ECOSMART™

October 10, 2017

To BCUC

RE: Submission to BCUC preliminary report on Site C.

Please find attached our response to BCUC main questions on solar energy listed in the BCUC preliminary report.

EcoSmart is a non-for-profit organization. We were the driving force behind SunMine the first utility-scale PV solar system installed in western Canada. Through this project and others under development, we have acquired large experience on solar technology in general.

Michel de Spot, the author of this note is the co-chair of the solar committee of CEABC and member of executive committee of the Division of Renewable Energy and Energy Efficiency (DEERE) of Engineers BC (EGBC).

The intent of this note is to provide BCUC with more in-depth understanding of the potential of utility-scale PV solar systems in BC.

If you have any question or need additional information, please do not hesitate to contact us.

Best regards,

Michel de Spot, P.Eng.
President and CEO
EcoSmart Foundation

ECOSMART™
2703, 124 B St Surrey, BC V4A 3N8. Canada
Ph. 604 689 4021 icare@ecosmart.ca www.ecosmart.ca ecosmartsun.com

**-What is the current BC installed capacity cost of a 5 MW utility solar PV instillation ($/Watt) and operating cost ($/year and $/MWh)?*

Actual system cost in $/W in BC

There is no example of 5 MW solar project in BC nor western Canada. The larger utility-scale solar project in BC is SunMine in Kimberley, a 1 MW solar photovoltaic (PV) farm designed by EcoSmart (the author of this note) and developed by Teck and the City of Kimberley with the help of EcoSmart. The system is now owned and operated by Kimberley and the electricity sold to BC Hydro under the SOP.
sunmine.ca https://ecosmartsun.com/category/sunmine/

Figure 1: SunMine

SunMine uses dual-axis trackers and is located at high altitude (1,300 m), in the best BC solar hotspot. Its capacity is amongst the highest in North America: nearly 2,000 kWh/kWp/yr [1] equivalent to a capacity factor of about 23 %. [2]

This is due to the technology (dual-axis and distributed inverters), the high level of irradiance (GHI: 1,304 kWh/m2/yr), albedo (snow in the winter) and low temperature. Low temperature, in particular, is a key factor in improving the photovoltaic (PV) performance (i.e. a decrease of -10°C increases the power by 4%).

[1] kWp: kilowatt peak or kilowatt of dc modules installed.
[2] For comparison, typical fixed system in BC produce in average 1,200 h/yr

Total installed cost of SunMine was 5.3 M$ or about $5.3/Wp. While SunMine has demonstrated that solar system can reach high capacity facto in BC, its cost is much greater than most actual solar projects worldwide.

The reasons for the cost difference include:

- Duration: The project took about 7 years to complete -from concept to operation, resulting in significant indirect costs (softBOS).
- Size: Small (1 MW) size compared to today's solar farms (often greater than 100 MW)
- Timing: The equipment was purchased in 2014/2015 when prices were significantly higher.
- Technology: Dual-axis trackers are much more expensive than fixed or horizontal-axis systems

System cost calculated from NREL data

International and in particular US technical literature provide some sight about cost of PC installation elsewhere. One of the most frequently quoted reference on PV system cost is the NREL report: *"U.S. Solar Photovoltaic System Cost Benchmark Q1 2016"* https://www.nrel.gov/news/press/2016/37745.html

The executive summary p.2 presents the graph in Figure 2 with the cost of various PV systems. Accordingly, the cost of utility-scale PV is $1.42/Wp. Some submissions to the BCUC have used this value as a basis to assess the cost of utility solar in BC.

This value is the result of an extensive study by NREL on many US PV system and is likely correct but its context must be understood before it can be applied to BC. In fact the 50-page report indicates that the price is:

- in US dollars,
- for a 100 MW system,
- calculated in Q1 2016, likely with 2015 prices,
- with DC/AC ratio of 1.4, and
- composed of various items such as: Modules, inverter, racking, electrical equipment, overhead, installation, permit, connection, contingency, and profit.

