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The next generation of performance modeling

Bottom-up models can help catch subtle installation mistakes and performance issues, saving time and money.

These models can particularly benefit heterogeneous sites with multiple orientations, string lengths, or device models.

1 Why modeling matters

...for commissioning

Catch mistakes during installation that could cost you over the lifetime of the system, such as miswiring strings

Determine in minutes whether the system is functioning properly, even without full sunshine

...for operations

Diagnose issues remotely and in the field by pinpointing underperforming strings and devices
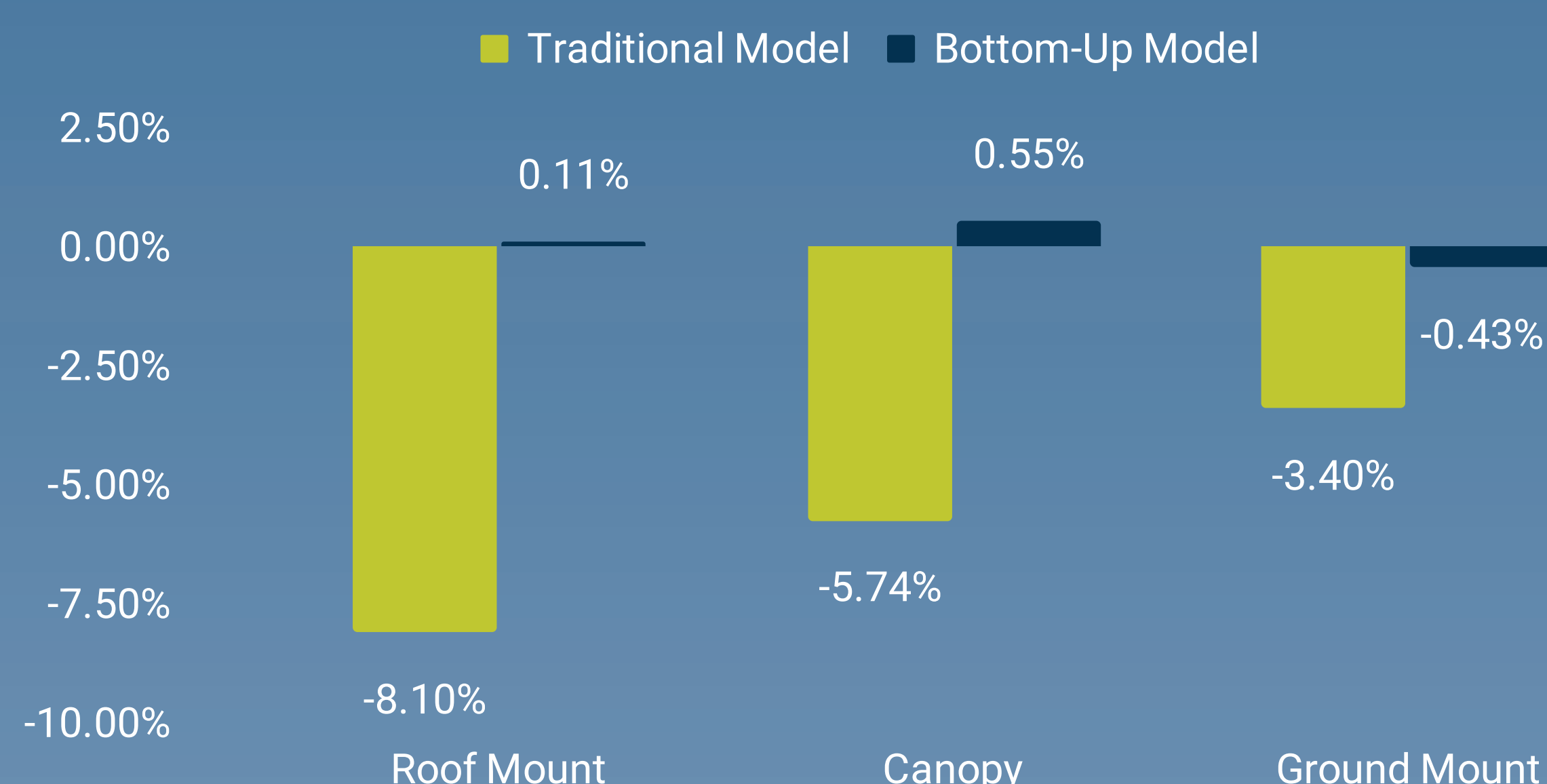
Easily distinguish sources of performance loss such as soiling and clipping without direct observation

