under consideration. This calculation was based upon the range of site locations and elevations in each region. The assumed representative air densities by region are shown in Table 2-2.

**Table 2-2: Regional Air Density Assumptions**

| Region | Representative Air Density (kg/m$^3$) |
|---|---|
| Vancouver Island | 1.20 |
| North Coast – Cariboo | 1.15 |
| Peace | 1.10 |
| Southern Interior | 1.05 |
| Rest of BC | 1.10 |

It is noted that although there was significant variation in site locations and elevations within each region, power curves for the above air densities were used for all sites in each region. GL GH considers this approach appropriate for this high-level assessment.

## 2.2 Net Energy Production Assessment

### 2.2.1 Gross Annual Energy Yield

Using the assumed annual mean wind speeds and the regionally representative wind speed frequency distributions assigned by GL GH to characterize the wind regime at each site, and applying the power curves for the appropriate turbine model and representative air density, gross annual energy production results were obtained for the 121 sites on a per-turbine basis. By extrapolating the per-turbine estimate to the installed capacity assumed at each site, the predicted gross annual energy yield for each site was determined.

### 2.2.2 Energy Loss Factor Assumptions

GL GH has developed a set of energy loss factors appropriate for the various regions, turbine models, and layout configurations represented by the 121 wind energy sites. These loss factors are applicable to the first 20 years of wind farm operation. The loss factors have been developed based on regional and turbine-specific considerations, and also taking into account the impact of site terrain on layout-dependent wake effects.

Table 2-3 outlines the loss factors used in this high-level assessment.

**Table 2-3: Energy Loss Factor Assumptions**

| Energy Loss Factor | Loss Range (%) |
|---|---|
| Wake effects | 3.0 - 7.0 |
| Availability | 5.2 - 6.2 |
| Electrical efficiency | 3.0 |
| Turbine performance | 3.5 - 4.6 |
| Environmental | 1.7 - 3.9 |
| Curtailment | 0 |
| **Total losses** | 16.3 - 21.9 |

The table above includes potential sources of energy loss that have been estimated or assumed. It is important to note that wind farm loss factors are site and project specific, and some high-level assumptions have been made in this assessment. For this analysis the following general approach has been adopted for each category of loss factors:

1. Wake effects: Losses at the 121 sites are dependent upon the layout configuration and wind speed and direction frequency distribution at each site. GL GH has classified each of the 121 sites into three assumed layout configurations: plateau, single ridge, and multiple ridge layouts. Array loss assumptions have been assigned according to these classifications, as indicated in Table 2-4.

   **Table 2-4: Wake Loss Assumptions**

   | Layout Configuration | Wake Effects |
   |---|---|
   | Plateau | 93.0% |
   | Ridgeline – multiple rows | 95.0% |
   | Ridgeline – single row | 97.0% |

   It is noted that no wake effect calculations have been undertaken in this exercise due to the limited scope and timescale of this study.

2. Availability: Estimates are made for anticipated wind turbine, balance of plant, and electrical grid availability. The turbine-specific availability losses are based upon a GL GH database of the

availability achieved by wind farms in North America. Standard loss factors have been applied by GL GH to account balance of plant and grid availability.

3. Electrical efficiency: This generic loss factor accounts for the electrical losses encountered when the wind farm is operational and will manifest itself as a reduction in the energy measured by an export meter. This is presented as an overall electrical efficiency and is based on the long-term average expected production pattern of the wind farm.

4. Turbine performance: These losses account for the differences between site wind flow conditions and those seen at simple terrain and neutral condition test sites on which power curve measurements are typically based. These losses include the effects of wind shear and atmospheric stability, as well as effects of the typical sub-optimal operation of turbines observed by GL GH at most operating wind farm sites. A calculation of hysteresis losses associated with high wind speed events has also been undertaken for each site, based on the appropriate power curve and the estimated site wind speed frequency distribution.

5. Environmental: Environmental losses include the effects of icing, dirt accretion and blade degradation, as well as losses associated with icing and low-temperature shutdown of turbines.

6. Curtailment: For this high-level assessment, it has been assumed that no wind sector management strategy or other curtailment would be required at any of the 121 sites.

Total losses were calculated for each site, and ranged between 16.3% and 21.9% depending on the regional, turbine-specific, and layout configuration considerations described above.

### 2.2.3 Results

The installed capacity, calculated annual energy production, and capacity factor for each of the 121 sites are presented in Appendix A. These results were used as inputs to the financial model described in Section 3.

The range of capacity factors estimated for sites within each of the five regions assessed is summarized as follows:

**Table 2-5: Net Capacity Factor Range**

| Region | Net Capacity Factor | |
|---|---|---|
| | Minimum | Maximum |
| Vancouver Island | 32% | 41% |
| North Coast – Cariboo | 30% | 36% |
| Peace | 30% | 41% |
| Southern Interior | 29% | 36% |
| Rest of BC | 24% | 37% |

These results should be considered indicative high-level estimates of energy production only, and caution is recommended when applying the results. Furthermore, it should be noted that capacity factors are turbine-specific parameters. As four different turbine models are considered in this assessment, the capacity factors reported are a function of both the wind resource predicted and turbine model assumed for each site. It is recommended that this be considered when interpreting the capacity factor results.