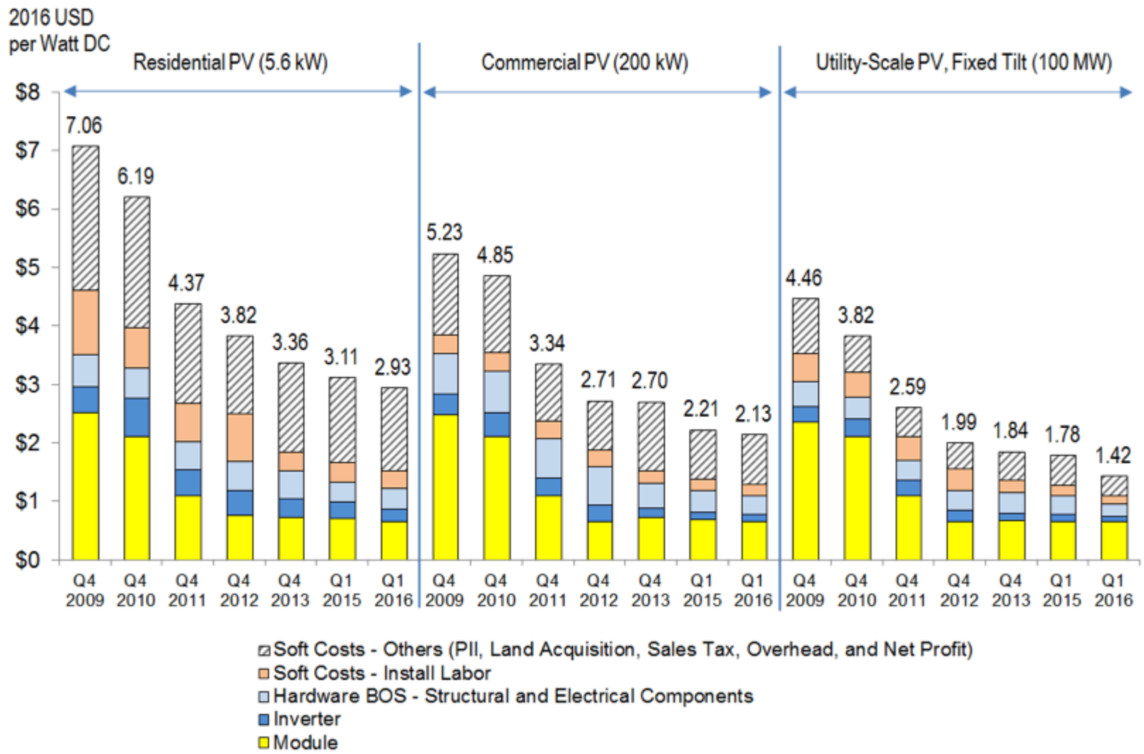


Figure 2: NREL PV System Cost

Page 22 of the report discusses the utility-scale PV model with a more detail graph (figure 3) showing that the cost of a 5 MW system is 1.82 $/Wdc

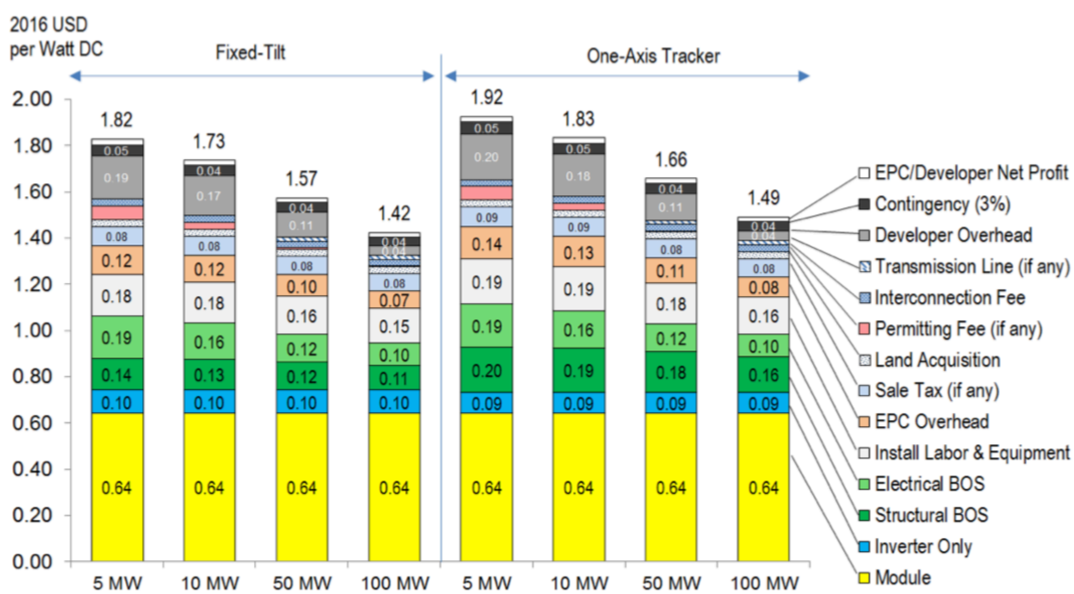


Figure 21. Q1 2016 U.S. benchmark: utility-scale PV total cost (EPC + developer) 2016 USD/Wdc

Figure 3: NREL Cost utility PV Systems

The values are outlined in Table 1, converted to Can $ and updated by EcoSmart to current costs in 2017.

