Introduction to Photovoltaic Metrology

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Outline

- Clean energy
- History of solar cells
- Global irradiation & photovoltaic power potential
- Solar cell efficiencies
- Photovoltaic metrology
- Experimental setup of MRI
- Uncertainty analysis
- References

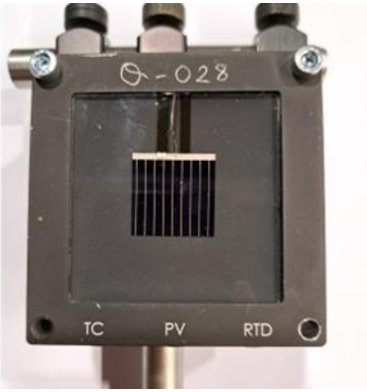
Clean energy

- Fossil fuels: 75% of global greenhouse gas emissions and ~90% of all carbon dioxide emissions
- Emissions need to be reduced by almost half by 2030 and reach net-zero by 2050
- Alternative sources of energy (clean, accessible, affordable, sustainable and reliable)
- Fossil fuels account for more than 80% of global energy production
- ~29% of electricity currently comes from renewable sources

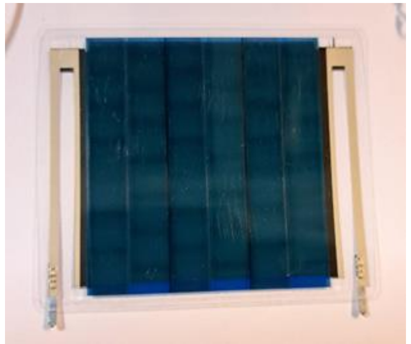
1. Renewable energy sources are all around us
2. Renewable energy is cheaper
3. Renewable energy is healthier
4. Renewable energy creates jobs

History of solar cells

- Photovoltaic effect → reported in 1839 by *Becquerel*, who observed a light-dependent voltage between electrodes immersed in an electrolyte
- Observed in an all-solid-state system in 1876 for the case of selenium → development of photocells based on Se and cuprous oxide
- 1941: a silicon cell was reported
- 1954: the forerunner of present silicon cells was announced (the first photovoltaic structure with reasonable efficiency)
- 1958: power sources in spacecrafts
- Early 1960s: the design of cells for space use had stabilized (major application until next decade)
- 1970s: reawakening of interest in terrestrial use of these devices → terrestrial use outstripped the space use
- 1980s: significant reduction in solar cell costs, newer device technologies
- A continual expansion of the range of commercial applications

