

Latest Developments

in photovoltaic solar energy use:

Applications, Costs, Competitiveness

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Electrical Energy Technology - Sustainable Energy Concepts

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Overview of Presentation



0. Introduction

1. Phases of PV development *PV 1.0: Off-grid PV*
2. Phases of PV development *PV 2.0: Grid-connected PV*
3. Phases of PV development *PV 3.0: Electricity dominated by PV*
4. Production & Price development in PV
5. World markets for PV

University of Paderborn (UPB)

Faculty for Electrical Engineering, Informatics & Mathematics
Electrical Energy Technology – Sustainable Energy Concepts
(EET – NEK)



Research area:

Sustainable Generation and Use of Energy

- Energy efficient buildings
- Wind power monitoring
- Decentralized energy systems
- Virtual energy storage
- Load shifting via remote control of loads
- Yield prediction & optimization of PV





Prof. Dr.-Ing. habil. Stefan Krauter

- 1998** Dipl.-Ing. for EE at University of Technology Munich
- 1993** Ph.D. at University of Technology Berlin
- 1996** Founder of SOLON AG (manufacturer of PV modules)
- 1998** Habilitation at University of Technology Berlin
- 1999** Founder of Rio-Solar Ltd (design & set-up of PV systems)
- 1998-2006** Visiting Professor at Federal University of Rio de Janeiro
(lectures, set-up of RE-lab, chairman of events *RIO 02-15*)
- 2006** Co-Founder of Photovoltaic Institute Berlin
(Testing & certification of PV modules & systems)
- 2008-2010** Professor at University of Applied Sciences Biberach
- Since 2010** Professor & Chair at University of Paderborn,
Vice-Director of Competence Center for Sustainable
Energy Technology (KET)

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2. Phases of PV development *PV 2.0: Grid-connected PV*

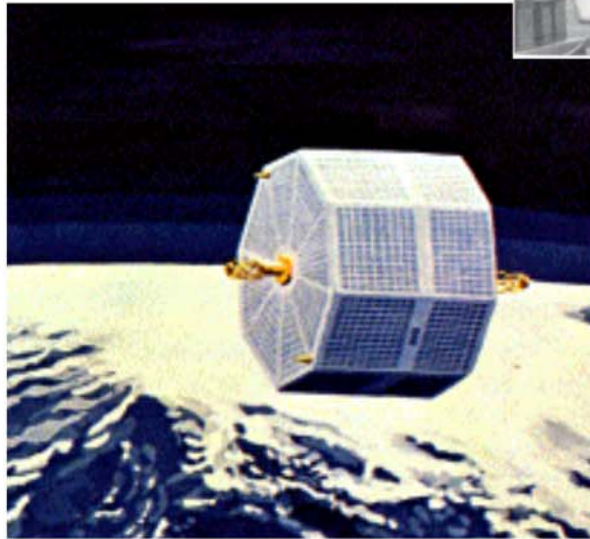
3. Phases of PV development *PV 3.0: Electricity dominated by PV*

4. Production & Price development in PV

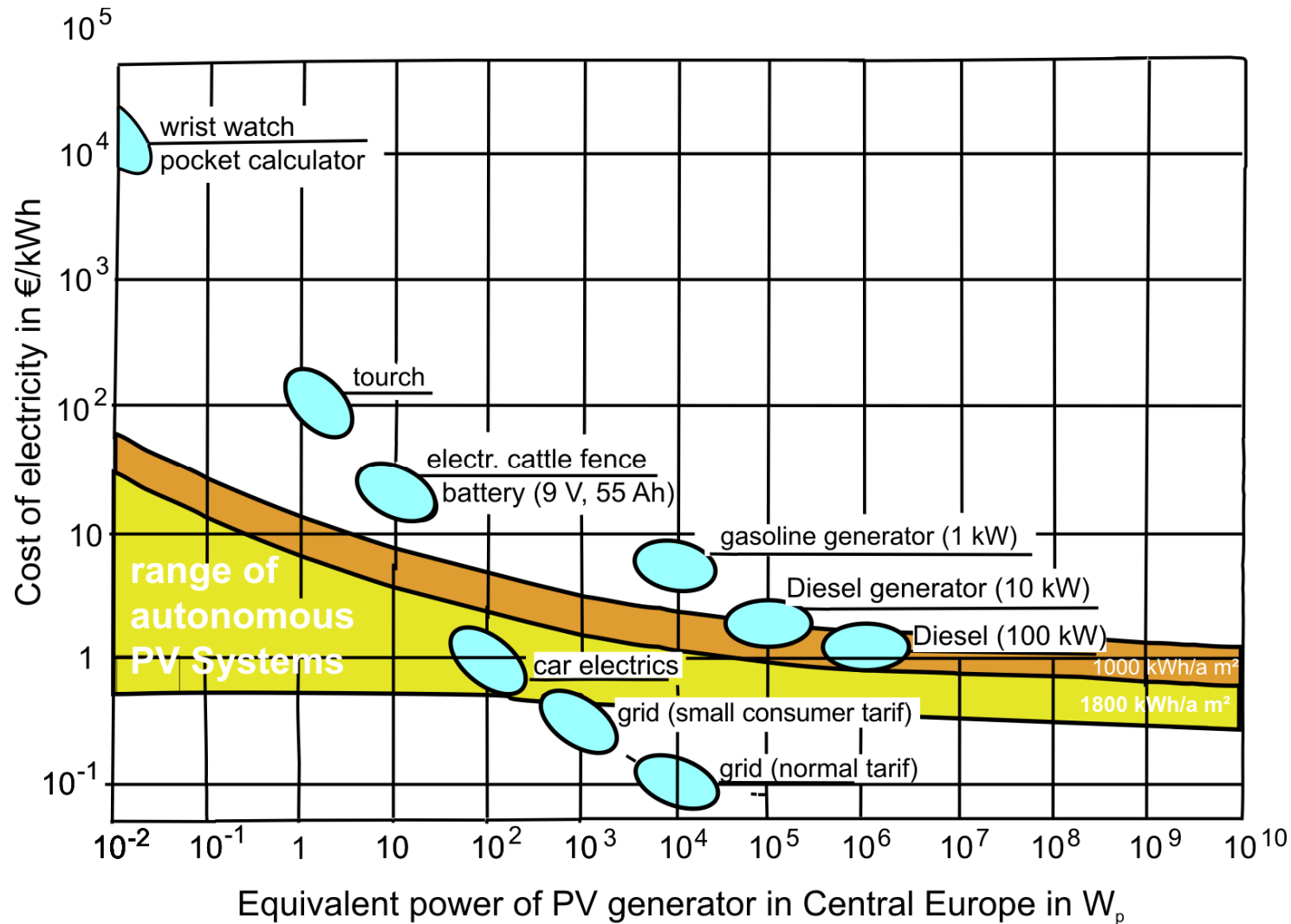
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First applications of PV (PV 1.0): Space & science fiction & remote power supply

