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A Commodity Today, Incompatible Tomorrow: the Paradox of PV?

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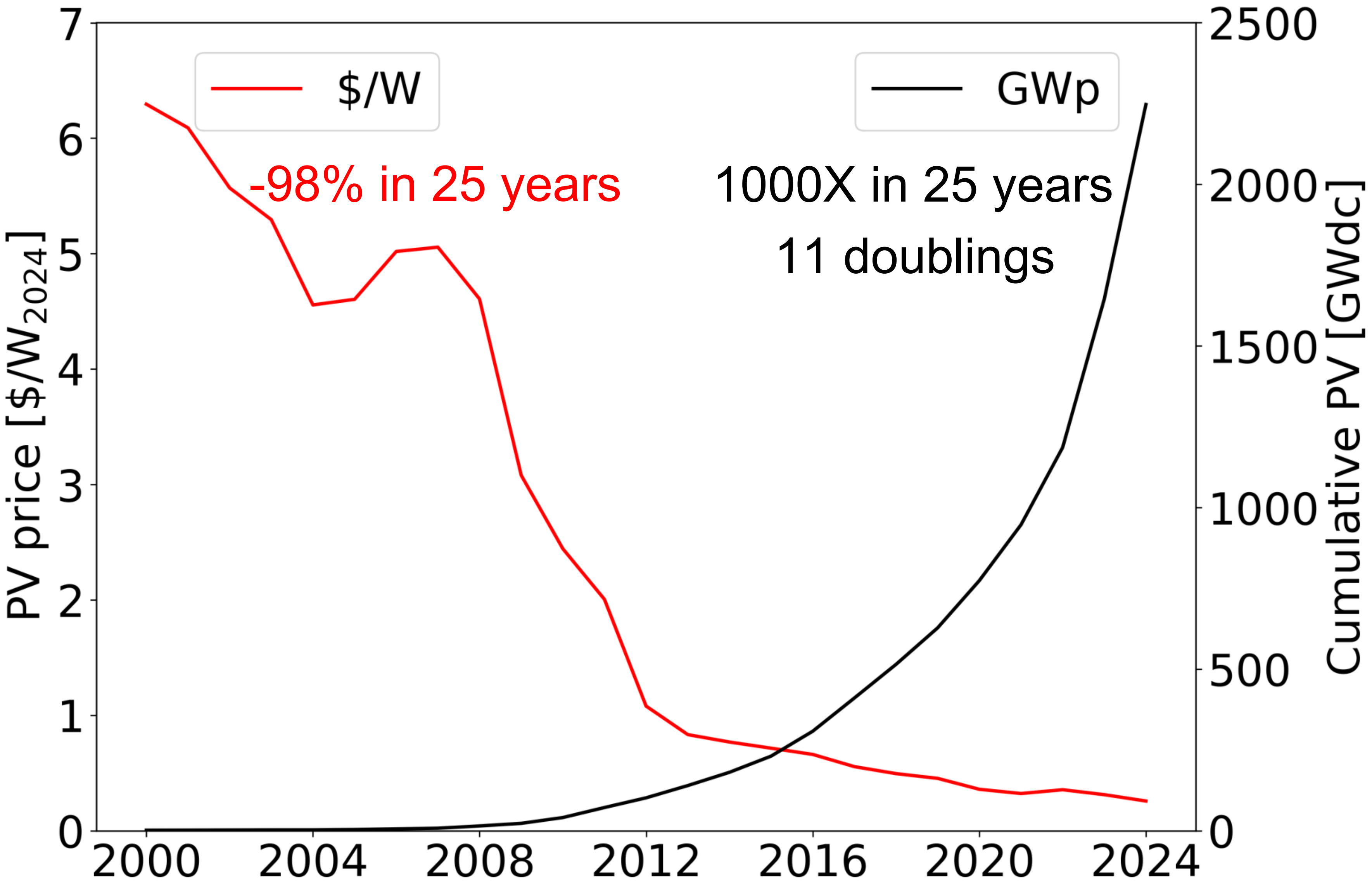
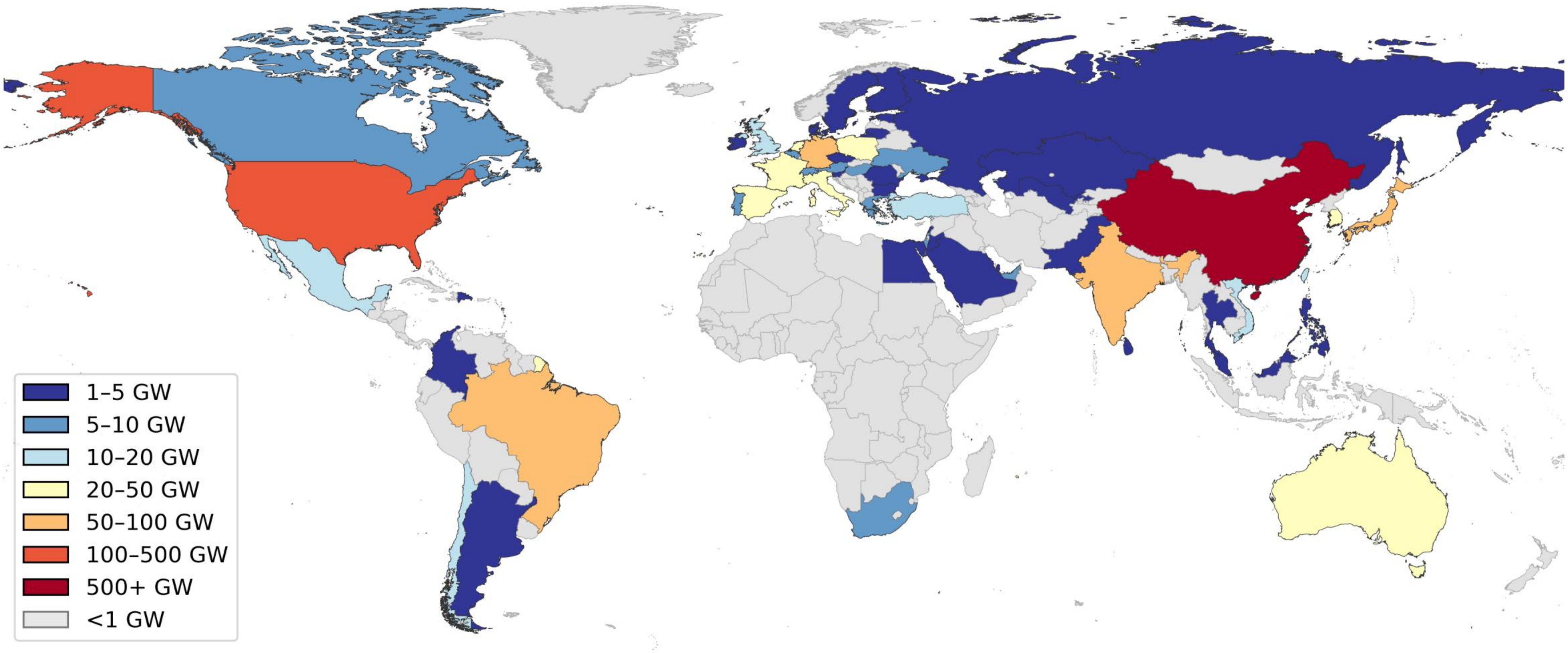
We have come far…