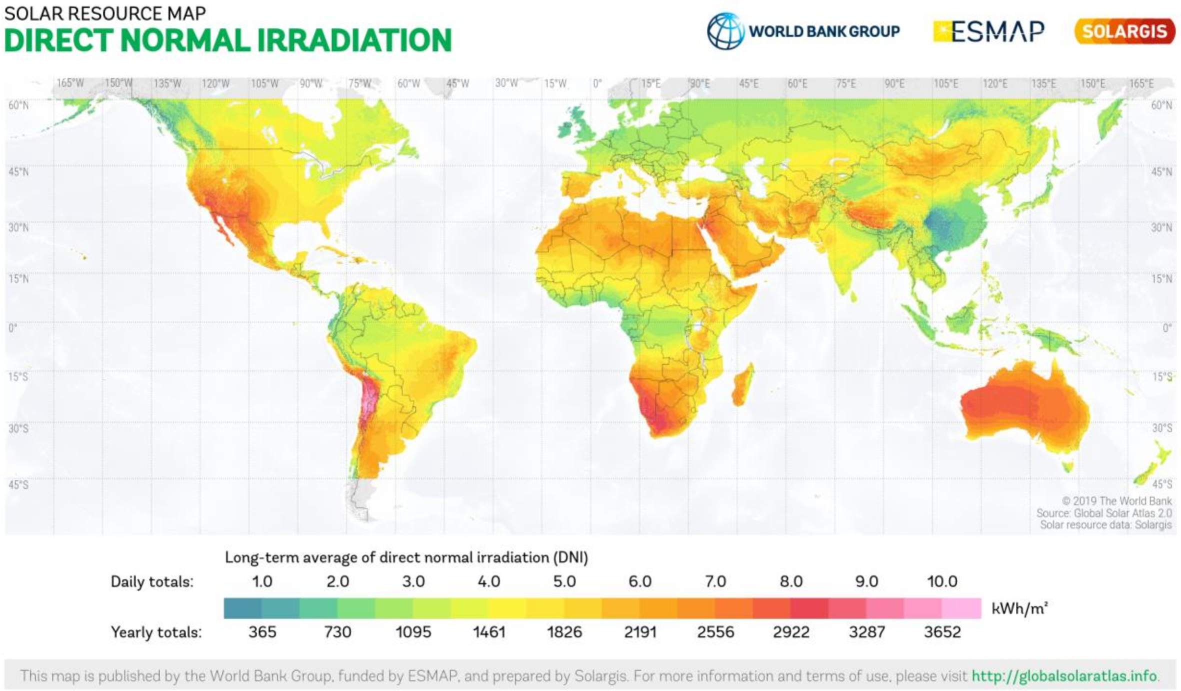


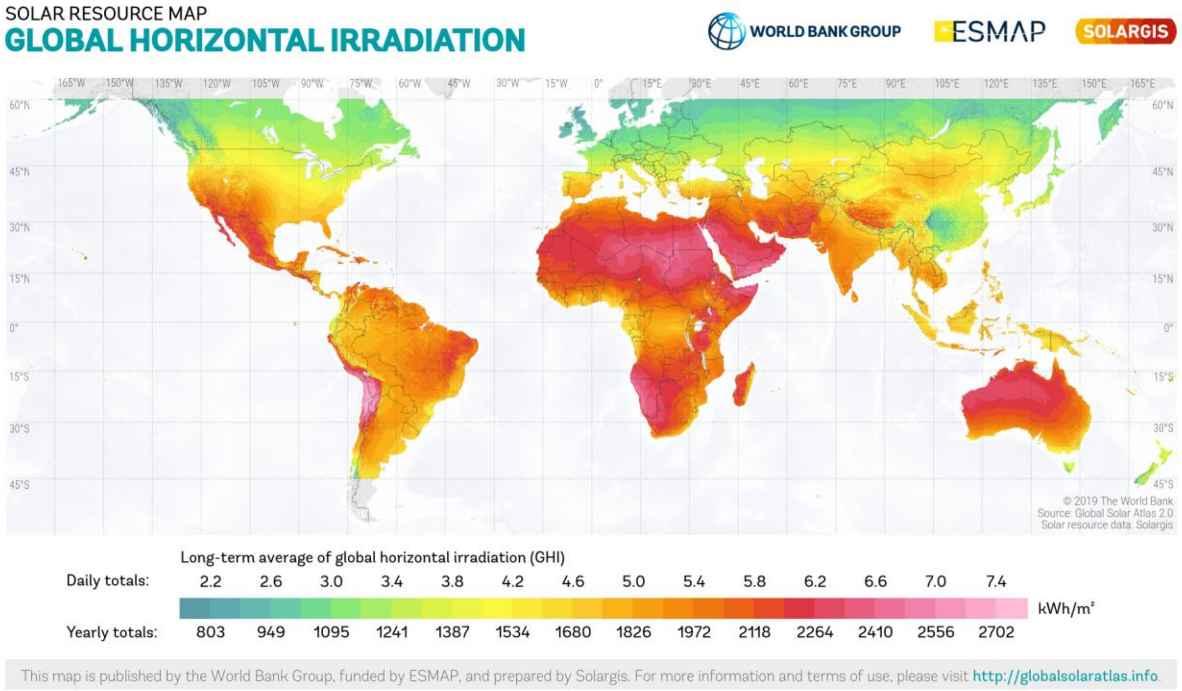
Crystalline silicon solar cell



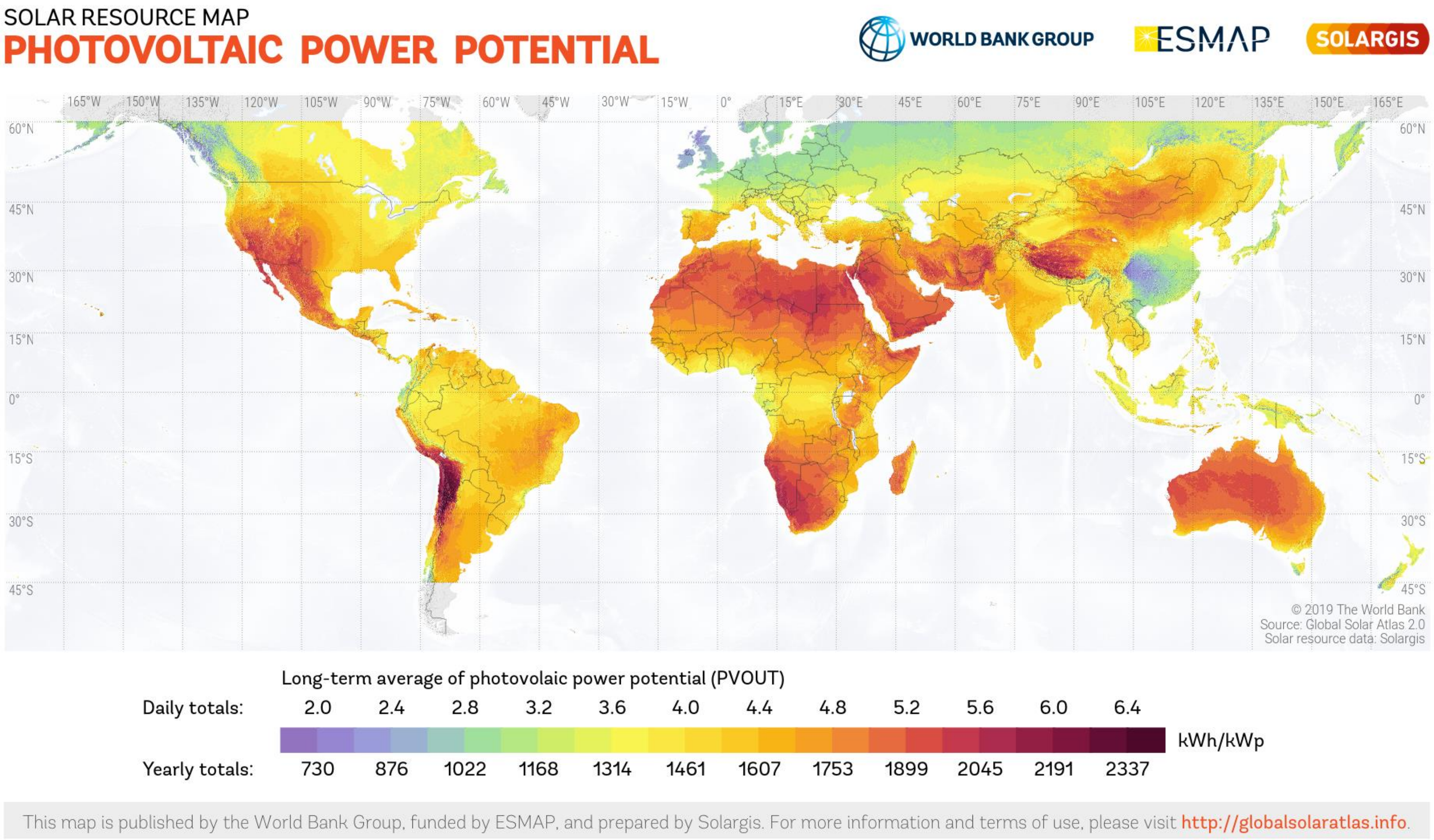
Organic solar cell