# 3 LEVELIZED COST OF ENERGY ESTIMATE

The Canadian Wind Energy Association (CanWEA) has requested that GL GH carry out an independent, high-level assessment of the expected levelized cost of energy associated with the 121 onshore wind energy sites listed in the BC Hydro Resource Options Database (RODAT) [1].

GL GH has considered the likely cost of wind farm development, construction and operation in the British Columbia market, based upon experience of project costs in the North American market. This includes a review of costs from more than 6 GW of built projects in the Northern United States and Canada. GL GH has considered the influence of current market conditions on these costs and likely adjustments to these costs for projects built in British Columbia.

It is important to note that costs and financing structure can be expected to vary significantly for individual wind farm projects. GL GH has attempted to address this within the analysis through consideration of a range of Base and High cost factor assumptions. Base costs are considered to be the 50$^{th}$ percentile of the estimated range of costs within a given category, and High costs are considered to be the 75$^{th}$ percentile of the estimated range of costs within a given category. As such, it is possible that this range will not be suitable for all projects in British Columbia. It should also be noted that the scope of this assessment did not include adjustments for cost related to specific site conditions and extreme remoteness.

All cost ranges presented are based on a high-level assessment of energy production and costs for the 121 wind projects considered in this study. The resulting LCOE calculations should therefore be treated as indicative only, pending a more detailed site specific review. Due to the limited amount of historical operating cost data in British Columbia, GL GH has taken into consideration information regarding current Capital Expenditure (CAPEX) and Operating Expenditure (OPEX) costs provided by the CanWEA Advisory Board Members, particularly with regard to additional costs resulting from the challenging terrain and remote nature of many BC wind energy projects. It should be noted that in every case where BC-specific cost factors have been used instead of North American cost data, the BC-specific cost factor is higher, resulting in higher total project costs.

## 3.1 Capital Expenditure Costs (CAPEX) Considerations

Costs associated with capital expenditure were classified into the categories defined in Table 3-1.

**Table 3-1: Capital Expenditure Cost Categories**

| CAPEX Category | Cost per unit | Description |
|---|---|---|
| Wind Turbine Costs | MW | Turbine Supply Agreement (TSA), storage, transportation to site, equipment options, commissioning, purchase of SCADA under TSA |
| Connection Charges | MW | Costs under the Interconnection Agreement (excluded at the request of the CanWEA Advisory Board due to the variability of this cost) |
| BOP - Civil Costs | MW | Foundations, Roads (on site and public), Crane Pad and Laydown areas, Mobilization, other such as waste disposal, clean up and landscaping |

| | | |
|---|---|---|
| BOP - Electrical Costs | MW | Substation, HV/fiber optic, cables, switch gear |
| BOP – Electrical Lines | MW | Electrical Lines within the project site |
| BOP - Other Hard Costs | MW | Met towers, O&M building, Spares, Communication |
| BOP Turbine Installation | MW | Work related to the installation of wind turbines |
| Transmission Line | km | Cost of building the transmission lines |
| Project Management (Developer/Owner) | project | Project & Construction Management |
| Development | project | External engineering studies such as Topography and Geotechnical surveys, Civil and Electrical Design |
| Advisors | project | Insurance, Legal Costs, Advisers |
| Contingency | MW | Allowance for weather or wind days, liquidated damages, contingency for BOP costs |

### 3.1.1 Turbine Costs

A high-level analysis was undertaken to compile turbine cost assumptions which are based on GL GH experience of onshore wind farm project development from 2011 to 2012 and current market research.

Costs for turbines from European and North American wind turbine manufacturers are estimated to have decreased by approximately 20% over the last two years due to changing market conditions and turbine supply. The reported costs in this study are in line with the March 2012 Bloomberg estimate of a turbine cost per MW of $1.21M, which is 4% lower from six months earlier [7]. It is important to note that turbine prices will vary between OEM's, regions, and turbine models.

GL GH has not projected future changes in the turbine supply or construction market, but notes that the prices used do reflect recent decreases in turbine supply costs. All costs are reported in 2012 Canadian Dollars.

### 3.1.2 Balance of Plant (BOP) Costs

The CanWEA Advisory Board provided current cost information with regard to the construction of Balance of Plant, which resulted in higher unit costs due to BC geography, and the remoteness of many development sites, as compared with national or North American average costs.

### 3.1.3 Transmission Costs

The distance to nearest transmission lines in kilometers for each of the 121 sites noted in Appendix A was obtained from [4] and [5]. A Base and High cost range for the cost of transmission lines was agreed to in consultation with the CanWEA Advisory Board. These reflect the higher real costs imposed by BC geography, and the remoteness of many development sites, as compared with national or North American average costs. In practice there may be sharing of transmission costs between projects, however, this assumption is not used within this analysis.

It should be noted that no detailed review of transmission interconnection has been undertaken in this study. As such, it is possible that this range will not be suitable for all projects in British Columbia, particularly those with especially challenging transmission interconnection considerations.

