A General Bifacial Photovoltaic Device Method to Predict System Performance with Albedo

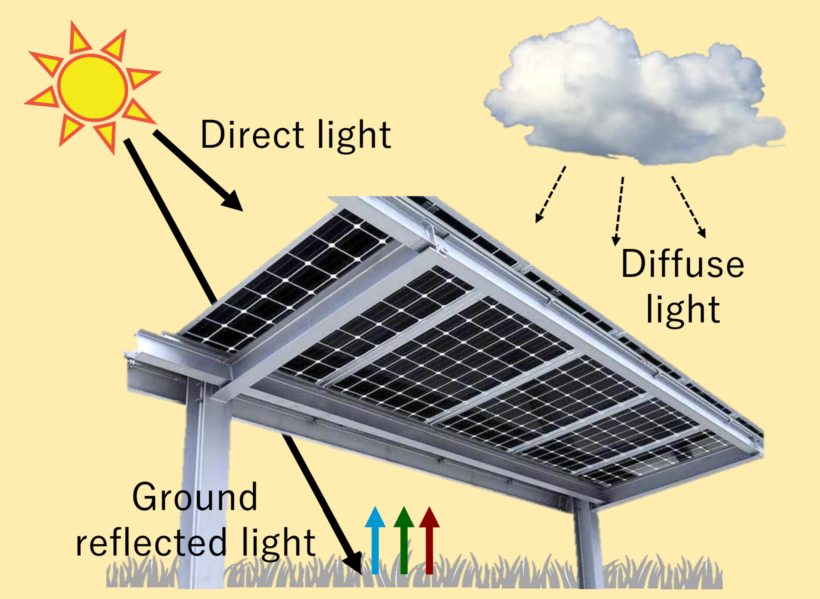
Erin M. Tonita[1], Christopher E. Valdivia[1], Annie C. J. Russell[1], Michael Martinez-Szewczyk[2], Mariana I. Bertoni[2], and Karin Hinzer[1]

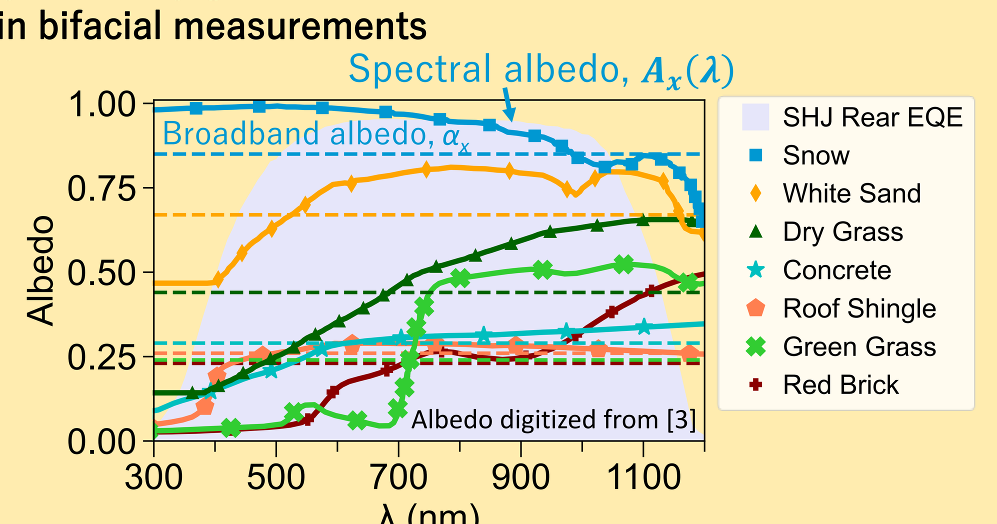
[1]SUNLAB, University of Ottawa, Ottawa, Ontario, Canada

[2]DEfECT Lab, Arizona State University, Tempe, Arizona, USA

INTRODUCTION

- Bifacial photovoltaics >80% of solar market-share by 2030[1]
- Rear irradiance varies 0-700 W/m², primarily driven by ground **albedo**[2]
- **No consensus on how to implement albedo in bifacial measurements**





Bifacial energy yield gain 5-15% or better![3]

