Fraunhofer ISE

Photovoltaics Report

Fraunhofer Institute for Solar Energy Systems, ISE
with the support of PSE Projects GmbH

Freiburg, 29 July 2024
www.ise.fraunhofer.de

CONTENT

Introduction

Preliminary Remarks

- The intention of this presentation is to provide up-to-date information. However, facts and figures change rapidly, and the given information may soon be outdated again.
- This work has been carried out under the responsibility of Dr. Simon Philipps (Fraunhofer ISE) and Werner Warmuth (PSE Projects GmbH).
- Price indications are always to be understood as nominal, unless this is stated explicitly. For example, prices in the learning curves are inflation adjusted.
- The slides have been made as accurate as possible and we would be grateful to receive any comments or suggestions for improvement.
  Please send your feedback to both simon.philipps@ise.fraunhofer.de and warmuth@pse-projects.de
- Please quote the information presented in these slides as follows:
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Quick Facts

Parameter	Value	Status	Reference	Date of data
Germany / EU27 / Worldwide				
PV installation market [GW]	7.5 / 41.4 / 240 GW 15.1 / 55.9 / 407 GW	End of 2022 End of 2023	BNA / SPE / IEA BNA / SPE / IEA	03/2023; 01/2023; 04/2023 06/2024; 12/2023; 04/2024
Cumulative installation [GW]	67.6 / 207 / 1,185 GW 82.7 / 263 / 1,581 GW	End of 2022 End of 2023	ISE / SPE / IEA ISE / SPE / IEA	03/2023; 12/2023; 04/2023 06/2024; 12/2023; 04/2024
PV power generation [TWh]	54.3_{net} / 209.1_{gross} / $1{,}321.9_{gross}$ 53.9_{net} / 246.8_{gross} / $1{,}641.6_{gross}$	2022 2023	ISE / EI / EI ISE / EI / EI	06/2024; 06/2024; 06/2024 06/2024; 06/2024; 06/2024
PV electricity share	$11.0\%_{net}$ / $7.4\%_{gross}$ / $4.5\%_{gross}$ $12.5\%_{net}$ / $9.0\%_{gross}$ / $5.5\%_{gross}$	2022 2023	ISE / EI / EI ISE / EI / EI	06/2024; 06/2024; 06/2024 06/2024; 06/2024; 06/2024
Worldwide				
c-Si share of production	97%	2023	ITRPV	04/2024
Record solar cell efficiency: III-V MJ (conc.)/mono-Si/CIGS/multi-Si/CdTe	47.6 / 27.3 / 23.4 / 24.4 / 21.0%	06/2024	Green et al.	06/2024
Germany				
Price PV rooftop system (3 to 10 kWp)	1,450 to 2,000 €/kWp	2023	BSW	11/2023
LCOE PV power plant	3.1 to 5.7 ct€ / kWh	2021	ISE	
Lowest/Latest PV-Tender Price (average, volume-weighted value)	4.33/5.17 ct€ / kWh	02/2018; 12/2023	BNA	12/2023

Executive Summary

PV Market: Global

- Photovoltaics is a fast-growing market: The Compound Annual Growth Rate (CAGR) of cumulative PV installations was about 26% between year 2013 to 2023.
- In 2023 producers from Asia count for 94% of total PV module production. China (mainland) holds the lead with a share of about 86%. Europe and USA/CAN each contributed 2%.
- Wafer size increased and by keeping the number of cells larger PV module sizes are realized allowing a power range beyond 700 W per module.
- In 2023, Europe's contribution to the total cumulative PV installations amounted to 20%. In contrast, installations in China accounted for 43% (previous year 37%) and North America for 10%.
- Si-wafer based PV technology accounted for about 97% of the total production in 2023. Mono-crystalline technology became the dominant technology in c-Si production while multi-crystalline technology is phasing out.
- Market shifts from subsidy driven to competitive pricing model (Power Purchase Agreements PPA).
- In addition to PV systems on buildings (Rooftop or Building-Integrated) and ground-mounted systems, more and more systems are being installed on agricultural land (Agrivoltaics) and bodies of water (Floating PV). Furthermore, vehicle-integrated PV enters the market.

Executive Summary

PV Market: Focus Germany

- In year 2023, Germany accounted for about 5.2% (82.7 GWp) of the cumulative PV capacity installed worldwide (1581 GWp) with about 3.7 million PV systems installed in Germany. In 2023 the newly installed capacity in Germany was about 15 GWp according to BNA; in 2022 it was 7.5 GWp.
- In 2023, PV accounts for 12.5% of net electricity generation and all renewable energies together for around 60%.
- In 2023 about 42 Mio. t CO_2 equivalent GHG emissions have been avoided due to 61 TWh PV electricity consumed in Germany.
- PV system performance has strongly improved. Before year 2000 the typical Performance Ratio was about 70%, while today it is in the range of 80% to 90%.
- Often residential and small commercial PV systems are installed with a battery storage and a charging station for electric mobility. Due to relative high electricity tariffs in Germany, self consumption is the prevailing business model. Another trend is the increased installation of balcony solar systems.
- With the increasing generation capacity from solar and wind, the integration of volatile electricity into the grids is becoming ever more important. Grid expansion, load management, smart grids, bidirectional charging of vehicle batteries etc. must be promoted to avoid temporary switching off of renewable power plants (curtailment).

Executive Summary

Solar Cell / Module Efficiencies

- The record lab cell efficiency* is 27.3% for mono-crystalline and 24.4% for multi-crystalline silicon wafer-based technology. The highest lab efficiency in thin film technology is 23.4% for CIGS and 21.0% for CdTe solar cells. Record lab cell efficiency for Perovskite is 25.2%.
- In the last 10 years, the efficiency of commercial mono-crystalline wafer-based silicon modules increased from about 16% to 22% and more. At the same time, the efficiency of CdTe module increased from 9% to nearly 20%.
- In the laboratory, the best performing modules are based on mono-crystalline silicon with 24.9% efficiency. Record efficiencies demonstrate the potential for further efficiency increases at the production level.
- In the laboratory, high concentration multi-junction solar cells achieve an efficiency of up to 47.6% today. With concentrator technology, module efficiencies of up to 38.9% have been reached.

* Only official lab record efficiencies with minimum cell area of 1 cm^2 are listed. Latest reference: Solar Cell Efficiency Tables (Version 64), Progress in Photovoltaics: Research and Applications, 06/2024

Executive Summary

Energy Payback Time

- Material usage for silicon cells has been reduced significantly during the last 18 years from around 16 g/Wp (in 2004) to about 2.2 g/Wp in 2023 due to increased efficiencies, thinner wafers (150µm) using diamond wire saws, and larger ingots.
- The Energy Payback Time of PV systems is dependent on the geographical location: PV systems manufactured in Europe and installed in Northern Europe require approximately 1.1 years to pay back the energy input, while PV systems installed in the South require 0.9 years to pay back the energy input, depending on the technology installed and the grid efficiency.
- A PV system located in Sicily using wafer-based Silicon modules has an Energy Payback Time of about one year. Assuming a 20-year lifetime, this type of system can produce twenty times the energy required to produce it.
- PV modules can be recycled to recover rare and valuable materials. Further research and development is needed to make these recycling processes even more in-depth and cost-effective.

Executive Summary

Price Development

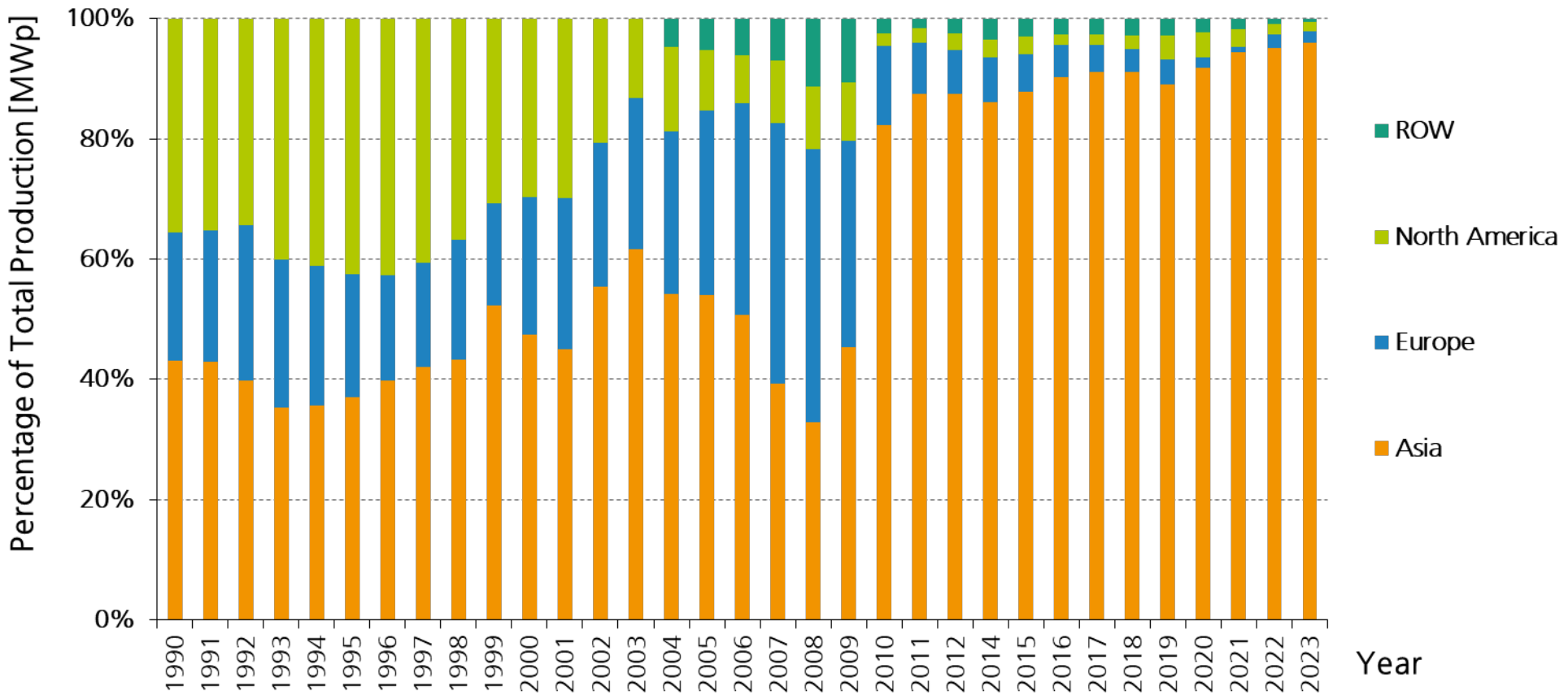
- Due to the coronavirus crisis and the associated disruptions to supply and trade chains, market prices rose noticeably in 2022 and at times some products were not available in sufficient quantities. In 2023 prices fell again.
- In Germany prices for a typical 10 to 100 kWp PV rooftop-system were around 14,000 €/kWp in 1990. At the end of 2023, such systems cost only 10% of the price in 1990. The compound annual growth rate (CAGR) of net prices has been -6.8% over the past 33 years.
- The Experience Curve – also called Learning Curve - shows that in the last 43 years the module price decreased by 24.4% with each doubling of the cumulated global module production. Cost reduction results from economies of scale and technological improvements. Global average Selling price (ASP) was about 0.20 US$/Wp in 2023.

1. PV Market

- By region
- By technology

PV Module Production by Region 1990-2023

Percentage of Total MWp Produced



Data: from 2000 to 2009: Navigant; from 2010 to 2021 IHS Markit; from 2022 estimates based on IEA and other sources. Graph: PSE Projects GmbH 2024 . Date of data: 04/2024

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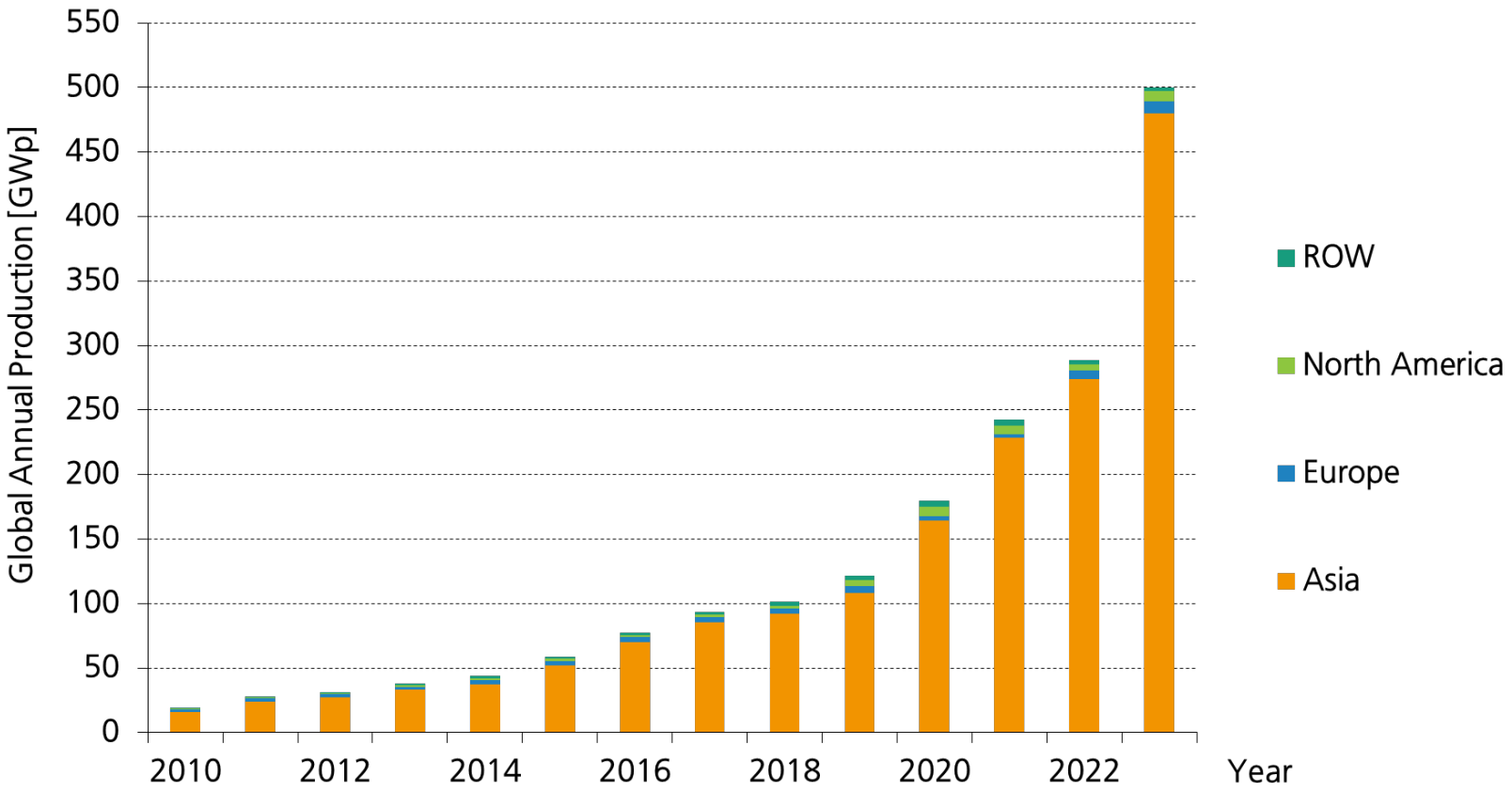
PV Module Production by Region

Global Annual Production



Annual Production Today

Annual production has increased 13-fold over the past decade. In 2023, approximately 95% of solar modules and their components came from Asia, primarily from China with a module production share of about 80%, which also controls more than 95% of the market for certain components such as ingots and wafers.

Data from 2000 to 2009: Navigant; from 2010 to 2021 IHS Markit; from 2022 estimates basaed on IEA and other sources. Graph: PSE Projects GmbH 2024. Date of data 04/2024

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EU PV Manufacturing Landscape – Status Quo

Overview of PV production along the value chain – July 2024

Nominal Production-Capacities in the region [GWp/a]:

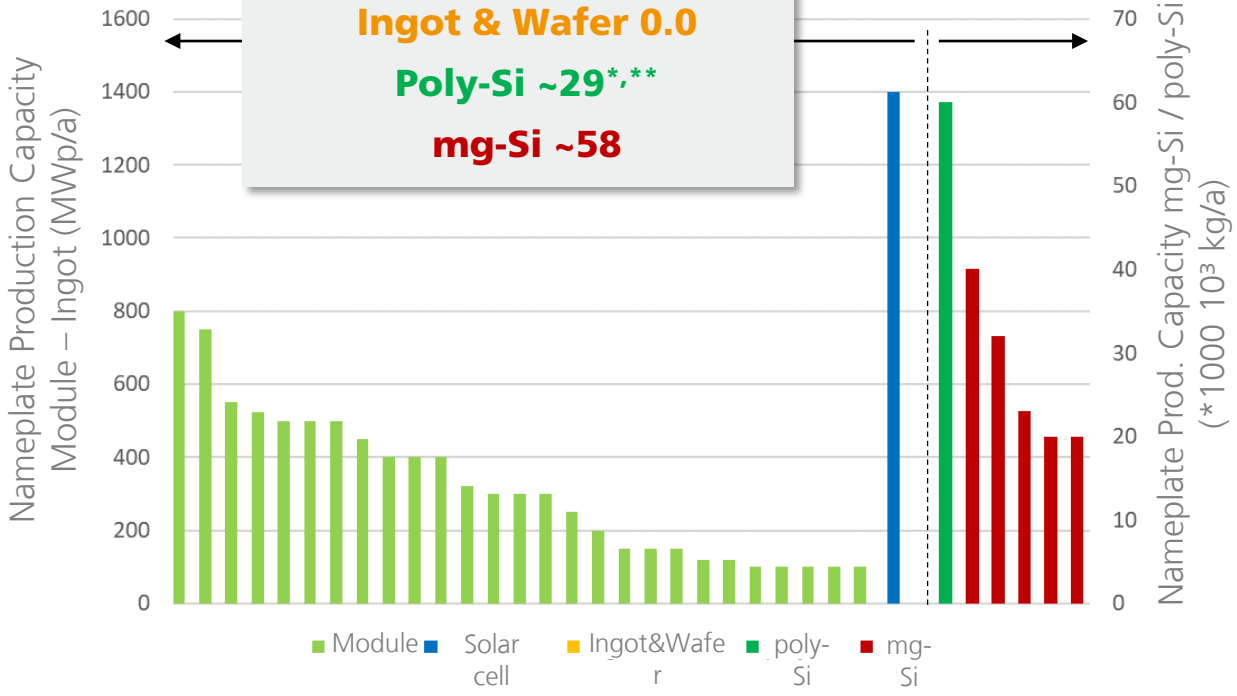
Module 8.6

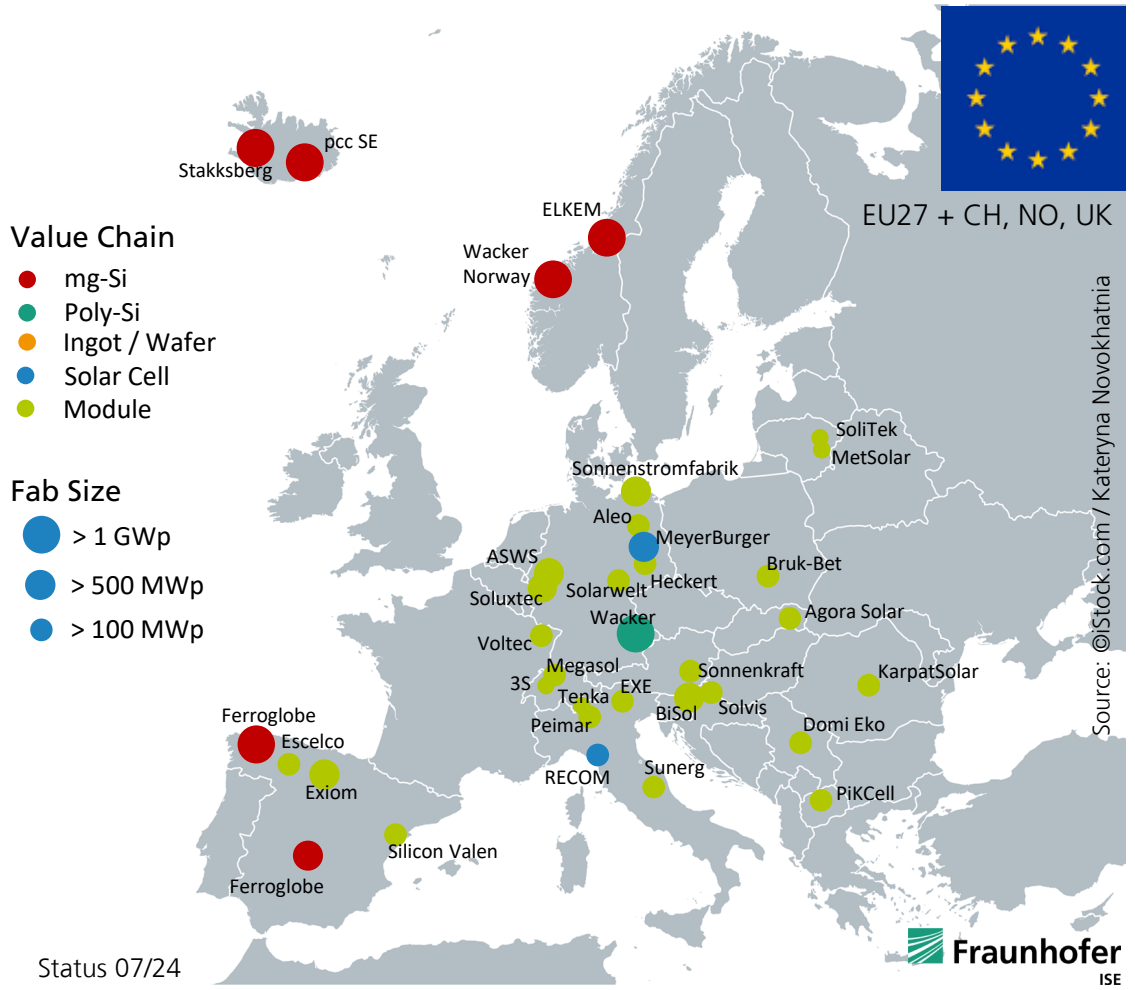
Solar Cells 1.4

Ingot & Wafer 0.0

Poly-Si ~29*,**

mg-Si ~58





* Currently 2,100 kg/MWp poly-Si required for Ingot production

** Most of the available poly-Si capacity is held in reserve for the semiconductor industry

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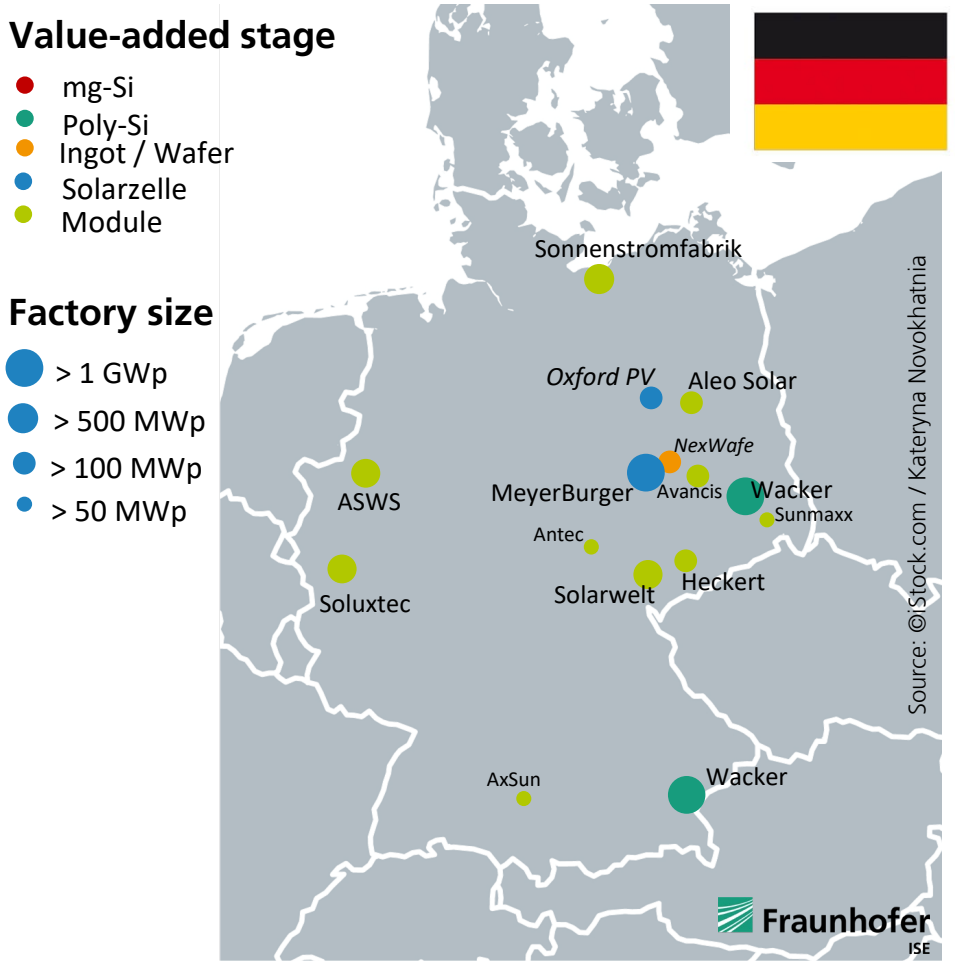
PV Production in Germany - Status Quo

PV module supplier – July 2024

Company	Location	Capacity [MW]	Website
ASWS	Mettmann	800	https://www.asws-solar.de/
Soluxtec	Bitburg	550	https://www.soluxtec.de/
Sonnenstromfabrik	Wismar	525	https://www.sonnenstromfabrik.com/de/
Solarwelt (Heckert)	Langenwetzendorf	400	https://www.heckertsolar.com/standort-lwd/
Heckert Solar	Chemnitz	400	https://www.heckertsolar.com
Aleo Solar	Berlin	300	https://www.aleo-solar.de/
Avancis	Torgau	100	https://www.avancis.de/
AxSun	Laupheim	50	https://www.axsun.de/
Sunmaxx	Ottendorf-Okrilla	50	https://sunmaxx-pvt.com/de

The production capacity for PV modules in Germany amounted to about 3.2 GWp in July 2024.

Data and Graph: Jochen Rentsch, Fraunhofer ISE 2024; last update: 07/2024



Status 05/07/24

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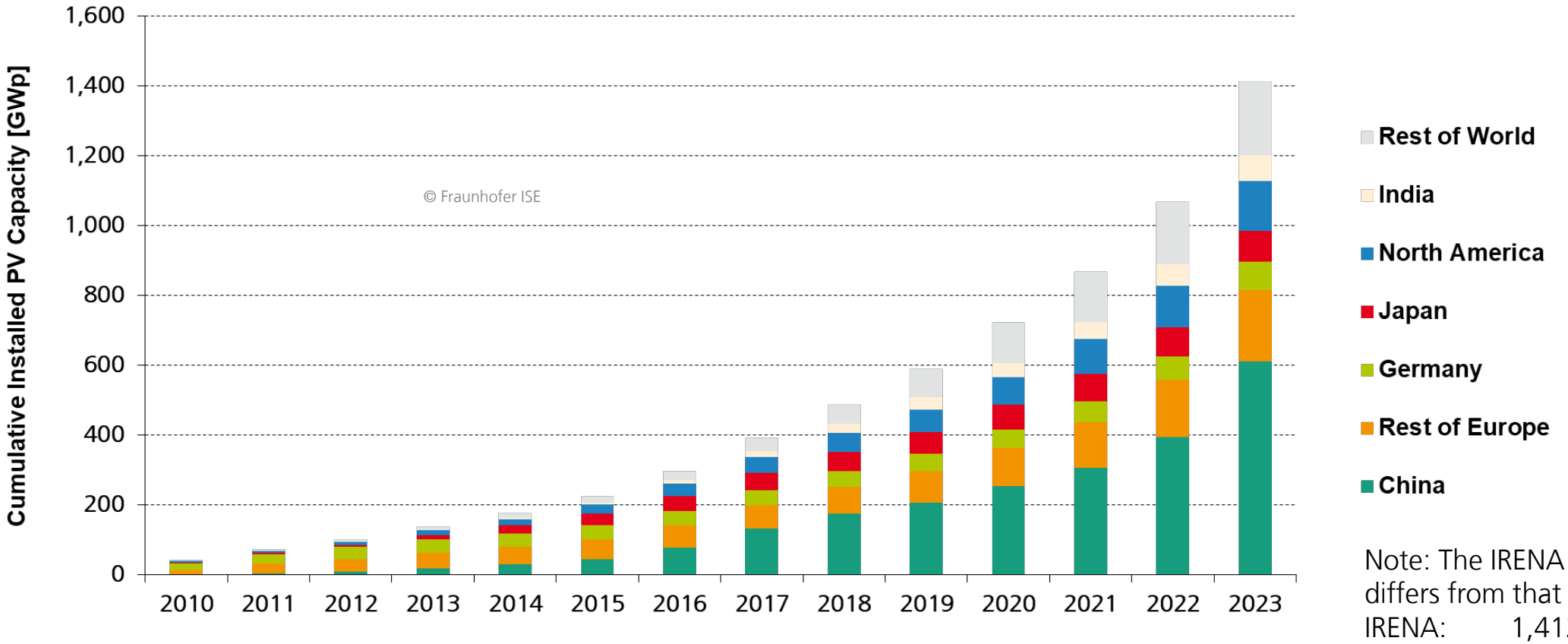
Global Cumulative PV Installation

by Region



Data: IRENA 2024. Graph: PSE Projects GmbH 2024. Date of data: April-2024

Note: The IRENA data shown here differs from that of the IEA PVPS:
IRENA: 1,412 GWp
IEA-PVPS: 1,581 GWp

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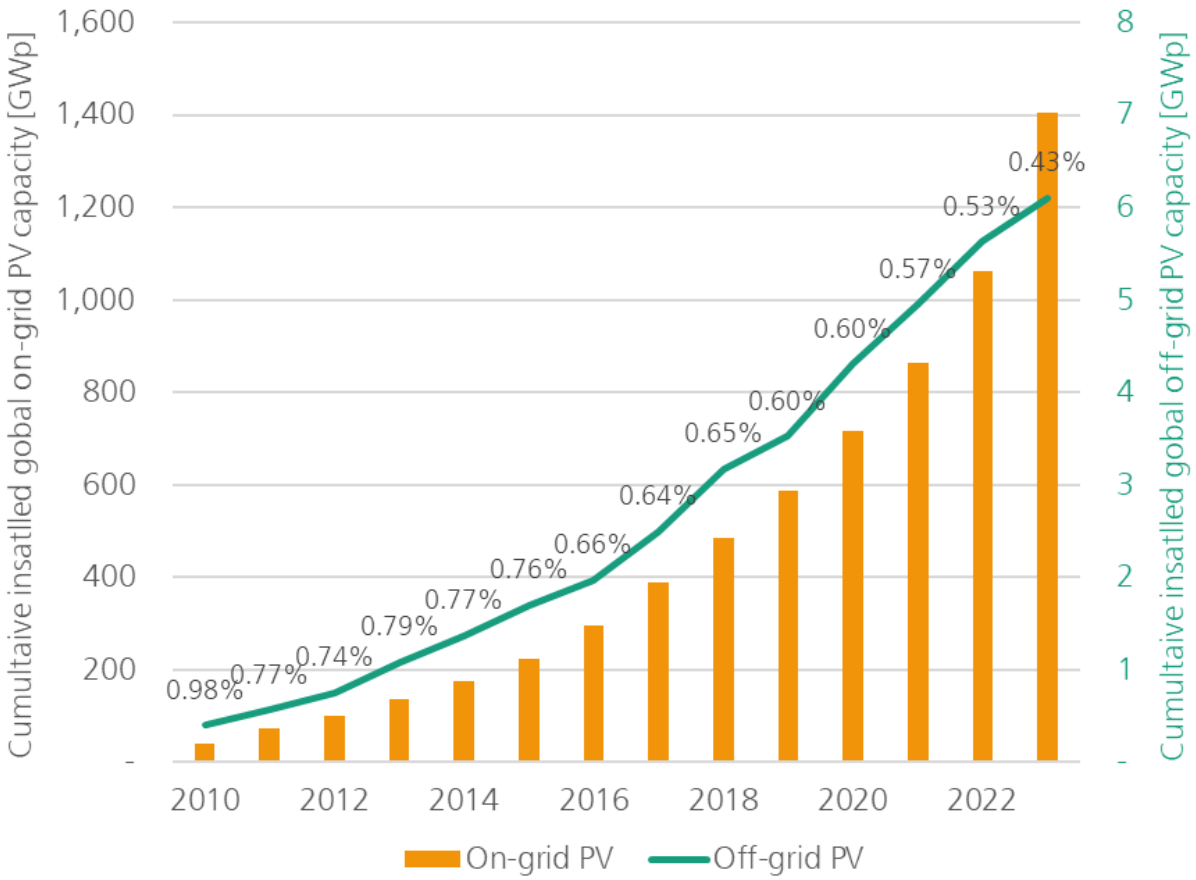
Global Cumulative PV Installation

by on-grid & off-grid installation type



Data: IRENA 2024. Graph: PSE Projects GmbH 2024. Date of data: 04/2024

Approximately 99.6% of today's installed PV capacity is connected to the grid.

The proportion of off-grid systems compared to the total cumulative systems has roughly halved over time from just under 1 % in 2010 to 0.43 % in 2023.

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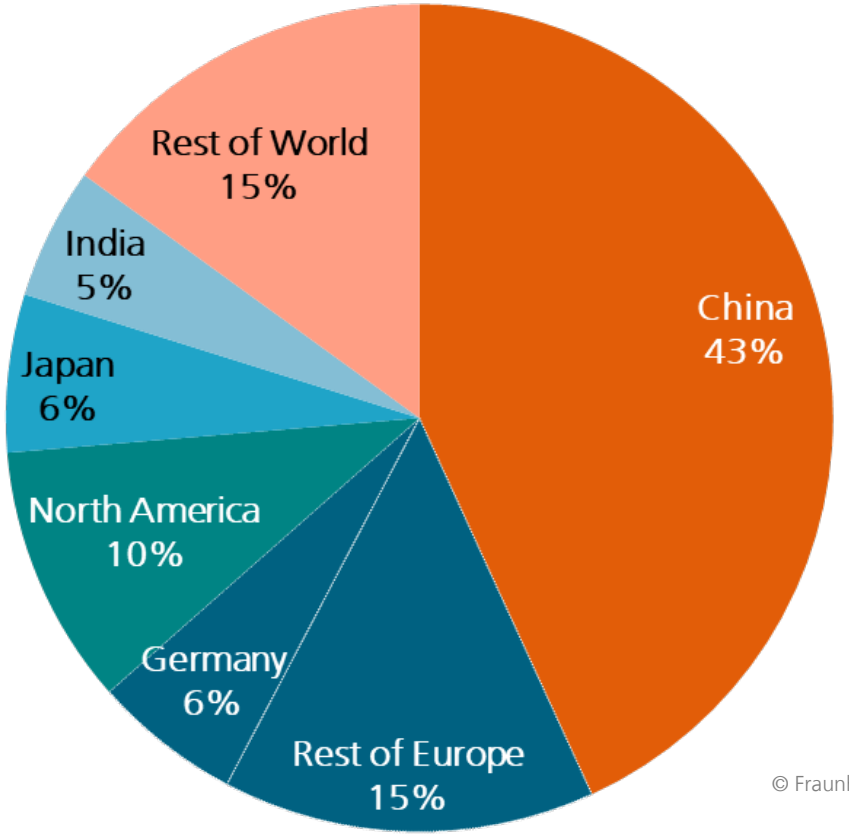
Global Cumulative PV Installation by Region

Status 2023



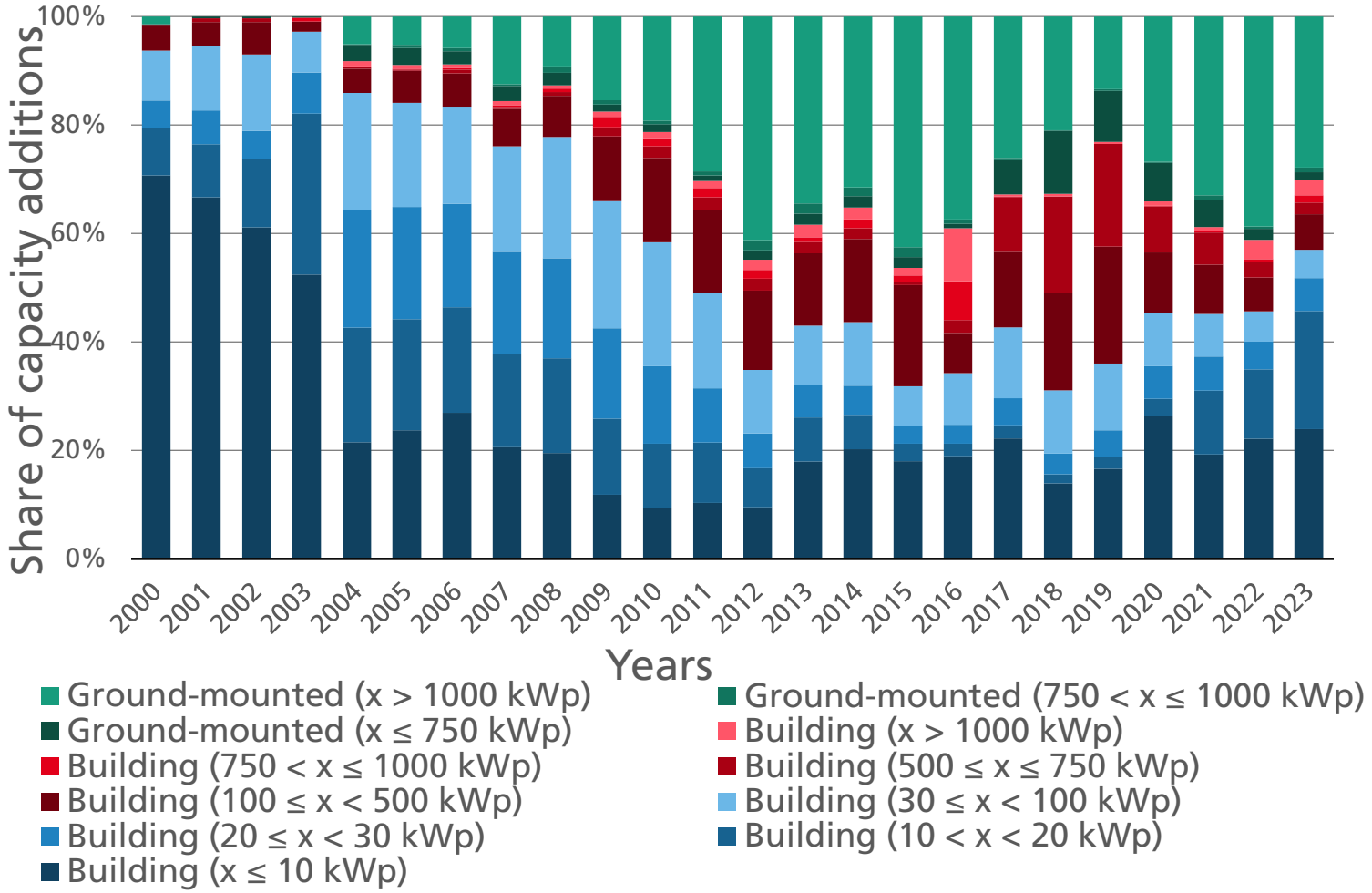
The total cumulative installations amounted to about 1,581 GWp according to IEA-PVPS at the end of year 2023; IRENA reports 1,412 GWp.

All percentages are related to global installed PV capacity, including off-grid systems.

Data: IEA-PVPS Snapshot of Global Market; IRENA 2024. Graph: PSE Projects GmbH 2024; Date of data: 04/2024

Annually Installed PV System Capacity in Germany

Percentage of Annual Capacity by System Size



The annual distribution of PV system size classes strongly depends on:

- Regulations
- Market incentives (like EEG)
- Tender procedures
- Bankability (trust of investors)

The "Building" category includes roofs, facades and plug-in systems

The "Ground-mounted" category includes bodies of water, parking lots and other structures

Source until year 2020: Fraunhofer ISE, own calculations based on EEG-master and -flow data (netztransparenz.de, Sept. 2021)
Source since 2021: Fraunhofer ISE, own calculations based on MaStR (Date: 18.03.2024) and data validation algorithm

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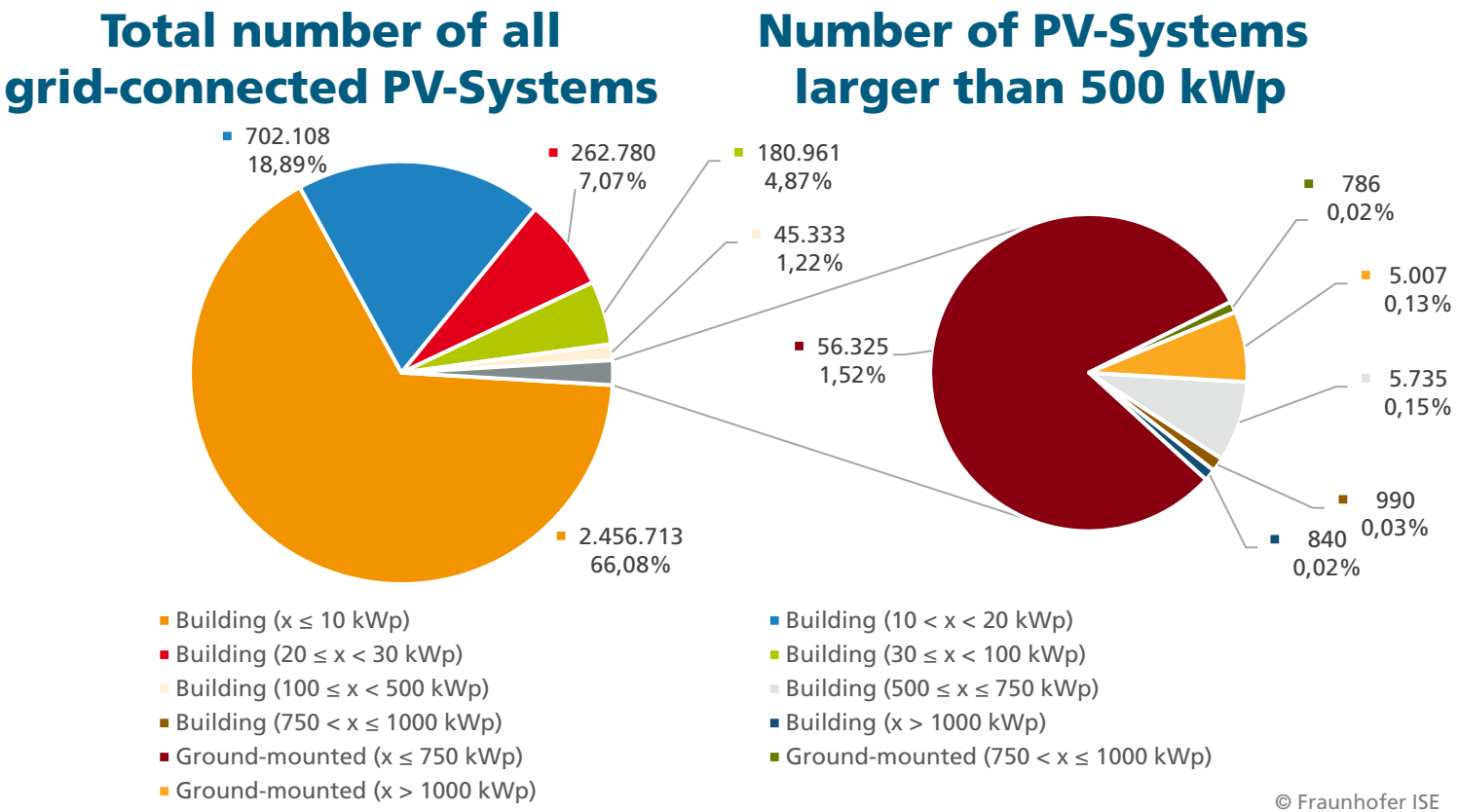
Share of Number of PV Systems Installed

Percentage of Cumulative Installations by System Size in Germany in 2023



End of 2023 about 3.7 million grid-connected PV-Systems were installed in Germany.

