ITALIAN NATIONAL AGENCY FOR
NEW TECHNOLOGIES, ENERGY AND
SUSTAINABLE ECONOMIC DEVELOPMENT

Il fotovoltaico: Numeri ed evoluzione tecnologica

Paola Delli Veneri

ENEA – Head of Solar Photovoltaics Division - **Project Coordinator**

The **Italian National Agency for New Technologies, Energy and Sustainable Economic Development**, is a public research body hosting **2300** researchers, technologists and administrative staff

- **Energy Technologies and Renewable Energy Source Department**
- Nuclear Fusion Department
- Sustainability Department
- Energy Efficiency Department
- Technology Transf Department

13 Research Centres
&
large laboratories

Rome Headquarters
Bruxelles bureau

Solar Photovoltaic Division

PV ovunque


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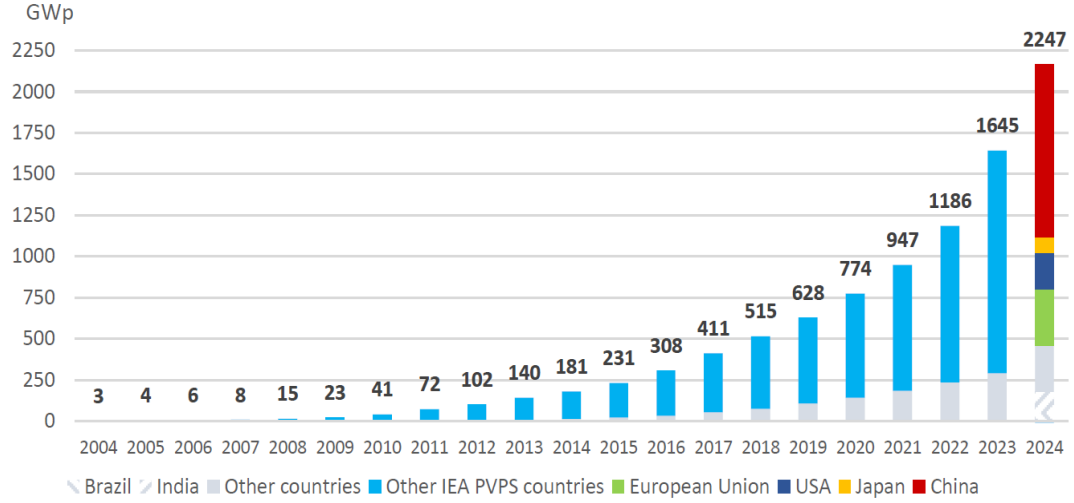
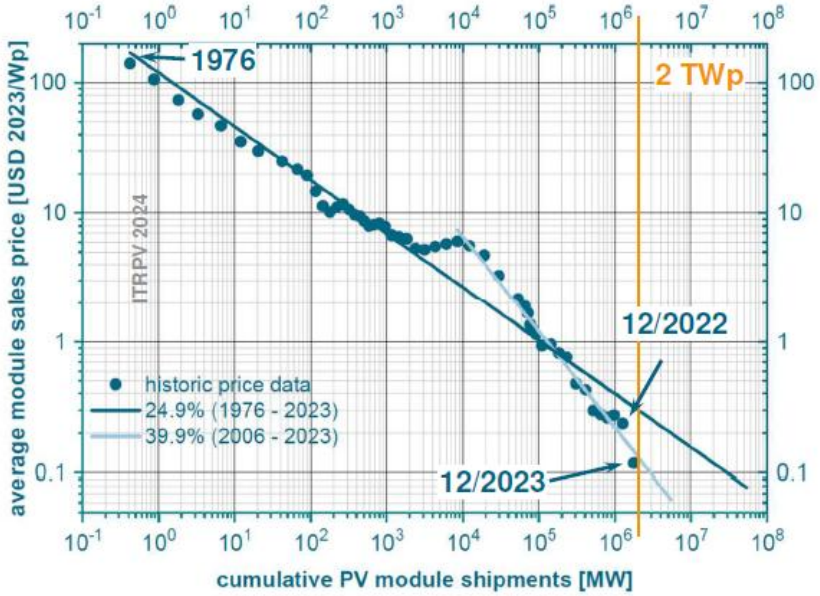
PV Numbers

…In the world more then **2 TWp** of PV Installed

Source IEA PVPS



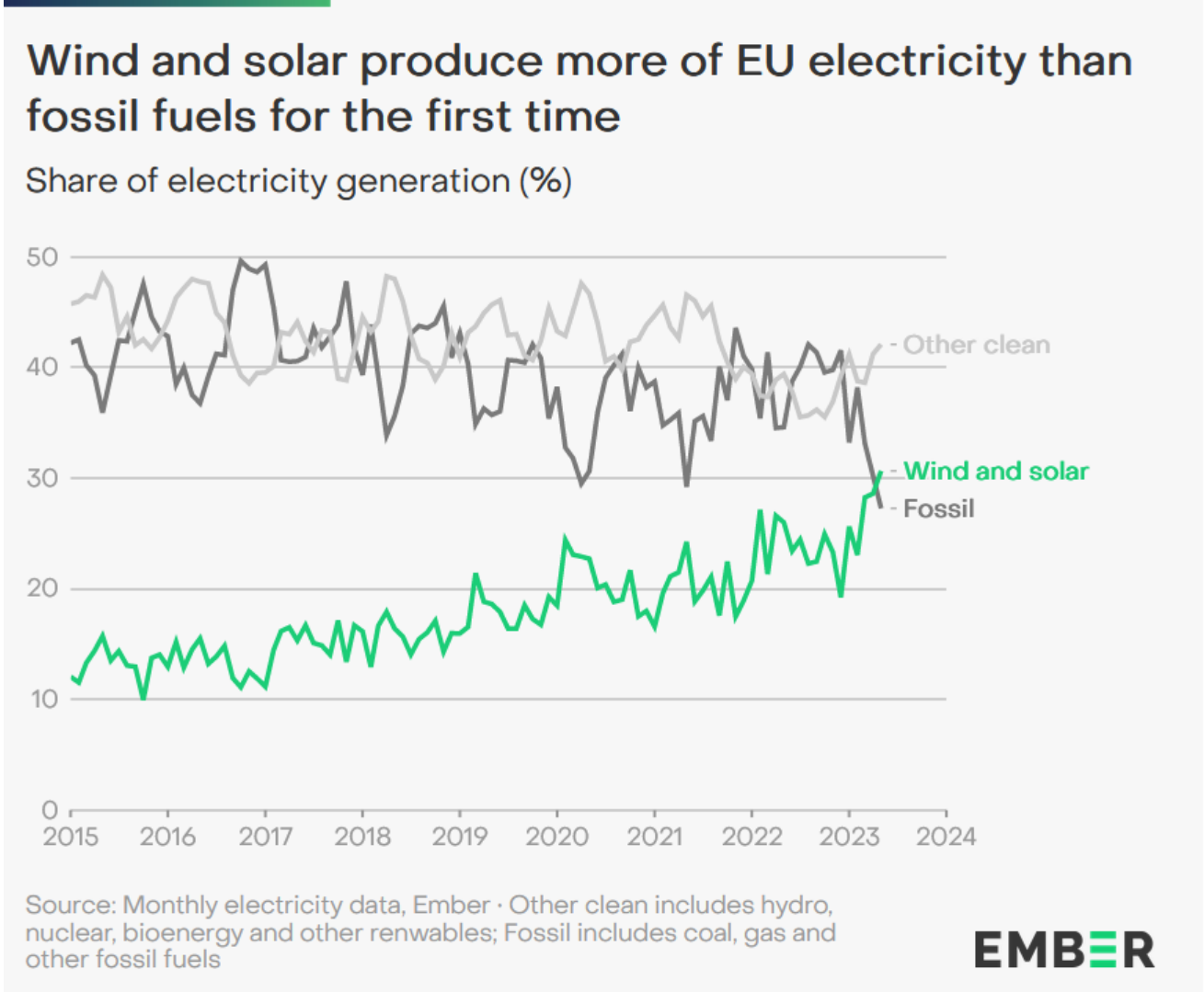


Price-experience curve for solar modules

avg. Module spot price at year end:
2022: 0.23 US$/Wp
2023: 0.12 US$/Wp
2024: 0.08 US$/Wp

Source ITRPV 16th edition, march 2025

There is always a first time.
For everything.



