EMRP-Project PhotoClass

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

"Towards an energy-based parameter for photovoltaic classification"

Stefan Winter

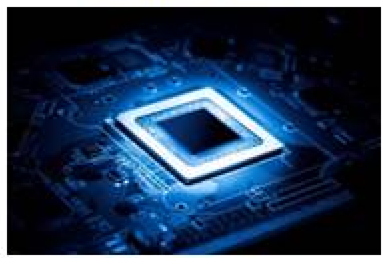
The gateway to Europe's integrated metrology community.

SI Unit

Environment

Energy

Fundamental



Health

Industry

- EURAMET's research programmes (EMRP and EMPIR) support the collaboration of European metrology institutes, industrial organisations and academia through Joint Research Projects (JRPs). They are structured around European Grand Challenges in such areas as Health, Energy, the Environment and also aim to progress fundamental science.

- See www.euramet.org for more details.

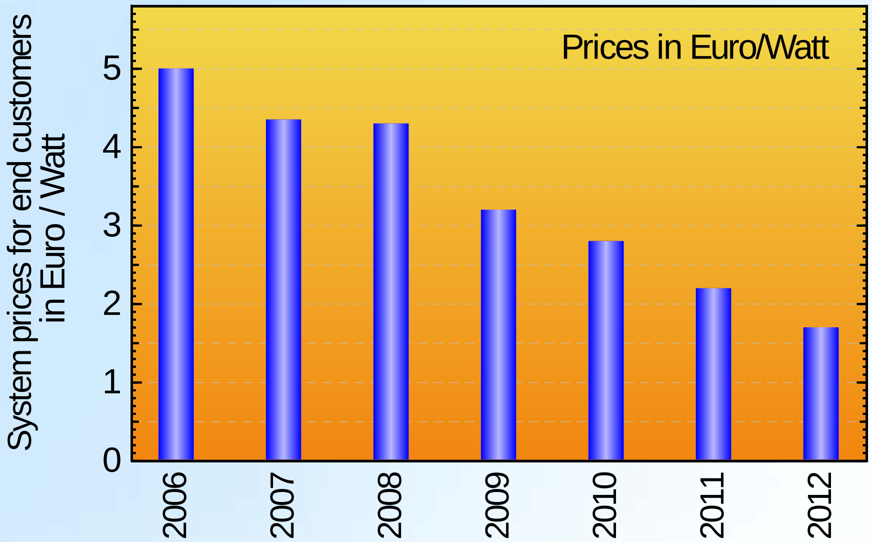
EMRP
European Metrology Research Programme
Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

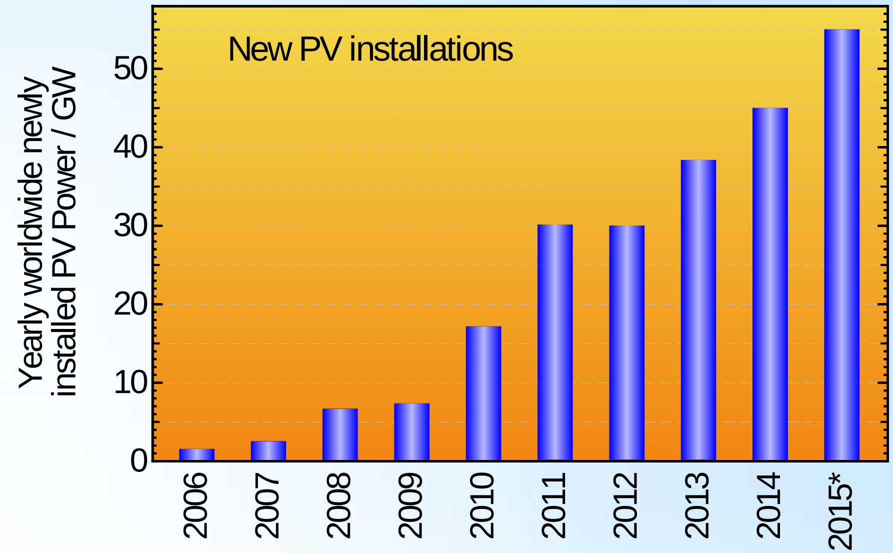
EMPIR EURAMET
The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Economic Impact of Measurement Uncertainty for Photovoltaics

PTB



Source of data: www.solarwirtschaft.de/preisindex



Source of data: EPIA (European Photovoltaic Industry Association) and for 2015 according to IHS market research institute

- Financial uncertainty = Global annual installation × Price × Uncertainty
- 2012: **Financial uncertainty** = 30 GW/year × 1.7 €/W × 1 % = **500 M€/year**

⇒ A measurement uncertainty of 1% leads to a financial uncertainty of 500 M€/year
⇒ High demand for high accuracy solar cell calibrations and realistic standards

Solar parks are financed from banks, who add the financial uncertainty arising from measurement uncertainty to the total amount to be financed. A low uncertainty leads to competitive advantage.