Table 1: NREL 2016 cost and 2017 update

	NREL			BC 2017		Notes related to BC 2017 Costs
System Size MW	5			5		
DC/AC ratio	1.4			1.2		
	USD	CAN$		CAN$		
	$/Wp		$/Wac	$/Wp	$/Wac	
Module	0.640	0.800	1.120	0.600	0.720	SPI prices Q4 2017
Inverter Only	0.100	0.125	0.175	0.071	0.085	SPI prices Q4 2017
Structural BOS	0.140	0.175	0.245	0.130	0.156	SPI prices Q4 2017
Electrical BOS	0.190	0.238	0.333	0.238	0.285	Assumed to be same as NREL
Installation	0.180	0.225	0.315	0.225	0.270	Assumed to be same as NREL
EPC Overhead	0.120	0.150	0.210	0.121	0.146	Includes EPC Contingency
Sale Tax (if any)	0.080	0.100	0.140		-	Prices without sales tax
∑ EPC Cost	*1.450*	*1.813*	*2.538*	*1.385*	*1.662*	
Land Acquisition	0.030	0.038	0.053	0.038	0.045	Assumed to be $387K altogether
Permitting Fee (if any)	0.060	0.075	0.105	0.040	0.048	
Interconnection Fee	0.030	0.038	0.053	0.040	0.048	Assumed to be $200K
Contingency (3%)	0.050	0.063	0.088	0.042	0.050	Additional contingency to EPC
Developer Overhead	0.190	0.238	0.333	0.150	0.180	10% of cost above
EPC/Developer Net Profit	0.020	0.025	0.035	0.025	0.030	Additional 2% as per NREL
∑ Developer Cost	*0.380*	*0.475*	*0.665*	*0.335*	*0.401*	
∑ Total System Cost	1.830	2.288	3.203	**1.719**	2.063	

- The main equipment prices (Modules, Inverters, racking) were recently obtained from suppliers at the SPI solar trade show in Las Vegas (Sept 2017)
- Total system cost is lower due to lower cost of modules and inverters.
- Solar specific equipment (modules, inverters, racks) represents less than 50% of the total cost.
- Solar industry normally indicates the cost in $/Wdc or Wp use standard. The cost in $/Wac is shown in the table to allow comparison with other renewable generation (hydro, wind,…)
- Cost per Wdc of a 5 MW PV system in BC in 2017 is ~ **1.72 CAD$/Wdc.** It is in the order of magnitude experienced by EcoSmart in recent developments.

Operating cost

O/M cost of solar system is calculated on a power installed basis (MW) not energy generated (MWh) because there is no moving part.[3] For a 5 MW size, typical O/M costs are between 1.5 and 2 ¢/Wp i.e ~ $100,000 per year.

100 MW system

It is worthwhile to examine also the cost of a 100 MW system to examine how a large-scale solar system would compare to Site C.