Global irradiation

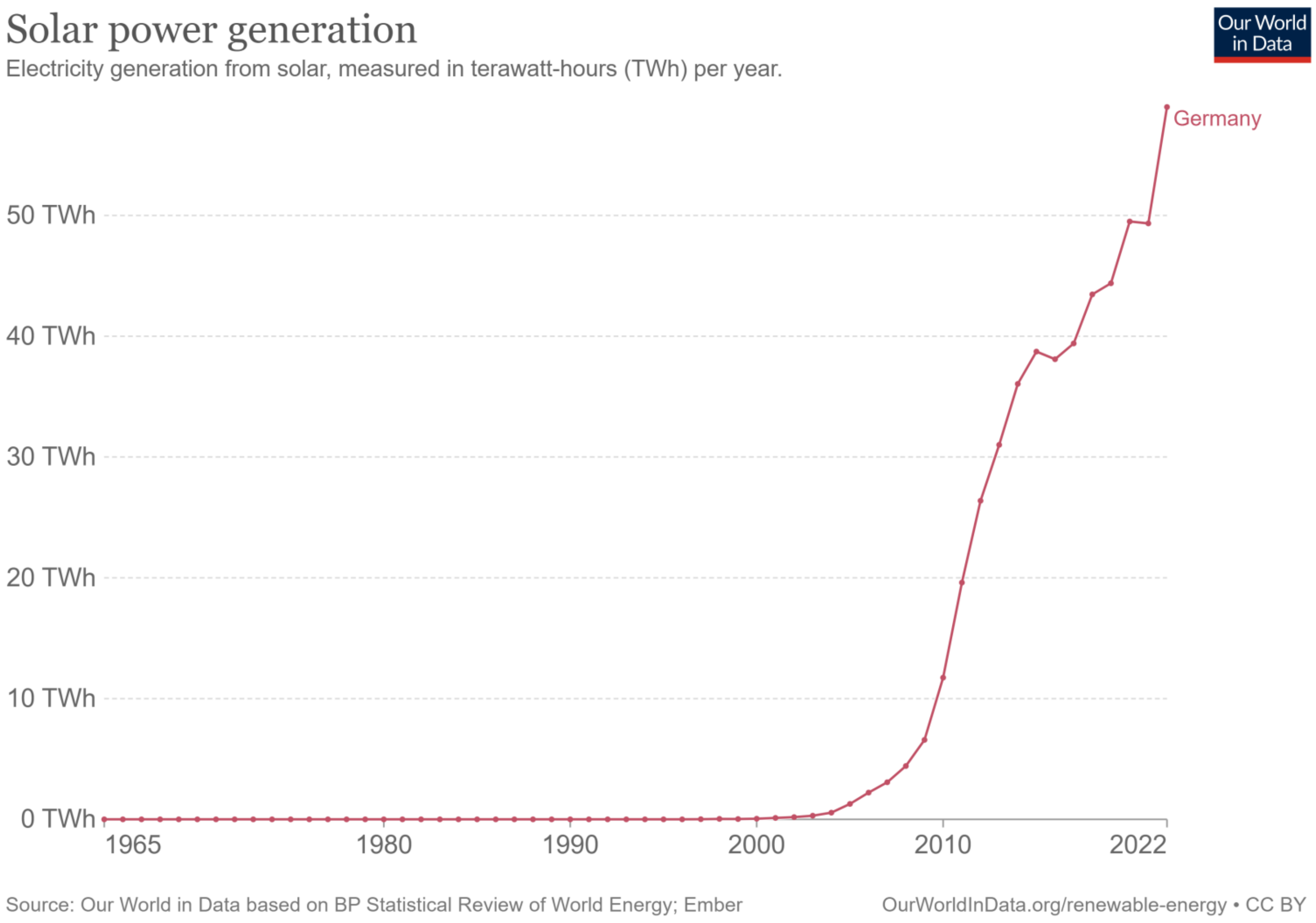




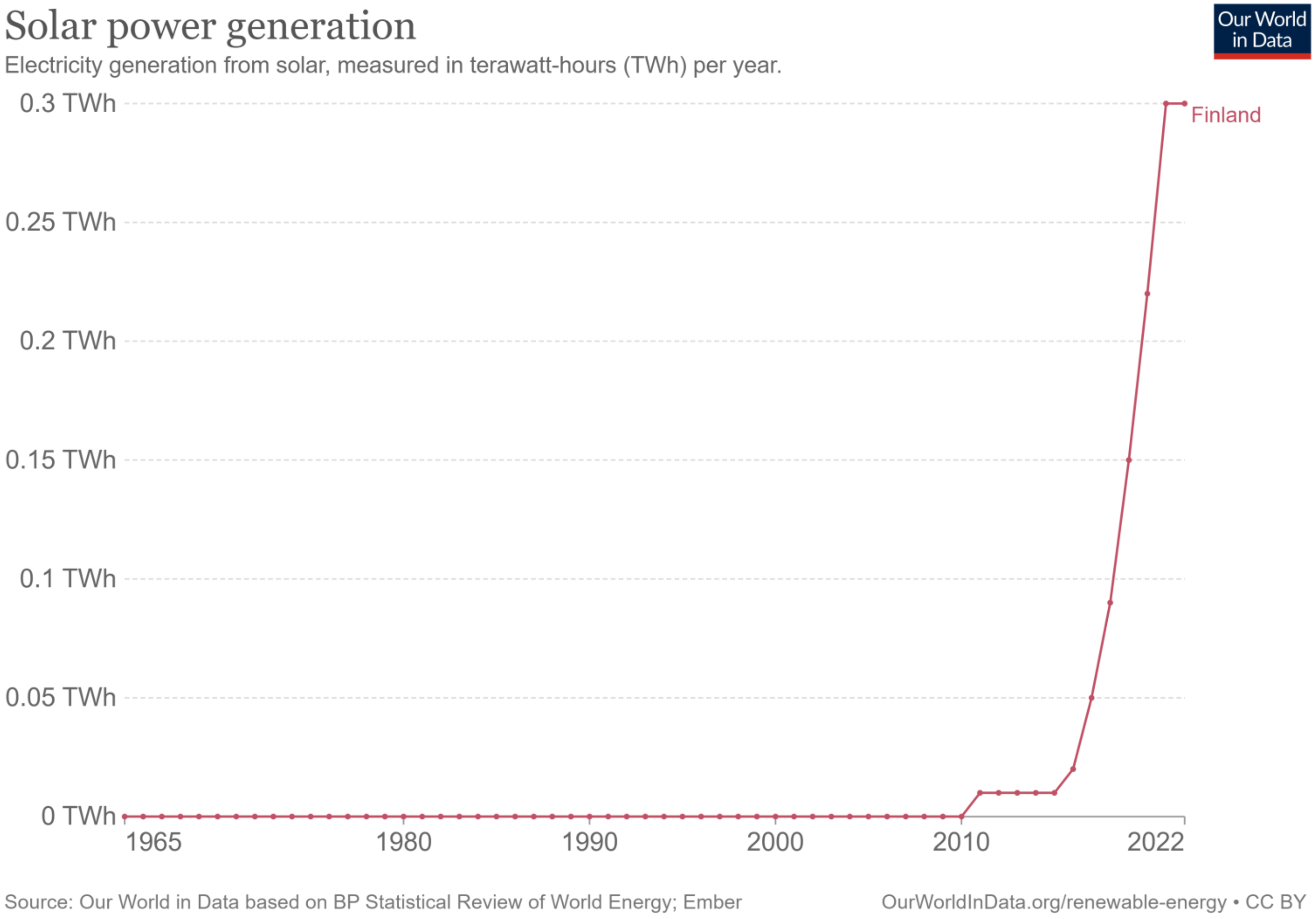
World photovoltaic power potential



