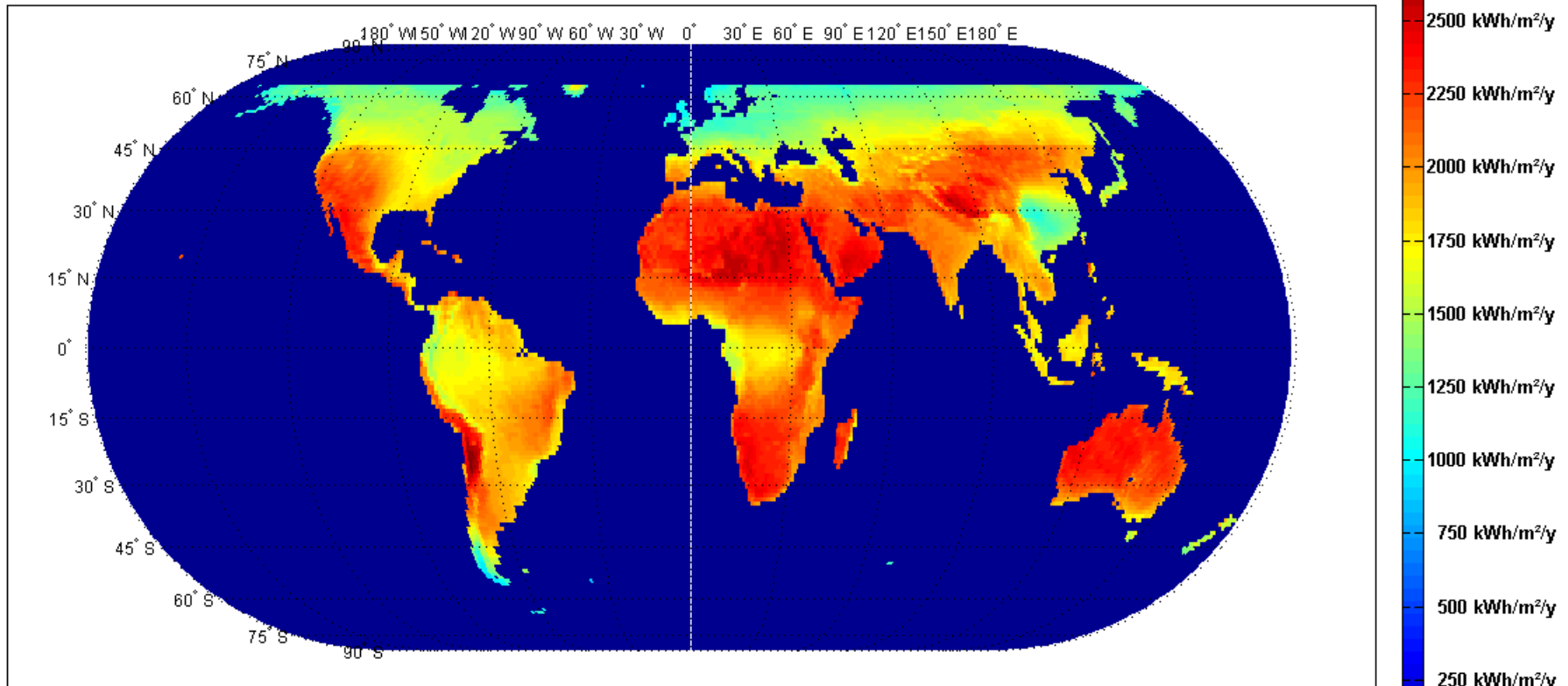

Sustainable Growth Potential of Photovoltaic Systems in a Global Perspective

Christian Breyer
76. Jahrestagung der DPG
Arbeitskreis Energie
Berlin, March 28, 2012



