First Modern Solar Cell, 1954, Museum of Solar Energy

Current trends in PV deployment and technology

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PATHFNDR Lunch Talk - 28 June, 2024

Leaders | The solar age

The exponential growth of solar power will change the world

An energy-rich future is within reach

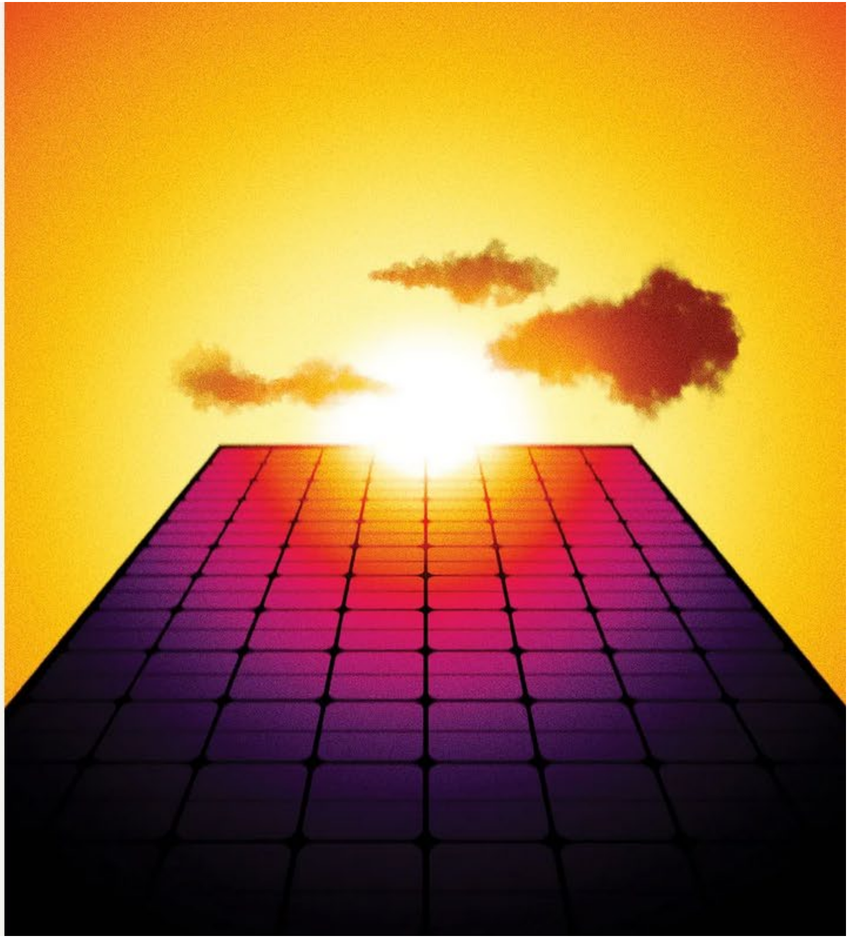


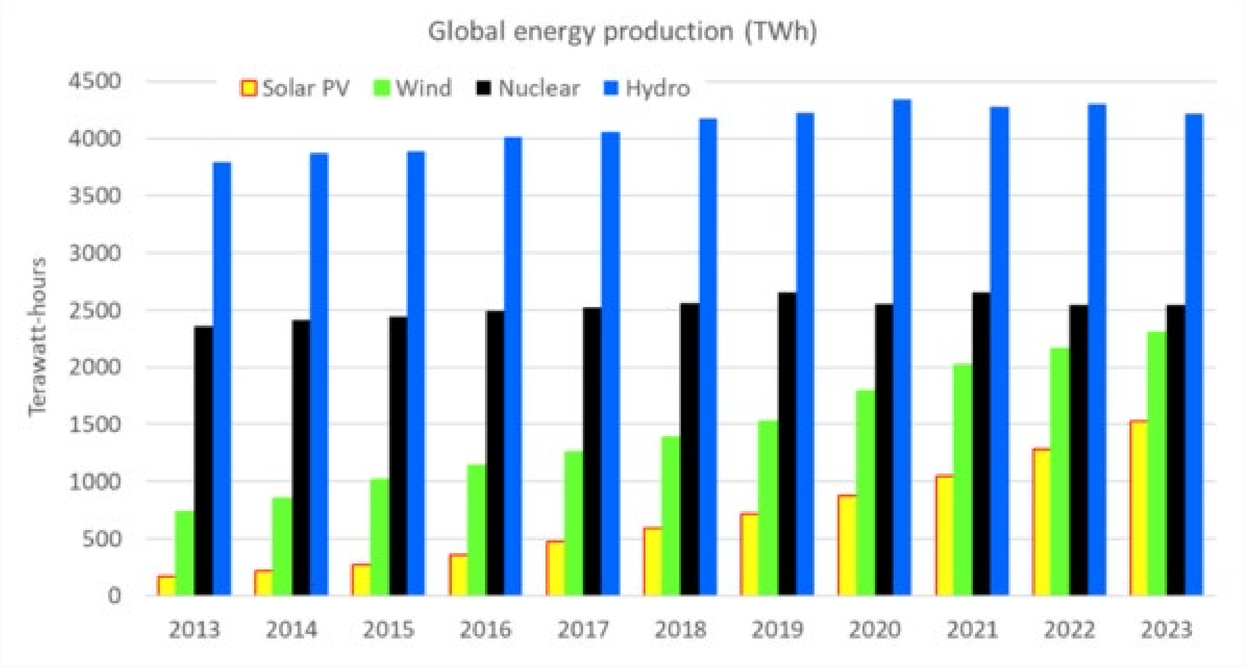
image: La Boca

The Economist, June 20th, 2024

Solar energy production can soon pass nuclear, hydro

Despite its relatively *low capacity factor*, solar generation is tracking to surpass

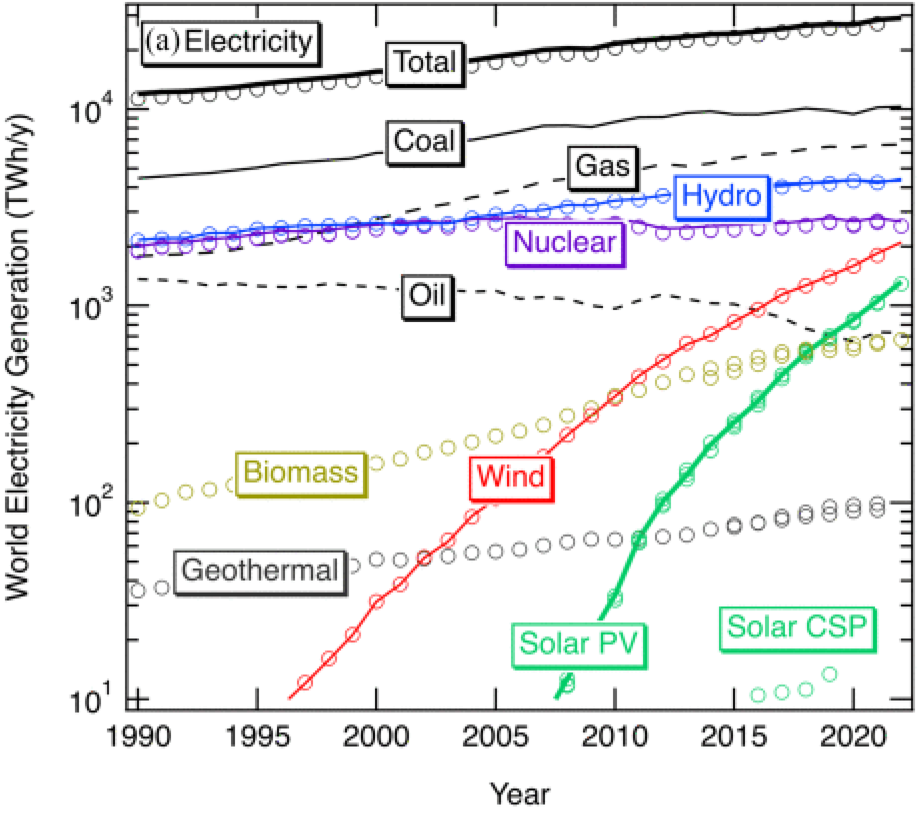
- **nuclear** in **2026**
- **wind** in **2027**
- **hydro** in **2028**
- **gas** in **2030**
- and **coal** in **2032**.



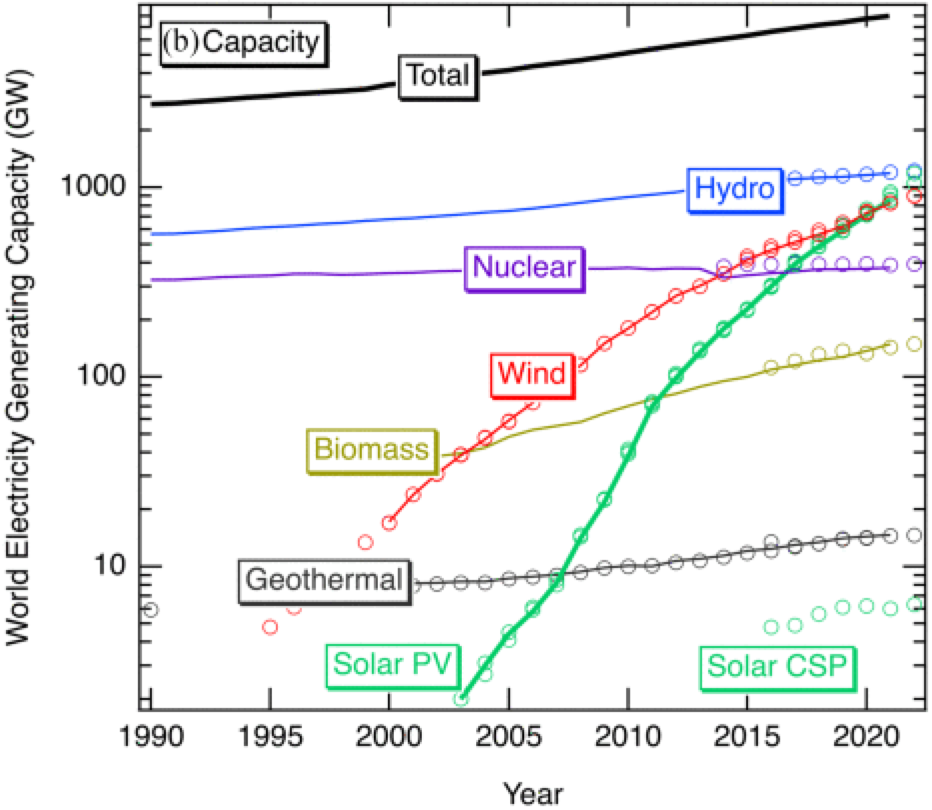
Source: R. Rüther and A Blakers, pv magazine, May 20, 2024