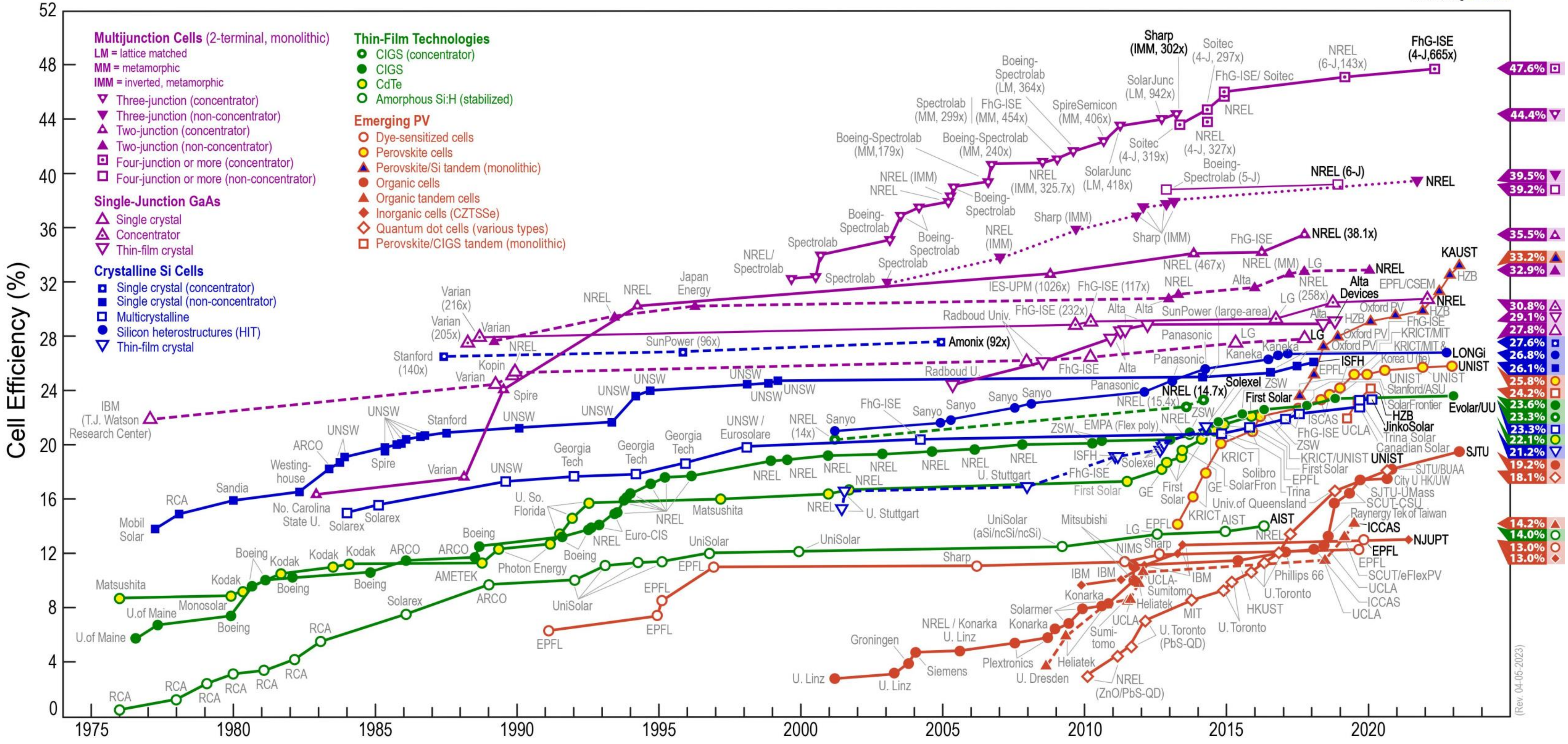
Solar power generation



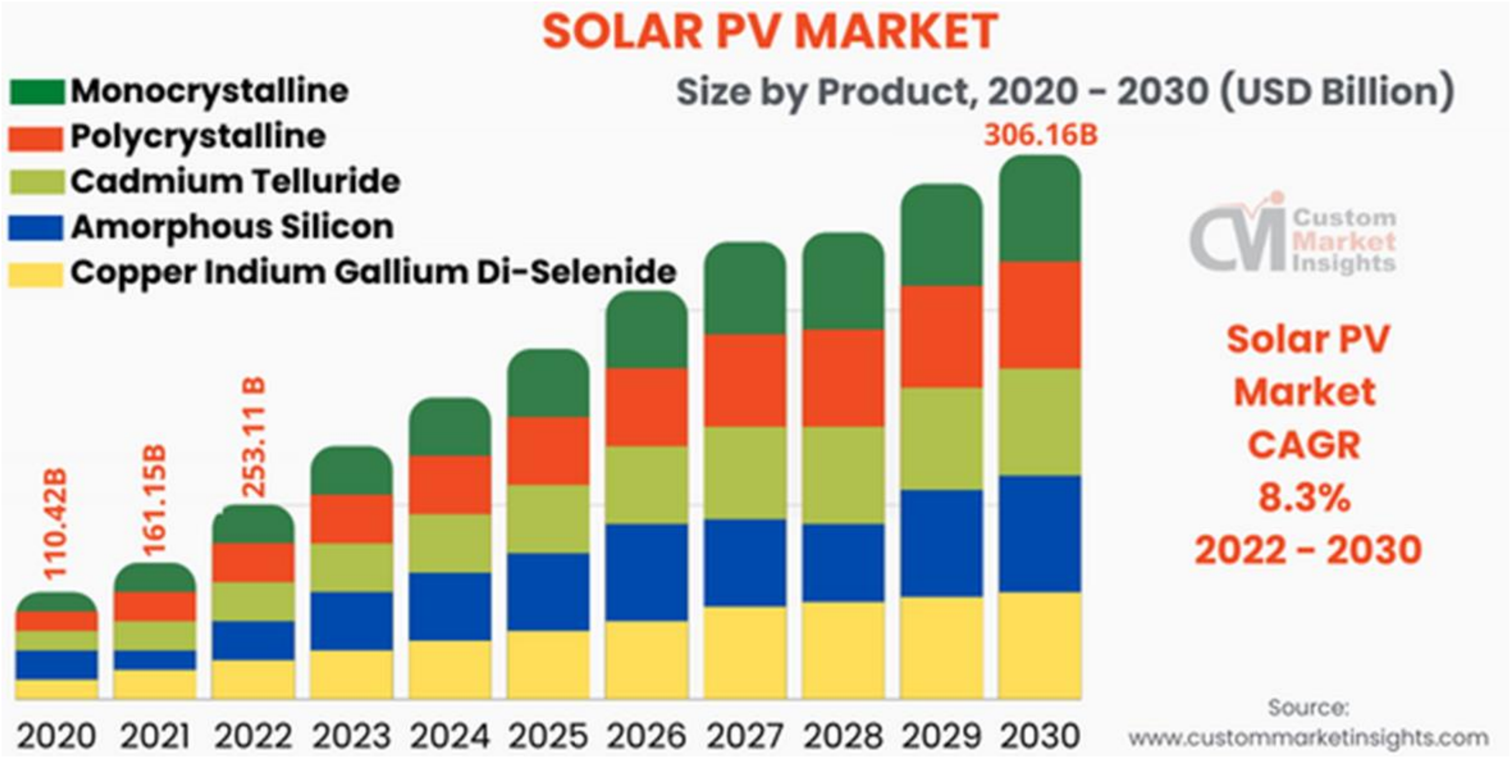
Solar power generation



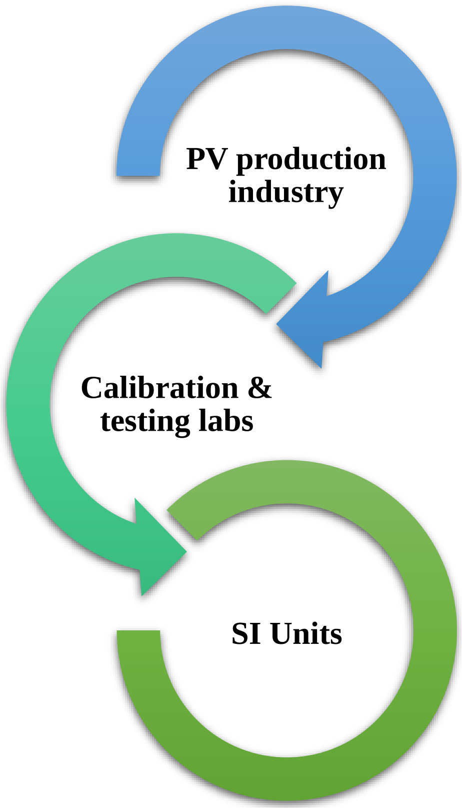
