Proposal and Evaluation of Subordinate Standard Solar Irradiance Spectra

Stefan Wilbert, Wilko Jessen, Chris Gueymard, Jesus Polo, Aitor Marzo, Lourdes Ramirez, Zeqiang Bian, Anton Driesse, Aron Habte, Frank Vignola, Peter Armstrong

30.10.2017

ISES Solar World Congress

Abu Dhabi

DLR

Content

- Introduction of subordinate standard spectra
- Evaluation of applicability for Photovoltaic (PV), Concentrating Photovoltaic (CPV) and Concentrating Solar Power (CSP)
- Recommendation for ISO 9845 update
  - *ISO 9845-1:1992. Solar energy -- Reference solar spectral irradiance at the ground at different receiving conditions -- Part 1: Direct normal and hemispherical solar irradiance for air mass 1,5*

Introduction of subordinate standard spectra

Standard spectra exist (IEC 60904 / ASTM G173 / ISO 9845)

- IEC/ASTM: GTI 37° tilt and DNI for clear, cloudless atmosphere, air mass 1.5 & sea level derived with SMARTS
- **IEC/ASTM spectra remain THE standard spectra (will be adapted by ISO 9845)**
  - These main spectra are & stay obligatory e.g. for efficiency rating of PV

However, additional subordinate standard spectra would be useful. Expectations:

- Subordinate standard spectra can represent sites with average atmospheric conditions different from those of IEC spectra better
- Efficiency derived from appropriate subordinate spectra for such sites more accurate than from IEC spectra




DLR

Introduction of subordinate standard spectra

Subordinate standard atmospheric conditions

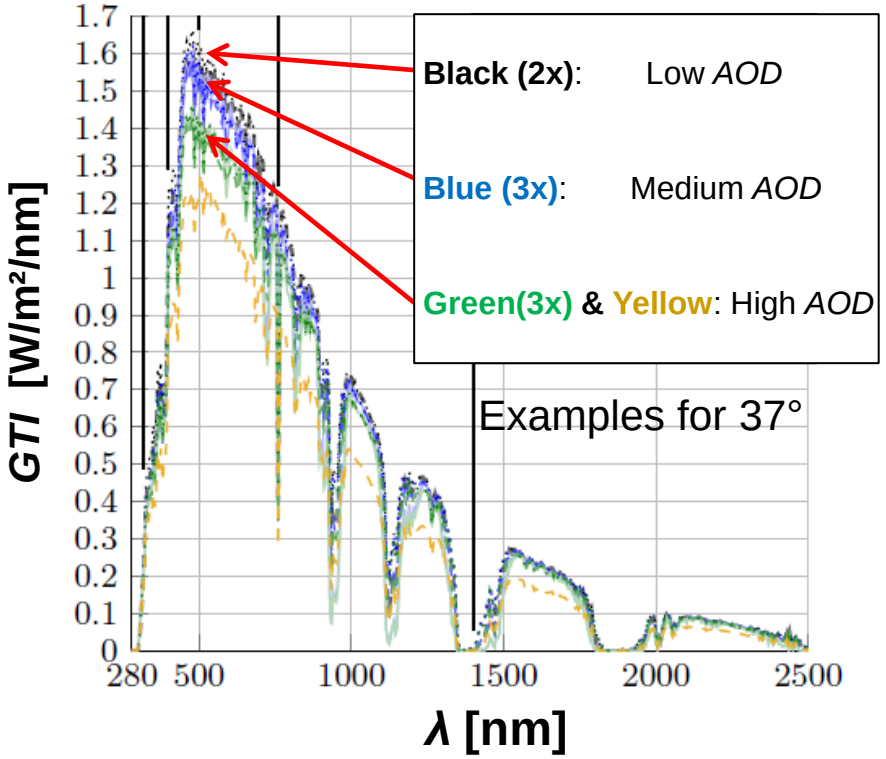
As in IEC/ASTM but additional variation of

- ***AOD*** [-]: *Aerosol optical depth*
- ***PW*** [cm]: *Precipitable water*
- **Elevation** [m] above sea level

9 atmospheric conditions (including IEC/ASTM & current ISO 9845)
Furthermore: 19 tilt angles (0° to 90° in steps of 5° & 37°)

Select subordinate spectrum closest to site's average AOD, PW, elevation & tilt angle