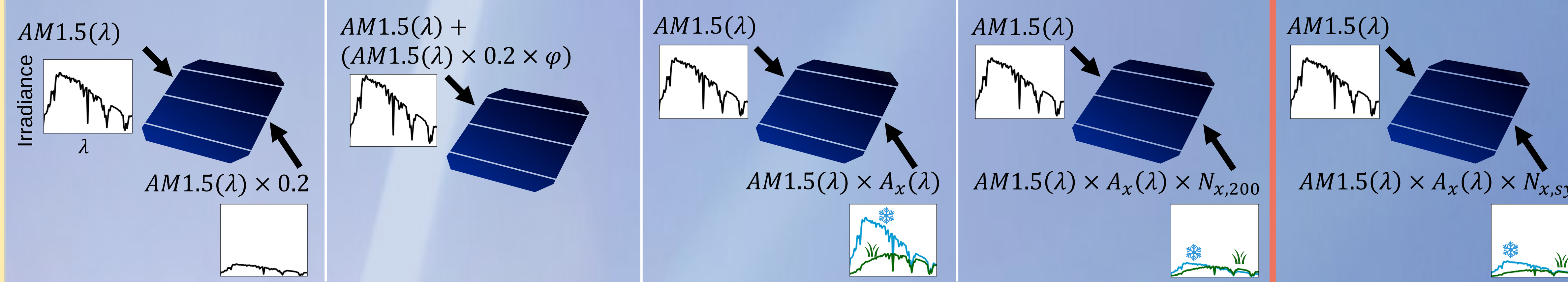
Broadband albedo

$$\alpha_x = \frac{\int_{280}^{3000} A_x(\lambda)\, AM1.5(\lambda)\, d\lambda}{\int_{280}^{3000} AM1.5(\lambda)\, d\lambda} \qquad \alpha_{EQE,x} = \frac{\int A_x(\lambda)\, EQE(\lambda)\, AM1.5(\lambda)\, \lambda\, d\lambda}{\int EQE(\lambda)\, AM1.5(\lambda)\, \lambda\, d\lambda}$$

MEASUREMENT METHODS

IEC METHODS [4]

SPECTRAL ALBEDO METHODS



Test rear scaling factors 0.1-0.25 (**100-250 W/m²**)

Lab implementation possible using a **spectral mismatch factor**

Bifacial
- Rear uniform AM1.5 scaling

Equivalent irradiance
- Adds **equivalent** of the **rear irradiance to the front**
- Requires bifaciality, φ

Max rear irradiance
- Accounts for power and spectral effects
- **Overestimates rear irradiance**

Fixed rear irradiance
- All scaled to **200 W/m²**, effect of spectral shape only

$$N_{x,200} = \frac{200\ W/m^2}{\int A_x(\lambda) \times AM1.5(\lambda) d\lambda}$$

Scaled rear irradiance
- Accounts for power and spectral effects
- **Scales rear to represents outdoor system operation**

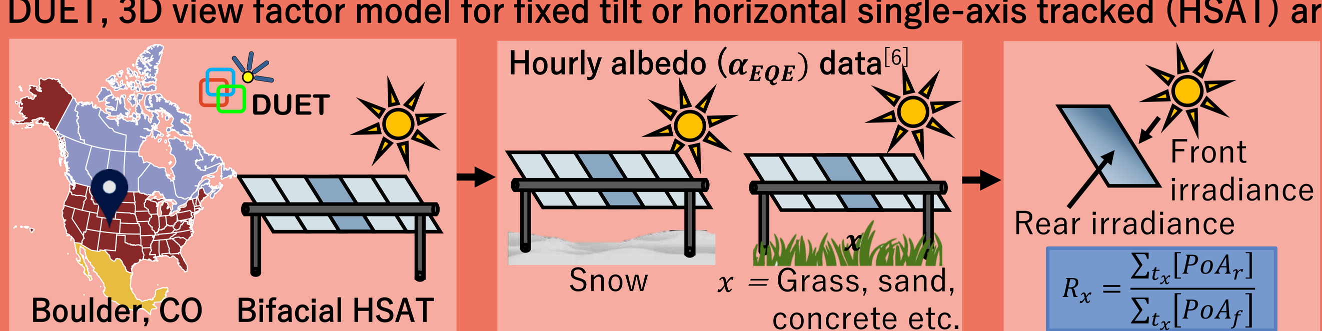
$$N_{x,sys} = \frac{R_x \int AM1.5(\lambda) d\lambda}{\int A_x(\lambda) \times AM1.5(\lambda) d\lambda}$$