Best Research-Cell Efficiencies



Photovoltaic market



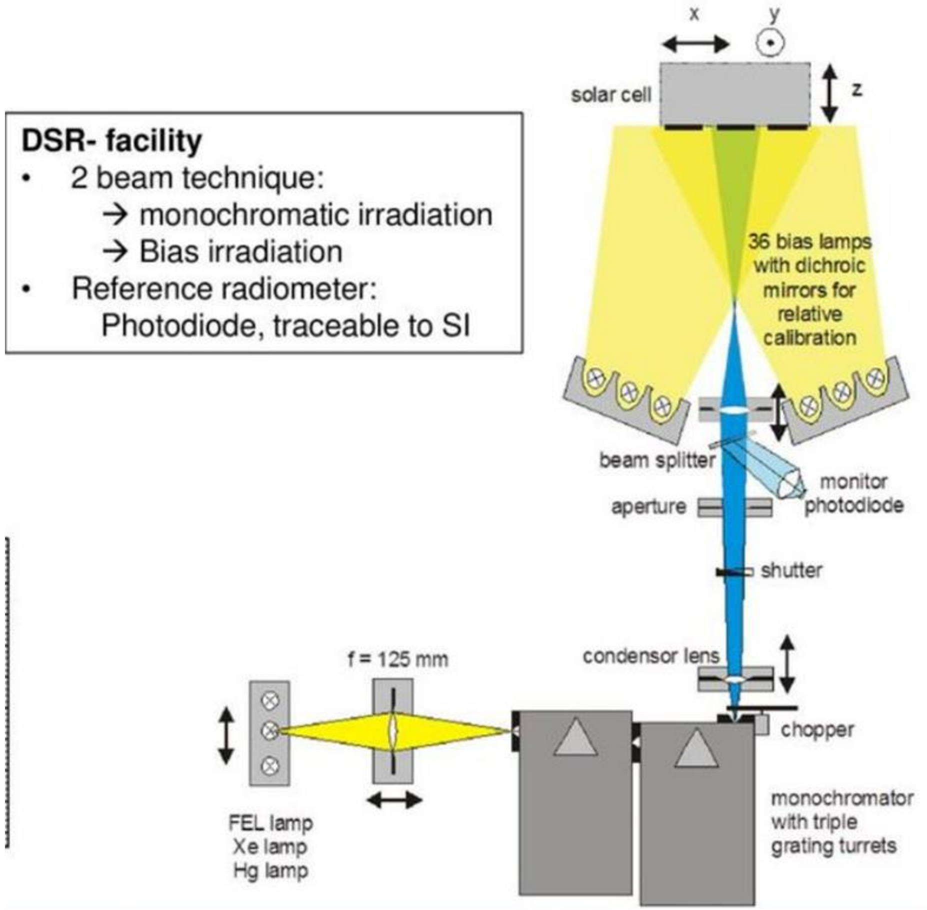
Traceability



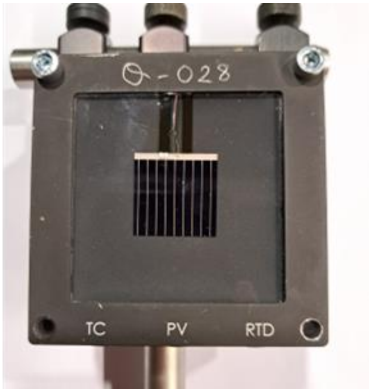
Photovoltaic metrology

$$\tilde{s}_{DUT}(\lambda, I_{bias}) = \frac{I_{DUT}(\lambda, I_{bias})/I_{MD,DUT}(\lambda)}{I_{Ref}(\lambda)/I_{MD,Ref}(\lambda)} . \tilde{s}_{Ref}(\lambda)$$

$$\tilde{s}_{AMx}(I_{bias}(E_b)) = \frac{\int_0^\infty \tilde{s}(\lambda, I_{bias}(E_b)). E_{\lambda,AMx}(\lambda) d\lambda}{\int_0^\infty E_{\lambda,AMx}(\lambda) d\lambda}$$