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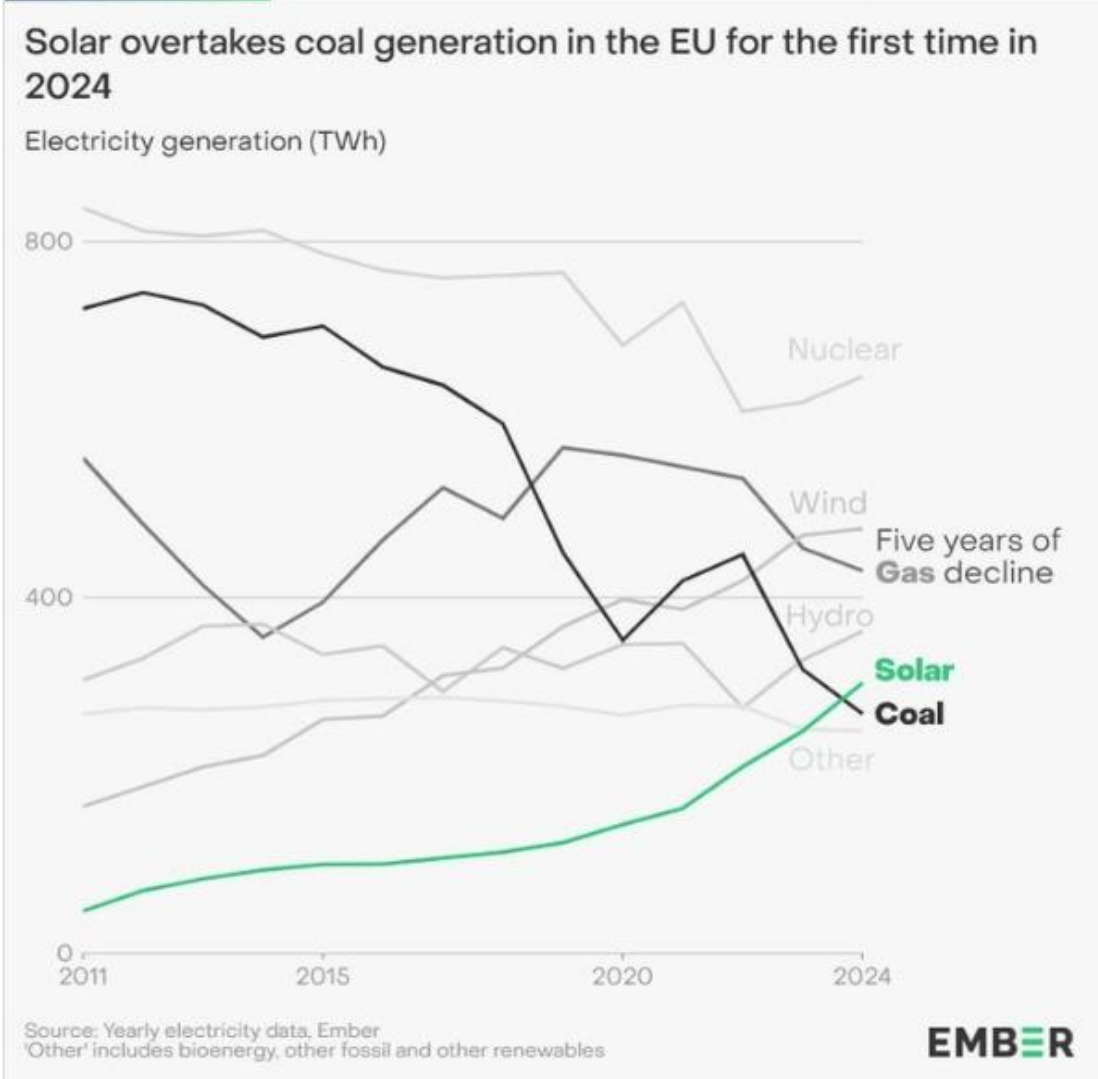

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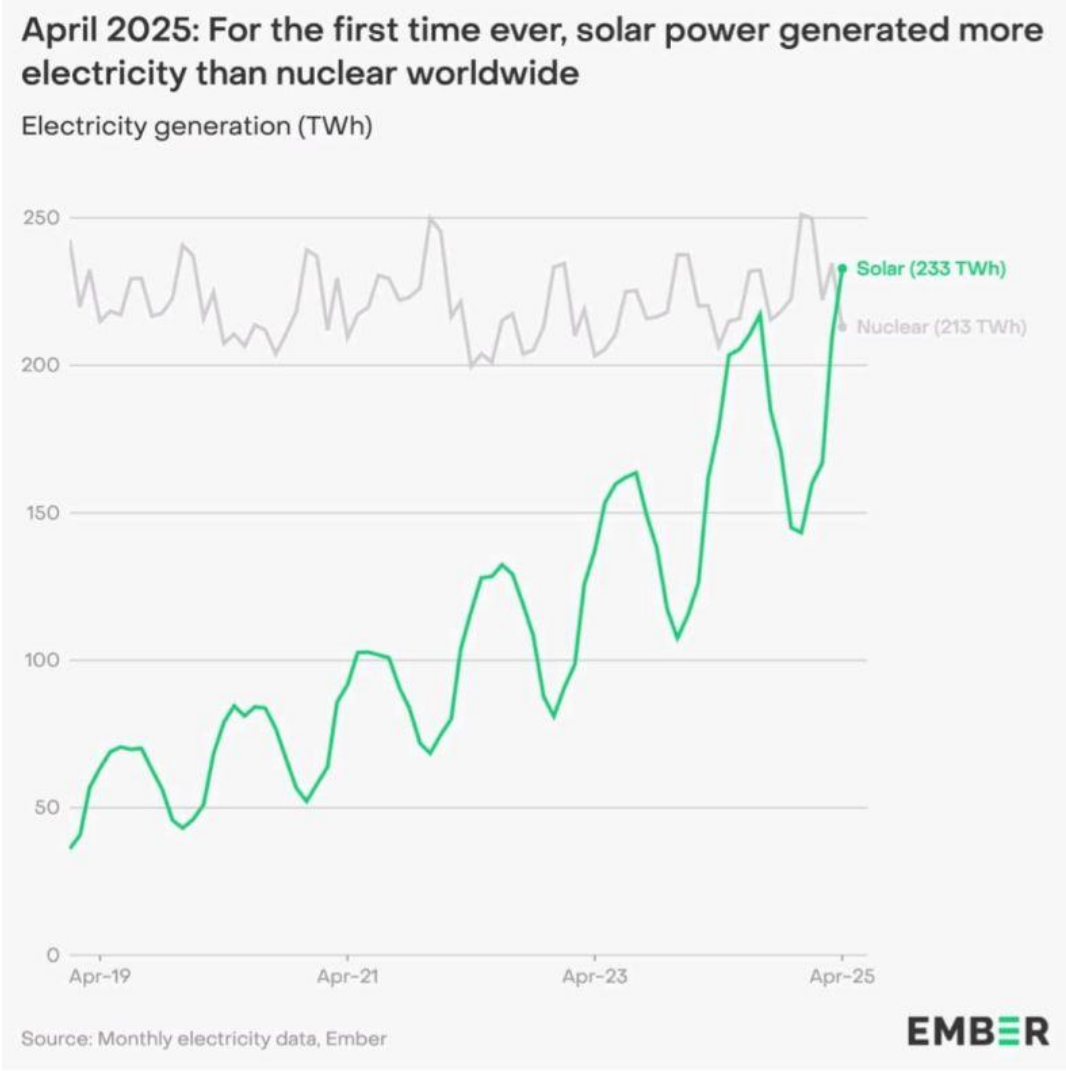
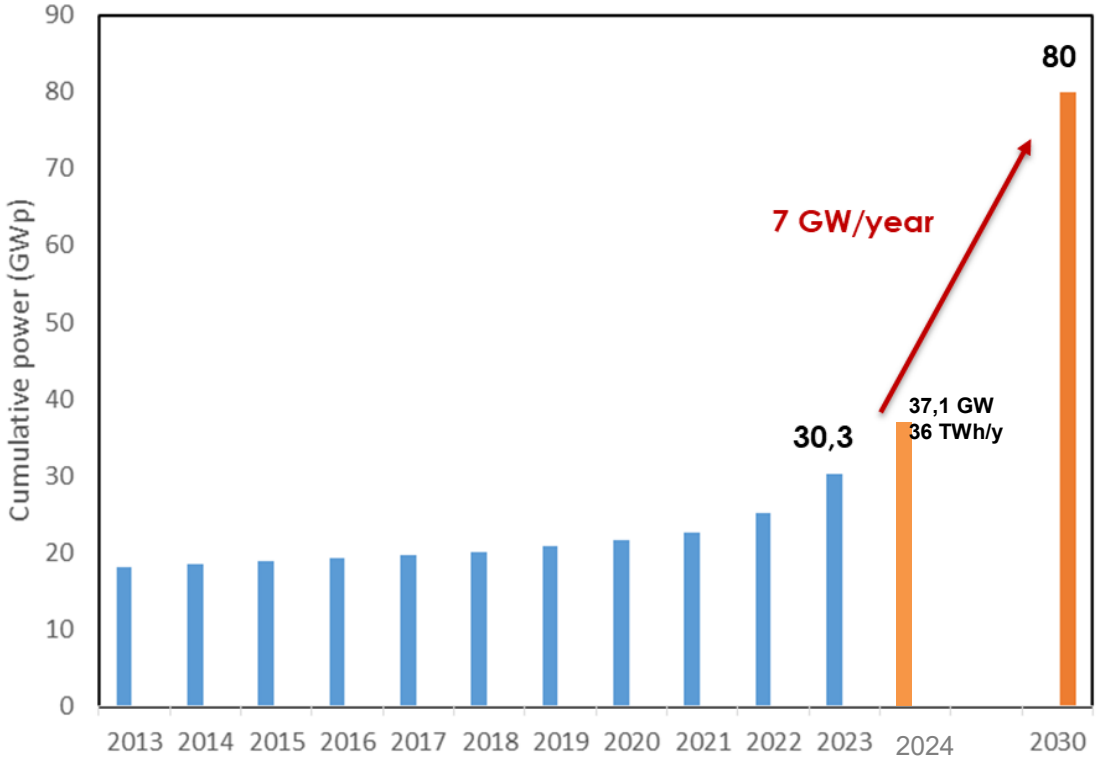


Integrated National Plan for Energy and Climate - PNIEC



…in ITALY

By 2030, 65% of electricity in Italy **will have to be generated from renewable sources** and almost half will be PV

Italy again in the PV top countries!!