Solar capacity has already surpassed nuclear, hydro

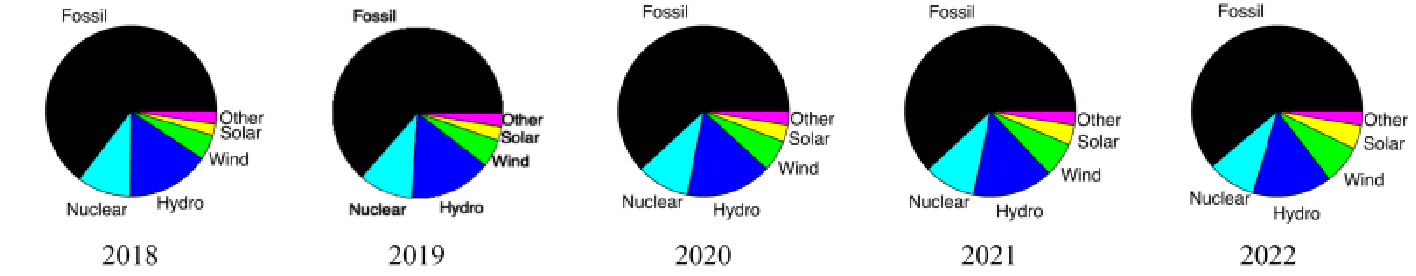
Electricity



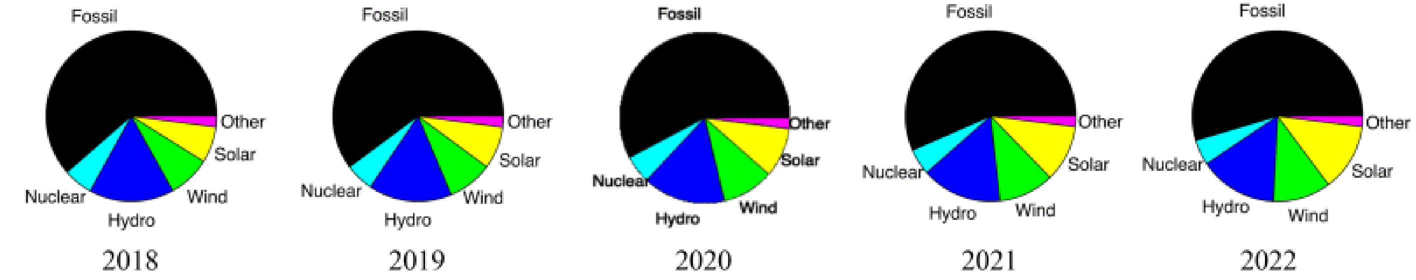
Capacity



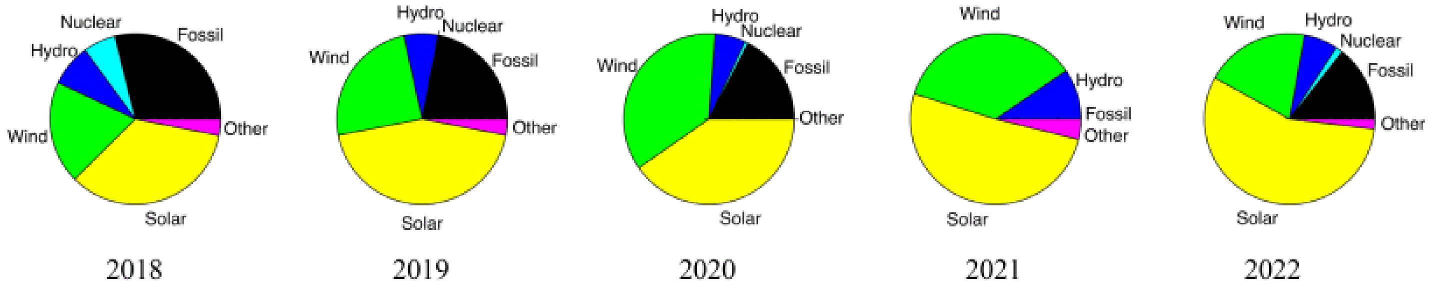
Source: N. M. Haegel and S. R. Kurtz, *IEEE Journal of Photovoltaics*, 13 (6), 2023



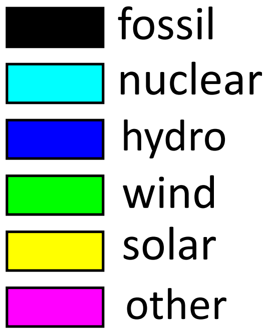
electricity generation



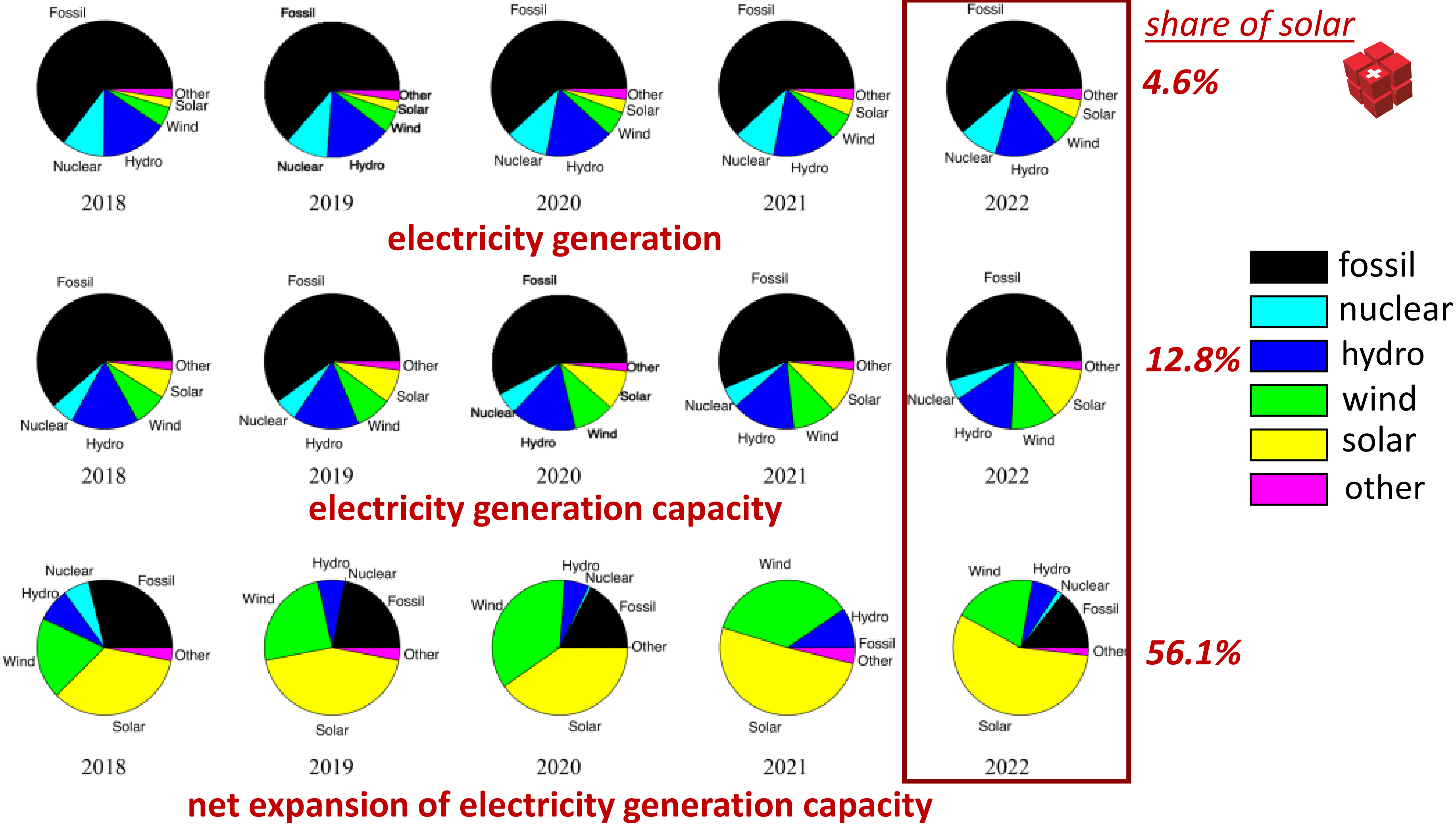
electricity generation capacity



net expansion of electricity generation capacity

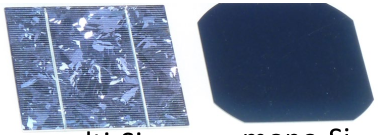


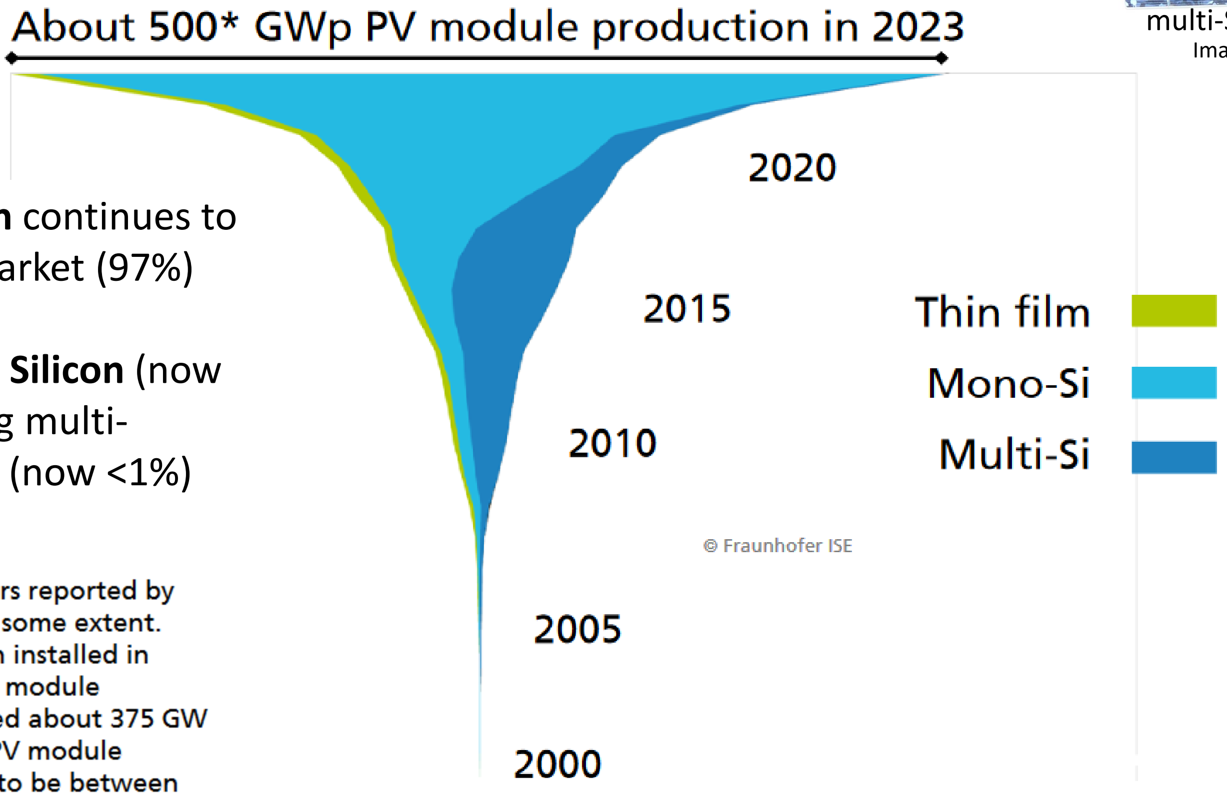
Source: N. M. Haegel and S. R. Kurtz, *IEEE Journal of Photovoltaics*, 13 (6), 2023