THE SCALED METHOD

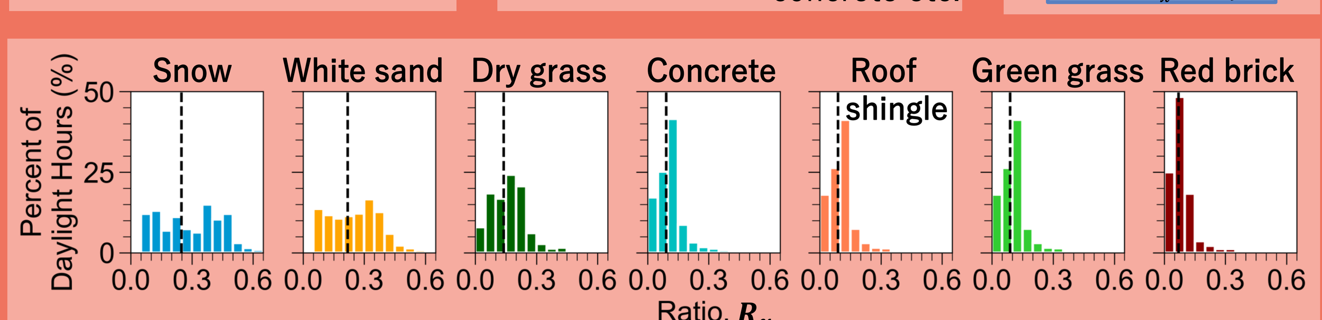
- $N_{x,sys}$ adjusts rear irradiance to field operating levels
- R_x is plane-of-array irradiance (PoA) rear-to-front ratio of an outdoor bifacial device with albedo x
- IEC standards suggest testing 100-250 W/m² on the rear (R_x=0.1-0.25)
- **Calibrate rear irradiance for each spectral albedo**

$$N_{x,sys} = \frac{R_x \int AM1.5(\lambda) d\lambda}{\int A_x(\lambda) \times AM1.5(\lambda) d\lambda}$$

DUET, 3D view factor model for fixed tilt or horizontal single-axis tracked (HSAT) arrays[5]



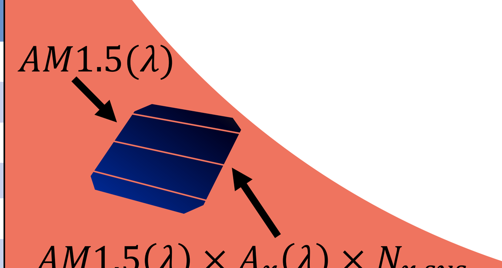
$$R_x = \frac{\sum_{t_x} [PoA_r]}{\sum_{t_x} [PoA_f]}$$



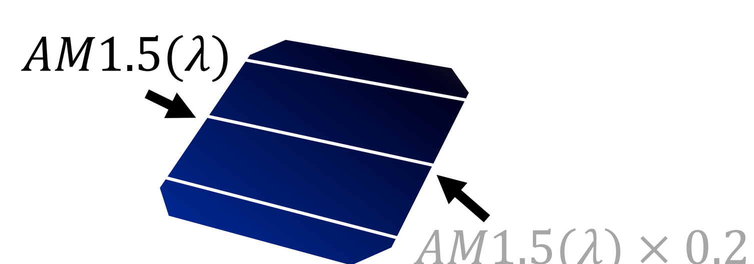
- Calibration works well for other locations around North America
  Ex) R_x 2% higher in Ottawa, 4% lower in Phoenix

Scaled rear irradiance method parameters

Spectral albedos, x		Snow	White sand	Dry grass	Concrete	Roof shingle	Green grass	Red brick
HSAT	R_x	0.248	0.219	0.139	0.092	0.089	0.089	0.070
	$N_{x,sys}$	0.263	0.292	0.304	0.318	0.322	0.320	0.341
	Rear irrad. (suns)	0.224	0.195	0.133	0.091	0.083	0.077	0.080
Latitude Fixed-Tilt	R_x	0.218	0.319	0.206	0.140	0.135	0.135	0.106
	$N_{x,sys}$	0.231	0.425	0.451	0.485	0.489	0.485	0.516
	Rear irrad. (suns)	0.197	0.285	0.197	0.138	0.126	0.117	0.121