RANKING	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
1	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA
2	JAPAN	JAPAN	JAPAN	USA	INDIA	INDIA	USA	USA	USA	USA	USA
3	USA	USA	USA	JAPAN	USA	USA	INDIA	VIETNAM	INDIA	INDIA	GERMANY
4	GERMANY	UK	UK	INDIA	JAPAN	JAPAN	JAPAN	JAPAN	JAPAN	BRAZIL	INDIA
5	ITALY	GERMANY	INDIA	UK	TÜRKIYE	AUSTRALIA	VIETNAM	GERMANY	GERMANY	SPAIN	BRAZIL
6	UK	SOUTH AFRICA	GERMANY	GERMANY	GERMANY	TÜRKIYE	AUSTRALIA	AUSTRALIA	BRAZIL	GERMANY	SPAIN
7	ROMANIA	FRANCE	SOUTH KOREA	THAILAND	SOUTH KOREA	GERMANY	SPAIN	SOUTH KOREA	SPAIN	JAPAN	JAPAN
8	INDIA	SOUTH KOREA	AUSTRALIA	SOUTH KOREA	AUSTRALIA	MEXICO	GERMANY	INDIA	AUSTRALIA	POLAND	ITALY
9	GREECE	AUSTRALIA	FRANCE	AUSTRALIA	BRAZIL	SOUTH KOREA	UKRAINE	SPAIN	SOUTH KOREA	AUSTRALIA	POLAND
10	AUSTRALIA	INDIA	CANADA	TÜRKIYE	UK	NETHERLANDS	SOUTH KOREA	NETHERLANDS	POLAND	NETHERLANDS	NETHERLANDS
RANKING EU	2	3	3	4	5	4	2	2	2	2	2
MARKET LEVEL TO ACCESS THE TOP 10											
	792 MW	779 MW	675 MW	818 MW	944 MW	1 621 MW	3 130 MW	3 492 MW	3 710 MW	4 200 MW	4 788 MW

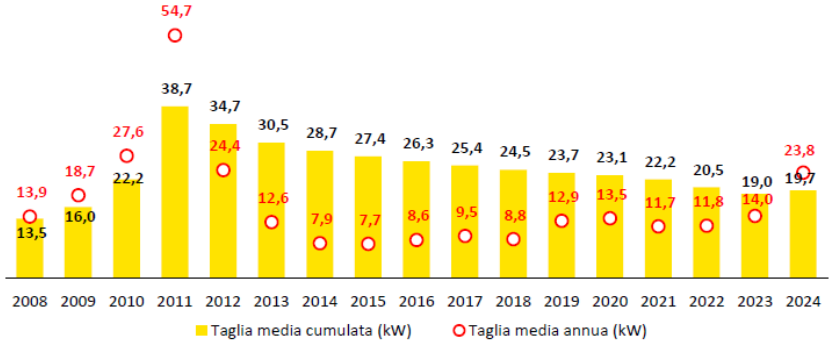
Source IEA PVPS
TRENDS IN PHOTOVOLTAIC APPLICATIONS 2024

EVOLUTION OF TOP 10 MARKETS

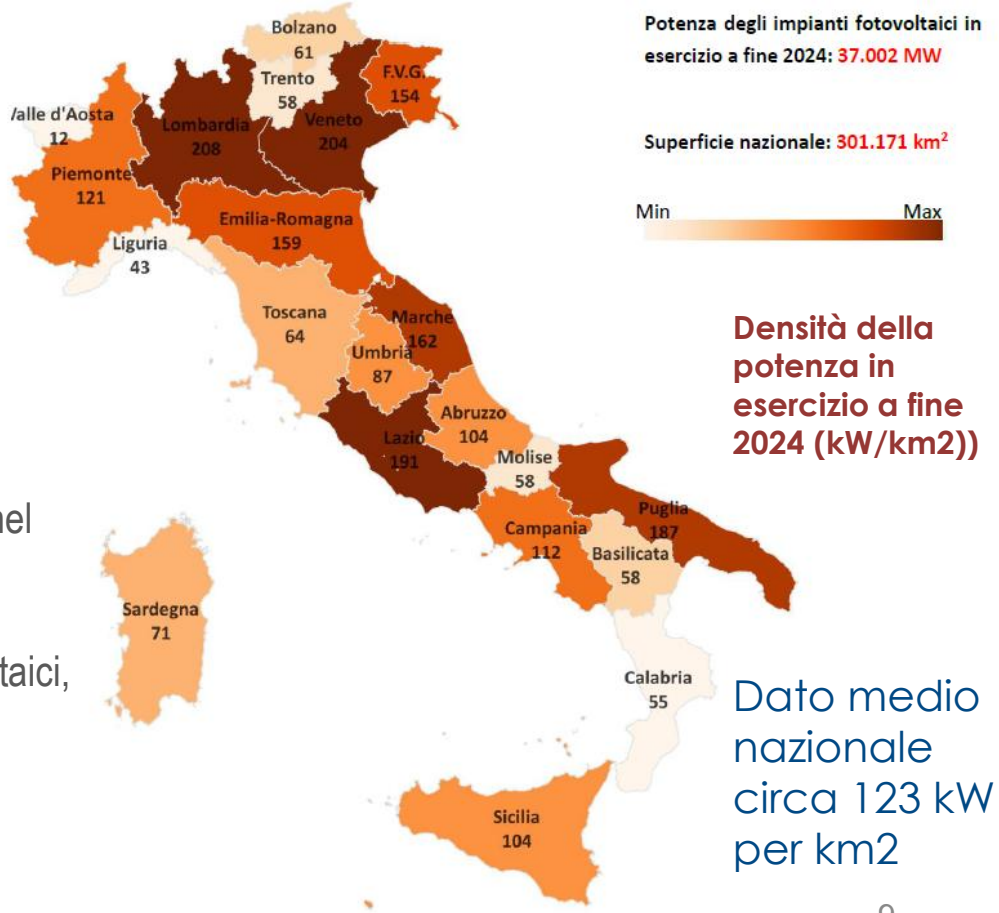
Top 10 countries for annual and cumulative installed capacity in **2024**

	FOR ANNUAL INSTALLED CAPACITY				FOR CUMULATIVE CAPACITY	
1	China	357.3 GW*	1	China	1048.5 GW*	
(2)	*European Union*	62.6 GW	(2)	*European Union*	339.4 GW	
2	USA	47.1 GW	2	USA	224.1 GW	
3	India	31.9 GW	3	India	124.6 GW	
4	Pakistan	17.0 GW	4	Germany	99.8 GW	
5	Germany	16.7 GW	5	Japan	96.9 GW	
6	Brazil	14.3 GW	6	Brazil	52.1 GW	
7	Spain	7.5 GW	7	Spain	47.2 GW	
8	Italy	6.6 GW	8	Australia	38.6 GW	
9	France	5.9 GW	9	Italy	37.0 GW	
10	Japan	5.5 GW	10	South Korea	31.7 GW	

PV plants in Italy



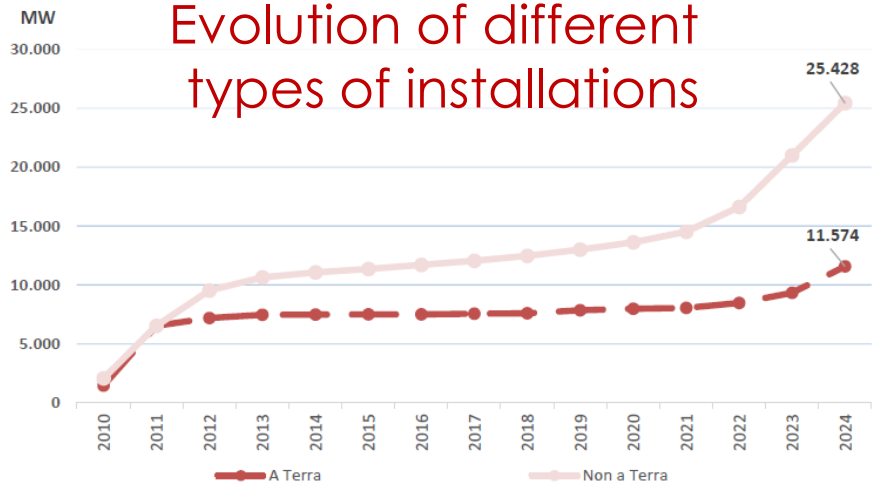
- La potenza media degli impianti entrati in esercizio nel corso del 2024 è pari a 23,8 kW;
- il dato di taglia media cumulata degli impianti fotovoltaici, attestandosi a 19,7 kW, ha interrotto la tendenza decrescente iniziata nel 2012.

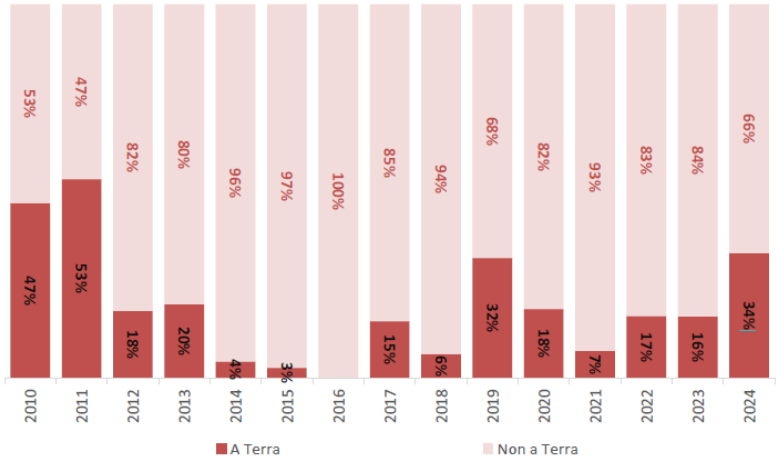


Dato medio nazionale circa 123 kW per km2

Source GSE – Rapporto statistico 2023 Solare FV

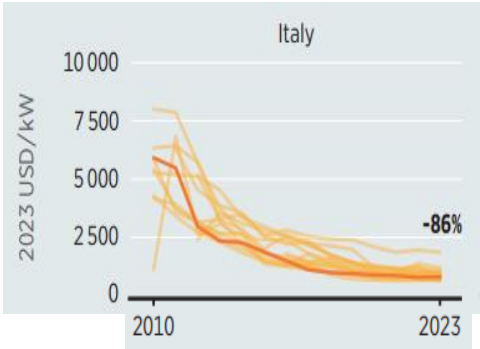
PV plants in Italy: applications and costs





