ICLEI Local Governments for Sustainability

100% RENEWABLES CITIES & REGIONS ROADMAP

Supported by:

Federal Ministry for Economic Affairs and Climate Action

IKI INTERNATIONAL CLIMATE INITIATIVE

on the basis of a decision by the German Bundestag

Capacity Building Module: Solar Energy Basics & Solar Photovoltaic Systems

CHAPTER 1:

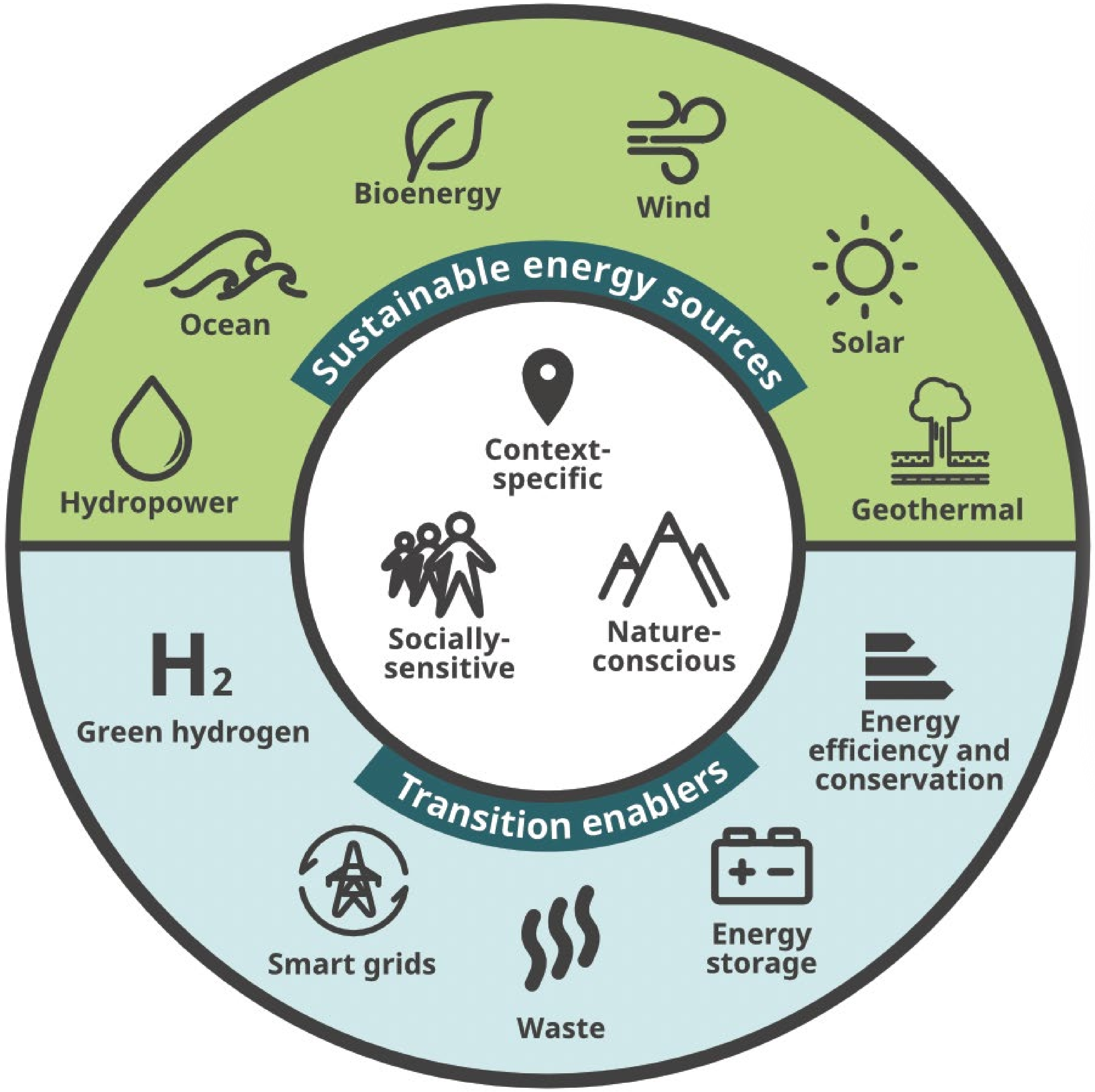
Overview of solar energy and photovoltaic systems

CONTENTS

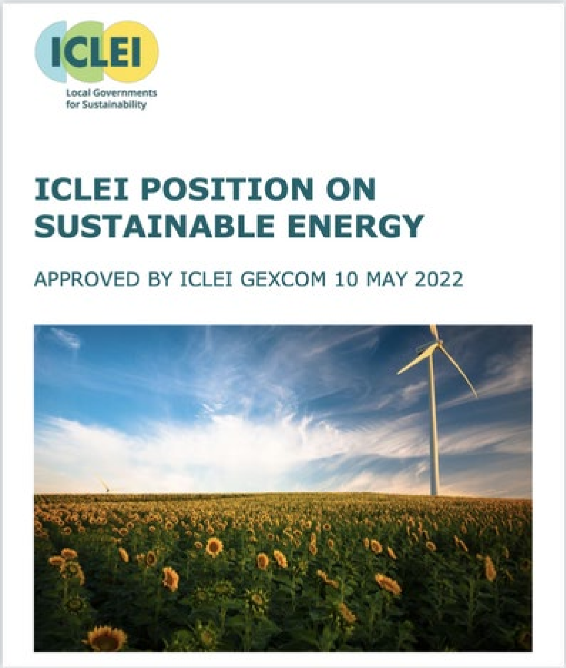
INTRODUCTION

SUSTAINABLE ENERGY & 100 % RENEWABLES

SUSTAINABLE ENERGY SOURCES



ICLEI's Sustainable Energy Position

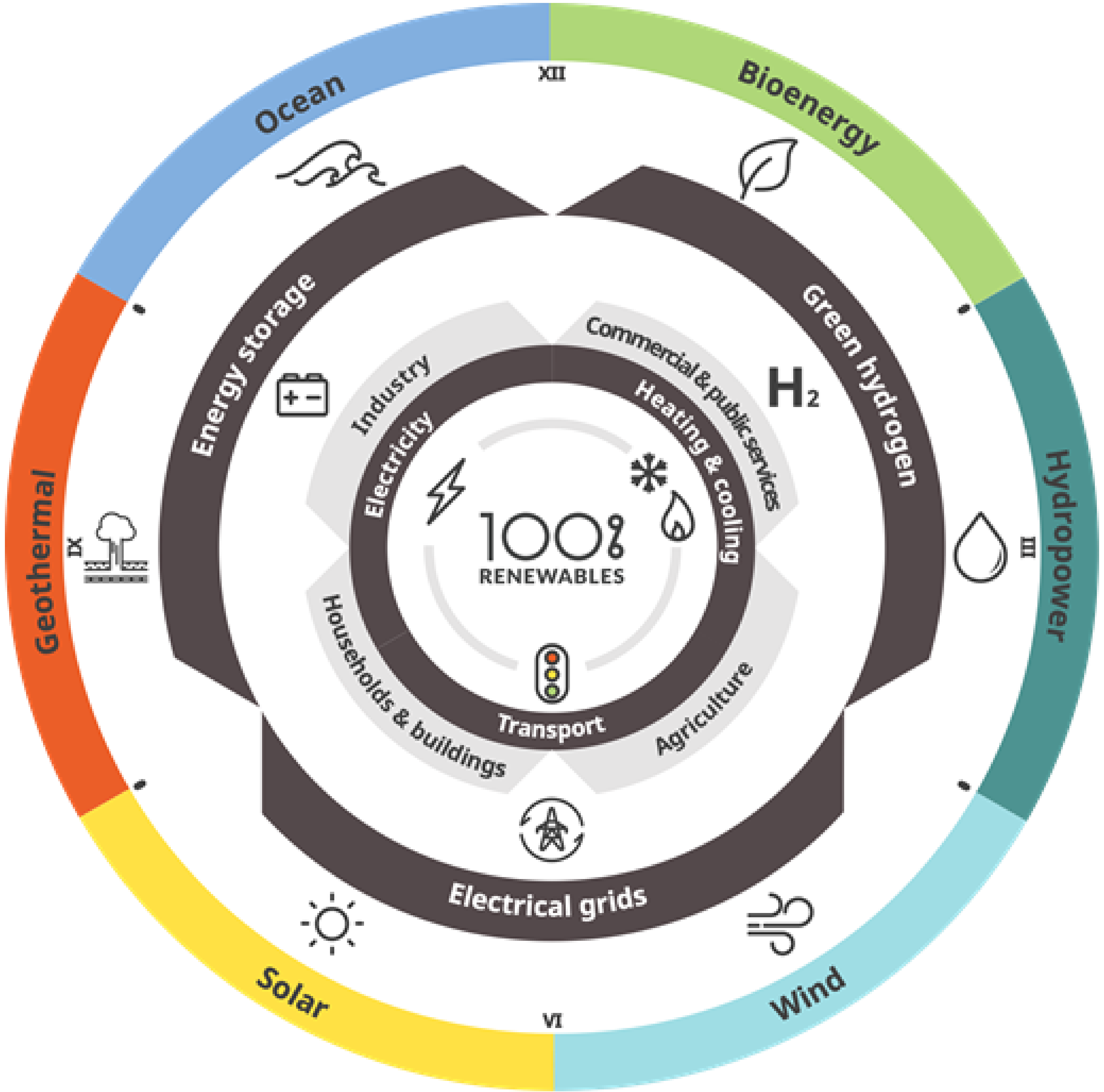

ICLEI
Local Governments for Sustainability
ICLEI POSITION ON SUSTAINABLE ENERGY
APPROVED BY ICLEI GEXCOM 10 MAY 2022

Scan to read the full text:

100% RENEWABLES CITIES AND REGIONS

" Renewable energy encompasses all renewable resources, including **bioenergy, geothermal, hydropower, ocean, solar and wind energy**. One hundred percent renewable energy means that all sources of energy to meet all end-use energy needs in a certain location, region or country are derived from renewable energy resources **24 hours per day, every day of the year**. Renewable energy can either be produced locally to meet all local end-use energy needs (power, heating and cooling, and transport) or can be imported from outside of the region using supportive technologies and installations such as **electrical grids, hydrogen or heated water**. Any **storage facilities** to help balance the energy supply must also use energy derived only from renewable resources.