Standard Test Conditions

- Reference solar spectrum AM1,5
- Irradiance E_{STC} = 1000 W/m²
- Cell-Temperature (25°C)
- Angular distribution
  - Important, but not defined
  - Effect about 10% for cloudy conditions

The STC describes Peak-Power conditions.

Description of AMx

PTB

4 Reference solar spectral irradiance distribution

The reference solar spectral distribution AM1.5 is given in Table 1 and Figure 1. This is a total distribution (direct + diffuse) of sunlight, corresponding to an integrated irradiance of 1 000 $W \cdot m^{-2}$ incident on a sun-facing plane surface tilted at 37° to the horizontal considering the wavelength-dependent albedo of a light bare soil, under the following atmospheric conditions:

- U.S. Standard Atmosphere with CO_2 concentration increased to current level (370 ppm), a rural aerosol model, and no pollution;
- precipitable water: 1,4164 cm;
- ozone content: 0,3438 atm-cm (or 343,8 DU);
- turbidity (aerosol optical depth): 0,084 at 500 nm;
- pressure: 1013,25 hPa (i.e., sea level).

Data contained in Table 1 have been generated using the solar spectral model SMARTS, Version 2.9.2. A general description of this model and its suitability to reproduce actual solar spectral irradiance distributions can be found in "Proposed Reference Irradiance Spectra for

Why 37°
instead of 48.2°?

Mean value of
49° (latitude border between USA and Canada) and
25° (latitude of south end of Florida)

Standard Test Conditions

- Reference solar spectrum AM1,5
  Will be reached only up to two times a day.
  In the evening the spectrum is more red, during noon and at cloudy days the spectrum is more blue.

- Irradiance E_{STC} = 1000 W/m²
  Only during summer time reachable

- **Cell-Temperature (25°C)**:
  - Perfect for tests with a flasher during production,
  - Unrealistic for real world application

- Angular distribution important, but not defined

Further reasons for a new metric

- € 50 billion annual market for PV, with strong future growth
- Sales currently based on "watts-peak" for conditions that are never achieved in operation, while the most important parameter for investors is energy yield
- Financial success of installations depends on energy generation rather than power values and there are cases that lower efficiency devices produce more energy
- **Focus on "watts-peak" can distort R&D efforts**
- Currently available metrology does not enable (judicial) expert assessors to clarify defects within the scope of warranty.

Consortium of PhotoClass

PTB

Funded Partners (NMI, EU):

PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

INTA

European Commission

LNE Le progrès, une passion à partager

MIKES Centre for metrology and accreditation

NPL National Physical Laboratory

VSL

Unfunded Partners (Industry):

Scuola universitaria professionale della Svizzera italiana SUPSI

TÜVRheinland® Genau. Richtig.

REGs (Universities, Research Institutes)

Fraunhofer ISE

Loughborough University

ISFH

Structure of PhotoClass

WP1: Develop an energy-based metric for photovoltaics:

$$I(T,E) = \int s(\lambda, T, E, \Omega) \cdot E_\lambda(\lambda, \Omega)\, d\lambda\, d\Omega$$

providing input parameters

WP3: Detector characterization

WP4: Source characterization methods

calibration

measurement

WP2: Reference devices

WP6: JRP Management and Coordination

WP5: Creating Impact

- Workshops
- Standardisation
- Exploitation
- Good Practice Guides
- Scientific Paper