### 3.1.4 Loan Fees and Contingency

Following discussion with the CanWEA Advisory Board, Loan Fees were estimated at 2% of total CAPEX and a Contingency of 10% was applied to total BOP costs.

### 3.1.5 Construction Loan Interest

Construction Loan Interest was estimated to be 2.0% and 2.5% for the Base and High cost cases, respectively.

## 3.2 Operating Costs (OPEX) Considerations

Costs associated with wind farm operations were classified into the categories defined in Table 3-2.

**Table 3-2: Operating Cost Categories**

| Operations and Maintenance Category | Cost per unit | Description |
|---|---|---|
| Turbine Scheduled O&M | WTG | Turbine fees, turbine labor, scheduled maintenance and service, tools and equipment; personnel costs such as travel and meals. |
| Turbine Unscheduled Repairs | WTG | Non-routine maintenance and service which varies during warranty and post warranty life of the project. |
| Balance of Plant (BoP) Maintenance | WTG | O&M conducted on site to components including collection system, substation, roads and fences; spare parts and consumables; vehicles. Waste management, security, O&M building rent, Office Supplies, |
| Utilities | MWh | Electrical usage, facility utilities, telecom expenses, IT costs. |
| Project Admin/Mgt Fees | Project | Project administration/management fees, inventory fees. |
| Wind Integration Charges | MWh | Not considered due to uncertain variability |
| Land Leases/Royalties | MWh | Lease payments or royalties payable to third party land owners |
| Insurance | MWh | Insurance premiums and/or deductibles with regard to the wind farm site |
| Property Tax/Business Rates | MW | Tax due with respect to the wind farm site |
| Outside Service | Project | Environmental expense; consultant fees including audit, IE, legal, tax services; meteorological data analysis, regulatory compliance. |

| | | |
|---|---|---|
| Other General & Admin | MWh | Production Shortfall Penalties, Generation Charges, Fuel, Co-Tenancy Fee, Bank/Guarantee fees, community involvement, License, permits and fees, Sales & Marketing Costs, Miscellaneous expenses, contingency. |

### 3.2.1 Topography considerations

The topography in British Columbia varies considerably across British Columbia. The majority of the 121 onshore wind projects considered in this assessment can be broadly characterized as being located on plateaus or mountain ridges. For the purposes of this high-level assessment, as discussed in Section 2.2.2, GL GH has classified each of the 121 projects into plateau and ridgeline sites. With the agreement of the Advisory Board, costs for projects situated on ridgeline locations were adjusted to capture additional cost associated with accessibility issues and more complex topography.

### 3.2.2 Turbine O&M Costs

Due the remoteness of many of the sites and lack of established third party O&M providers, it is assumed that longer-term extended service and maintenance agreements provided by the original equipment manufacturer (OEM) will be the most practical option for turbine operations and maintenance. These agreements are typically for a fixed fee and include scheduled and unscheduled maintenance. While this provides a level annual cost, it does come at a premium due to the lack of competition from owner operations and third party providers.

At the end of the extended service agreement, the project will need to purchase strategic and regular spare parts. Again, due to the remoteness of many of the sites, and the inability to share parts procurement with other sites, it is assumed that a project owner will need to purchase considerably more spares than a site with easy access to parts suppliers. The assumption for Unscheduled Turbine Maintenance is therefore higher than compared with national or North American average costs.

### 3.2.3 Balance of Plant

Wind farms in BC face additional challenges with remote sites, long access roads, snow clearing and transmission line operations from weather and natural hazards. The CanWEA Advisory Board noted that many of the future wind development areas will require significant transmission infrastructure to reach the grid and this is likely to result in higher than normal transmission maintenance costs.

### 3.2.4 Project Administration / Management Fees

These fees vary considerably depending on the corporate strategy which may determine that all corporate costs associated with the asset management of the wind farm should be charged directly to the wind project. Other projects may have a fixed annual charge of between $200k to $300k.

### 3.2.5 Land Lease and Royalties

Land lease and royalty cost factors have been increased over national or North American average costs to reflect lease and benefits payments to both government and First Nations. This assessment does not include revenue calculations; therefore it was not possible to apply a percentage to total revenue. Following discussion with the CanWEA Advisory Board an assumption was made of $2.50 to $4.00 per MWh for the Base and High cost cases, respectively.

### 3.2.6 Property Taxes and Business Rates

The CanWEA Advisory Board provided the cost ranges for this category based on actual experience.

### 3.2.7 Other Assumptions

At the request of the CanWEA Advisory Board, no interconnection costs are included (these include not only infrastructure at the point of interconnection, but can also include upgrades to transmission infrastructure anywhere between the point of interconnection and the load centre if transmission limits are exceeded). Furthermore, the $10/MWh wind integration charge, applied by BC Hydro in levelizing the cost of wind in comparison to other resource options, was not included in the analysis.

The Cost assumptions used in the analysis are listed in Table 3.3 for the Base and High cost cases.

