Solar PV
and Cold Climate

A Winning Combination

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Outline of Presentation

• Solar PV: Global Situation
• Situation in Canada
• Solar PV in Cold Climates: A Potential to be Exploited
• Context of Stand-alone Grids in Canadian Far North
• Relevance of Nergica
Solar PV: Global Situation

Unprecedented growth

- Added PV capacity worldwide (48%/year)
- In 10 years 50 times more PV

Evolution of PV module cost in US (-11%/year)

Solar PV Global Capacity and Annual Additions, 2006-2016
Solar PV: Global Situation
Forecasts exceeded

Forecast levelized cost of PV: 2016-2027

Chile: 2.91¢/kWh @ 2,400 kWh/kWp
Abu Dhabi: 2.42¢/kWh @ 2,200 kWh/kWp
Solar PV: Global Situation
Pioneering countries

REN21 Renewables 2017 Global Status Report
Situation in Canada
Use remains marginal

- Use remains marginal
- 0.5% of total production
- PV: 2.91 GW
- 97.25% of which is in Ontario

Outline of situation: 2017-2018 GW DC
- 97.25% of total production
- Marginally increasing over time

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Situation in Canada
Projections through 2040

**Growth rate by energy source**

- **PV growth rate** by 2040: 234% produced by PV
- **Penetration rate in country** 4%

Additions for electricity generation:
- Hydro
- LNG
- Biomass
- Wind
- Solar
Test your knowledge!
Can you rank these cities and villages according to their PV potential?

<table>
<thead>
<tr>
<th>City</th>
<th>PV Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuujjuaq (QC)</td>
<td>1033 kWh/kWp</td>
</tr>
<tr>
<td>Beijing</td>
<td>1148 kWh/kWp</td>
</tr>
<tr>
<td>Moscow</td>
<td>803 kWh/kWp</td>
</tr>
<tr>
<td>London</td>
<td>728 kWh/kWp</td>
</tr>
<tr>
<td>Arviat (NU)</td>
<td>1143 kWh/kWp</td>
</tr>
</tbody>
</table>
Advantages of Solar PV in Cold Climates
A potential to be exploited
Advantages of Solar PV in Cold Climates
A potential to be exploited

PV potential comparison
NRCan vs. measurements taken at Nergica's site

Summary January-June 2018

<table>
<thead>
<tr>
<th>Community</th>
<th>PV Potential [kWh/kWp/year]</th>
<th>Deviation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Resources Canada</td>
<td>kWh/kWc/6 months @ 33°</td>
<td>624.00</td>
</tr>
<tr>
<td>Nergica PV system</td>
<td>kWh/kWc/6 months for 15.6 kWc @ 30°</td>
<td>629.43</td>
</tr>
<tr>
<td></td>
<td>kWh/kWc/6 months for 15.6 kWc (φ&lt;68°)</td>
<td>9,734.40</td>
</tr>
<tr>
<td></td>
<td>kWh/kWc/6 months for 15.6 kWc</td>
<td>9,819.11</td>
</tr>
<tr>
<td></td>
<td>Deviation [%]</td>
<td>-0.87%</td>
</tr>
</tbody>
</table>
Advantages of Solar PV in Cold Climates

1st advantage: cold

<table>
<thead>
<tr>
<th>Technology</th>
<th>Temperature coefficient [%/°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-Si</td>
<td>-0.43 to -0.45</td>
</tr>
<tr>
<td>Thin-film Si</td>
<td>-0.48</td>
</tr>
<tr>
<td>Silicon wafer-based</td>
<td>-0.45</td>
</tr>
<tr>
<td>a-Si single junction</td>
<td>0.13</td>
</tr>
<tr>
<td>CdTe</td>
<td>-0.21</td>
</tr>
<tr>
<td>CIGS</td>
<td>-0.36</td>
</tr>
</tbody>
</table>

Variation of maximum power with respect to temperature ($T_{cell}$) for Nergica’s research site -0.43%/°C.
Advantages of Solar PV in Cold Climates

2nd advantage: longer service life of PV modules

(Nunavut Arctic College)

- System commissioned in 1994
- 69 modules installed on college building façade
- Visual inspection conducted in 2014

Results of visual inspection
Advantages of Solar PV in Cold Climates

2nd advantage: longer service life of PV modules

(Houseboat *Icarus*)