**Important:
Far away from
electrical grid**



Market for autonomous PV systems



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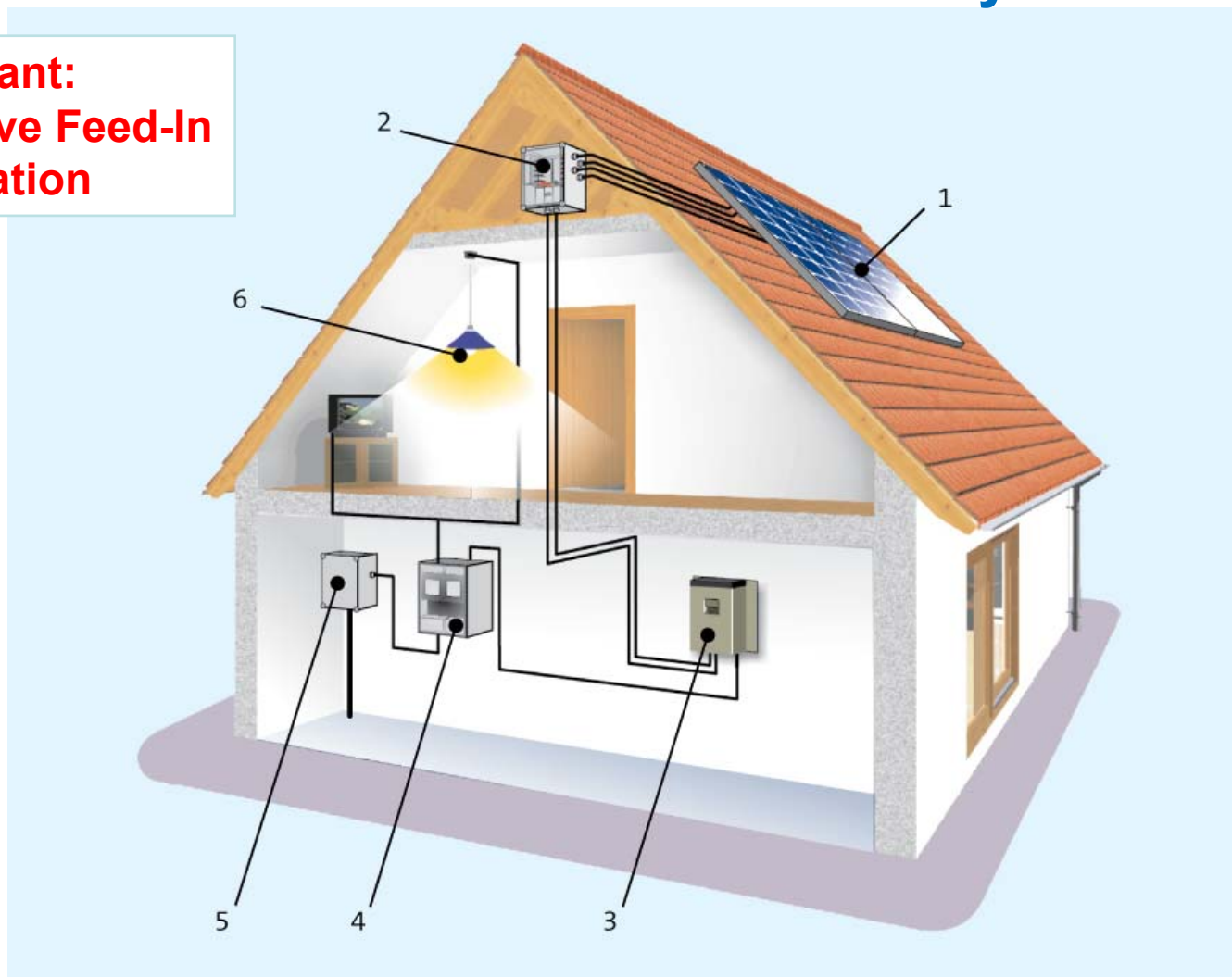
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PV 2.0: Grid-connected PV systems

**Important:
Effective Feed-In
Legislation**



© www.solarpraxis.de

1 PV generator, 2 Junction box, 3 Inverter, 4 kWh-counter for consumption and PV injection, 5 grid connection, 6 local loads

PV grid-connected houses in Freiburg, Germany



PV in the urban environment: Solar Façade (Berlin 1990, 17 kW)



**Solar modules also serve as shading elements:
Energy saving for air-conditioning!**



Grid-connected PV on Munich airport (2.2 MW)



Source: MUC

11 MW PV power plant in Cerpa, Portugal

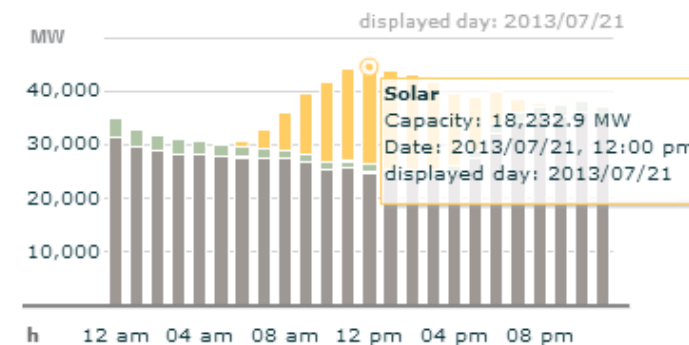


Source: EU

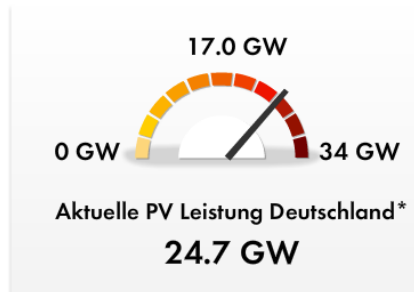
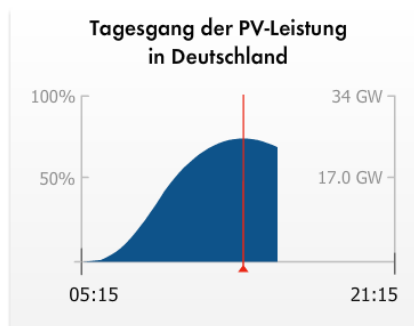
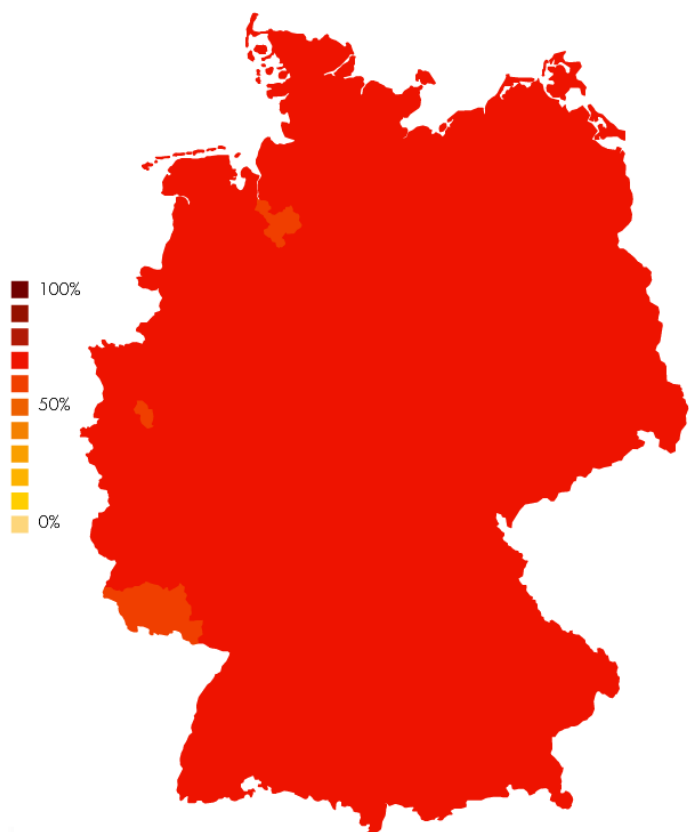
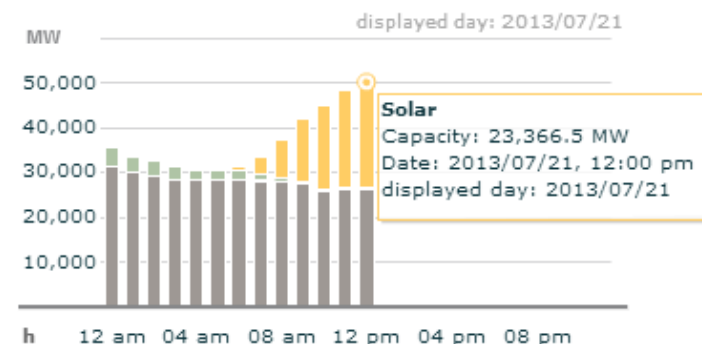
Record Grid-PV (21/7/2013): 24.7 GW

(more than all German nuclear power plants together - ever)

Planned production (power)