**Table 3-3: CAPEX and OPEX Cost Assumptions**

| Assumptions for LCOE Calculation | Plateau | | Ridgeline | | Measure |
|---|---|---|---|---|---|
| | Base | High | Base | High | |
| **CAPEX Costs** | | | | | |
| Turbine Cost | 1,200k | 1,600k | 1,260k | 1,680k | MW |
| BOP – Civil | 325k | 375k | 375k | 450k | MW |
| BOP - Electrical (substation/HV/fiber optic/cables/switch gear) | 110k | 140k | 110k | 140k | MW |
| BOP – Electrical lines within project site | 100k | 135k | 115k | 150k | MW |
| BOP – Other Hard Cost | 50k | 75k | 50k | 75k | MW |
| Transmission line | 400k | 700k | 400k | 700k | Km |
| BOP Turbine Installation | 75k | 125k | 90k | 140k | MW |
| Project Mgt (Developer/Owner) | 2,000k | 4,000k | 2,000k | 4,000k | Project |
| Development | 3,000k | 6,000k | 3,000k | 6,000k | Project |
| Advisers | 2,000k | 7,000k | 2,000k | 7,000k | Project |
| Contingency | 66k | 85k | 74k | 96k | MW |
| **OPEX Costs** | | | | | |
| Turbine Scheduled O&M | 50k | 90k | 50k | 90k | WTG |
| Turbine Unscheduled O&M | 31k | 37k | 34k | 40k | WTG |
| Balance of Plant | 9.5k | 12.8k | 10.8k | 14.7k | WTG |
| Utilities | 0.14 | 0.33 | 0.14 | 0.33 | MWh |
| Project Admin/ Management Fees | 200k | 600k | 200k | 600k | Project |
| Land Lease/ Royalties | 2.5 | 4.0 | 2.5 | 4.0 | MWh |
| Insurance | 0.95 | 1.37 | 0.95 | 1.37 | MWh |
| Property Tax/Business Rates | 8k | 10k | 8k | 10k | MW |
| Outside Services | 100k | 300k | 100k | 300k | Project |
| Other General & Admin | 0.31 | 0.4 | 0.31 | 0.4 | MWh |

### 3.3 Levelized Cost of Energy (LCOE)

The LCOE calculation is based on a standard methodology provided by NREL [8] and is on a pre-tax basis in order to reflect the approach taken in materials published by BC Hydro [9] related to the calculation of Unit Energy Cost. The equation considered is as follows:

$$\mathbf{LCOE} = \frac{\mathbf{(FCR \times ICC) + AOE}}{\mathbf{AEP}\boldsymbol{net}}$$

Where **LCOE** = Levelized cost of energy ($/MWh)
**FCR** = fixed charge rate (%)
$= \frac{d(1+d)^n}{(1+d)^n - 1}$
**ICC** = installed capital cost
**AEP*net*** = net annual energy production or P50 (MWh/year)
**AOE** = levelized operating expenses
**d** = discount rate (%) (assumed to be 8% or 10%)
**n** = operational life (assumed to be 20 years)

The LCOE for each of the 121 sites are presented in Appendix A. Minimum and maximum values determined for sites within each of the five regions are presented in Table 3-4.

**Table 3-4: LCOE Results – 8% Discount Rate**

| Region | Levelized Cost of Energy [$/MWh] | | | |
|---|---|---|---|---|
| | Base Cost | | High Cost | |
| | Minimum | Maximum | Minimum | Maximum |
| Vancouver Island | 83 | 122 | 116 | 187 |
| North Coast – Cariboo | 88 | 110 | 121 | 158 |
| Peace | 80 | 129 | 111 | 195 |
| Southern Interior | 89 | 124 | 124 | 184 |
| Rest of BC | 96 | 155 | 133 | 235 |

Supply curves have been prepared for the Base and High cost cases for each of the 121 sites considered based on an 8% discount rate, as presented in Appendix B.

At the request of CanWEA, GL GH has also calculated the LCOE results based on a 10% discount rate to assess the sensitivity associated with higher financing costs. The results from this sensitivity analysis are presented in Table 3-5 on a regional basis.

**Table 3-5: LCOE Results – 10% Discount Rate**

| Region | Levelized Cost of Energy [$/MWh] | | | |
|---|---|---|---|---|
| | Base Cost | | High Cost | |
| | Minimum | Maximum | Minimum | Maximum |
| Vancouver Island | 92 | 137 | 128 | 209 |
| North Coast – Cariboo | 98 | 123 | 135 | 176 |
| Peace | 89 | 145 | 124 | 220 |
| Southern Interior | 99 | 138 | 137 | 205 |
| Rest of BC | 107 | 174 | 148 | 265 |

# 4 CONCLUSIONS

The results of the high-level energy production assessment show significant increases in energy production as compared to the values stated in the RODAT [1], for the majority of the 121 sites. This is primarily due to the higher efficiency turbine models used in this assessment for a majority of the sites.

The range of capacity factors estimated for sites within each of the five regions assessed is summarized in Table 4-1.