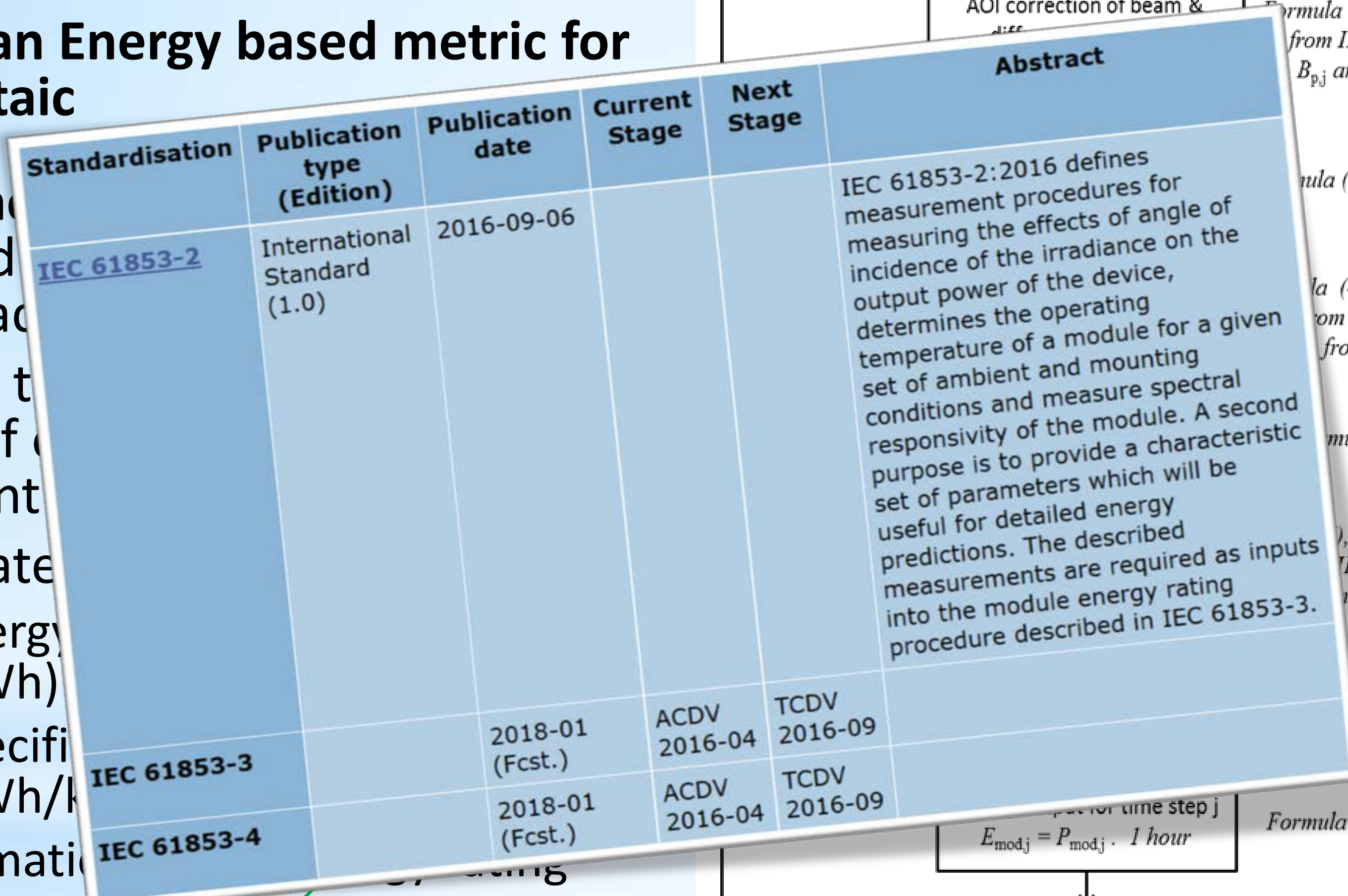
All technical WPs will create impact.