Table 2: NREL cost 100 MW system and 2017 estimates

	NREL			BC 2017		Notes related to BC 2017 Costs
System Size MW	100			100		
DC/AC ratio	1.4			1.2		
	USD	CAN$		CAN$		
	$/Wp		$/Wac	$/Wp	$/Wac	
Module	0.640	0.800	1.120	0.500	0.600	SPI prices Q4 2017
Inverter Only	0.090	0.113	0.158	0.058	0.070	SPI prices Q4 2017
Structural BOS	0.156	0.195	0.273	0.100	0.120	SPI prices Q4 2017
Electrical BOS	0.096	0.120	0.168	0.120	0.144	same as NREL
Installation	0.162	0.203	0.284	0.203	0.243	same as NREL
EPC Overhead	0.083	0.104	0.146	0.071	0.086	Includes EPC Contingency
Sale Tax (if any)	0.079	0.099	0.139		-	Prices without sales tax
∑ *EPC Cost*	**1.307**	**1.634**	**2.287**	**1.053**	**1.263**	
Land Acquisition	0.030	0.038	0.053	0.005	0.006	Assumed to be $1M altogether
Permitting Fee (if any)	0.003	0.004	0.005	0.005	0.006	
Interconnection Fee	0.028	0.036	0.050	0.005	0.006	Assumed to be $1 M altogether
Transmission	0.019	0.023	0.032	0.005	0.006	
Contingency (3%)	0.042	0.052	0.073	0.032	0.038	Additional contingency to EPC
Developer Overhead	0.042	0.052	0.073	0.032	0.038	3% of cost above
EPC/Developer Net Profit	0.020	0.024	0.034	0.013	0.016	Additional 1.33% as per NREL
∑ *Developer Cost*	**0.183**	**0.228**	**0.320**	**0.097**	**0.116**	
∑ Total System Cost	**1.490**	**1.862**	**2.607**	**1.149**	**1.379**	

- The main equipment cost (modules, inverters, racking) is lower due to the volume.
- Solar specific equipment (modules, inverters, racks) represents less than 60% of the total cost.

[3] Solar system does not wear out by the energy produced, but derates under exposure to the light.

- Cost per Wdc of a 100 MW PV system in BC in 2017 is ~ **1.15 CAD$/Wdc.** It is in the order of magnitude of recent projects in the US.

What would a reasonable forecast of the cost be in F2025 and F2035?

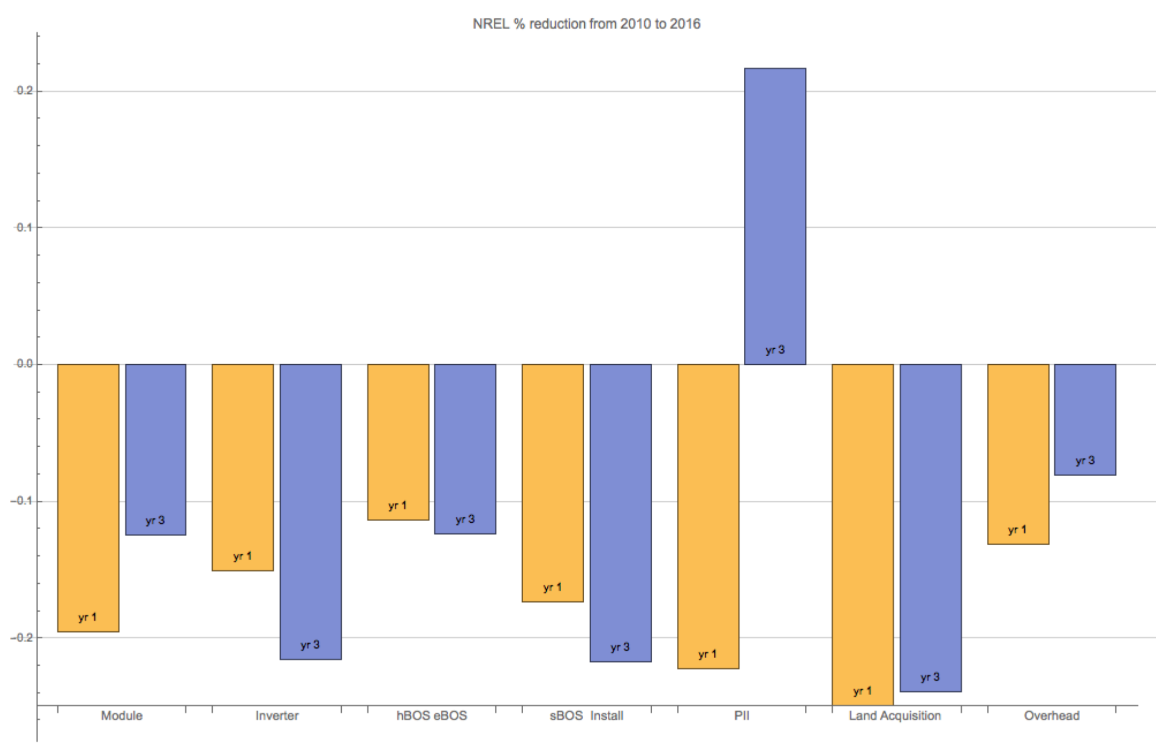
To be competitive and comparable with other generation technologies (hydro, wind) utility-scale solar systems should in the range of 100 MW and above.