3 What bottom-up models capture

- Multiple orientations
- Multiple string lengths
- String resistance
- Per-MPPT clipping
- Inverter efficiency
- Tracker function
- GHI sensor data
- Satellite irradiance data

4 Comparing model precision

Difference between expected and measured energy production

Legend: Traditional Model, Bottom-Up Model

- Roof Mount: Traditional -8.10%, Bottom-Up 0.11%
- Canopy: Traditional -5.74%, Bottom-Up 0.55%
- Ground Mount: Traditional -3.40%, Bottom-Up -0.43%

2 Structuring performance models

Traditional

Inputs:
- DC Capacity
- AC Capacity
- Module Temp
- Temp Coefficient
- Irradiance

$$\text{Energy} = \text{Min}\left(\text{AC Capacity}, \frac{\text{PoA Irradiance} \times \text{DC Capacity} \times \text{Module Temp}^{(\text{I-Temp Coefficient})}}{1000}\right)$$

5-Parameter Model → Energy

Bottom-up

Inputs:
- Pressure
- Ambient Temp
- GHI
- Time
- Location
- BoM Temp
- Wind Speed/Dir

Model nodes: Decomposition, DNI, DHI, SAT, Digital Twin, Soiling, Transposition, Sky Diffuse, POA Module, SPA, Solar Position, Ground Diffuse, IAM, PoA Cell, Cell Temp, CEC, Single Diode Model, AC Clip, Inv Efficiency, MPPT/Limit

Outputs: AC Power, String Voltage, String Current, IV Curve

5 Bottom-up models in action

Catching installation mistakes
160 kW DC, Rooftop, Car Dealership

Bottom-up models revealed that certain modules were wired incorrectly, resulting in lower string voltage and output power than expected

Diagnosing performance issues
200 kW DC, Rooftop, Office

Bottom-up models pinpointed an auxiliary unit on an inverter that had failed, causing a 20% system loss without producing a fault

Tracking small failures
50 kW DC, Canopy, Manufacturing

Bottom-up models showed that higher-than-expected inverter voltage caused curtailment and reduced output that could have been mistaken for passing clouds
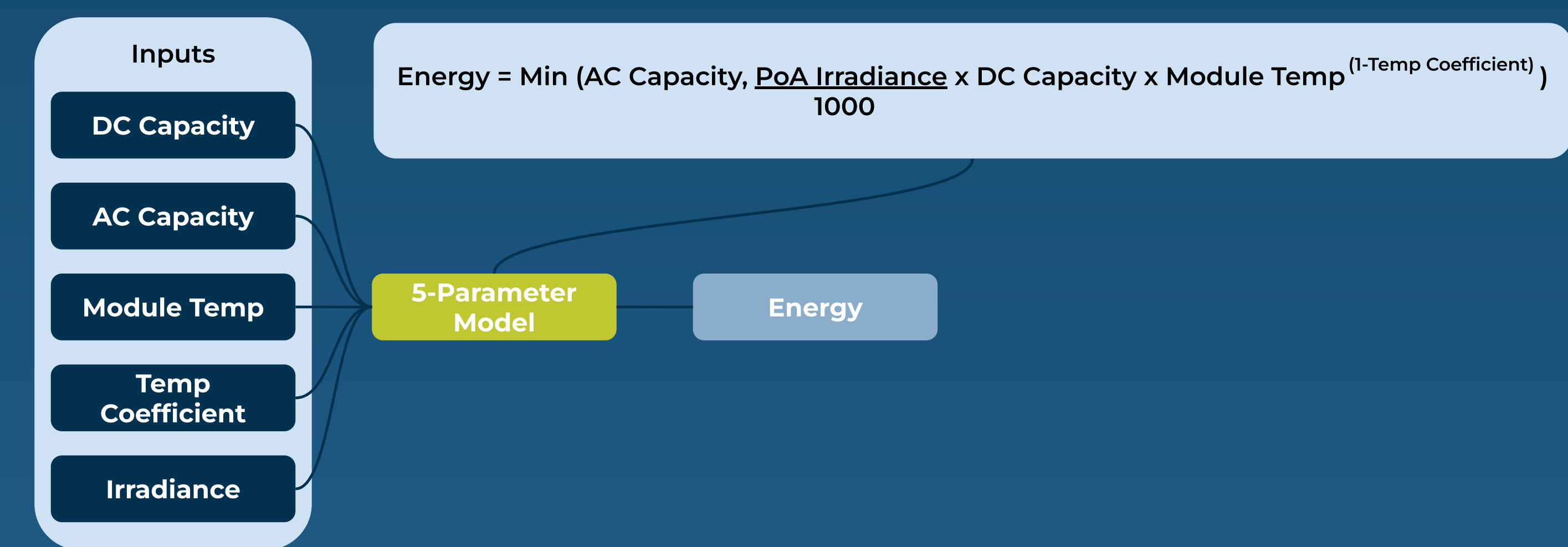
6 Further Reading