ADAPTED IEC METHODS



$AM1.5(\lambda) \times 0.2$

$\mathbf{AM1.5(\lambda) \times R_x}$

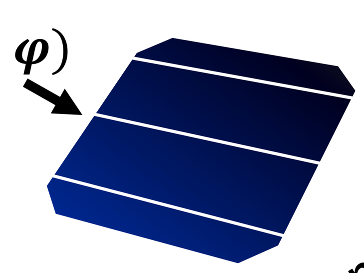
Calibrated plane-of-array irradiance ratio from scaled method

Adapted IEC Methods for Albedo

Spectral albedos, x	Snow	White sand	Dry grass	Light sand	Conc-rete	Roof	Green grass	Red brick	Soil
Broadband albedo, α_x	0.85	0.67	0.44	0.33	0.29	0.26	0.24	0.23	0.19
EQE-weighted albedo, $\alpha_{EQE,x}$	0.94	0.75	0.46	0.34	0.29	0.28	0.28	0.21	0.18
R_x	**0.248**	**0.219**	**0.139**	**0.106**	**0.092**	**0.089**	**0.089**	**0.070**	**0.061**

$AM1.5(\lambda) + (AM1.5(\lambda) \times 0.2 \times \varphi)$

$\mathbf{AM1.5(\lambda) + (AM1.5(\lambda) \times R_x \times \varphi)}$

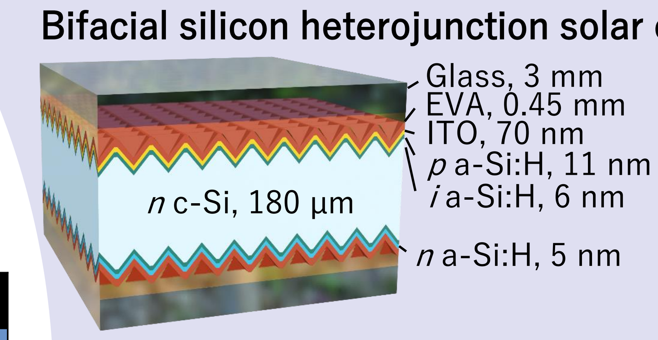


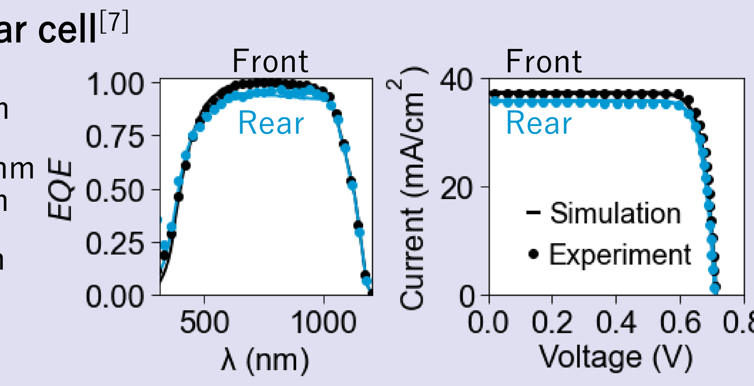
Contact: etoni044@uottawa.ca

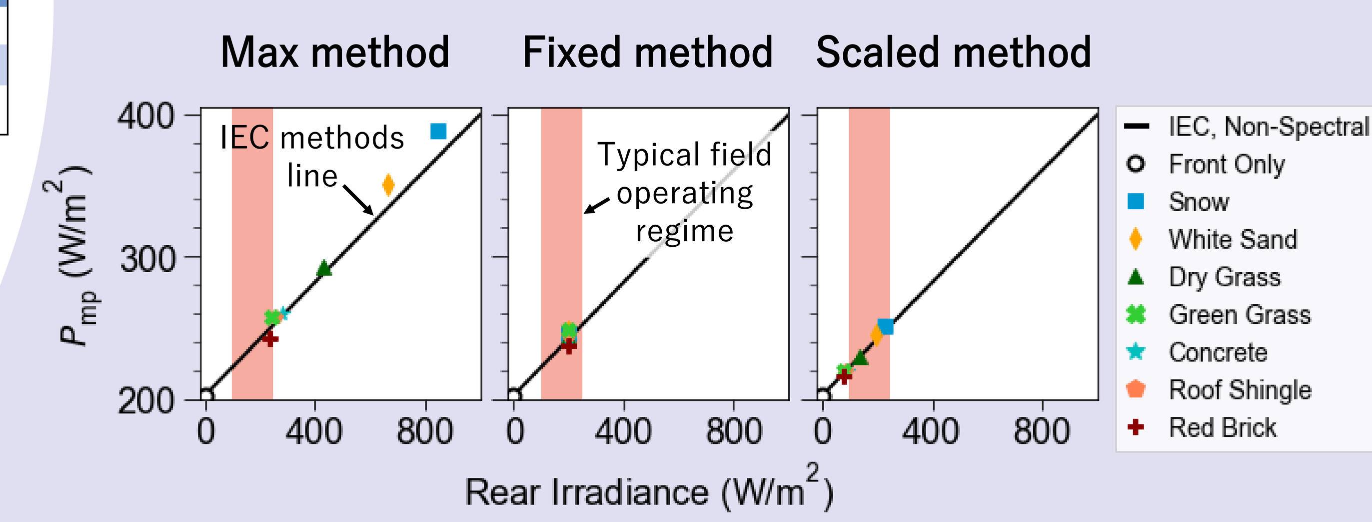
CELL PERFORMANCE

Maximum power (P_{mp}) modelled for **each method** using developed Sentaurus optoelectronic model for textured devices under bifacial illumination[7]

Bifacial silicon heterojunction solar cell[7]







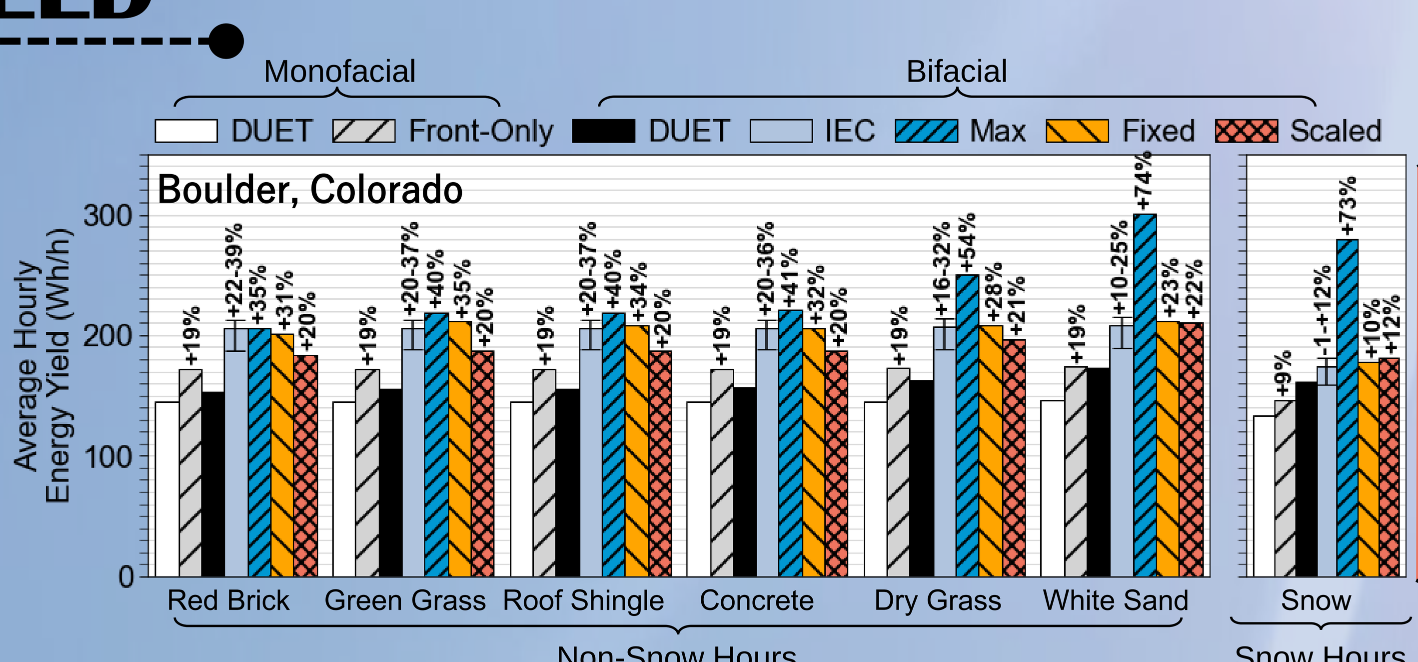
Scaled method reduces rear incident irradiance to levels typical during field operation