ENG55

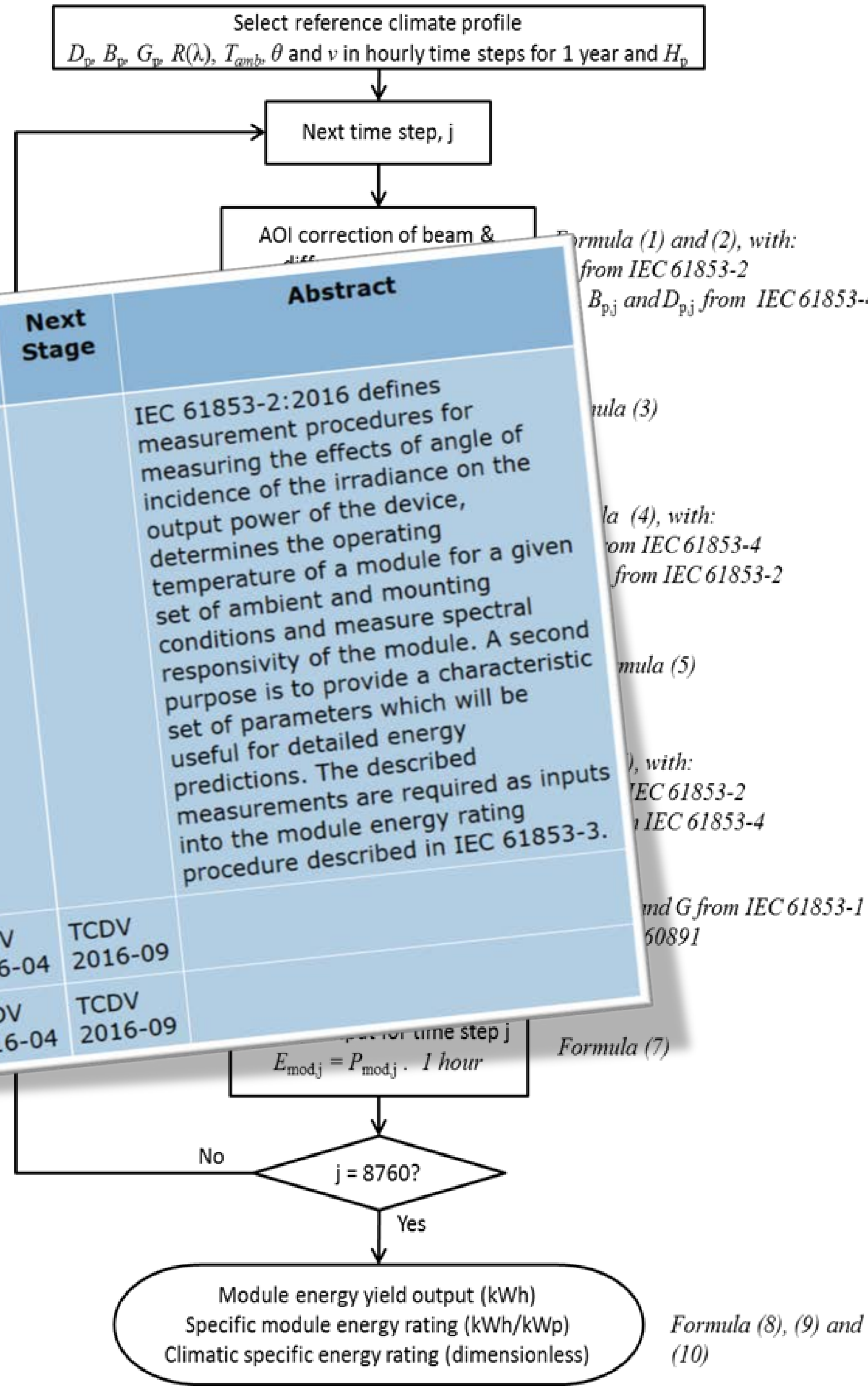
WP1: Modelling

Develop an Energy based metric for photovoltaic

- Use En… instead … approac…
- Define t… hour of … ambient…
- Calculate …
  - Energy … (kWh) …
  - Specifi… (kWh/k…
  - Climati… …y rating (dimensionless) ✓
- Calculate the uncertainty ✓
- Standard and geospatial climatic datasets ✓

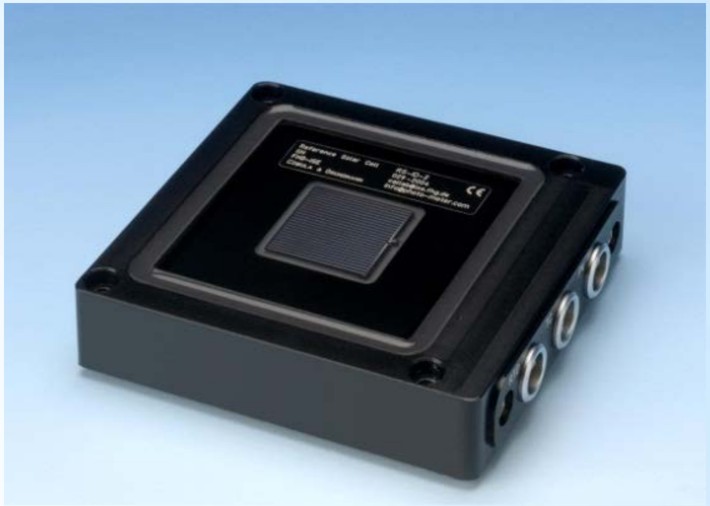


Standardisation	Publication type (Edition)	Publication date	Current Stage	Next Stage	Abstract
IEC 61853-2	International Standard (1.0)	2016-09-06			IEC 61853-2:2016 defines measurement procedures for measuring the effects of angle of incidence of the irradiance on the output power of the device, determines the operating temperature of a module for a given set of ambient and mounting conditions and measure spectral responsivity of the module. A second purpose is to provide a characteristic set of parameters which will be useful for detailed energy predictions. The described measurements are required as inputs into the module energy rating procedure described in IEC 61853-3.
IEC 61853-3		2018-01 (Fcst.)	ACDV 2016-04	TCDV 2016-09	
IEC 61853-4		2018-01 (Fcst.)	ACDV 2016-04	TCDV 2016-09	



WP2: Reference devices

- Definition of required specs and selection of reference devices ✓
- **Development and optimization of new reference devices** ✓
- Validation of various improved calibration / characterization methods: Comparison ongoing

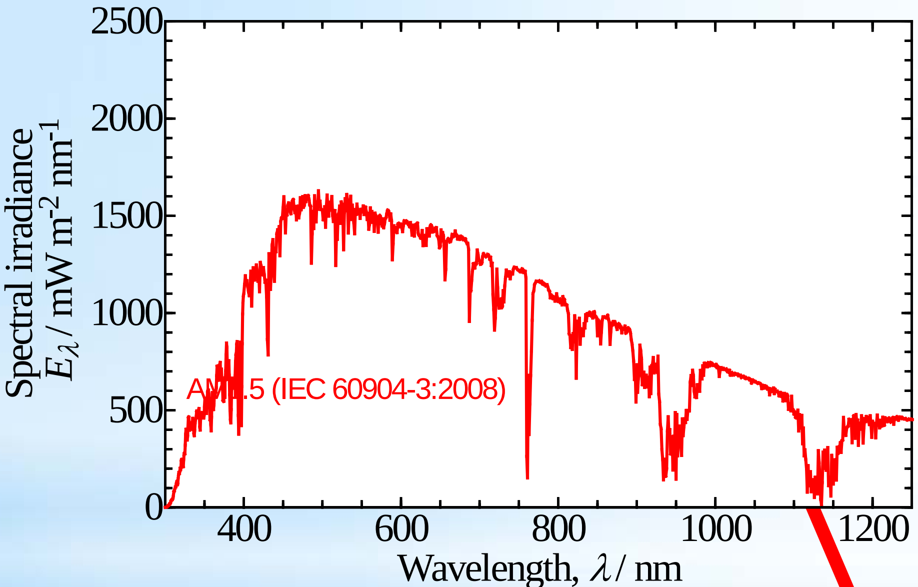


Good News Story:

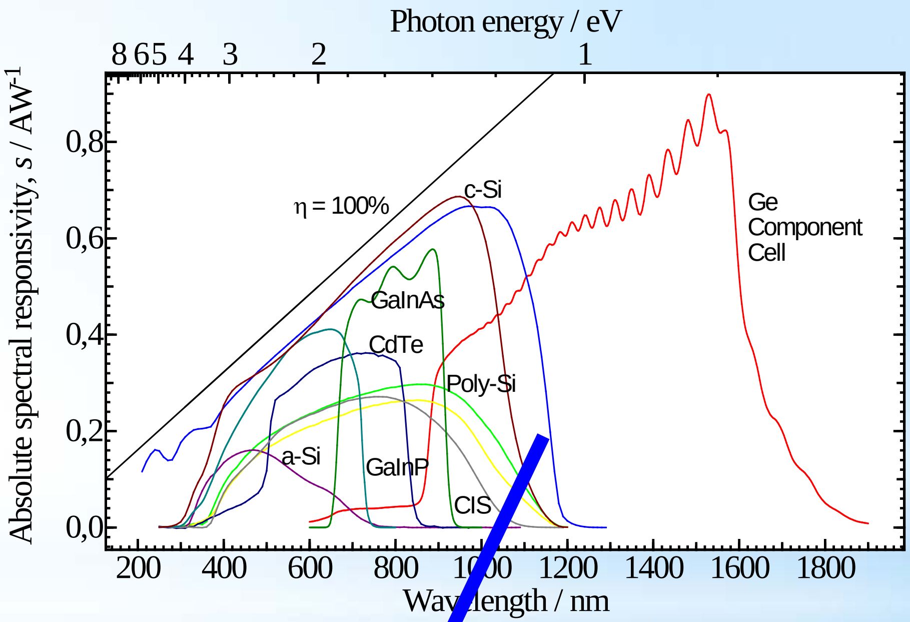
New Reference devices of Fraunhofer ISE are commercially available. Within the WP 2 new reference devices are developed. The aim of this work package is to develop new PV reference devices that exhibit device stability of better than 0.1 %, and provide a wider coverage of operating spectral range and linearity. Additional filtering is used to match the spectral response to various cell technologies. A set of new cell technologies based on n-type silicon cells are selected to be used. The WPVS housing was improved regarding manufacturing, with additional options for shunted outdoor cells for quality assurance. Additionally the thermal conduction of the cell in the WPVS housing was improved. All this improvements are included in the available version of the WPVS reference elements.

Metrological background

Reference solar spectrum AM1.5 according to IEC 60904-3:2008



Spectral responsivity of different solar cells



$$\text{Photocurrent:} \quad I = \int E_{\lambda,\mathrm{Norm}}(\lambda) \cdot s(\lambda)\, \mathrm{d}\lambda$$

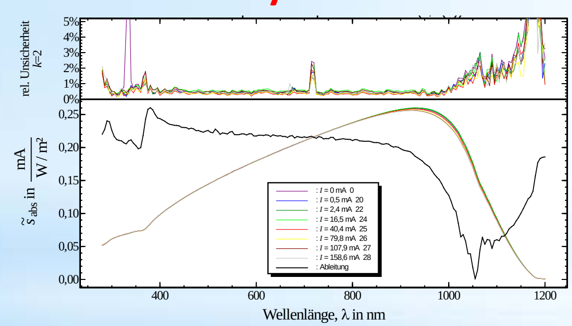
WP3 ... on

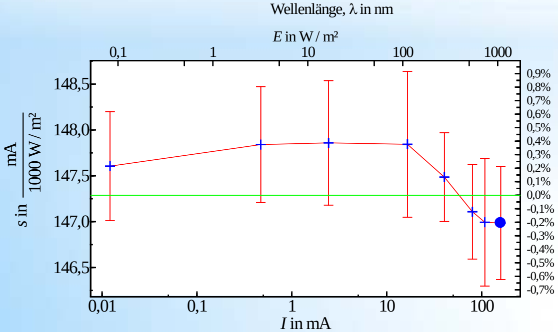
EU PVSEC student award goes to REG(LU)

Task 1: New techniques:

- Compressed sensing method (NPL) ✓
- Polychromatic method (REG(LU)) ✓
- Wavelength traceability via FTS (PTB) ✓
- Supercontinuum Laser SR-facility (VSL) ✓

