



PROFESSIONAL TRAINING REPORT

Sathyabama Institute of Science and Technology (Deemed to be University)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

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VATIO®



Certificate OF INDUSTRY INTERNSHIP

This is to certify that

BENIN JM

Studying **3rd Year, B.E, EEE** in **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY**

has successfully completed the Industry Internship Programme at VATIO Energy India Pvt Ltd, Chennai
through Online from 21st July to 05th August 2021 in the area of
"Solar Photovoltaic system & its Design Practices"

Best wishes from VATIO Energy for future endeavors !

G.Rajaganesan, Director – Technical
VATIO Energy India Pvt Ltd.



05th August 2021

Date

Executive Summary

PV Market: Global

- Photovoltaics is a fast-growing market: The Compound Annual Growth Rate (CAGR) of cumulative

PV installations including off-grid was 34% between year 2010 to 2020.

- In year 2020 producers from Asia count for 95% of total c-Si PV module production. China (mainland) holds the lead with a share of 67%. Europe contributed with a share of 3%; USA/LAN with 2%.
- Wafer size increased enabling larger PV module size allowing a power range from +600 W per

module.

- In 2020, Europe's contribution to the total cumulative PV installations amounted to 22% (compared to 24% in 2019). In contrast, installations in China accounted for 33% (same value as the year before).
- Si-wafer based PV technology accounted for about 95% of the total production in 2020. The share of mono-crystalline technology is now about 84% (compared to 66% in 2019) of total c-Si production.
- Market shifts from subsidy driven to competitive pricing model (Power Purchase Agreements

PPA).

Executive Summary

Solar Cell / Module Efficiencies

- The record lab cell efficiency is 26.7% 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 25.5%.

- In the last 10 years, the efficiency of average commercial wafer-based silicon modules increased

from

about 1 % to 20%. At the same time, CdTe module efficiency increased from 9% to 19%.

- In the laboratory, best performing modules are based on mono-crystalline silicon with 24.4% 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 47.1% today. With concentrator technology, module efficiencies of up to 38.9% have been reached.

Executive Summary

Energy Payback Time

- Material usage for silicon cells has been reduced significantly during the last 16 years from around 16 g/Wp to about 3 g/Wp due to increased efficiencies, thinner wafers and diamond wire sawing as well as larger ingots.
- The Energy Payback Time of PV systems is dependent on the geographical location: PV systems in Northern Europe need around 1.2 years to balance the input energy, while PV systems in the South equal their energy input after 1 year and less, depending on the technology installed and the grid efficiency.
- A PV system located in Sicily with wafer-based Silicon modules has an Energy Payback Time of around one year. Assuming 20 years lifespan, this kind of system can produce twenty times the energy needed to produce it.

Executive Summary

Inverters

- Inverter efficiency for state-of-the art brand products is 98% and higher.
- The market share of string inverters is estimated to be 64%. These inverters are mostly used in residential, small and medium commercial applications in PV systems up to 150 kWp. The market share of central inverters, with applications mostly in large commercial and utility-scale systems, is about 34%.
A small proportion of the market (about 1%) belongs to micro-inverters (used on the module level). The market share for DC / DC converters, also called "power optimizers", is estimated to be 5% of the total inverter market.
- Trends: Digitalisation, Repowering, new features for grid stabilization and optimization of self-consumption; storage; utilization of innovative semiconductors (SiC or GaN) which allow very high efficiencies and compact designs; 1500 V maximum DC string voltage.

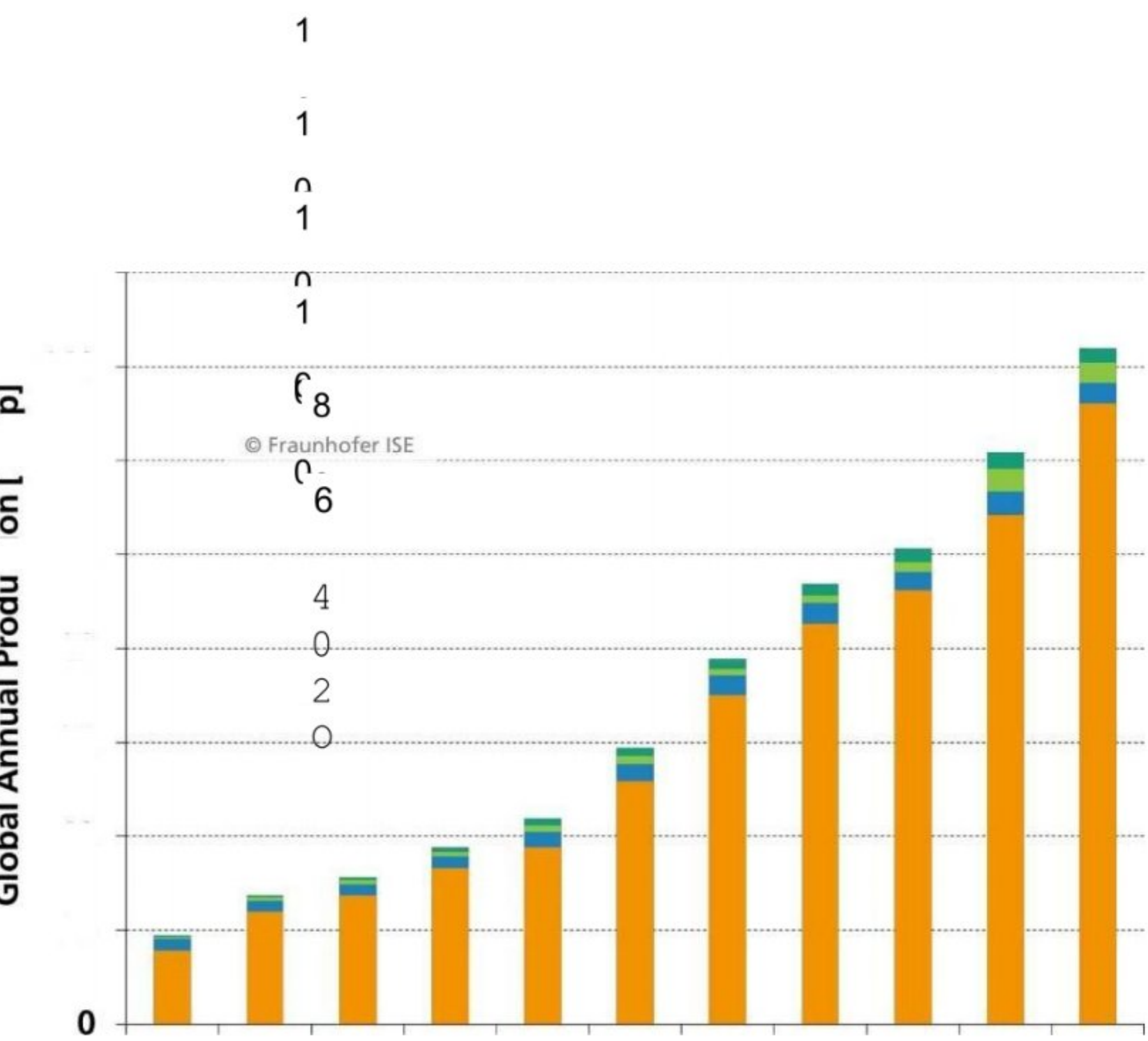
Executive Summary

Price Development

- In Germany prices for a typical 10 to 100 kWp PV rooftop-system were around 14,000 €/kWp in 1990. At the end of 2020, such systems cost only 7.4% of the price in 1990. This is a net-price regression of about 92% over a period of 30 years.
- The Experience Curve – also called Learning Curve - shows that in the last 40 years the module price decreased by 26% with each doubling of the cumulated module production. Cost reduction results from economies of scale and technological improvements.

PV Module Production by Region

Global Annual Production



Data: IHS Markit 2021. Graph: PPE Projects GmbH 2021

About 82% of the global PV module production was from Asia in year 2010. It increased to about 92% of total global production in year 2020. The annual production has increased by a factor of 7 in this decade.