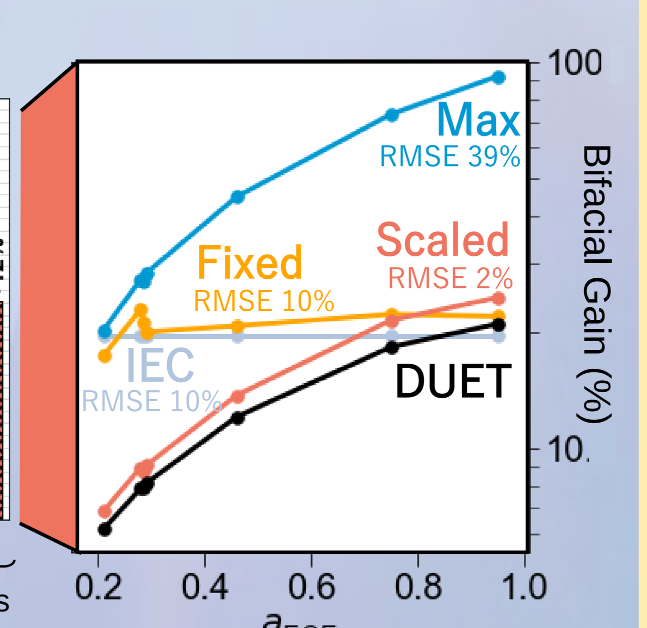
ENERGY YIELD

- **Methods evaluated via estimations of outdoor performance**
- HSAT energy yield, E_x, calculated with DUET[5]
- Estimations calculated with:

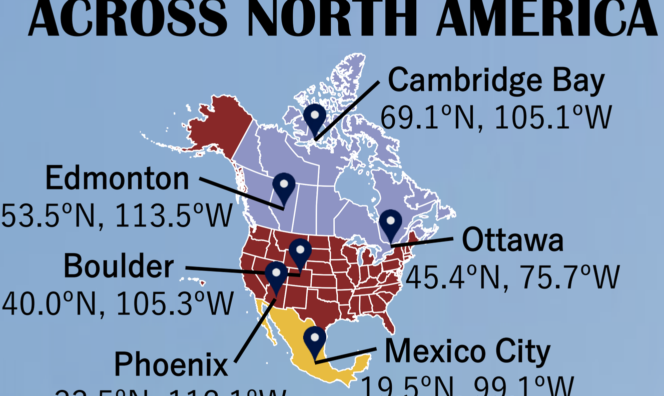
$$E_x = PoA_{f,tot} \times \frac{P_{mp,x}}{1000\ W/m^2} \times Area$$