In 2023, around 500,000 plug-in systems (up to 600 W feed-in power), so-called balcony solar systems, were installed in Germany [1].

Source: Fraunhofer ISE, own calculations based on MaStR (Date: 18.03.2024) and data validation algorithm

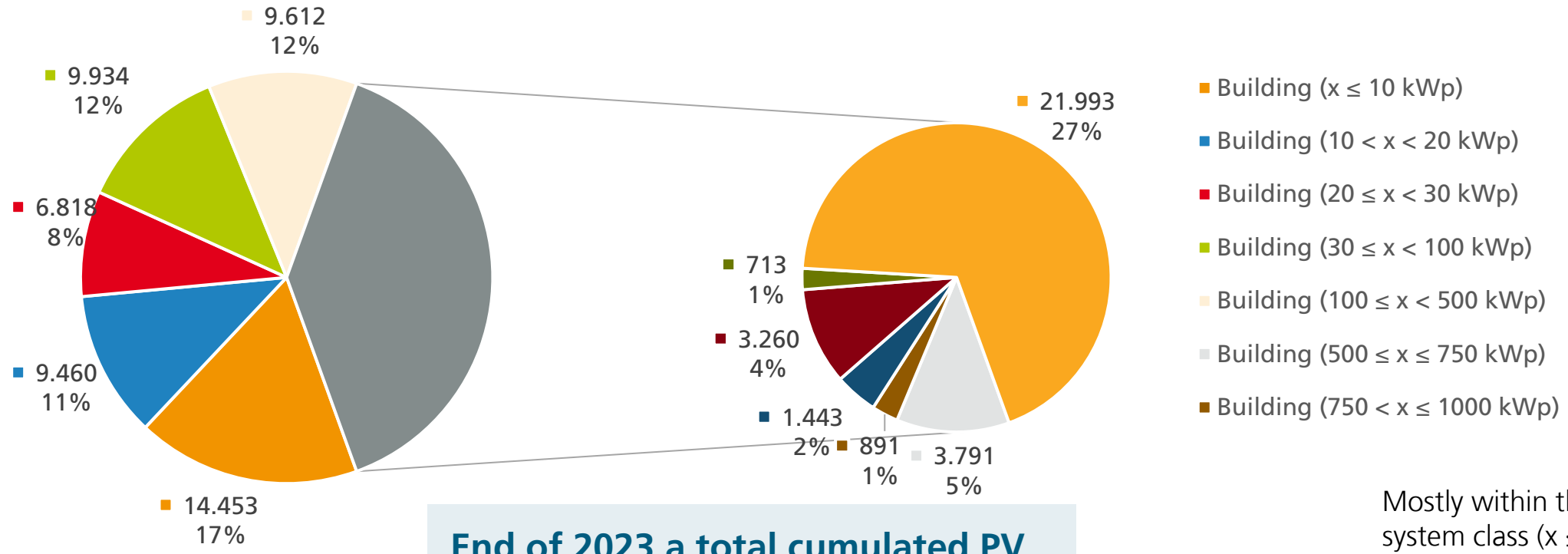
[1] Includes reported plug-in systems and systems assigned to this category according to MaStR (Date: 18.03.2024) and additional estimates by Fraunhofer ISE

Share of Capacity of PV-Systems Installed

Percentage of Cumulative Installations by System Size in Germany in 2023

PV Capacity in MW_p and percentage of all grid-connected PV-Systems

PV Capacity in MW_p and percentage of Systems larger than 500 kWp



End of 2023 a total cumulated PV capacity of about 82.4 GWp was installed in Germany.

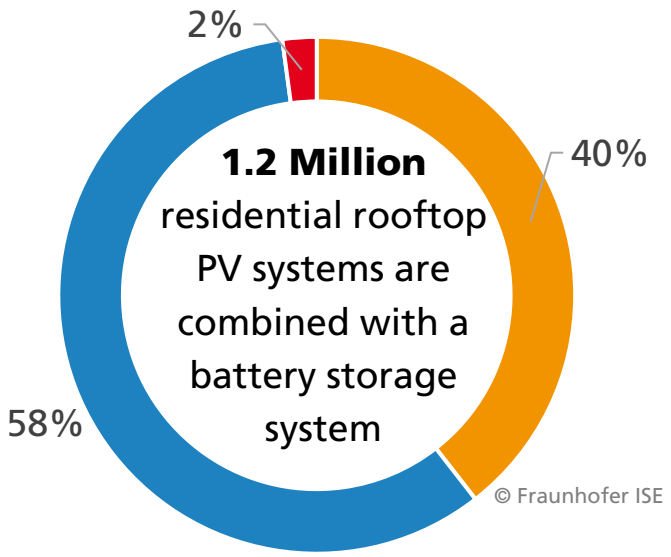
Mostly within the building PV system class (x ≤ 10 kW_p), balcony solar systems (up to 600 W feed-in power) accounted for 380 MW_p in 2023 in Germany [1].

Source: Fraunhofer ISE, own calculations based on MaStR (Date: 18.03.2024) and data validation algorithm
[1] Includes reported plug-in systems and systems assigned to this category according to MaStR (Date: 18.03.2024) and additional estimates by Fraunhofer ISE

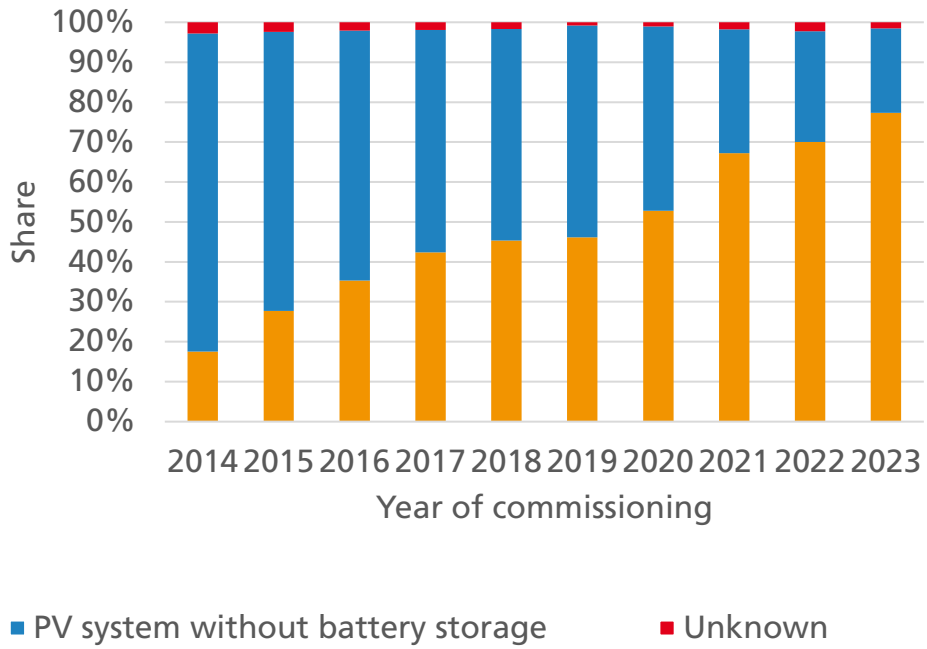
Share of PV-Installations with Battery Energy Storage Systems (BESS)

Residential Rooftop Systems in Germany

Until the end of 2023:



By year of commissioning:



PV systems with battery storage | PV system without battery storage | Unknown

By the end of 2023 over 40% (1.2 million units) of all residential PV-systems are combined with a BESS.

The share of residential rooftop PV-systems with a BESS increased from below 20% for commissioning in 2014 to almost 80% in 2023.

Residential rooftop PV systems are defined as all systems on buildings with a maximum capacity of 30 kWp according to MaStR-Data.

Source: Marktstammdatenregister - MaStR (Date: 01.04.2024)

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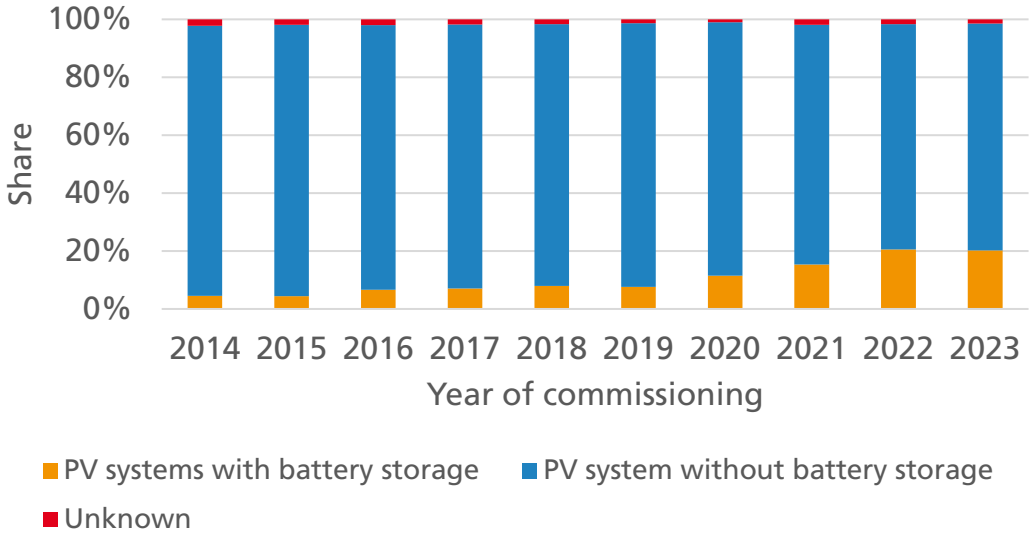
Share of PV-Installations with Battery Energy Storage Systems (BESS)

Commercial and Utility-Scale Systems in Germany

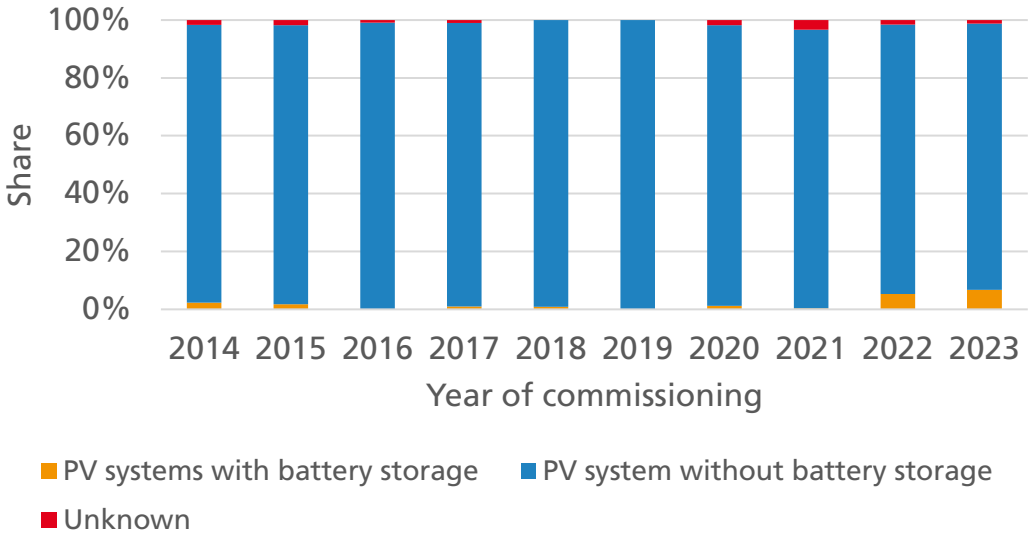
Commercial rooftop



The share of PV installations with BESS increased from 5% for commissioning in 2014 to 20% in 2023 in the commercial rooftop sector.

Commercial rooftop PV systems are defined as all systems on buildings with a capacity greater than 30 kWp according to MaStR-Data.

Utility-scale ground-mounted



There is a significant increase in PV with BESS shares in 2022 and 2023 to around 7% in the utility-scale PV power plant sector.

Utility-scale ground-mounted PV systems are defined as all ground-mounted systems with a capacity greater than 1 MWp according to MaStR-Data.

Source: Marktstammdatenregister - MaStR (Date: 01.04.2024)

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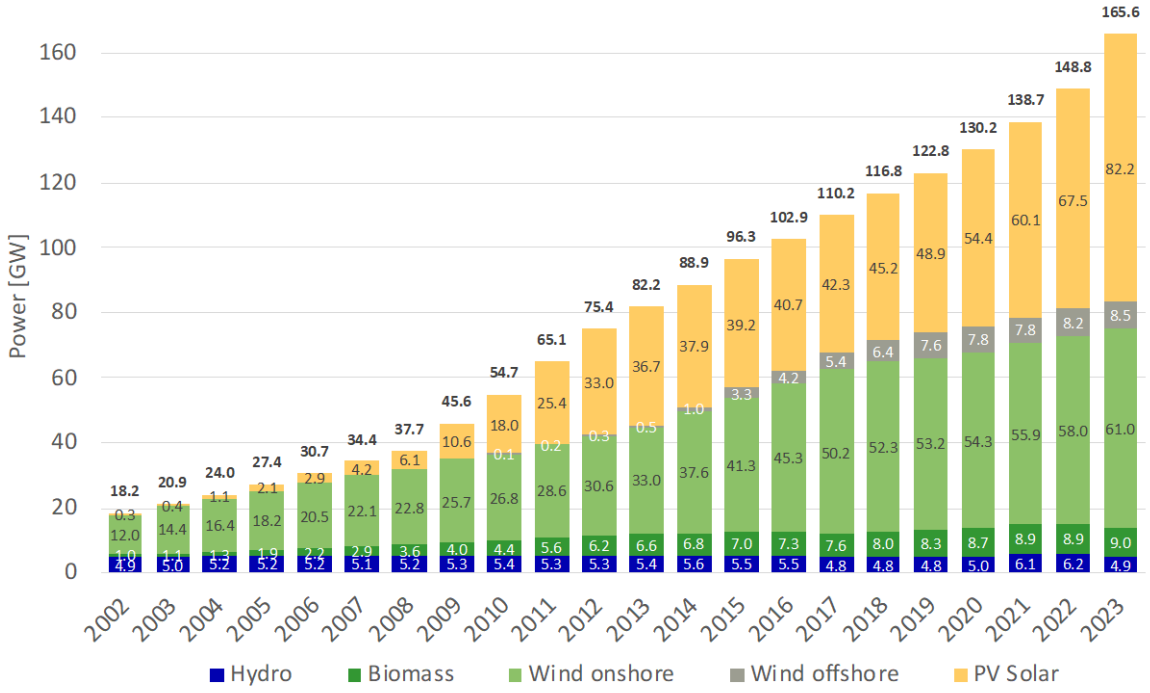
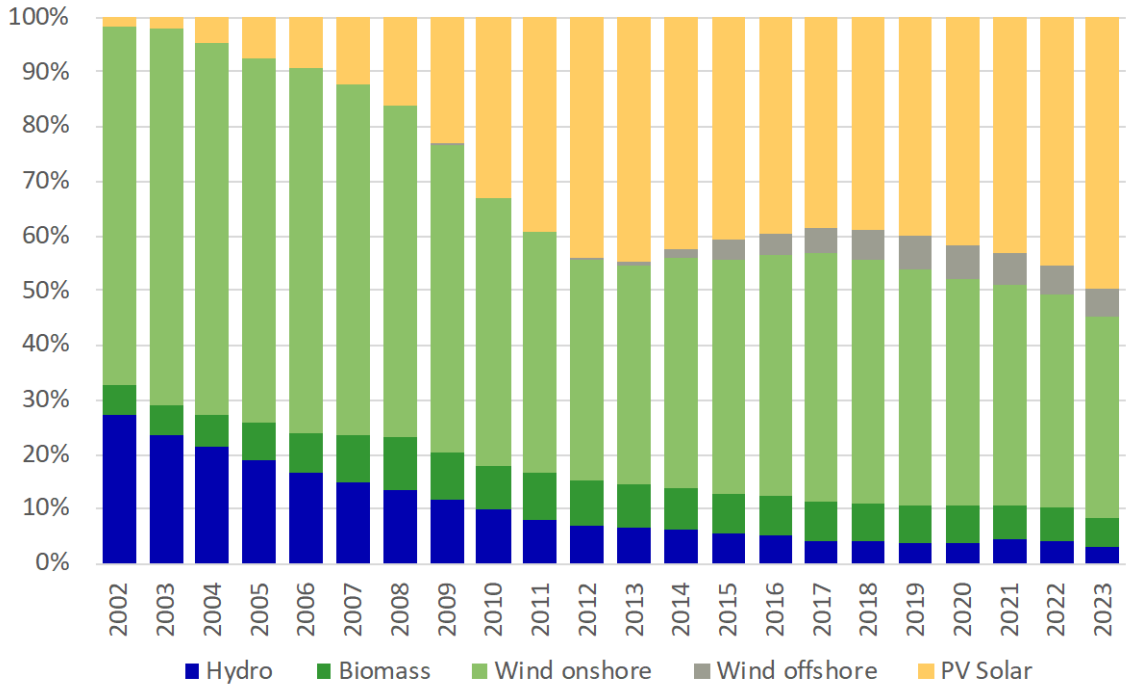
Electrical Capacity of Renewable Energy Sources (RES)

Germany





165.6 GW of total 261.6 GW net installed electricity generation capacity in Germany were from renewable energy sources (RES) in Germany in year 2023. This results in a RE share of 63.3% of total capacity.

Data:: Energy Charts by Prof. Dr. Bruno Burger. Date of data: 03/2024

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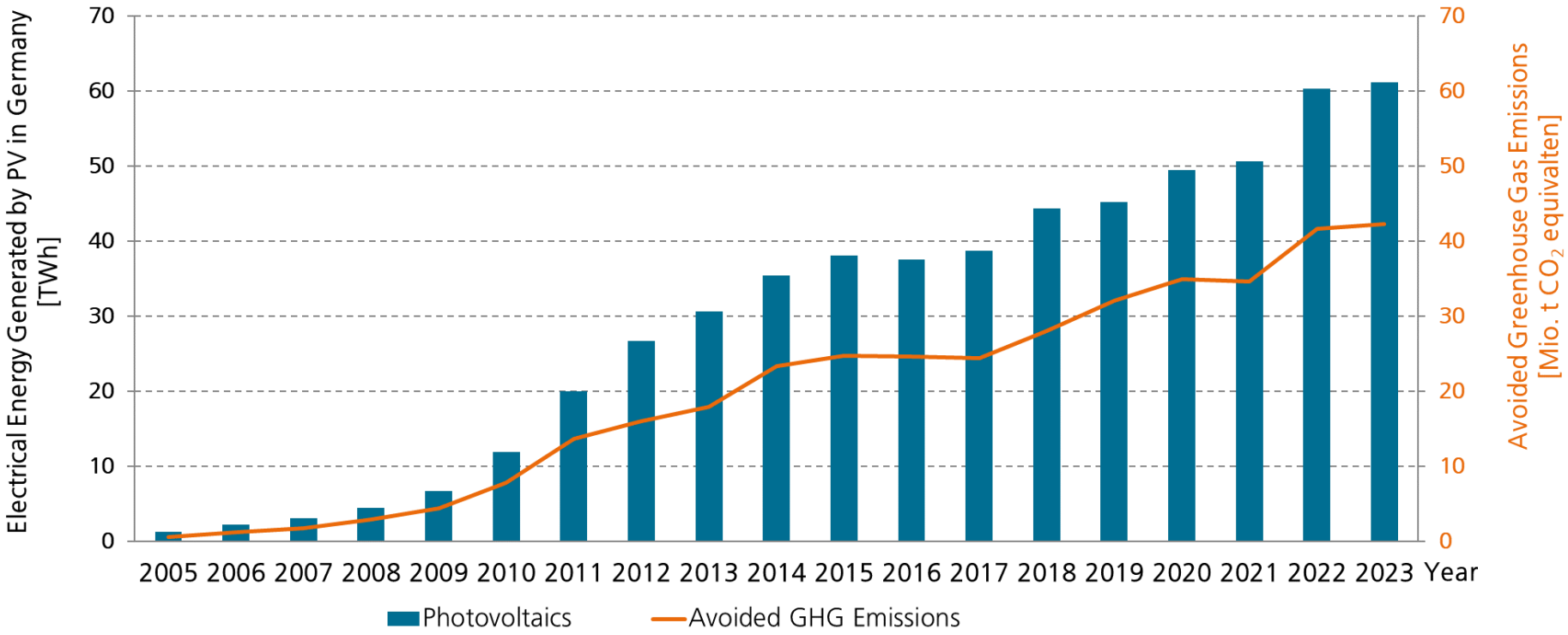
PV Energy Generated and Resulting GHG Avoided Emissions

Germany



In 2023 Greenhouse Gas emissions of about 42 Mio. t CO_2-equivalent were avoided due to 61 TWh PV electricity consumed in Germany.