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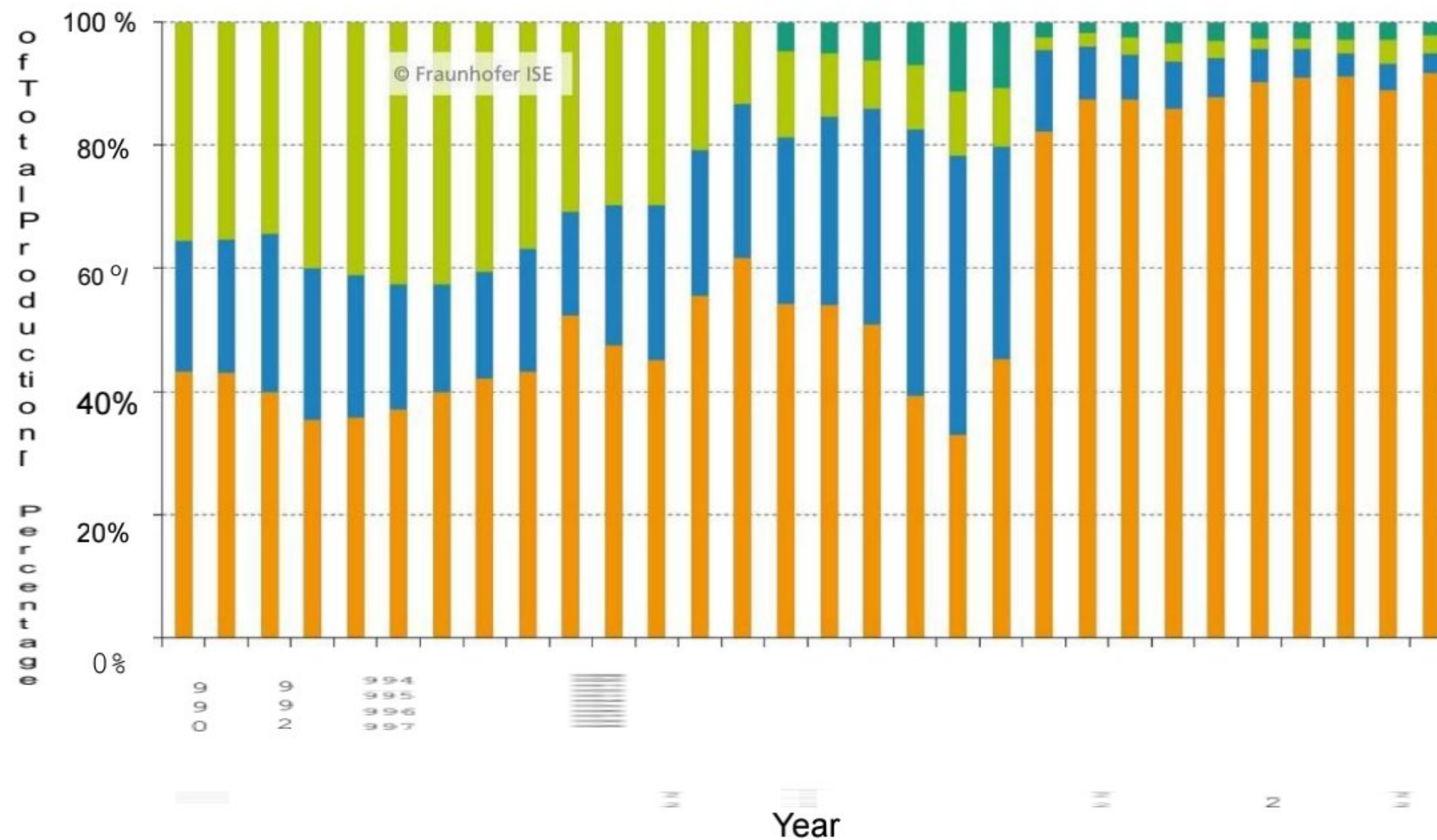
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1. PV rket

- region
- technology

PV Module Production by Region 1990-2020

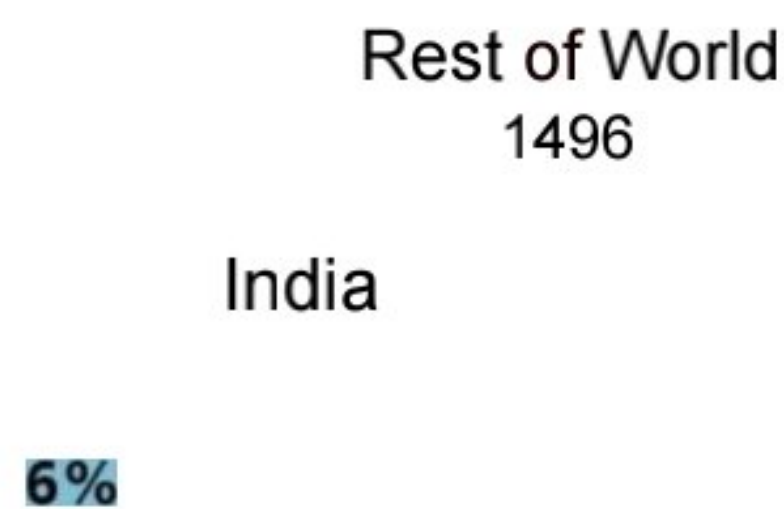
Percentage of Total MWp Produced



Data: Up to 2004 Strategies Unlimited; 2005 to 2009 Navigant Consulting; since 2010: IHS Markit. Graph: PSE Projects GmbH 2021

Global Cumulative PV Installation by Region

Status 2020

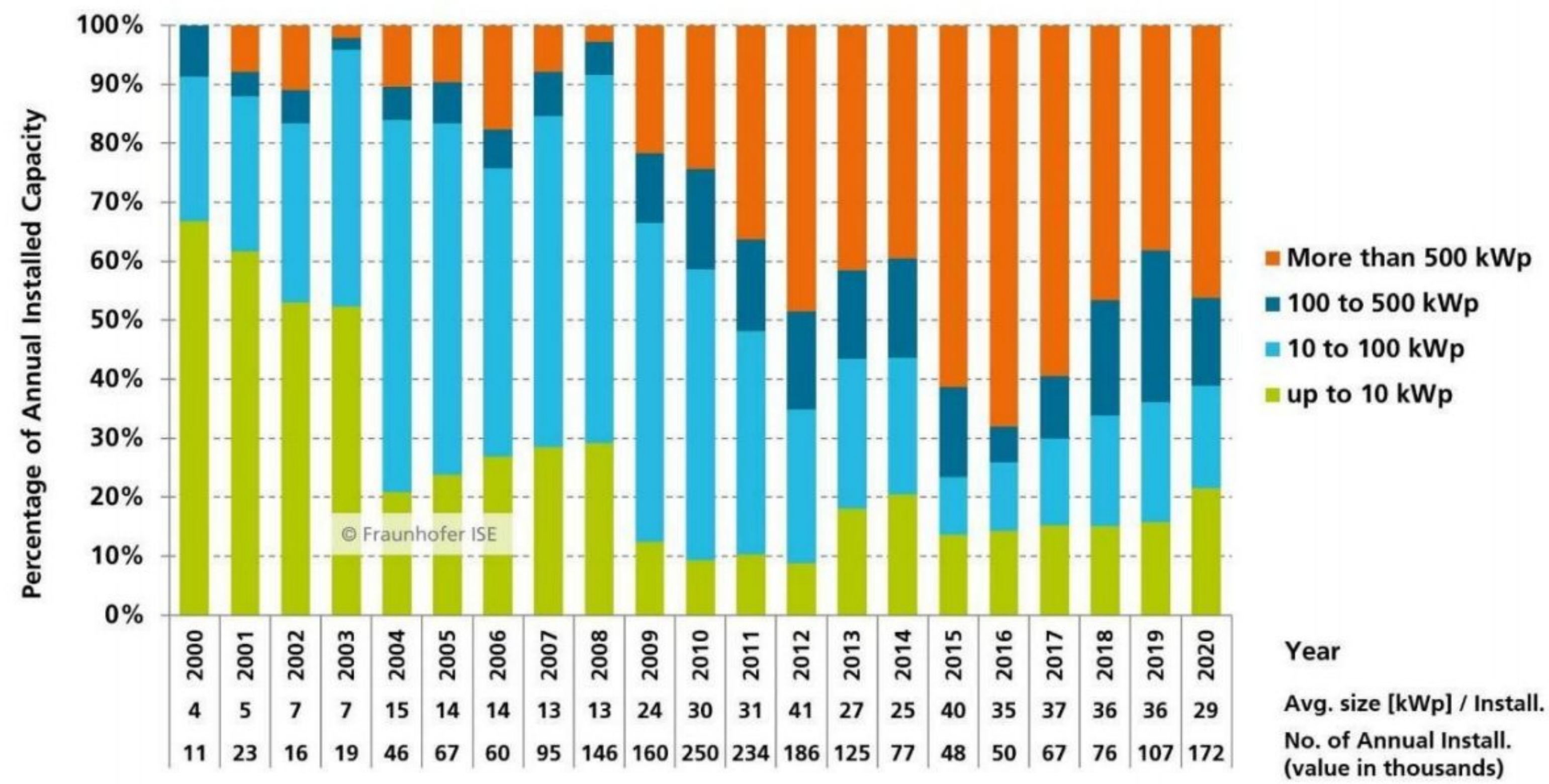


The total cumulative installations amounted to 708 GWp at the end of year 2020.