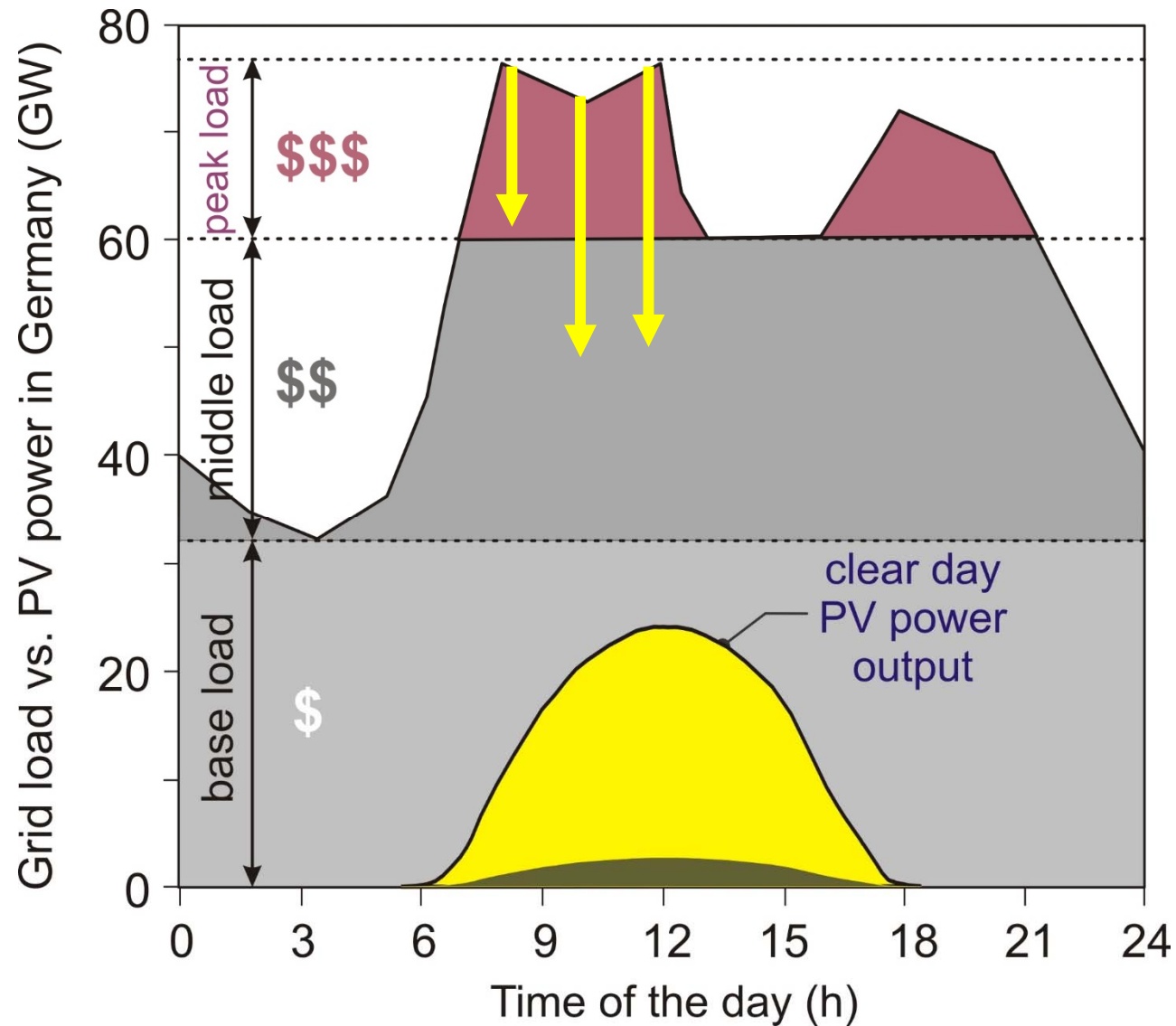
Actual production (power)



*Hochgerechnete Leistung aller lt. Bundesnetzagentur am Stichtag 31.05.2013 installierten PV-Anlagen mit insgesamt 33.93 GW Nennleistung.

Source: SMA & EEX Transparency

Load curve & PV electricity in Germany






Since 2012:

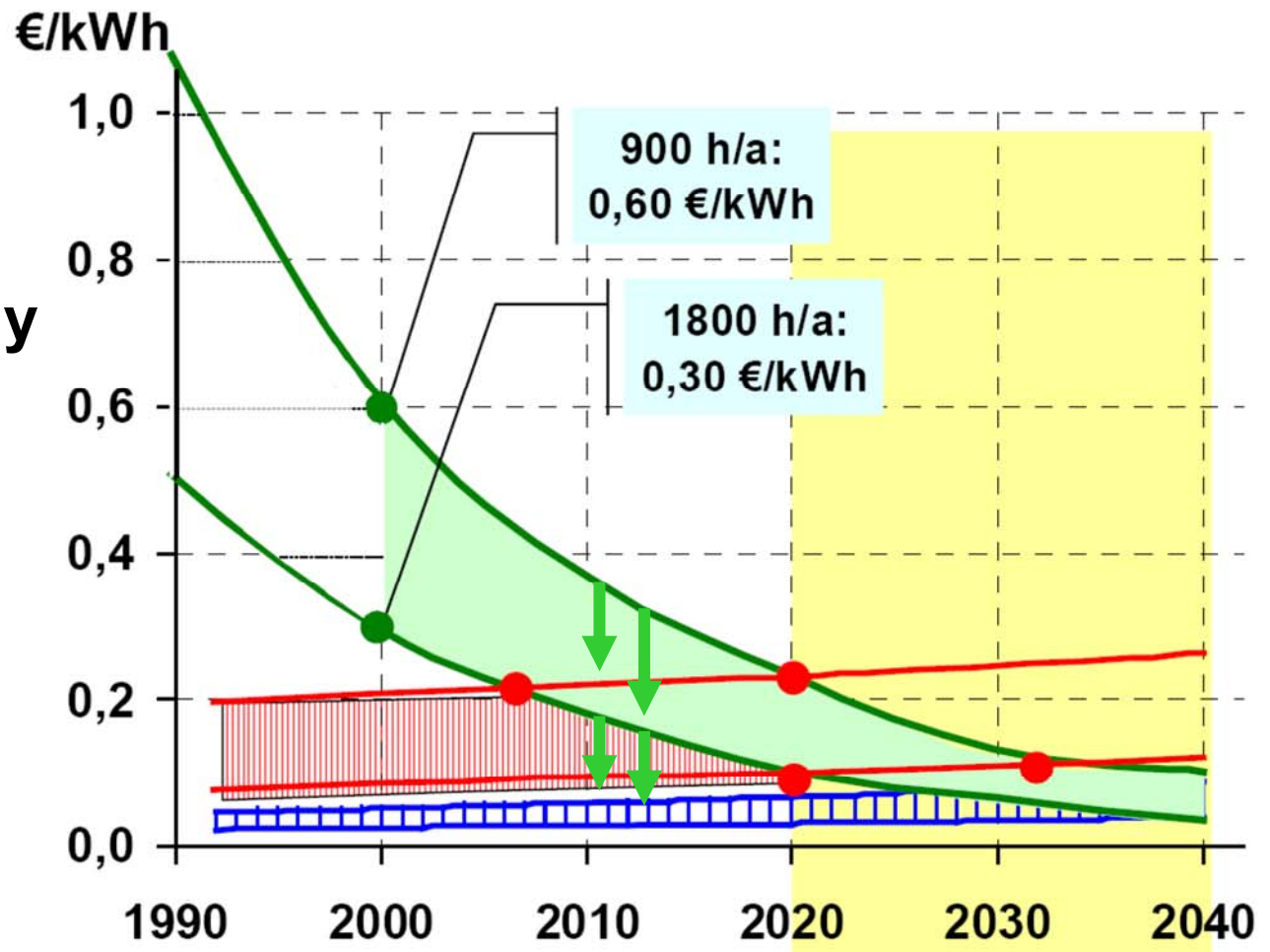
PV electricity cheaper than consumer tariff