-IRENA Coalition for Action

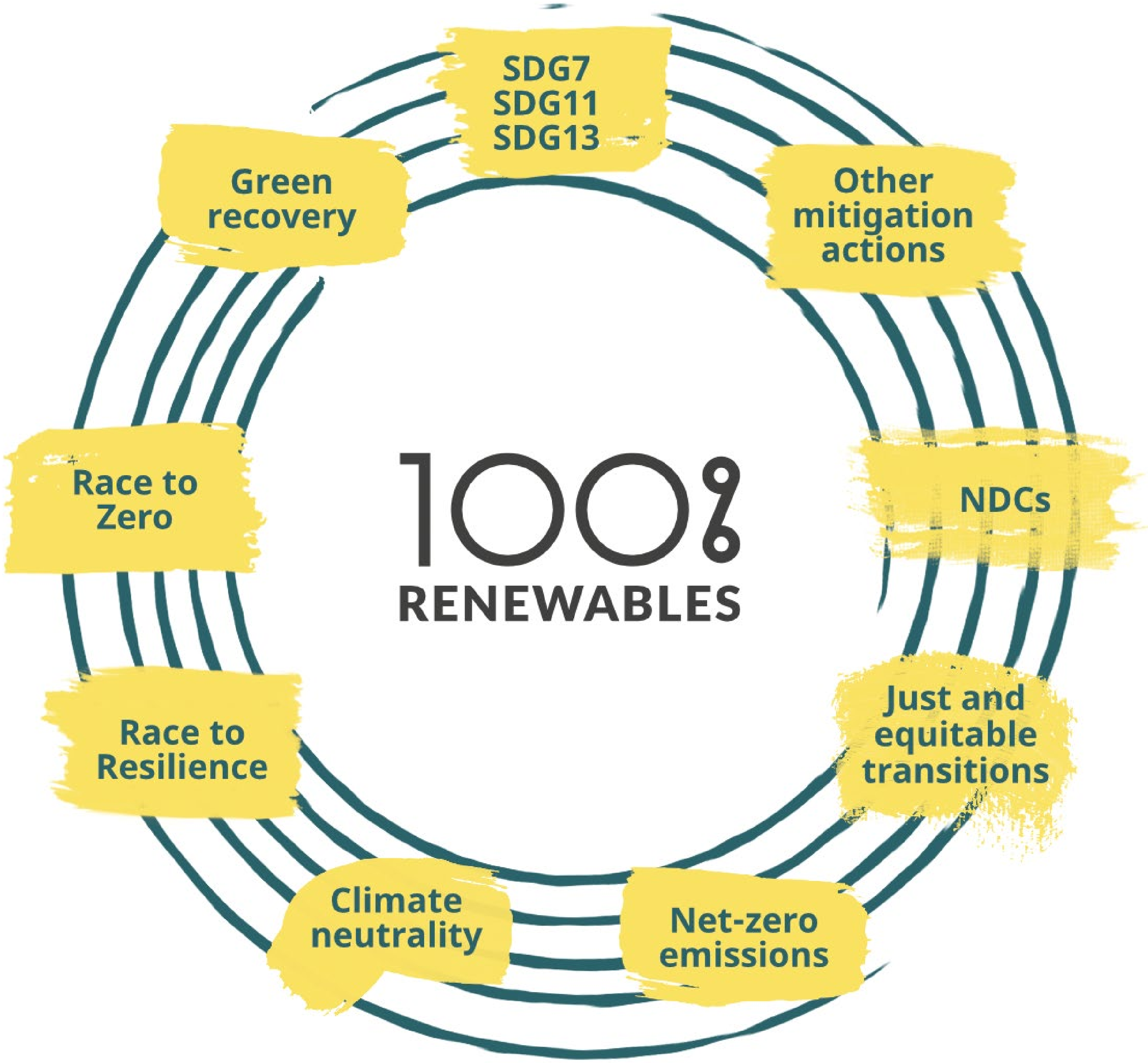


Graphical representation of 100% renewable energy by ICLEI - Local Governments for Sustainability

100% RENEWABLES AS A CORNERSTONE

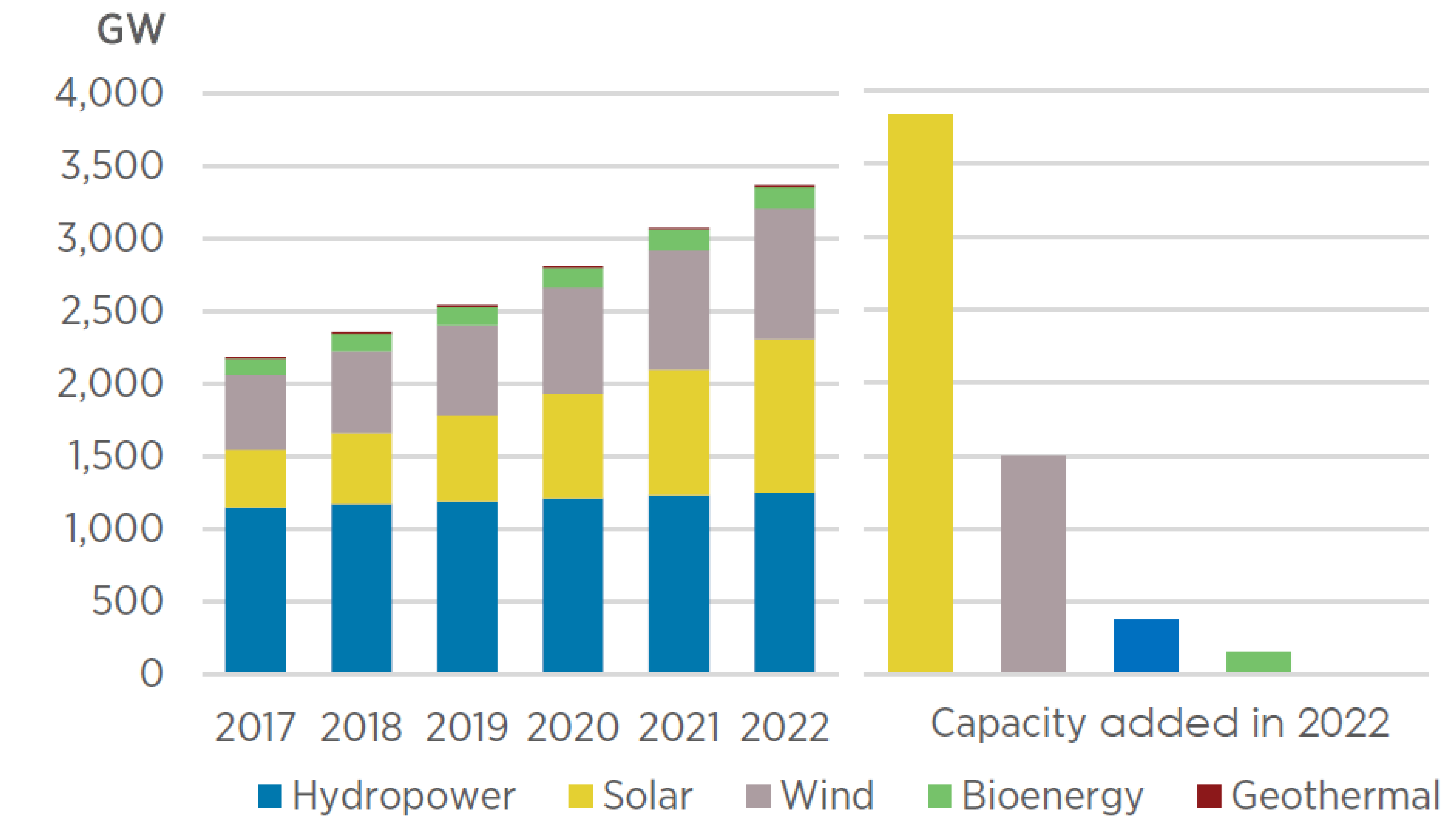
Decarbonizing energy supply through renewable energy sources, deployed in a socially- and environmentally-conscious way, is key to achieving various climate and socio-economic goals:

- Transitioning towards a renewables-based energy system is a cornerstone on the way to net-zero emissions and a ensuring a just transition
- Renewable energy can help enhance climate adaptation and resilience efforts
- Improved access to clean and modern energy and associated welfare benefits
- Use of SE sources will improve energy security and independence at local and national levels
- Zero operational emissions from SE (incl. pollutants) brings additional health benefits compared to fossil fuels