The NREL report provides 7-year historical cost of 100 MW solar systems from 4.46 $/Wp in 2009 to $1.42 $/Wp in 2016 a decrease of 31%

A more detailed analysis of the NREL data reveals that the various cost component have different year to year variation rates. It also shows that there is big "jump" in costs from 2010 to 2011.

Figure 4 presents the cost decrease for each item with two scenarios starting from 2009 (future increase/decrease extrapolated from changes between 2009 and 2016 – thus including the big jump - yr 1) or 2011 (excluding the big jump - yr 3). It shows for example that the decrease of module costs has slowed down since 2011 while the PII costs (Permitting, Interconnection, Inspection) have actually increase since 2011.

Figure 4: Cost increase by cost item

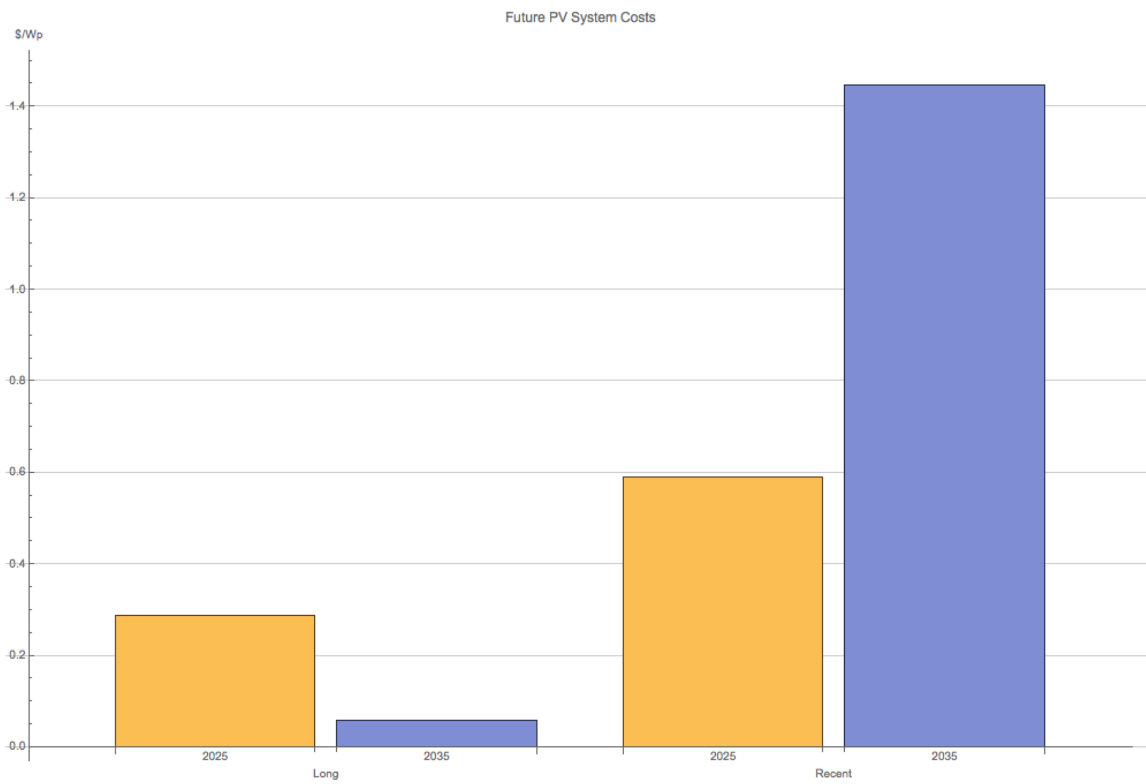


With these rates and under these 2 scenarios, the projection of cost to 2015 and 2015 is calculated in Table 3 and Figure 5.

Table 3: Projected PV System Cost $/Wp

	Variation rate calculated from	
	2009	2011
2025	0.29	0.59
2035	0.06	1.45

Figure 5: Project PV System Costs



One of these scenarios – with the rates calculated from 2011 instead of 2009, shows actually a cost increase in 2035 from today. It is caused by an increase of PII costs.

The above clearly indicates than while the price of solar technology will decrease, the total system cost depends on other factors such as labor, price of raw material (steel, aluminum, copper, zinc, etc.), overhead, profit and most critically on the PII cost (permitting, interconnection and commissioning) that are mostly in the control of utilities and government.