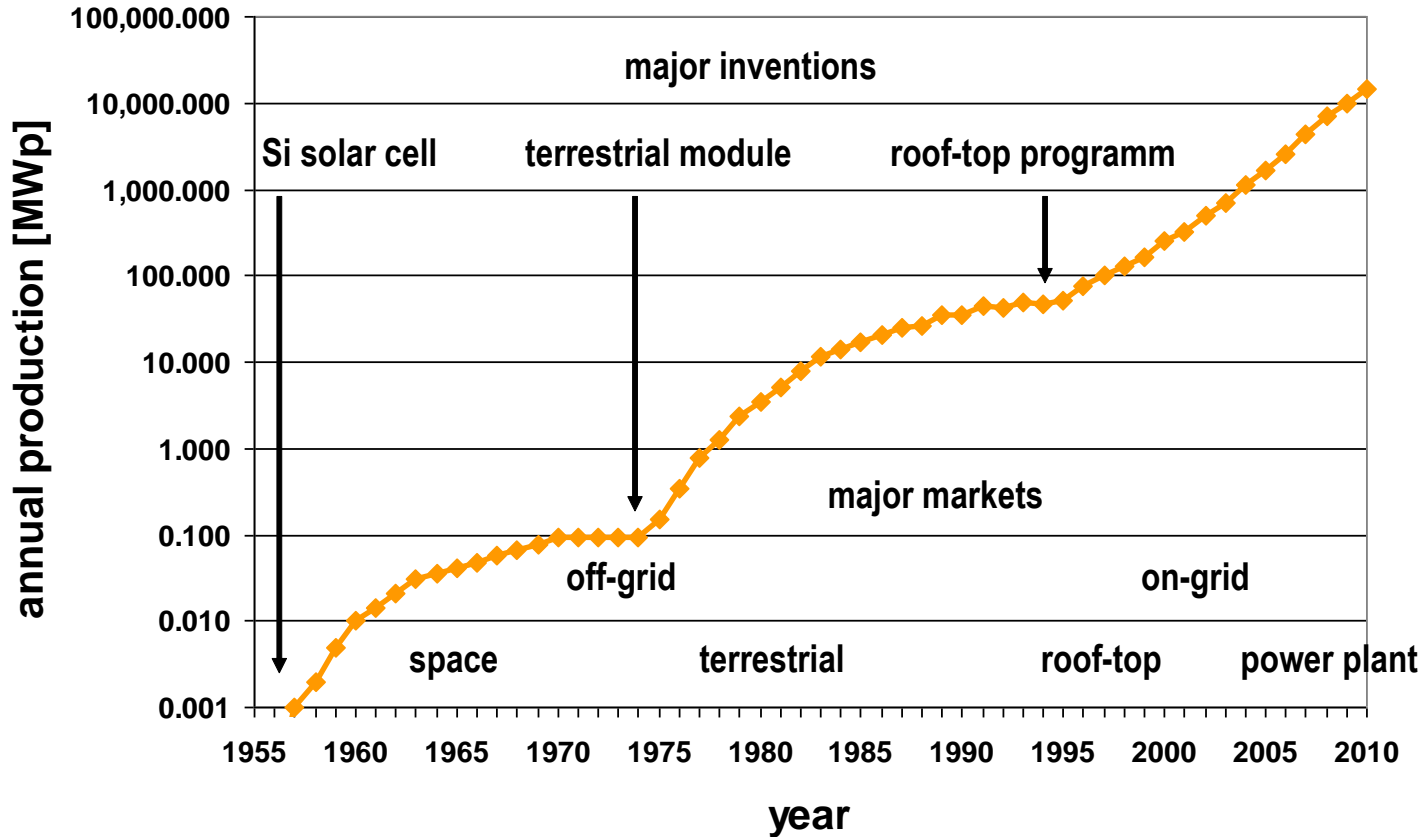
irradiation 0-axis fixed tilted optimal tilt angle



data source: NASA SSE 6.0, calculation by HDKR model 1h interval at mean day of month for all months of the year

source: Breyer Ch. and Schmid J., 2010. Population Density and Area weighted Solar Irradiation: global Overview on Solar Resource Conditions for fixed tilted, 1-axis and 2-axes PV Systems, 25th PVSEC/ WCPEC-5, Valencia, September 6–10