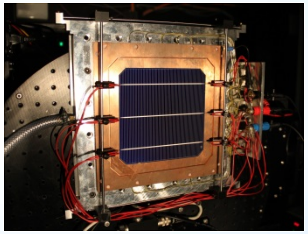
Task 2: Linearity



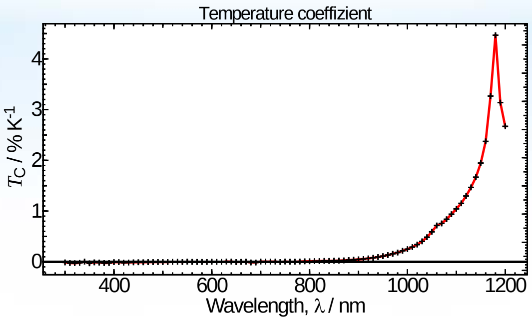


Task 3: Temperature

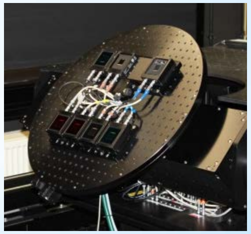
Climate chambers



Solar cell chuck

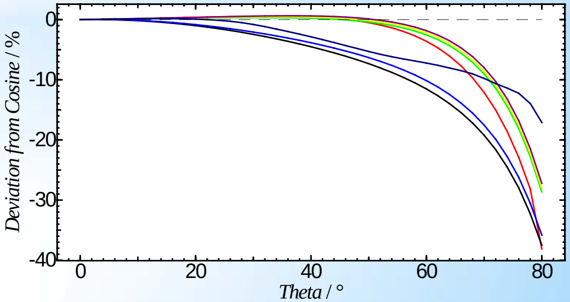


Task 4: Angular dependence



indoor

outdoor



WP4: Source characterisation

- Characterization of the solar spectrum,
  Spectral Sky Scanning ✓
- Spectral characterization of pulsed solar simulators ✓
- Characterization of LED based solar simulator ongoing
- Simultaneous uniformimeter based on photodiode array ongoing
- Uncertainty of spectral measurements ✓

WP5: Impact

- **Draft standard i**
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  pre
- Sup ewables Directive

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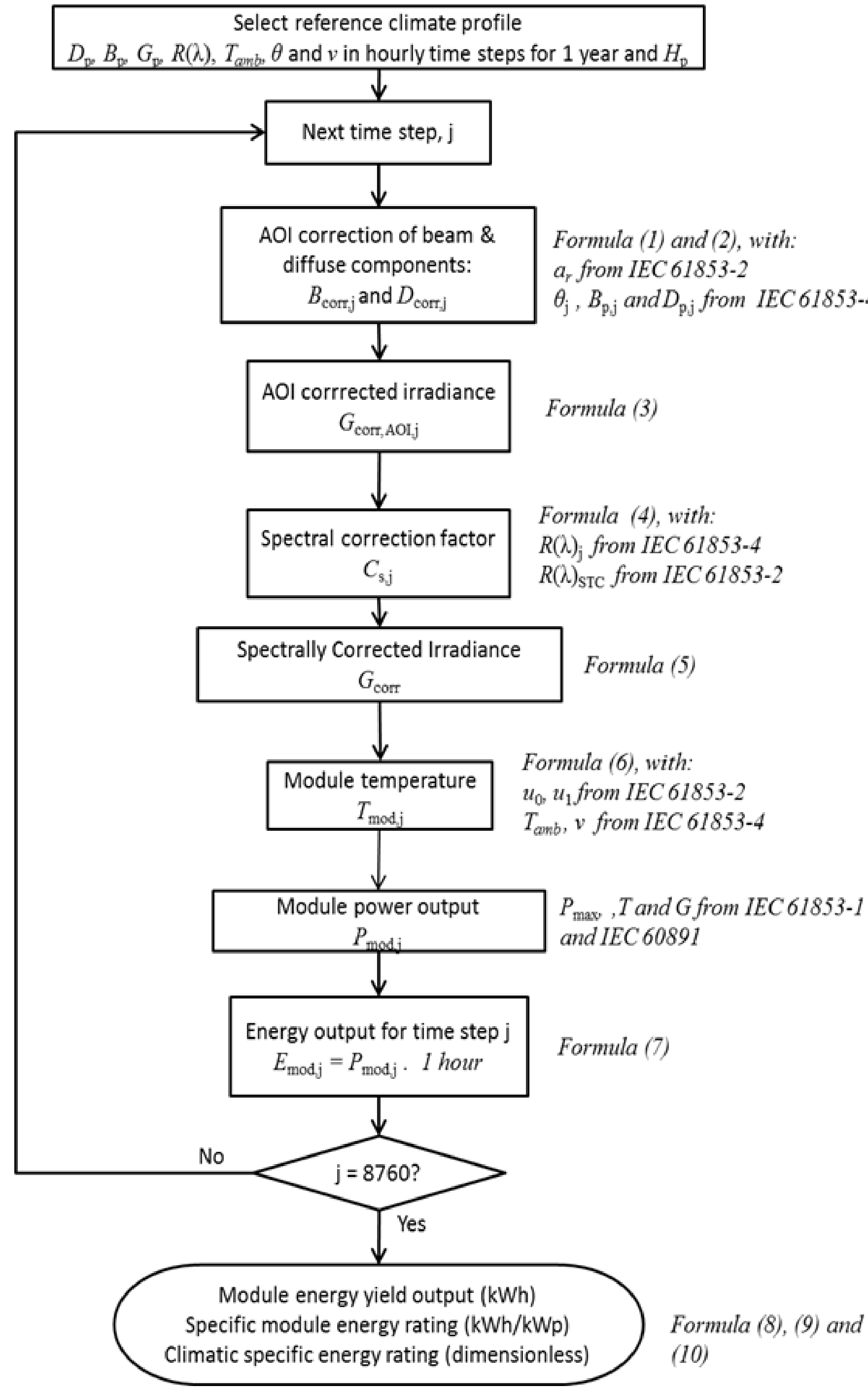
IEC 61853-4		2018-01 (Fcst.)	ACDV 2016-04	TCDV 2016-09	