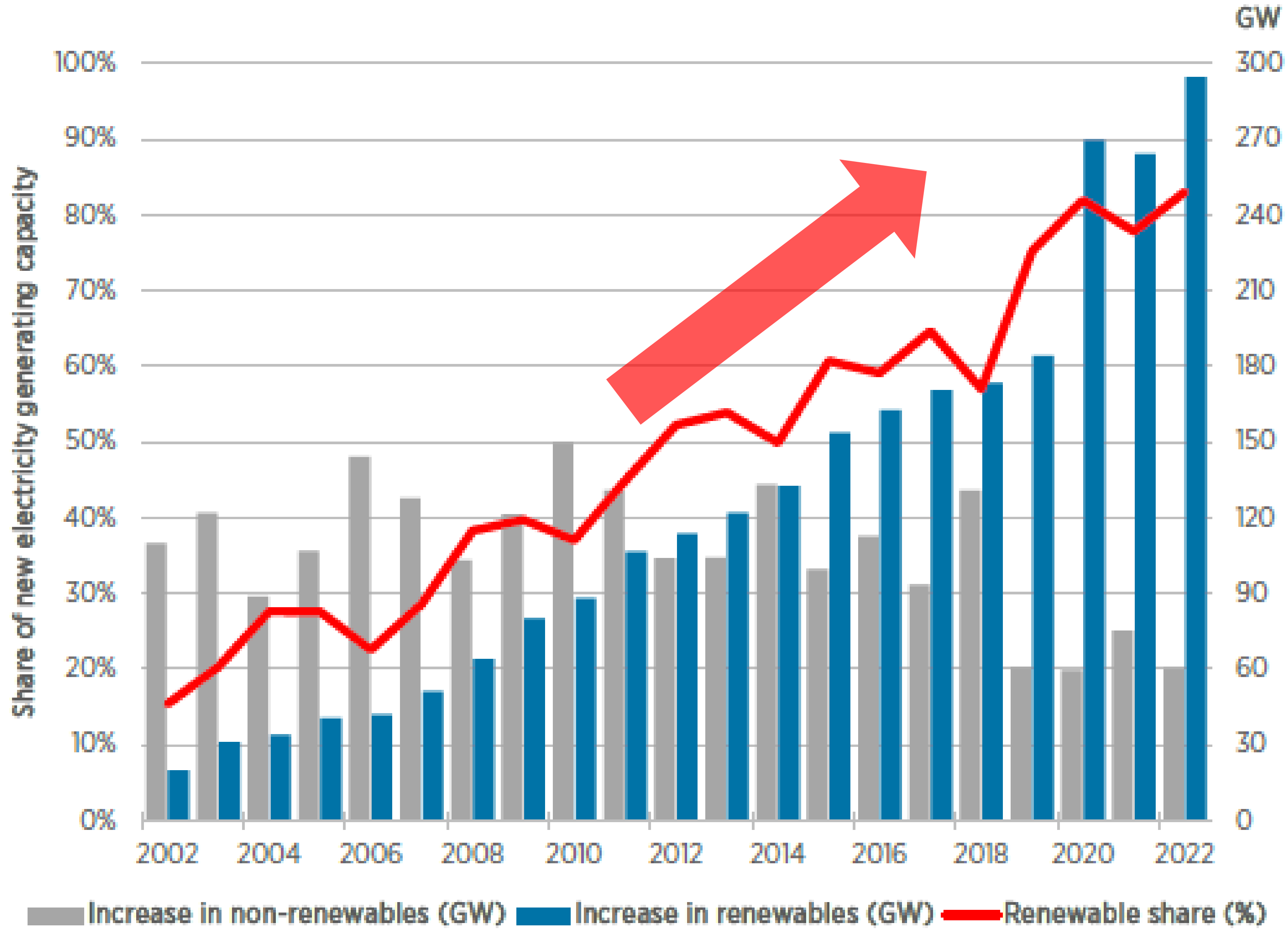


GLOBAL STATUS OF RENEWABLES

Graph 1: Renewable power capacity growth in 2022

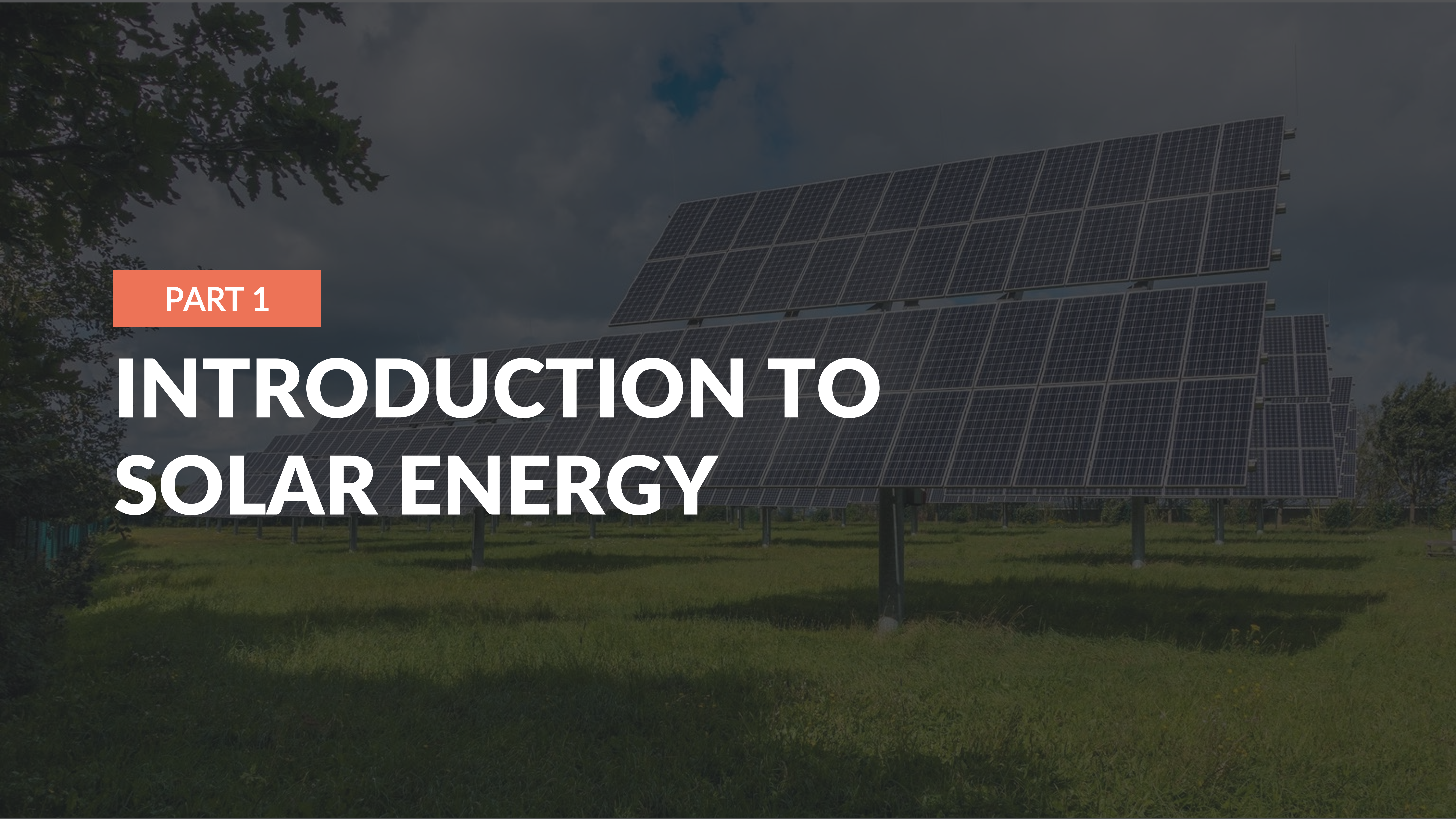


Graph 2: Renewable share of annual power capacity expansion



Solar energy dominated RE capacity expansion, surging by 192 GW (+22%) in 2022.

Source: Graph 1, 2: IRENA, Renewable Capacity Highlights 2023



PART 1

INTRODUCTION TO SOLAR ENERGY

ENERGY FROM THE SUN

Solar thermal energy conversion

- 'Heat' is utilized.
- Applications: steam generation, cooking, water heating, drying, cooling & power generation, etc.

Photovoltaic energy conversion

- 'Light' is utilized to convert energy.
- Applications: Electric power generation

Photochemical energy conversion

- 'Light' is utilized in a chemical reaction.
- Applications: Organic matter for fuel production

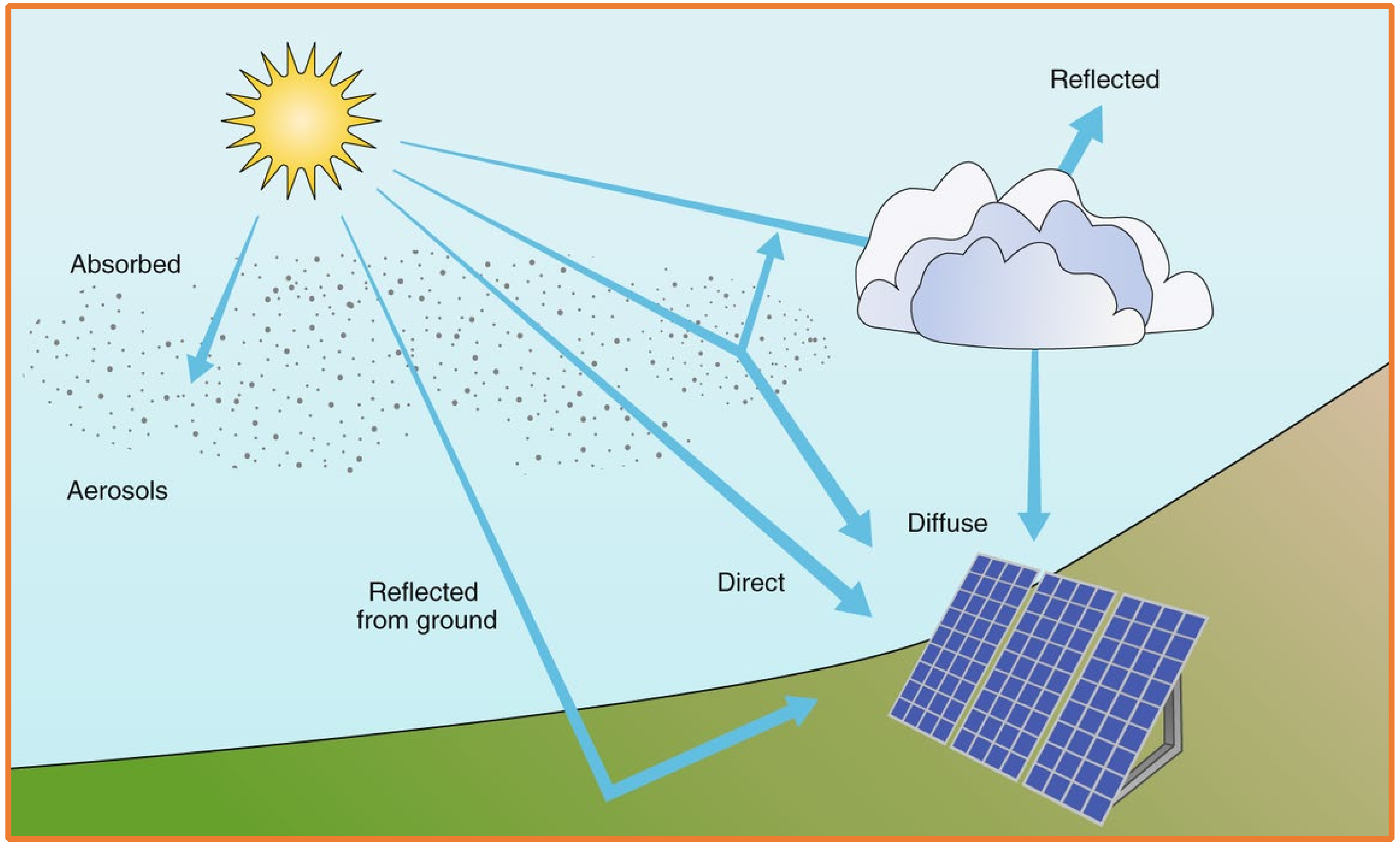
This module focuses on 'photovoltaic energy conversion'.

SOLAR RADIATION

- **Solar *irradiance*** (W/m²) is the solar energy measured on surface per unit area
- **Solar *irradiation*** (kWh/m²) is the integration of solar irradiance over a day
- **Magnitude**:
  - Solar irradiance = 1,000 W/m² (noon, sunny day)
  - Solar constant = 1,367 W/m²
- Reflection, absorption & scattering

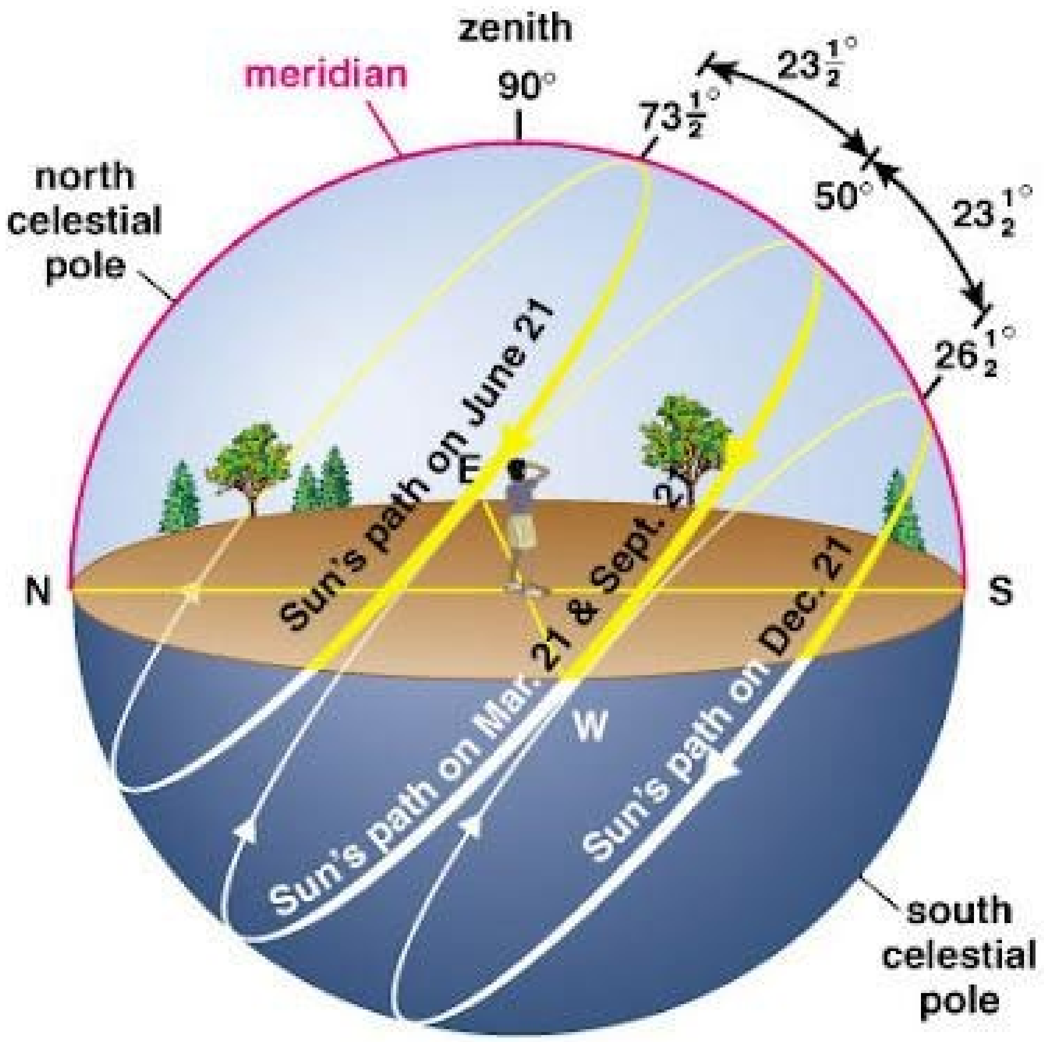
Irradiance	Irradiation
G	H
W/m²	kWh/m²
Unit of power	Unit of energy – Sum over year