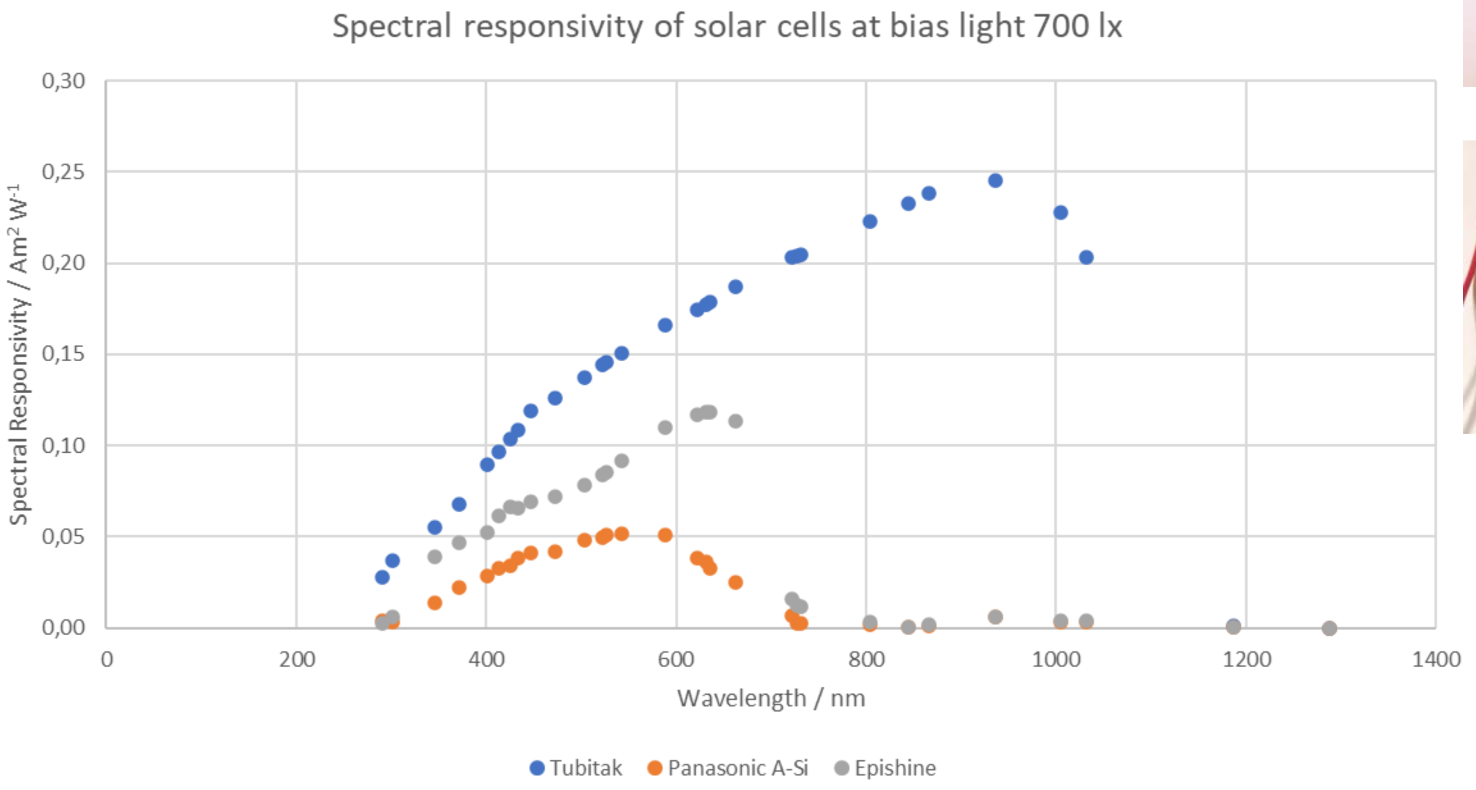


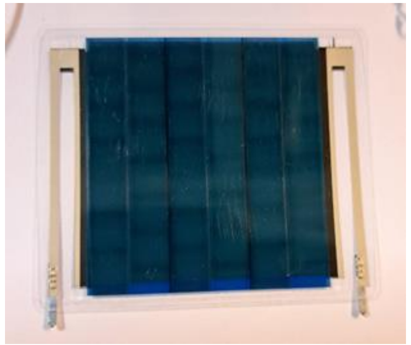
Differential spectral responsivity (DSR) setup



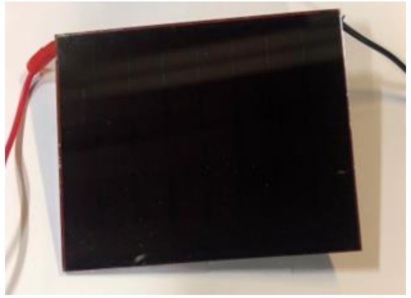
World photovoltaic scale (WPVS) solar cell

Differential spectral responsivities

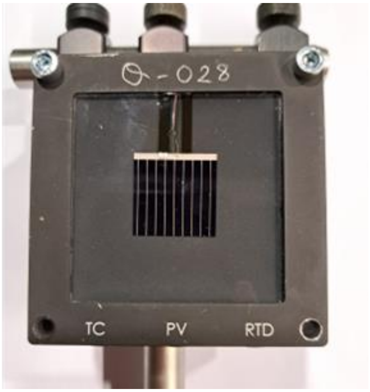




Epishine organic indoor solar cell
Area: 50 x 50 mm^2
Flexible, Thickness: 0,2 mm
6 cells, V_{oc} = 3,8 V



Amorphous silicon solar cell
Panasonic AM-1815CA
Area: 48,5 x 58,3 mm^2
Thickness: 1,3 mm
8 cells, V_{oc} = 4,9 V



Tubitak reference cell
Area: 20 x 20 mm^2

Uncertainty analysis

Uncertainty contributors	Uncertainty range
The reference detector	u(s_{ref}(600 nm))=0,035% up to u(s_{ref}(1180 nm)=3,6%
Aperture	u=0,03%
Non-uniformity of spectral irradiance	u<0,02%
Measurement electronics	u(lock-in)<0,01% , u(TIA)<0,07%
Reference plane	u<0,07%
Bias spectrum	u<0,1%
Bandwidth	u<0,001% to 0,2%
Wavelength	u<0,03%
Reproducibility/Noise	u<0,08%
Temperature	u<0,01%

References

- I. Kröger, D. Friedrich, and S. Winter, "Calibration of solar cells beyond STC using the DSR method," in *2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC)*.
- Martin A. Green, *Solar cells operating principles technology and system applications*. Prentice Hall, 1982.
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Thank you