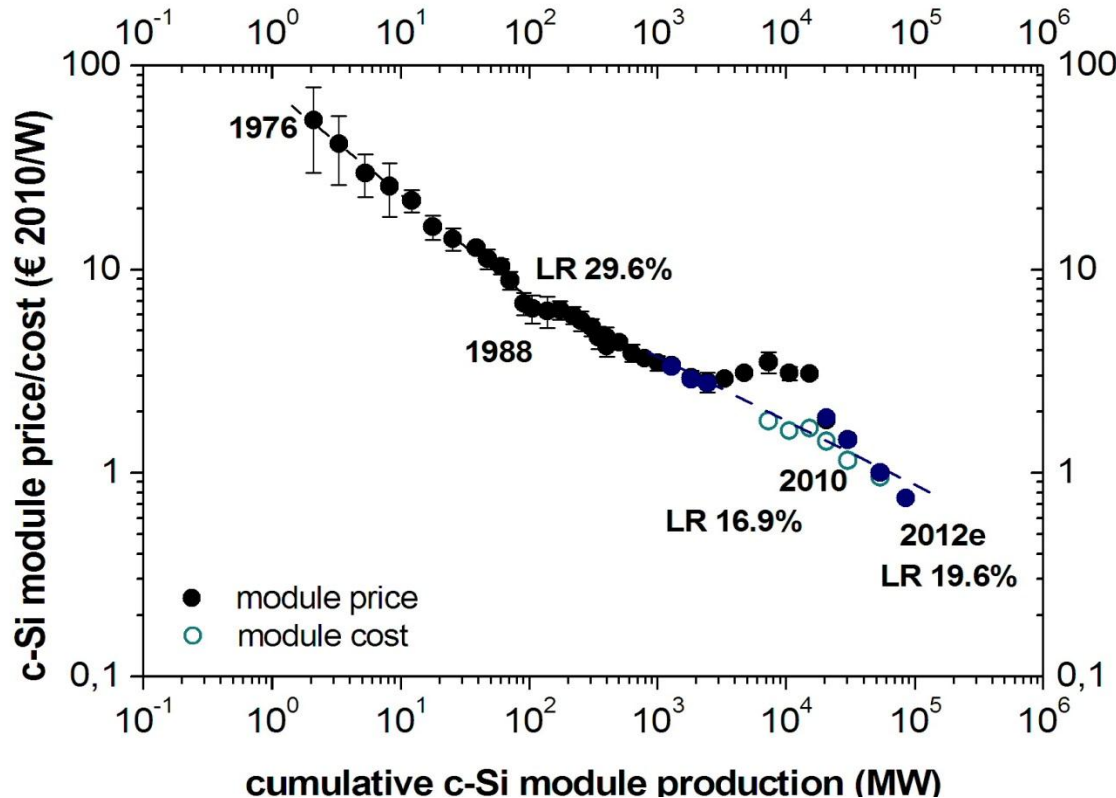
Historic PV Diffusion Phases



- constant high growth rates of >30% p.a. in all diffusion phases
- growth rate of 45% over last 15 years

source: Breyer Ch. et al., 2010. Research and Development Investments in PV – A limiting Factor for a fast PV Diffusion?, 25th EU PVSEC/ WCPEC-5, Valencia, September 6–10

PV Learning Rate: Stable over 50+ years



- learning rates in comparable industries
 - ~40% DRAMs (by getting smaller)
 - ~35% flat panels (by getting larger)
- typical learning rates in power sector
 - ~10% renewable power (wind, STEG)
 - negative nuclear power
- similar learning rates for PV inverter
- technology base for ongoing cost reduction is fast growing