Solar energy received on the earth



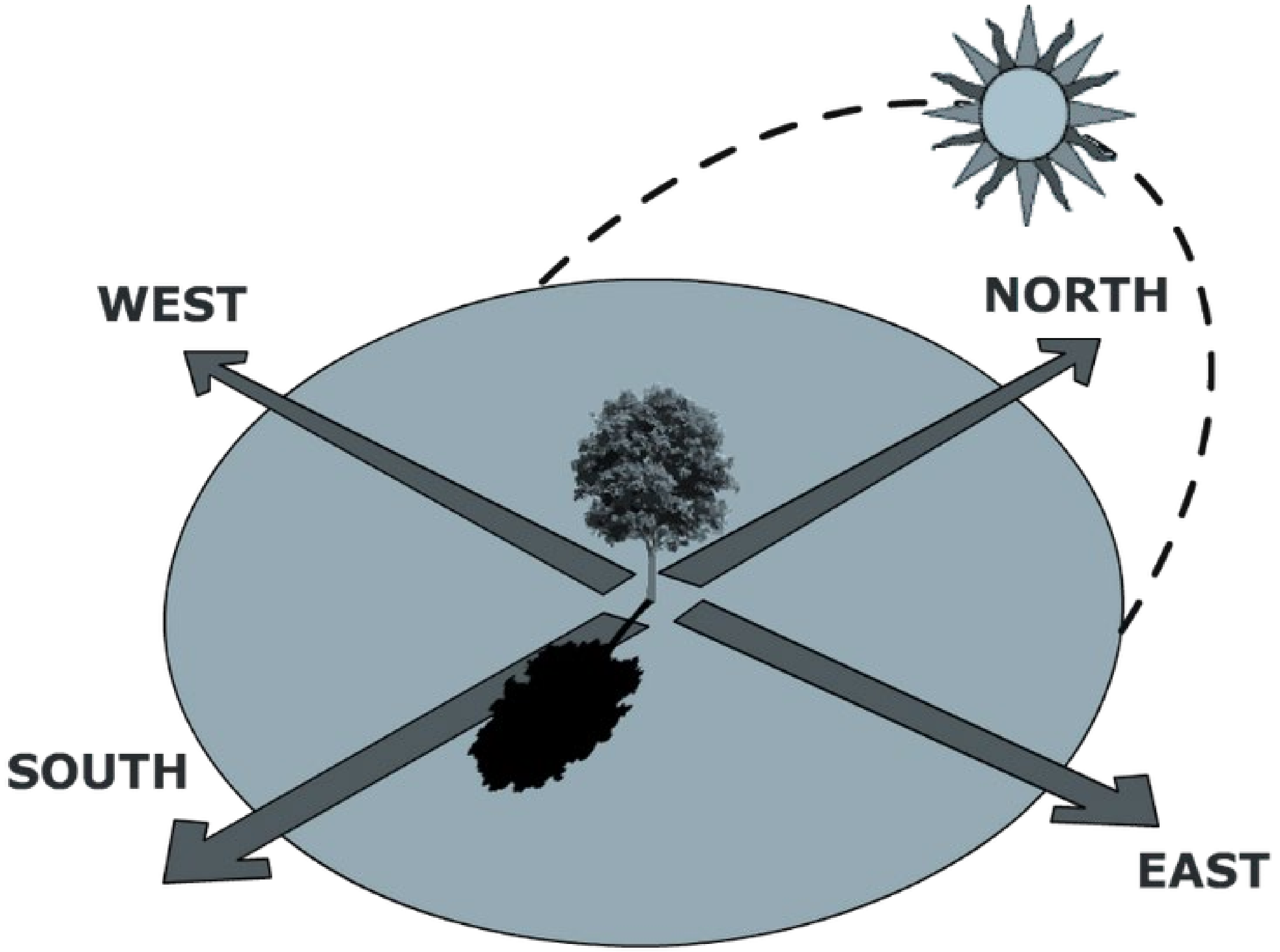
Total radiation (global radiation) = Direct radiation + Diffuse radiation

GEOMETRY OF THE SUN'S PATH



Geometry of the sun's path

Source: PV Education



Path of the sun in the southern hemisphere

Source: PV Education

Optimal absorption angle

> Perpendicular rays = Max. power density

∴ Ideal angle for absorbing surfaces

Dynamic sun angles

> Depends on the location, time, and day

∴ Affects energy capture efficiency

RADIATION DISTRIBUTION ON THE EARTH’S SURFACE

What is ‘air mass’?

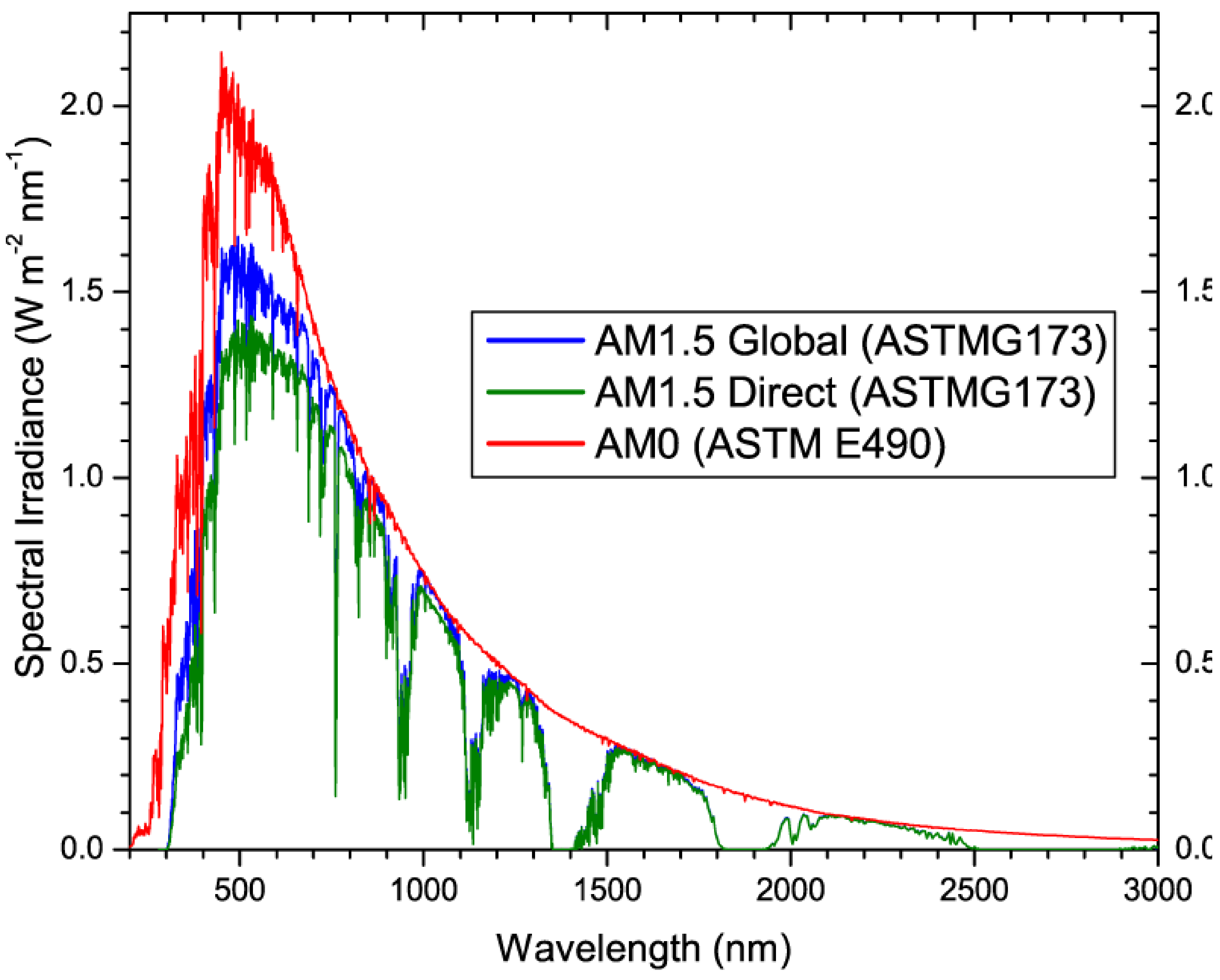
- The length of the path light takes through the atmosphere, normalized to the shortest path (i.e. with the sun directly overhead)

Why is it relevant?

- Measures light power reduction
- Absorption by air and dust

Spectrum name	Power density, W/m²	Applications
Air Mass (AM) 1.5 Global	1000	Flat plate modules
AM 1.5Direct	900	Solar concentrator
AM 0 (Standard)	1480	Space

Distribution of radiation on earth surface (spectrum)



PEAK SUN HOURS (PSH)

Sunlight reception and solar panels

- Optimal sun position: direct sunlight at midday
- Peak sun hour definition: 1000 W/m² for an hour

Output estimation

- 300-watt panel generates 300 watt-hours
- Average 500 W/m² in an hour is equal to 0.5 peak sun hours.

Sunlight's impact on energy

- Sunlight fluctuation: morning = 500 W/m²; midday = 1,100 W/m².
- Sunlight strength affects panel energy; mornings give fewer PSH than midday.

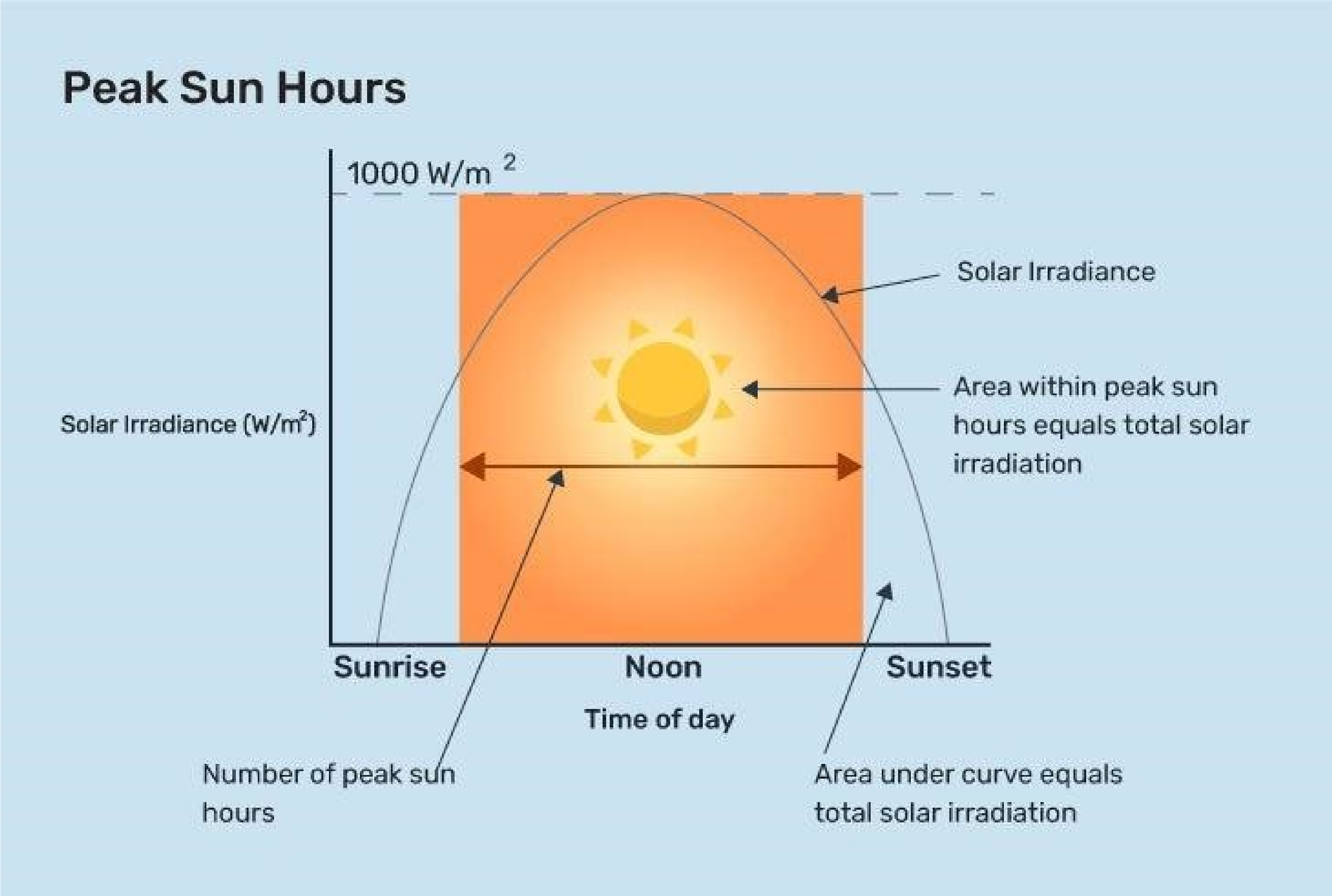


Image source: https://www.solarreviews.com/blog/peak-sun-hours-explained

Global peak sun hours map provided by global solar atlas

CALCULATING OUTPUT AND REQUIRED CAPACITY

Output calculation using PSH

PSH = 5.8

For a 5 kW system, estimated output:

=5 kW x 5.8 PSH = 29 kWh per day

Capacity estimation using PSH

PSH = 7

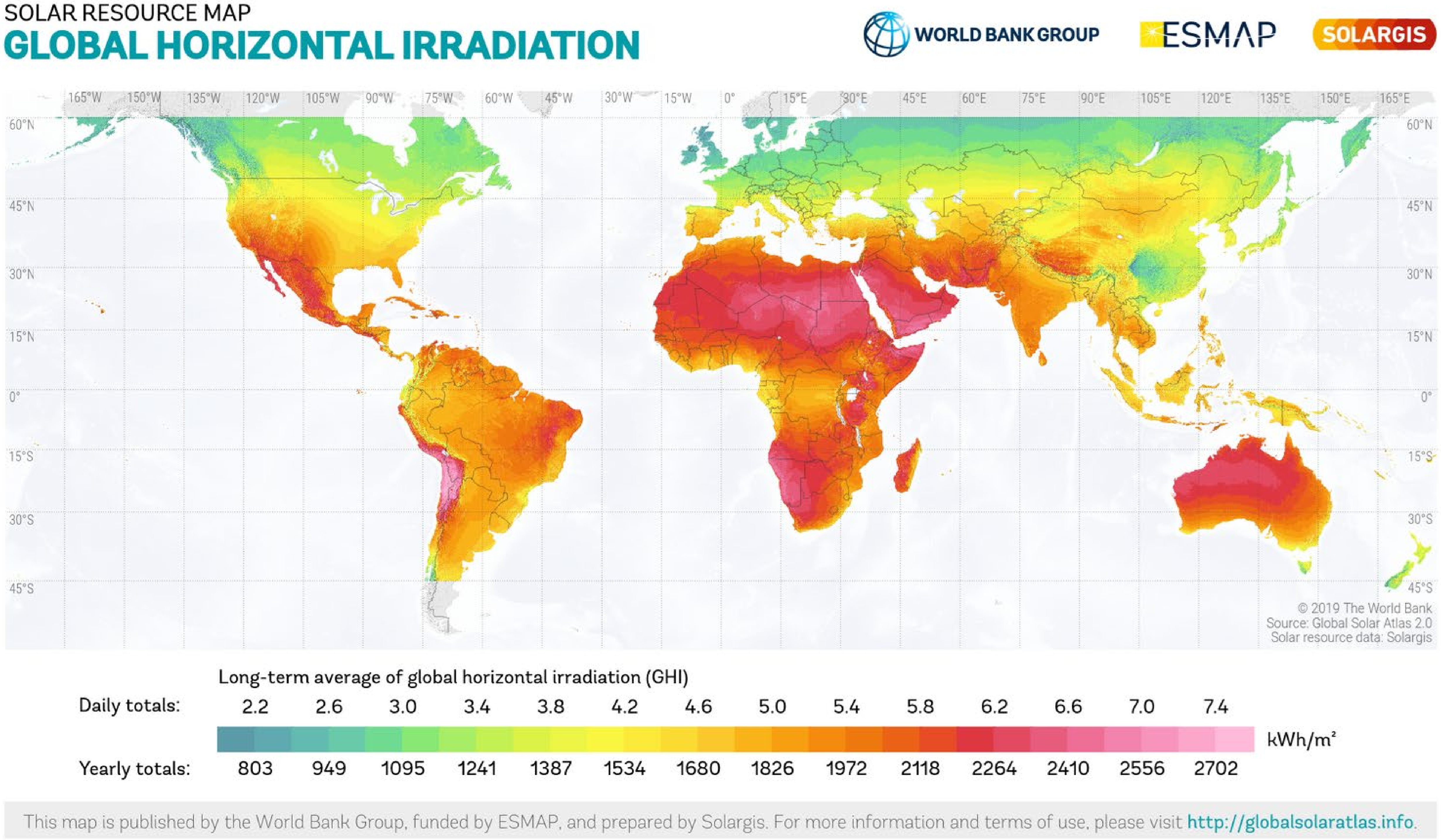
Annual (previous year) consumption of electricity = 25,000 kWh

Daily consumption of electricity = 25,000 kWh / 365 days = 68.49 kWh per day

68.49 kWh per day / 7 peak sun hours per day = 9.78 kWh

One should install a 10kW solar PV system

GLOBAL HORIZONTAL IRRADIATION (GHI)



GHI is useful in designing solar PV power plants

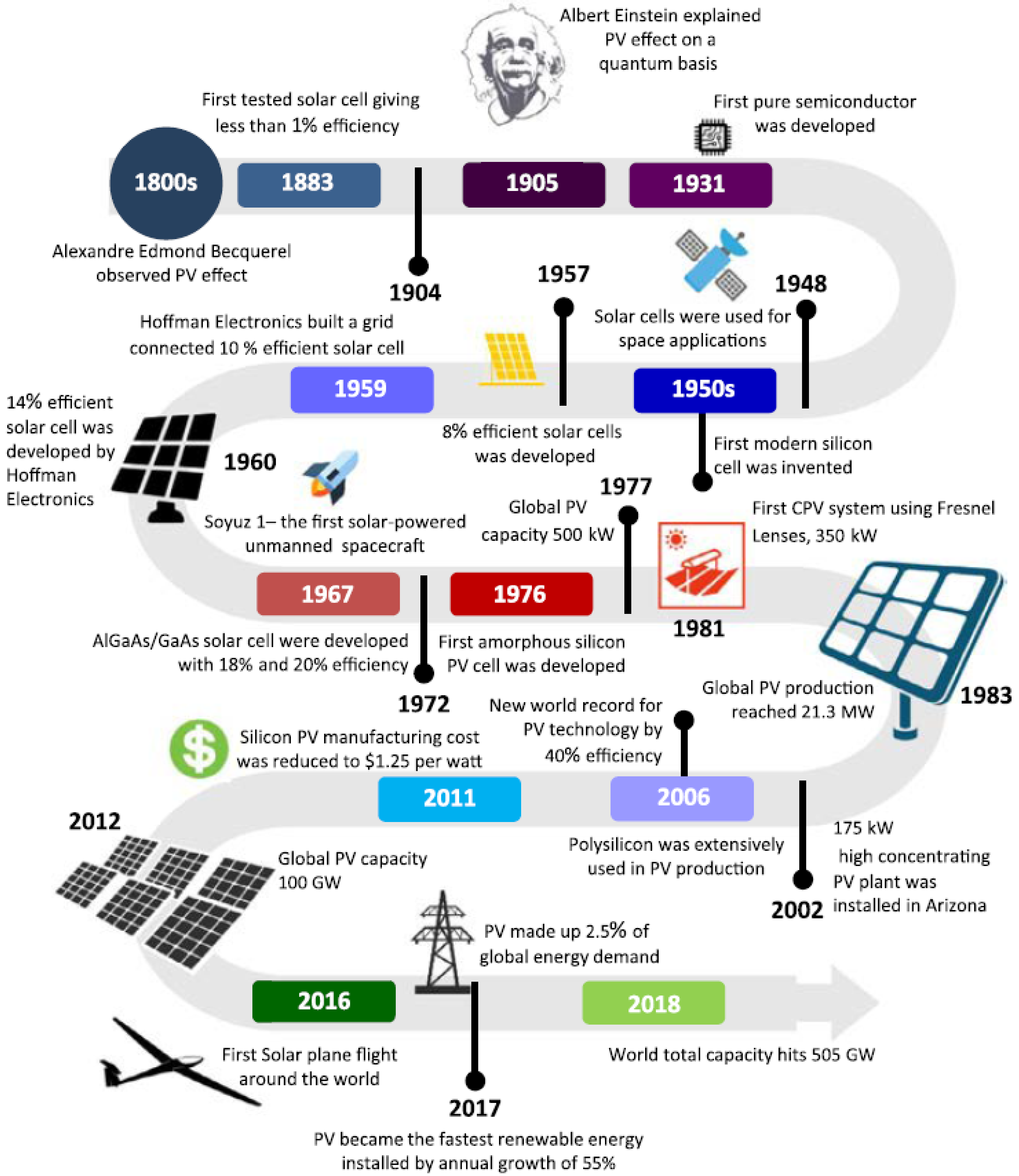
- A total of 173,000 terawatts (trillions of watts) of solar energy strikes the Earth continuously (~in an hour)

  > More than 10,000 times the world's total energy use

PART 2

INTRODUCTION TO SOLAR PV SYSTEMS

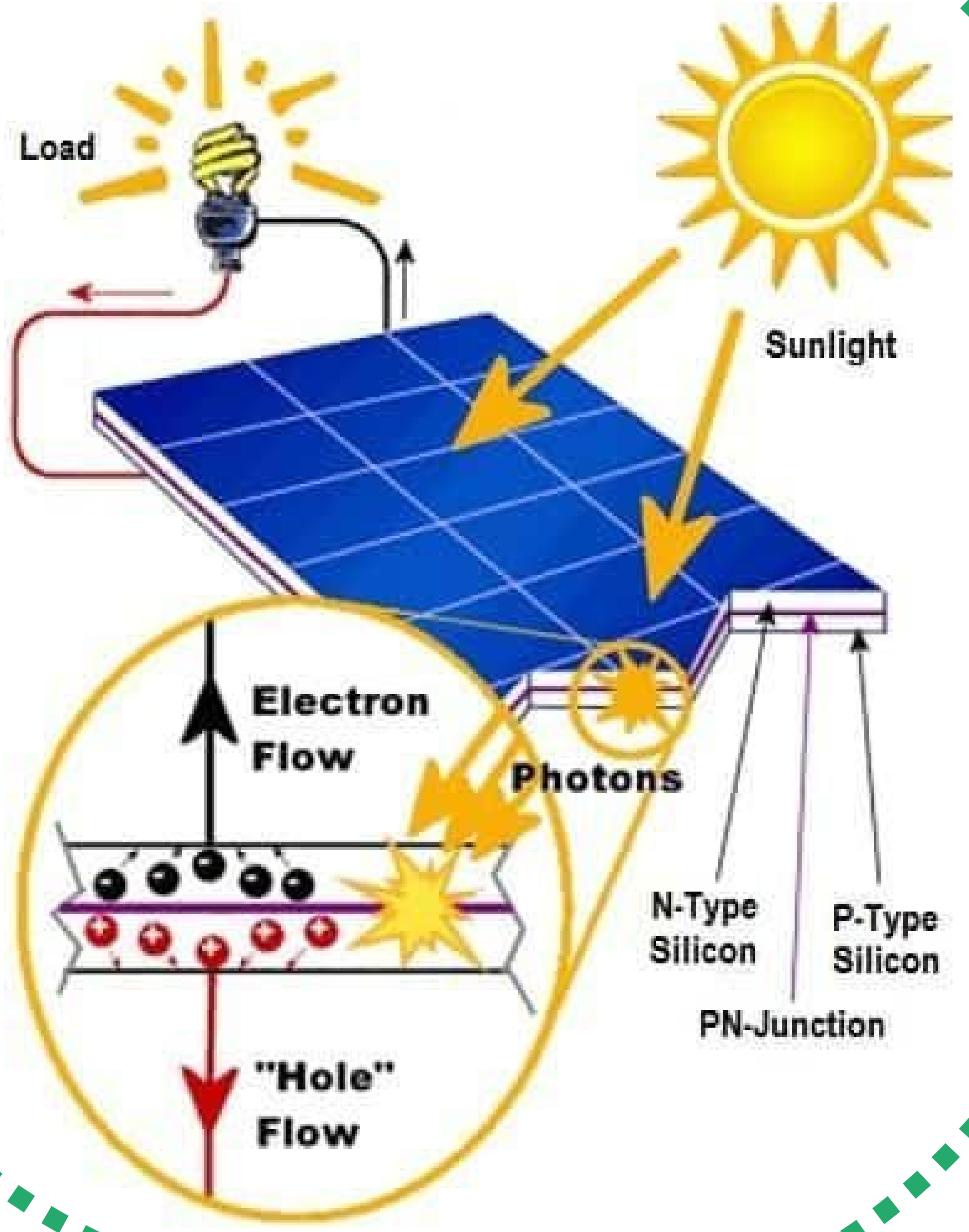
THE DEVELOPMENT OF SOLAR PV TECHNOLOGY



OPERATION OF A SOLAR PHOTOVOLTAIC CELL

P-N junction: Separate charges
Charge Movement: Electrons move to one side, creating electricity.