http://photoclass.ptb.de

IEC 61853 Part 3

Provides formulas for Energy rating:

- In-plane global irradiance corrected for **angular incidence effects**
- **Spectrally** corrected global in-plane irradiance
- Calculation of **module temperature**, depending on irradiance, ambient temperature and wind speed



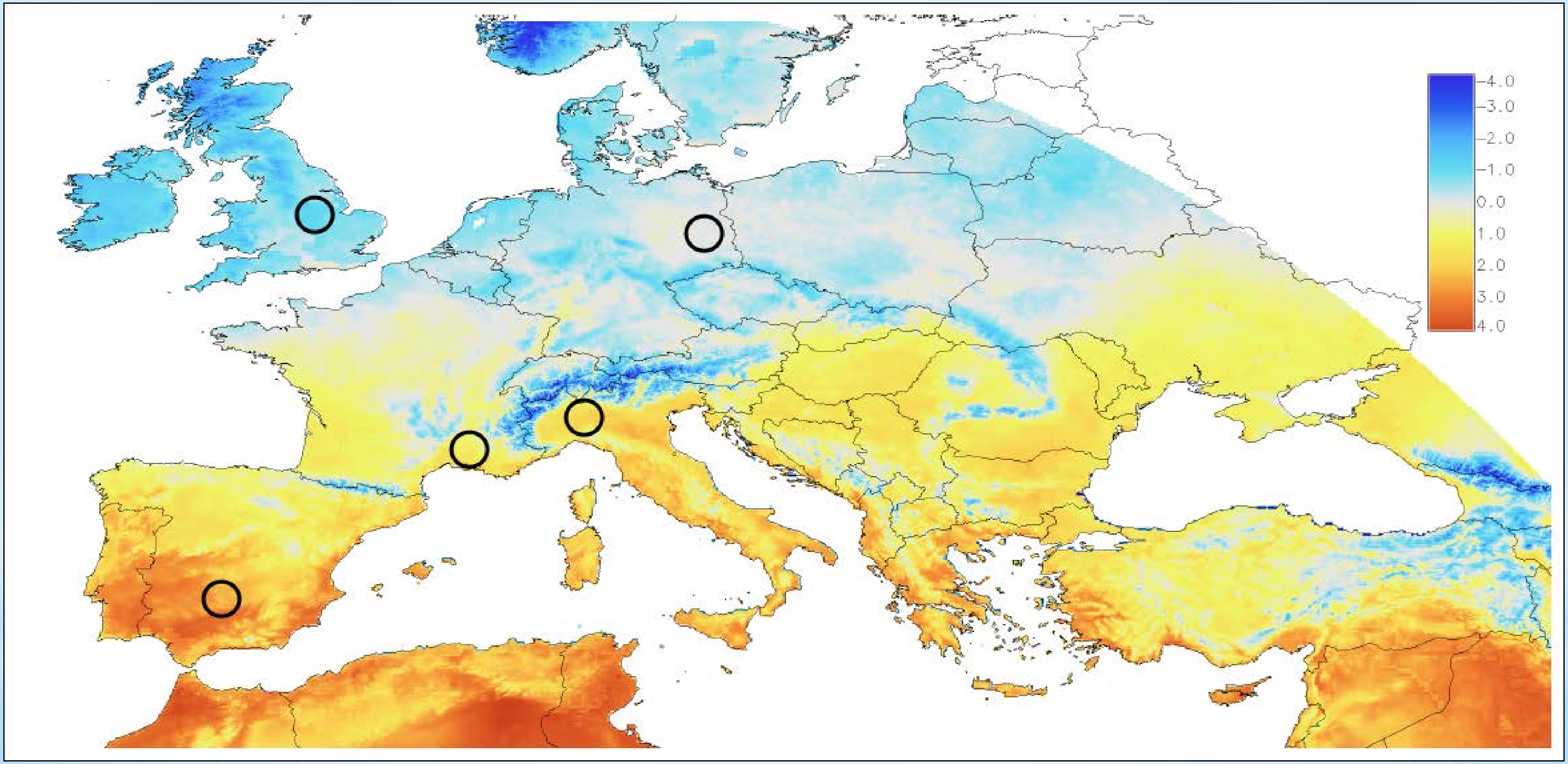
IEC 61853 Part 4

Starting with one standard reference climatic profile

	A	B	C	D	E	F	G	H	I	J	K	L	
1	Day in Year	Hour	Sun elevation (degrees)	Sun incidence angle	Wind speed	Ambient temperature	Direct Normal Irradiance	Global horizontal irradiance	Global in-plane irradiance	Direct in-plane irradiance	Spectral irradiance 306.8-327.8nm	327.8-362.5nm	362. 407.
4273	178	23	0,000	0,000	1,596	15,320	0,000	0,000	0,000	0,000	0,000	0,000	
4274	179	0	0,000	0,000	3,427	13,840	0,000	0,000	0,000	0,000	0,000	0,000	
4275	179	1	0,000	0,000	3,234	13,160	0,000	0,000	0,000	0,000	0,000	0,000	
4276	179	2	0,000	0,000	3,035	12,480	0,000	0,000	0,000	0,000	0,000	0,000	
4277	179	3	0,000	0,000	2,843	11,800	0,000	0,000	0,000	0,000	0,000	0,000	
4278	179	4	0,000	0,000	3,093	12,220	0,000	0,000	0,000	0,000	0,000	0,000	
4279	179	5	8,832	0,379	3,358	12,640	127,659	68,100	52,216	0,846	0,006	0,993	
4280	179	6	18,998	13,013	3,641	13,060	415,326	235,200	188,904	93,522	0,423	4,183	
4281	179	7	29,611	26,065	3,171	15,410	578,218	416,900	383,378	254,062	1,330	8,387	
4282	179	8	40,374	39,395	2,717	17,750	662,884	588,100	582,583	420,705	2,549	12,915	
4283	179	9	50,902	52,909	2,272	20,100	505,110	666,700	682,589	402,917	3,614	16,064	
4284	179	10	60,487	66,541	1,361	21,280	788,403	861,200	910,144	723,238	5,018	20,832	
4285	179	11	67,499	80,230	0,470	22,450	859,642	946,600	1012,948	847,175	5,856	23,389	
4286	179	12	68,957	85,942	0,482	23,630	745,623	923,000	985,680	743,754	5,860	23,143	
4287	179	13	63,885	72,272	0,378	23,380	516,084	802,600	839,761	491,577	5,112	20,450	
4288	179	14	55,094	58,608	0,394	23,120	529,086	737,600	762,403	451,641	4,346	18,262	