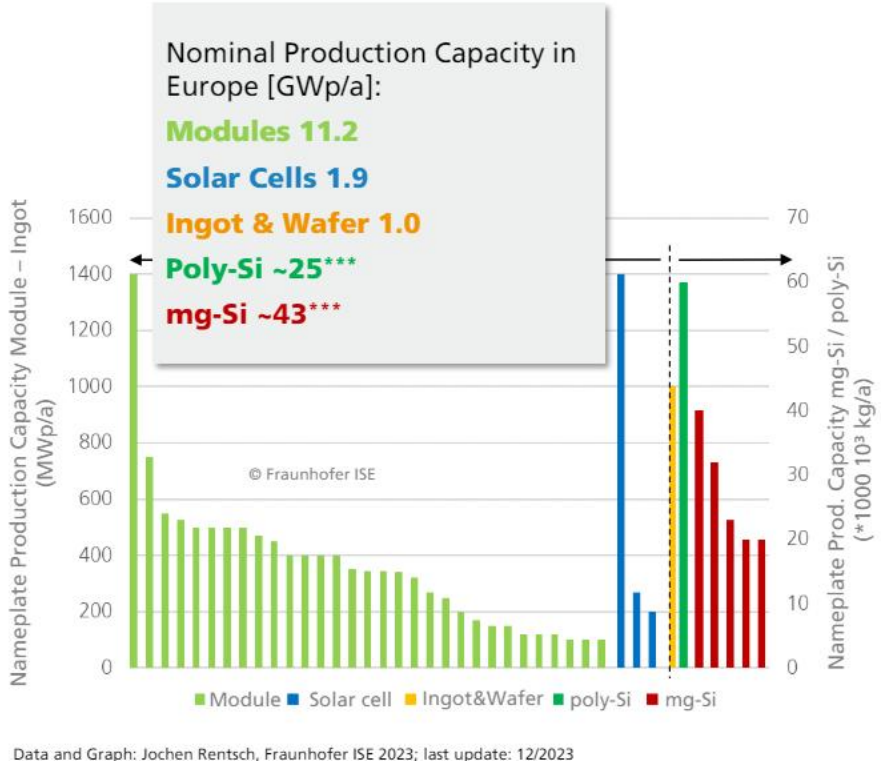
Source GSE

Utility scale PV

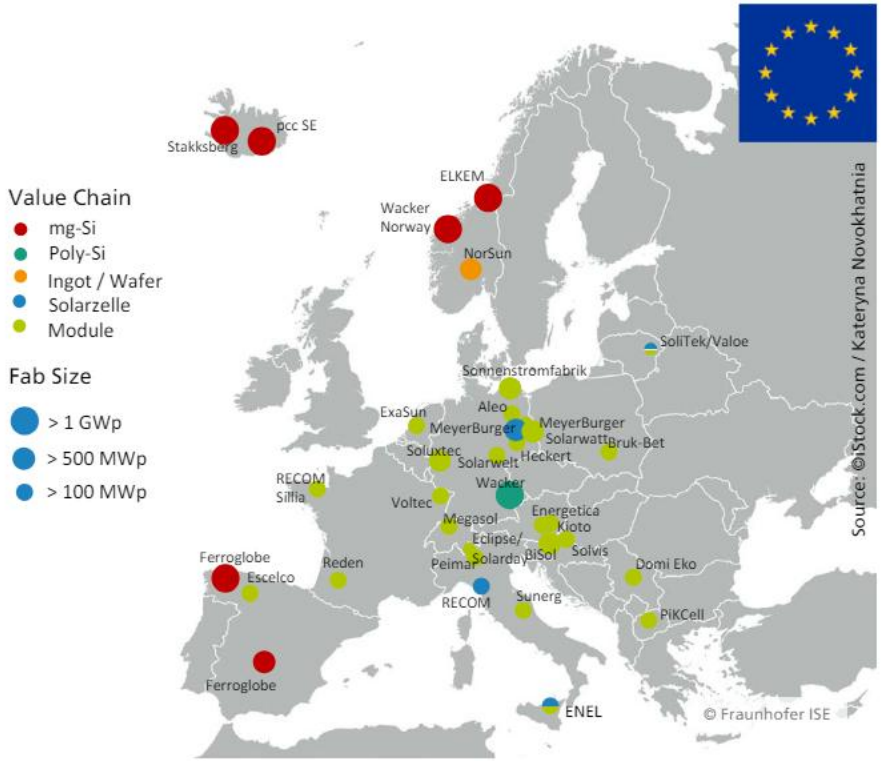


Source IRENA – Renewable power gneration costs in 2023

Current EU c-Si Manufacturing landscape:
status quo, End of 2023



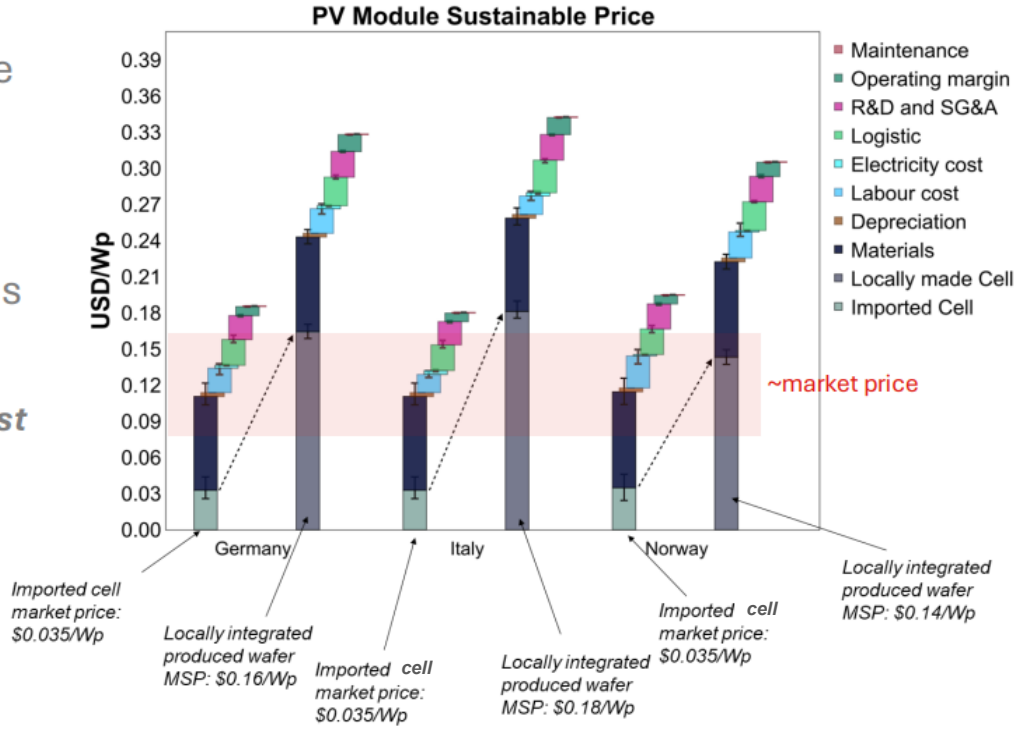
Data and Graph: Jochen Rentsch, Fraunhofer ISE 2023; last update: 12/2023



Source: PV Report; Fraunhofer Institute for Solar Energy Systems, ISE - 2024

PV modules sustainable price in EU

- Module MSP is over 0.30 USD/Wp in these three locations
- With imported cells, ~0.18-0.20 USD/Wp
- Materials and logistics are important drivers
  Aside from upstream drivers like ***electricity cost***



Not only should **Europe** have access to energy from PV, but it should also have access to the means of **producing the PV generating devices** itself.

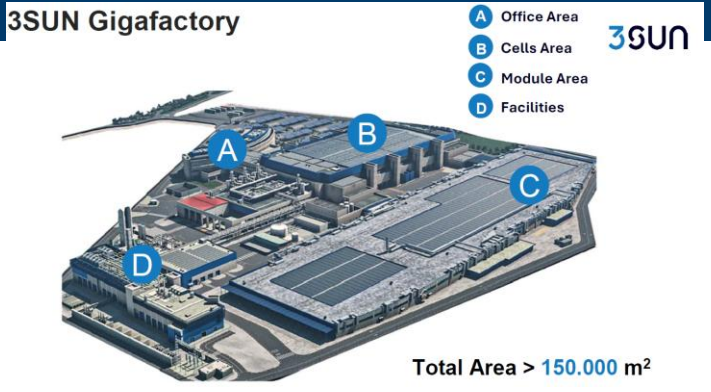
PREMIUM for EU PV modules would help!

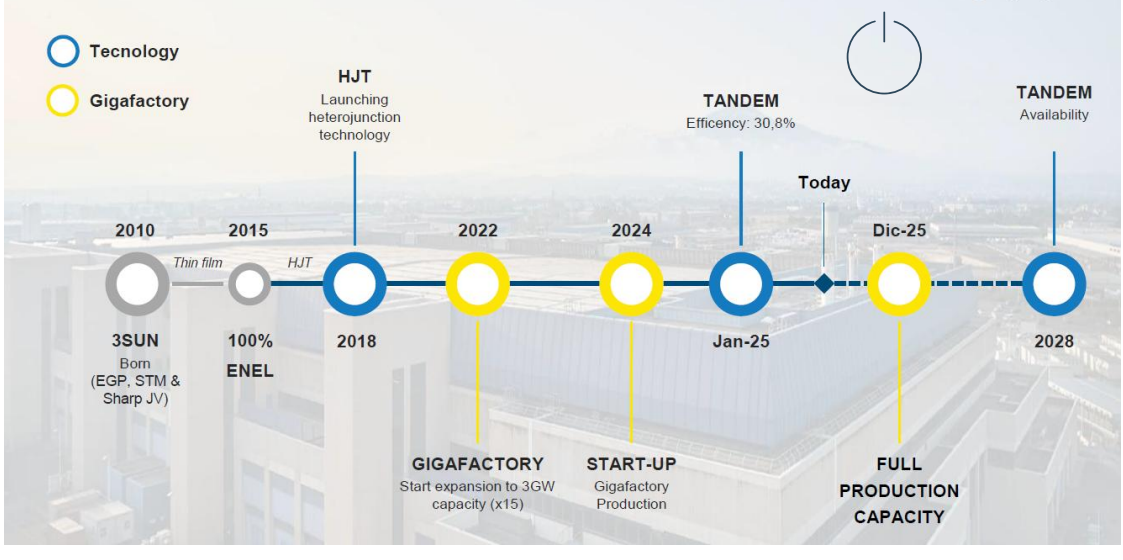
Reshoring PV Manufacturing to Europe: Can EU-made PV Compete in a Global Market? EUPVSEC 2024 Atse Louwen et al, Eurac Research, UNSW

Main industrial initiatives in Italy – 3SUN

Europe largest PV cell and module factory – 3GW/year

3SUN





Strong technology know-how

- **Cell efficiency record holder with 25 %** for industrialized Heterojunction cell (ISFH certified)

Main industrial initiatives in Italy – FUTURA SUN

A new **1.4 GW factory** is under development in north-east Italy to supply Italian and European market with premium quality modules (n-type TOPCon and xBC)

The factory, fully powered by renewable energy and with an annual production capacity of 1.4 GW, will create more than 250 direct jobs and 380 indirect jobs, becoming a technological hub for the local community.