Photon absorption: Sunlight hits the panel, transferring energy to the silicon

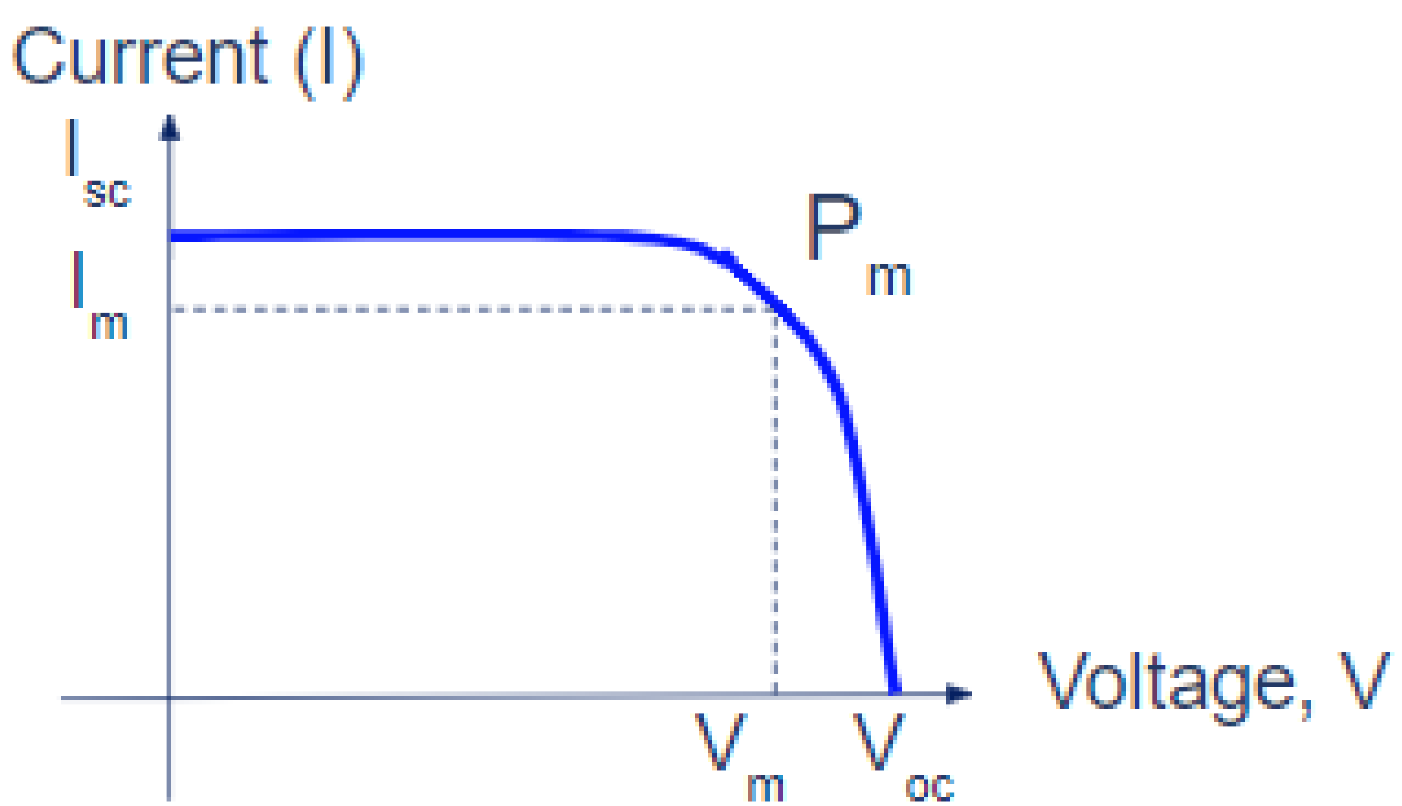


Solar cell: A device that converts solar energy into electrical energy

A solar cell is operated by a photovoltaic effect. Process when two materials, when hit by light, make electricity

SOLAR PHOTOVOLTAIC CELL – CURRENT VOLTAGE CHARACTERISTICS (I-V CURVE)

A solar cell is operated by a photovoltaic effect



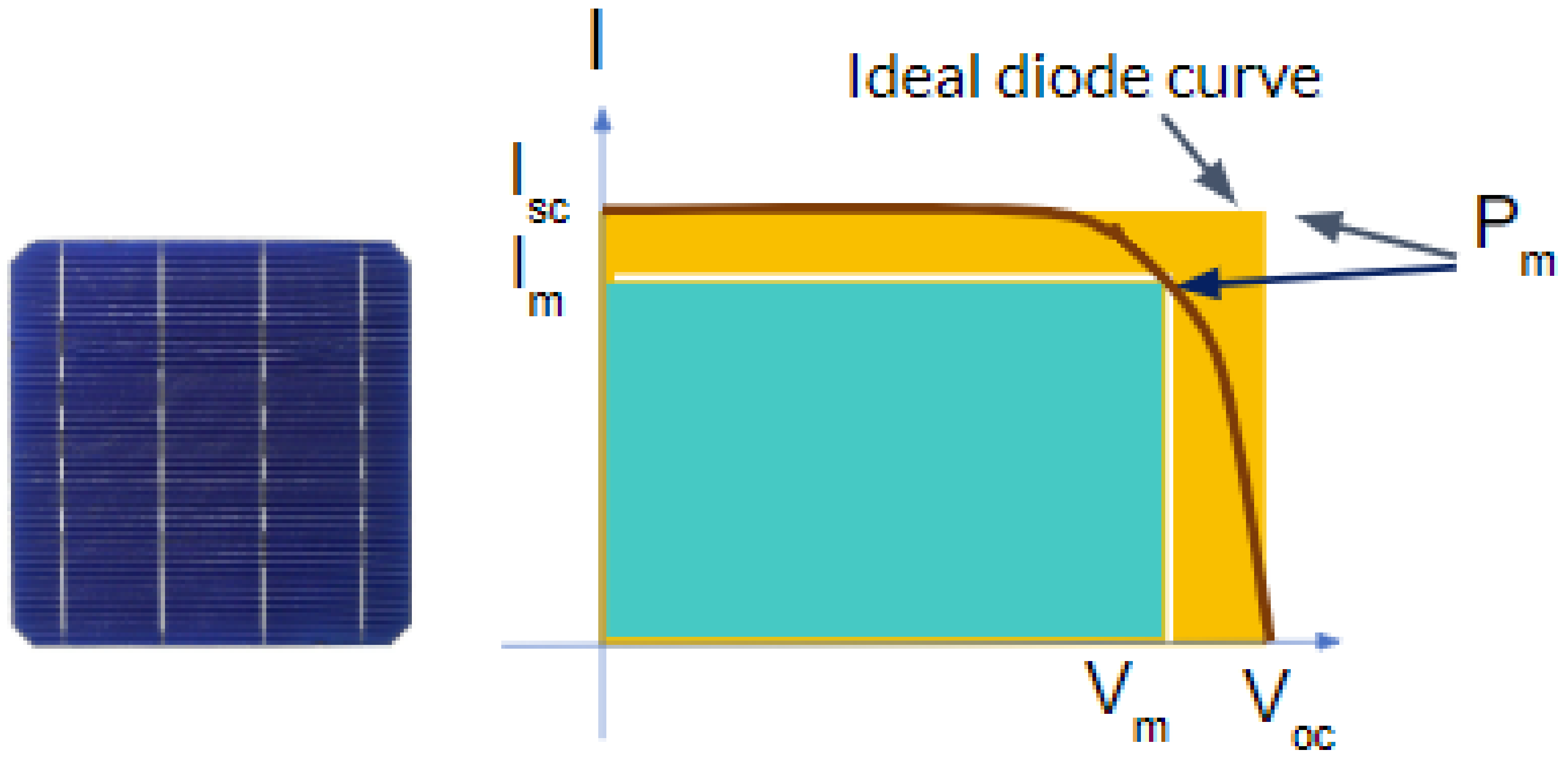
Solar cell parameters

V_{oc} - Open circuit voltage
I_{sc} - Short circuit current
P_m - Maximum power point
I_m, V_m -Current and voltage at maximum power point
FF - Fill factor
η - Efficiency
R_s - Series resistance
R_{sh} - Shunt resistance

The current (I) is shown on the positive y–axis in a representation of an I–V plot of a solar cell

SOLAR CELL PARAMETERS

Solar cell and I–V curve



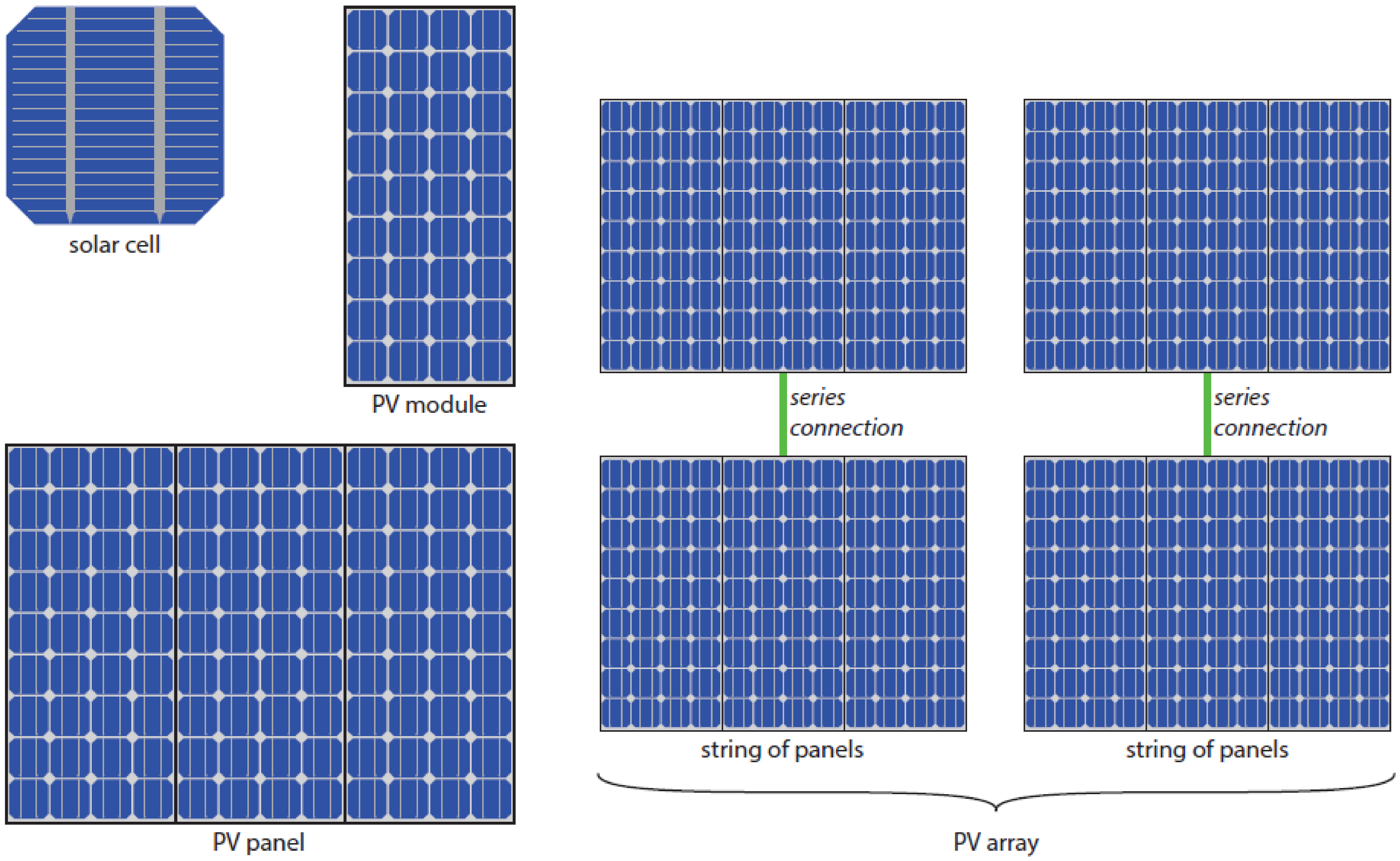
Fill factor (FF) is the measure of the 'squareness' of the solar cell i.e. the ratio of maximum power from the actual solar cell to the maximum power from an ideal solar cell

Efficiency (η) is defined as the ratio of energy output from the solar cell to input energy from the sun.