Proposed GTI spectra

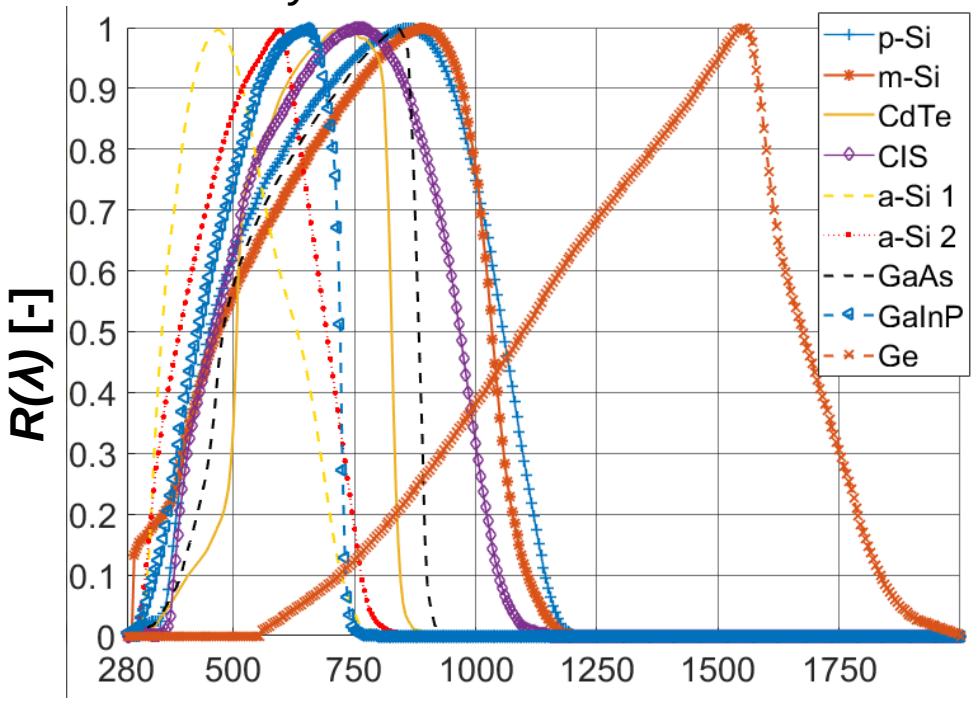


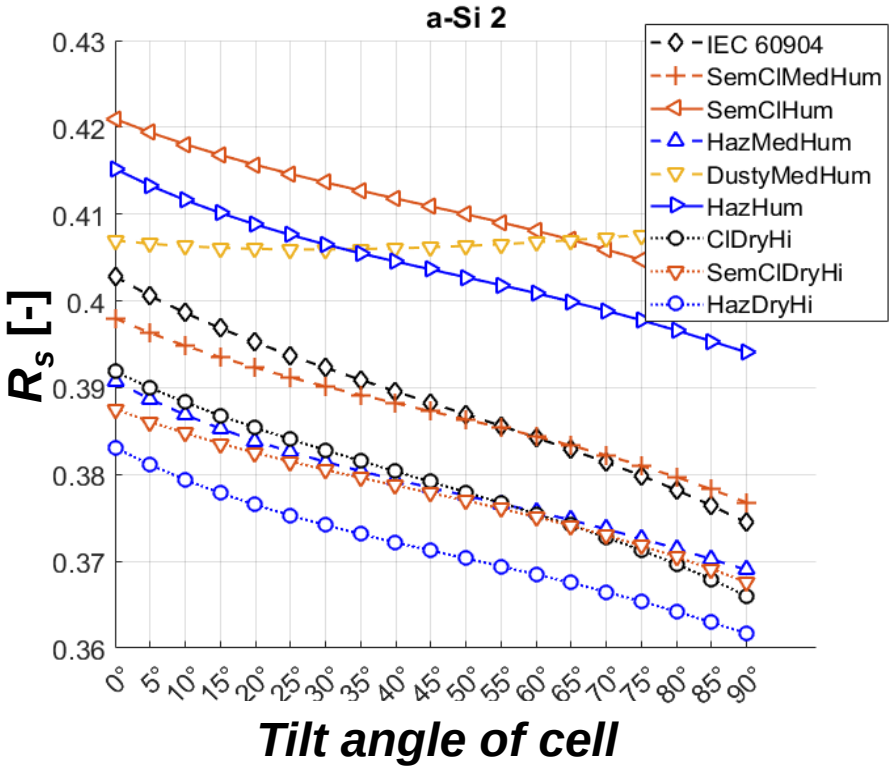
Tested DNI spectra (not recommended as subordinate standard spectra)