**PV „BACK ON TRACK“
ON
20% LEARNING
CURVE**

**doubling of cumulated
production volume**

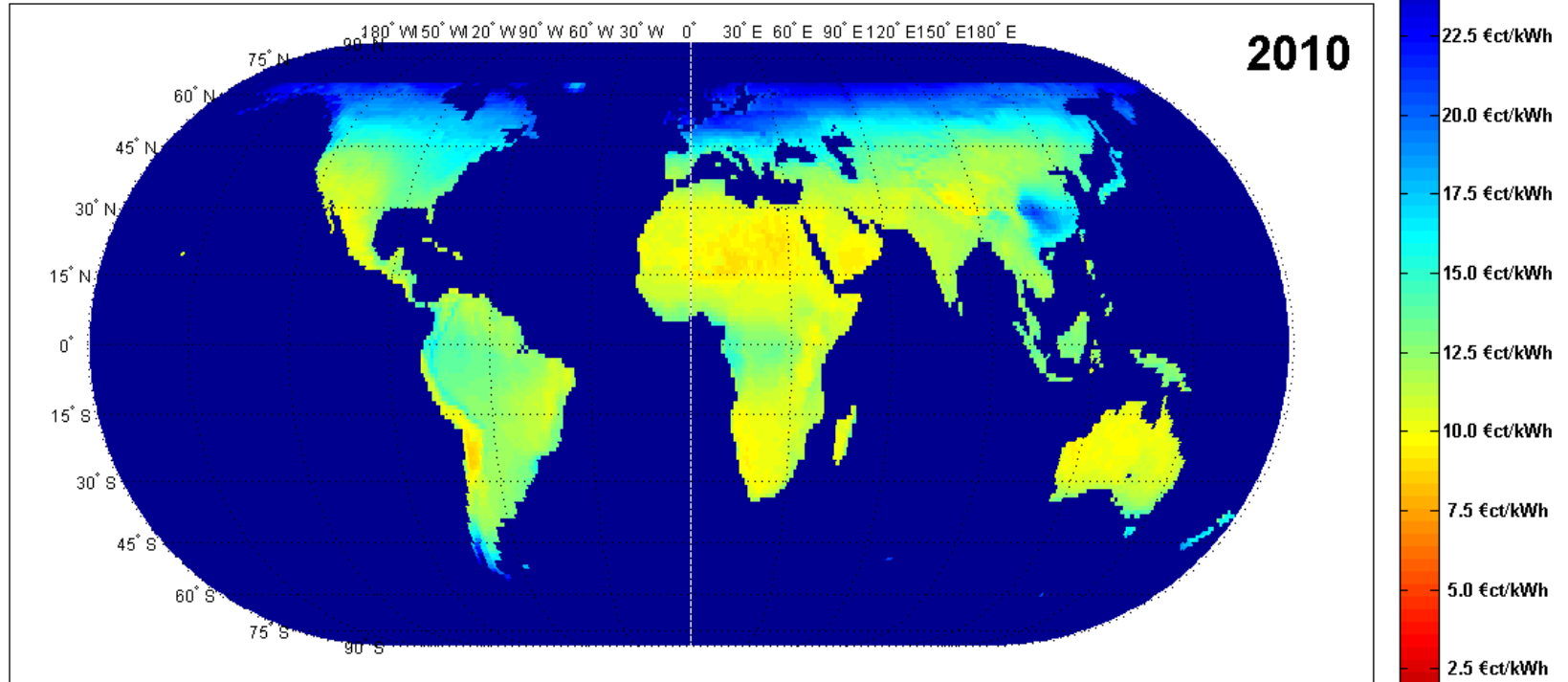


-20% price reduction

source: Kersten F., Görig M., Breyer Ch., et al., 2011. PV-Learning Curves: past and future drivers of cost reduction, 26th EU PVSEC, Hamburg, September 5–9

Breyer Ch., Kersten F., et al., 2010. Research and Development Investments in PV – A limiting Factor for a fast PV Diffusion?, 25th EU PVSEC/ WCPEC-5, Valencia, September 6–10