Cost reduction values achieved 8 years ahead of time

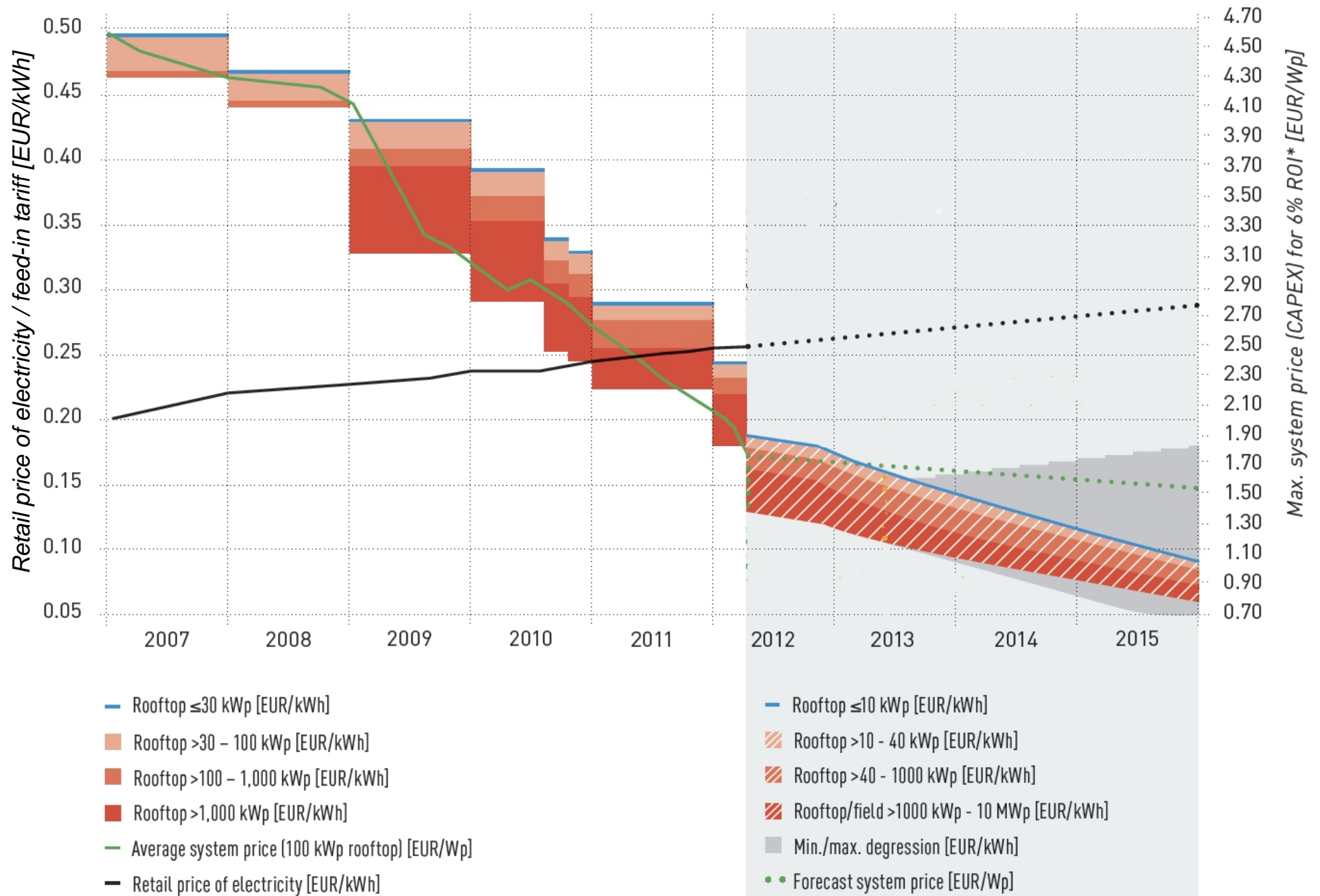
Costs for electricity supply (grid & PV)

Source: Hoffmann 2000, Krauter 2010

-  PV
-  Peak load
-  Base load



Feed-in-Tariff (FiT) vs. electricity price in Germany



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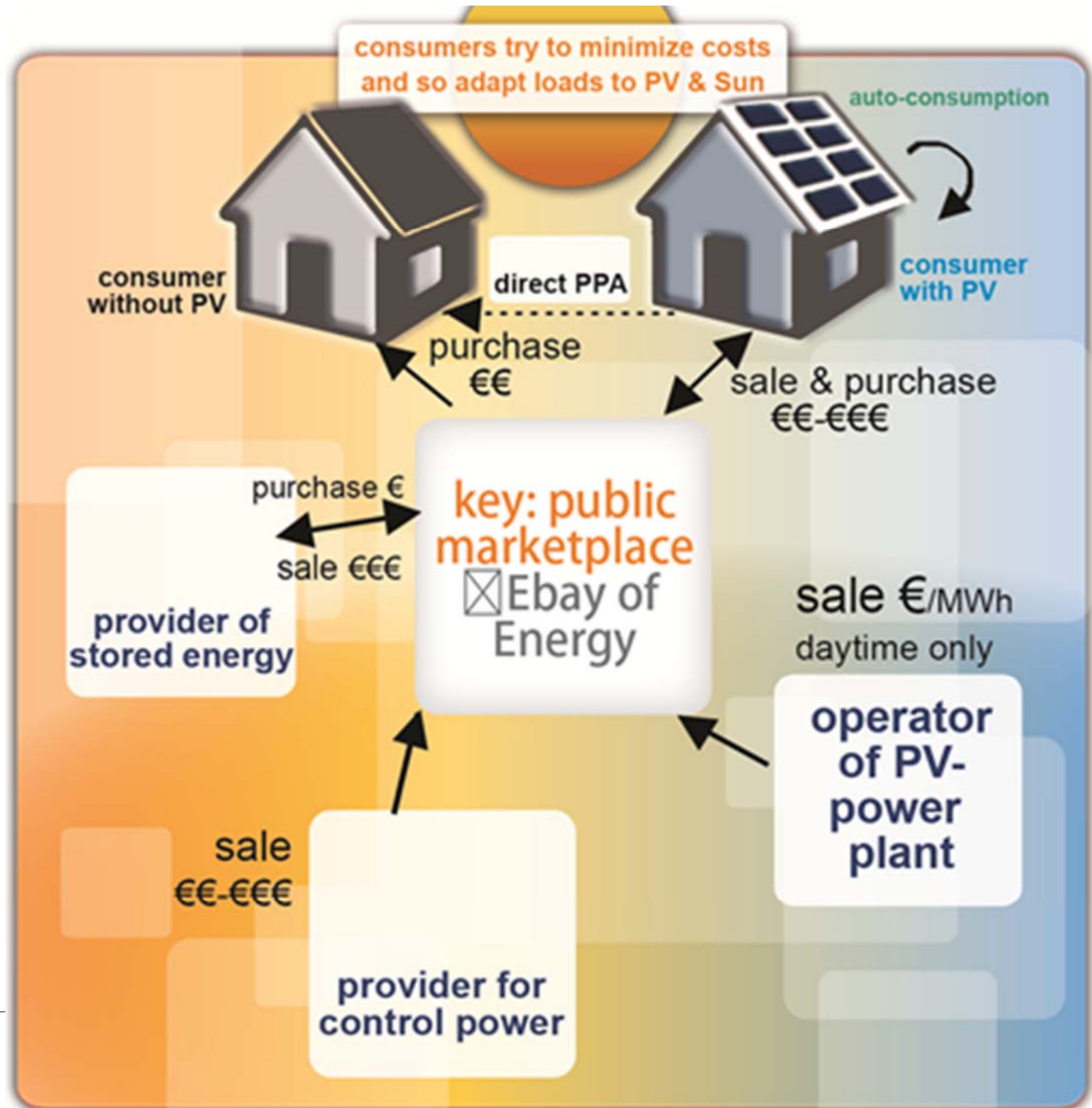
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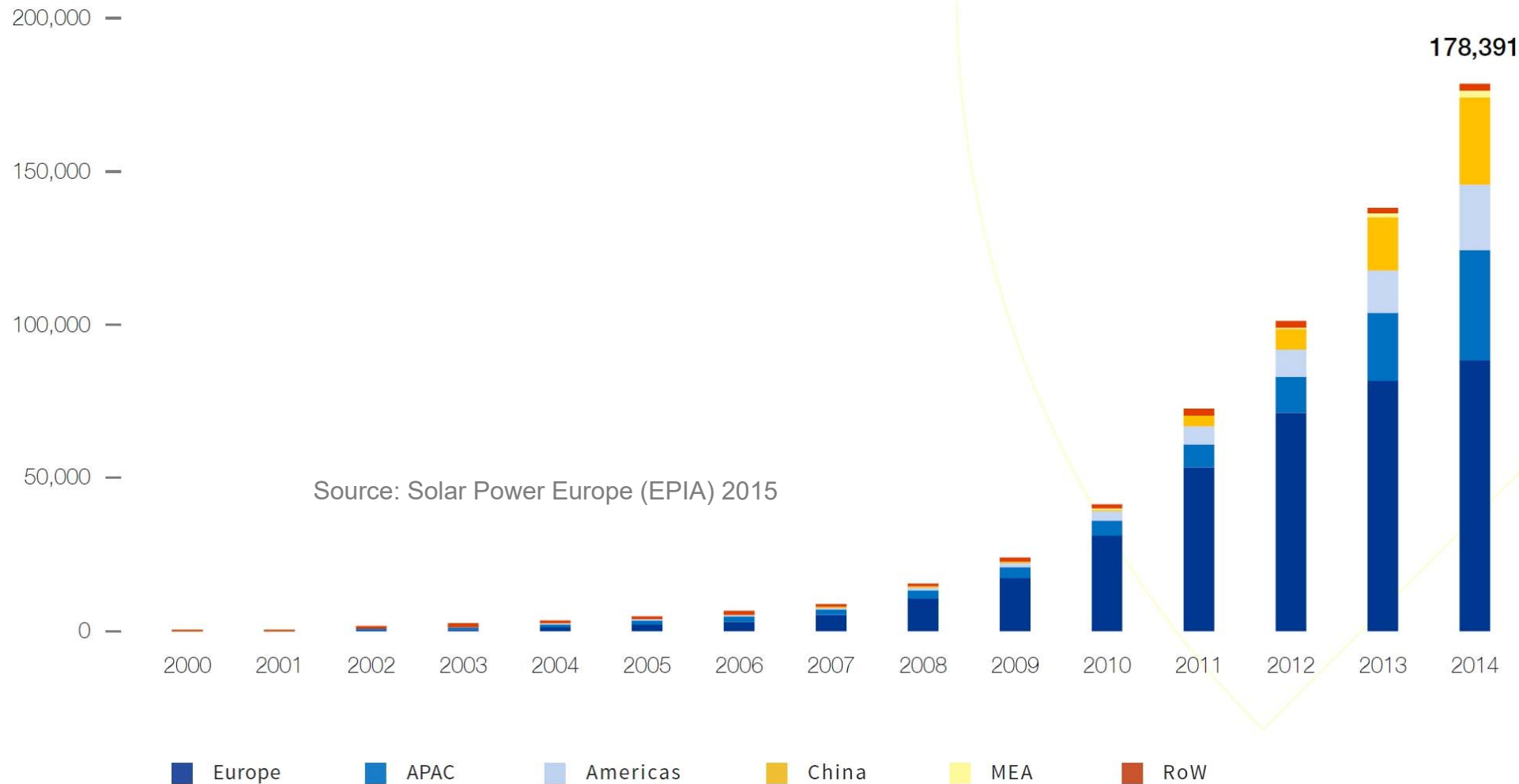
PV 3.0: Electricity market dominated by PV