**Table 4-1: Net Capacity Factor Range**

| Region | Net Capacity Factor | |
|---|---|---|
| | Minimum | Maximum |
| Vancouver Island | 32% | 41% |
| North Coast – Cariboo | 30% | 36% |
| Peace | 30% | 41% |
| Southern Interior | 29% | 36% |
| Rest of BC | 24% | 37% |

GL GH has applied a high-level calculation of LCOE using Base Case and High Case cost assumptions. Minimum and maximum values determined for sites within each of the five regions assessed were as presented in Table 4-2.

**Table 4-2: LCOE Results – 8% Discount Rate**

| Region | Levelized Cost of Energy [$/MWh] | | | |
|---|---|---|---|---|
| | Base Cost | | High Cost | |
| | Minimum | Maximum | Minimum | Maximum |
| Vancouver Island | 83 | 122 | 116 | 187 |
| North Coast – Cariboo | 88 | 110 | 121 | 158 |
| Peace | 80 | 129 | 111 | 195 |
| Southern Interior | 89 | 124 | 124 | 184 |
| Rest of BC | 96 | 155 | 133 | 235 |

When comparing the LCOE results to the values reported in the RODAT [3], it should be noted that GL GH did not apply any site specific scaling factors other than an adjustment to account for higher costs likely to be associated with projects situated on ridgelines. GL GH is not aware of the detailed assumptions used in the RODAT calculation of unit energy cost, however it appears that the fundamental calculation of LCOE is similar.

It should be noted that the cost ranges presented are based on a high-level assessment of the energy production and costs for the 121 wind projects considered in this study, and should be treated as indicative only pending a more detailed review of the sites considered.

# 5 REFERENCES

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6. IEC 61400-12-1, "Wind turbines - Part 12-1: Power performance measurements of electricity producing wind turbines, Annex G," 2005.

7. Bloomberg New Energy Finance Wind Price Index March 06 2012

8. "2010 Cost of Wind Energy Review" Technical Report NREL/RP-5000-52920 April 2012.