Data: BMU, BDEW, BMWi, Federal Environmental Agency (UBA) 02/2024. Graph: PSE Projects GmbH 2024

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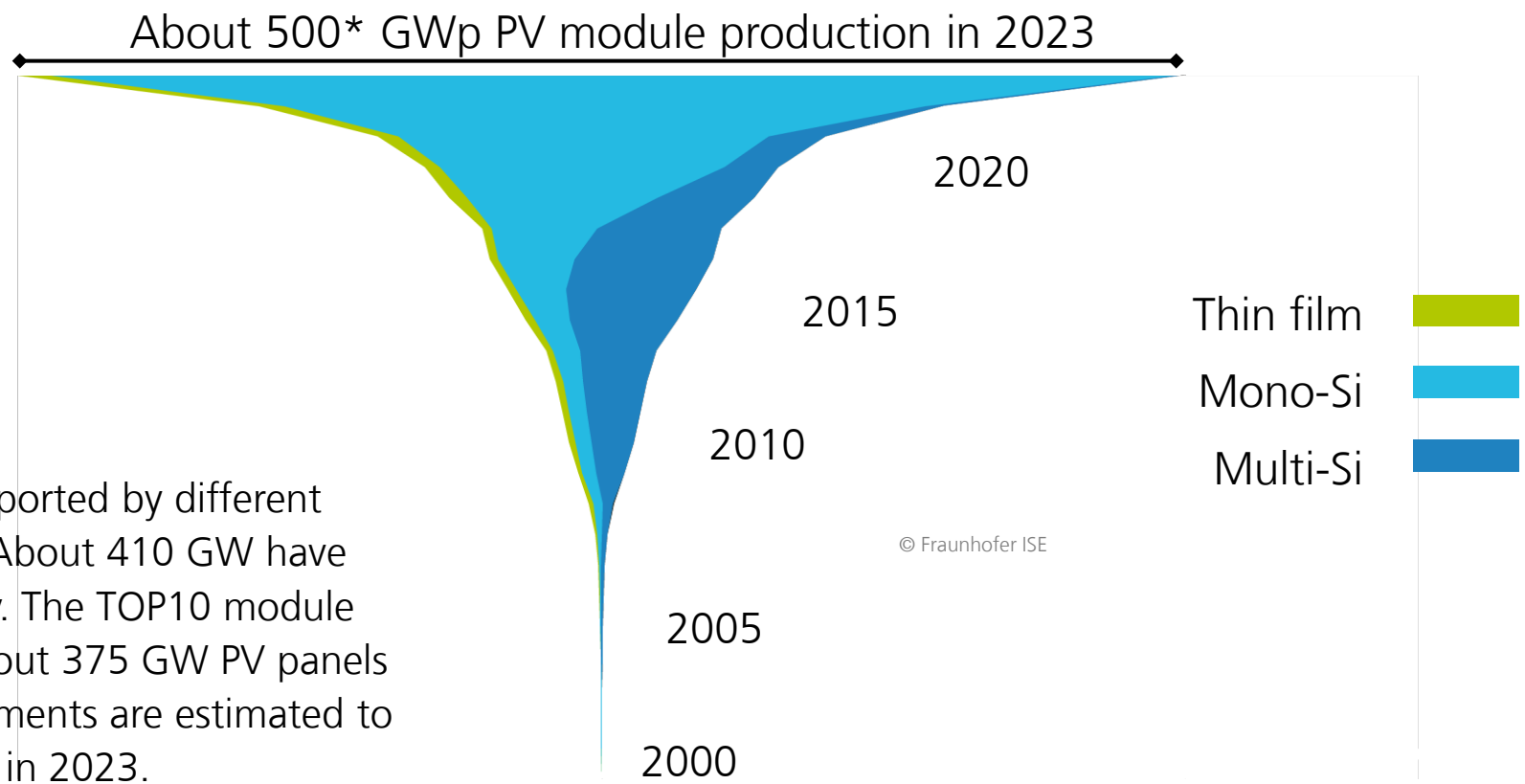
Annual PV Production by Technology

Worldwide (in GWp)



*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.

Data: from 2000 to 2009: Navigant; from 2010 to 2021 IHS Markit; from 2022 estimates based on IEA and other sources. Graph: PSE Projects GmbH 2024 . Date of data: 04/2024

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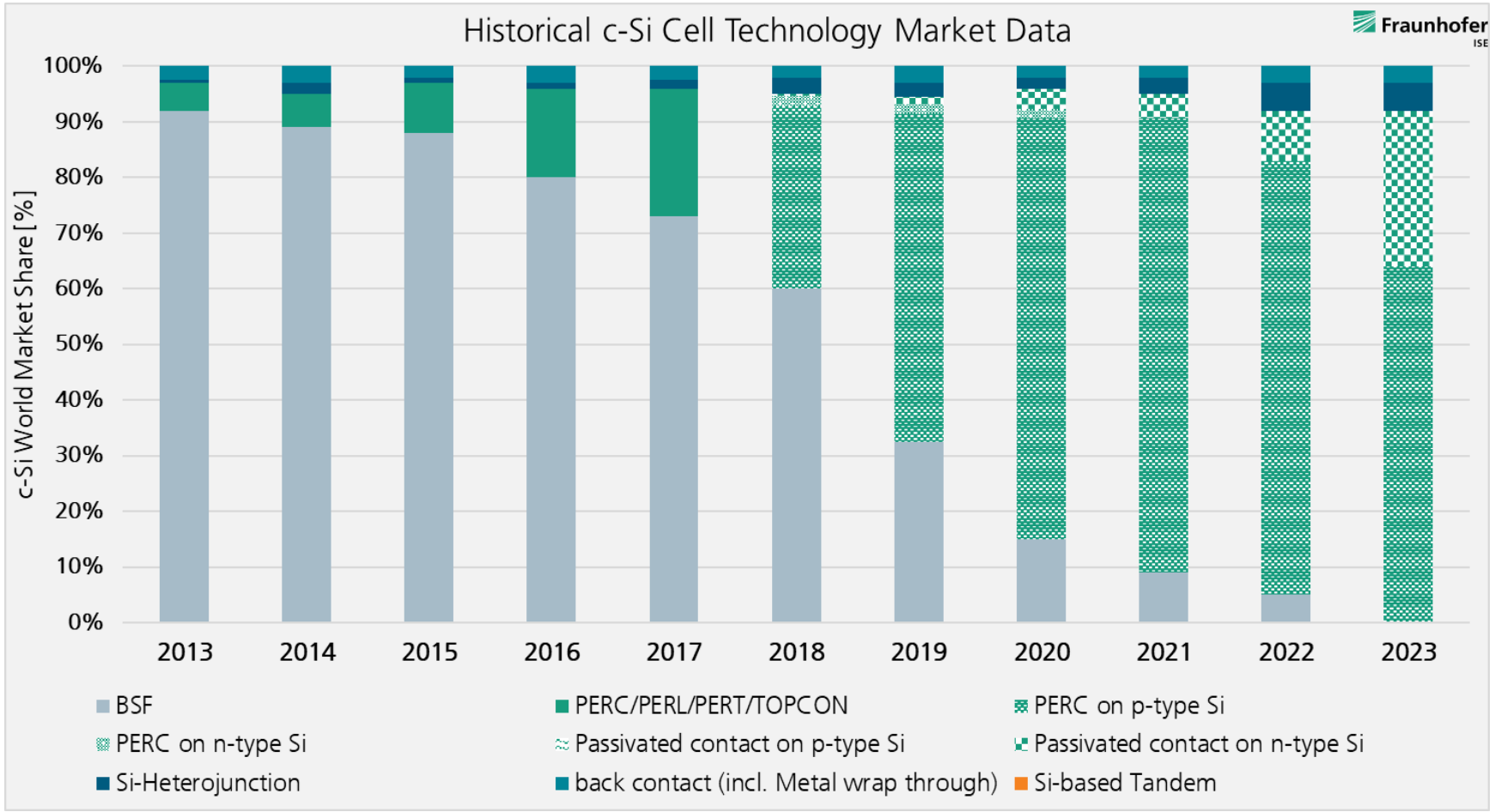
Technology Overview

Different crystalline-Silicon Cell Technology Market Shares



Source: based on ITRPV 2013-2024

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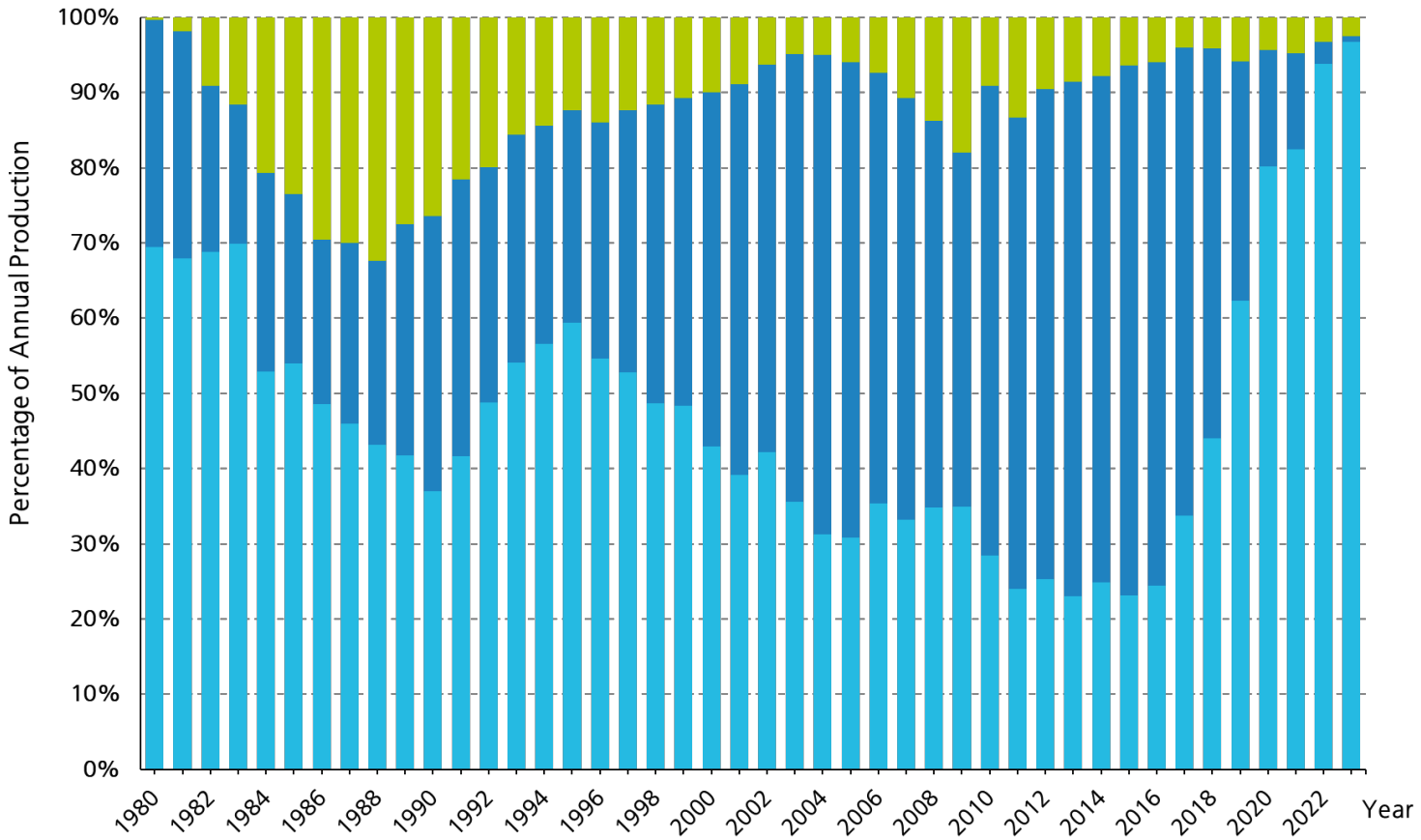
PV Production by Technology

Percentage of Global Annual Production



Production 2023* (GWp)

Thin film	13	
Multi-Si	4	
Mono-Si	485	
Total	502	(ITRPV)

*estimated

Data: from 2000 to 2009: Navigant; from 2010 to 2021 IHS Markit; from 2022 estimates based on IEA and other sources. Graph: PSE Projects GmbH 2024 . Date of data: 04/2024

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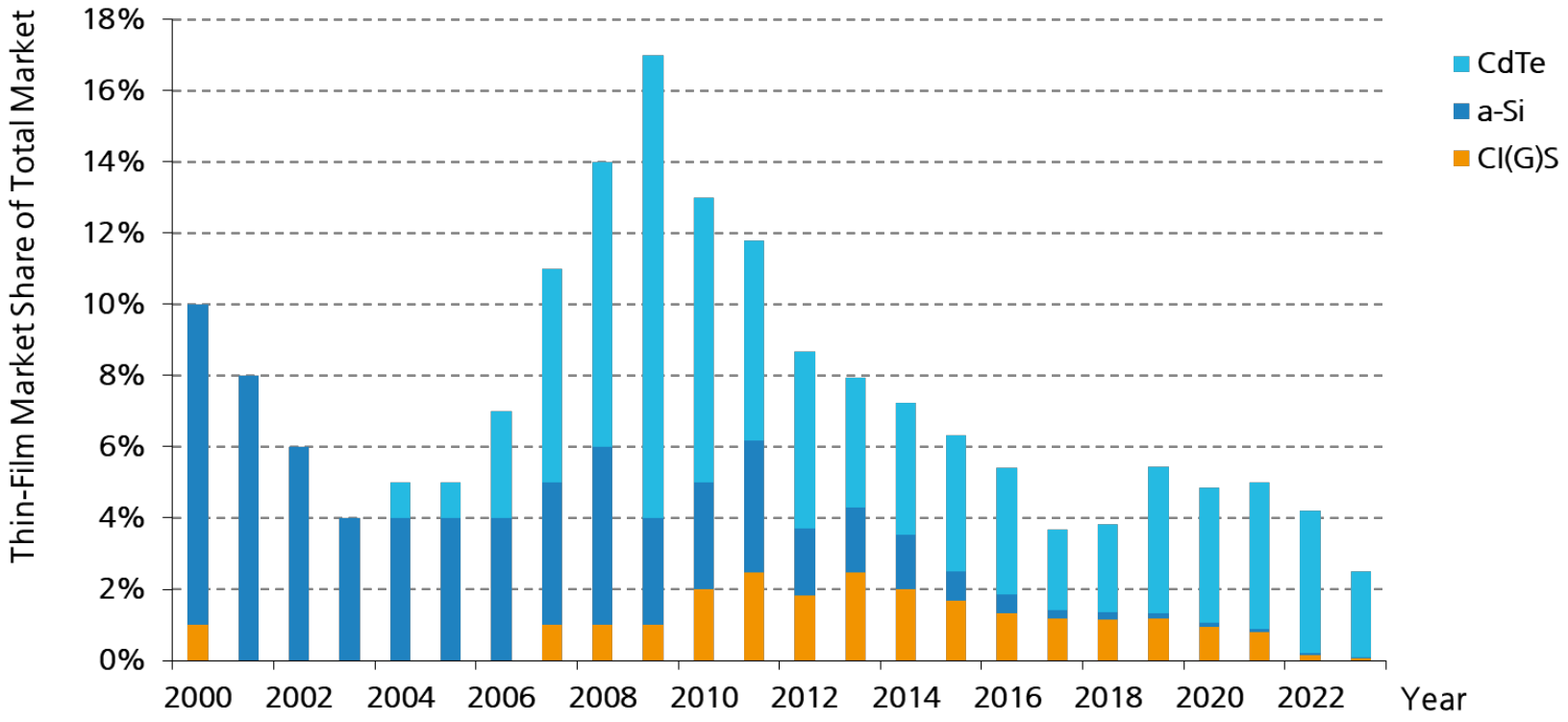
Market Share of Thin-Film Technologies

Percentage of Total Global PV Production



Thin-Film technology contributed in year 2023 with about 2.5% to the total PV-market.

Data: from 2000 to 2009: Navigant; from 2010 to 2021 IHS Markit; from 2022 estimates based on IEA and other sources. Graph: PSE Projects GmbH 2024 . Date of data: 04/2024

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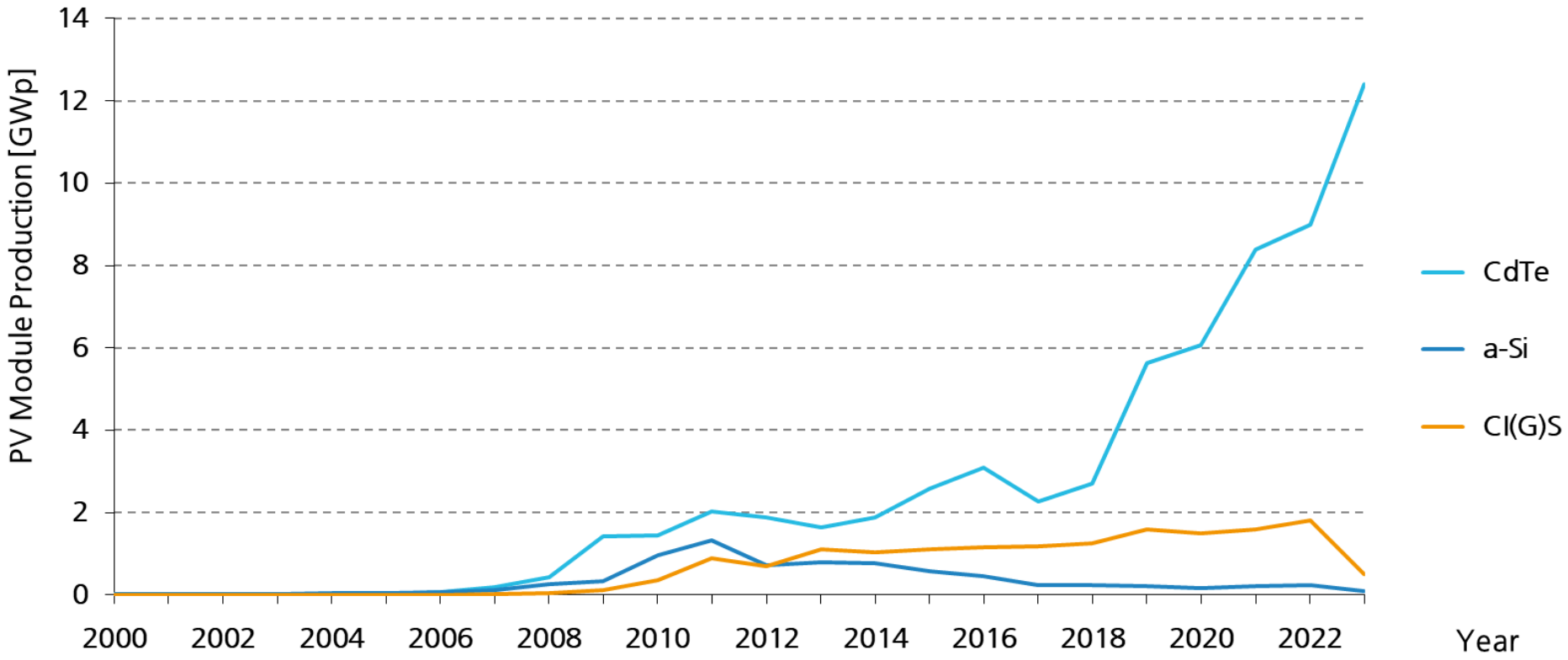
Thin-Film Technologies

Annual Global PV Module Production



Data: from 2000 to 2009: Navigant; from 2010 to 2021 IHS Markit; from 2022 estimates based on IEA and other sources. Graph: PSE Projects GmbH 2024 . Date of data: 04/2024

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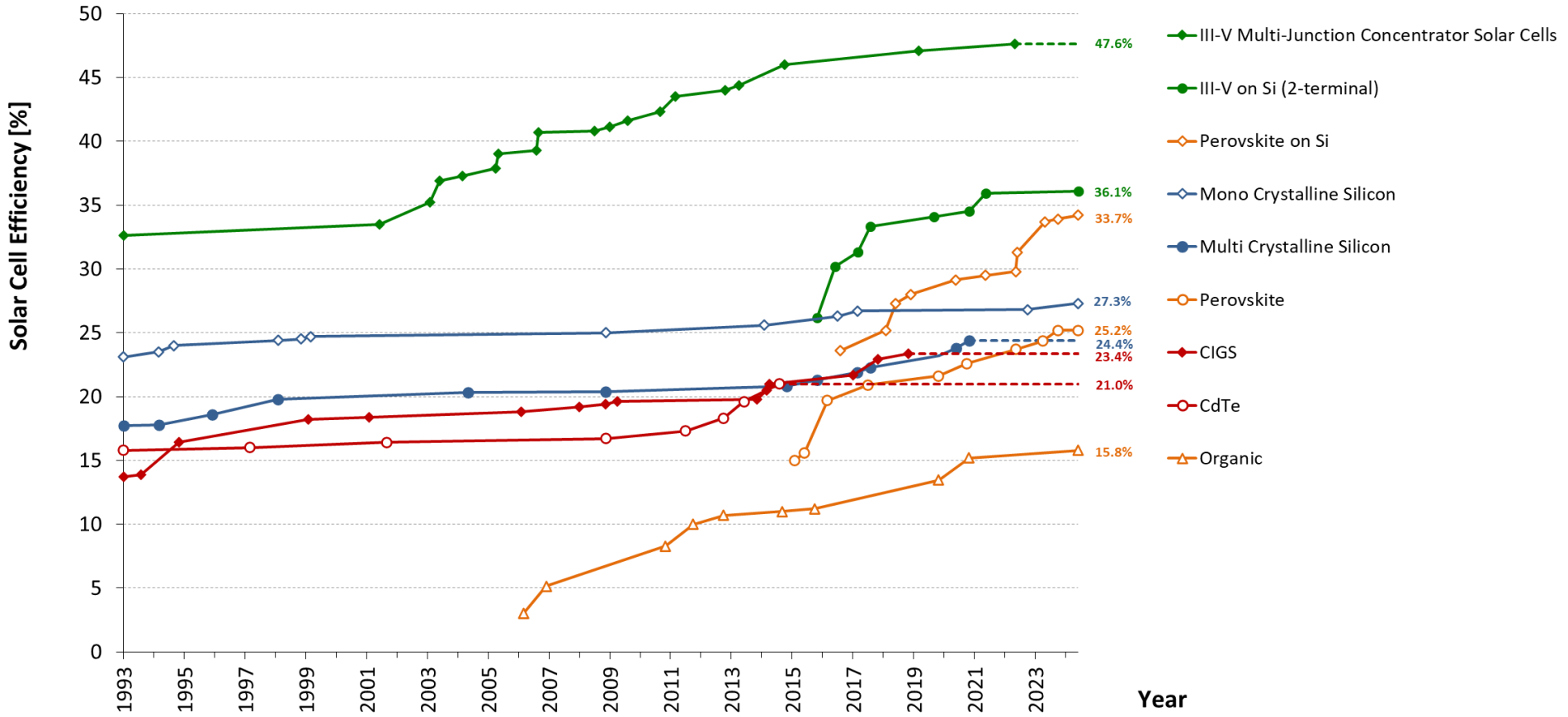
2. Solar Cells / Modules / System Efficiency