"Solar photovoltaic capacity" [dataset], IRENA (2025) – processed by Our World in Data + IEA PVPS Task 1 Snapshot of Photovoltaics 2025

…yet a world of opportunities exists

2024: 58 countries with ≥ 1 GW_{AC} installed… **and >150 countries yet to reach 1 GW_{AC}**



"Solar photovoltaic capacity" [dataset], IRENA (2025) – processed by Our World in Data

How mature are PV products?

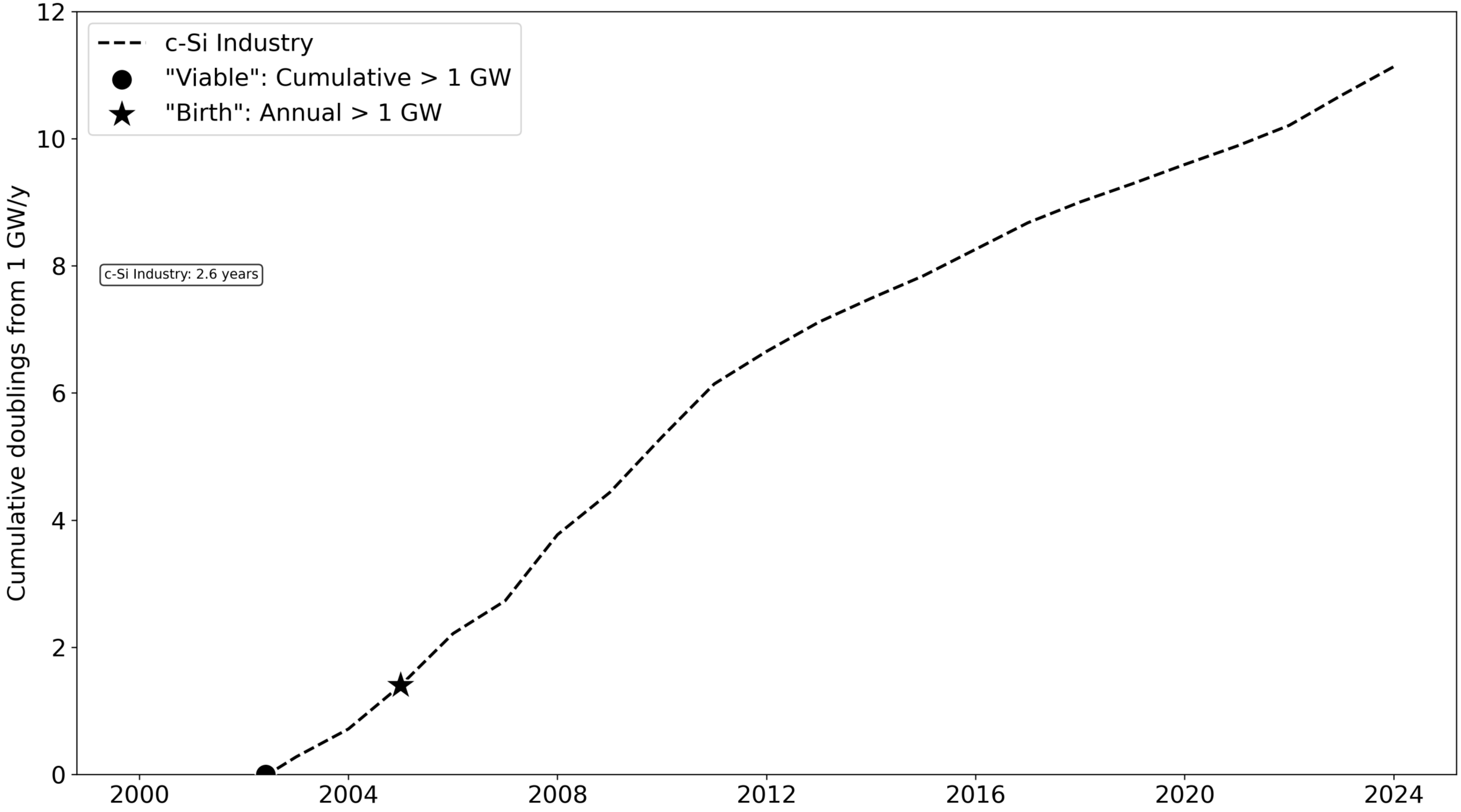
Maturity and reference points

Reference moment: semi-viable (embryo ⇒ fetus). 