Source: N. M. Haegel and S. R. Kurtz, *IEEE Journal of Photovoltaics*, 13 (6), 2023

PV market share by technology





2023* share

Thin film *2.6%*

Mono-Si *96.6%*

Multi-Si *0.8%*

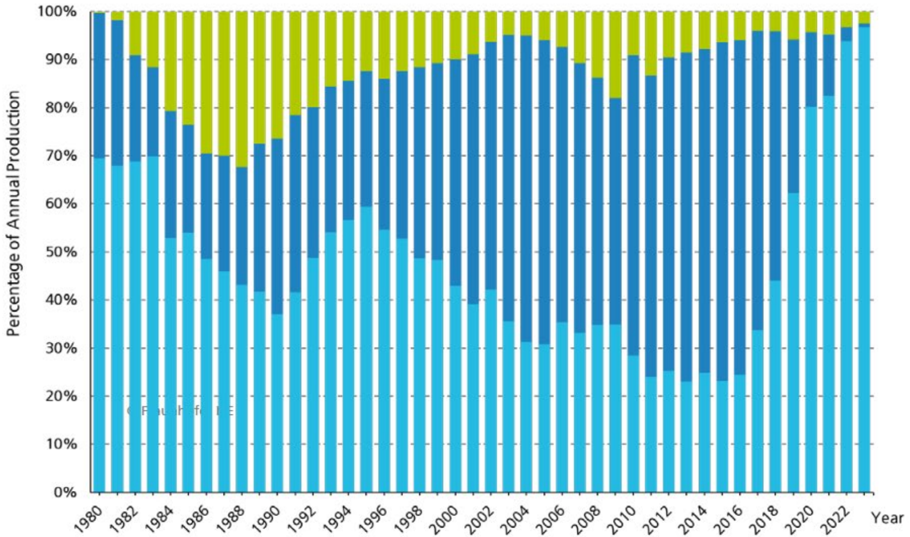
Crystalline Silicon continues to dominates the market (97%)

mono-crystalline Silicon (now 96.6%) overtaking multi-crystalline Silicon (now <1%)

*2023 production numbers reported by different analysts vary to some extent. About 410 GW have been installed in 2023 globally. The TOP10 module producer together shipped about 375 GW PV panels in 2023. Total PV module shipments are estimated to be between 460 and 502 GW in 2023.

Source: Fraunhofer ISE

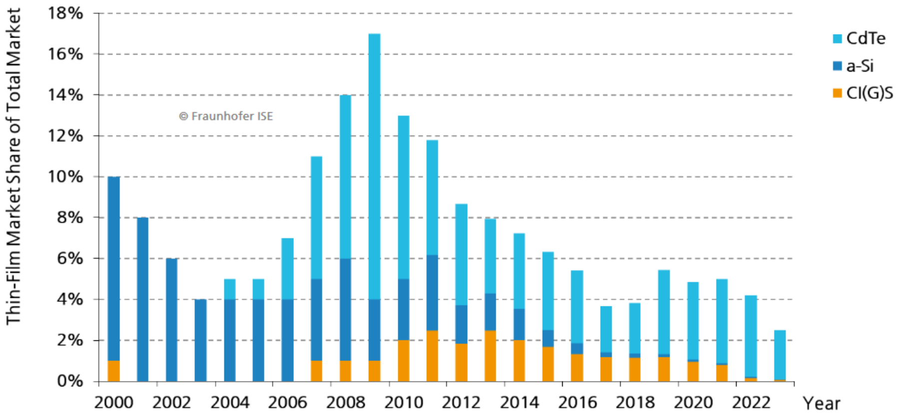
PV market share by technology



Production 2023* (GWp)		
Thin film	13	
Multi-Si	4	
Mono-Si	485	
Total	502	(ITRPV)

*estimated numbers

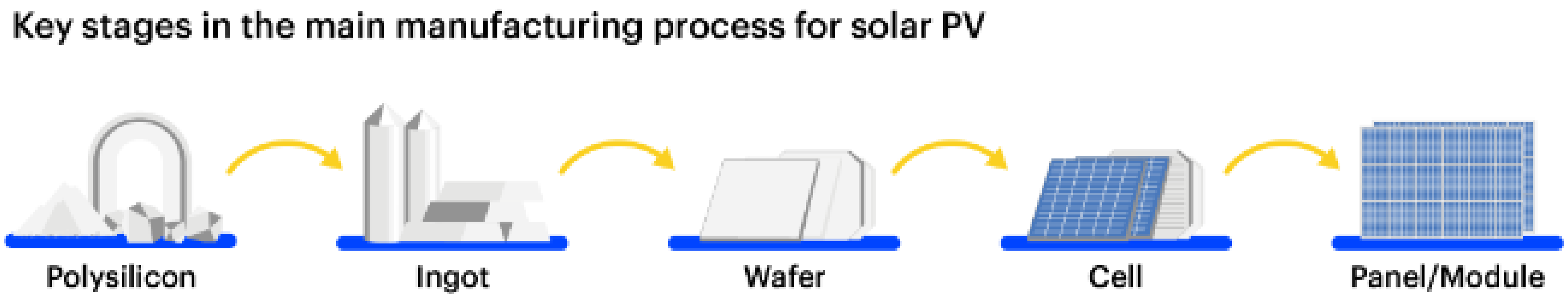
Evolution of the market share from 1980 to 2023
Fall of thin film and multi-Si technologies and the re-emergence of mono-Si due to improvements in wafer fabrication and increased efficiencies



In thin film, amorphous silicon is steadily replaced by cadmium telluride (CdTe) and CI(G)S (copper indium gallium disellenide) technologies due to their higher efficiencies

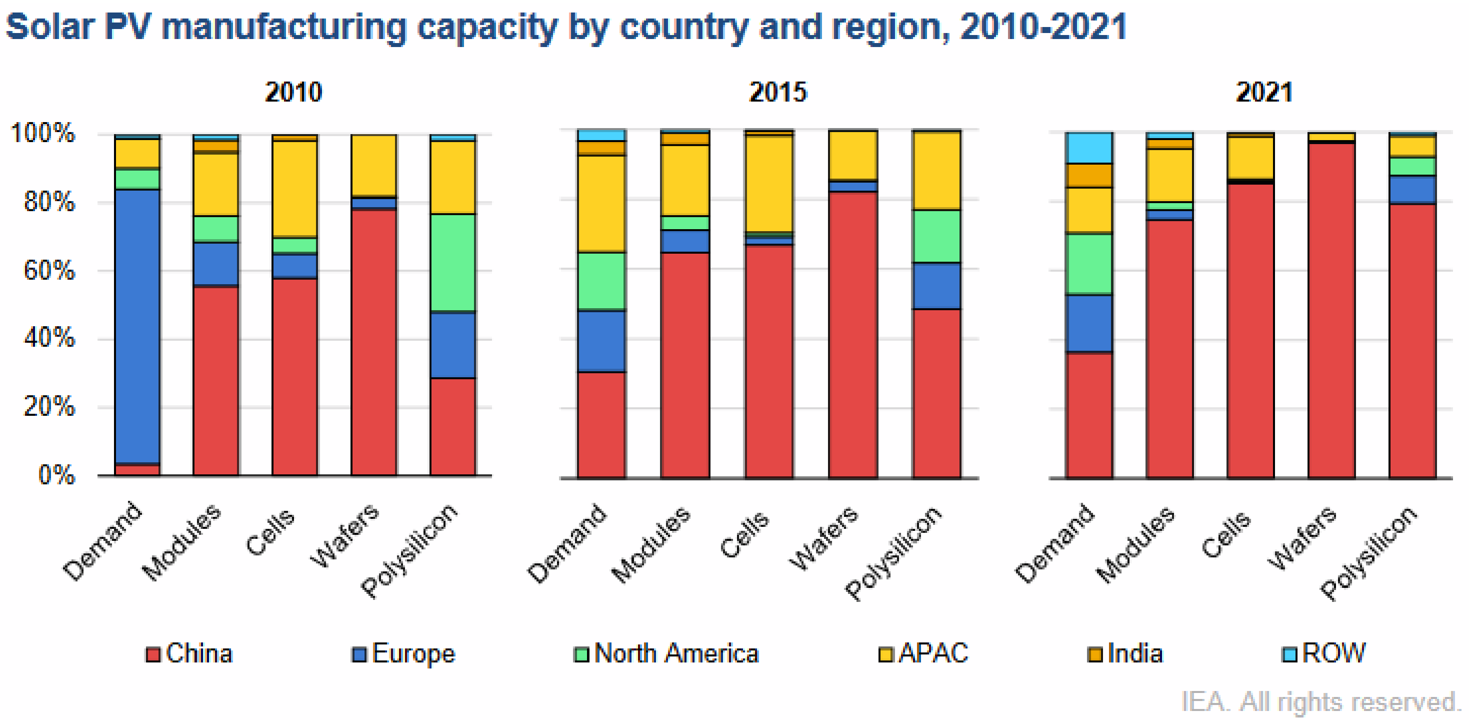
Source: Fraunhofer ISE

Stages in the manufacturing process of c-Si PV



Source: IEA

PV market share by process and country

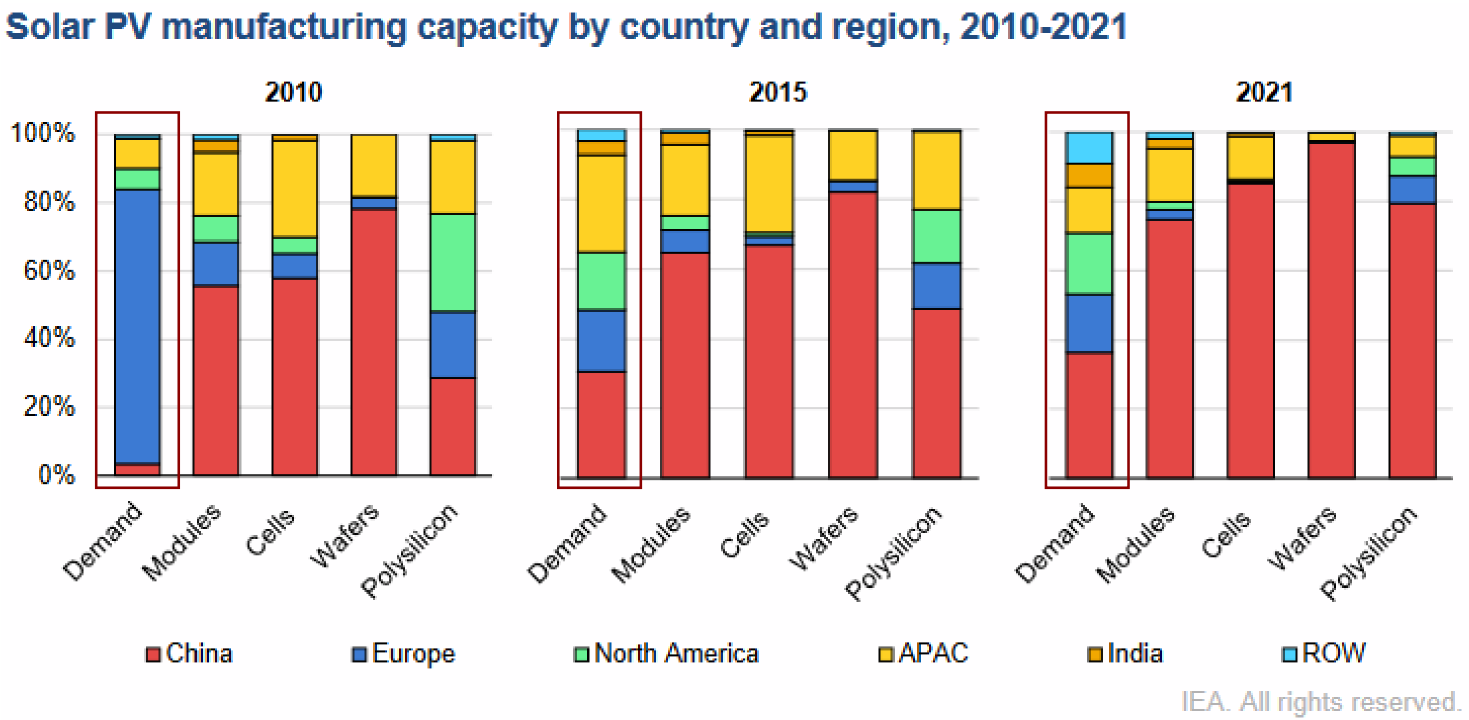


Notes: APAC = Asia-Pacific region excluding India. ROW = rest of world.

Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

Source: IEA

PV market share by process and country



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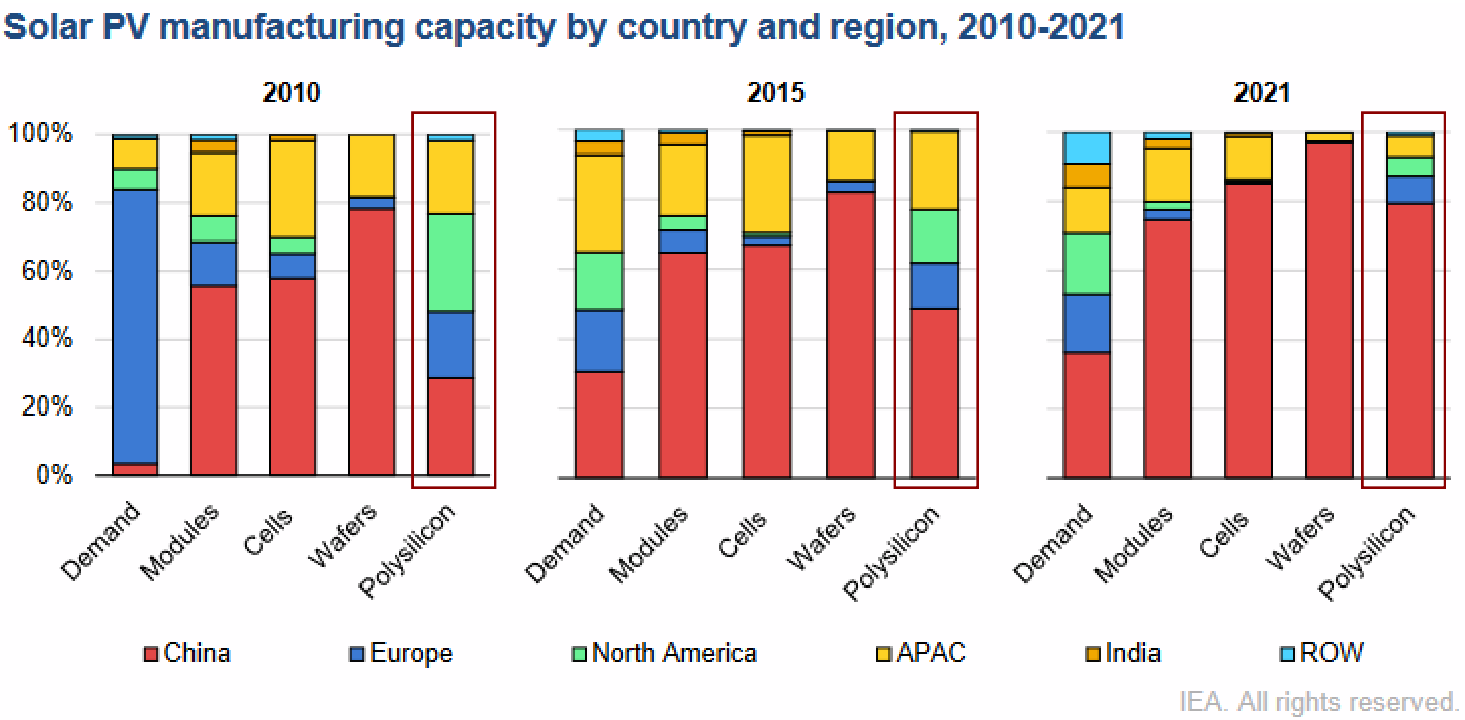

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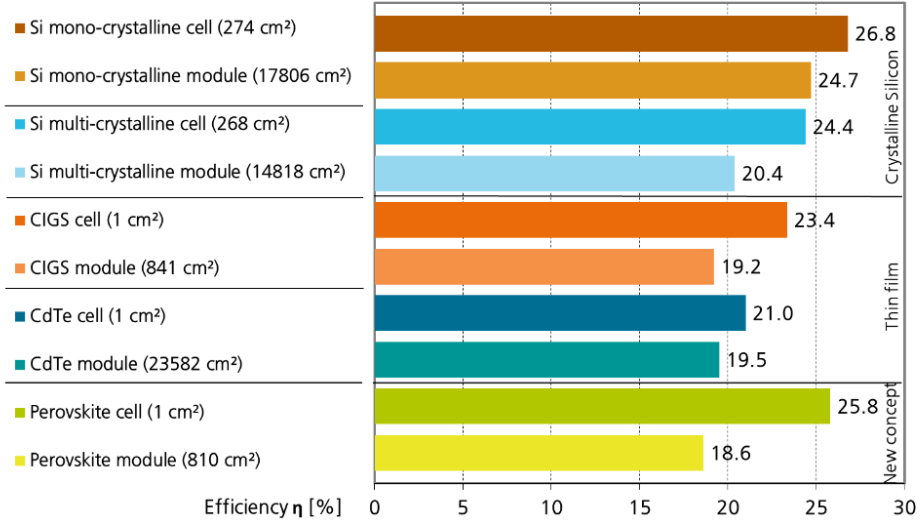
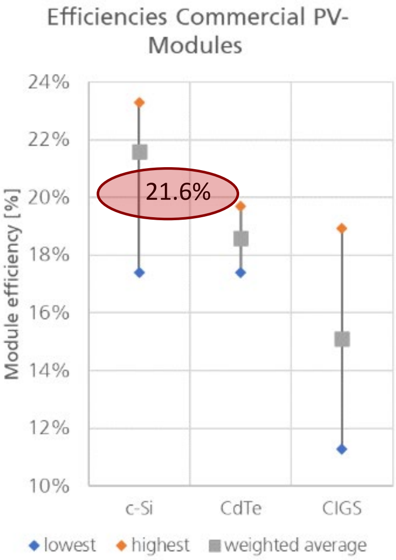
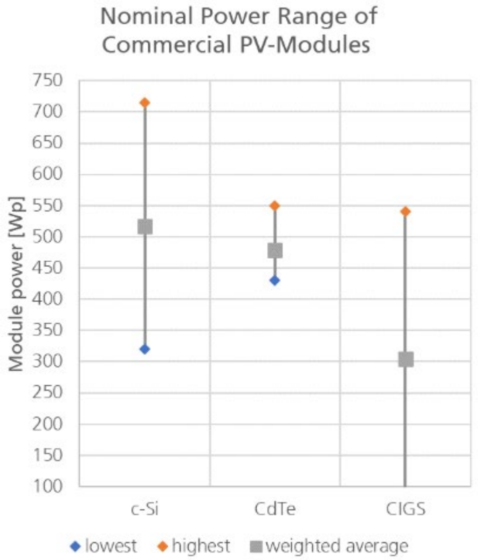
Source: IEA

PV performance in the lab and on the market

Efficiency comparison of technologies (best lab cell vs. module)





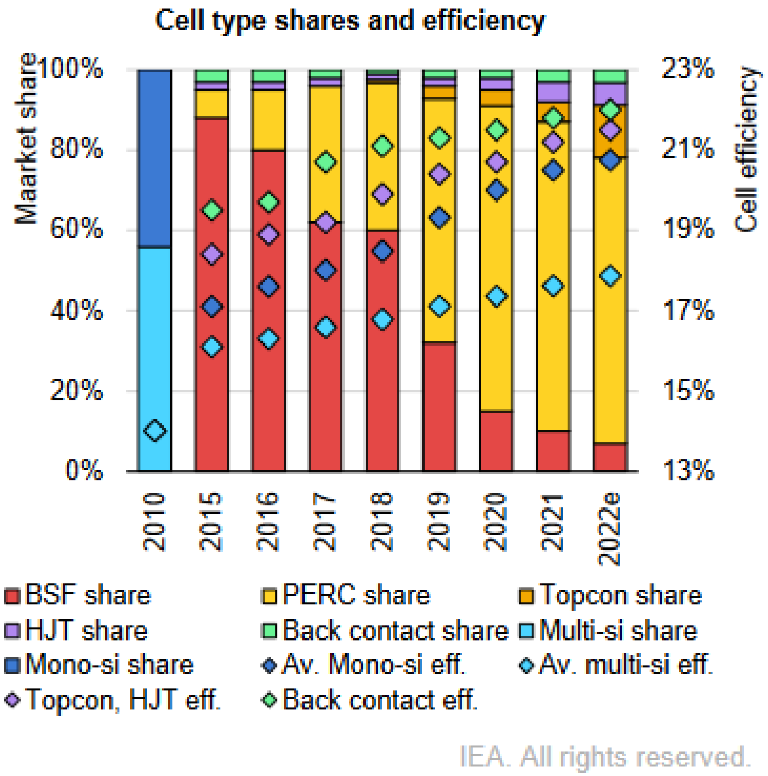


Data: Green et al.: Solar Cell Efficiency Tables (Version 63), Progress in PV: Research and Applications 2023. Graph: PSE Projects GmbH 2024. Date of data: 10/2023

- Trends observed in laboratories don't often follow the trends observed in production
(e.g. CIGS solar cells in production are performing worse than CIGS solar cells in the lab compared to CdTe)
- Large range of efficiencies for commercial Si modules (many manufacturers) compared to CdTe (smaller number of plants)