- Development in the Laboratories
- Development in the PV Industry
- Performance Ratio (PR)

Development of Laboratory Solar Cell Efficiencies

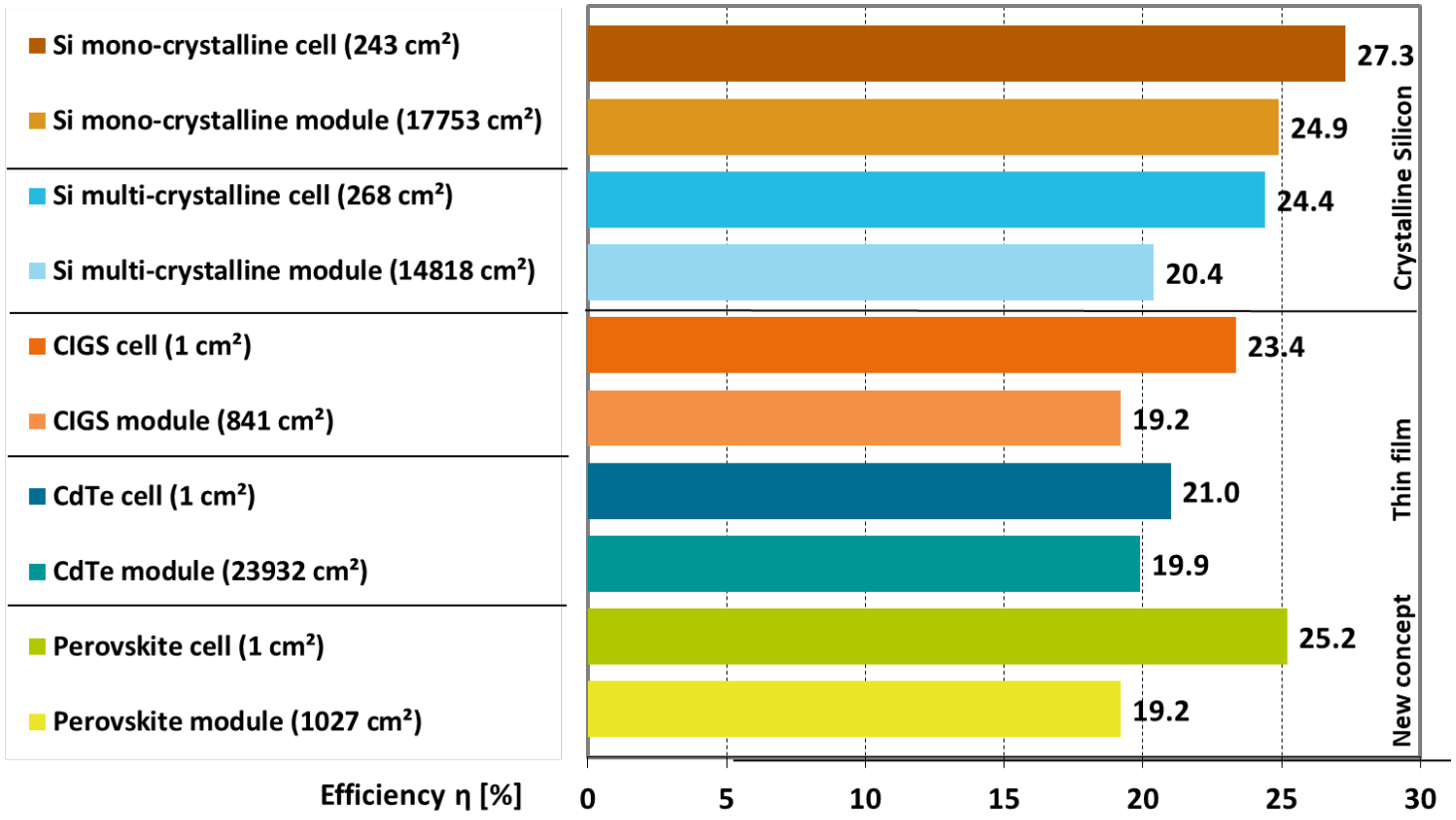


Data: Solar Cell Efficiency Tables (Versions 1 to 64), Progress in Photovoltaics: Research and Applications, 1993-2024. Graph: Fraunhofer ISE 2024. Date of data: 06/2024

Only official lab record efficiencies published in the Solar Cell Efficiency Tables, Progress in Photovoltaics: Research and Applications are included in the graph.

Efficiency Comparison of Technologies

Best Lab Cells vs. Best Lab Modules



Note: In mass production, the cell-to-module ratio (CTM) improved in past years by reducing losses and using possible gains when integrating solar cells in modules.

Fraunhofer ISE provides SmartCalc.CTM software suite for precise Cell-to-Module (CTM) power loss analysis. It considers geometrical losses, optical losses and gains as well as electrical losses.

www.cell-to-module.com

Data: Green et al.: Solar Cell Efficiency Tables (Version 64), Progress in PV: Research and Applications 2024. Graph: PSE Projects GmbH 2024. Date of data: 06/2024

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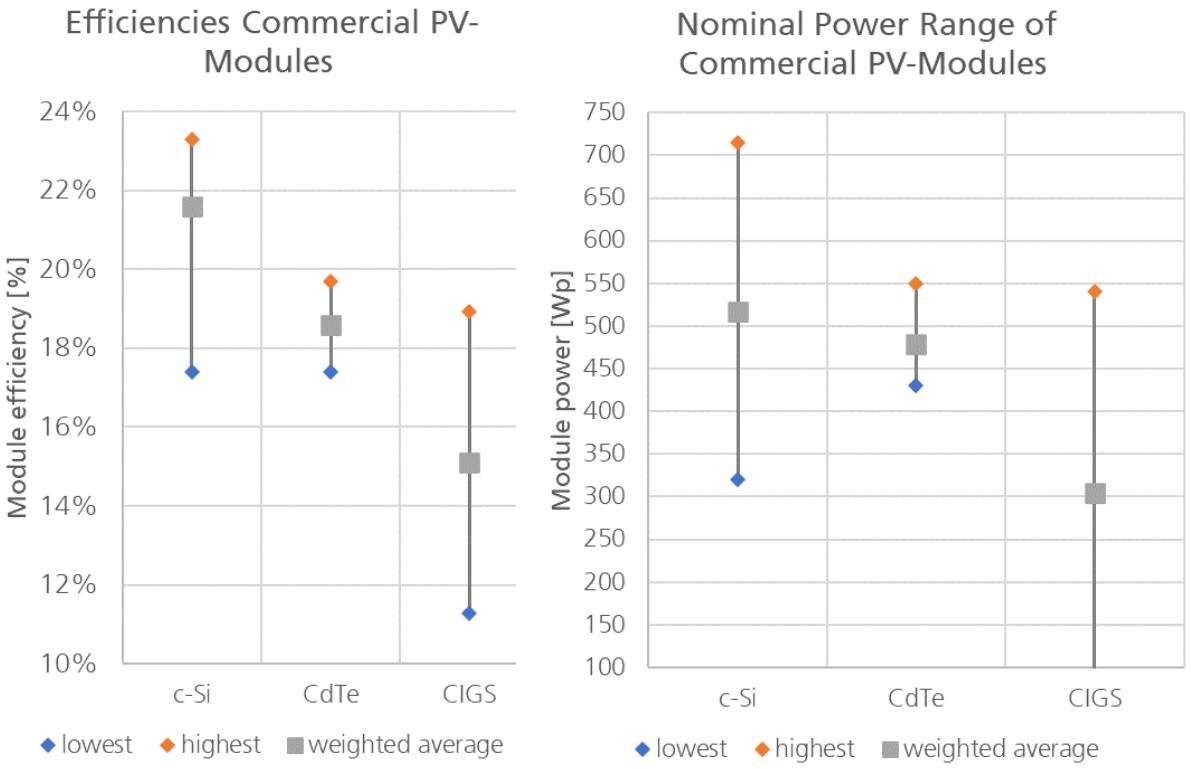
Current Efficiencies and Power of Commercial PV Modules

Sorted by technology



- Total weighted average efficiency of crystalline Silicon(c-Si) wafer-based modules is 21.6% in Q4-2023 (was 20.9% in Q4-2022); weighting factor is total shipments in year 2023. Lowest module efficiency in this group is 17.4% (was 17.2% one year before) and highest value is 23.3% (was 23.2% in 2022).
- Top 10 manufacturers represent about 75% of total shipment volume and origin mainly in Asia.
- Predominant c-Si technology is mono-PERC with half-cut cells and Multi-Busbar.

Note: The selection is based on modules from the top 10 manufacturers in 2023 (except CIGS), with module data sheets available worldwide at the end of January 2024. For CIGS technology, only a very limited amount of supplier data was available, and the products indicated are manufactured for niche markets such as building integrated PV (BIPV) or flexible module applications, so comparability with the other two technologies is limited.

Data Source: company product data sheets; Graph: PSE Projects GmbH 2024; Date of data: 02/2024

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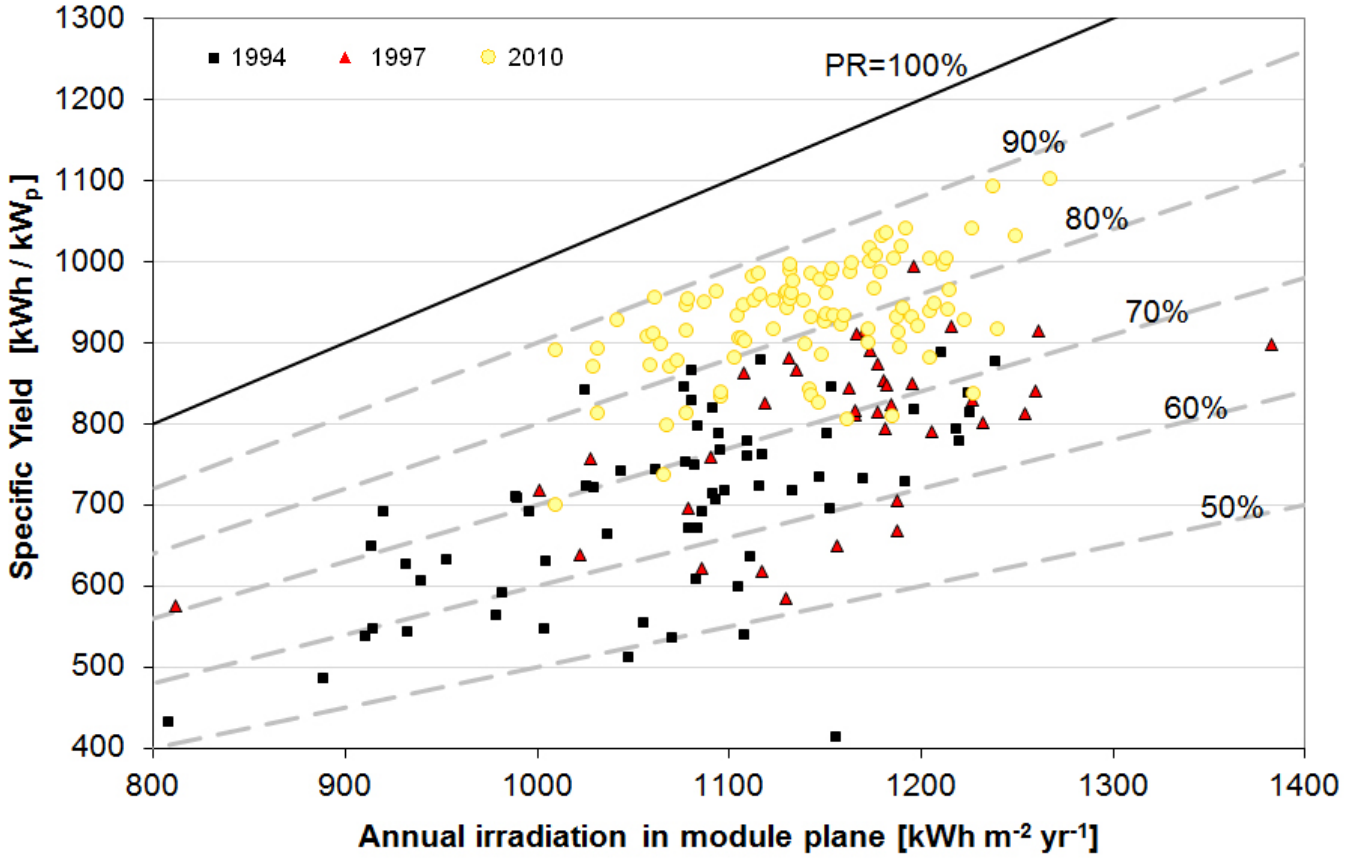
Performance Ratio Development for PV Systems

Germany



- In the 1990's
  - Typical PR ~70 %
  - Widely ranging PR values
- Today
  - Typical PR ~83 %
  - Less variance in PR as compared to 1990's

Source: Fraunhofer ISE "1000 Dächer Jahresbericht" 1994 and 1997; 2011 system evaluation, CPIA 2021

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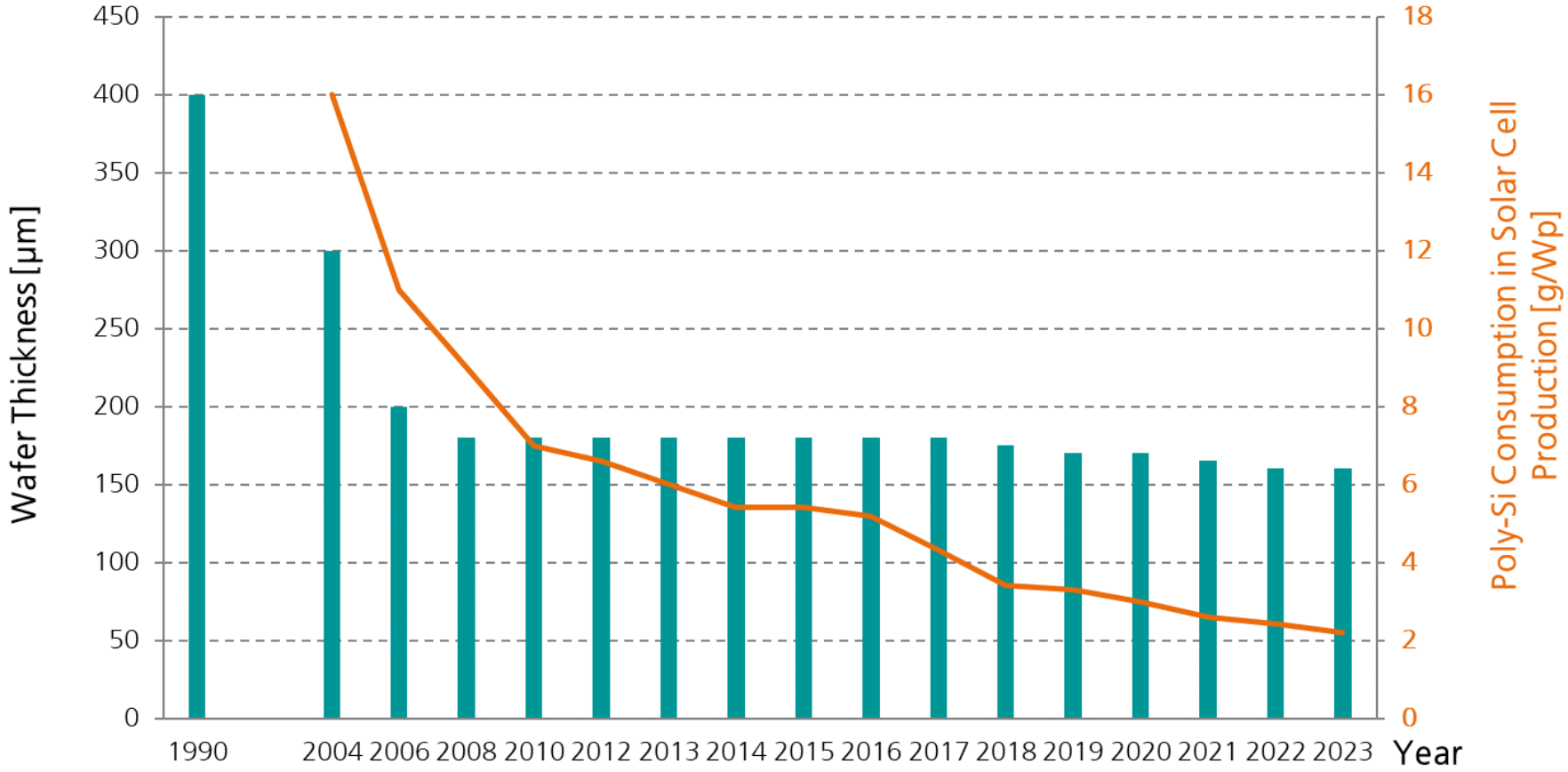
3. Life Cycle Assessment (LCA) and Sustainability Aspects

- Silicon usage, wafer thickness and kerf loss for c-Si
- EPBT: Development and comparison

c-Si Solar Cell Development

Wafer Thickness [µm] & Silicon Usage [g/Wp]



Data: until 2012: EU PV Technology Platform Strategic Research Agenda, from 2012: ITRPV; from 2016 ISE without; 2017 ongoing with recycling of Si. Graph: PSE Projects GmbH 2024; date of data: 04/2024

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Historic Trend in Energy Payback Time

Harmonized study data for mono-crystalline silicon rooftop PV systems

Learning Rate:
Each time the cumulative production doubled, the EPBT went down by 12.8 % for the last 24 years.

Harmonization methodology
based on Koppelaar (2016) harmonized results and harmonization parameters

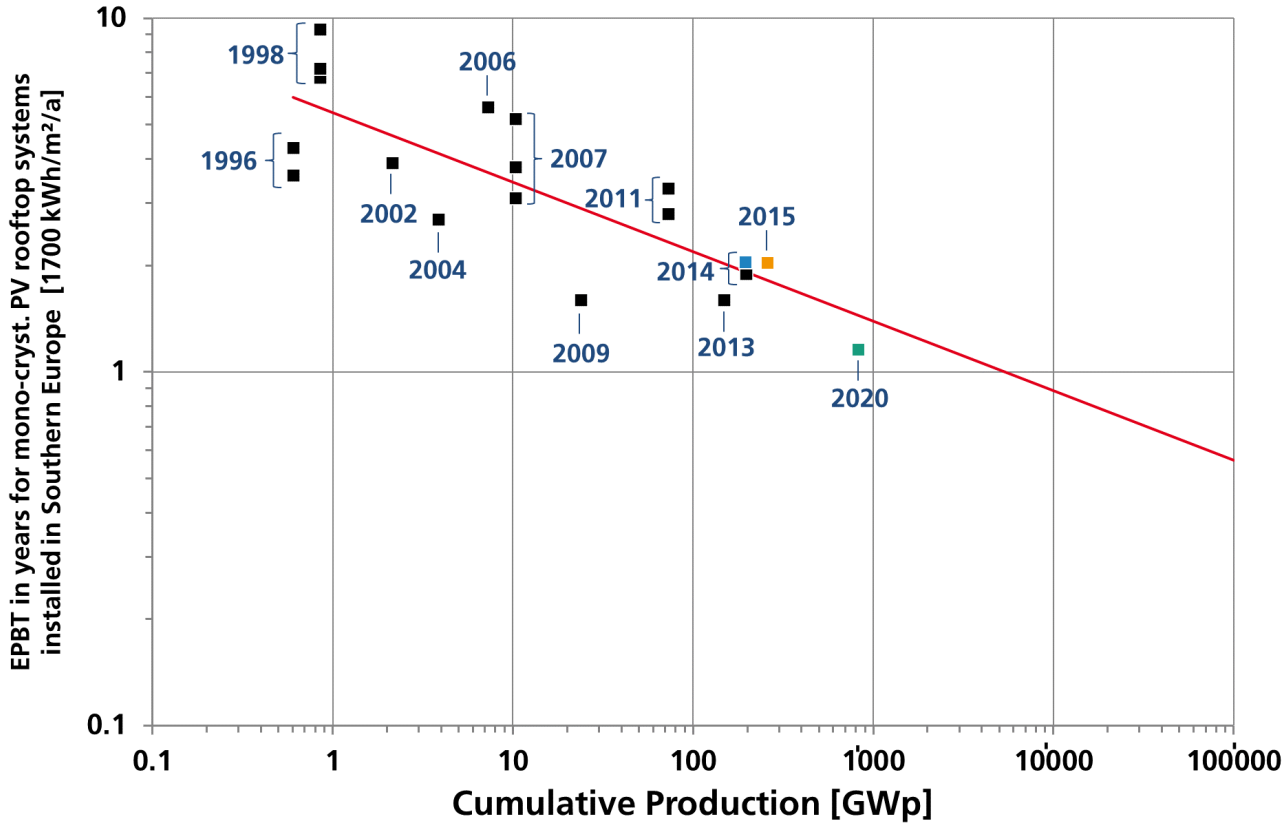
1) Performance Ratio
based on average annual PV yield during lifetime

PV system lifetime	25
Degradation	0.70%
PR (initial)	80%
PR (incl. average degradation during lifetime)	**73.6%**