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

Number of PV Systems Annually Installed in Germany

Percentage of Annual Capacity by System Size



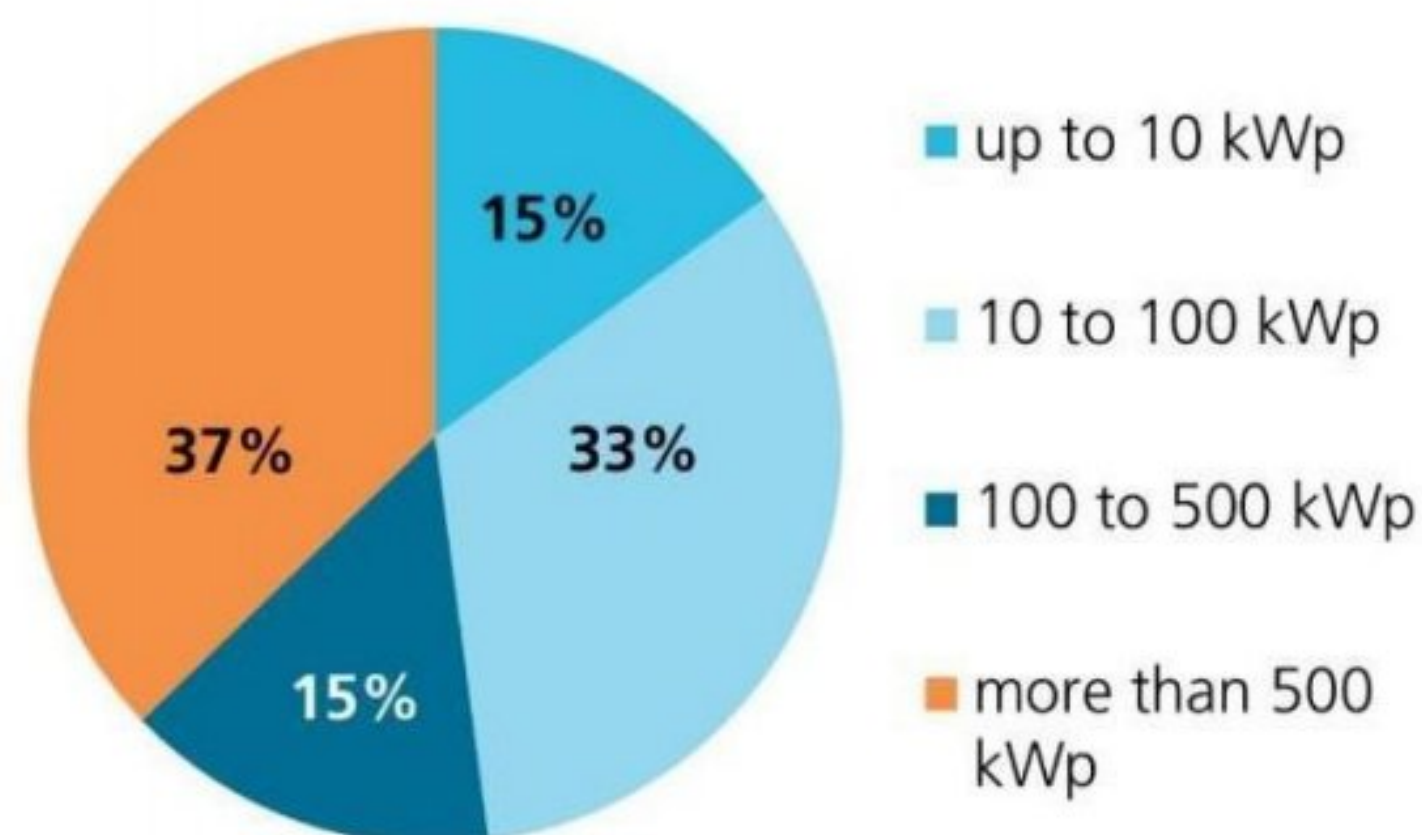
According to BNA at end of year 2020 in Germany a total cumulated PV capacity of 54 GW was installed.

Data: up to 2008: extrapolation from utilities data; since 2009: Bundesnetzagentur (BNA); The compilation is done by filtering initial PV-System operation date. Graph: PSE Projects GmbH 2021

Share of Capacity and Number of PV-Systems Installed

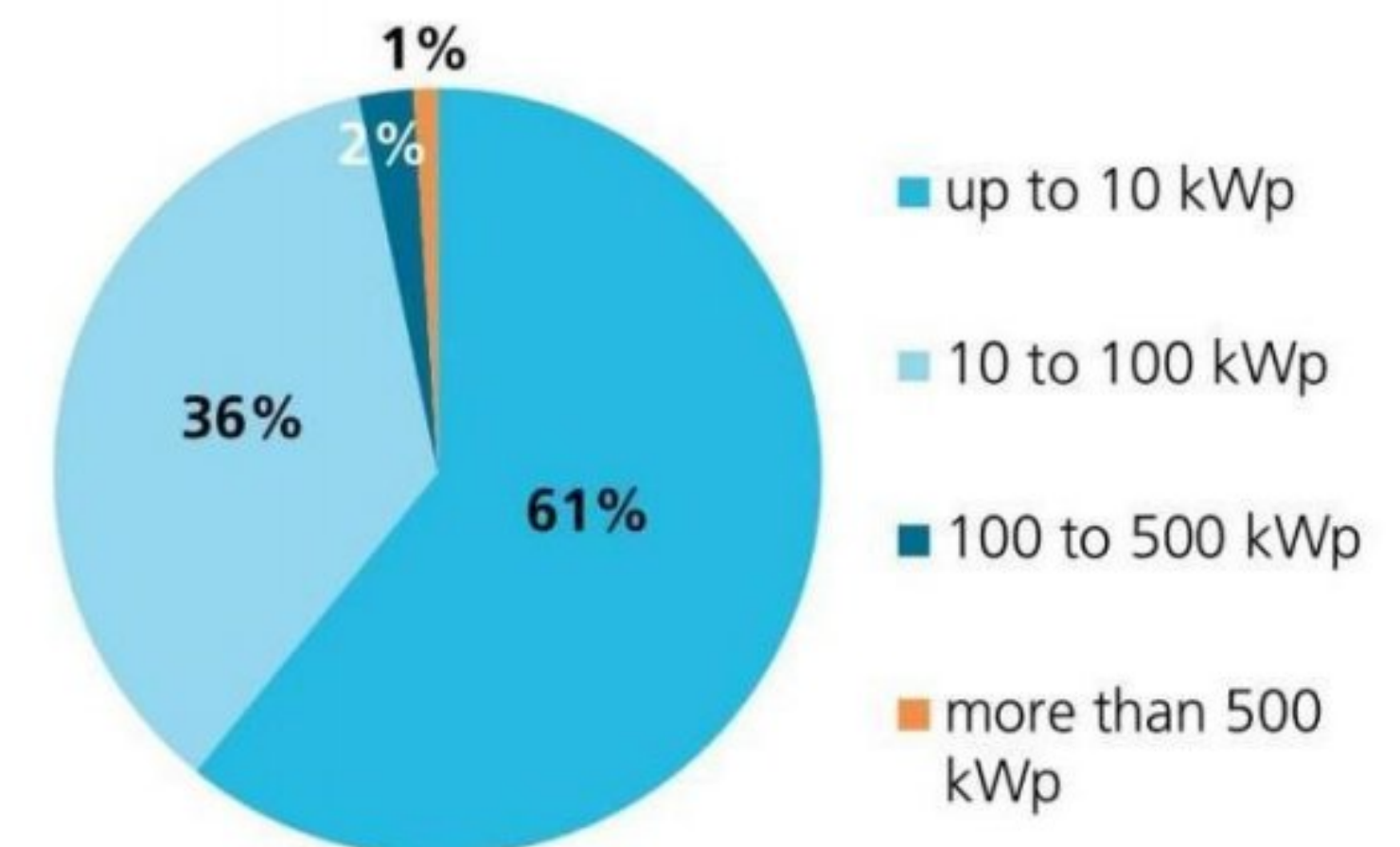
Percentage of Cumulative Installations in Germany

Share of PV-Systems in Germany
by cumulative capacity (2020)



© Fraunhofer ISE

Share of PV-Systems in Germany
by cumulative numbers (2020)