What are the regional solar radiation levels in BC, and how do they compare to other jurisdictions with higher levels of solar PV penetration (Arizona, California, Germany)?

Solar irradiance is normally measured by annual Global Horizontal Irradiance (GHI). Irradiance varies widely according to the location. For example, in BC it ranges from 817 kwh/m2/a in Prince Rupert to 1,356 kwh/m2/a in Cranbrook.[4]

Comparison to California and Arizona

Table 4 compares the 2 BC locations to some locations in the US.

Table 4: Irradiance at selected locations

	GHI	DNI	DIF	Tot	Avg °C	T Corrected
Prince Rupert	817	918	431	1,349	6.9	n/a
Cranbrook	1,356	1,652	543	2,195	5.9	Base
Sacramento	1,803	2,033	562	2,595	15.5	2,111
San Francisco	1,716	1,770	631	2,402	13.8	2,126
Phoenix, AZ	2,117	2,519	566	3,084	22.5	2,049

Although, the GHI at Phoenix is much higher than at Cranbrook, the energy produced may be lower when taking into account the system set up and environmental context.

GHI is the total energy received on a horizontal surface. Because of the angle of incidence of sunrays, at equal irradiance GHI will be lower at higher latitude. The irradiance is composed of direct irradiance (DNI: light coming directly from the sun) and diffused irradiance (DIF: light diffused by water and dust in the atmosphere). The total DNI + DIF represents the irradiance received in the plan-of-array (POA) of a system that will always faces the sun. It is the power available to a dual-axis tracker and the maximum power a solar system can get from the sun. It is a more representative value to compare 2 systems in different locations.

The efficiency of a PV module decreases by 0.4% by each °C increase. The table calculates the power correction based on the temperature difference with Cranbrook. In consequence, when corrected for temperature, <u>a PV system in Cranbrook may have a better yield than a similar system in Phoenix.</u>

[4] showing that location is key to solar performances.

Compared to Germany

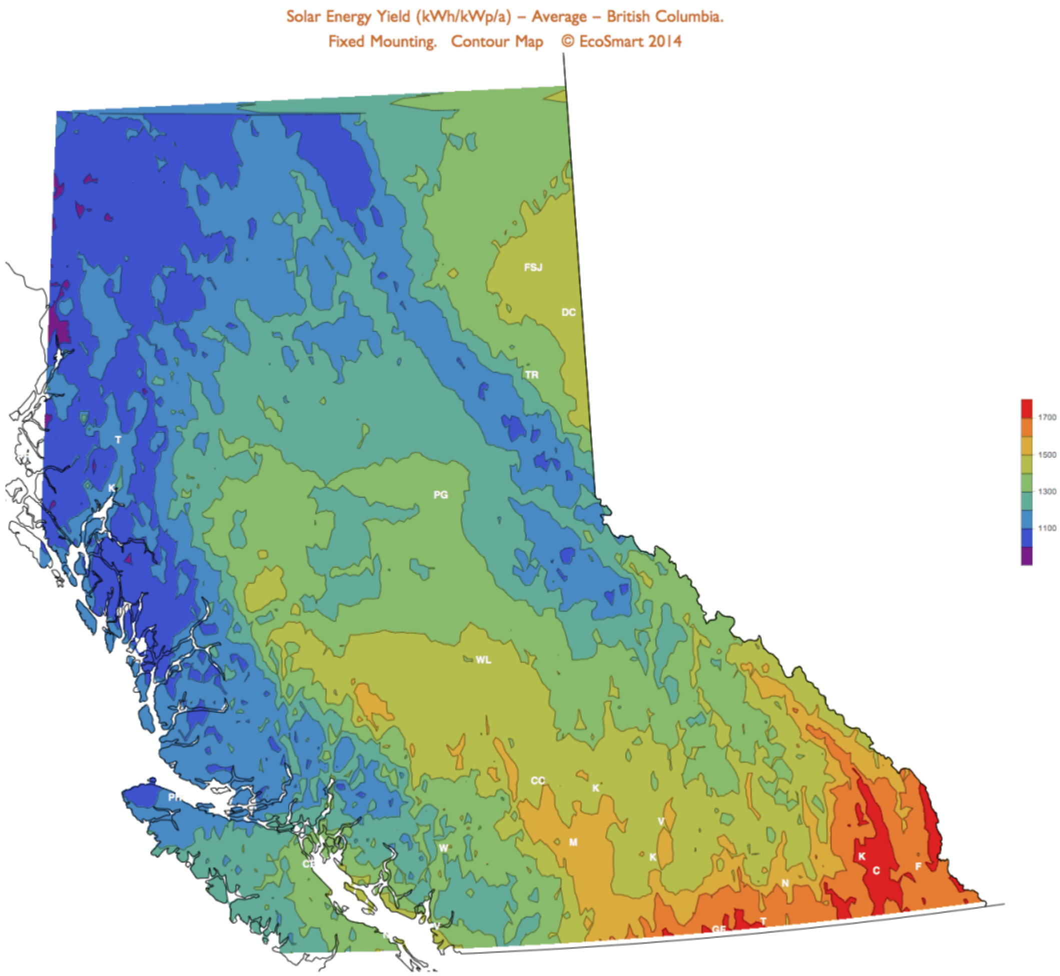
Almost all BC locations have better GHI than Germany. Considering that latitude and temperature are similar, almost all PV system installed in BC will have a better yield than in Germany. (Table 5)