2) Grid efficiency
for converting PV yield in primary energy equivalents

grid efficiency	**35%**

EPBT of Leccisi (2016), Louwen (2014) and Friedrich (2020) were harmonized with 1) PR (incl. average degradation) and 2) grid efficiency to results of Koppelaar (2016)*



Data: Fraunhofer ISE. Graph: PSE Projects GmbH 2021

Irradiation: 1700 kWh/m²/a at an optimized tilt angle; **Years:** Estimated average year of original data

* Koppelaar (2016) - Solar-PV energy payback and net energy: Meta-assessment of study quality, reproducibility, and results harmonization, Renewable and Sustainable Energy Reviews
Leccidi et al. (2016) - The Energy and Environmental Performance of Ground-Mounted Photovoltaic Systems—A Timely Update, Energies
Louwen et al. (2014) - Life-cycle greenhouse gas emissions and energy payback time of current and prospective silicon heterojunction solar cell designs, Progress in Photovoltaics
Friedrich et al. (2020) - Global Warming Potential and Energy Payback Time Analysis of Photovoltaic Electricity by Passivated Emitter and Rear Cell (PERC) Solar Modules, submitted JPV

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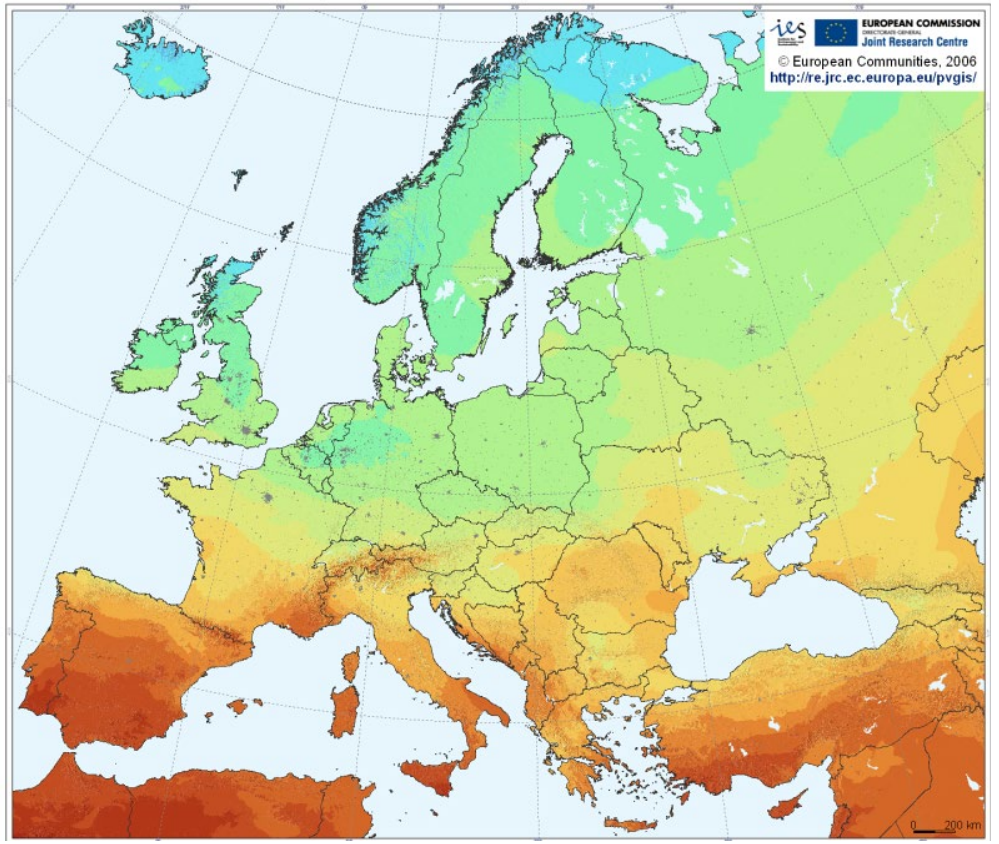
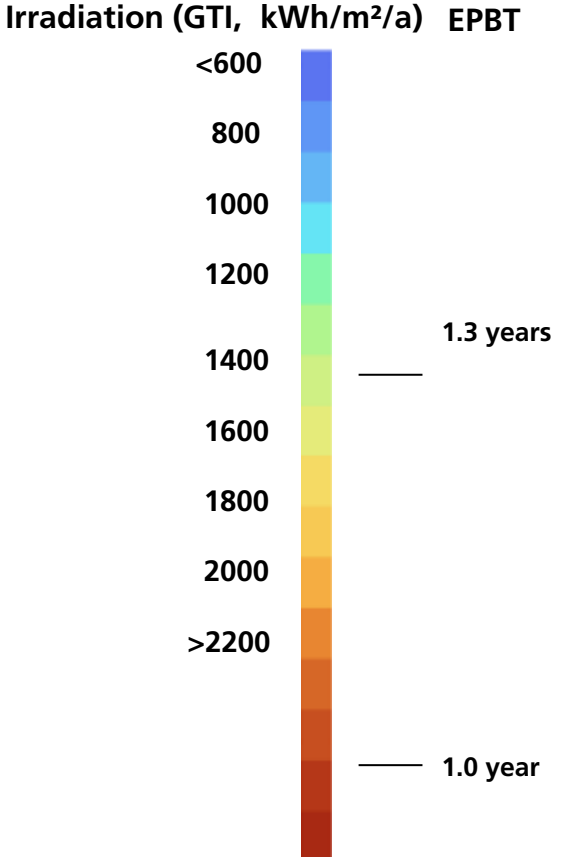
Energy Pay-Back Time of Silicon PV Rooftop Systems

Geographical Comparison

- Rooftop PV system using mono-crystalline silicon cells* produced in China
- EPBT is dependent on irradiation, but also on other factors like grid efficiency**.
- Better grid efficiency in Europe may decrease the EPBT by typically 9.5 % compared to PV modules produced in China.





Data source: Fraunhofer ISE. Image: JRC European Commission. Graph: PSE Projects GmbH 2020 (Modified scale with updated data from Fraunhofer ISE)

*Cz PERC cells module with 19.9% efficiency
**relation between primary energy to produced electricity in the grid used for manufacturing of the PV system

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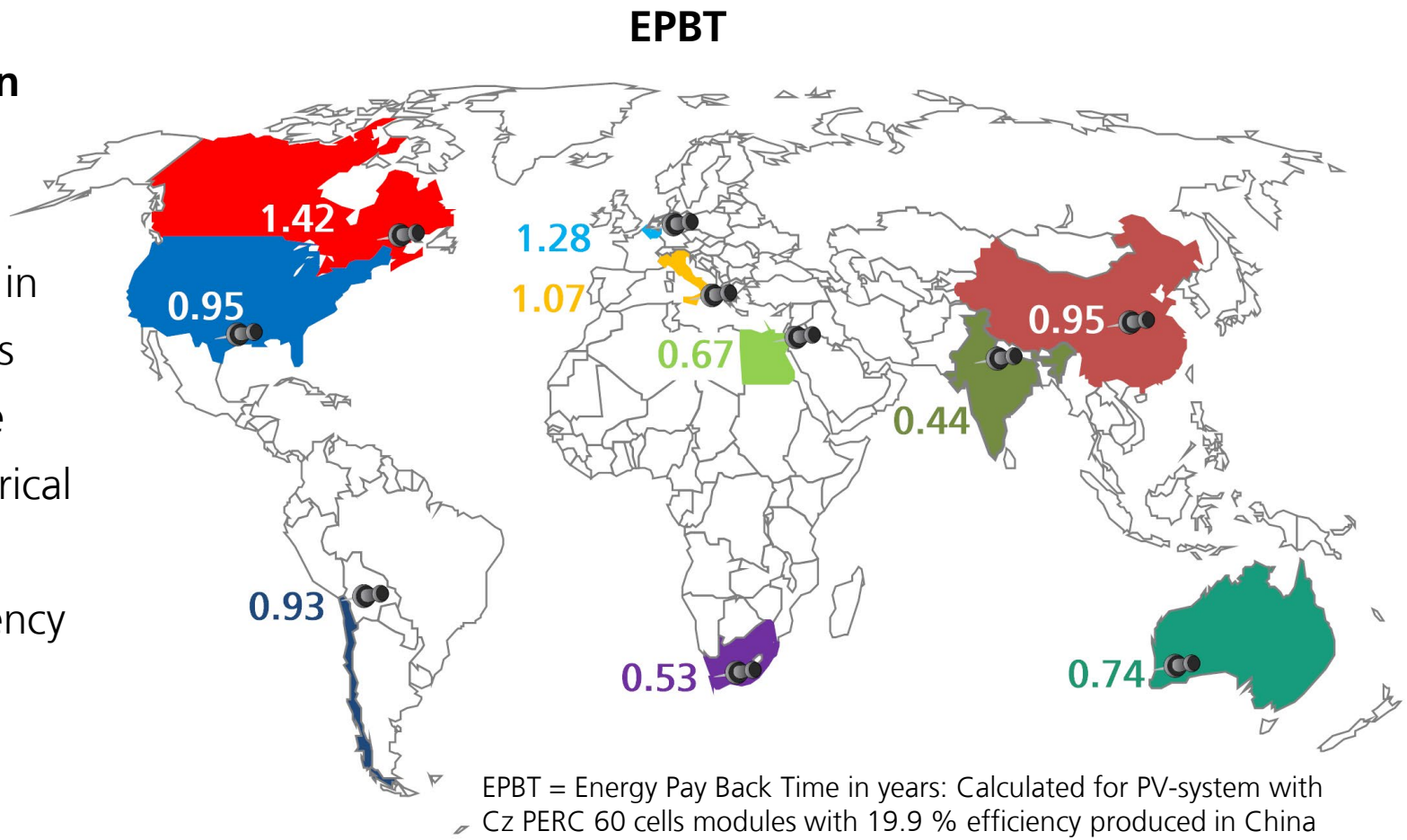
World Map EPBT of Silicon PV Rooftop Systems

Comparison of EPBT China

Influencing Factors and Interpretation

- **EPBT:** the lower, the better
- **Irradiation:** the higher, the better
- **Grid efficiency:** the higher, the better in countries where upstream production is located; (better energy mix to generate electrical power; less losses in the electrical transmission network). At downstream (where PV is installed) a low grid efficiency reduces the EPBT.



EPBT = Energy Pay Back Time in years: Calculated for PV-system with Cz PERC 60 cells modules with 19.9 % efficiency produced in China

Data source: Fraunhofer ISE.

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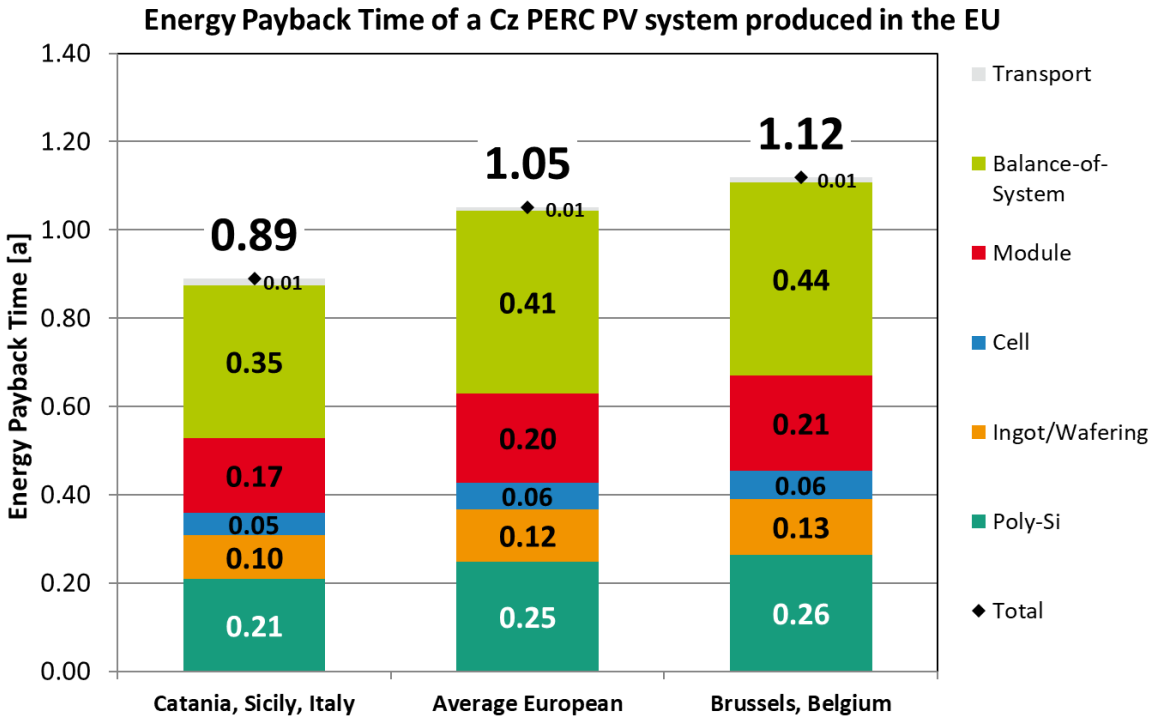
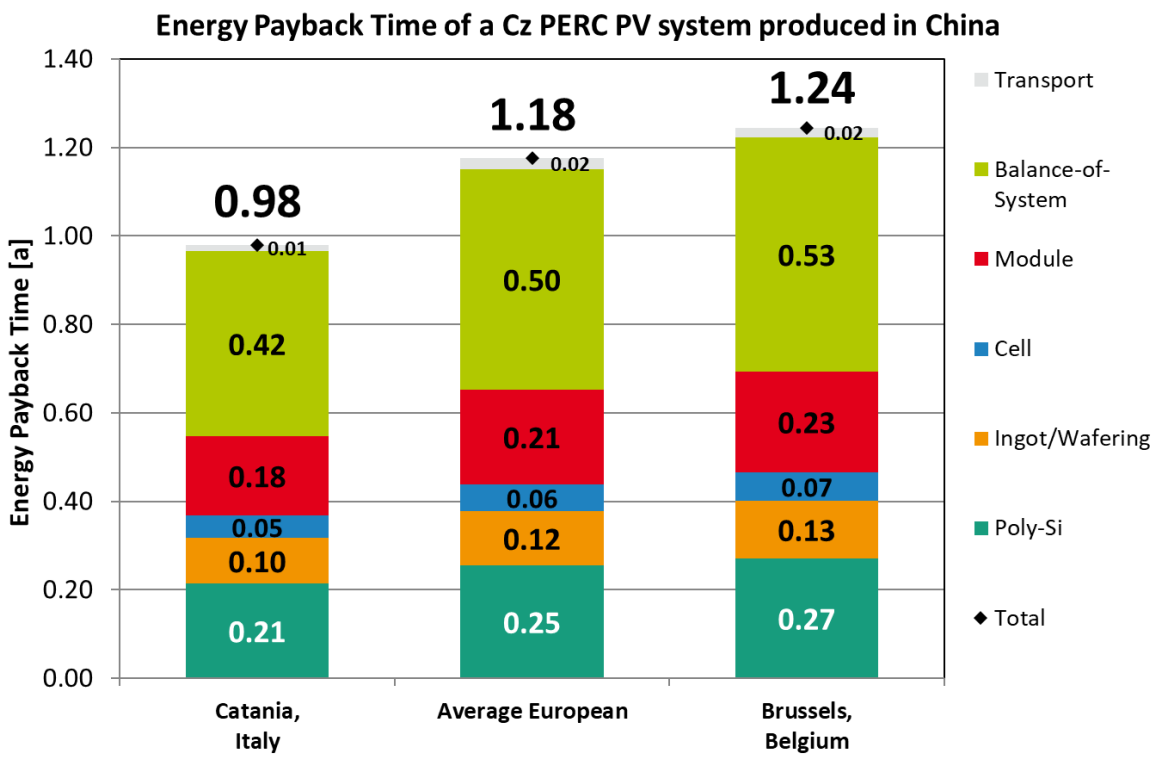
Energy Pay-Back Time of Silicon PV Rooftop Systems –

Comparison of EPBT China / EU, local Irradiation and Grid Efficiency 2021





EPBT for PV systems produced in Europe is shorter than for those produced in China because of better grid efficiency in Europe.

Data source: Fraunhofer ISE. Calculations for year 2021 made at 22-July 2022

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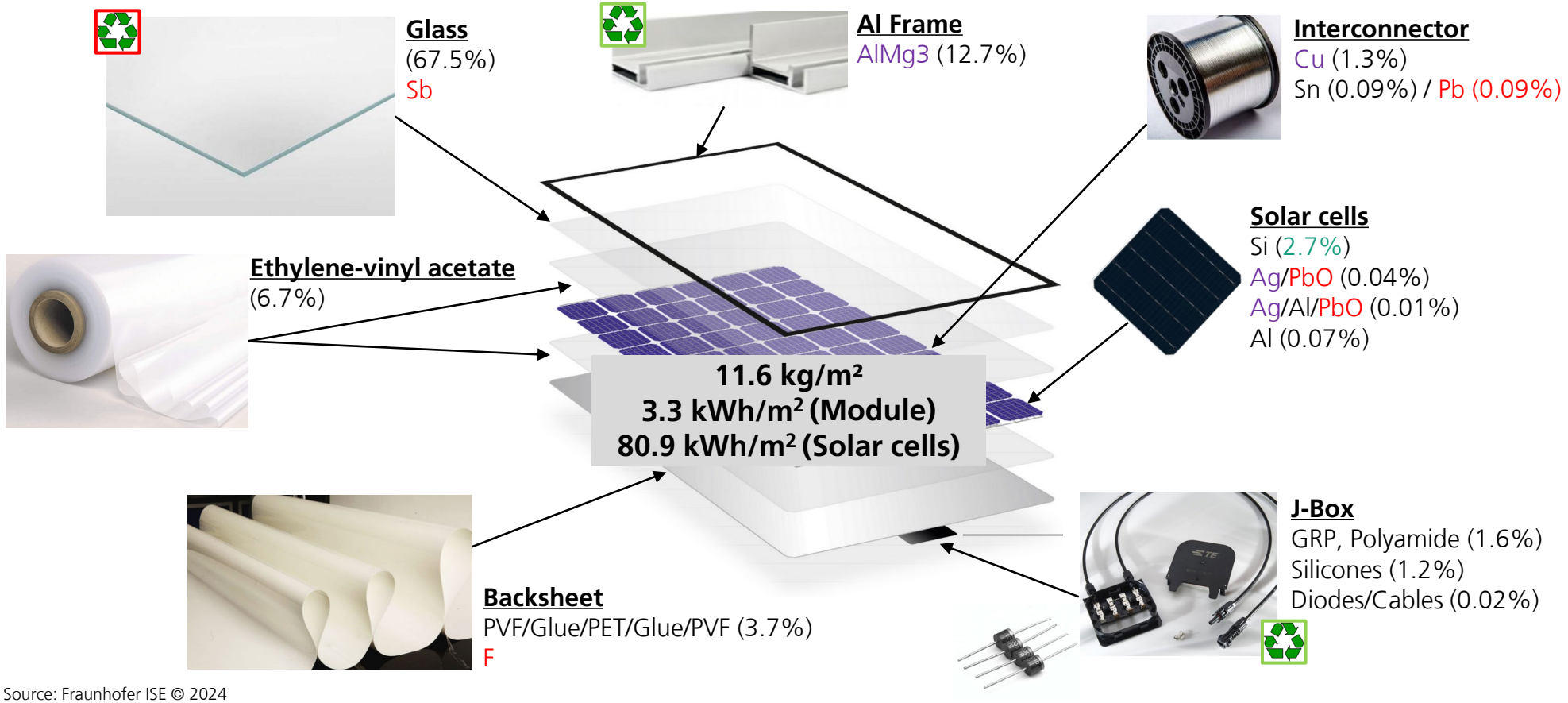
PV-Module

Materials and Components



Please note: Highly transparent glass can also be produced without antimony (Sb), and some European suppliers are doing so. It is technically feasible to recycle and reuse almost 100% of the materials used in PV modules. The European WEEE Directive stipulates that at least 80% of the module mass of old modules must be processed and recycled for reuse. For economic reasons, however, only the glass, frame and junction box (J-Box) are recycled today.

