Bifacial Photovoltaic Module Energy Yield in Northern Canada

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Bifacial Photovoltaic Modules

- Bifacial PV absorbs light from both front and rear surfaces.
- **Bifacial gain** is dependent on environmental conditions, including setup geometry, weather, and location.

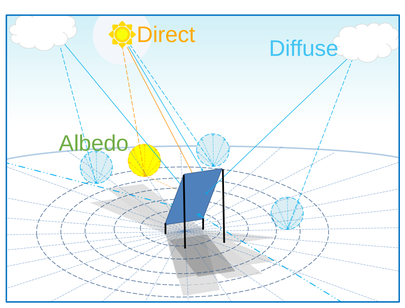
$$\text{bifacial gain (\%)} = \left(\frac{EY_{bifacial} - EY_{monofacial}}{EY_{monofacial}}\right) \times 100$$

Simulation Software

- **MATLAB** framework.
- Considers many parameters, including weather, location (latitude and longitude), PV cell characteristics, racking, and shading.
- Typical meteorological conditions taken from Canadian Weather Year for Energy Calculation (**CWEC**) files.

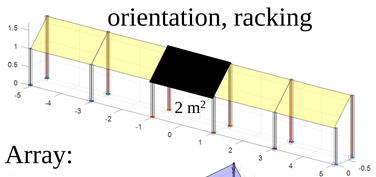
Test Parameters

- Portrait orientation
- Tilt angle = location latitude
- Panel area = 1.94 m^2
- Ground clearance = 2 m
- Bifaciality = 95%
- Albedo = 0.2 for grass
  = 0.6 for snow

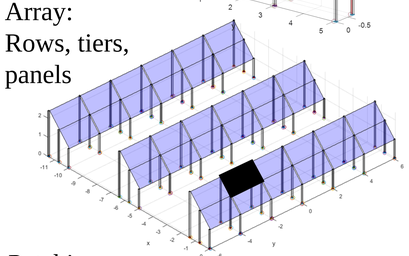


Geometry

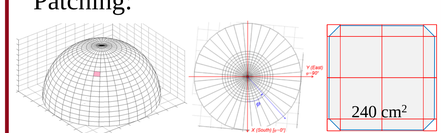
Rotation, tilt, clearance, orientation, racking



Array: Rows, tiers, panels



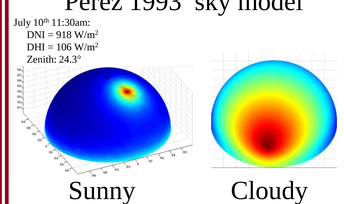
Patching:



Sky Ground Cell

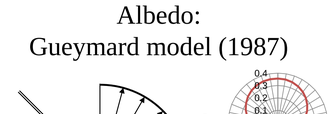
Optics

Anisotropic sky dome: Perez 1993 sky model



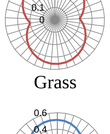
Sunny Cloudy

Albedo: Gueymard model (1987)



Grass

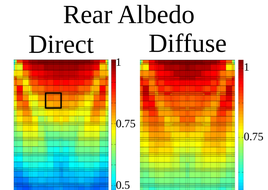
Surface	Albedo	(f_{af}/f_{ab})
Grass	0.2	(1/1)
Snow	0.6	(1.5/0.5)



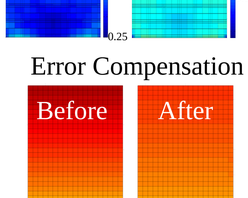
Snow

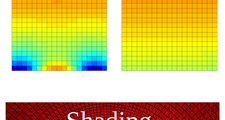
Irradiance

Rear Albedo



Error Compensation





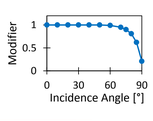
Electrical

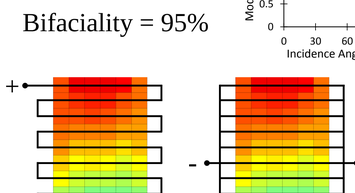
Convert front & rear profiles to cell irradiance & temperature