POLICY FRAMEWORK

National Recovery and Resilience Plan (NRRP)

AGRISOLAR

2,35 Mld €
Target: min. 1,38 GW

AGRIVOLTAIC

1,1 Mld € for Innovative agrivoltaic
Target: min. 1,04 GW

Transizione 5.0 Decree

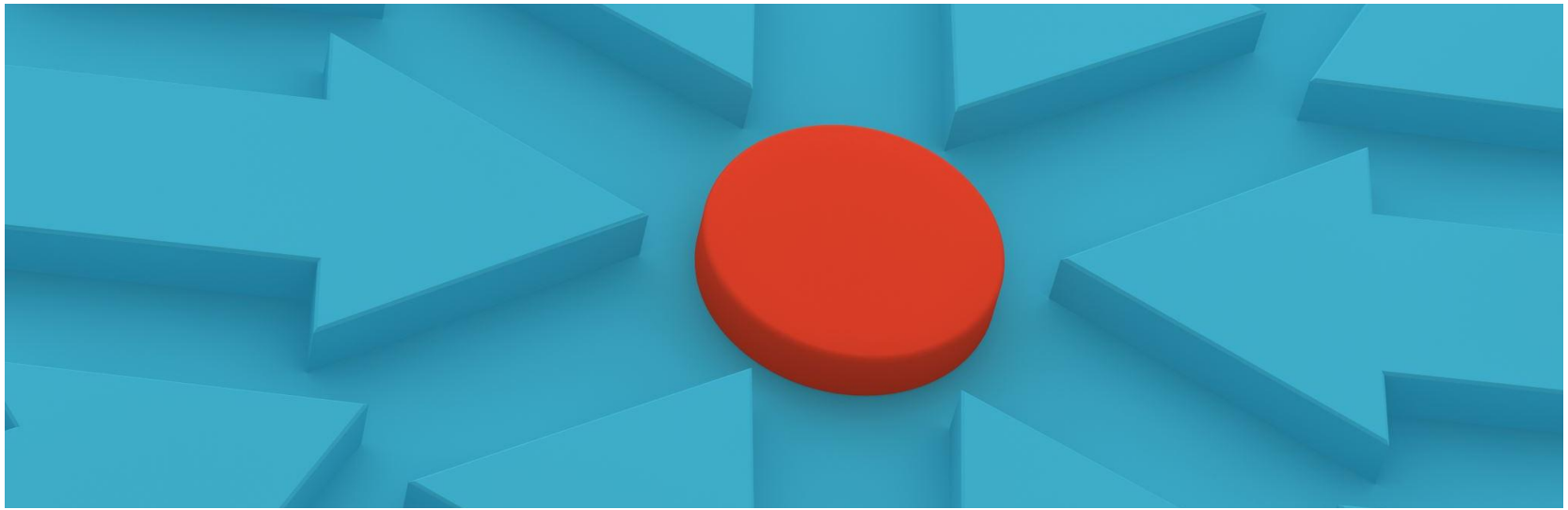
Tax credits for companies investing in energy efficiency and digital transformation projects. To be eligible for the tax credit, **PV modules must be manufactured in EU Member States with defined performance levels.**

The Italian PV network

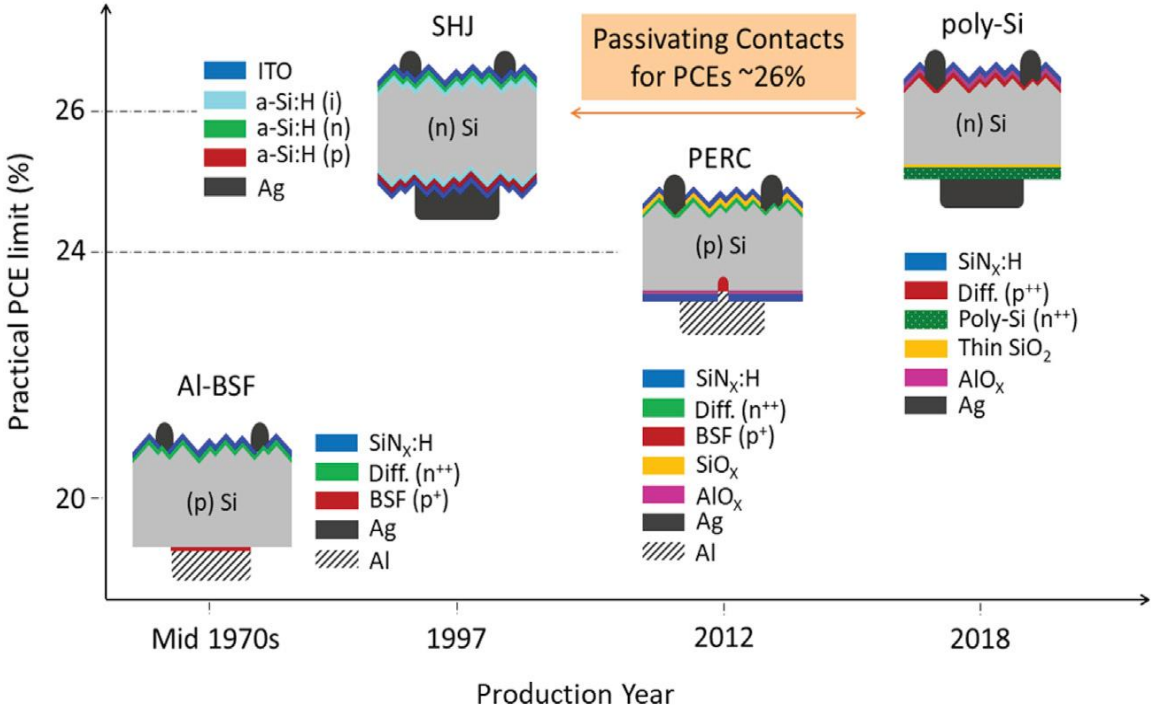
Objective of the Italian PV network:

- Connect/promote research initiatives
- Connect industry to research
- Guide policy to promote industrial initiatives and research programmes
- Contribute to the training/experience of young researchers

technology trend



Evolution of Si solar cell design for industrial production

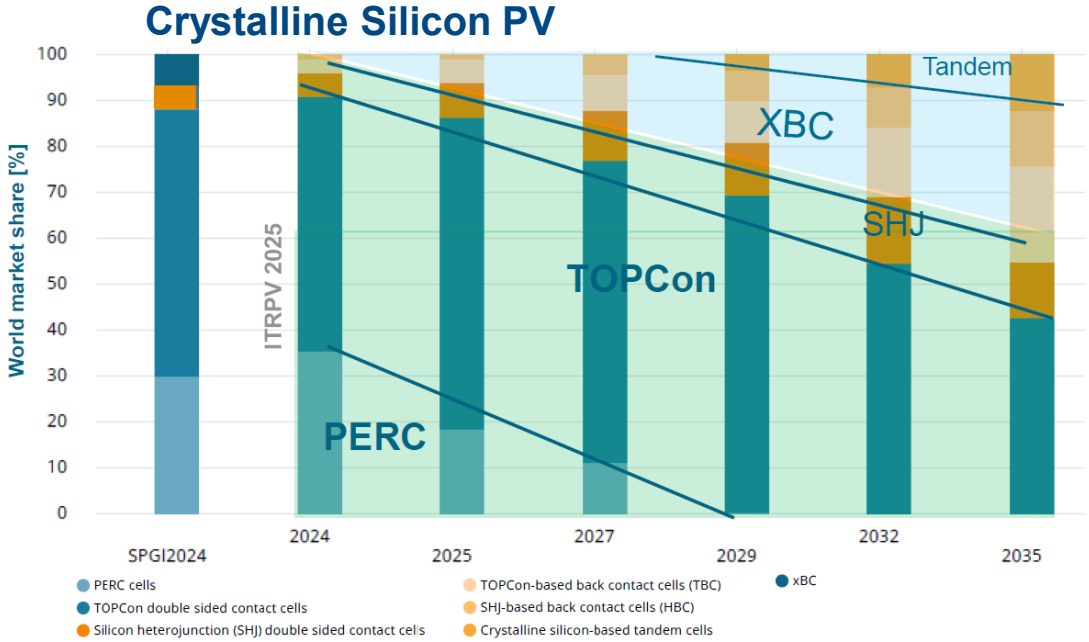


PERC design is currently the mainstream cell technology, overtaking the back-surface field (Al-BSF) design of mid 1970s, and will most likely retain this position until 2025-30.

Eventually, upon reaching practical efficiency limits, cell structures deploying passivating contacts (SHJ or poly-Si based) are expected to replace PERC.

A. Razzaq, at al., Joule 6, 514–542, 2022, https://doi.org/10.1016/j.joule.2022.02.009

PV cell technologies in the market



- c-Si technologies dominate the market (around 98%)
- from PERC to TOPCON technology
- SHJ share increases
- tandem next?