Source: Fraunhofer ISE

PV market shares and efficiencies by cell type



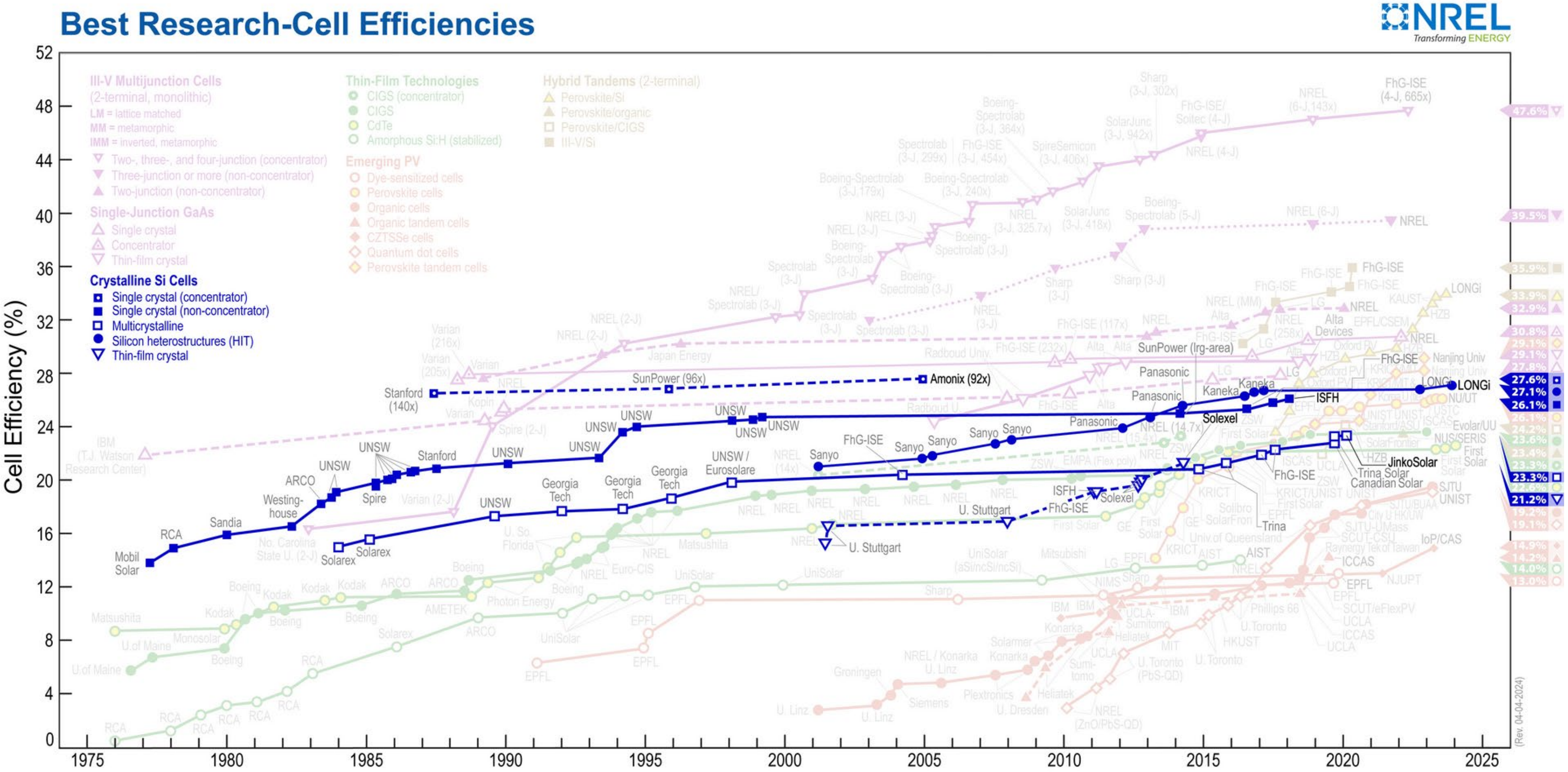
Since 2015, average cell efficiencies have increased from 17% to 21%

Advanced cell design are expected to increase their shares in the future with cell efficiencies >22%

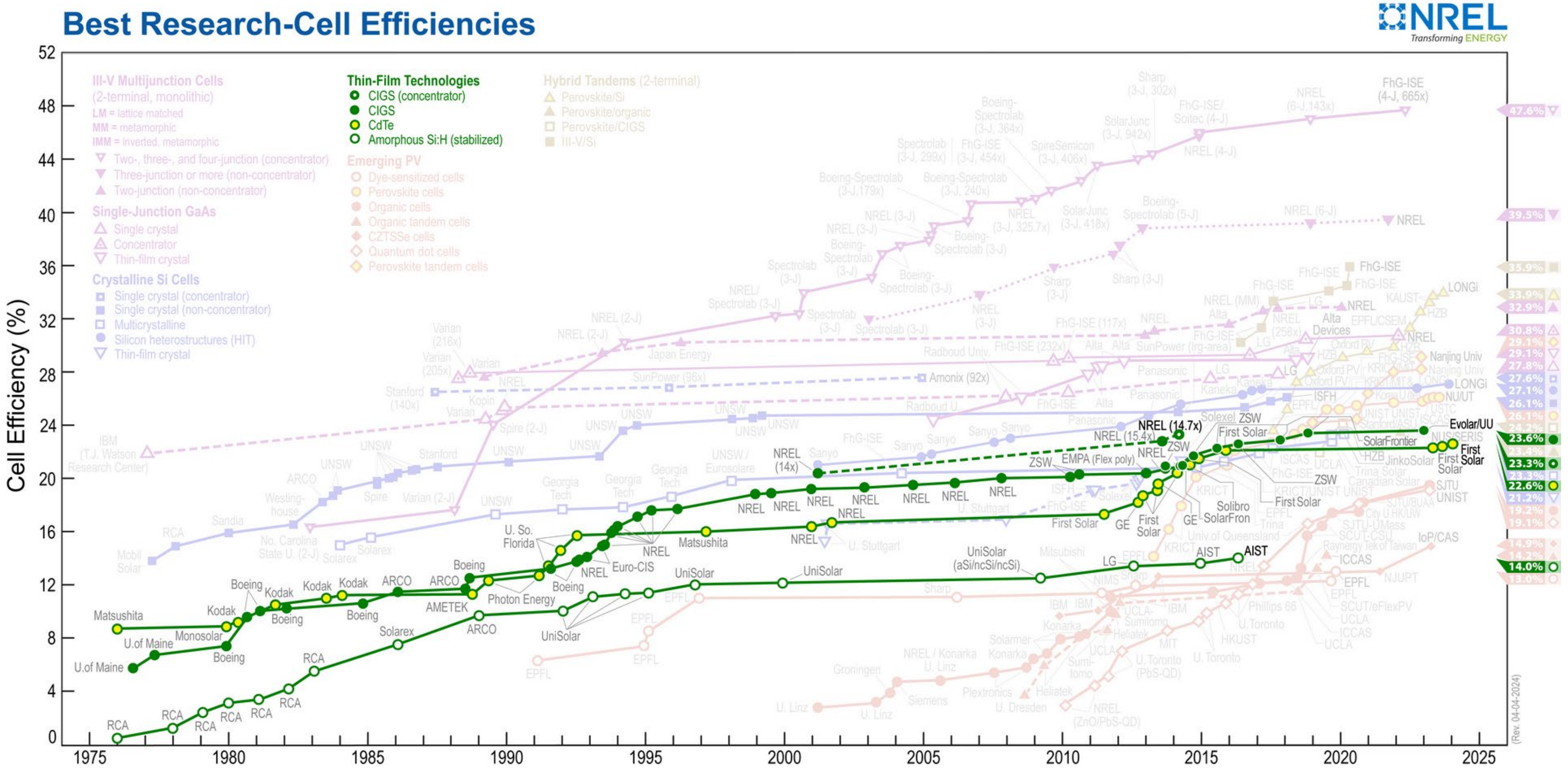
BSF = Back surface field
PERC = Passivated Emitter and Rear Cell
TOPCon = Tunnel Oxide Passivated Contact