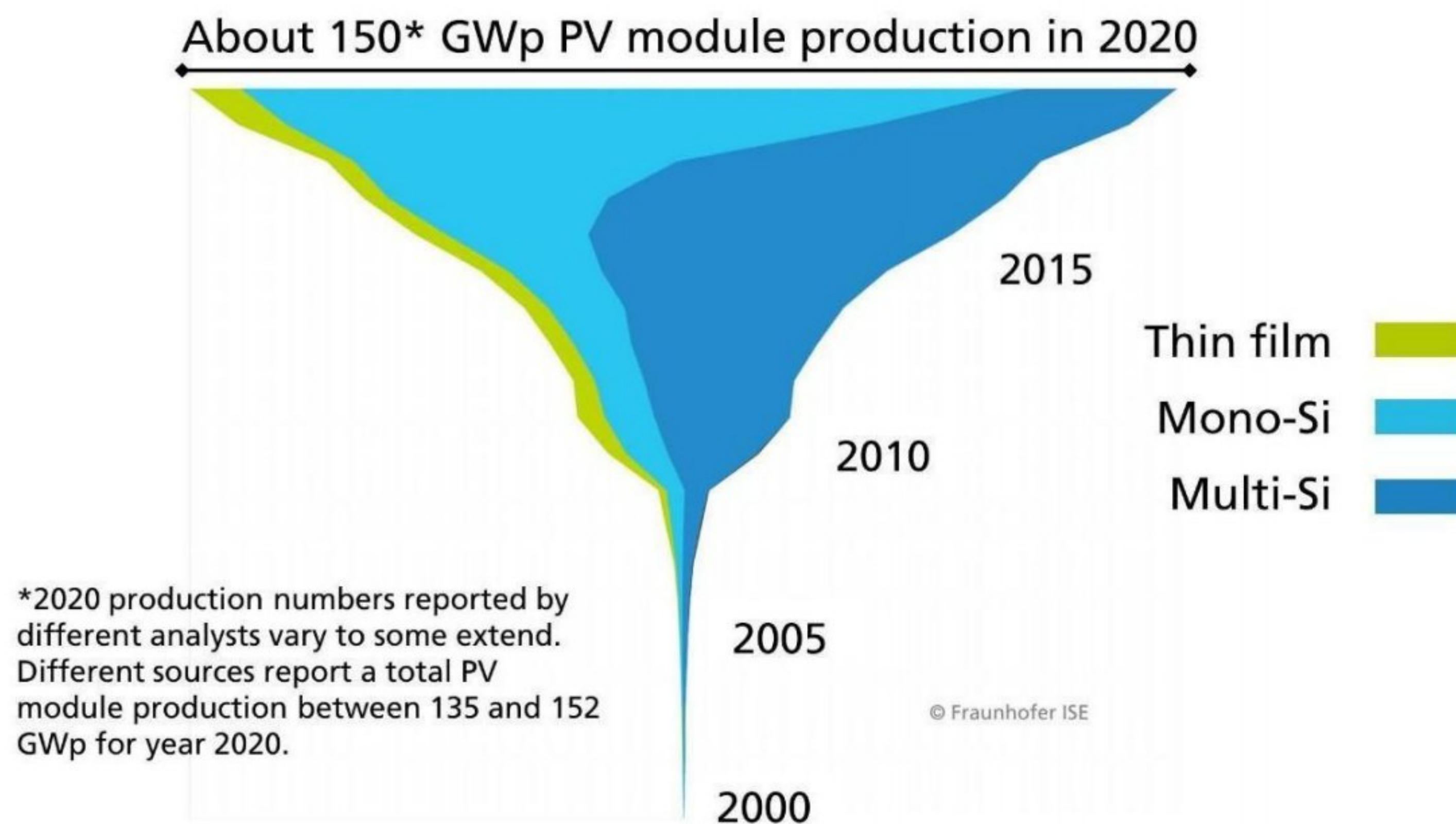


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While the larger PV-systems account for about a third of the total installed capacity, the number of large-scale systems with more than 500 kWp is only about 1% of the total installed systems.

Data: Bundesnetzagentur 2021. Graph: PSE Projects GmbH 2021

Annual PV Production by Technology Worldwide (in GWp)

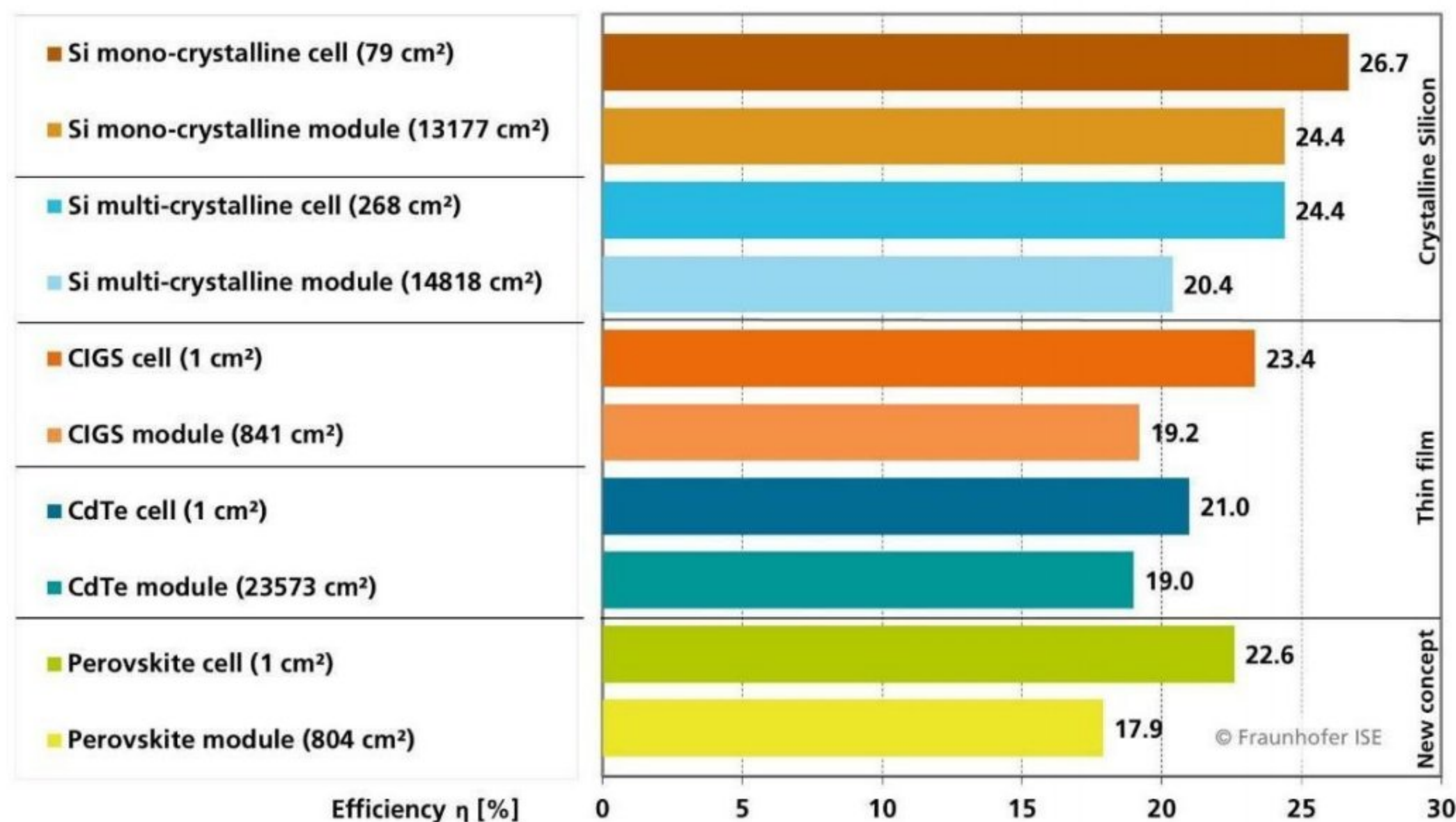


Data: from 2000 to 2009: Navigant; from 2010: IHS Markit. Graph: PSE Projects GmbH 2021