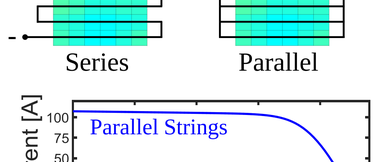
72 cells: 1-diode model each

QE + AM1.5G

Bifaciality = 95%



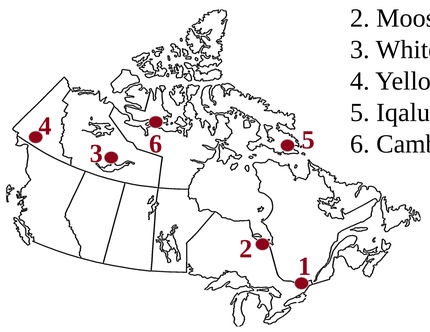




Annual Energy Yield

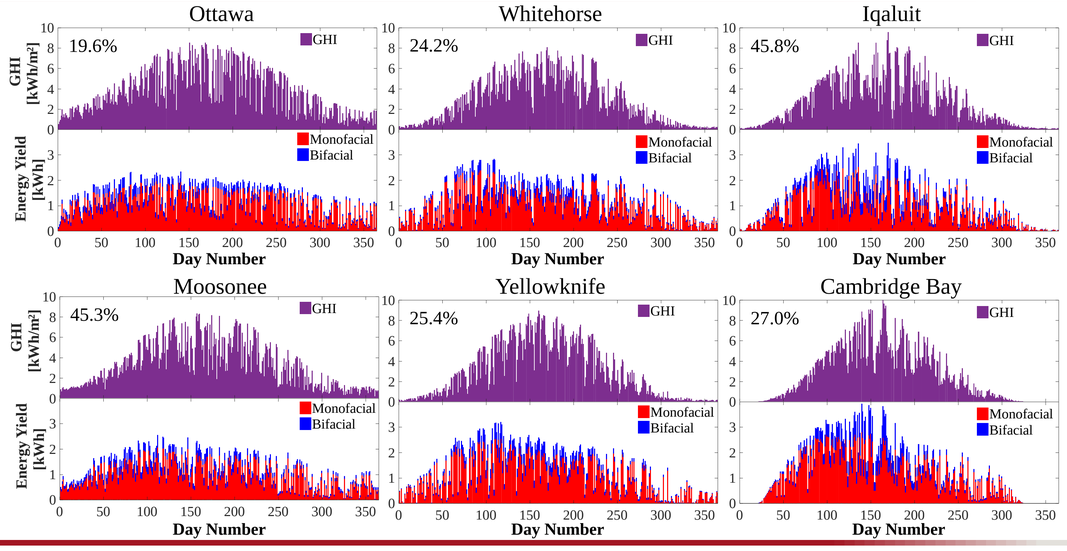
- Energy yield (bifacial and monofacial) per day in each location:

1. Ottawa, ON
2. Moosonee, ON
3. Whitehorse, YT
4. Yellowknife, NT
5. Iqaluit, NU
6. Cambridge Bay, NU



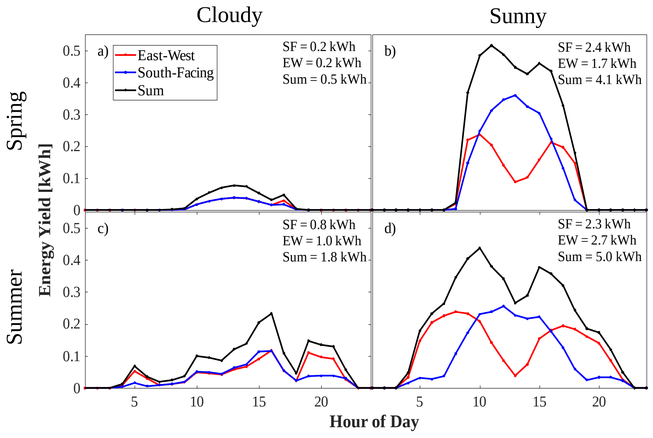
Simulation Locations in Canada

Location	Coordinates	Monofacial Energy (kWh)	Bifacial Energy (kWh)	DHI/GHI (%)	Average Albedo	Average Temp (°C)	Bifacial Gain (%)
Ottawa	45.42° N 75.70° W	375	449	61.7	0.30	6.90	19.6
Moosonee	51.27° N 80.64° W	316	459	66.4	0.36	0.38	45.3
Whitehorse	60.72° N 135.06° W	345	429	56.5	0.40	0.23	24.2
Yellowknife	62.45° N 114.37° W	355	446	54.4	0.42	-3.36	25.4
Iqaluit	63.75° N 68.52° W	300	438	68.1	0.48	-8.07	45.8
Cambridge Bay	69.11° N 105.06° W	357	454	57.8	0.48	-12.87	27.0