4289	179	15	44,842	45,037	0,528	22,870	390,271	581,100	582,242	276,143	3,069	14,034	
4290	179	16	34,119	31,620	0,511	22,240	175,961	373,700	363,159	92,255	1,695	8,916	
4291	179	17	23,405	18,439	0,555	21,610	16,615	162,800	158,836	5,255	0,587	3,908	
4292	179	18	13,017	5,609	0,640	20,980	0,000	55,200	53,850	0,000	0,110	1,220	
4293	179	19	3,248	0,000	0,931	19,640	0,000	27,500	26,267	0,000	0,000	0,375	
4294	179	20	0,000	0,000	1,361	18,310	0,000	0,000	0,000	0,000	0,000	0,000	
4295	179	21	0,000	0,000	1,836	16,970	0,000	0,000	0,000	0,000	0,000	0,000	

Altogether: 24x365 = 8760 lines and 39 columns

IEC 61853 Part 4



Map of difference in MPR between CdTe and c-Si modules, given in percentage points.

T. Huld et al: „Photovoltaic Energy Rating Data sets for Europe " in Solar Energy

Outlook 1 (PVEnerate)

- More detailed look at spectral and angular dependent radiance of sky and their effect on energy rating
- Simultaneous hyperspectral sky measurement instead of sky scanning
- Comparison with satellite data and extrapolation to historical data

Outlook 3 (PVEnerate)

Hot topic at standardisation meetings of IEC:

- Metrological assessment of bifacial solar modules
- Open questions:
  - How to define and to measure the bifacial gain and bifaciality
  - How much does it depend on module properties and how much on installation conditions
  - How to measure STC power,
    e.g. from one side in production and from two side in laboratory, what are the effects
  - How much does the yield depend on: STC power, module properties, tilt angle, height, albedo, mounting structure, surrounding of the module (stand alone module, solar park)
- BIPV Questions

Outlook 4 (PVEnerate)

Hot topic at standardisation meetings of IEC:

- Metrological assessment of bifacial solar modules
- Two new standards needed:
  - Standard test conditions (STC): e.g. IEC 60904-1-2
  - Energy rating, e.g. IEC 61853-5