Source: IEA

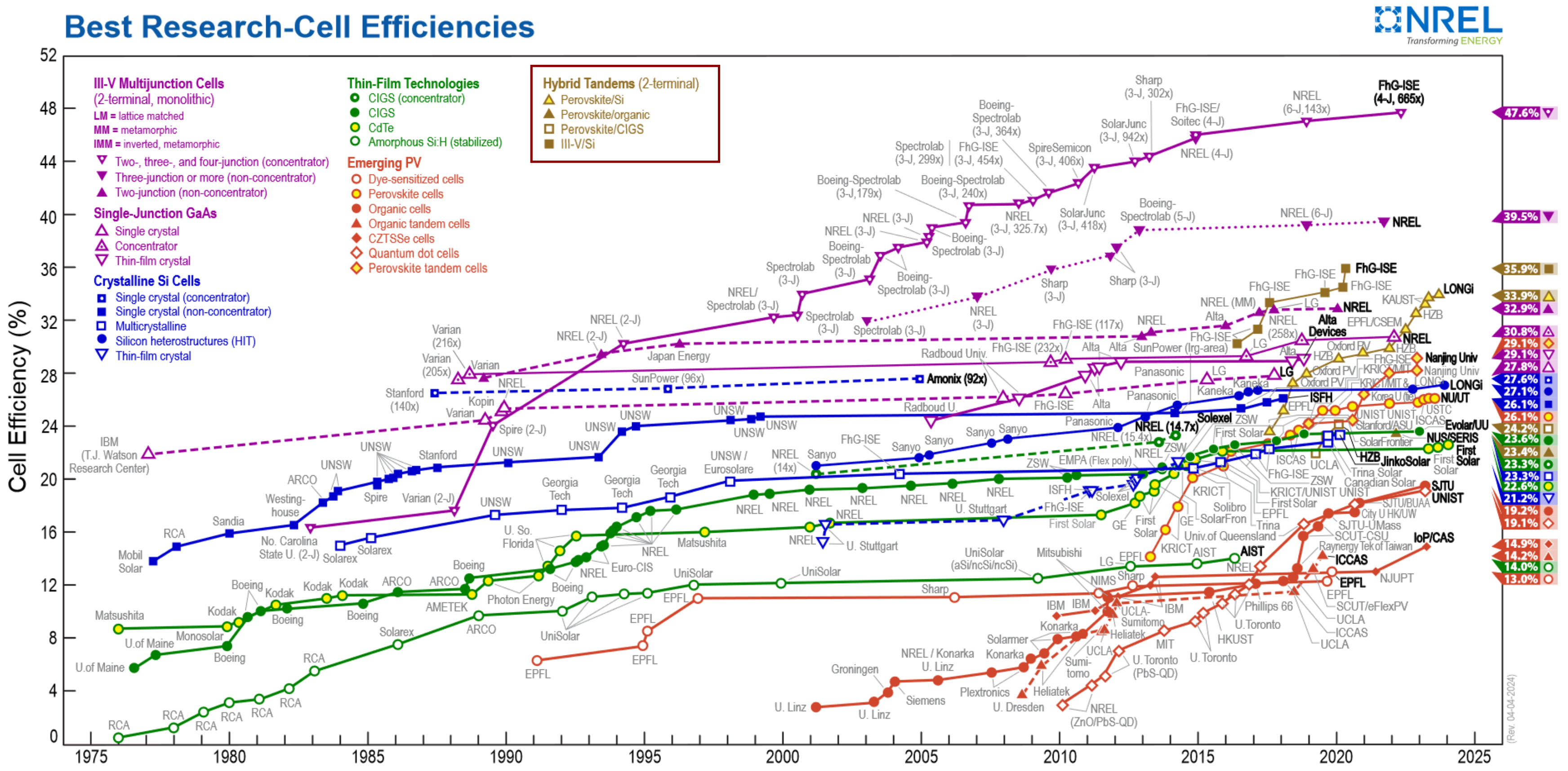
Crystalline Si Cells



Thin-film technologies

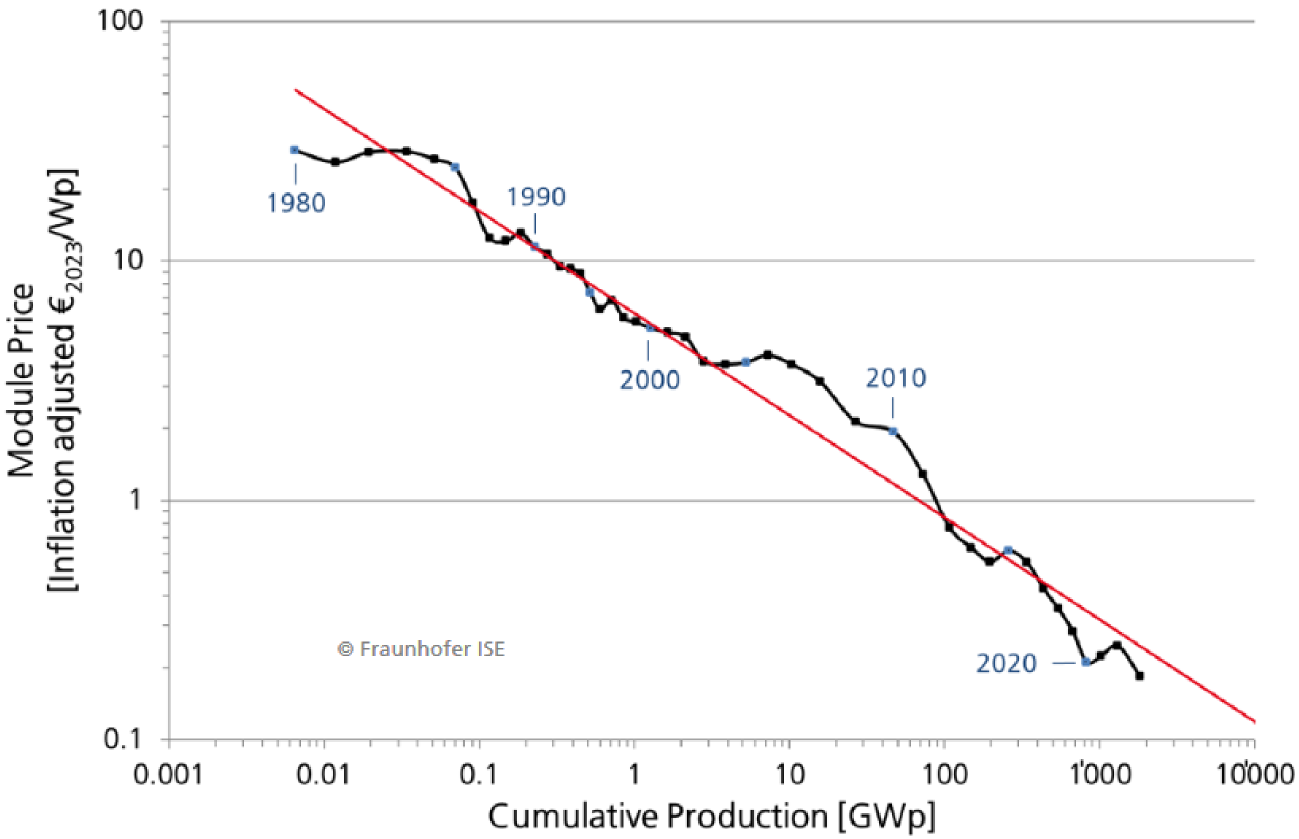


PV Breakthroughs in the Lab



Source: NREL

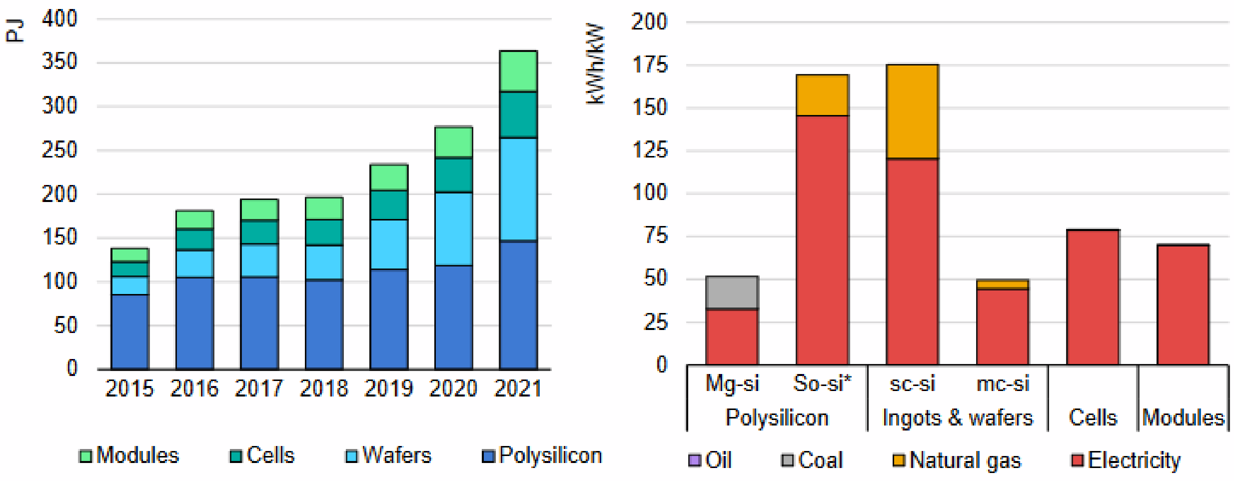
PV cost evolution



Source: Fraunhofer ISE

PV production energy demand

Energy consumption of solar PV manufacturing by segment, 2015-2021 (left), and energy intensity per segment (right)



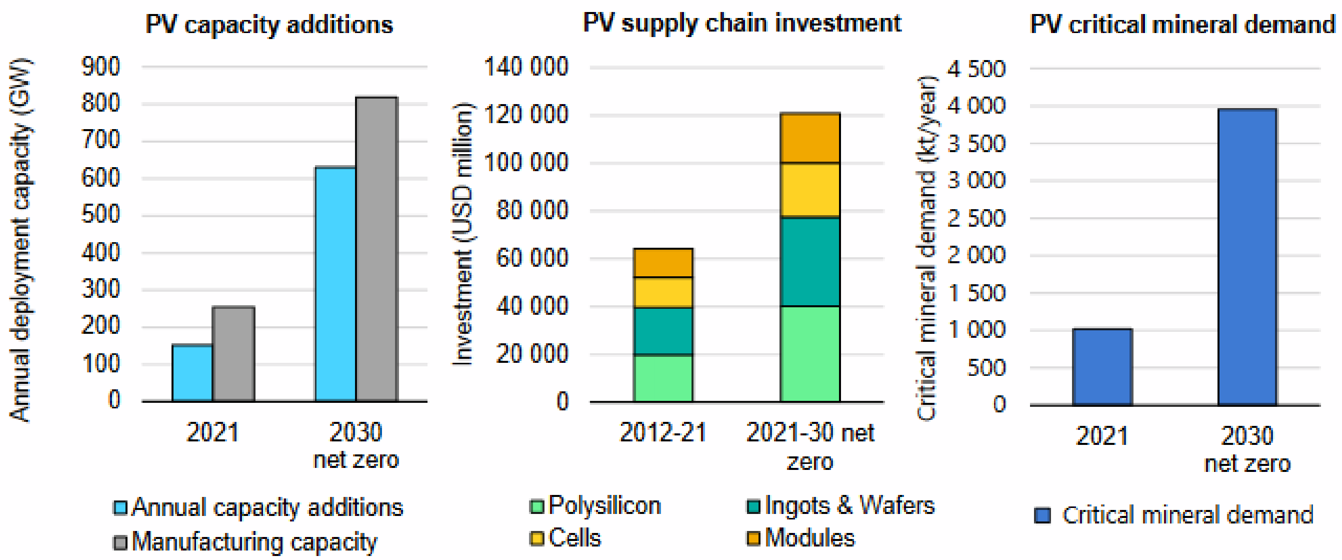
Notes: Mg-si = metallurgical-grade silicon. So-si* = solar-grade silicon using the Siemens process. sc-si = monocrystalline wafers. mc-si = multicrystalline wafers.

Source: Right graph: IEA-PVPS (2020).

Source: IEA

PV market expansion needed to reach Net Zero

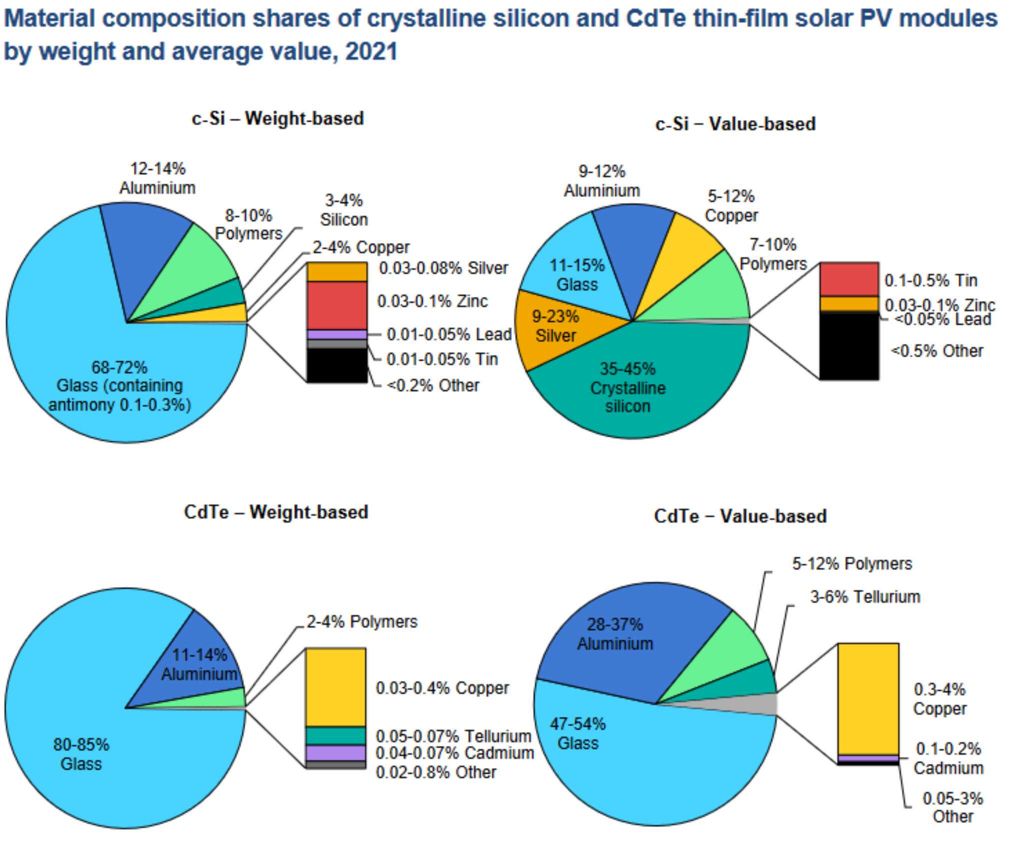
Solar PV capacity additions (left), supply chain investment (centre) and mineral demand (right), 2021 and 2030 under the IEA Net Zero by 2050 Scenario



Sources: Left graph: IEA (2021f). Centre graph: IEA analysis based on BNEF (2022b), PVPS, PV InfoLink, SPV and RTS PV. Right graph: IEA (2021d).