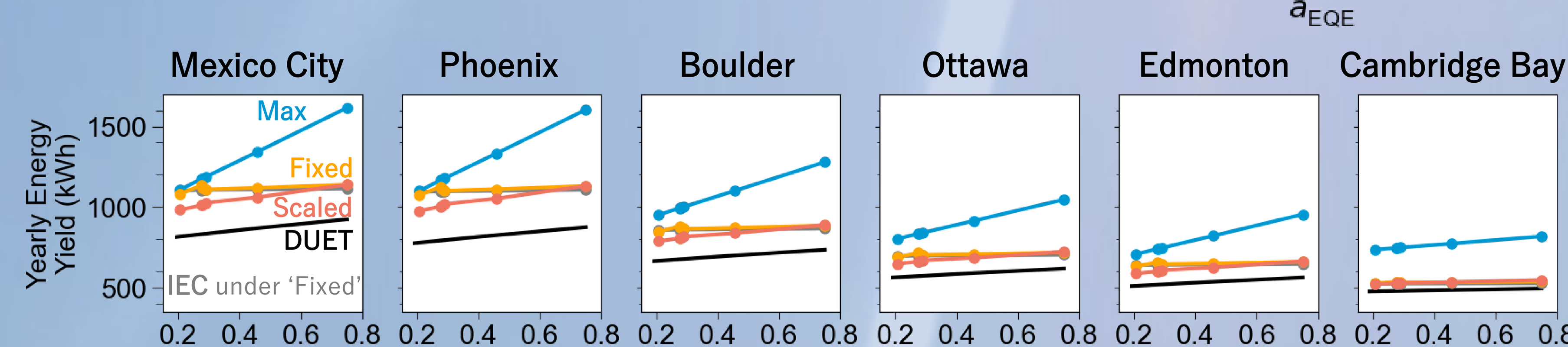
- Overestimation expected





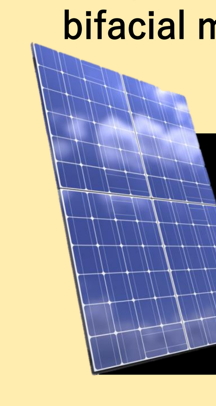
ACROSS NORTH AMERICA





CONCLUSIONS

- **Scaled rear irradiance method** best represents outdoor operation and predicts **bifacial gain** with a **simple calculation** to **within 2%** of outdoor systems across North America
- **IEC** bifacial measurement standards can be **adapted to include broadband or spectral albedo**
- Adapted IEC methods for albedo could **inform future bifacial module power ratings**



Monofacial efficiency ~20.2%
Bifacial efficiency
Soil ~21.4%
Grass ~22.0%
Sand ~24.6%
Snow ~25.2%

$$\eta = \frac{P_{mp,bi.}}{P_{inc,mono.}}$$

Performance of Spectral Albedo Adapted IEC Bifacial Method

Albedo	P_{mp} (W/m²) Scaled	IEC	Adapted IEC
Snow	251.9		251.5
White sand	245.7		245.8
Dry grass	230.0		230.0
Concrete	220.5	242.1	220.7
Roof shingle	219.8		220.2
Green grass	220.3		220.2
Red brick	216.2		216.4
Average difference	-	**20 W/m²**	**0.2 W/m²**

REFERENCES

1. International Technology Roadmap for Photovoltaic (ITRPV), 2021 Results, Ed. 13, Frankfurt, Germany (2022).
2. A. Onno, N. Rodkey, A. Asgharzadeh, S. Manzoor, Z. J. Yu, F. Toor, and Z. C. Holman, "Predicted power output of silicon-based bifacial tandem photovoltaic systems," *Joule*, 4, 580-596 (2020).
3. T. C. R. Russell, R. Saive, A. Augusto, S. G. Bowden, and H. A. Atwater, "The influence of spectral albedo on bifacial solar cells: a theoretical and experimental study," *IEEE J. of Photovolt.*, 7(6), 1611-1618 (2017).
4. IEC 60904-1-2: Photovoltaic devices – Part 1-2: Measurement of current-voltage characteristics of bifacial PV devices, Ed.1.0 2019-01 (2019).
5. A. C. J. Russell, C. E. Valdivia, C. Bohémier, J. E. Haysom, and K. Hinzer, "DUET: A novel energy yield model with 3D shading for bifacial photovoltaic systems," *IEEE J. of Photovolt.* (2022).
6. M. Sengupta, Y. Xie, A. Lopez, a. Habte, G. Maclaurin, and J. Shelby, "The National Solar Radiation Data Base (NSRDB)," *Renew. and Sustain. En. Rev.*, 89, 51-60 (2018).
7. E. M. Tonita, C. E. Valdivia, M. Martinez-Szewczyk, M. R. Lewis, M. I. Bertoni, and K. Hinzer, "Effect of air mass on carrier losses in bifacial silicon heterojunction solar cells," *Solar Energy Materials & Solar Cells*, 230, 111293(2021).

FIND OUT MORE: E. M. Tonita, C. E. Valdivia, A. C. J. Russell, M. Martinez-Szewczyk, M. I. Bertoni, and K. Hinzer, "A general bifacial photovoltaic device method to predict system performance," Submission Under Revision (2022).

uOttawa · SUNLAB · Arizona State University · DEfECT · Mitacs · Ontario · NSERC CRSNG