(Rest is back-up
only)

Crucial:
Free access to
the grid and the
control power
market!

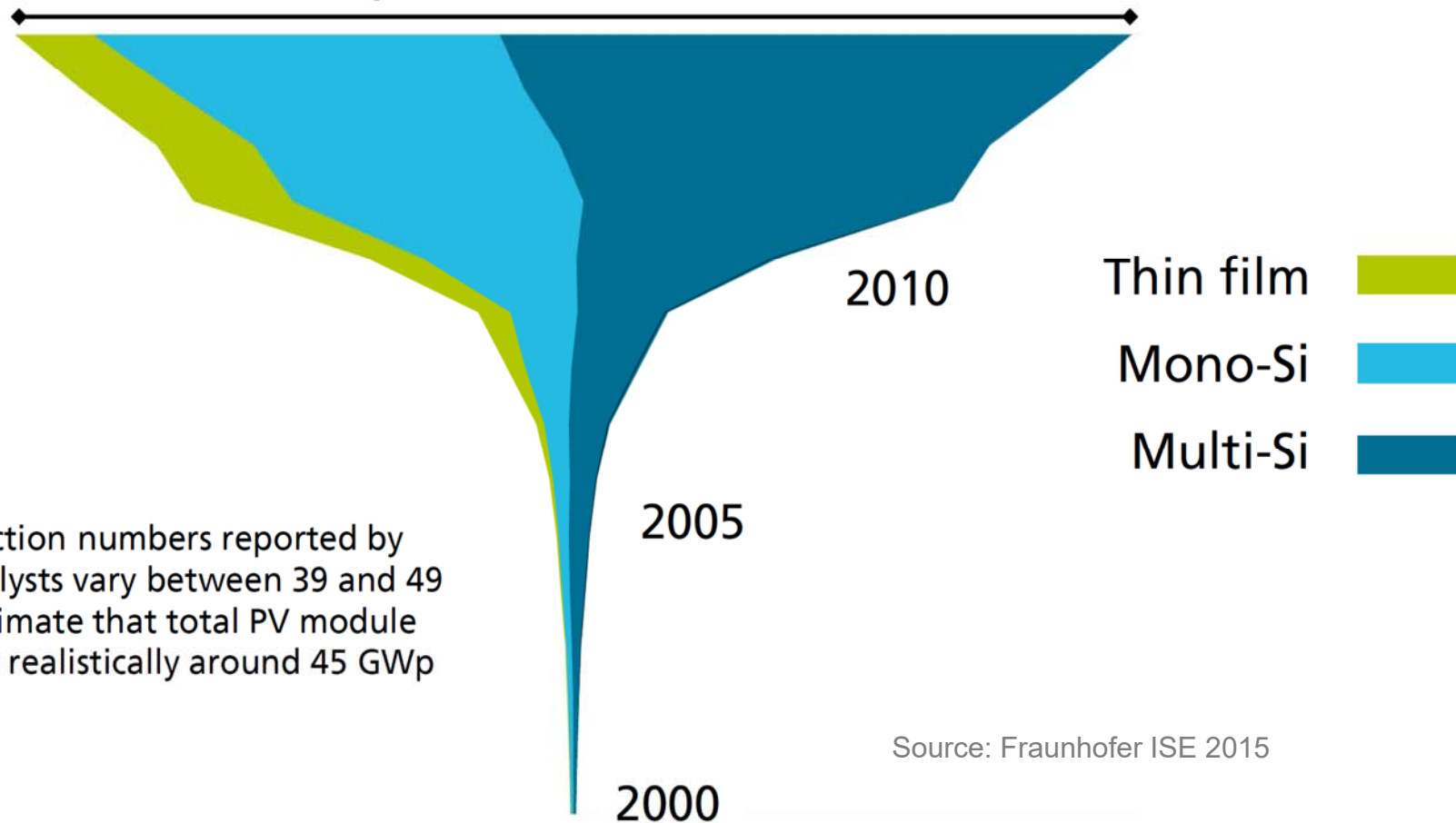


PV cumulative global installed capacity until 2014 (in MW)



Annual production & PV technologies shares

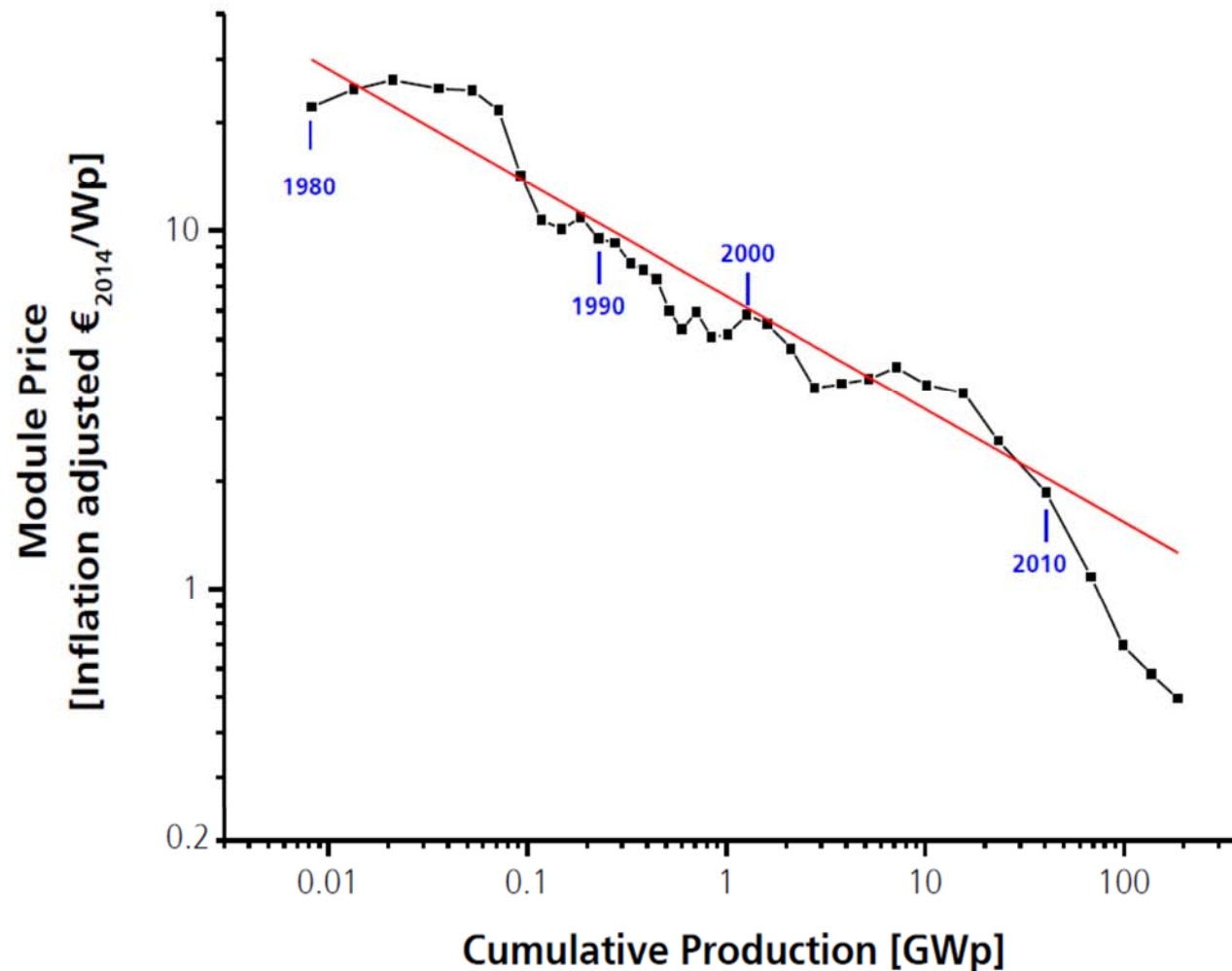
About 47.5* GWp PV module production in 2014