2. Solar Cells / Modules / System Efficiency

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

Efficiency Comparison of Technologies: Best Lab Cells vs. Best Lab Modules

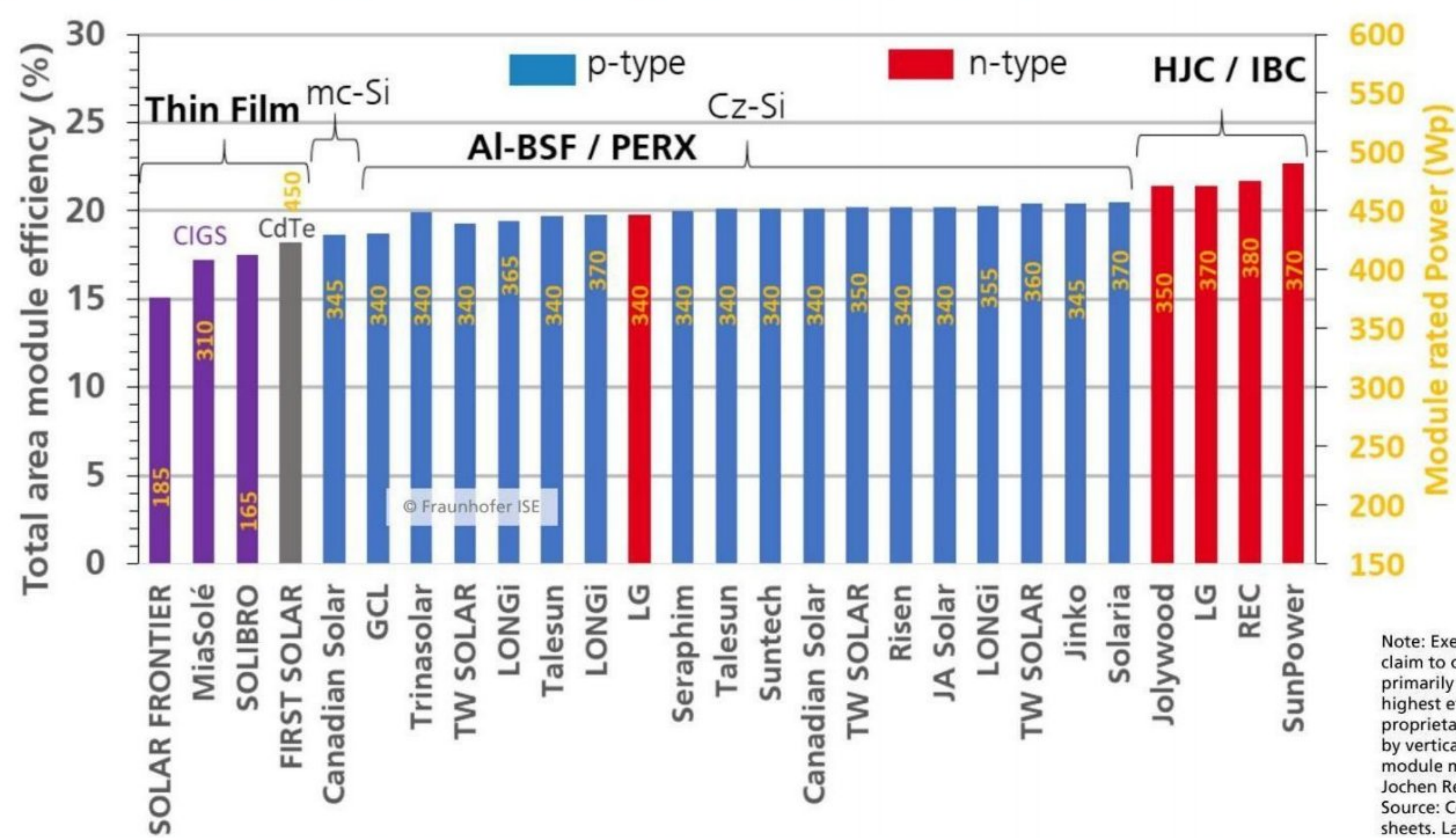


Note: In mass production Cell-to-Module ratio (CTM) improved in past years by reducing losses and using possible gains when integrating solar cells in modules. Fraunhofer ISE provides SmartCalc.CTM software suite for the precise CTM power loss analysis. It considers geometrical losses, optical losses & gains as well as electrical losses.

www.cell-to-module.com

Data: Green et al.: Solar Cell Efficiency Tables (Version 58), Progress in PV: Research and Applications 2020. Graph: PSE Projects GmbH 2021

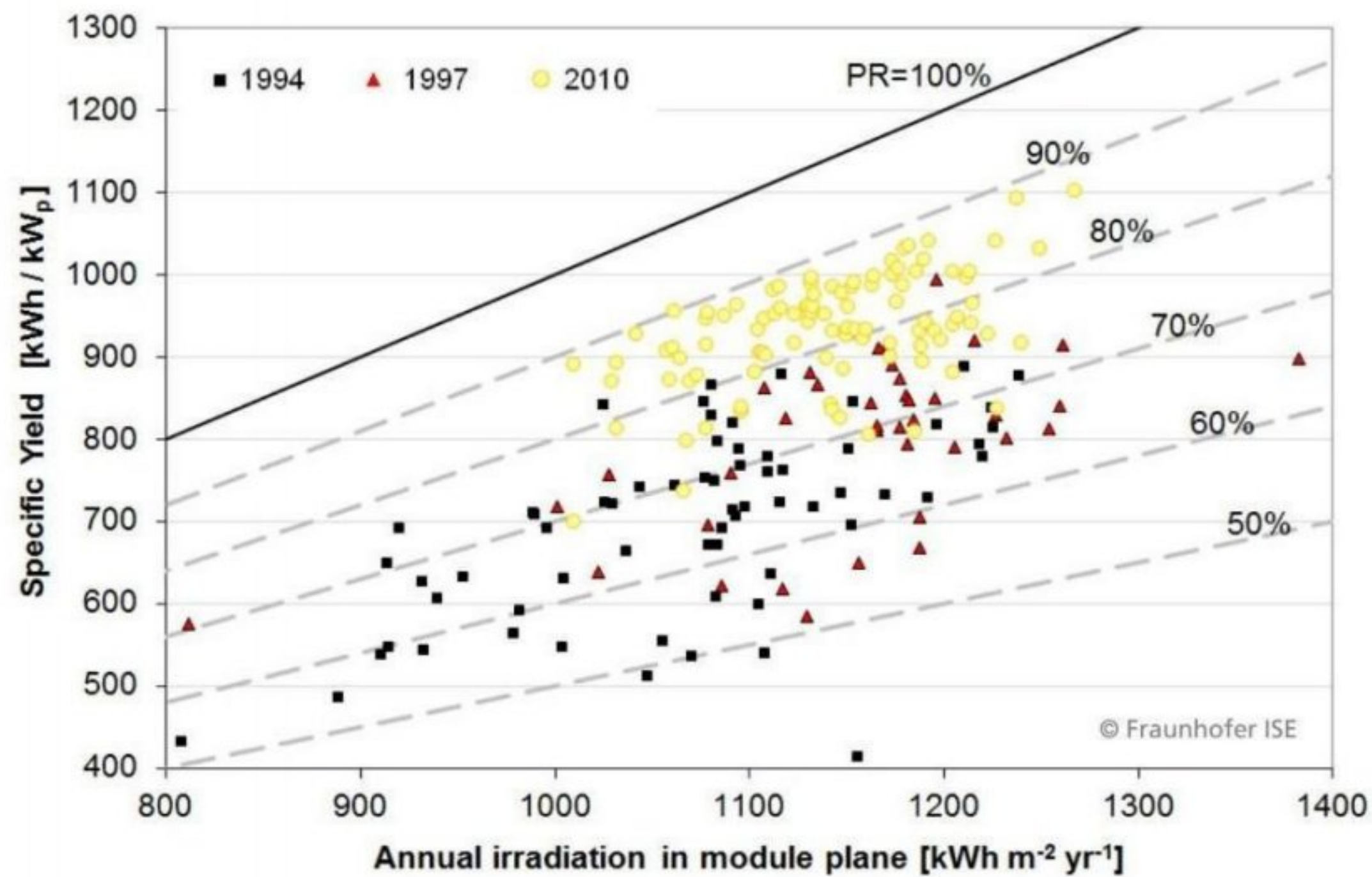
Current Efficiencies and Power of Selected Commercial PV Modules Sorted by Bulk Material, Cell Concept and Efficiency



Note: Exemplary overview without claim to completeness; Selection is primarily based on modules with highest efficiency of their class and proprietary cell concepts produced by vertically integrated PV cell and module manufacturers; Graph: Jochen Rentsch, Fraunhofer ISE. Source: Company product data sheets. Last update: Nov. 2019.

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

3. Energy Return of Invest (EROI) & Energy Payback Time (EPBT)

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

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%

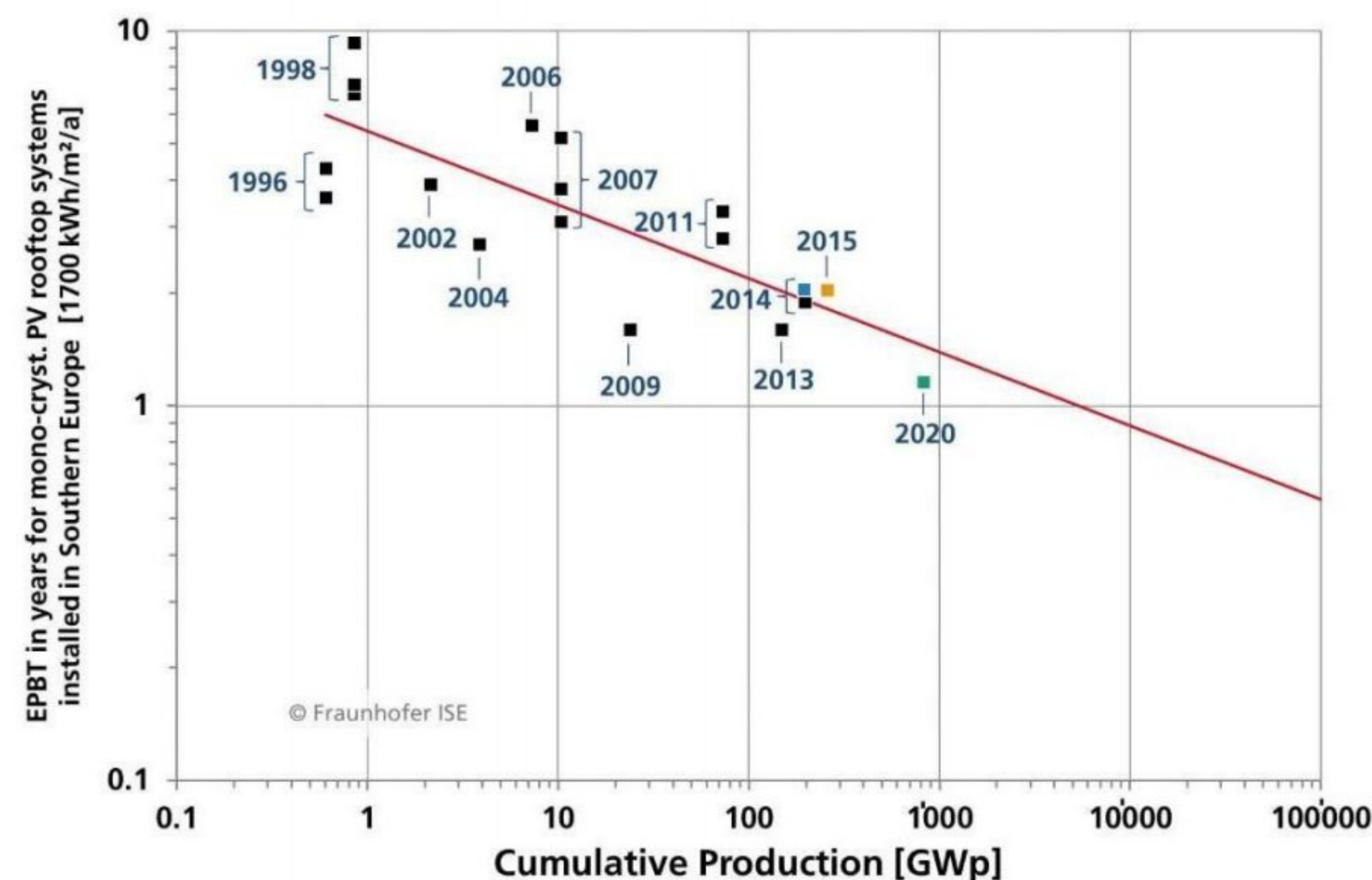
PR (incl. average degradation during lifetime) 73.6%