Subordinate standard GTI spectra

Application of subordinate standard spectra

- Use subordinate spectra & spectral responsivity ***R(λ)*** to derive:
  "*PV cell responsivity to broadband irradiance,* R_s"
  = spectrally weighted average of the spectral responsivity ***R(λ)***
- **Rough estimation of yield from device data sheets**
  - For small scale power plants
  - For pre-selection of PV modules in larger projects before detailed yield analysis





Test of applicability at five exemplary sites

1. Select most appropriate subordinate spectrum for site

2. Calculation of broadband responsivity for different PV cells:
   - For tested spectrum
   - For IEC spectrum
   - For a reference data set:
     - 1-year time series in 10-min resolution of site specific spectra
       - simulated using SMARTS +SEDES2 based on AERONET and BSRN input data

3. **Question:**
   ¿ Is the broadband responsivity for the test spectrum closer to the result of the time series than for the IEC spectrum?

Evaluation using the spectral mismatch

3. Question:

¿ Is the broadband responsivity for the test spectrum closer to the result of the time series than for the IEC spectrum? → spectral mismatch

Responsivity to broadband irradiance **for a tested spectrum**

Average responsivity to broadband irradiance **for the site's time series of spectra**

$$\delta_{RS}(\mathrm{stdSpec}, \mathrm{Site}) = \frac{R_{\mathrm{S,stdSpec}} - \overline{R_{\mathrm{S,Site}}}}{\overline{R_{\mathrm{S,Site}}}}$$

Spectral mismatch
= relative deviation with respect to time series of spectra

Question in other words:

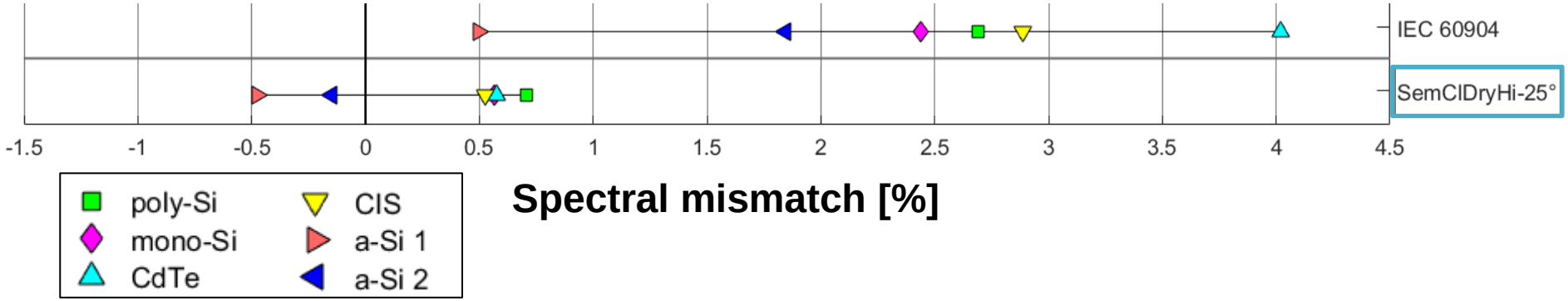
¿ Is δ_{RS} for the selected subordinate spectrum closer to zero than for IEC?

Test of applicability for PV and GTI

Example PV at Tamanrasset

- average $AOD_{500} = 0.254$ → Med *AOD*
- average $PW = 0.81\ \mathrm{cm}$ → Low *PW*
- 1377 m → High elevation
- Latitude & tilt = 22.8° → 25°

→ Subordinate standard spectrum: semi-clean, dry, high elevation, 25° (SemClDryHi-25°)