- $Maximum\ power\ point, P_m = \mathrm{I_m} \times V_m$
- $FF = \frac{Max\ power\ from\ real\ cell}{Max\ power\ from\ ideal\ cell} = \frac{V_m I_m}{V_{oc} I_{sc}}$

- $\eta = \frac{Max\ cell\ power}{Incident\ light\ intencity} = \frac{V_m I_m}{P_{in}}$
- $\eta = \frac{V_{oc} I_{sc} FF}{P_{in}}$

SOLAR CELLS, PV MODULES, PV PANELS & PV ARRAY



Source: Solar Energy: Fundamentals, Technology, and Systems – Delft University of Technology, 2014

AVAILABLE PHOTOVOLTAIC TECHNOLOGIES

Generation	Technology	Efficiency
1st Generation	Silicon based: crystalline silicon, Passivated Emitter and Rear Contact (PERC), etc.	Reasonable efficiency high cost
2nd Generation	Thin film: Amorphous silicon a-Si; Cadmium telluride CdTe; Copper indium gallium selenide CIGS; Polymer solar cell; Organic solar cell	Low efficiency
3rd Generation	Technological combination of thin film & silicon: III junction solar cell for space applications (Gallium arsenide); Nanoparticles; Dye-sensitive solar cell; Perovskite solar cell	High efficiency

N-type bifacial TOPCon solar panel
Source: Sun EVO solar co.

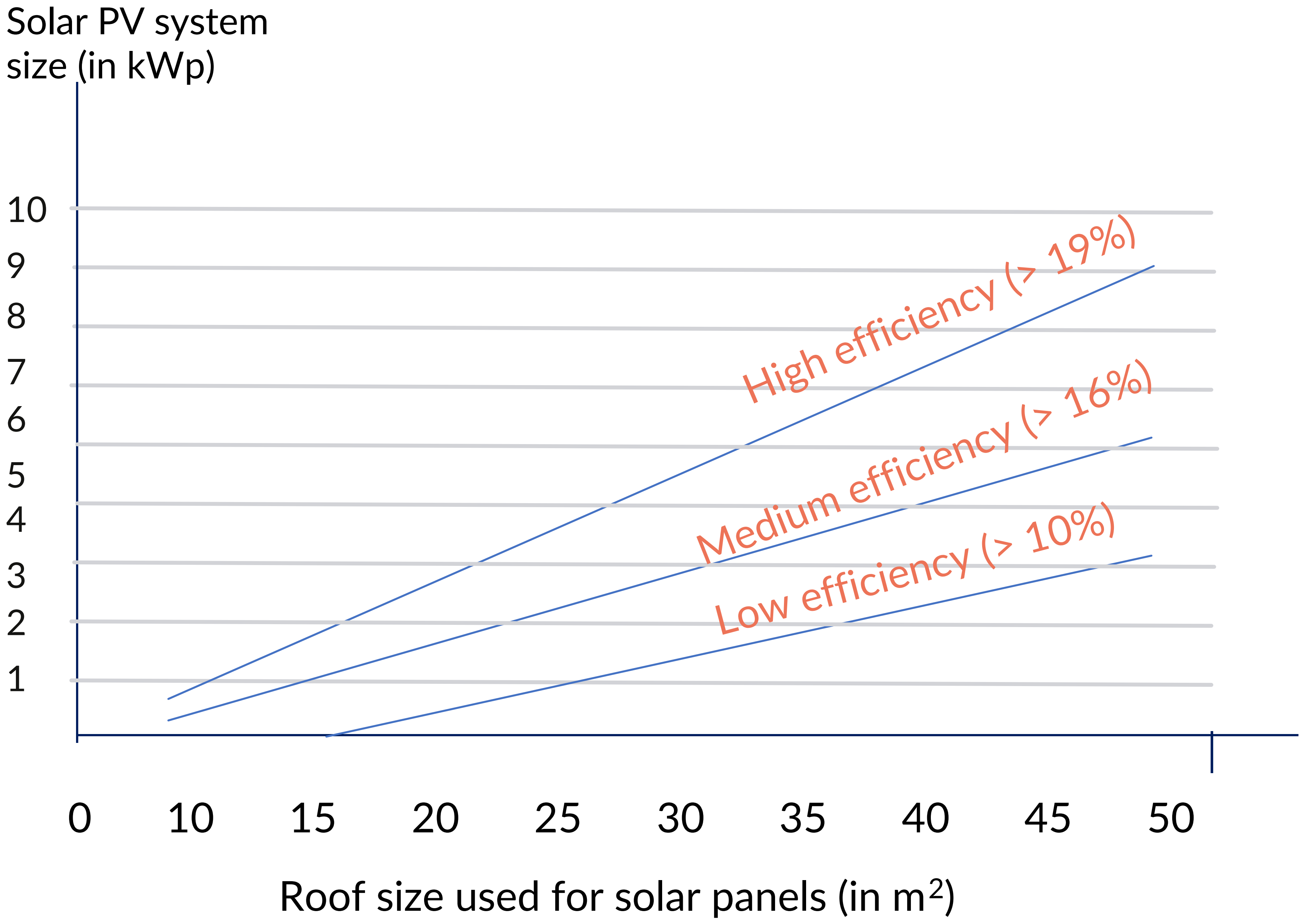

Thin-film cadmium Telluride (CdTe) solar panels
Image: Toledo Solar


Silicon hetrojunction Thin-film (HJT) modules
Image: Waaree

LAND REQUIRED CAN VARY

High-efficiency PV Modules

- Space efficiency: High-efficiency modules generate more electricity per area.
- Better conversion: They convert more sunlight into usable power.
- Greater output: Produces more power for the same space.
- Fewer modules: Need fewer modules needed for the same electricity output.



Peak Radiation × Area × Efficiency = Power produced (Watts)

TECHNICAL SPECIFICATIONS OF A PV MODULE

Hetero Junction Technology (HJT)

MODEL TYPES AND RATINGS AT STANDARD TEST CONDITIONS (1000W/m^2, AM 1.5, 25°C)[2]								
NOMINAL VALUES		FS-6430 FS-6430A	FS-6435 FS-6435A	FS-6440 FS-6440A	FS-6445 FS-6445A	FS-6450 FS-6450A	FS-6455 FS-6455A	FS-6460 FS-6460A
Nominal Power[3] (-0/+5%)	P_{MAX} (W)	430	435	440	445	450	455	460
Efficiency (%)	%	17.4	17.6	17.8	18.0	18.2	18.4	18.6
Voltage at P_{MAX}	V_{MAX} (V)	182.6	183.6	184.7	185.7	186.8	187.8	188.8
Current at P_{MAX}	I_{MAX} (A)	2.36	2.37	2.38	2.40	2.41	2.42	2.44
Open Circuit Voltage	V_{OC} (V)	219.2	219.6	220.0	220.4	221.1	22.2.0	222.9
Short Circuit Current	I_{SC} (A)	2.54	2.55	2.55	2.56	2.57	2.58	2.59
Maximum System Voltage	V_{SYS} (V)	1500[5]						
Limiting Reverse Current	I_R (A)	5.0						
Maximum Series Fuse	I_{CF} (A)	5.0						
RATINGS AT NOMINAL OPERATING CELL TEMPERATURE OF 45°C (800W/m^2, 20°C air temperature, AM 1.5, 1m/s wind speed)[2]								
Nominal Power	P_{MAX} (W)	324.7	328.5	332.4	336.0	339.9	343.6	347.3
Voltage at P_{MAX}	V_{MAX} (V)	170.9	172.0	173.1	174.1	175.2	176.2	176.3
Current at P_{MAX}	I_{MAX} (A)	1.90	1.91	1.92	1.93	1.94	1.95	1.97
Open Circuit Voltage	V_{OC} (V)	207.0	207.3	207.7	208.0	208.8	209.6	210.4
Short Circuit Current	I_{SC} (A)	2.05	2.06	2.06	2.06	2.07	2.08	2.09

TEMPERATURE CHARACTERISTICS		
Module Operating Temperature Range	(°C)	-40 to +85
Temperature Coefficient of P_{MAX}	T_K (P_{MAX})	-0.32%/°C [Temperature Range: 25°C to 75°C]
Temperature Coefficient of V_{OC}	T_K (V_{OC})	-0.28%/°C
Temperature Coefficient of I_{SC}	T_K (I_{SC})	+0.04%/°C

Canadian solar high efficiency heterojunction cell technology 415–440 Watts

Thin film technology

ELECTRICAL DATA | STC*

CS6R	415H-AG	420H-AG	425H-AG	430H-AG	435H-AG	440H-AG
Nominal Max. Power (Pmax)	415 W	420 W	425 W	430 W	435 W	440 W
Opt. Operating Voltage (Vmp)	33.6 V	33.7 V	33.7 V	33.8 V	33.8 V	33.9 V
Opt. Operating Current (Imp)	12.34 A	12.48 A	12.62 A	12.76 A	12.89 A	13.02 A
Open Circuit Voltage (Voc)	40.0 V	40.1 V	40.1 V	40.1 V	40.2 V	40.2 V
Short Circuit Current (Isc)	13.23 A	13.28 A	13.33 A	13.38 A	13.43 A	13.48 A
Module Efficiency	21.3%	21.5%	21.8%	22.0%	22.3%	22.5%
Operating Temperature	-40°C ~ +85°C					
Max. System Voltage	1500V (IEC) or 1000V (IEC)					
Module Fire Performance	CLASS C (IEC61730)					
Max. Series Fuse Rating	25 A					
Application Classification	Class A					
Power Tolerance	0 ~ + 5 W					

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m^2, spectrum AM 1.5 and cell temperature of 25°C. Measurement uncertainty: ±3 % (Pmax).

ELECTRICAL DATA | NMOT*

CS6R	415H-AG	420H-AG	425H-AG	430H-AG	435H-AG	440H-AG
Nominal Max. Power (Pmax)	317 W	321 W	325 W	329 W	332 W	336 W
Opt. Operating Voltage (Vmp)	32.2 V	32.3 V	32.3 V	32.3 V	32.4 V	32.4 V
Opt. Operating Current (Imp)	9.85 A	9.95 A	10.06 A	10.17 A	10.27 A	10.37 A
Open Circuit Voltage (Voc)	38.1 V	38.1 V	38.1 V	38.2 V	38.2 V	38.3 V
Short Circuit Current (Isc)	10.66 A	10.70 A	10.74 A	10.78 A	10.82 A	10.86 A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m^2 spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

MECHANICAL DATA

Specification	Data
Cell Type	HJT cells
Cell Arrangement	108 [2 X (9 X 6)]
Dimensions	1722 X 1134 X 30 mm (67.8 X 44.6 X 1.18 in)
Weight	23.0 kg (50.7 lbs)
Front Glass	2.0 mm heat strengthened glass with anti-reflective coating
Back Glass	1.6 mm heat strengthened glass
Frame	Anodized aluminium alloy
J-Box	IP68, 3 bypass diodes
Cable	4 mm^2 (IEC)
Cable Length (Including Connector)	Portrait: 410 mm (16.1 in) (+) / 290 mm (11.4 in) (-); landscape: 1100 mm (43.3 in)*
Connector	T6 or PV-KST4/xy-UR, PV-KBT4/xy-UR (IEC 1000 V) or PV-KST4-EVO2/XY, PV-KBT4-EVO2/XY (IEC 1500 V)
Per Pallet	35 pieces
Per Container (40' HQ)	910 pieces

* For detailed information, please contact your local Canadian Solar sales and technical representatives.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.26 % / °C
Temperature Coefficient (Voc)	-0.24 % / °C
Temperature Coefficient (Isc)	0.04 % / °C
Nominal Module Operating Temperature	41 ± 3°C

First solar Series 6 Advanced thin film solar technology 430-460 Watts

TECHNICAL SPECIFICATIONS OF A PV MODULE

Some important parameters to consider:

- IV curve of PV module
- Efficiency
- Light induced degradation
- Potential induced degradation
- Temperature coefficient
- Linear Warranty, etc.