*2014 production numbers reported by different analysts vary between 39 and 49 GWp. We estimate that total PV module production is realistically around 45 GWp for 2014.

Source: Fraunhofer ISE 2015

Development of PV costs



**Generation cost of PV
in Brazil (incl. import etc.):**
2000: 0.40 \$US/kWh
2015: 0.08 \$US/kWh

Data: from 2006 to 2010 estimation from different sources : Navigant Consulting, EUPD, pvXchange; from 2011 to 2014: IHS. Graph: PSE AG 2015

1. “Long” time ago (2000-2010):
Production & Installation in Germany

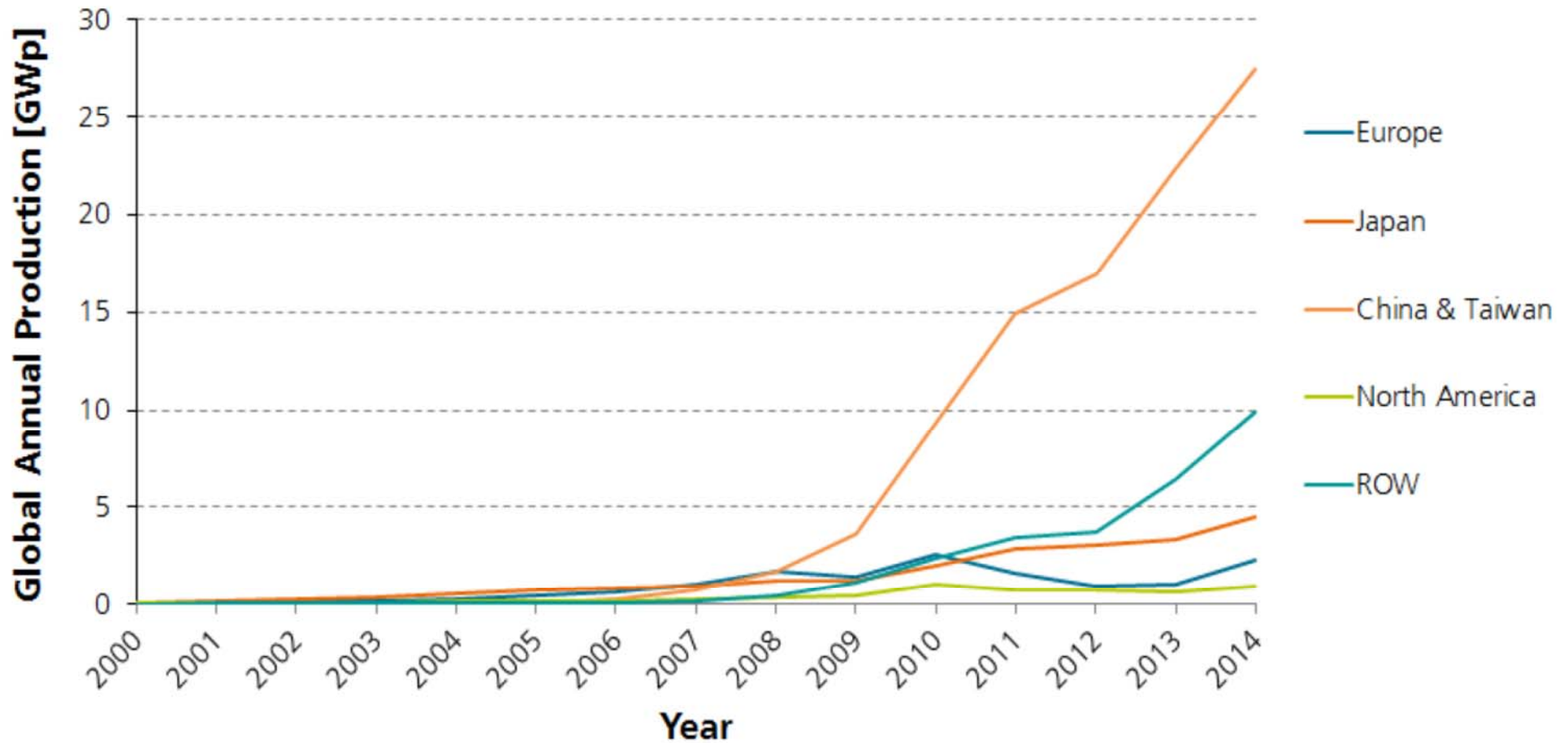
2. Until recently (2010-2012):
Production in China
Installation in Germany

3. Now:
Production in China/Taiwan/Japan
Installation in China, Japan, USA, Indonesia,
Middle East, S-America, Africa

New Non-FiT Markets

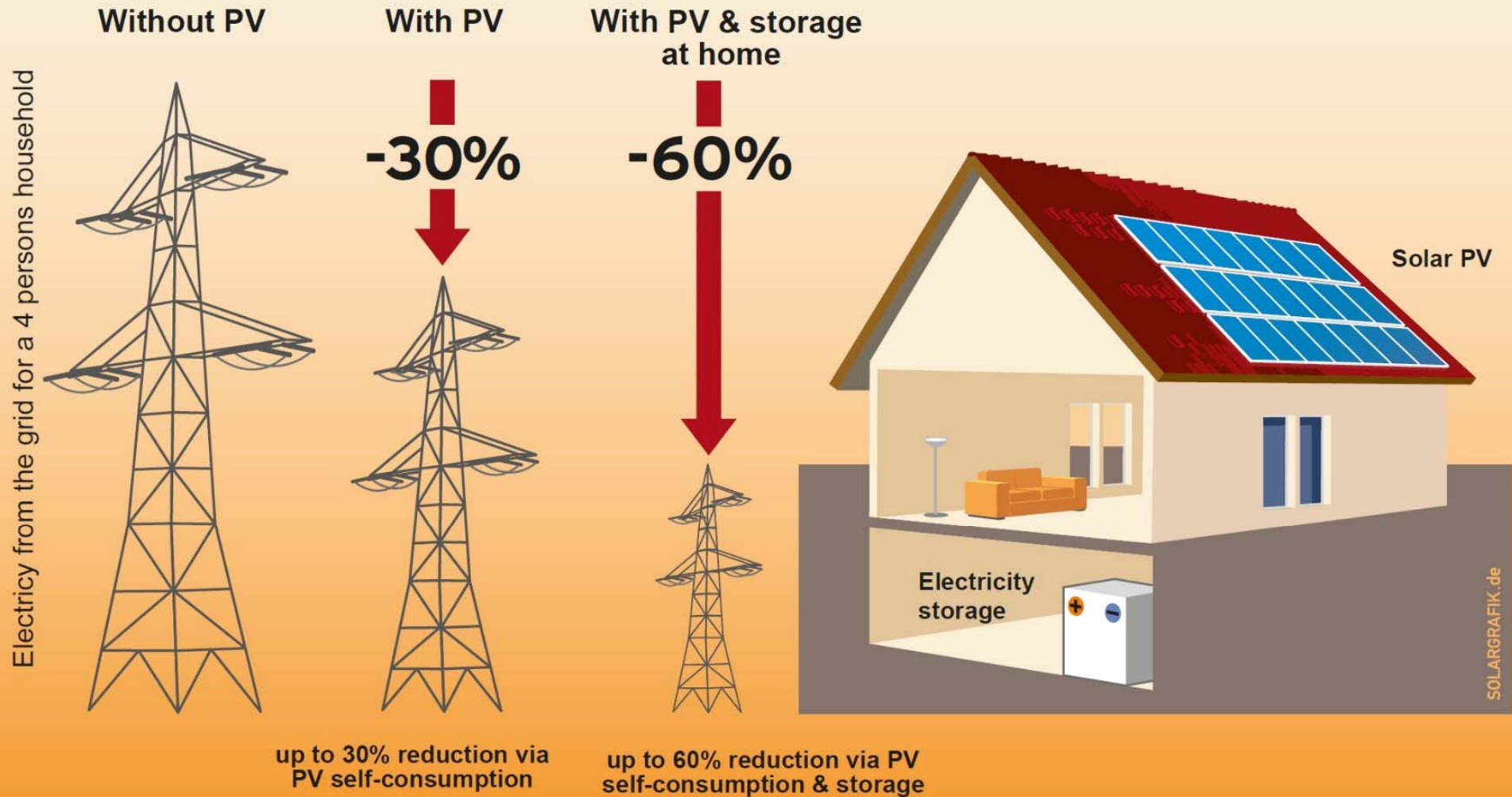
Development of PV production by region/country