2) Grid efficiency

for converting PV yield in primary energy equivalents

grid efficiency 35%

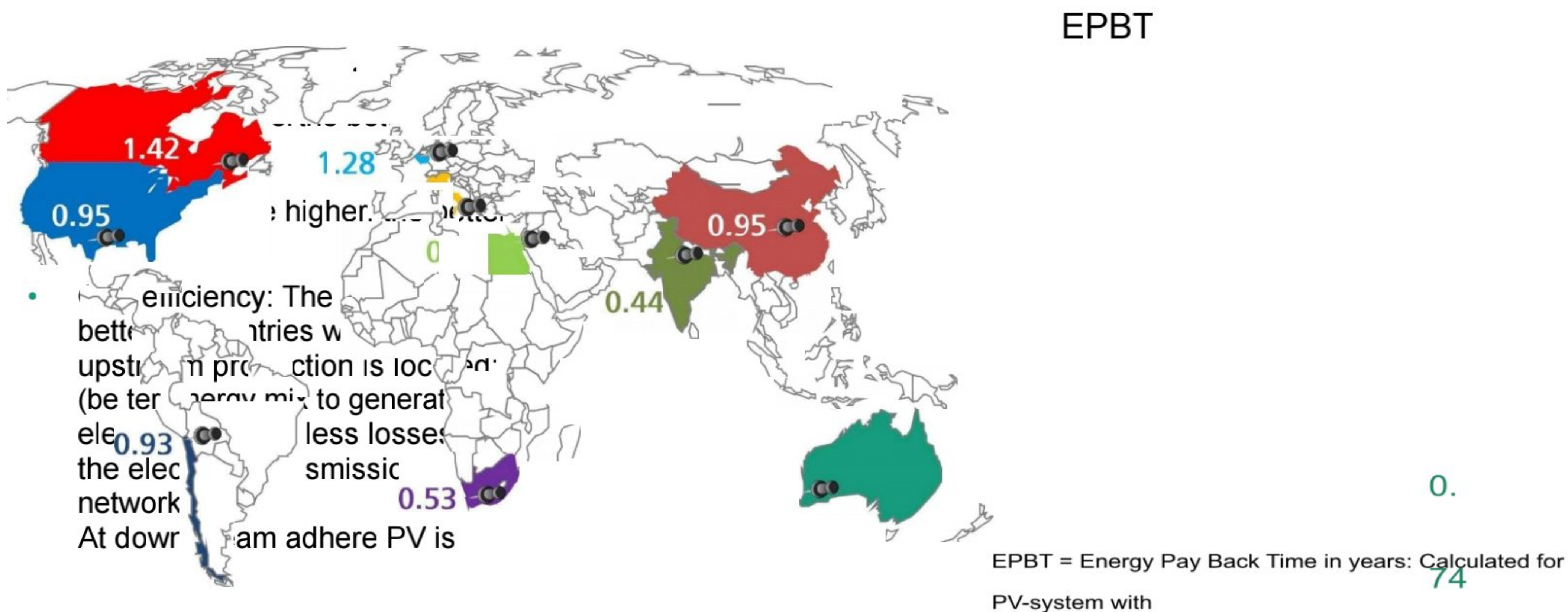
EPBT of Leccisi (2016), Louwen (2014) and Friedrich (2020) were harmonized with
1) PR (incl. average degradation) and 2) grid efficiency to results of Koppelaar (2016)*



Data: Lorenz Friedrich, Fraunhofer ISE. Graph: PSE 2021

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

World Map EPBT of Silicon PV Rooftop Systems — Comparison of EPBT China



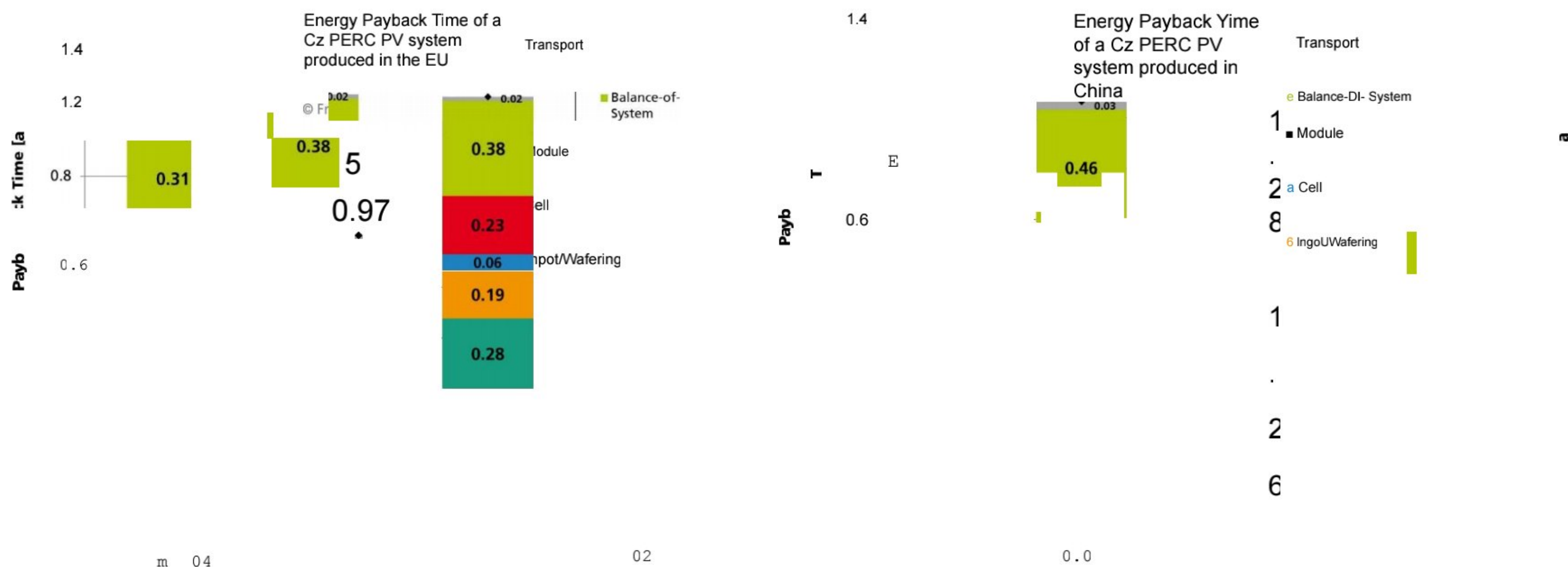
ins a ed) a for grid efficiency

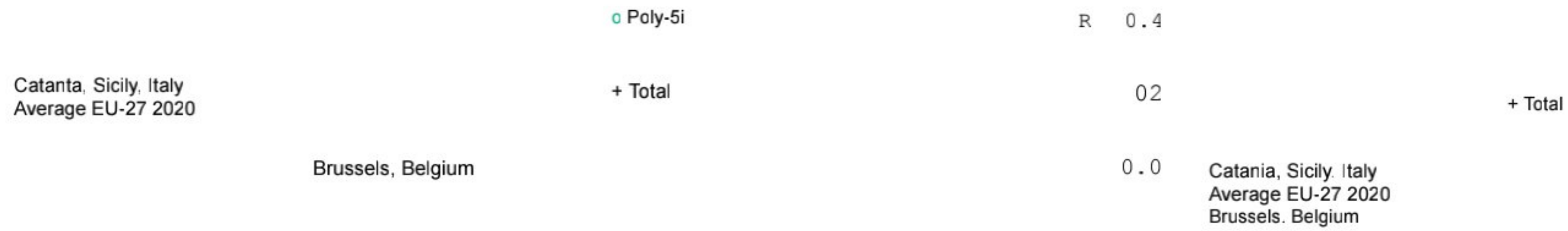
reduces the EPBT.