Specifications	Units	Value
Maximum power	P_{max} [Wp]	300
Maximum power voltage	V_{pmax} [V]	32.8
Maximum power current	I_{pmax} [A]	9.16
Open circuit voltage	V_{oc} [V]	39.85
Short circuit current	I_{sc} [A]	9.71
Module efficiency	η [%]	18.4
Power tolerance	[W_p]	-0/+5
Temperature coefficient I_{sc}	[%/K]	0.03
Temperature coefficient V_{oc}	[%/K]	-0.30
Temperature coefficient P_{max}	[%/K]	-0.38
Module weight (± 1 kg)	[kg]	19
Dimensions (H × L × D ± 1 mm)	[mm]	1650 × 990 × 38

STANDARD TEST CONDITIONS AND WORKING CONDITIONS OF PV MODULES

Standard Test Conditions (STC)

Cell temperature = 25°C

Irradiance = 1000 W/m^2

Air mass = 1.5

Power P in (W) = Voltage V in (V) x Current, I in (A)

Nominal Operating Cell Temperature, NOCT

NOCT is closer to real-world conditions than STC

Ambient temperature= 50°C

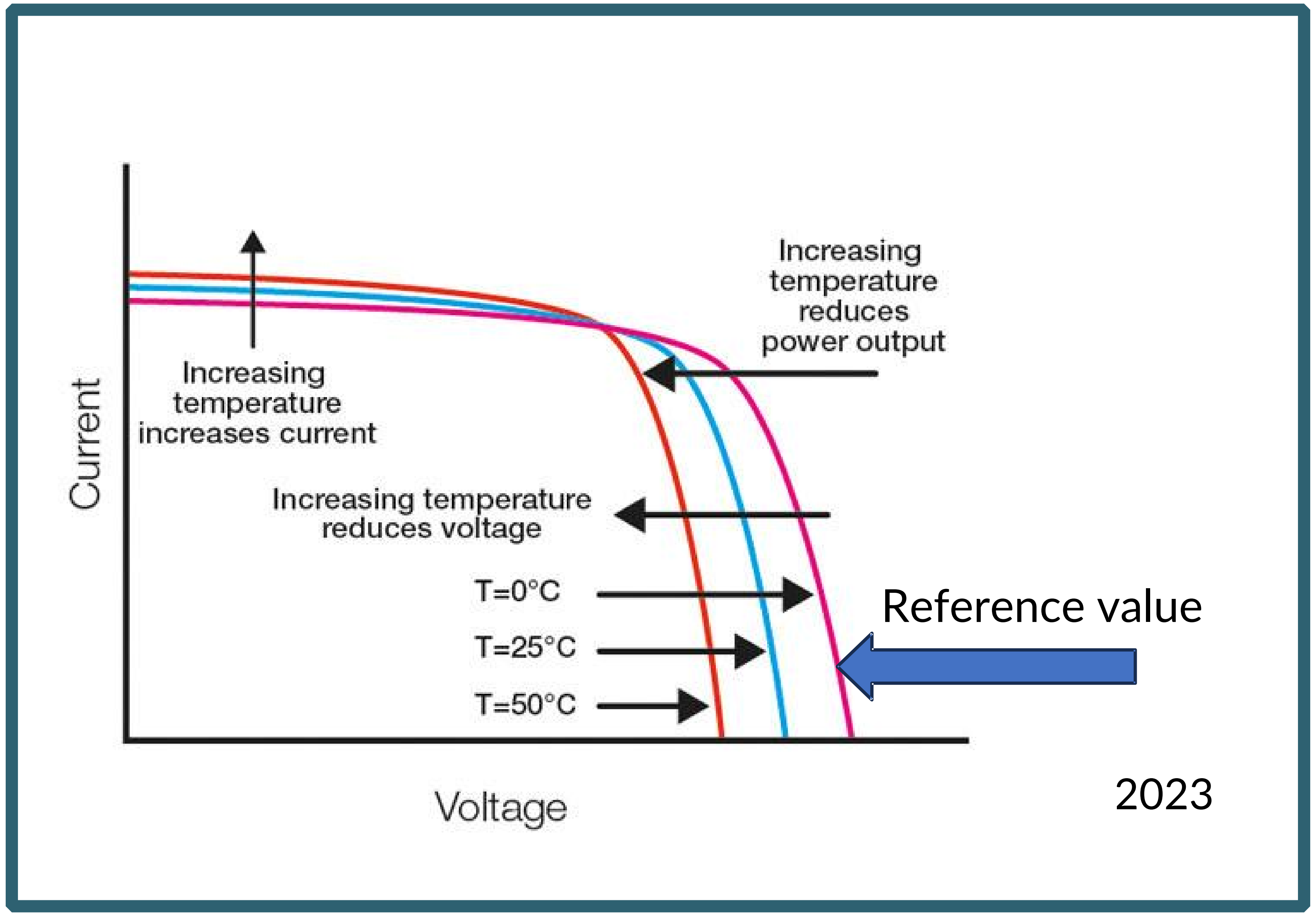
Irradiance = 800 W/m^2

Air mass = 1.5

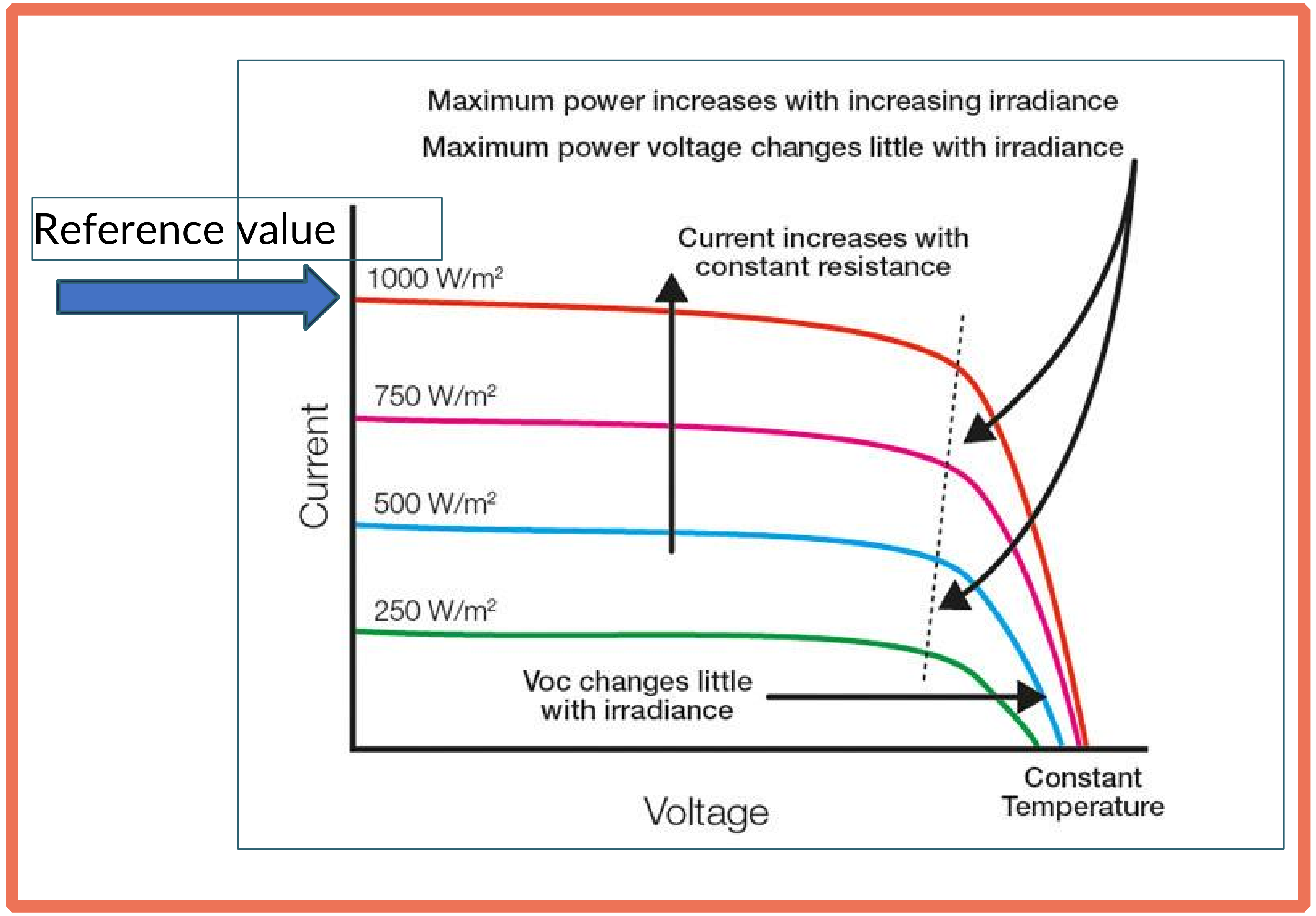
Wind speed = 1 m/s

WORKING CONDITIONS OF PV MODULE WITH VARIED RADIATION AND TEMPERATURE

Performance with varied temperature



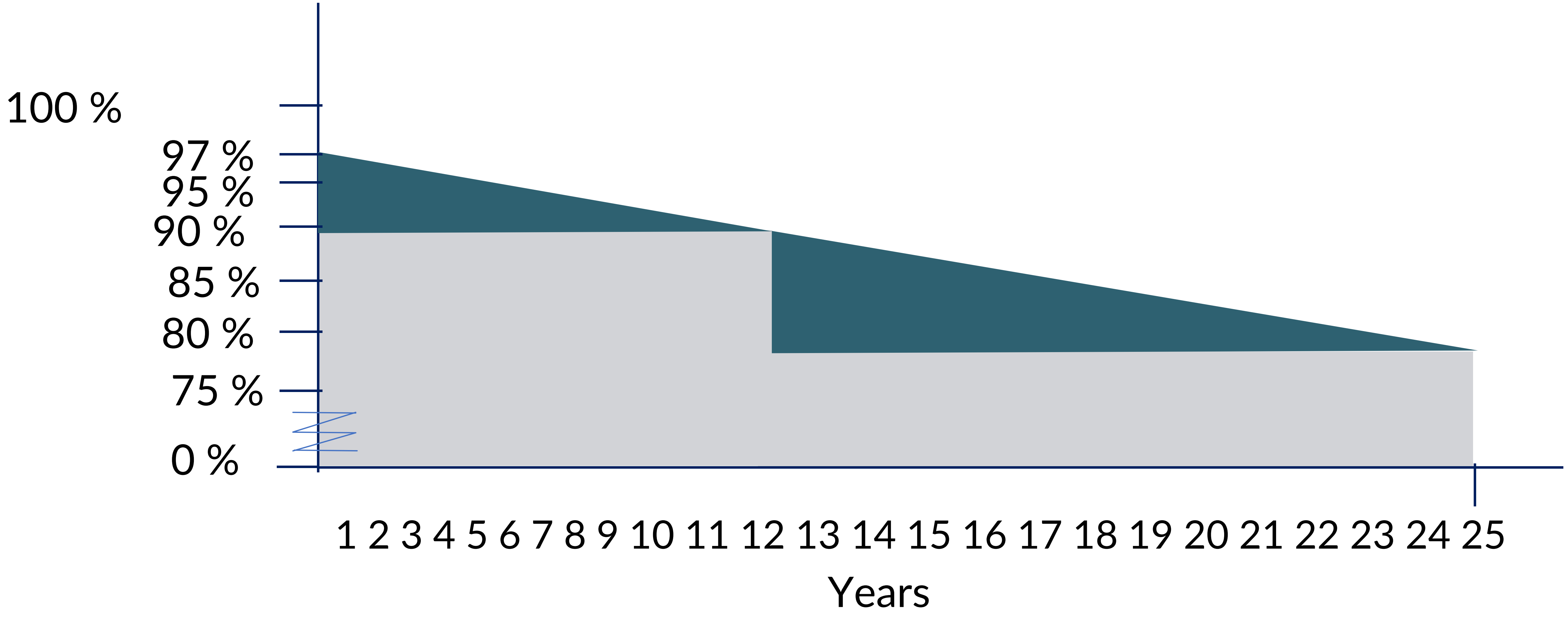
Performance with varied solar radiation



Power P in (W) = Voltage V in (V) x Current, I in (A)

LINEAR VS NON-LINEAR WARRANTY OF A PV MODULE

Guaranteed module performance, %



Standard guarantee

Linear guarantee

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on the basis of a decision by the German Bundestag

END OF CHAPTER 1 OF 3

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