Cumulative doublings compare to this moment.

Status	Human		Tree		PV
Semi-viable		Embryo ⇒ Fetus 3 Months		Seedling: first leaf above ground (< 1 year)	1 GW cumulative after sales are >0.25 GW/y (2000→ 2002, 2 years)
Established		Birth: 9 months		Sapling: (>50 cm height) (~3 years)	1 GW/y sales (~3 years: 2005)


From a monoculture view…



c-Si Industry
"Viable": Cumulative > 1 GW
"Birth": Annual > 1 GW
c-Si Industry: 2.6 years
Cumulative doublings from 1 GW/y
0
2
4
6
8
10
12
2000
2004
2008
2012
2016
2020
2024

…to an orchard of diverse technologies

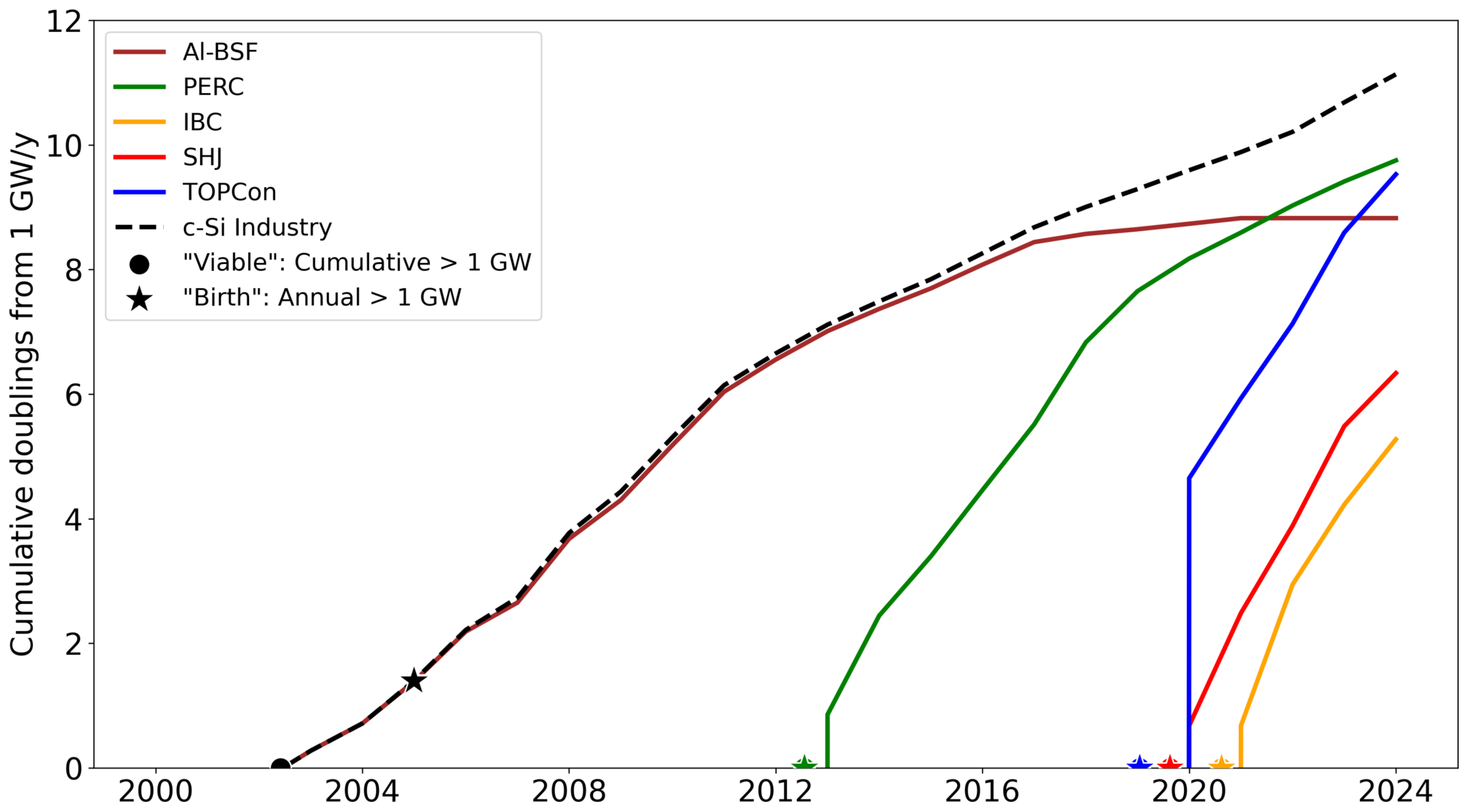
Al-BSF 'Oak'
Slow

PERC 'Apple tree'
Rapid growth, peak productivity

TOPCon 'Bamboo'
Explosive growth

IBC 'Citrus' Long development to maturity

HJT 'Japanese Maple' Premium specialty



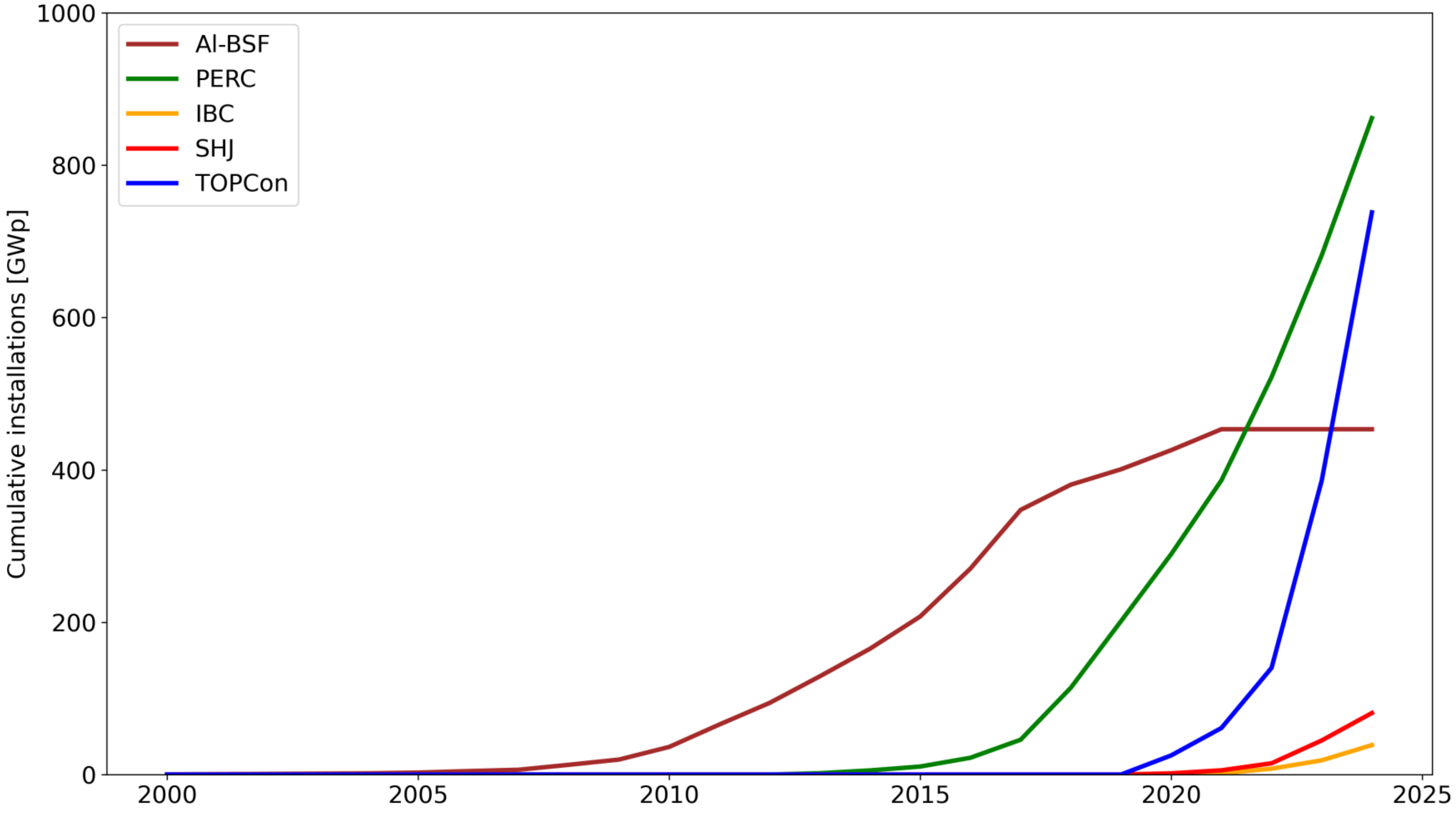
Al-BSF
PERC
IBC
SHJ
TOPCon
c-Si Industry
"Viable": Cumulative > 1 GW
"Birth": Annual > 1 GW
Cumulative doublings from 1 GW/y
0
2
4
6
8
10
12
2000
2004
2008
2012
2016
2020
2024

$$\text{Risk} = \text{likelihood} \times \underbrace{\textbf{magnitude} \times \text{impact}}_{\text{hazard}}$$

Small children… small problems
Big children… big problems

PERC & TOPCon are TW-scale toddlers

- **Al-BSF**: ~450 GW deployed, but growth was gradual over ~25 years → most failure modes are now well characterized.
- **PERC & TOPCon**: scaling much faster, in just a few years → less time to discover reliability issues
- **Failures & degradation**: strongly tied to specific technologies and bills of materials (BOMs)
→ some risks still emerging and not fully understood.



Data compiled from IEA PVPS Task 1, ITRPV, Tier-1 PV module manufacturer annual reports

When things go wrong…

Low quality → Early failures & safety risks

Inadequate O&M → Accelerated losses

Poor design, site selection & extreme weather events → Catastrophic losses

[1] Optimisation of Photovoltaic Systems for Different Climates – 2025, IEA PVPS Task 13 [2] Degradation and Failure Modes in New Photovoltaic Cell and Module Technologies – 2025, IEA PVPS Task 13
[3] Guidelines for Operation and Maintenance of Photovoltaic Power Plants in Different Climates – 2022, IEA PVPS Task 13 [4] PV Magazine: Tornado rips through solar farm in Florida, 17/10/2024