Source: Fraunhofer-ISE, Navigant Consulting 2015



New trend: PV & home storage: Up to 60% less electricity from the grid

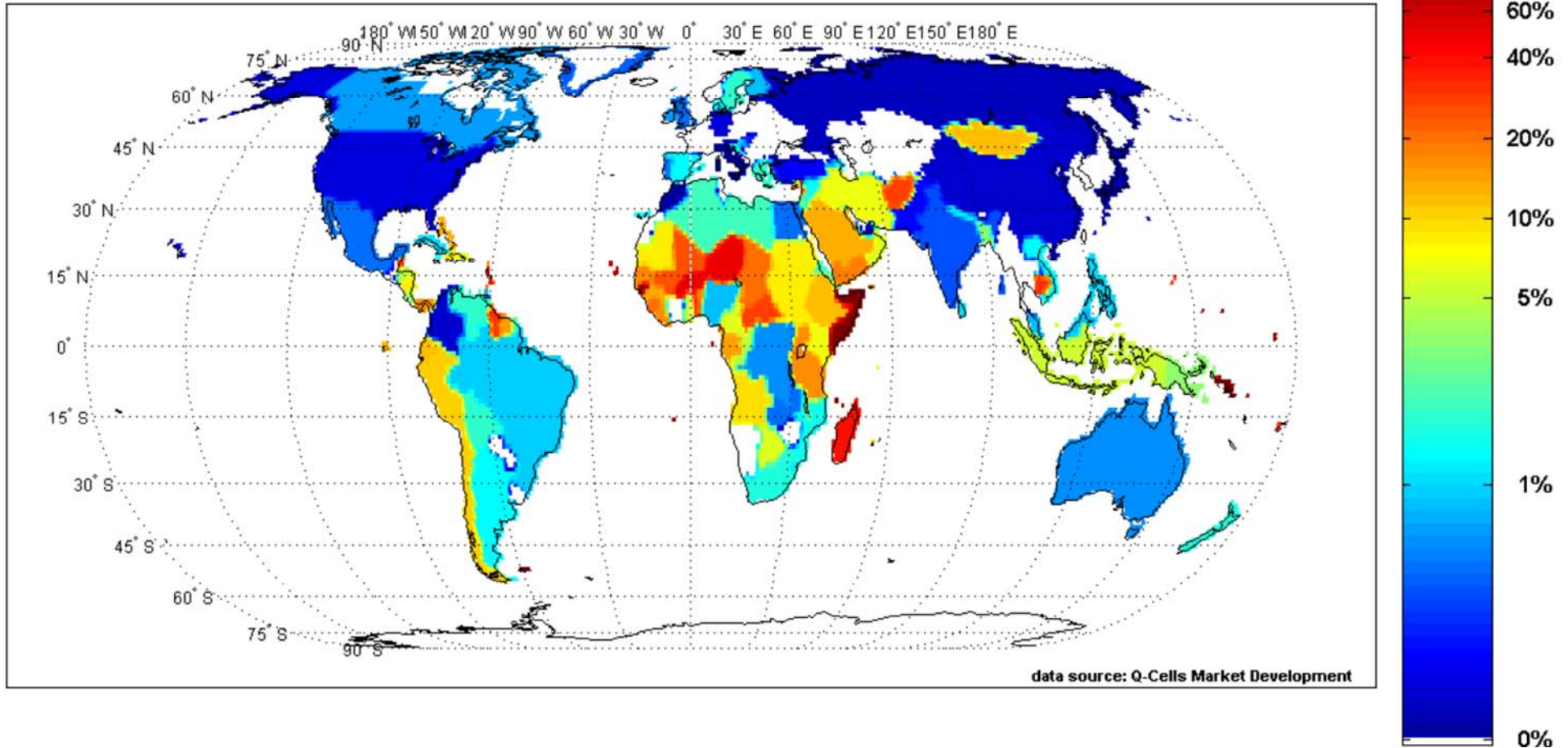
German case:
For Brazil 100% can be achieved



Base: Household with 4 persons: 4500 kWh/a, PV generator of 5 kW, effective storage capacity: 4 kWh

New Markets: Substitution of Diesel power plants (500 GW) by PV

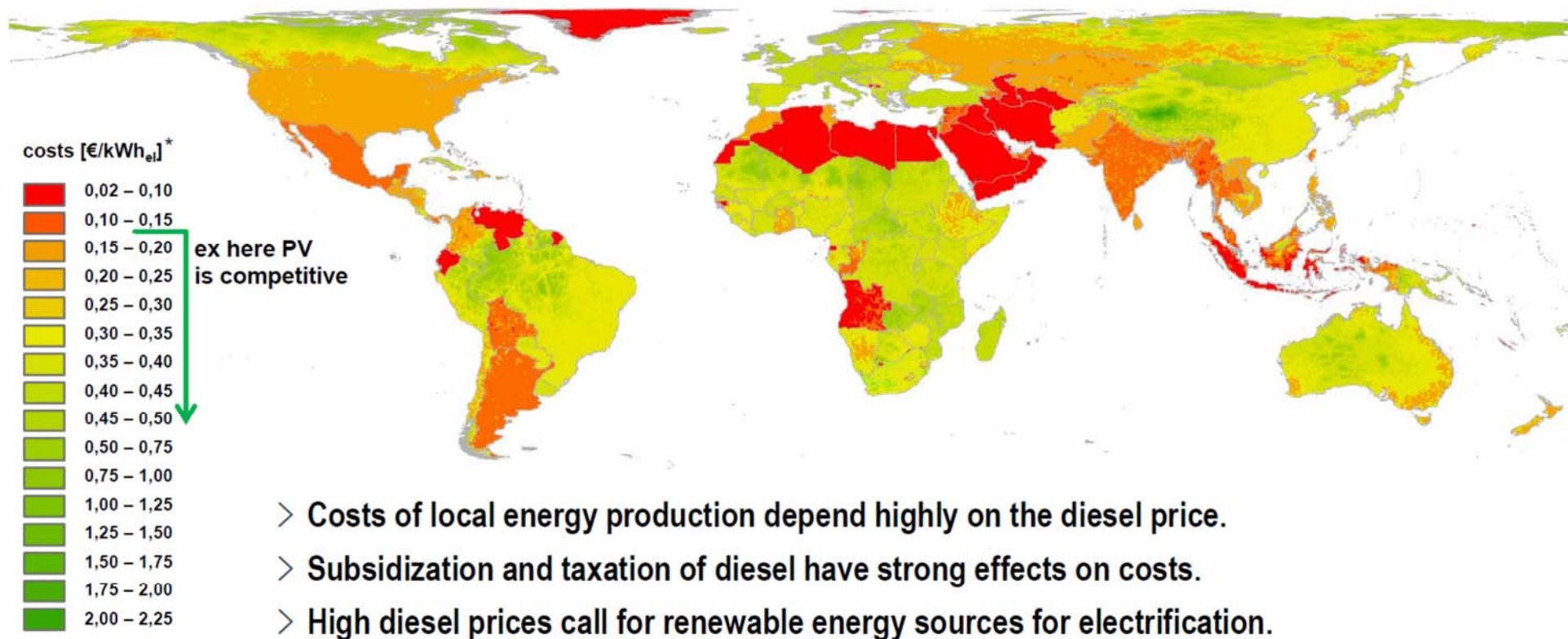
Share of diesel power plant capacity to total power plant capacity