Sources International Technology Roadmap for Photovoltaics (ITRPV) 2023 Results - 16th edition (March 2025)

Record cell efficiencies:

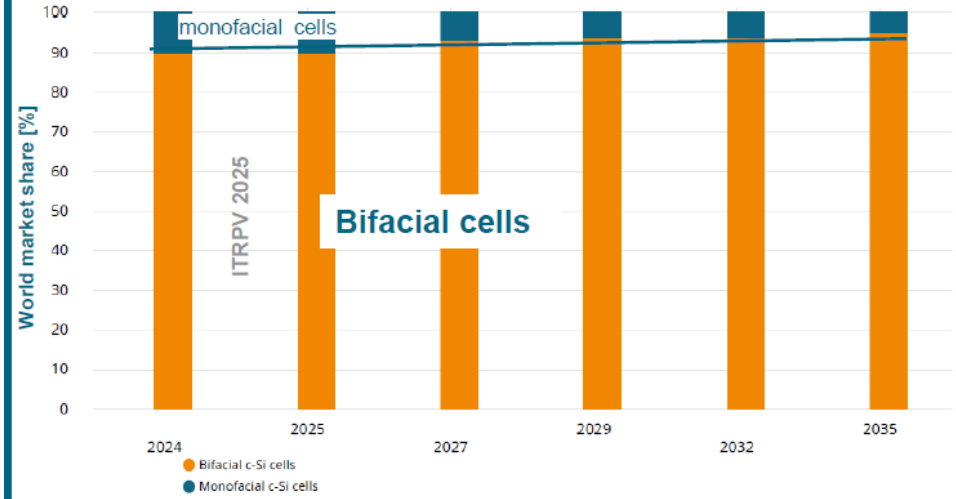
Silicon: 27.8%

Perovskite: 26.7%

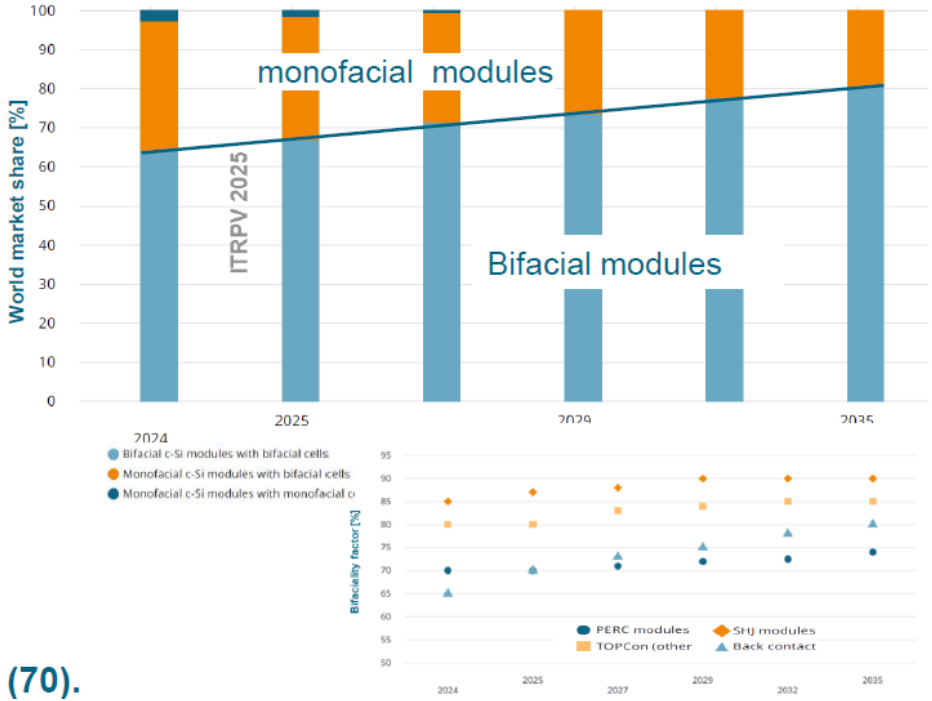
Perovskite/silicon tandem: **34.9%**

Solar Cells: Bifacial products

Trend: Bifacial cells
→ bifacial cells will be in “dual” use

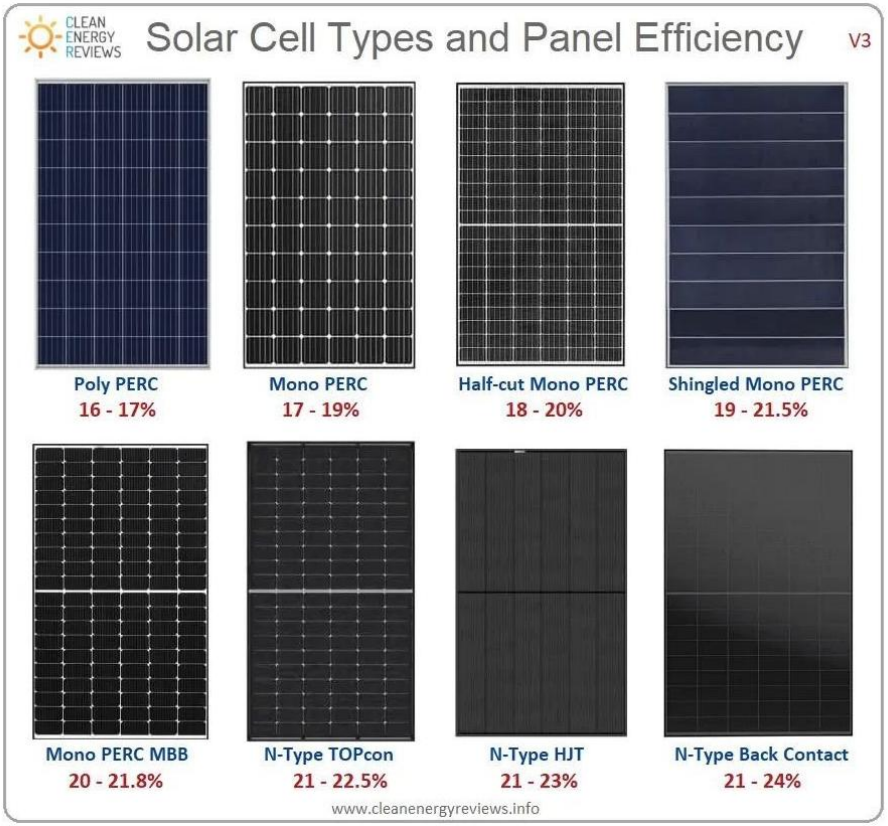


Trend: Bifacial modules
→ today: close to 100%



→ **Bifacial cells are standard today**
→ **are used in mono- and bifacial modules**
→ **Bifaciality of cell concepts today:**
SHJ leads (87)..TOPCon (80)..PERC (70) …IBC (70).

Sources International Technology Roadmap for Photovoltaics (ITRPV) 2023 Results - 16th edition (March 2025)



Average efficiency values of modules for different technologies

ENEA

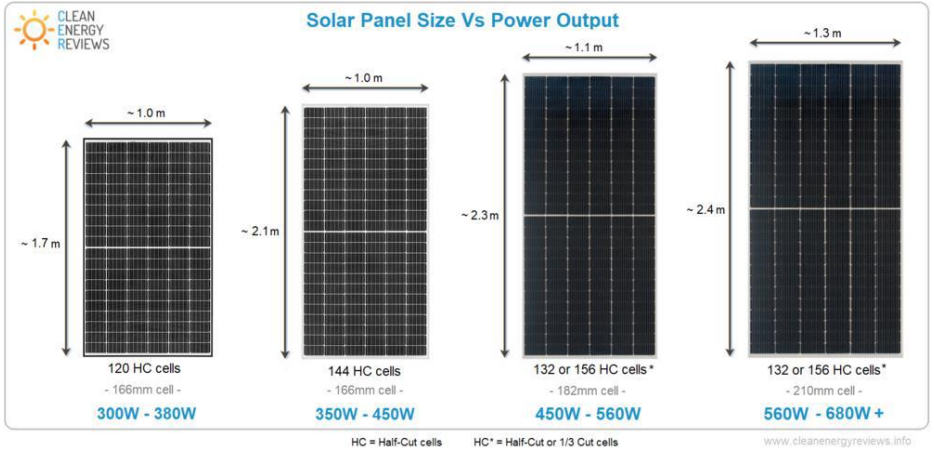
CLEAN ENERGY REVIEWS — Most Efficient Residential Solar Panels 2024 * V4.5 Feb 2024

Manufacturer	Model	Power Rating	Cell Technology	Efficiency
SUNPOWER	Maxeon 7	445W	N-Type **IBC**	24.1 %
AIKO	Black Hole Series	470W	N-Type **ABC** Back Contact	23.8 %
RECOM	Black Tiger	460W	N-Type **TOPcon** Back Contact	23.6 %
AEG	BC Premium	460W	N-Type **ABC** Back Contact	23.6 %
LONGi Solar	Hi-MO 6 Scientist	455W	N-Type **HPBC** Hybrid Back Contact	23.3 %

CLEAN ENERGY REVIEWS — Most Powerful Solar Panels * Jan 2024 V3.6

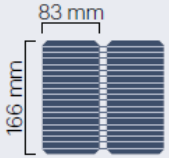
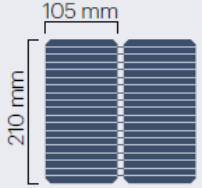
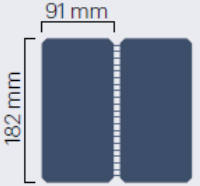
Manufacturer	Model	Power (W)	Cell Size	Wafer Type	Cell Technology	Efficiency %	Date Announced *
HUASUN	Himalaya G12-132	750 W	210mm	N-Type	HJT, Bifacial	24.16%	Q4 2023 *
TW SOLAR	210-66HJT	744 W	210mm	N-Type	HJT, Bifacial	23.94%	Q4 2023 *
risen	Hyper-Ion	740 W	210mm	N-Type	HJT, Bifacial	23.89%	Q4 2022 *
AKCOME	iPower 7	730 W	210mm	N-Type	HJT, Bifacial	23.5%	Q2 2023 *
Trinasolar	Vertex N	700 W	210mm	N-Type	TOPCon, Bifacial	22.5%	Q3 2023 *

Residential → Utility-scale



Evolution of mainstream photovoltaic module designs

a

	2000	2015	2018	2022	2025
Cumulative installed capacity	1 GWp	250 GWp	500 GWp	1,000 GWp	2,000 GWp
PV module price	$5 per Wp	$0.5 per Wp	$0.35 per Wp	$0.2 per Wp	$0.1 per Wp
PV module efficiency	12–14%	16–17%	18–19%	20–21%	22–25%
Mainstream PV					
Number of ribbons	3	5	9–16	11–24	9–20 (Back contacted cells)
Wafer size	M0	M2	M6-HC	G12-HC	M10-HC