Replacing modules: they don’t make them like they used to

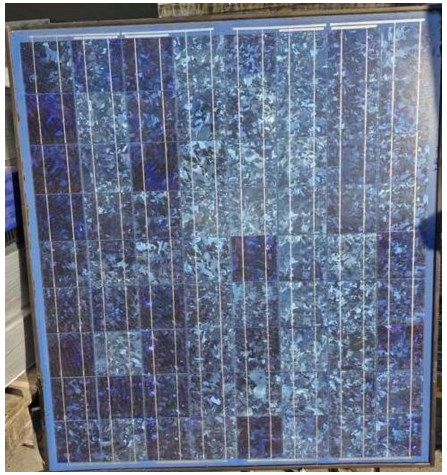
1998-2002

Solarex MSX-120, η ≈ 11%

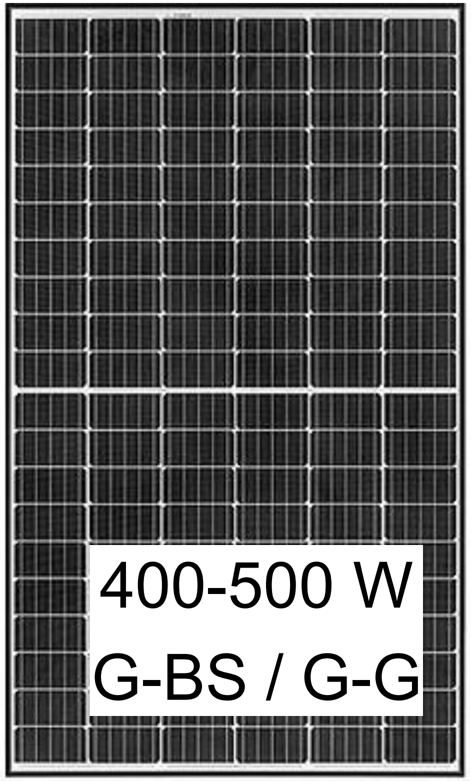
24 Vdc OR 48 Vdc ⇒ user-selectable

IP54 junction box with screws,

bypass diodes *optional*



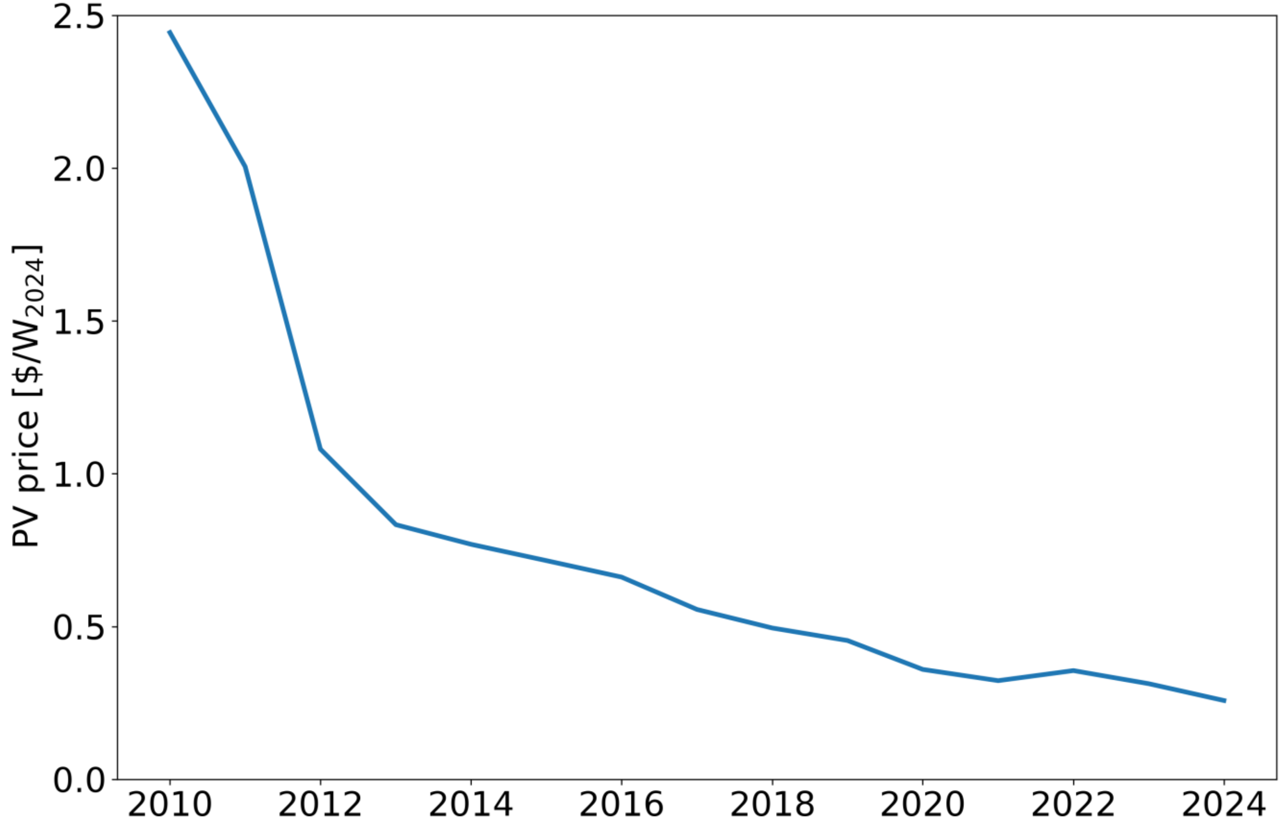
2022



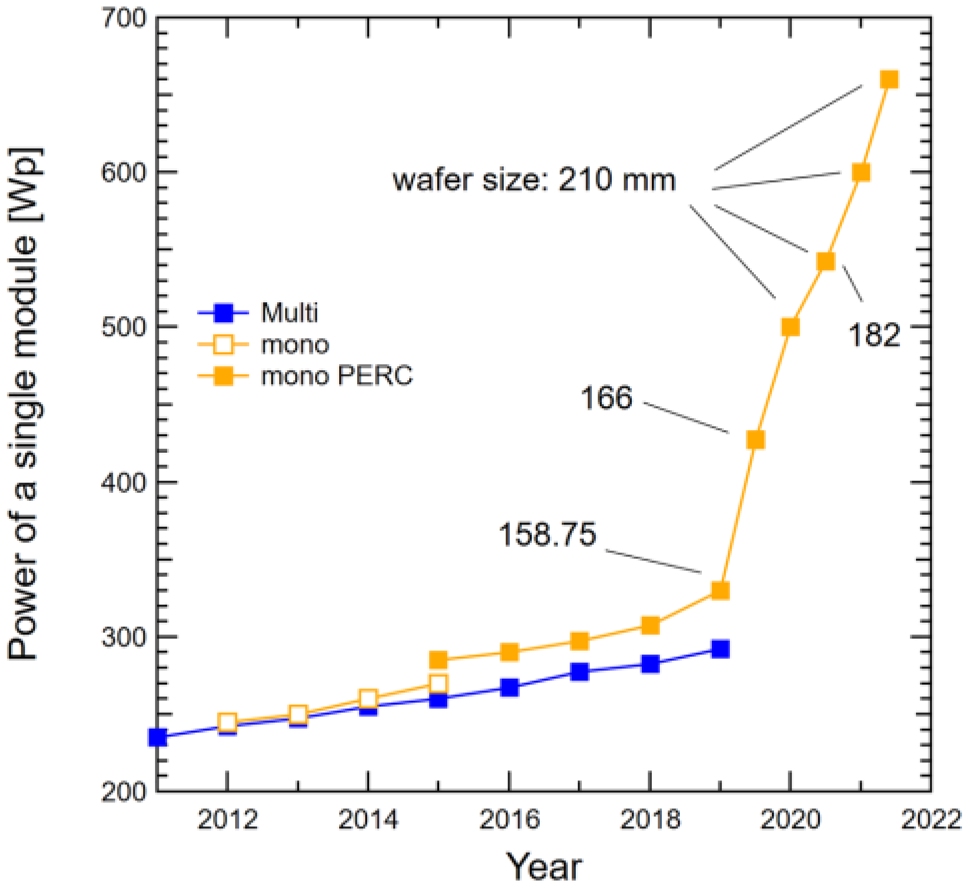
2024

L	**1.1 m**	**1.7 m**	**2.4 m**
W	1 m	1.1 m	1.3 m
D	**50 mm**	**35 mm**	**33** mm

The first Paradox of PV:
PV modules are price-wise a commodity, yet are not compatible physically nor electrically



IRENA (2025); Nemet (2009); Farmer and Lafond (2016)
with major processing by Our World in Data



Yifeng Chen et al [PiP 3626, 2022]

Let’s Talk Warranties: Module warranties as health insurance

Think of a module warranty like **health insurance**:

- It doesn’t cover every ache or wrinkle that comes with age.
- It only pays out if something goes *seriously wrong*.

For modules, that means:

- Small dips in power are expected and not covered.
- The warranty only kicks in if performance falls *far below the promised curve*.

Warranty is paid on the ΔP in year y, not full power!

Even then, the **manufacturer decides** the remedy:

- A “replacement organ” (new module)
- A “cash payout” (but at **today’s low prices**)
- Or a “patch-up job” (repairs, sometimes)

Repowering decisions aren’t usually driven by warranties — because **payouts are limited, slow, and often not very useful** (cash at today’s low module prices doesn’t cover your actual system costs).

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Repowering & Revamping Challenges

Technical

- **Inverters**
  - Lifetime < modules
  - Voltage mismatch
  - No replacements/parts
- **Backsheets**
  - Safety issue, no reuse
  - Warranty claims
- **Trackers**
  - Module size change, may void warranty
- **Incompatible racking**
- **Cabling & string lengths**

Contracts and Legal

- **Re-negotiate Contracts**
  - See PPA below
  - Land contracts (don't decrease size of land used – lower lease cost, but land-owner bad will)
- **PPA**
  - Many have older, $$ PPA contracts
  - Turning off powerplant to repower risks violating PPA contracts
- **Grid connection**
  - Long connection queues
  - Re-engineering costs
  - May not be able to expand capacity in that grid location