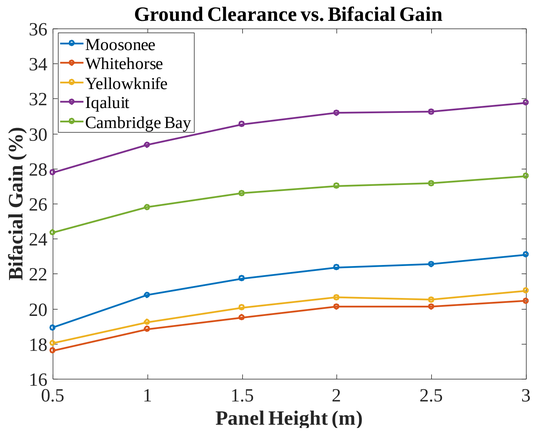
East-West Panel Configuration

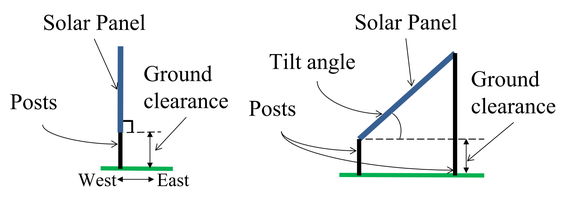
- **Fixed panel tilt** at 90^0.
- **Fixed azimuth angle** at 90^0 (East).
- **Two daily power peaks** when sunny: one in the morning, one in the afternoon. Energy yield is similar when cloudy.



Hour of Day vs. Energy Yield for a) a cloudy spring day, b) a sunny spring day, c) a cloudy summer day, and d) a sunny summer day in Yellowknife, NT

Ground Clearance

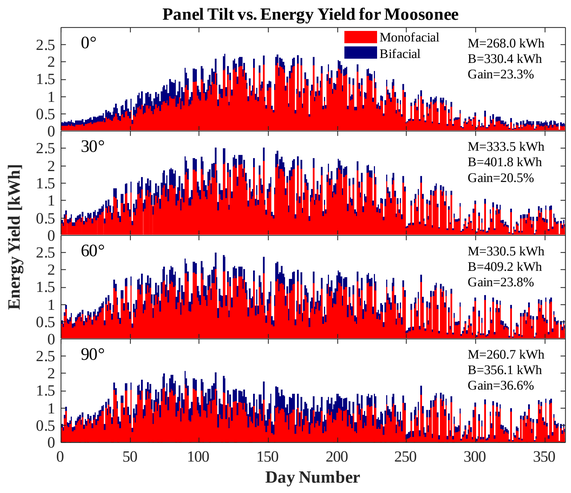




Panel geometry for east-west (left) and regular south-facing (right) solar panels

Tilt Angle

- **Varied panel tilt** between 0^0 and 90^0.
- Some locations have **up to 5° difference** between ideal tilt angle for bifacial and monofacial panels for **maximum energy yield**.



Location	Ideal Monofacial Tilt Angle (°)	Ideal Bifacial Tilt Angle (°)
Ottawa	40.0	42.5
Moosonee	42.5	47.5
Whitehorse	52.5	52.5
Yellowknife	52.5	52.5
Iqaluit	52.5	55.0
Cambridge Bay	57.5	62.5

Conclusions

- **Bifacial gain is high** in northern locations in Canada (>24%).
- A **mix of east-west and south-facing**, latitude-tilt panels can broaden daily power output.
- **Higher ground clearance** results in more bifacial gain up to a bifacial gain limit.
- **Higher tilt angles** result in more power in winter, but less power in summer.

[1] Chu Tu Li, *"Development of field scenario ray tracing software for the analysis of bifacial photovoltaic solar panel performance,"* M.A.Sc. Thesis, University of Ottawa, 2016.

[2] Christopher. E. Valdivia, Chu Tu Li, Annie Russell, Joan E. Haysom, Rui Li, David Lekx, Mohsen M. Sepeher, Dan Henes, Karin Hinzer, Henry P. Schriemer, "Bifacial Photovoltaic Module Energy Yield Calculation and Analysis," in *44th IEEE Photovoltaic Specialist Conference*, 2017.