Diffuse irradiance modelling in sub-hourly PV system yield simulations

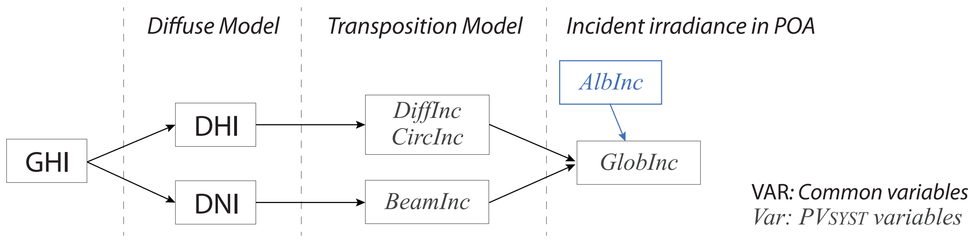
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Abstract

This study aims to reduce biases in diffuse irradiance modelling at subhourly time scales, which is critical for accurate photovoltaic system performance simulations. Typically, this process involves estimating diffuse horizontal irradiance (DHI) from global horizontal irradiance (GHI) and then applying a decomposition model to determine the irradiance on the PV module plane. While models like Erbs and Perez are standard, they introduce biases when applied to fine time scales (e.g., 1-minute) without adaptation. Leveraging global ground-based datasets, this work compares common DHI and decomposition models and proposes reparametrized coefficients specifically for subhourly scales. The results demonstrate that these improvements reduce mean bias in yearly simulation estimates. We also discuss requirements for further improvements.

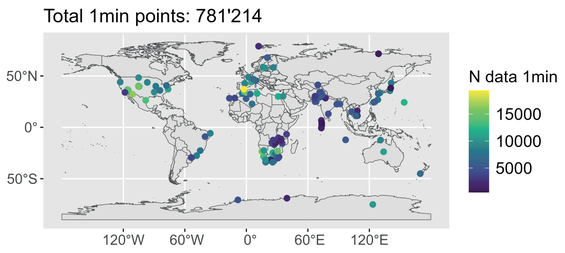
1 IRRADIANCE DECOMPOSITION MODELS



PVsyst < v8.1 : models fitted to hourly data ➔ Subhourly bias!
PVsyst ≥ v8.1 : model refitted to all dt ≤ 60 min ➔ Consistency across timesteps

2 METHOD: DATASET + FILTERING

Data: 1min ground-measured GHI, DHI, DNI at 113 sites[1]



Filtering: 1 min + hourly

1min data standard filtering[2]
- Physically-possible limits tests
- Extremely-rare limits tests
- Closure equation tests
- K-index tests
- Z < 85°

« Perfect hours »: keep only hours with all 1min unflagged.

☑ Aggregation at all timesteps are based on same data.

? Possible bias: morning/evening data loss.

[1] A. Forstinger et al., dx.doi.org/10.23646/3491b1a6-e32d-4b34-9dbb-ee0affe49e36 (2021).
[2] A. Forstinger et al., 10.18086/swc.2021.38.02 (2021)

3 DIFFUSE IRRADIANCE MODELS: FROM GHI TO DHI

PVSYST < v8.1 : Erbs model[3]

$$K_d = \mathrm{DHI}/\mathrm{GHI} = f(\mathrm{GHI}, K_t)$$

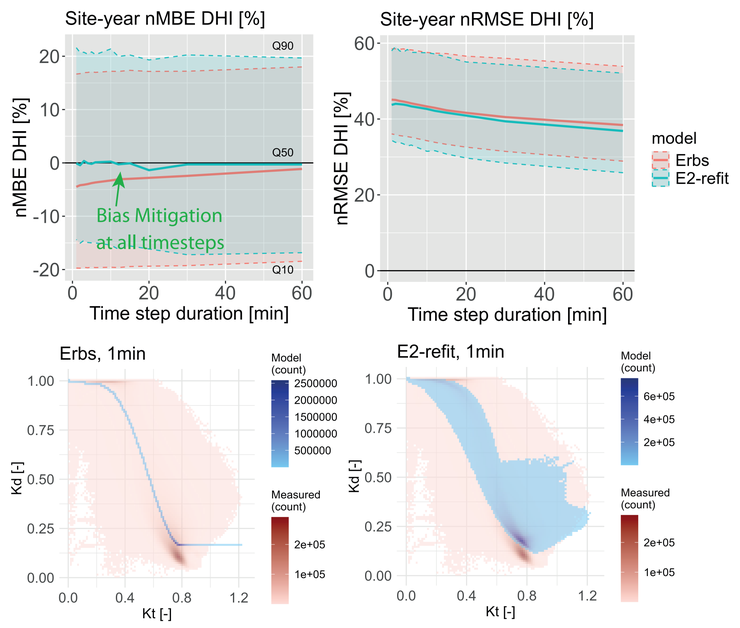
- Good correlation for hourly data.
- One predictor only, fails to capture subhourly dynamics.

PVSYST ≥ v8.1 : Engerer2 (E2) model[4]

$$K_d = \mathrm{DHI}/\mathrm{GHI} = f(\mathrm{GHI}, K_t, \mathrm{AST}, Z, \Delta K_{tc}, K_{de})$$

- Five predictors, capture part of cloud enhancement.
- Need refit on extended dataset and at all timesteps.

NB: Predictors in both models are calculated only from latitude, longitude, time and GHI.



Refit results:
Site-years statistics:

☑ nMBE successfully reduced < 0.5% for any dt, using the refitted E2 model instead of Erbs model.