9. BC Hydro Resource Options Workshop #1 Session IV Unit Cost Methodology

# APPENDIX A

## Levelized Cost of Energy Results

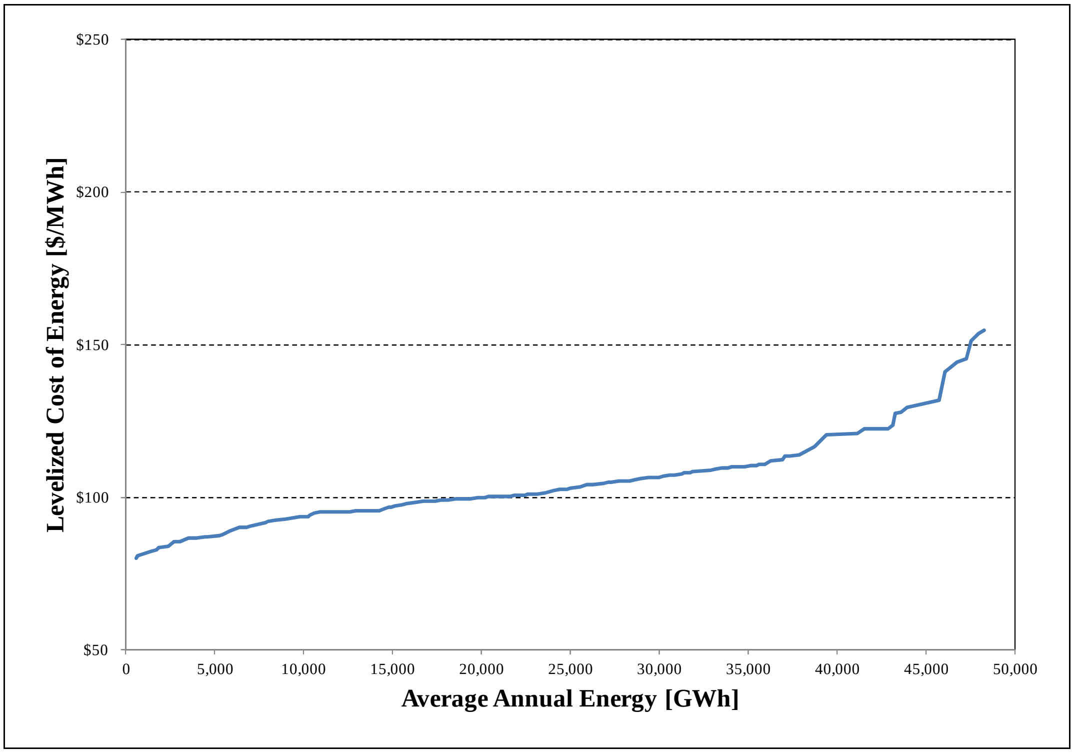
| Site ID | Distance to Transmission (km) | Wind Speed (m/s) | Capacity (MW) | Turbine Model | Annual Production (GWh) | Net Capacity Factor | Levelized Cost of Energy ($/MWh) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Base | High |
| BC01 | 225 | 6.2 | 94.3 | D | 240 | 29% | 153 | 230 |
| BC02 | 220 | 6.6 | 85.1 | D | 237 | 32% | 144 | 218 |
| BC03 | 215 | 6.7 | 71.3 | D | 207 | 33% | 145 | 221 |
| BC04 | 130 | 6.7 | 87.4 | D | 254 | 33% | 122 | 180 |
| BC05 | 125 | 5.6 | 142.6 | D | 301 | 24% | 152 | 218 |
| BC06 | 115 | 5.6 | 142.6 | D | 301 | 24% | 151 | 216 |
| BC07 | 105 | 6.4 | 128.8 | D | 344 | 31% | 120 | 173 |
| BC08 | 265 | 7.3 | 161.0 | D | 523 | 37% | 110 | 161 |
| BC09 | 260 | 7.2 | 144.9 | D | 458 | 36% | 110 | 162 |
| BC10 | 330 | 6.8 | 163.3 | D | 474 | 33% | 122 | 181 |
| BC11 | 305 | 6.5 | 151.8 | D | 408 | 31% | 132 | 195 |
| BC12 | 280 | 6.6 | 108.1 | D | 306 | 32% | 141 | 212 |
| BC13 | 265 | 7.2 | 161.0 | D | 512 | 36% | 112 | 164 |
| BC14 | 240 | 6.5 | 78.2 | D | 214 | 31% | 155 | 235 |
| BC15 | 210 | 6.6 | 232.3 | D | 643 | 32% | 110 | 158 |
| BC16 | 210 | 6.5 | 140.3 | D | 384 | 31% | 128 | 187 |
| BC17 | 165 | 6.9 | 289.8 | D | 853 | 34% | 99 | 139 |
| BC18 | 5 | 6.5 | 167.9 | D | 460 | 31% | 105 | 146 |
| BC19 | 5 | 6.8 | 103.5 | D | 302 | 33% | 100 | 141 |
| BC20 | 5 | 6.9 | 103.5 | D | 311 | 34% | 97 | 137 |
| BC21 | 25 | 6.8 | 218.5 | D | 638 | 33% | 99 | 138 |
| BC22 | 0 | 6.6 | 259.9 | D | 720 | 32% | 96 | 133 |
| BC23 | 25 | 6.6 | 103.5 | D | 293 | 32% | 106 | 150 |
| BC24 | 135 | 6.4 | 131.1 | D | 339 | 30% | 121 | 175 |
| BC25 | 85 | 6.6 | 158.7 | D | 439 | 32% | 105 | 150 |
| BC26 | 10 | 6.1 | 163.3 | D | 399 | 28% | 111 | 154 |
| NC01 | 70 | 7.4 | 561.2 | D | 1729 | 35% | 88 | 121 |
| NC02 | 50 | 7 | 234.6 | D | 678 | 33% | 96 | 134 |
| NC05 | 155 | 6.6 | 262.2 | D | 703 | 31% | 109 | 153 |
| NC06 | 185 | 6.9 | 200.1 | D | 568 | 32% | 108 | 155 |
| NC07 | 25 | 6.9 | 117.3 | D | 340 | 33% | 103 | 145 |
| NC08 | 10 | 6.5 | 195.5 | D | 514 | 30% | 102 | 143 |
| NC09 | 30 | 7.2 | 333.5 | D | 995 | 34% | 90 | 125 |
| NC10 | 15 | 7 | 96.6 | D | 285 | 34% | 101 | 143 |
| NC11 | 25 | 6.6 | 75.9 | D | 212 | 32% | 110 | 158 |
| NC12 | 20 | 7.2 | 75.9 | D | 236 | 36% | 98 | 141 |
| PC01 | 130 | 7.4 | 151.8 | D | 511 | 38% | 97 | 139 |
| PC02 | 140 | 7 | 138.0 | D | 423 | 35% | 108 | 156 |
| PC03 | 145 | 8.7 | 61.5 | B | 208 | 39% | 114 | 173 |
| PC04 | 130 | 8.5 | 103.7 | C | 348 | 38% | 101 | 148 |
| PC05 | 125 | 8.9 | 95.3 | B | 331 | 40% | 97 | 142 |