Source: C. Breyer, RLI, 5th ARE Workshop Academia meets Industry, 27th EUPVSEC, Frankfurt 2012

Cost comparison: Substitution of Diesel gen-sets by PV

Electricity generation costs of pure diesel grids



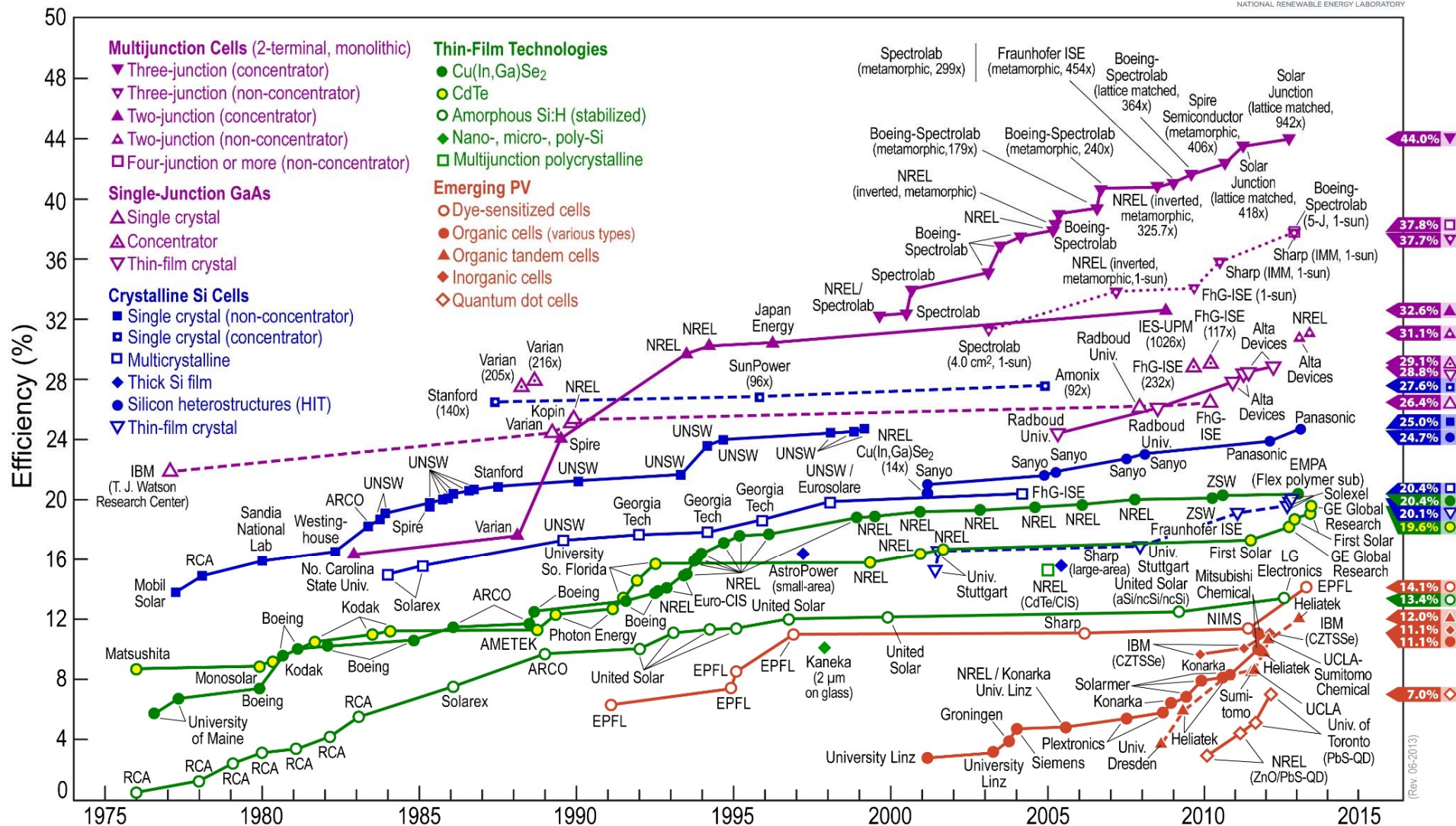
* 1 l diesel corresponds
to ca. 3 kWh_{ei}

model based on: Szabo S. et al., 2011. Energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension, Environ. Res. Lett., 6, 034002

Source: C. Breyer, RLI, 5th ARE Workshop Academia meets Industry, 27th EUPVSEC, Frankfurt 2012

Thank you for your attention !

Best Research-Cell Efficiencies



Actual (8/15) share of grid-connected PV in Brazil

www.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm

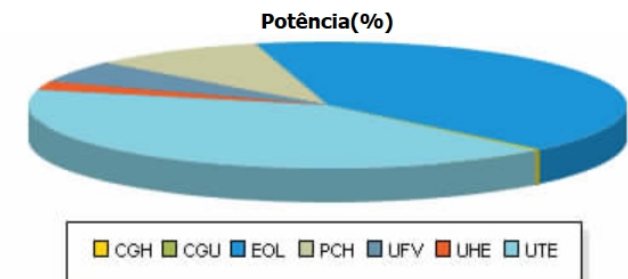
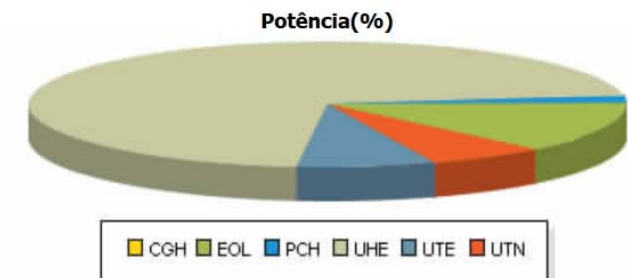
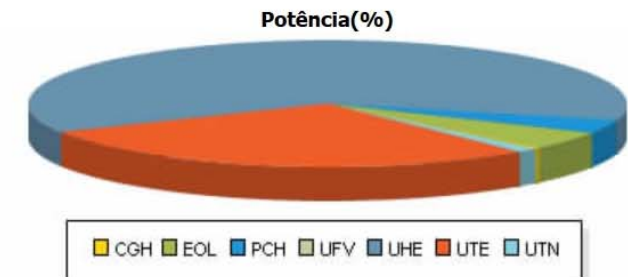
Source: ANEEL 2015

Empreendimentos em Operação				
Tipo	Quantidade	Potência Outorgada (kW)	Potência Fiscalizada (kW)	%
CGH	516	355.306	357.183	0,26
EOL	266	6.504.333	6.482.397	4,69
PCH	467	4.828.452	4.815.410	3,48
UFV	25	15.236	11.236	0,01
UHE	197	87.699.904	85.127.318	61,56
UTE	2.760	40.955.701	39.504.373	28,57
UTN	2	1.990.000	1.990.000	1,44
Total	4.233	142.348.932	138.287.917	100

Os valores de porcentagem são referentes a Potência Fiscalizada. A Potência Outorgada é igual a considerada no Ato de Outorga. A Potência Fiscalizada é igual a considerada a partir da operação comercial da primeira unidade geradora.

Empreendimentos em Construção			
Tipo	Quantidade	Potência Outorgada (kW)	%
CGH	1	848	0
EOL	114	2.805.582	13,06
PCH	35	422.475	1,97
UHE	11	15.269.142	71,08
UTE	20	1.634.639	7,61
UTN	1	1.350.000	6,28
Total	182	21.482.686	100

Empreendimentos com Construção não iniciada			
Tipo	Quantidade	Potência Outorgada (kW)	%
CGH	42	28.149	0,14
CGU	1	50	0
EOL	346	8.169.654	41,37
PCH	130	1.846.429	9,35
UFV	40	1.096.523	5,55
UHE	4	447.000	2,26
UTE	148	8.161.891	41,33
Total	711	19.749.696	100



Exponential growth to be expected !