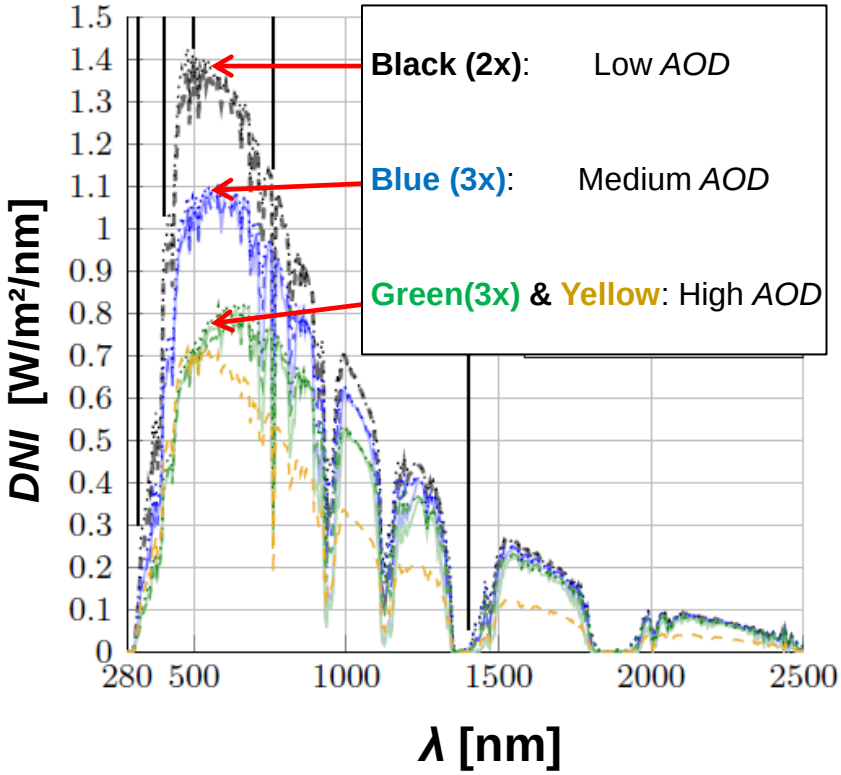
→ SemClDryHi-25° more appropriate than IEC/ASTM

- Same result for subordinate spectra for other 4 sites

Negative test results for CPV and CSP (DNI)

- DNI spectra for the selected atmospheric conditions do not reduce the spectral mismatch

- High sensitivity of DNI to aerosol conditions → many different aerosol conditions needed
  - Also variation of the spectral dependence of the AOD (Angström exponent)
  - Selection of the appropriate spectrum too complicated



DNI spectra therefore not recommended as subordinate standard spectra

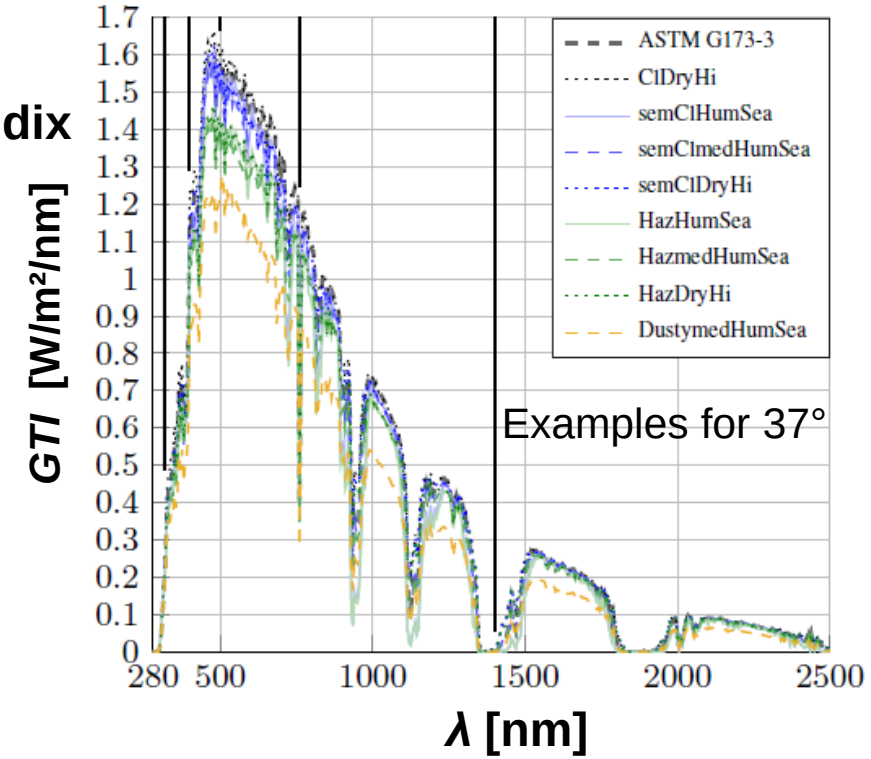
Conclusion and outlook

Subordinate standard GTI spectra defined

- 9 atmospheric conditions and several tilt angles

Tests for GTI at five sites positive

GTI spectra will be proposed in the upcoming draft of ISO 9845 as an appendix



Thank you for your attention!

Questions & comments are welcome!

stefan.wilbert@dlr.de

This work was partly funded by the

HELMHOLTZ | ASSOCIATION