- Modules from the 1980s
- Still in operation on a boathouse

Performance degradation:
- Initial degradation of 3%
- 0.6%/year

In summary:
- *Boathouse Icarus*: 0.6%/year
- *Arctic College*: 0.64%/year
- Production guarantee:
  - 0.68%/year with 97% on first year
  - 0.8%/year if one includes an initial degradation of 3%
Advantages of Solar PV in Cold Climates

3rd advantage: high wind speeds

The relationship between solar irradiation and module temperature is rather logical

High data dispersion
Advantages of Solar PV in Cold Climates

3rd advantage: high wind speeds

Boundary conditions: 0 and 18 m/s

Performance improvement

\[ \ln\left(\frac{T_m - T_a}{E}\right) \]

Up to 8.4% above maximum power

King et al., 2004
Advantages of Solar PV in Cold Climates

4th advantage: reflective property of snow

Advantages of a higher tilt angle:
• Lower snow accumulation
• Higher reflected radiation
• Possible increase in benefit of cold winds

Bifacial PV modules can take maximum advantage of high albedo values
Context of Stand-alone Grids in Canadian Far North

Production dependent on fossil fuels

\[ \text{LCO}_\text{diesel} = \text{CAPEX} + \text{OPEX} + \frac{P_{\text{diesel}}}{\eta_{\text{diesel}}} \]

\[ \text{LCO}_\text{diesel} < 3.9 \text{TWh} \]

\[ P_{\text{diesel}} \sim 2 \text{T$} \]

\[ \text{LCO}_\text{diesel} \sim 0.7 - 1.3 \text{T$/kWh} \]
Context of Stand-alone Grids in Canadian Far North

1st advantage: favourable LCOE

Assumptions:
- Service life: 30 years
- Discount rate: 2%/year
- Project cost: $10/Wc
- OPEX: 1% of investment
- Rate of degradation: 0.5%/year

Average LCOE PV = $0.41/kWh
Reduction of 53%

Solar Energy Integration in Nunavik

Diesel displacement rate: 20%
Cost of energy produced ($/kWh)

Avoided emissions (tonnes CO2)
- 250 kWc solar array
- 1 MWc solar array

Population:
- 224 - 500
- 501 - 1000
- 1001 - 1500
- 1501 - 2000
- 2001 - 2500
- 2501 - 3000

Solar potential:
- 1,100 – 2,200 kWh / kWc
- 900 – 1,100 kWh / kWc
- Nunavik boundary

Scale: 1:5,000,000

Design: Alexandre COLIN
Date: 20 juillet 2018

Projection: NAD 1983 MTM 5

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Context of Stand-alone Grids in Canadian Far North

2nd advantage: stable LCOE with respect to that of diesel

Cost of diesel poised to trend upwards
Context of Stand-alone Grids in Canadian Far North

2nd advantage: stable LCOE with respect to that of diesel

What is the role of the carbon market?

Who is targeted in Quebec?

- Industry sector
- Electricity sector
- Fuel distributors
Context of Stand-alone Grids in Canadian Far North
2\textsuperscript{nd} advantage: stable LCOE with respect to that of diesel

What is the role of the carbon market?

What is the cost in Canada?
$10/\text{tonne}$ in 2018
$50/\text{tonne}$ in 2022
$3.7\text{¢}/\text{kWh}$
Context of Stand-alone Grids in Canadian Far North

2\textsuperscript{nd} advantage: stable LCOE with respect to that of diesel

\[
LCOE_{PV} = \frac{CAPEX + OPEX}{kWh \text{ over project lifetime}}
\]

- Known at start of project
- Advantages of cold climate
  - Few interventions
  - Longer service life of modules
- Slightly lower rate of degradation

but...
Context of Stand-alone Grids in Canadian Far North

3rd advantage: government support for deployment of renewables
Context of Stand-alone Grids in Canadian Far North
3rd advantage: government support for deployment of renewables
Relevance of Nergica
Unique research infrastructures in Canada
Relevance of Nergica
Technical assistance and applied research activities

• Operational performance assessment
• Sizing of hybrid diesel-PV-storage systems
• Validation or adaptation of technological solutions for solar systems
• Analysis of impact of snow on energy production through image processing
• Use of solar energy to improve energy quality
• Instrumentation and data quality control
"I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."

[Thomas Edison, conversations with Henry Ford, 1931]
This webinar was produced as part of the Opten research program.
Questions period