Antonin Faes, et al, Building-integrated photovoltaics, Nature review clean Technology (2025) - https://doi.org/10.1038/s44359-025-00059-9

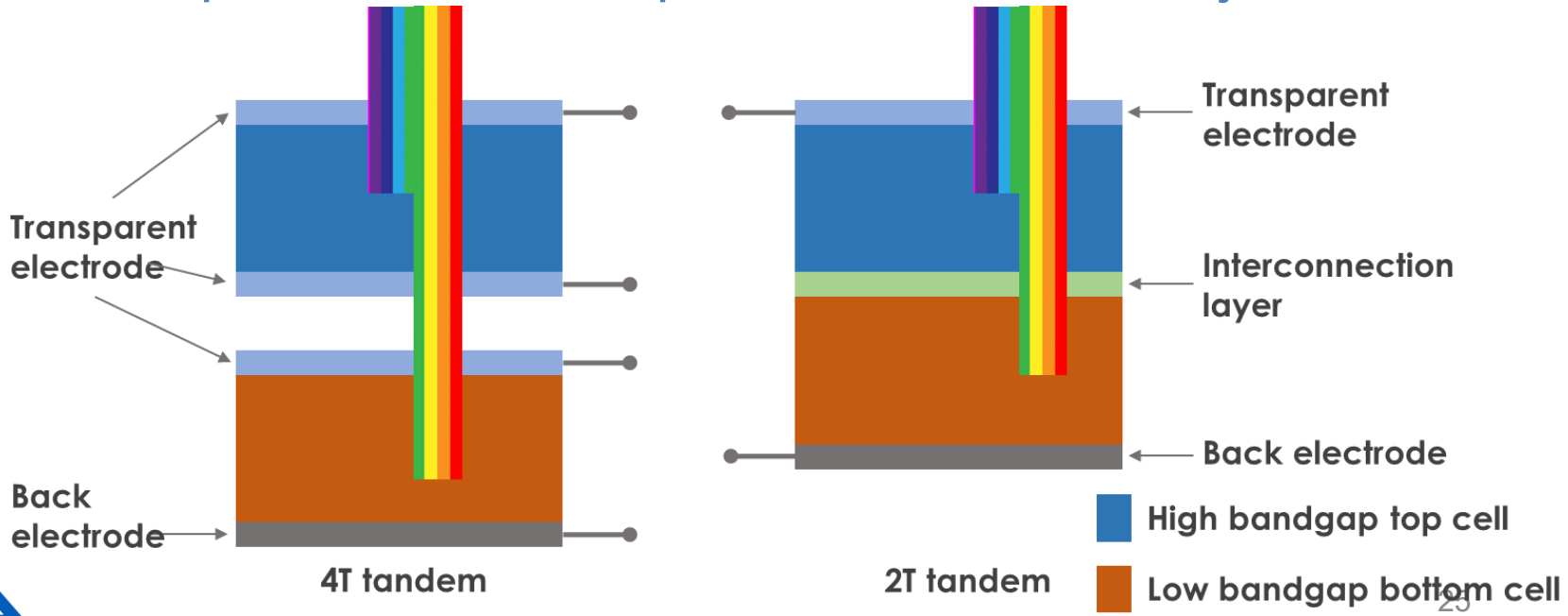
PV Research….to-do list

- Performance enhancement and cost reduction of PV devices
- Lifetime, reliability and sustainability enhancements.
- New applications through integration of Photovoltaics
- Maximize the energy produced by PV plants

Beyond 30% efficiency: Tandem solar cells

New PV generation: tandem solution

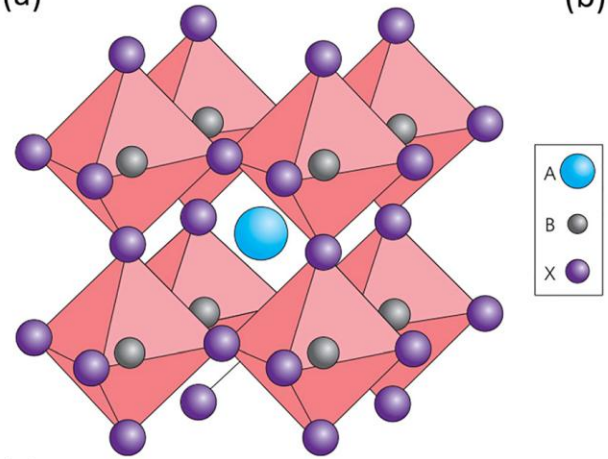
Multi-junction tandem solar cells involve the stacking of solar cells with different bandgaps (highest on the sun-facing side) allowing each cell to absorb different parts of the solar spectrum more efficiently



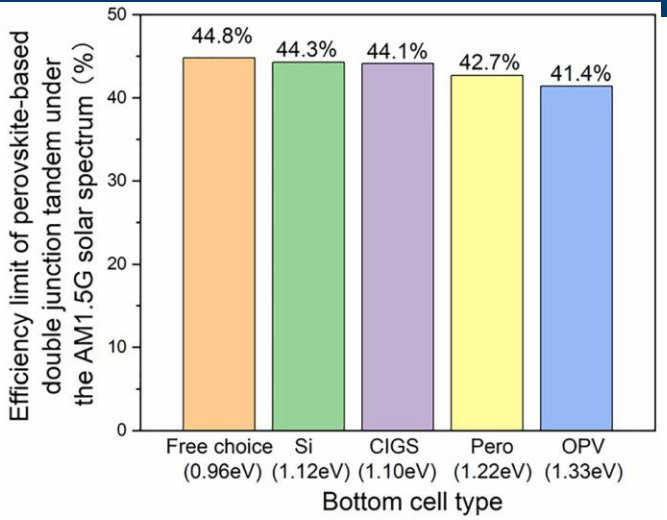
Perovskite for tandem solar cells

Efficiency limit of various perovskite-based tandem solar cells

(a)



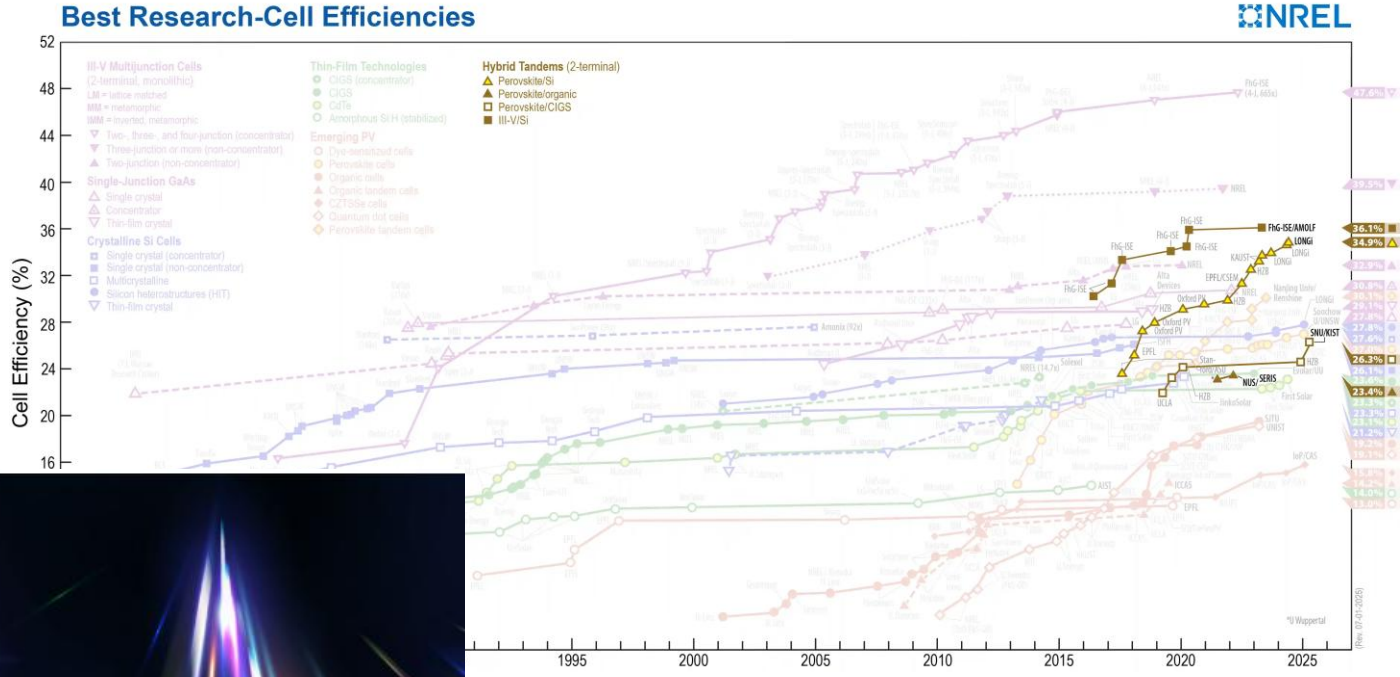
(b)



(c)

Bottom Cell Type	Low bandgap(eV)	High bandgap (eV)	Open Circuit Voltage V_{OC} (V)	Short Circuit Current J_{SC} (mA/cm^2)	PCE (%)
Free choice	0.96	1.63	2.032	24.6	44.8
Si	1.12	1.73	2.273	21.6	44.3
CIGS	1.10	1.72	2.246	21.8	44.1
Perovskite	1.22	1.81	2.441	19.3	42.7
OPV	1.33	1.88	2.609	17.4	41.4

Record tandem perovskite/Si cell

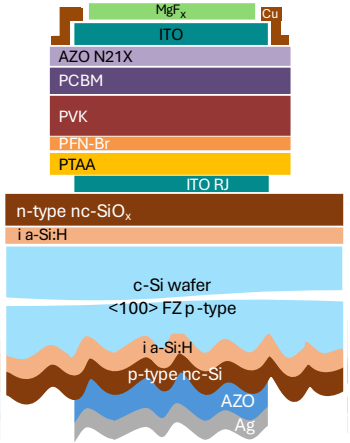


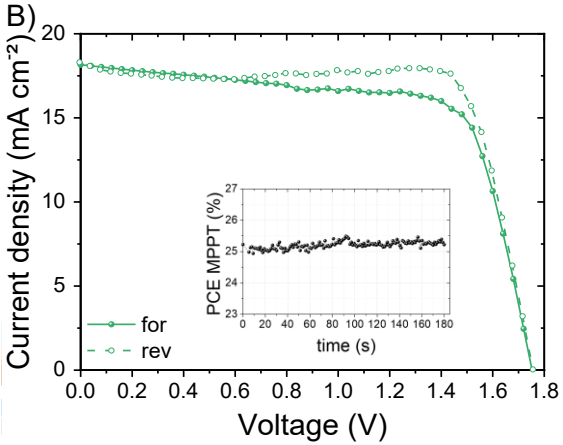
April, 2025 – LONGI record!