| Site ID | Distance to Transmission (km) | Wind Speed (m/s) | Capacity (MW) | Turbine Model | Annual Production (GWh) | Net Capacity Factor | Levelized Cost of Energy ($/MWh) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Base | High |
| PC06 | 105 | 8.6 | 242.9 | B | 812 | 38% | 87 | 122 |
| PC07 | 120 | 7.7 | 116.4 | C | 351 | 34% | 109 | 157 |
| PC08 | 90 | 8 | 40.5 | C | 126 | 35% | 127 | 195 |
| PC09 | 70 | 9.1 | 207.0 | A | 599 | 33% | 100 | 140 |
| PC10 | 55 | 9 | 298.3 | B | 1046 | 40% | 80 | 111 |
| PC11 | 85 | 9.5 | 126.0 | A | 384 | 35% | 101 | 144 |
| PC12 | 75 | 8 | 96.1 | C | 305 | 36% | 101 | 145 |
| PC13 | 75 | 9.9 | 135.0 | A | 431 | 36% | 95 | 135 |
| PC14 | 55 | 9.2 | 144.0 | A | 423 | 33% | 100 | 141 |
| PC15 | 35 | 9.2 | 108.0 | A | 317 | 33% | 100 | 142 |
| PC16 | 45 | 9.5 | 99.0 | A | 302 | 35% | 99 | 141 |
| PC17 | 10 | 7.4 | 103.5 | D | 348 | 38% | 88 | 124 |
| PC18 | 5 | 8.5 | 139.2 | C | 477 | 39% | 83 | 116 |
| PC19 | 25 | 9.4 | 117.0 | A | 360 | 35% | 94 | 132 |
| PC20 | 50 | 9 | 159.9 | B | 573 | 41% | 81 | 113 |
| PC21 | 15 | 9.4 | 99.0 | A | 305 | 35% | 94 | 132 |
| PC22 | 130 | 6.3 | 207.0 | D | 552 | 30% | 117 | 165 |
| PC23 | 80 | 7.1 | 55.2 | D | 176 | 36% | 113 | 169 |
| PC24 | 50 | 6.8 | 117.3 | D | 345 | 34% | 105 | 149 |
| PC25 | 20 | 7.2 | 158.7 | D | 505 | 36% | 92 | 129 |
| PC26 | 5 | 8.7 | 126.1 | B | 427 | 39% | 82 | 115 |
| PC27 | 15 | 7.4 | 110.4 | D | 356 | 37% | 87 | 122 |
| PC28 | 20 | 9.6 | 153.0 | A | 482 | 36% | 90 | 126 |
| PC29 | 0 | 6.4 | 89.7 | D | 235 | 30% | 104 | 147 |
| PC32 | 10 | 6.6 | 151.8 | D | 418 | 31% | 99 | 138 |
| PC34 | 25 | 6.9 | 351.9 | D | 1034 | 34% | 91 | 126 |
| PC36 | 20 | 6.7 | 172.5 | D | 486 | 32% | 97 | 136 |
| PC37 | 75 | 8.7 | 70.7 | B | 244 | 39% | 95 | 139 |
| PC38 | 5 | 6.7 | 131.1 | D | 377 | 33% | 101 | 141 |
| PC40 | 5 | 7.8 | 116.4 | C | 350 | 34% | 95 | 133 |
| PC41 | 10 | 9 | 46.1 | B | 165 | 41% | 84 | 123 |
| PC42 | 20 | 9 | 61.5 | B | 216 | 40% | 85 | 124 |
| PC43 | 50 | 8.3 | 40.5 | C | 135 | 38% | 107 | 161 |
| PC44 | 30 | 7.9 | 35.4 | C | 111 | 36% | 109 | 165 |
| PC45 | 70 | 6.5 | 48.3 | D | 135 | 32% | 129 | 194 |
| PC47 | 0 | 7.9 | 35.4 | C | 108 | 35% | 100 | 148 |
| PC48 | 25 | 8.3 | 151.8 | C | 484 | 36% | 85 | 120 |
| SI01 | 20 | 6.5 | 246.1 | D | 640 | 30% | 103 | 144 |
| SI02 | 10 | 6.4 | 69.0 | D | 183 | 30% | 114 | 163 |
| SI03 | 20 | 6.5 | 151.8 | D | 394 | 30% | 106 | 148 |
| SI04 | 5 | 6.9 | 96.6 | D | 285 | 34% | 100 | 140 |