Source: IEA

PV critical material demand

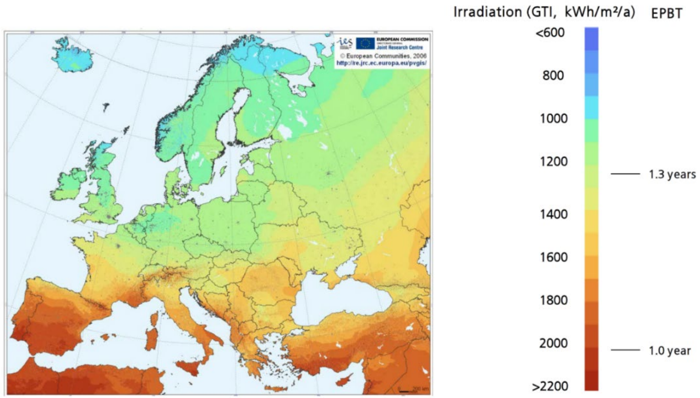


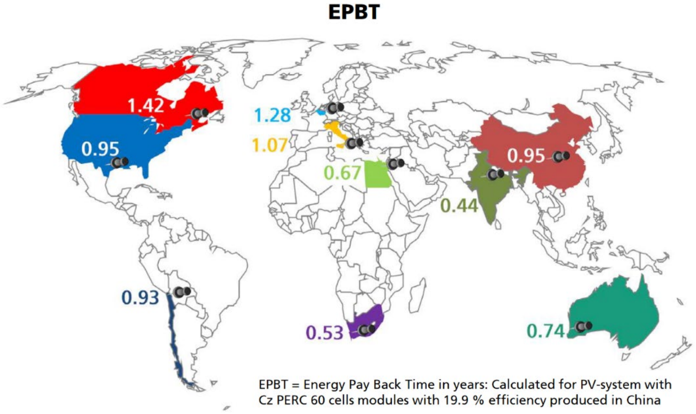
Notes: Calculations of value-based composition are based on average 2021 market prices of materials, i.e. aluminium: USD 2 500/Mt; copper: USD 9 408/Mt; silver: USD 803/kg; crystalline silicon: USD 34/kg; and solar-grade glass: USD 590/Mt. Value-based assessments are sensitive to currently high commodity price volatility.

Sources: Estimates of material composition based on Soren (2022), Frischknecht et al. (2020), Carrara et al. (2020), Giurco et al. (2019), IRENA (2017), World Bank (2017), IRENA and IEA-PVPS (2016), Latunussa et al. (2016), Fizaine and Court (2015), Elshkaki and Graedel (2013), and Candelise et al. (2011). Material prices are derived from USGS (2022) and Bloomberg (2022a).

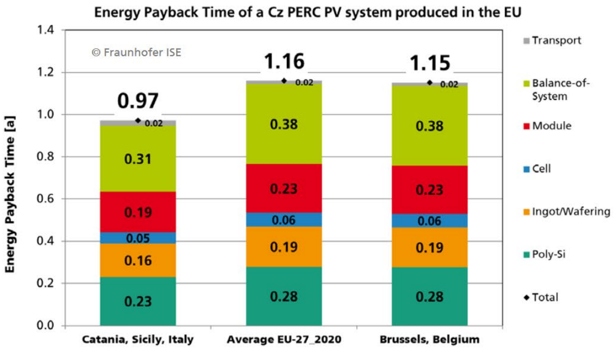
Source: IEA

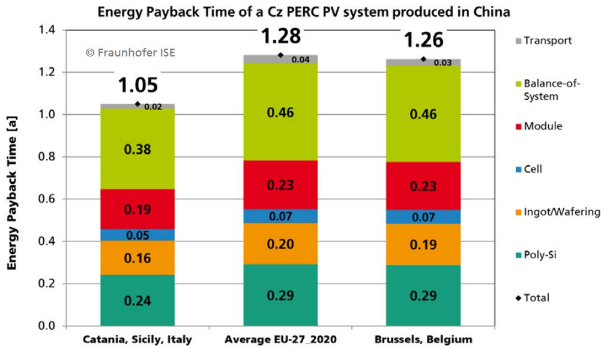
Embodied energy and Energy payback time (EPBT)





Energy payback time varies between 0.5 – 1.5 years depending on installation location

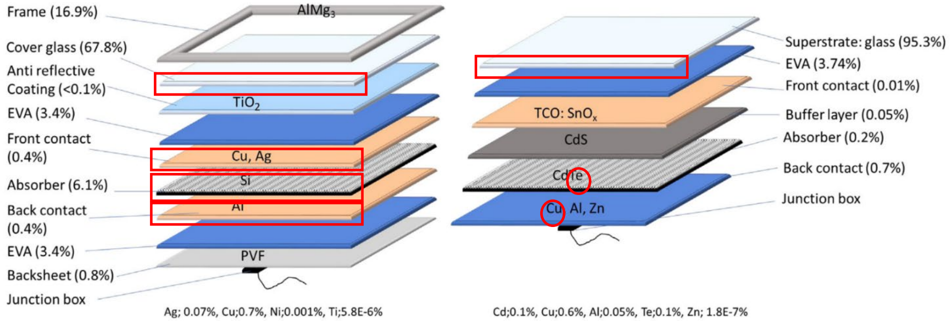




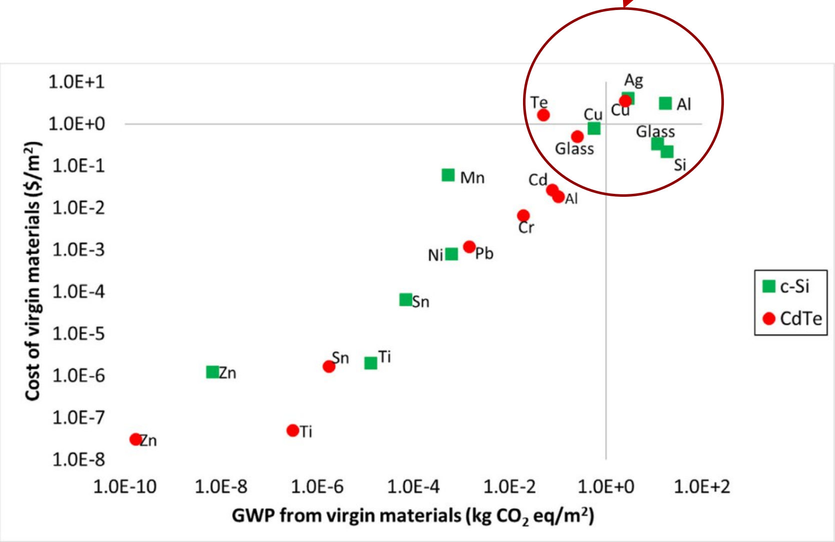
Manufacturing location (specifically the country's energy mix) impacts the energy payback time

Source: Fraunhofer ISE

Recyclability of solar PV panels



focus on expensive and impactful materials



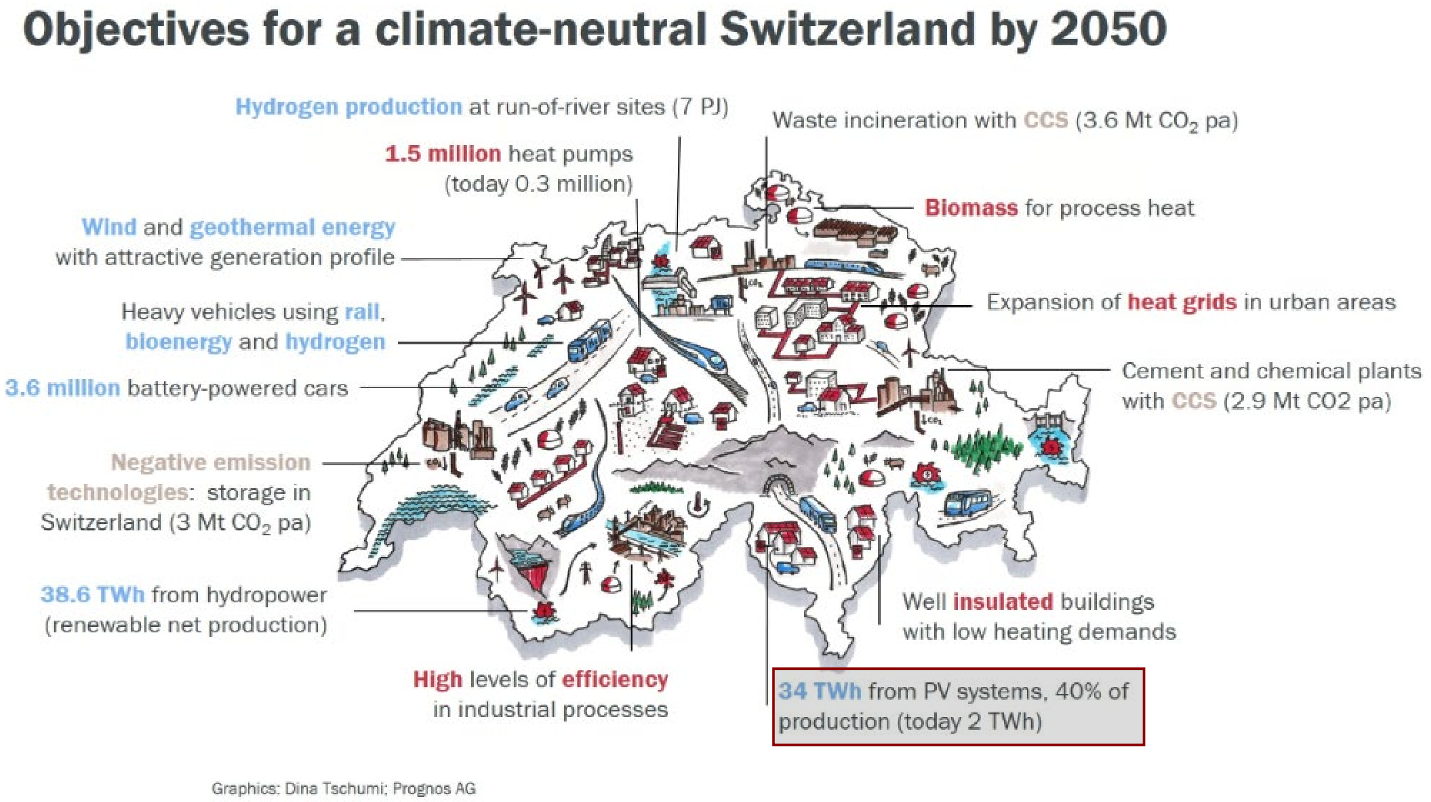
In practice:

- *First solar*: manufacturer of CdTe solar cells with end-of-life (EoL) recycling claiming 90% material recovery (link)
- *Veolia*: recycling of c-Si solar PV modules at EoL claiming 95% material recovery (link)