Color legend:

Available/harmless materials
Rare/valuable materials
Hazardous substances

Recycling takes place

Downcycling takes place

Source: Fraunhofer ISE © 2024

Mass fraction of substance in relation to total module mass of 11.6 kg/m² (100%) given in brackets; Date of data: 2021

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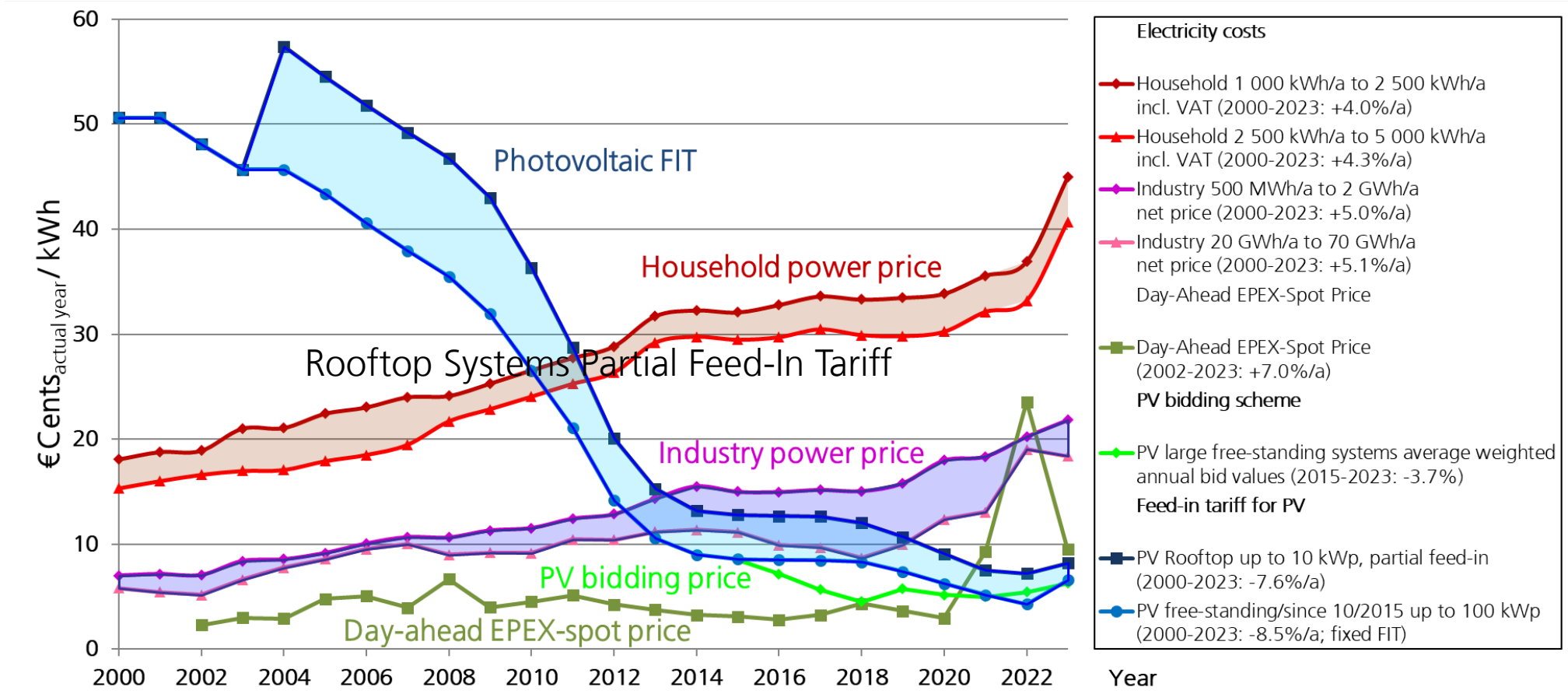
4. Price Development

- Electricity costs
- Market incentives in Germany
- Costs for PV systems
- Price Learning Curve

Electricity Prices, PV Feed-In Tariffs (FIT) and Bidding Scheme in Germany

With Photovoltaic Rooftop Systems Partial Feed-In Tariff



Data: BNA; energy-charts.info; Design: B. Burger - Fraunhofer ISE. Graph: PSE Projects GmbH 2024; Date of data: 04/2024

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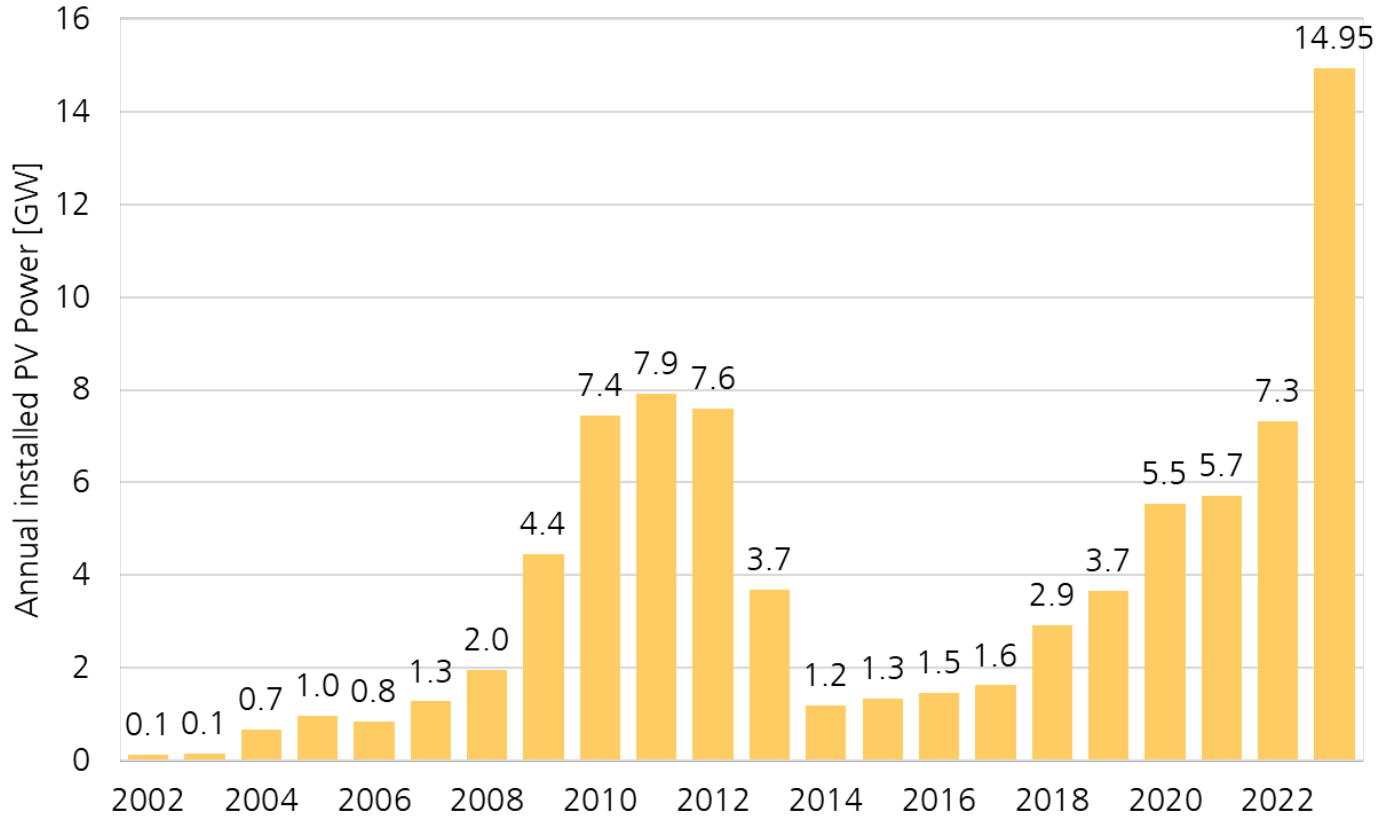
PV Market Development and Incentive Schemes in Germany



Data: BNA. Graph: B. Burger, Fraunhofer ISE Energy-Charts. Date of Data: 03/2024

Market Incentive	Start	End
1'000 Roofs Program	1990	1995
Cost-covering remuneration	1993	1999
100'000 Roofs-Program	1999	2003
EEG	2000	ongoing
PV Tendering scheme	2015	ongoing

The EEG 2023 law relies on a massive expansion of renewable energies with total installed PV capacity targets of 215 GW in year 2030 and 400 GW in 2040. In 2023, new PV systems totaling around 15 GW capacity have been connected to the grid. 9 GW capacity was announced for 2024. From 2026 on, the expansion target is 22 GW of new installations on an annual basis.

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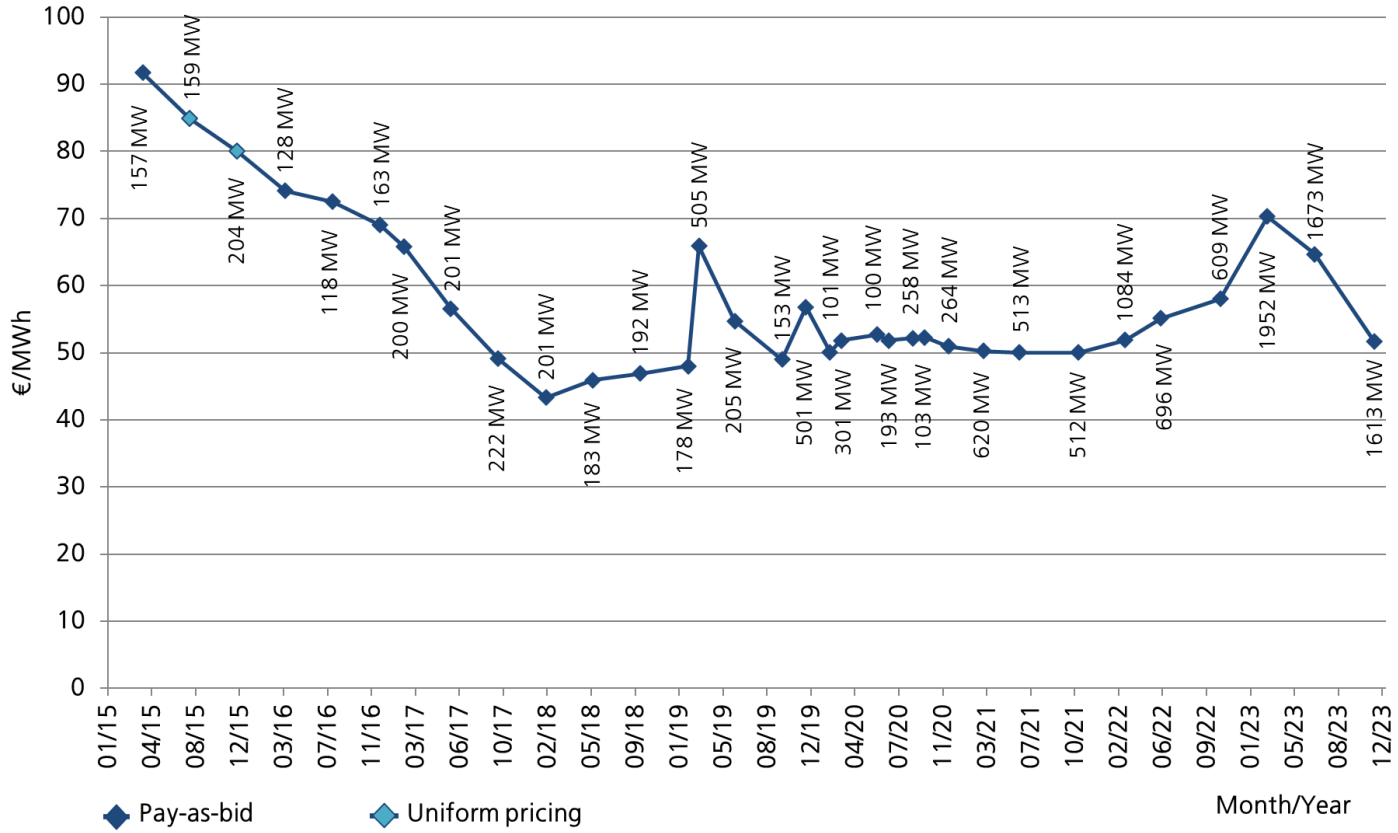
PV Tender Scheme in Germany for Free-Standing Systems

Average, quantity weighted award value



Data: BNA. Graph: PSE Projects GmbH 2024 – Date of data: Feb-2024

- The PV tender scheme for large ground-mounted systems started in April 2015. The total capacity of this scheme amounted to 14.1 GW in Dec. 2023 with 5.2 ct€ / kWh as latest average quantity weighted award price.
- PV-rooftop and special tenders are not displayed in the graph.

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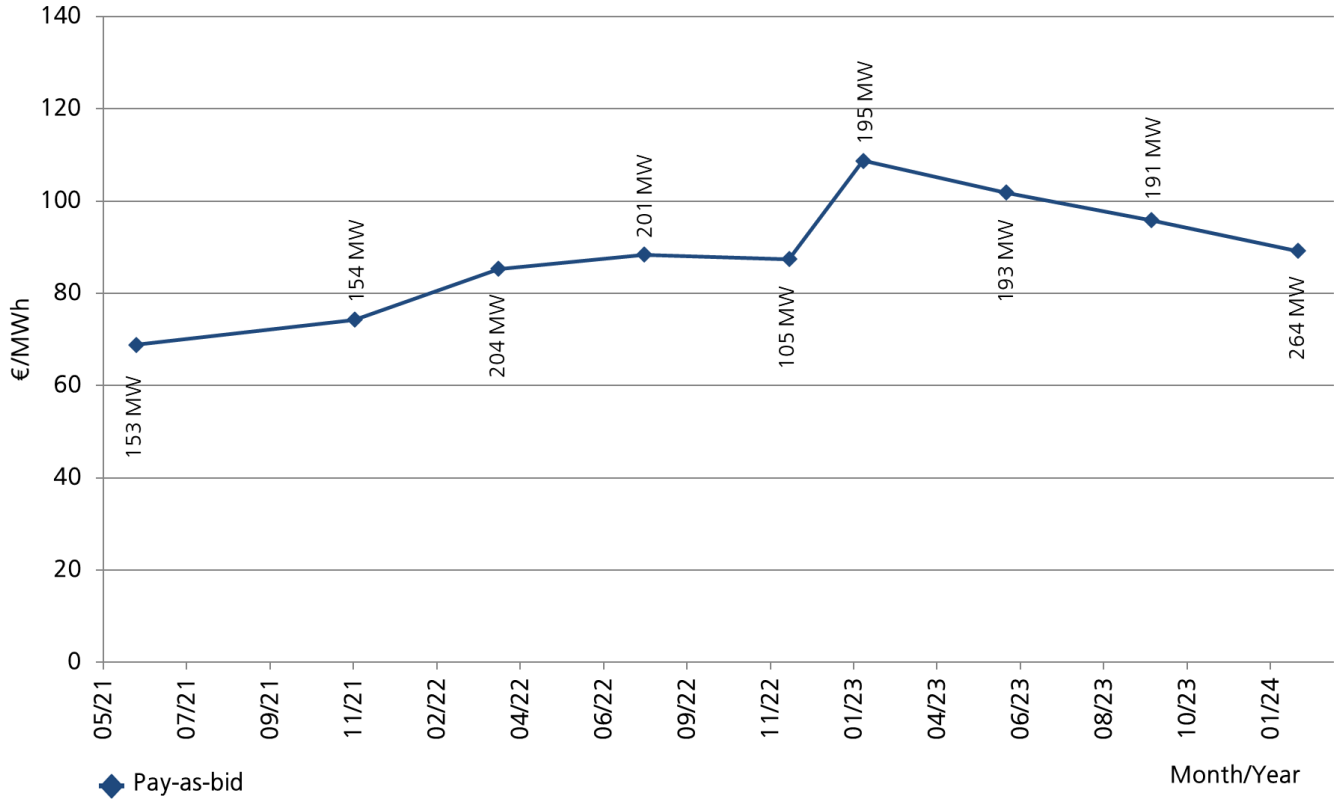
PV-Tender in Germany for Large Rooftop-Systems

Average, quantity weighted award value



Data: BNA. Graph: PSE Projects GmbH 2024 – Date of data: 03/2024

- PV-Tender scheme for large rooftop systems (>750 kW) started in June 2021 and total capacity of this scheme accumulates to 1.66 GW by Feb-2024 with 8.9 ct€ / kWh as latest average quantity weighted award price.
- Lowest PV-Tender Round was in June 2021 with 6.88 ct€ / kWh as average quantity weighted award price.

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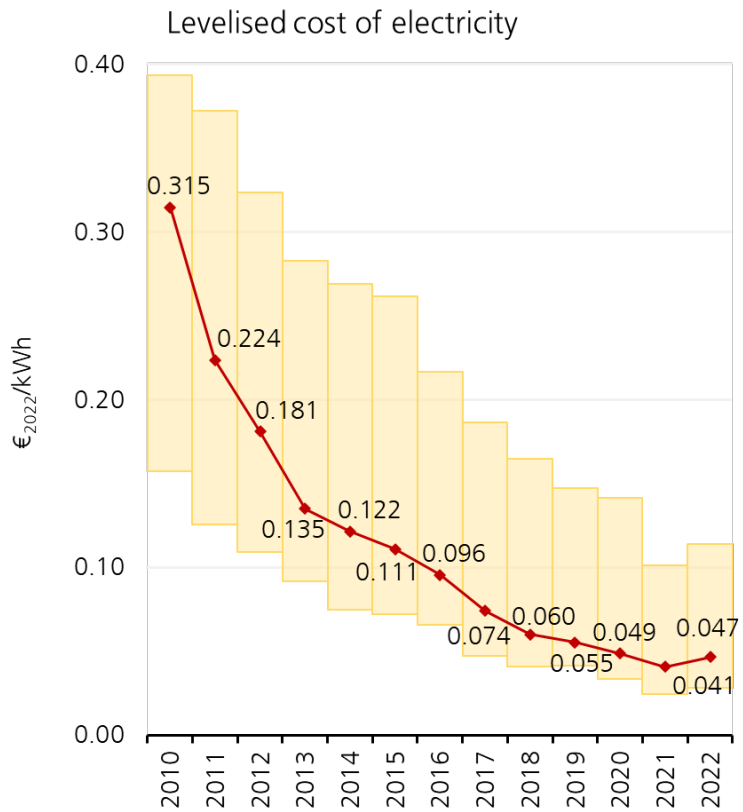
Global Weighted Average Levelised Costs of Electricity for Large PV Systems

(with 5th percentile and 95th percentile)



Data: IRENA (2023), Renewable Power Generation Costs in 2022, International Renewable Energy Agency, Abu Dhabi. Currency converted from USD to EUR. Date of data: Sep-2023

- The global weighted average LCoE was in year 2022 for large PV systems 0.047 €/kWh (= 47 €/MWh).
- The 5th percentile is a value associated with the location within the data where 5% of data is below that value. In year 2022 the 5th percentile was 0.029 €/kWh (= 29 €/MWh).
- The 95th percentile is the value where 5% of the data has a larger value. In year 2022 the 95th percentile was 0.114 €/kWh (= 114 €/MWh).
- The LCoE decreased by about 15% on year-to-year basis in the last 12 years.

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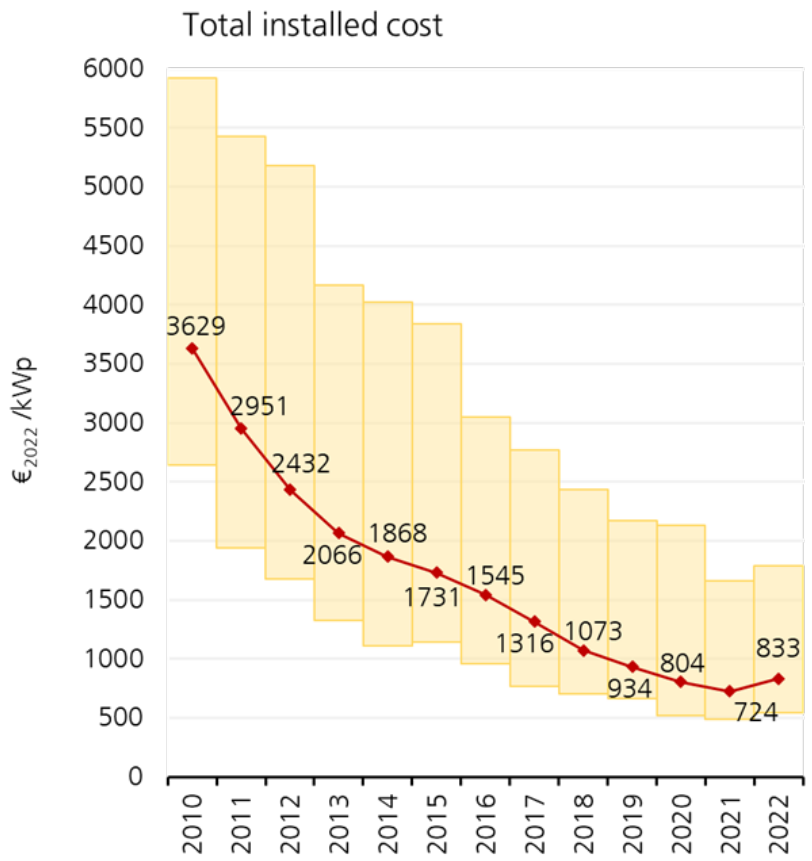
Global Weighted Average Total Installed Costs For Large PV Systems

(with 5th percentile and 95th percentile)



Data: IRENA (2023), Renewable Power Generation Costs in 2022, International Renewable Energy Agency, Abu Dhabi. Currency converted from USD to EUR. Date of data: Sep-2023

- The global weighted average total cost for large PV systems was 833 €/kWp in year 2022.
- The 5th percentile is a value associated with the location within the data where 5% of data is below that value. In year 2022 the 5th percentile was 541 €/kWp.
- The 95th percentile is the value where 5% of the data has a larger value. In year 2022 the 95th percentile was 1786 €/kWp.
- Total installed cost for large PV systems decreased by about 12% on year-to-year basis in the last 12 years.