Financial

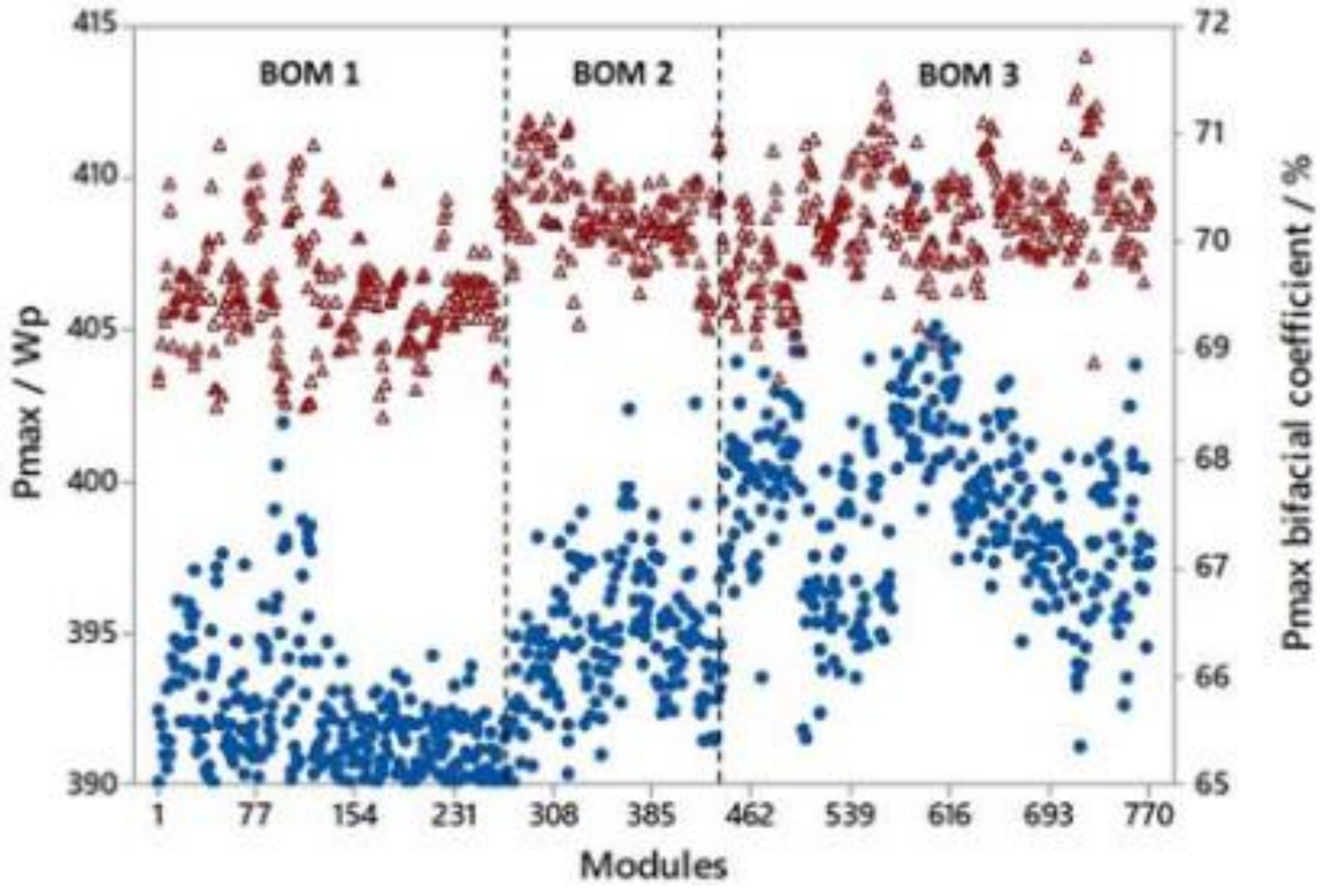
- **Re-engineering**
  - Costs are high
  - More complex than green-field
  - Building permitting scope
- **Tax Credits & incentives**
  - May vary by location
  - Vary by system vintage

Ovaitt et al, PVSC 2025

2nd paradox of PV: Increased warranty durations, more product and BOM variations, while testing is limited in time and cost