Source: Maani et al., *Sci. Total Environ.*, 2020, 735, 138827

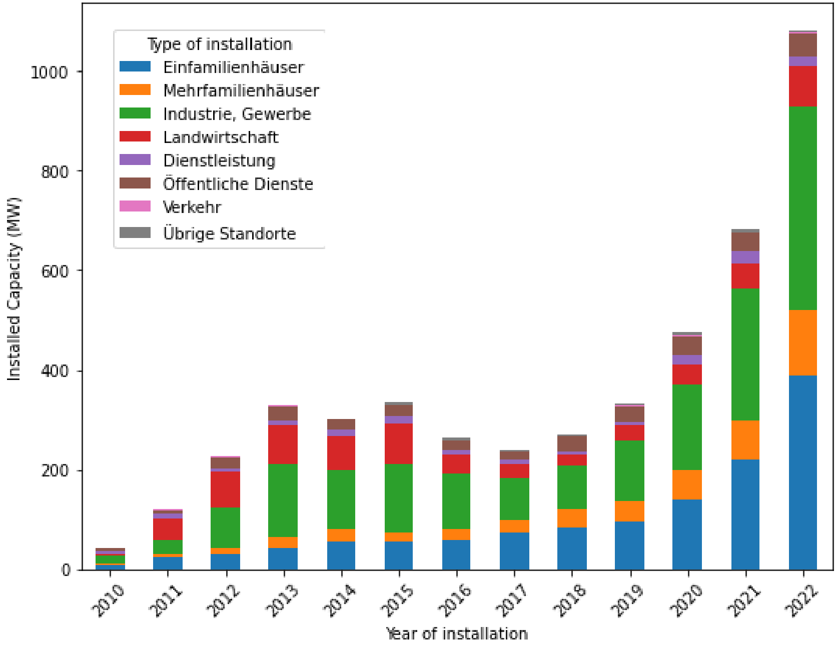
PV in Switzerland

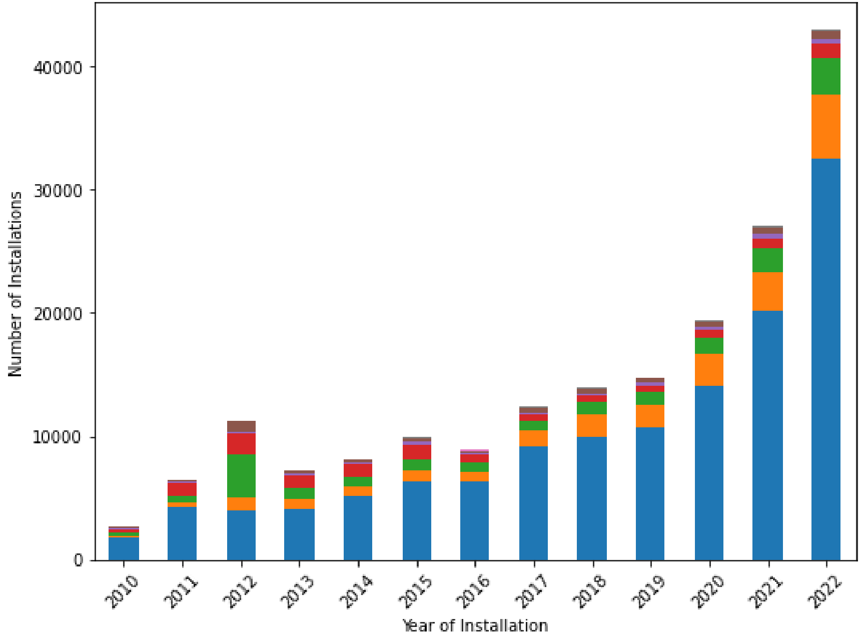
The energy perspective for Switzerland is solar



Switzerland: photovoltaics installations on a smaller scale

Annual installation capacity in Switzerland from 2010

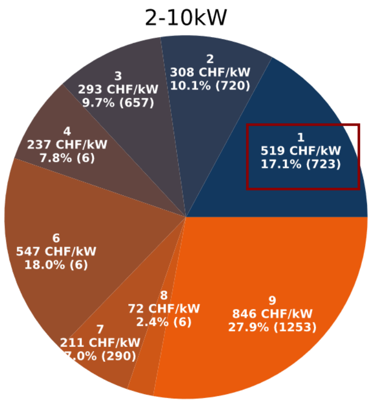


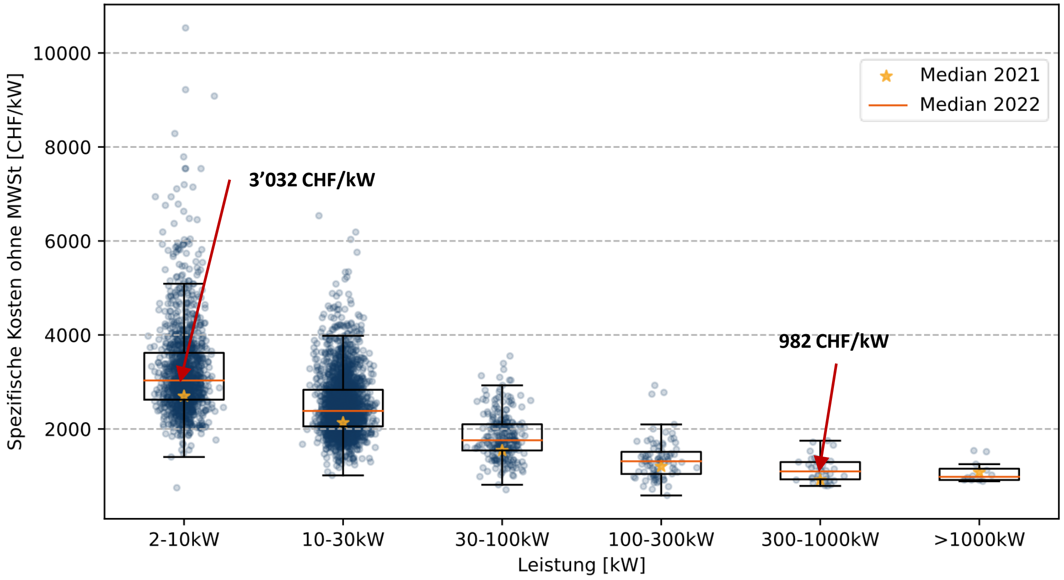


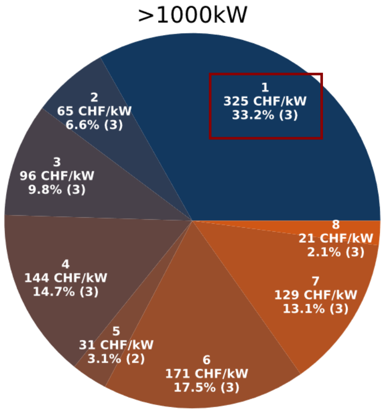
Swiss PV installations met 6.7 % of total demand in 2022, with 10% projected for 2024.
Large portion of installation is coming on residential and non-residential buildings, as opposed to utility-scale.

Source: BFE, Statistik Sonnenenergie, 2010-2022

Size-dependence PV cost







- 1 Module
- 2 Wechselrichter
- 3 Montagesystem
- 4 Elektromaterial
- 5 Baustellenabsicherung und permanente Sicherheitsmassnahmen
- 6 Arbeitskosten
- 7 Verwaltung und Planung
- 8 Logistik und Transport
- 9 Sonstige

EnergieSchweiz 2023, Photovoltaikmarkt: Preisbeobachtungsstudie 2022

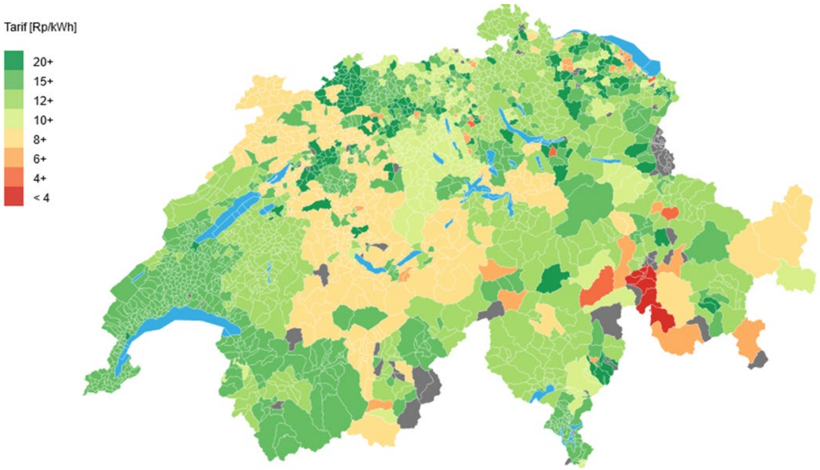
Disturbances in the supply chain can lead to price increase

	Median Spezifische Kosten [CHF/kW]					Veränderung im Vergleich zum Vorjahr			
Leistungsbereich [kW]	2018	2019	2020	2021	2022	2019	2020	2021	2022
2-10	2953	2914	2692	2696	3032	-1%	-8%	0%	12%
10-30	2214	2201	2071	2131	2384	-1%	-6%	3%	12%
30-100	1589	1466	1407	1529	1759	-8%	-4%	9%	15%
100-300	1236	1217	1132	1202	1312	-2%	-7%	6%	9%
300-1000	1016	990	919	913	1097	-3%	-7%	-1%	20%
>1000		777	819	1075	982		5%		-9%

EnergieSchweiz 2023, Photovoltaikmarkt: Preisbeobachtungsstudie 2022

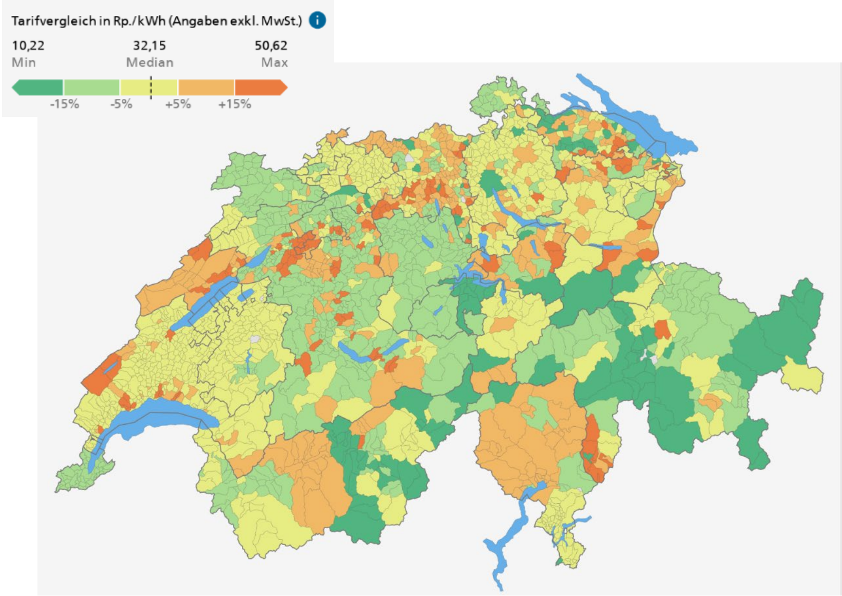
Economic viability of PV: feed-in and electricity tariffs

Feed-in tariff



https://www.vese.ch/pvtarif/

Electricity tariff



https://www.strompreis.elcom.admin.ch/

PV technology in the context of the building sector

- *How long is the emission payback time?*
  - What are the embodied emissions for a particular PV technology?
  - What is the grid intensity when importing to the grid? What is the grid intensity when exporting from the grid?

- *How adapted is a particular technology to the building context?*
  - Building-applied or building-integrated?
  - Ability to capture diffuse light vs. direct light?
  - Longevity?

Thank you for your attention

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