⚠ nRMSE remains high:

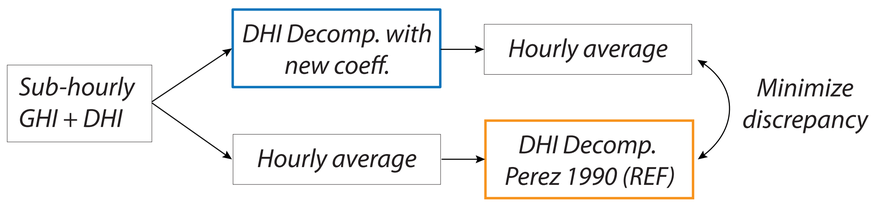
- Error at a given step of the simulation can be high, but compensated throughout the year.
- «Kd vs Kt » plots hint that RMSE could be further reduced by using more coefficients in the parametrization.

[3] D.G. Erbs et al., 10.1016/0038-092x(82)90302-4 (1982).
[4] N. A. Engerer et al., 10.1063/1.5097014 (2019).

4 TRANSPOSITION TO PLANE OF ARRAY: FROM (GHI,DHI) TO DIFFUSE COMPONENTS

Previous model:
Perez model for diffuse decomposition into circumsolar, vertical horizon band irradiance, isotropic diffuse[5]
Set of coefficients fitted using mostly hourly measured data in 1990.
➔ Systematic downward bias at shorter time steps

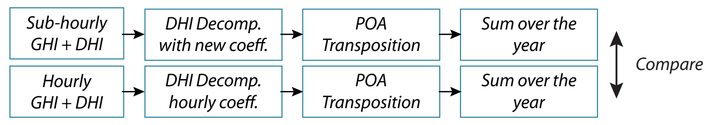
Refit for all timestep durations:
Since no plane of array data are available, Perez hourly model is used as reference.

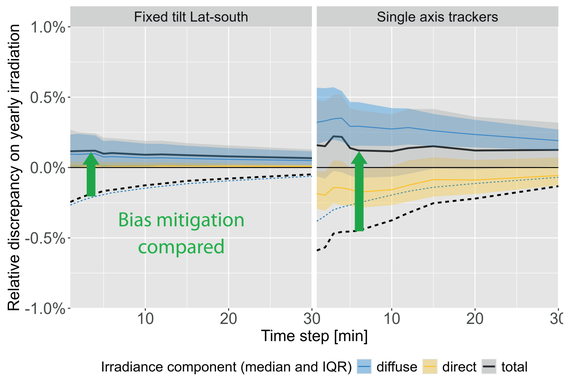


Least-squares fit of coefficients to minimize RMSE between average decomposed irradiance and decompose averaged irradiance (reference).

[5] R. Perez et al., 10.1016/0038-092X(90)90055-H (1990).

Simulation bias for typical system types with different plane-of-array:





Refit results:
Site-years statistics:

☑ Discrepancy on total irradiation < 0.25% at any dt, using the refitted Perez coefficients.

⚠ Comparison relative to dt=60min, no 1 min data available.

➔ POA database needed for absolute reference.

5 IMPACT ON SOLAR RESOURCE FOR TYPICAL POWER PLANTS

System types:

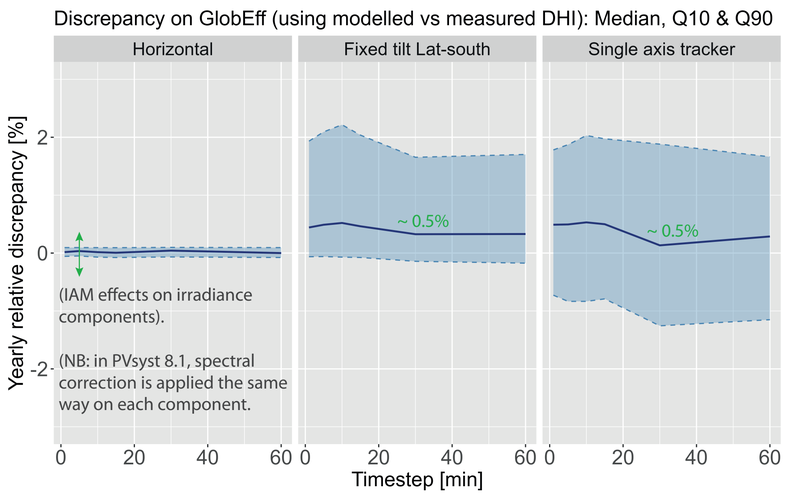
- Horizontal PV: used as reference
- Fixed tilt: tilt = latitude, bifacial, GCR 40%
- Single Axis tracker: bifacial, backtracking, GCR 40%

Method:
Compare differences on *GlobEff* between mulation carried with

- Measured GHI and DHI input
- Measured GHI and modeled DHI input

NB: GlobEff is GlobInc with IAM and spectral corr. applied on irradiance components.

Site-years statistics:



Results:

☑ Very small discrepancy on horizontal plane (residual one due to IAM).

☑ Median bias ~0.5%, consistent with DHI residual bias.

➔ More asymmetric distribution for fixed tilt (~0 to 2%) than for trackers (-1 to 2%))

? Additional small spread expected using different spectral model on each component.

? A small impact is also expected on the electrical shading

Summary

Reparametrizing the diffuse irradiance and transposition models successfully maintains a consistent mean bias across all subhourly timescales. Comparing the diffuse modelling against measurements from numerous sites reveals a median impact of approximately 0.5% on solar resource estimation, with a spread between -1% and +2%. Performance could be further enhanced by improving fitting convergence and using models with additional parameters. Regarding the transposition model, our reparameterization eliminates the artificial bias caused by the unmodified use of Perez's 1990 coefficients, keeping the bias below 0.25% for typical systems. Nevertheless, a comprehensive dataset of 1-minute plane-of-array data is required to fully characterize modelling errors at short time scales.