Table 5: Comparison with Germany

Location	GHI kwh/m2/yr
Prince Rupert	817
Cranbrook	1,356
Berlin	1,091
Munich	1,161
Hamburg	1,069

Where are the best locations in BC to install utility scale solar from he perspective of (i) regional solar radiation levels, and/or (ii) available transmission capacity?

EcoSmart has produced a series of solar map based on 10 x10 km satellite solar data available on our web site at https://ecosmartsun.com/canadian-solar-maps-province/



The map of BC indicates in red the top hotspots for solar energy such as Cranbrook, Trail or Grand Forks. Other regions in orange have also excellent solar resources such as the Okanagan (Osoyoos, Oliver, Penticton) , or the south central interior (Merritt, Cache Creek). Regions in light green are also quite good (Chilcotin, Peace region,…)

Solar systems are more flexible than hydro or wind and can be installed near transmission line.

What would be a reasonable assumption regarding utility scale solar PV capacity factor and life?

As indicated before the capacity factor varies according to the location and the type of mounting (fixed or tracker). Table 6 shows capacity factor for selected locations in BC.

Table 6: Capacity factors

Location	Fixed	Dual-axis
Cranbrook	16%	22%
Vancouver	13%	18%
Prince Rupert	10%	13%

The PV modules derate over time by 20% over 25 yr. This value is often guaranteed by the manufacturer. For that reason, the lifetime of a PV system is often calculated over 25 year. Inverters have a similar lifetime. Other components such as structure, wiring, controls, transformer can have a much longer life and thus the system can continue to operate after 25 year by simply replacing modules and inverters.[5]

Assuming the solar investment was financed by BC Hydro, and using a 6 percent discount rate, what is the estimated levelized cost in today's dollars of a 5MW utility solar PV investment made in in (a) F2025 and (b) F2035, assuming delivery at (i) the plant gate and (ii) delivered to the Lower Mainland. Please show supporting assumptions (including capital cost assumptions, real power losses etc.) and calculations.

Once again, the result depends on the location, size and mounting (fixed or tracker). For example, the LCOEs at the gate of two PV Fixed System (5 MW and 100 MW) in Cranbrook are shown in Table 7.

Table 7: Capacity Factors

Size MW	$/Wp	O/W ¢/Wp	LCOE $/MWh
5	1.72	2	124.5
100	1.15	1.5	84.81

Assumptions: 2% CPI, discount rate 6%, Period 25 year

Please describe any recent developments in utility solar PV that have the potential to significantly decrease costs, increase efficiency and/or increase flexibility (for example, through the use of smart inverters).

The most important development is the increasing use of trackers. Their cost and performance have improved dramatically in recent years. 90% of the tracker made

[5] In 25 years, cost of modules and inverters are likely to be much lower.

today is Horizontal Axis Tracker (HAT). Unfortunately, this type of tracker is not very efficient in our latitude because the higher angle of incidence with the sunrays and potential snow issues.[6] The best mounting for northern latitude is dual-axis tracker. They improve significantly the yield versus a fixed system (40% in the case of SunMine) but are much more expensive because there is presently not enough supply and competition to control the cost. In our view, a cost-effective tracker adapted to Canadian conditions would be the best solution to reduce the costs and increase efficiency in BC and Canada.

[6] With HAT, at noon, the modules are horizontal.