Tandem with efficiency higher than 30% also in Italy

2T perovskite/Si tandem solar cells

Monolithic

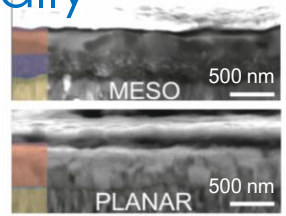


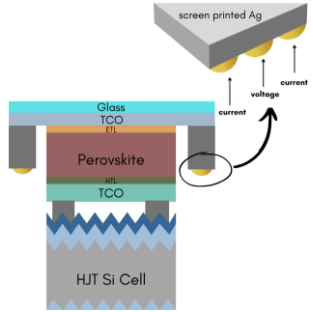


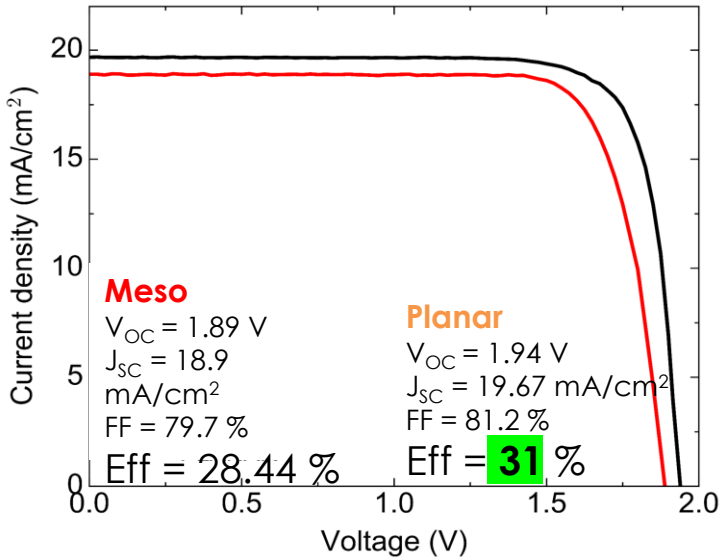
- No ALD, solution-processed buffer layer
- **25.3%** with two-step hybrid process (evap. + spin coating) for perovskite.

E. Magliano et al, ACS Applied Materials & Interfaces 17 (11), 2025

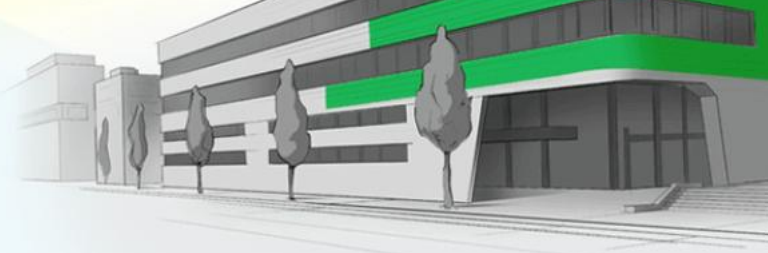
Mechanically stacked



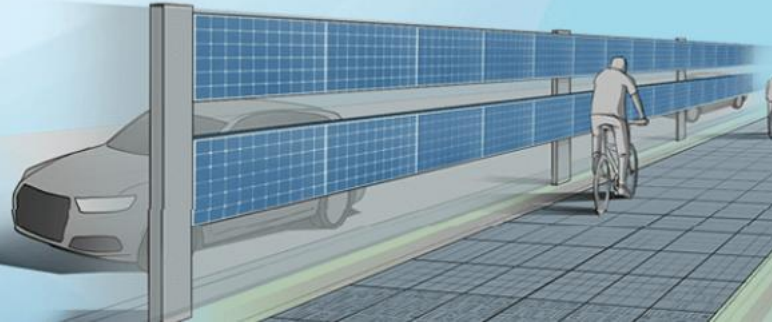




E. Nonni, Solar Energy Materials and Solar Cells, *Volume 29215, 2025*



INTEGRATED PHOTOVOLTAICS



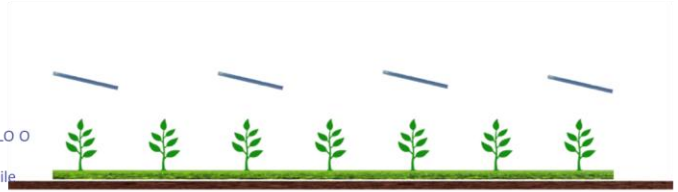
Standard Photovoltaic

Agrivoltaic

Agrivoltaic: Some definitions

Different levels of integration between FV and agriculture

AGRIVOLTAICO ELEVATO
(SISTEMI FISSI, A INSEGUIMENTO SU SINGOLO O DOPPIO ASSE)
Attività agricola su tutta la superficie disponile

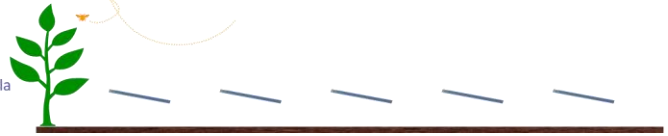


PNRR

AGRIVOLTAICO VERTICALE
Attività agricola su quasi tutta la superficie disponibile

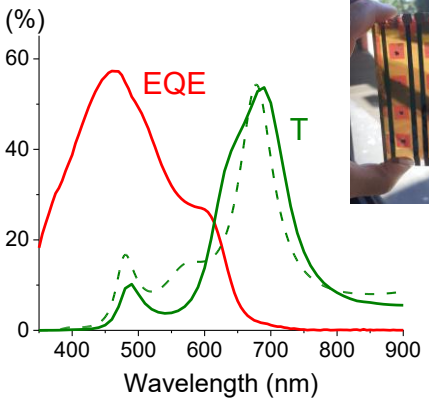
AGRIVOLTAICO INTERFILARE
Attività agricola solo nelle aree tra le file di moduli
$S_{agr} \geq 0.7\ S_{tot}$

FOTOVOLTAICO A TERRA (MITIGATO)
L'attività agricola, se esistente, è per assicurare la mitigazione degli impatti

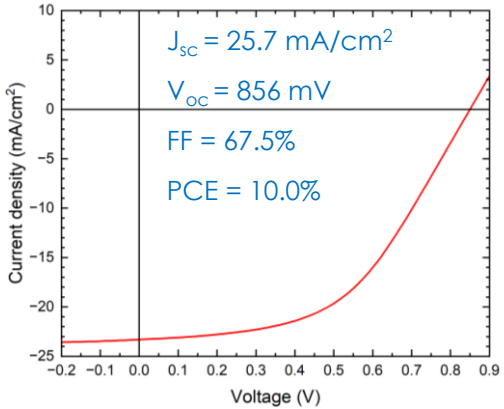


Some results from FV programme 2022-24: Agrivoltaics

Thin film Si



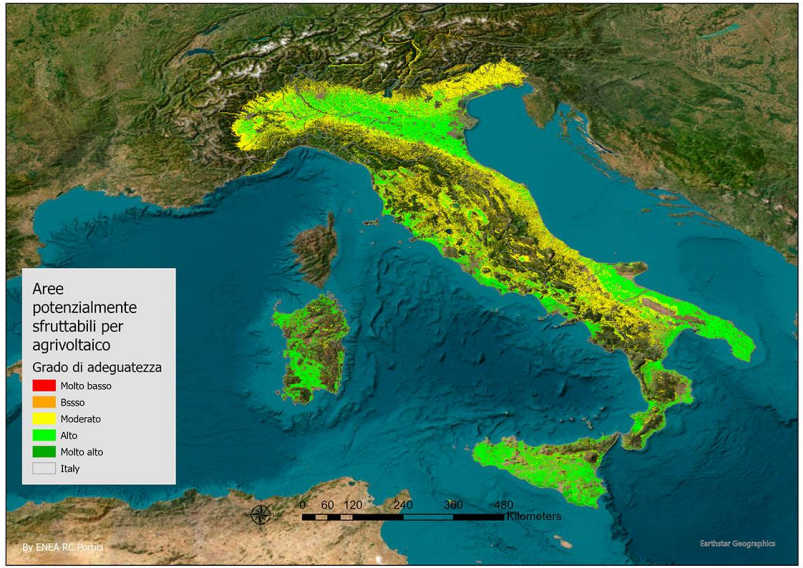
OPV



AgriPV demo ENEA18kW

Algovoltaic demo ENEA

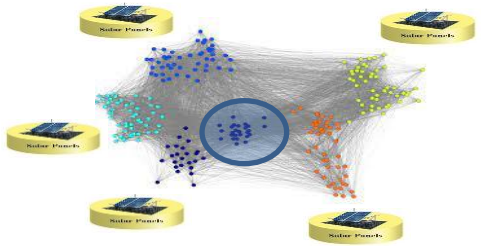
Optimizing PV plant energy production and ….where?



Spatial Multicriteria Analysis for a Regional Assessment of Eligible Areas for Sustainable Agrivoltaic Systems in Italy

G. Fattoruso at al.,Sustainability Volume 16 (2) 2024 Article number 911

Assessment of solar photovoltaic potential at an urban level at the scale of a single building



Diverging Behaviour Detection with GeoMetrics

Not only GW of installed power capacity but also and above all electricity produced (GWh)

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