Data: Lorenz Friedrich, Fraunhofer ISE. Graph: PSE 2020

Cz PERC 60 cells modules with 19.9 % efficiency
produced in China

Energy Pay-Back Time of Silicon PV Rooftop Systems — Comparison of EPBT China / EU, local Irradiation and Grid Efficiency





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

Data: Lorenz Friedrich, Fraunhofer ISE. Design: PSE 2020

4. Inverters

- Inverter/Converter Market



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Market 2020

Inverter / Converter	Power	Efficiency	Market Share (Estimated) *	Remarks
String Inverters	up to 150 kWp	up to 98%	• 3 17 €-cents Np	
	64.4% Central Inverters		• Easy to replace	
	More than 80 kWp	up to 98.5%	• - 4 €-cents App	
	33.7%		• High reliability	
			• Often sold only together with service contract	
Micro-Inverters				90%-97%
Module Power				



1.4%

- - 25 G-cents /Wp
- Ease-of-replacement concerns

DC/DC
Converters
(Power
Optimizer)

Module Power up to
99.5% Range

5.1 %

- - 8 €-cents /Wp
- Ease-of-replacement concerns
- Output is DC with optimized current

n
t

› Still a DC AC inverter is needed

Data: IHS Mark it 2021. Remarks: Fraunhofer ISE 2020. Design: PSE 2021

'Total Market Share related to shipment in MWac is greater than 100%A because DC/DC converters are required to be paired with string inverters

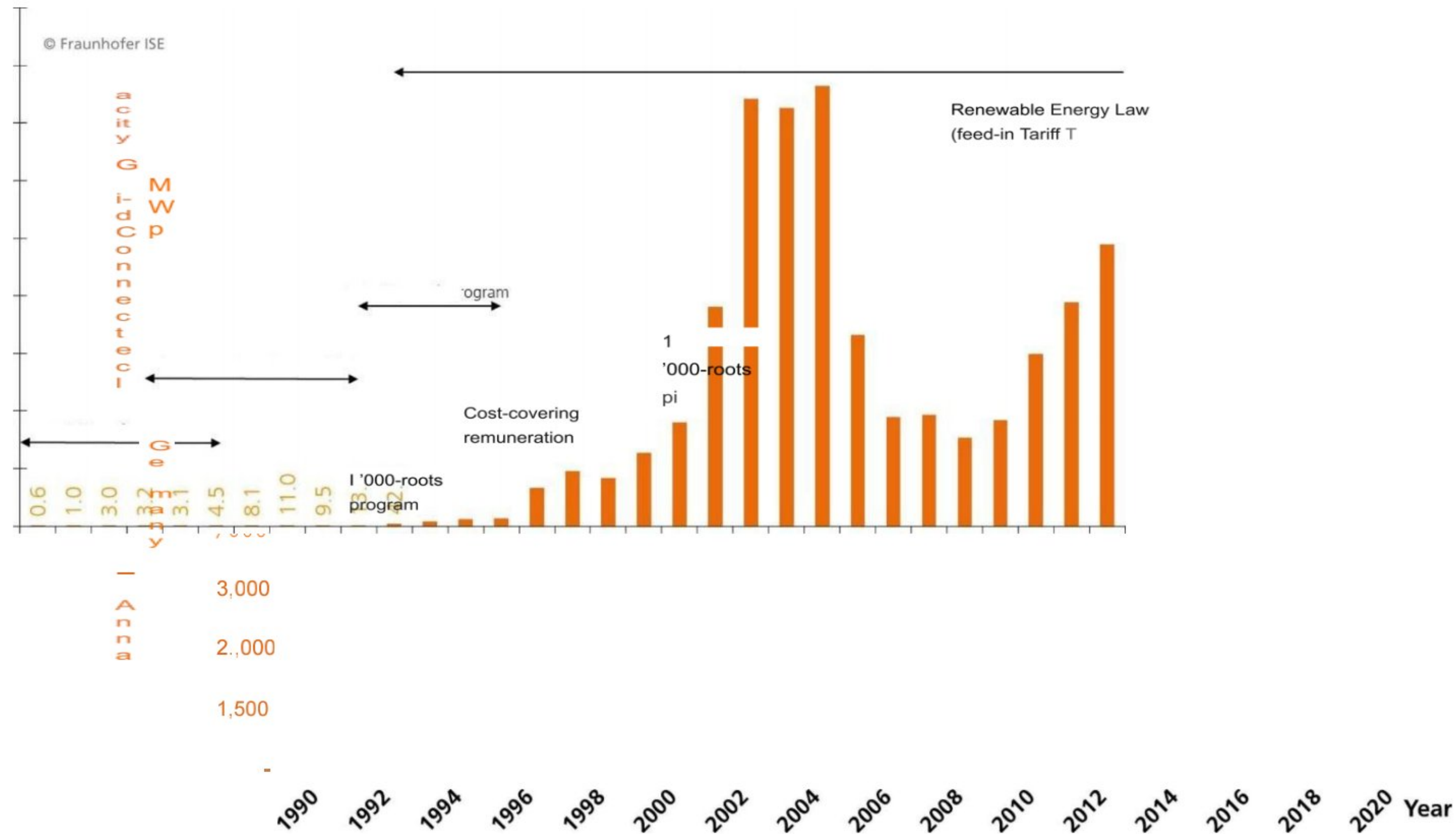
5. Price Development

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



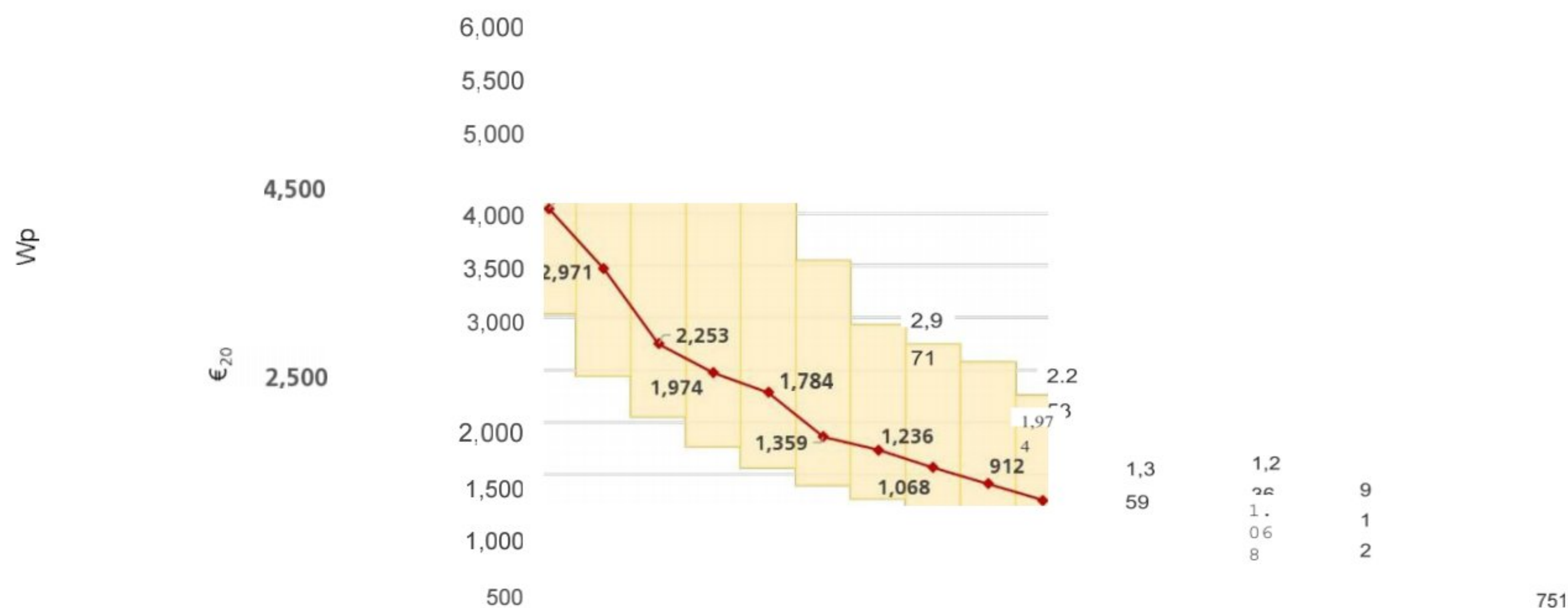
Solar Market Development

Subsidy Schemes in Germany



Data: BNA. Graph: PSE 2021

Global Weighted Average Total Installed Costs For Large PV Systems (with Sth percentile and 95th percentile)



Total installed cost for large PV systems decreased by about 16% on year-to-year basis in the last decade.