"Live" BOM updating in production

Testing: x2/x3 IEC ≠ field reality

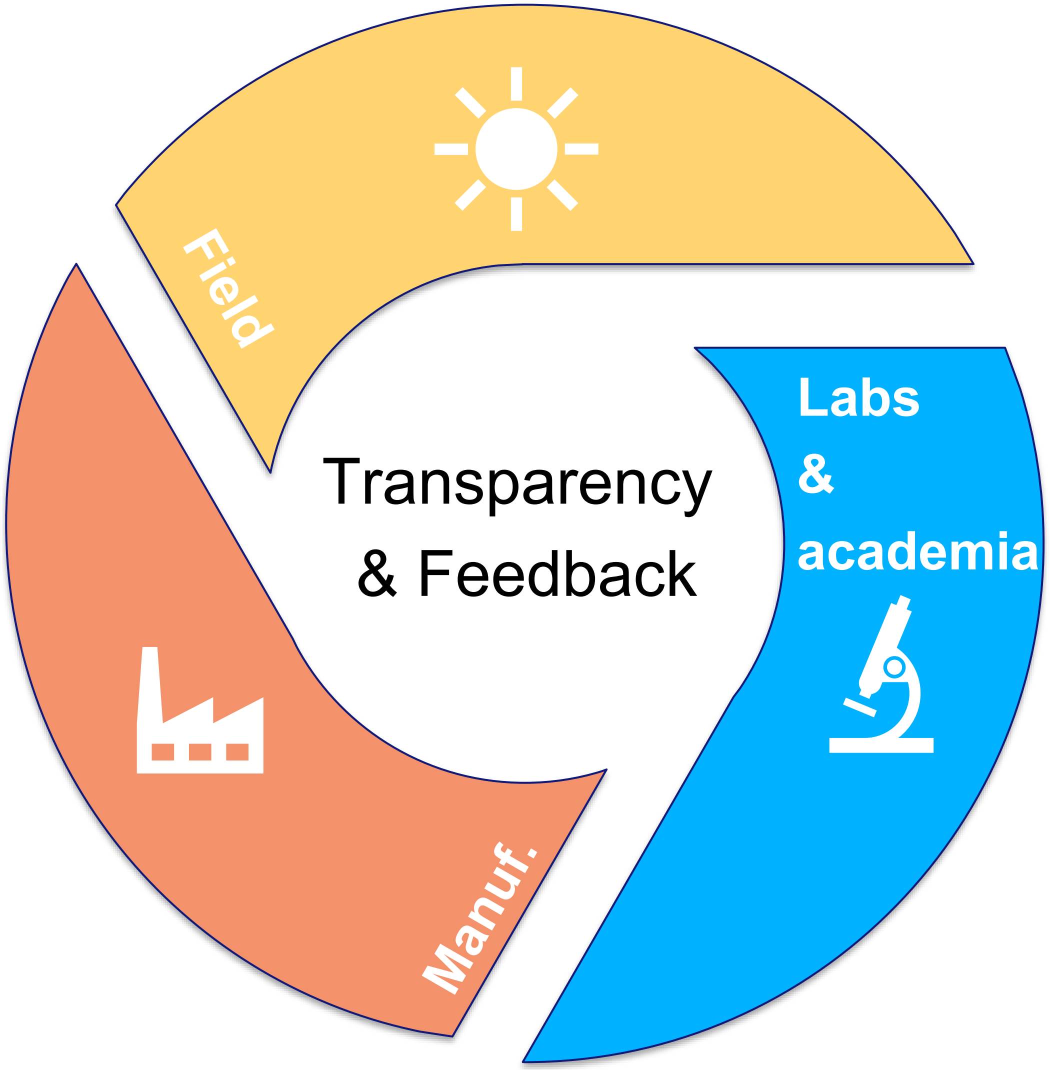


Standards lag; risk shifts to owners

Ruperto Gómez et al [EU PVSEC 2020]

Warranty length ↑ test scope not

What is needed: **Transparency**, Reliability & Maturity

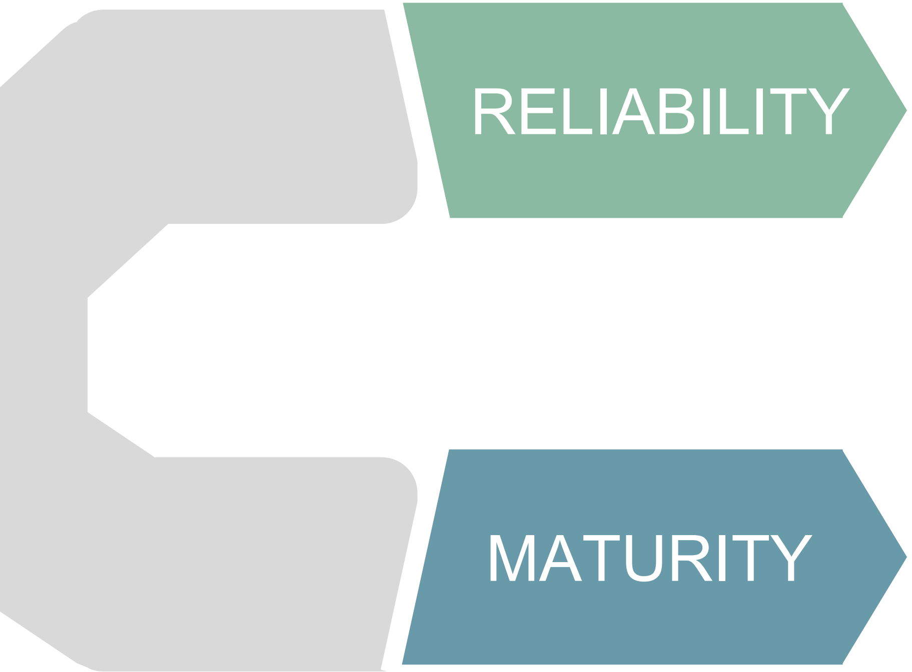


Transparency in BOM, degradation data and failure modes, also for recycling

Data Sharing of field data as industry resource, incl. warranty claims

Fair Testing with random sampling and open results that benefit all consumers. E.g. PBAM: *public* test per 100 MW made / imported

What is needed: Transparency, **Reliability & Maturity**



Grid Confidence

- PV is a **critical grid asset** → failures ripple system-wide
- **Tests** should be **linked to warranty**: duration, power limit for degradation
- Ensures investors can depend on 25+ years of performance.
- Learn from other industries: roofing materials, cars, buildings,…

Cost & Market Balance

- Longer warranties, recycling, and transparency add costs.
- Margins are thin: module cost ⇔ sales price ⇔ viability
- Need competitive pricing without eroding long-term value.
  - Warranties are useless if companies are bankrupt

The way out

The first Paradox of PV: PV modules are price-wise a commodity, yet are not compatible physically nor electrically

PV modules as *true, reliable, replaceable* components (commodities)

Physically: yes… mostly

Electrically: yeah?

Second paradox of PV: Increased warranty durations, more product and BOM variations, while testing is limited in time and cost

Transparency in PV modules & systems and tests linked to warranty terms

Testing: stronger together, public-facing results

BOM transparency + in-field testing

Conclusions

Installed PV modules are obsolete

- Plan for replacements… now
- Discuss with legal / financial / regulatory stakeholders… now

We need more transparency

- Trust but verify… and **share data**
- Mandatory reporting of failures or degradation
- PBAM-like public test results

Testing & data must have scale and speed

- Warranties longer & more stringent ⇒ tests too
- Learn from other industries

The industry needs to grow up

- Financial viability for stakeholders
- Warranties are useless if companies are bankrupt
- See transparency

Next steps

IEA PVPS Task 13 will report on *Best Practices for Repowering & Revamping* (2026–2029).

We are seeking:

- Data & case studies on repowering/revamping
- When it happened (or not), and why
- Causes: degradation, extreme weather, financial, other
- Implemented solutions

👉 **Take the survey** or contact us directly:
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Silvana.Ovaitt@nrel.gov

IEA PVPS Task 13 Industry Survey: Repowering & Revamping of PV Systems

tinyurl.com/IEARepoweringSurvey

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