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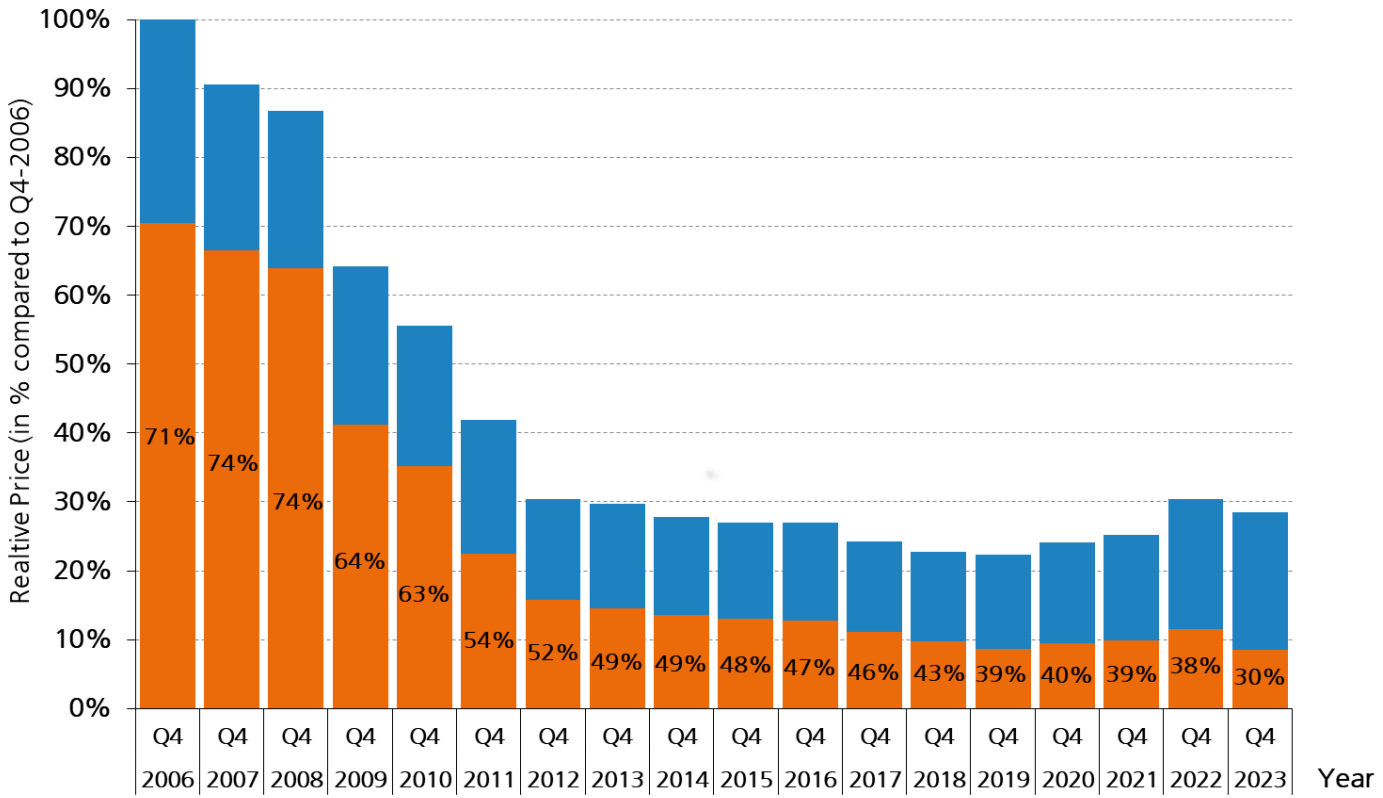
Price Development for PV Rooftop Systems in Germany

(10kWp - 100kWp)



Balance of System (BOS) encompasses all components of a PV system excluding the PV modules. These are the inverter, mounting system, switches, wiring and installation work, for example.

Data: BSW-Solar. Graph: PSE Projects GmbH 2024. Date of data: 11/2023

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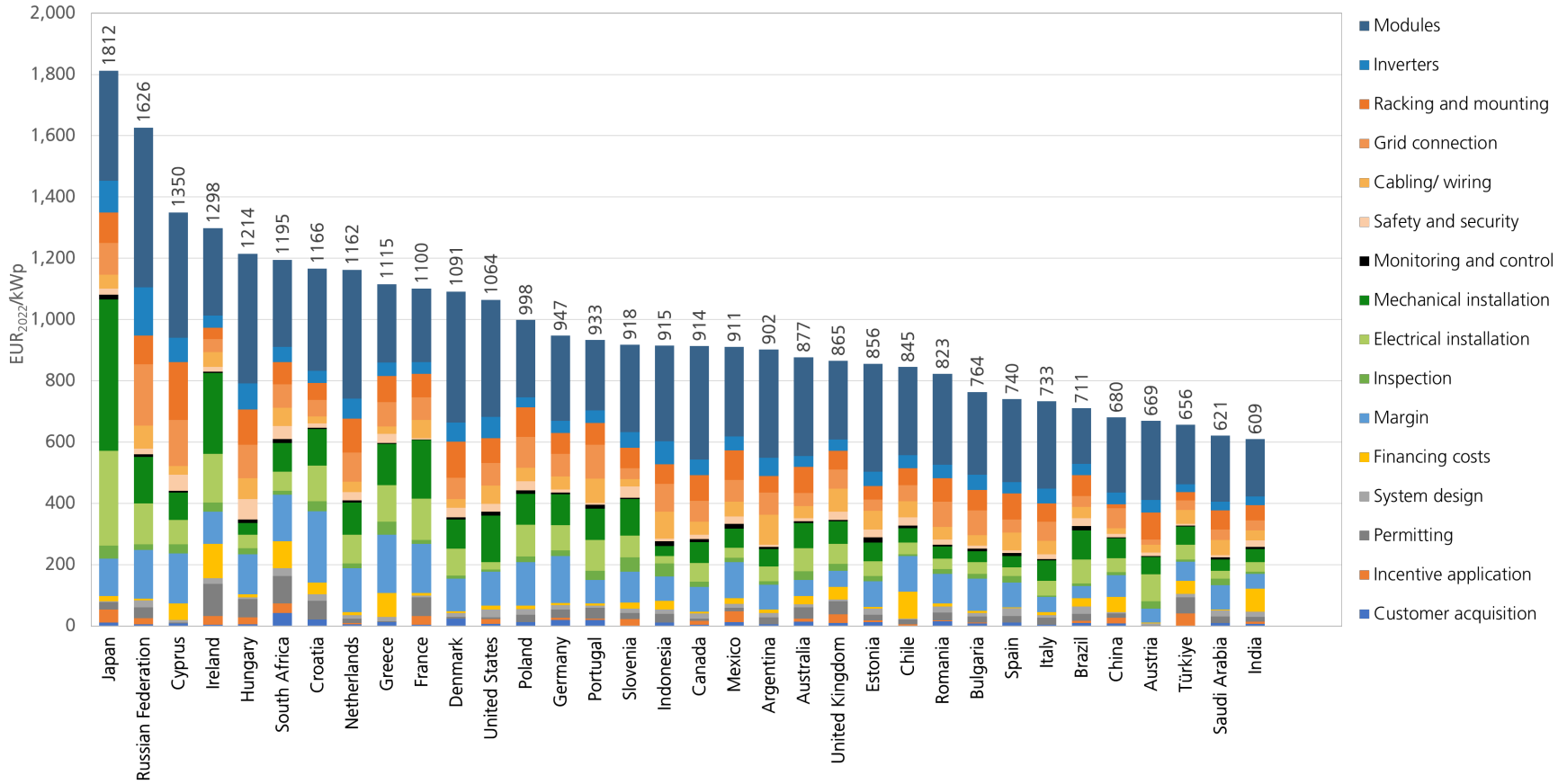
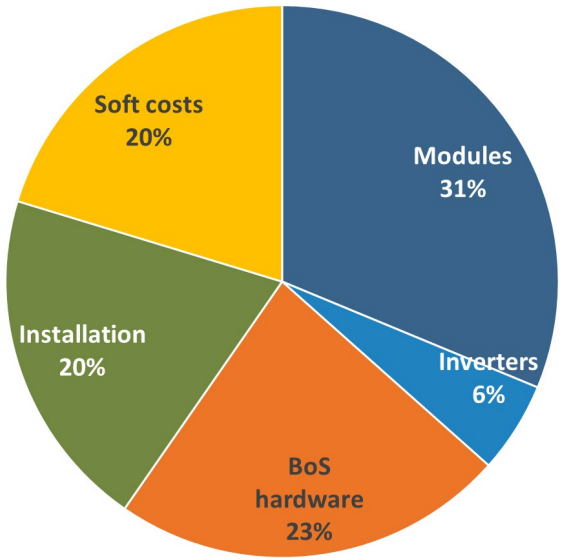
Breakdown of Utility-scale PV Total Installed Costs

By Country in 2022



Breakdown of cost components
(average of available country data):



Data: IRENA (2023), Renewable Power Generation Costs in 2022, International Renewable Energy Agency, Abu Dhabi. Currency converted from USD to EUR. Date of data: Sep-2023

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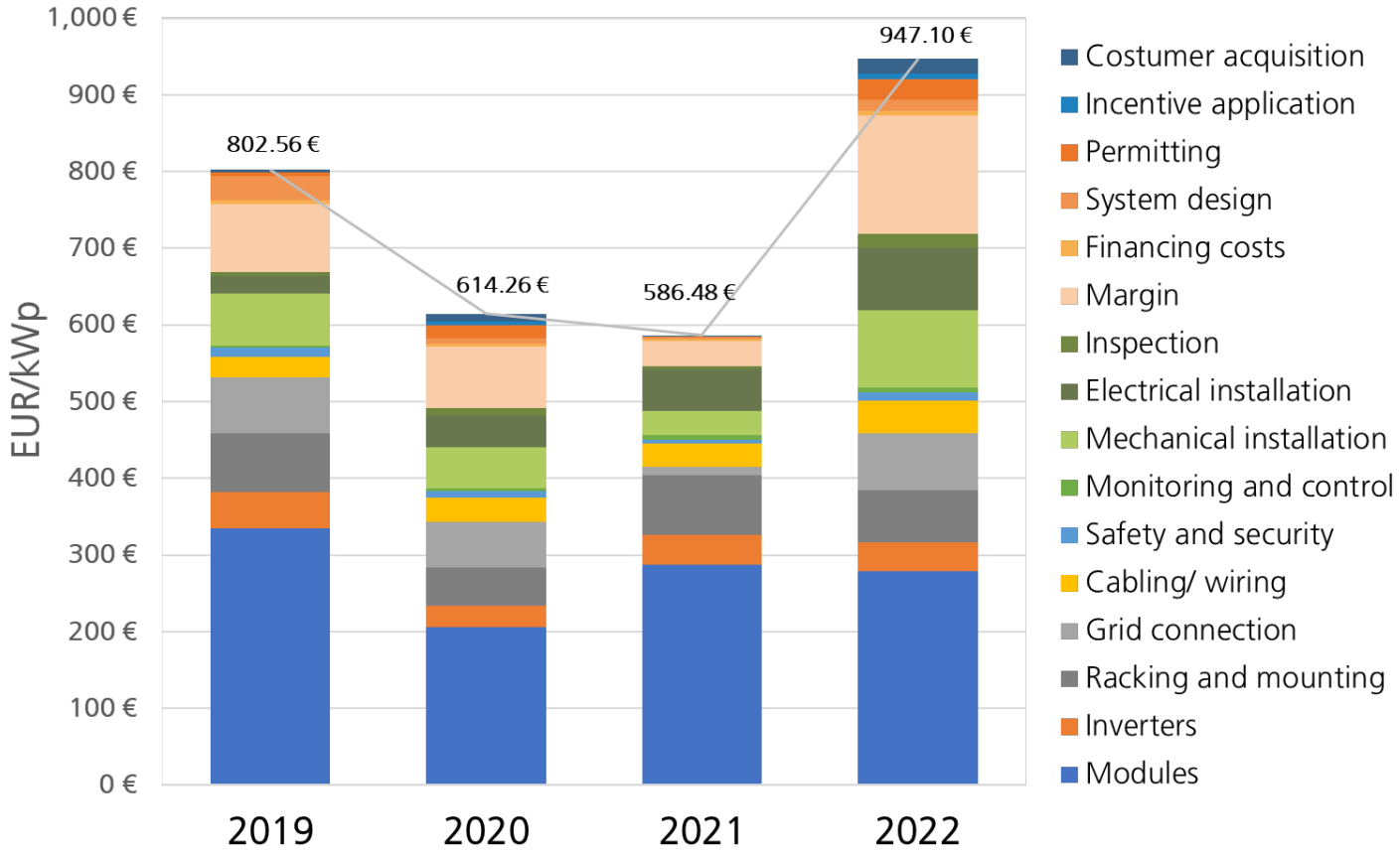
Breakdown of Total Installation Costs of Utility-Scale PV

Germany 2019 to 2022



Supply bottlenecks due to the coronavirus crisis led to price turbulence in 2022.

Data: IRENA (2023), Renewable Power Generation Costs in 2022, International Renewable Energy Agency, Abu Dhabi. Currency converted from USD to EUR. Date of data: Sep-2023

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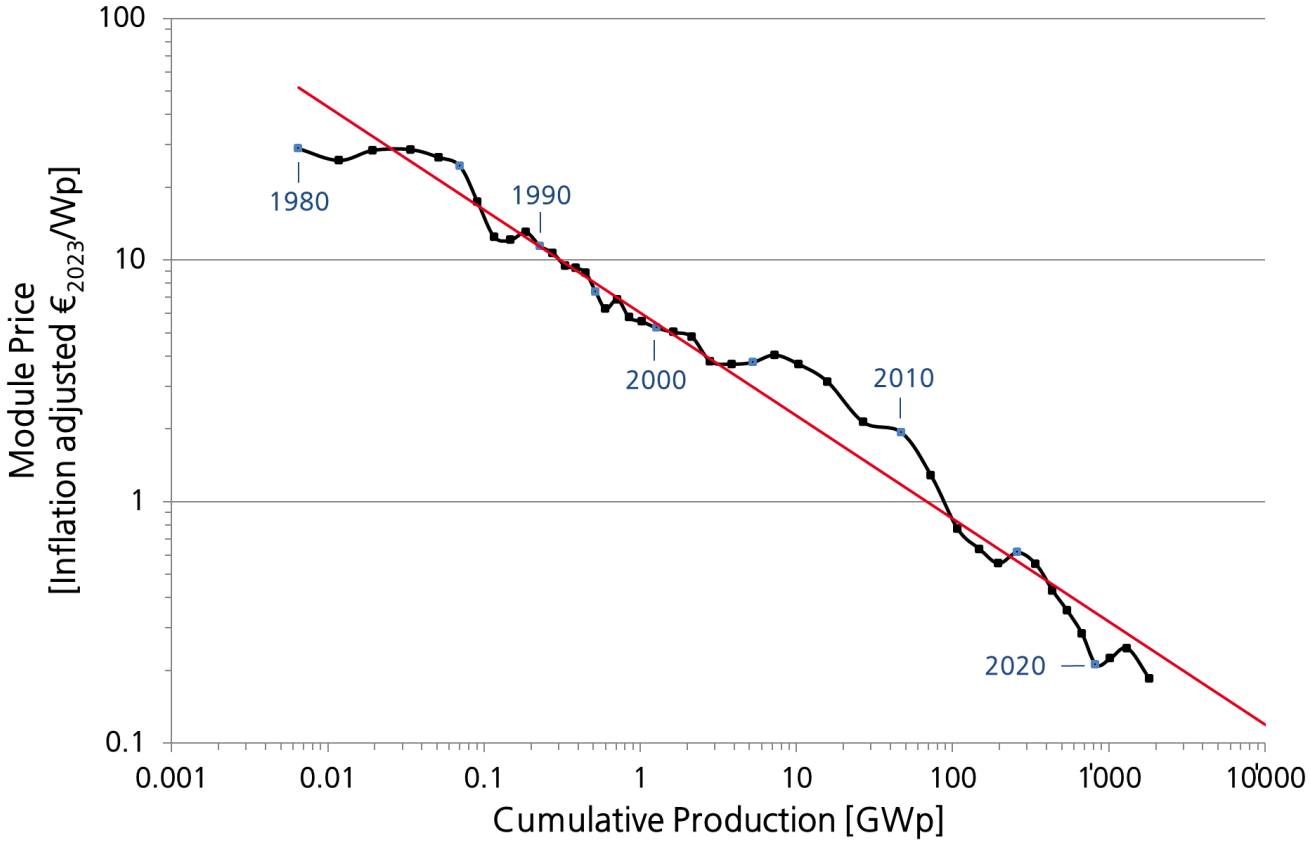
Price Learning Curve

Includes all Commercially Available PV Technologies



Learning Rate:
Each time the cumulative PV module production doubled, the module price dropped about 24.4% over the past 43 years.

Data: from 1980 to 2010 estimation from different sources: Strategies Unlimited, Navigant Consulting, EUPD, pvXchange; from 2011: IHS Markit; from 2022: ISE; Graph: PSE Projects GmbH 2024

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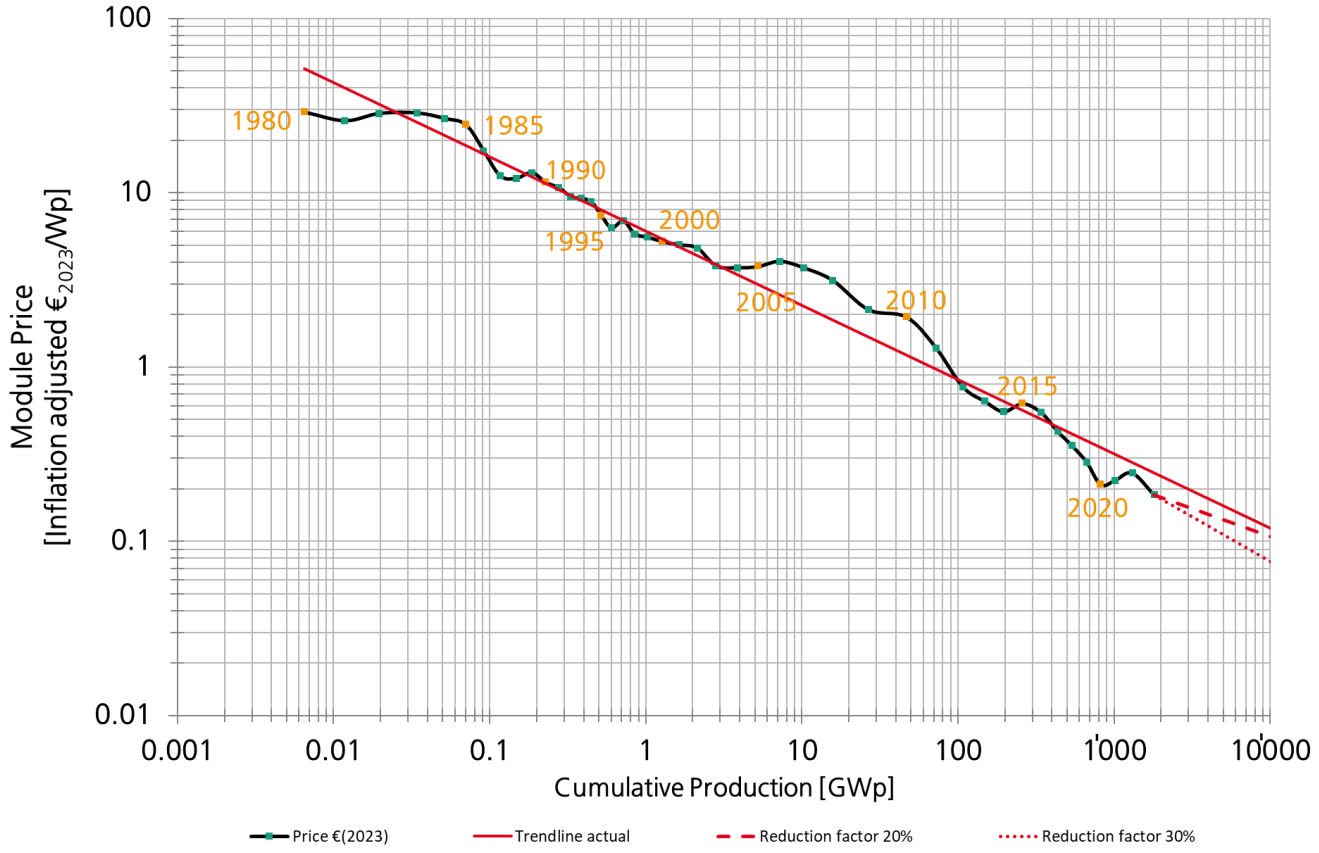
Price Learning Curve

Includes all Commercially Available PV Technologies



Learning Rate:
Each time the cumulative PV module production doubled, the module price dropped about 24.4% over the past 43 years.

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Further Reading

Selected studies and analyses

fraunhofer-ISE Energy Charts

Study: Levelized Cost of Electricity - Renewable Energy Technologies

Recent facts about photovoltaics in Germany

Power Generation from Renewable Energy in Germany

What will the Energy Transformation Cost? Pathways for Transforming the German Energy System by 2050

Sustainable PV Manufacturing in Europe – An Initiative for a 10 GW Green Fab

Meta Study: Future Crosssectoral Decarbonization Target Systems in Comparison to Current Status of Technologies

Abbreviations

Abbreviation	Explanation	Abbreviation	Explanation
AC	Alternating Current	**HCPV**	High Concentrator Photovoltaic
Al-BSF	Aluminum Back Surface Field	**HJT (also HIT)**	Heterojunction with Intrinsic Thin-Layer
BESS	**Battery Energy Storage Systems**	**IBC**	Interdigitated Back Contact (solar cells)
BIPV	Building Integrated PV	**LCOE**	Levelized Cost of Energy
BOS	Balance of System	**LCPV**	Low Concentrator Photovoltaic
CdTe	Cadmium-Telluride	**MJ**	Multi Junction
CI(G)S	Copper Indium (Gallium)Diselenide	**MPP**	Maximum Power Point
CPV	Concentrating Photovoltaic	**n-type**	Negatively doped wafer (with phosphorous)
c-SI	Crystalline Silicon	**PERX**	Passivated emitter and rear cell
CTM	**Cell-to-Module**	**PR**	Performance Ratio
Cz	Czochralski Method	**p-type**	Positively doped wafer (with boron or gallium)
DC	Direct current	**PV**	Photovoltaic
EEG	Renewable Energy Source Act (Erneuerbare-Energien-Gesetz, EEG)	**RE**	Renewable Energies
EI	The Energy Institute	**ROI**	Return on Investment
EPBT	Energy Payback Time	**SI**	Silicon
EROI	Energy Return of Invest	**SIC**	Silicon carbide
FZ	Floating Zone	**TOPCon**	Tunnel Oxide Passivated Contact
GaAs	Gallium Arsenide	**VAT**	Value Added Tax
GaN	Gallium nitride		

Acknowledgements

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Ralf Preu	ISE
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Jochen Rentsch	ISE
Gerhard Stryi-Hipp	ISE
Tobias Reuter	ISE
Harry Wirth	ISE
Werner Warmuth	PSE Projects GmbH

The information provided in this Photovoltaics Report is very concise by its nature . Its principal purpose is to provide a rough overview about the current solar PV market, the technologies and the environmental impact.

However, there are many more aspects. These and further details can be provided by Fraunhofer ISE upon request. Please contact us if you are interested in receiving a tailor-made offer.

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Thank You for Your Interest

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