King, D.L, Boyson, W.E., & Kratochvill, J.A. (2004). Photovoltaic array performance model. Sandia National Laboratories.
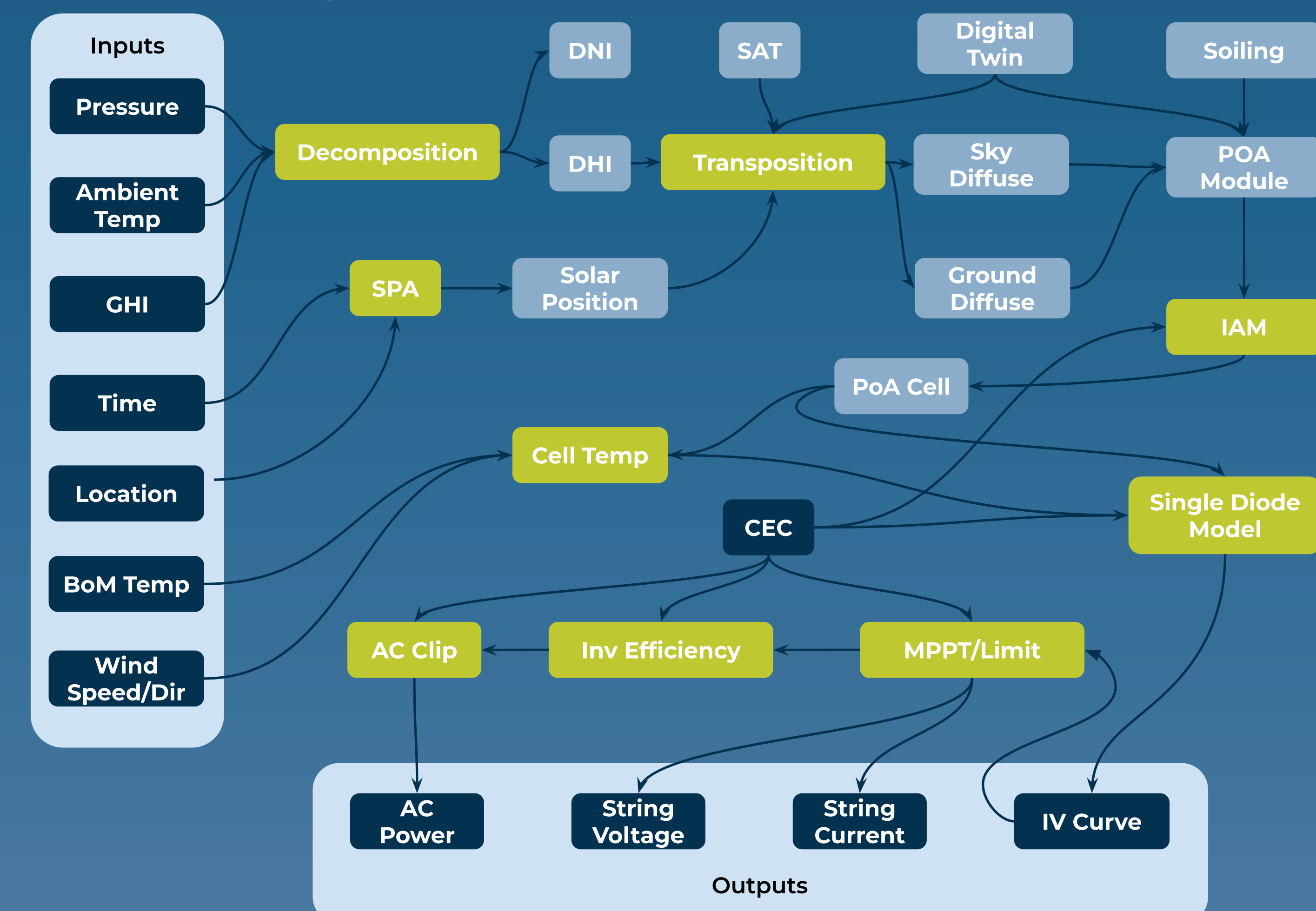
Holmgren, W.F., Hansen, C.W., & Mikofski, M.A. (2018). Pvlib python: a python package for modeling solar energy systems. Journal of Open Source Software, 3(29), 884.