The Sth percentile is a value

associated
with the
location
within the
data where
5% of data is
below that

value. In year 2019 the 5th percentile was 539 GkWp. The 95th

percentile is the value where 5% of the data has is a larger value. In

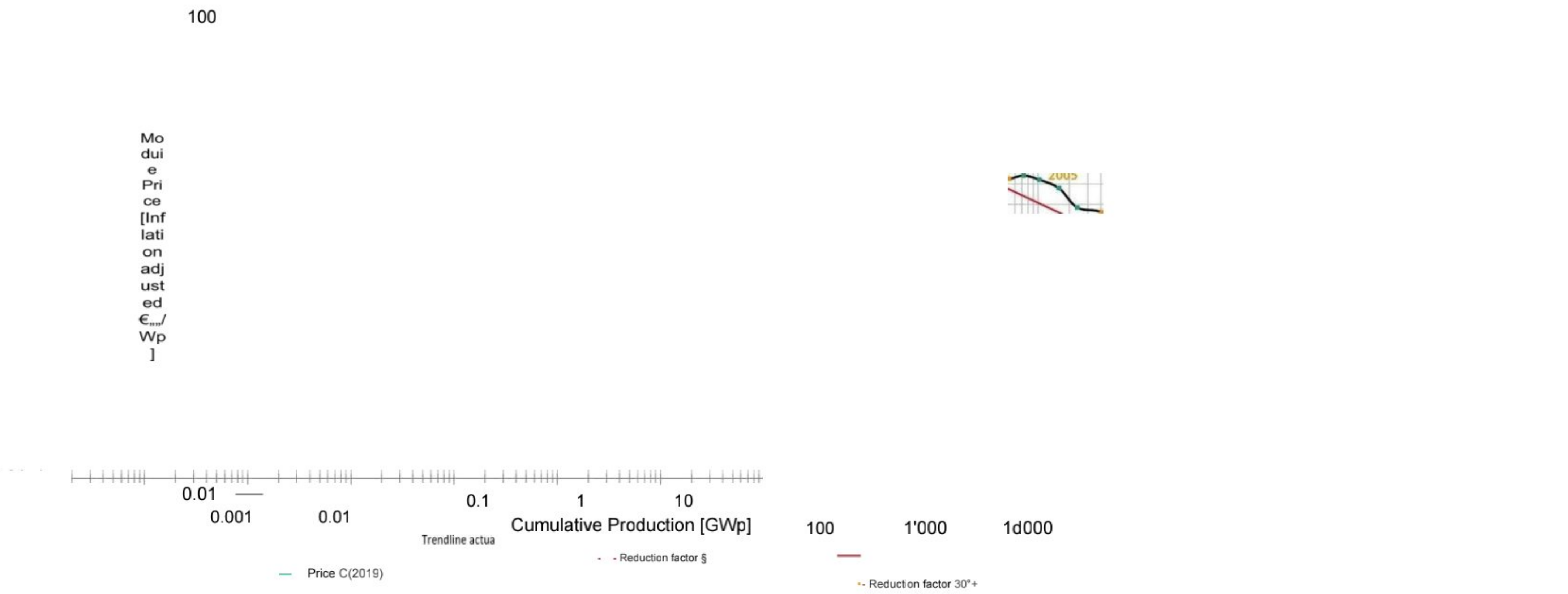
year 2019
the 95th
percentile
was 1751
€/kWp.

2		2						
0	2	0		2	2	2	2	2
0	0	2		0	0	0	0	0

Data: IRENA (2020), Renewable Power Generation Costs in 2019, International Renewable Energy Agency, Abu Dhabi. Currency converted from USD to EUR.

Price Learning Curve

Includes all Commercially Available PV Technologies



Learning Rate:

Each
time

the
cumula
tive PV
modul
e
produc

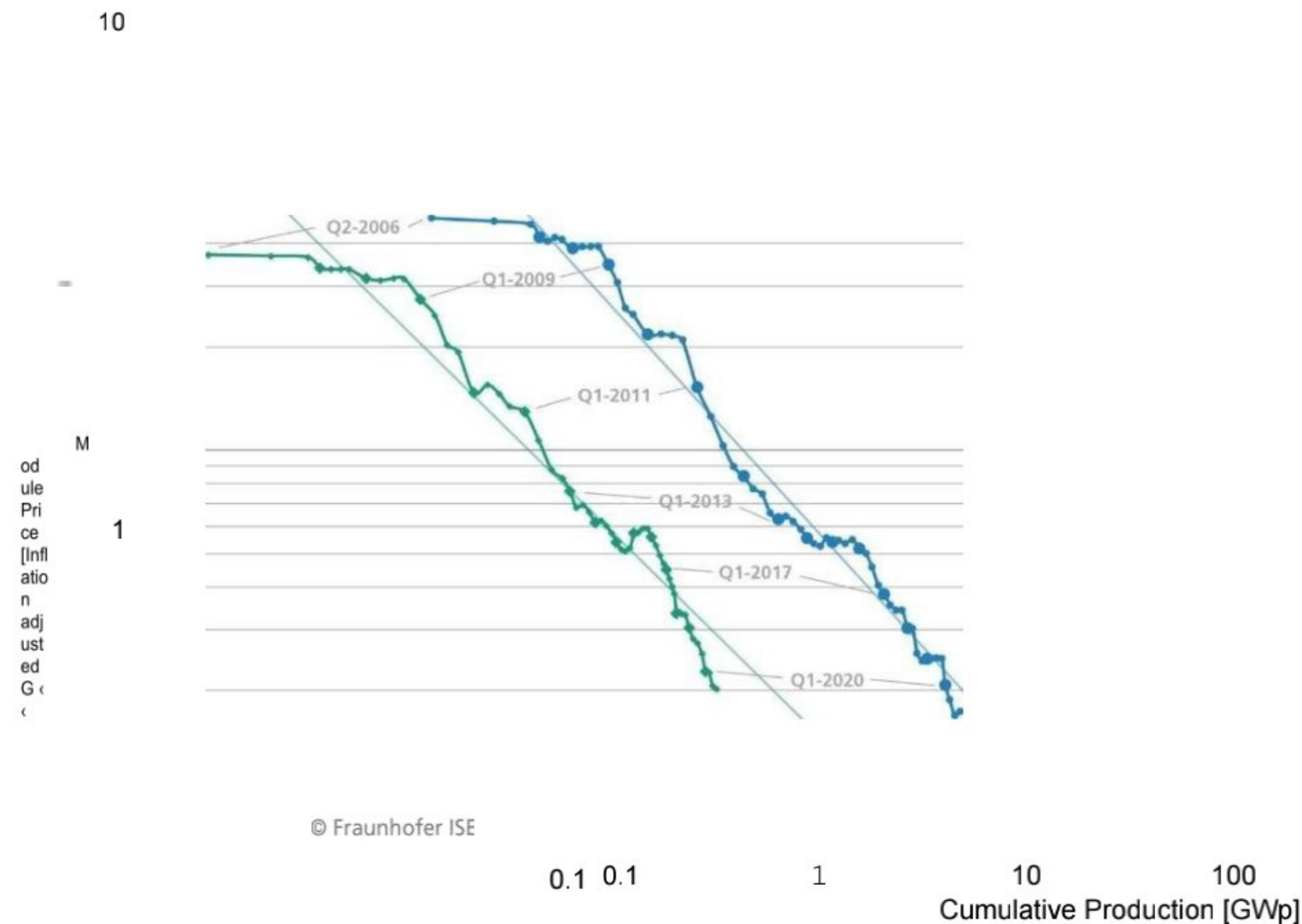
tion
double
d, the
price
went

down
by
25%
for the
last 40
years.

Data: from 1980 to 2010 estimation from different sources: Strategies Unlimited, Navigant Consulting, EUPD, pvXchange; from 2011: IHS Markit; Graph: PSE 2021

Price Learning Curve by Technology

Cumulative Production up to Q4-2020



Estimated cumulative PV module
production up to Q4-2020:

e c-Si 773 GWp
+ Thin Film 52 GWp

Crystalline Technology
(from Q2-2006 to Q4-2020) LR 32
Thin Film Technology
(from Q2-2006 to Q4-2020) LR 30

Data: from 2006 to 2010 estimation from different sources : Navigant Consulting, EUPD, pvXchange; from 2011: IHS Markit. Graph: PSE 2021

Abbreviations

[illegible]

Photovoltaic

Renewable Energies

Return on Investment

Silicon

Silicon carbide

Value Added Tax

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Acknowledgements

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The information provided in this 'Photovoltaics Report' is very concise by its nature and the purpose is to provide a rough overview about the Solar PV market, the technology and environmental impact.

There are many more aspects and further details can be provided by Fraunhofer ISE. Upon request, you are welcome to receive a tailor-made offer.

Please contact us if you are interested in ordering this service.

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