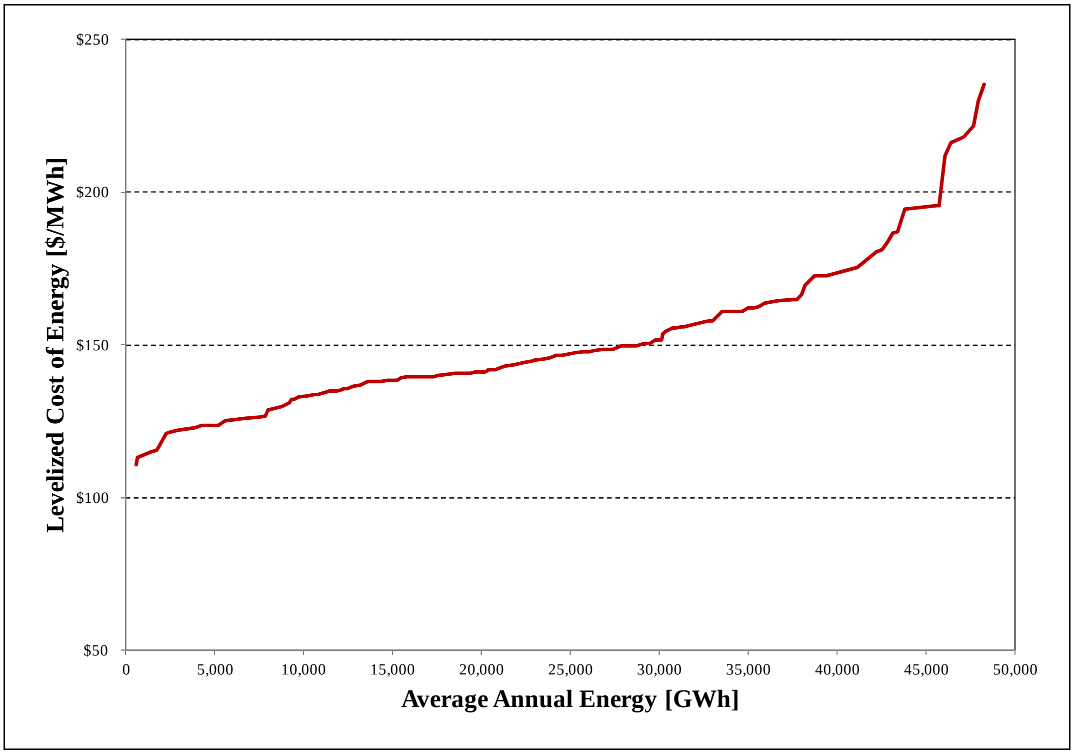
| Site ID | Distance to Transmission (km) | Wind Speed (m/s) | Capacity (MW) | Turbine Model | Annual Production (GWh) | Net Capacity Factor | Levelized Cost of Energy ($/MWh) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Base | High |
| SI05 | 10 | 6.7 | 144.9 | D | 393 | 31% | 100 | 141 |
| SI06 | 5 | 6.4 | 131.1 | D | 333 | 29% | 107 | 150 |
| SI08 | 0 | 6.4 | 117.3 | D | 298 | 29% | 107 | 150 |
| SI09 | 0 | 6.4 | 96.6 | D | 245 | 29% | 107 | 151 |
| SI10 | 10 | 7 | 117.3 | D | 338 | 33% | 96 | 135 |
| SI11 | 10 | 6.4 | 138.0 | D | 350 | 29% | 107 | 150 |
| SI12 | 5 | 7.3 | 186.3 | D | 566 | 35% | 89 | 124 |
| SI13 | 20 | 6.7 | 236.9 | D | 642 | 31% | 100 | 138 |
| SI14 | 20 | 7 | 82.8 | D | 238 | 33% | 99 | 142 |
| SI15 | 25 | 7 | 303.6 | D | 874 | 33% | 94 | 130 |
| SI16 | 5 | 6.8 | 662.4 | D | 1835 | 32% | 95 | 131 |
| SI18 | 35 | 7.3 | 117.3 | D | 372 | 36% | 95 | 135 |
| SI19 | 35 | 6.9 | 55.2 | D | 163 | 34% | 111 | 162 |
| SI20 | 20 | 7.3 | 41.4 | D | 129 | 35% | 105 | 156 |
| SI22 | 5 | 7 | 48.3 | D | 145 | 34% | 102 | 149 |
| SI23 | 20 | 7.7 | 192.3 | C | 546 | 32% | 100 | 139 |
| SI26 | 10 | 6.8 | 103.5 | D | 287 | 32% | 100 | 141 |
| SI27 | 5 | 7.2 | 89.7 | D | 280 | 36% | 95 | 134 |
| SI28 | 20 | 7.3 | 89.7 | D | 284 | 36% | 95 | 136 |
| SI29 | 20 | 6.9 | 117.3 | D | 338 | 33% | 103 | 145 |
| SI30 | 15 | 6.8 | 151.8 | D | 420 | 32% | 99 | 138 |
| SI31 | 25 | 6.6 | 144.9 | D | 385 | 30% | 104 | 146 |
| SI32 | 10 | 6.9 | 34.5 | D | 102 | 34% | 110 | 164 |
| SI33 | 35 | 6.4 | 48.3 | D | 123 | 29% | 124 | 184 |
| SI37 | 5 | 6.7 | 34.5 | D | 98 | 32% | 112 | 166 |
| SI38 | 5 | 6.5 | 103.5 | D | 280 | 31% | 108 | 151 |
| VI02 | 45 | 6.9 | 172.5 | D | 537 | 36% | 90 | 127 |
| VI04 | 25 | 7 | 62.1 | D | 197 | 36% | 94 | 137 |
| VI05 | 20 | 6.9 | 255.3 | D | 795 | 36% | 87 | 121 |
| VI06 | 15 | 7 | 117.3 | D | 373 | 36% | 88 | 124 |
| VI07 | 10 | 7.2 | 165.6 | D | 547 | 38% | 83 | 116 |
| VI08 | 20 | 6.8 | 41.4 | D | 129 | 36% | 105 | 156 |
| VI09 | 50 | 7.1 | 55.2 | D | 179 | 37% | 99 | 147 |
| VI10 | 50 | 6.7 | 34.5 | D | 105 | 35% | 122 | 187 |
| VI11 | 10 | 6.3 | 48.3 | D | 136 | 32% | 110 | 161 |
| VI12 | 5 | 7.5 | 48.3 | D | 172 | 41% | 87 | 126 |
| VI13 | 10 | 7.2 | 34.5 | D | 114 | 38% | 93 | 140 |
| VI14 | 10 | 8.2 | 35.4 | C | 122 | 39% | 93 | 138 |
| VI15 | 35 | 7.4 | 41.4 | D | 145 | 40% | 98 | 146 |

# APPENDIX B

## Supply Curves




**Supply Curve – Base Cost**




**Supply Curve – High Cost**