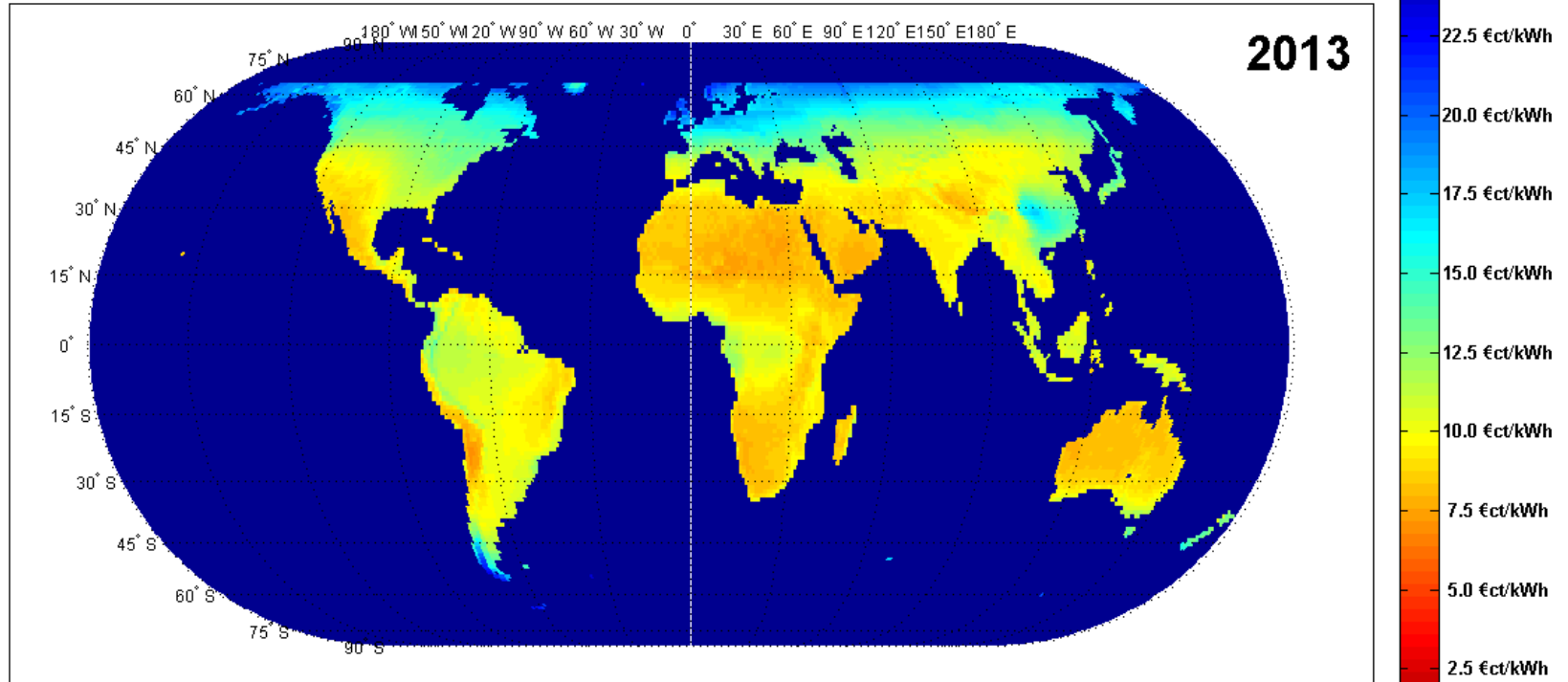
0-axis fixed tilted local LCOE in year 2010, scenario: realistic



PV power plant installations in >50 MW, 6.8% WACC, 1.4 \$/€, system adapted to local conditions, 30% industry growth rate, 15-20% learning rate

source: Breyer Ch. et al., 2010. Fuel-Parity: New Very Large and Sustainable Market Segments for PV Systems, IEEE EnergyCon, Manama, December 18–22

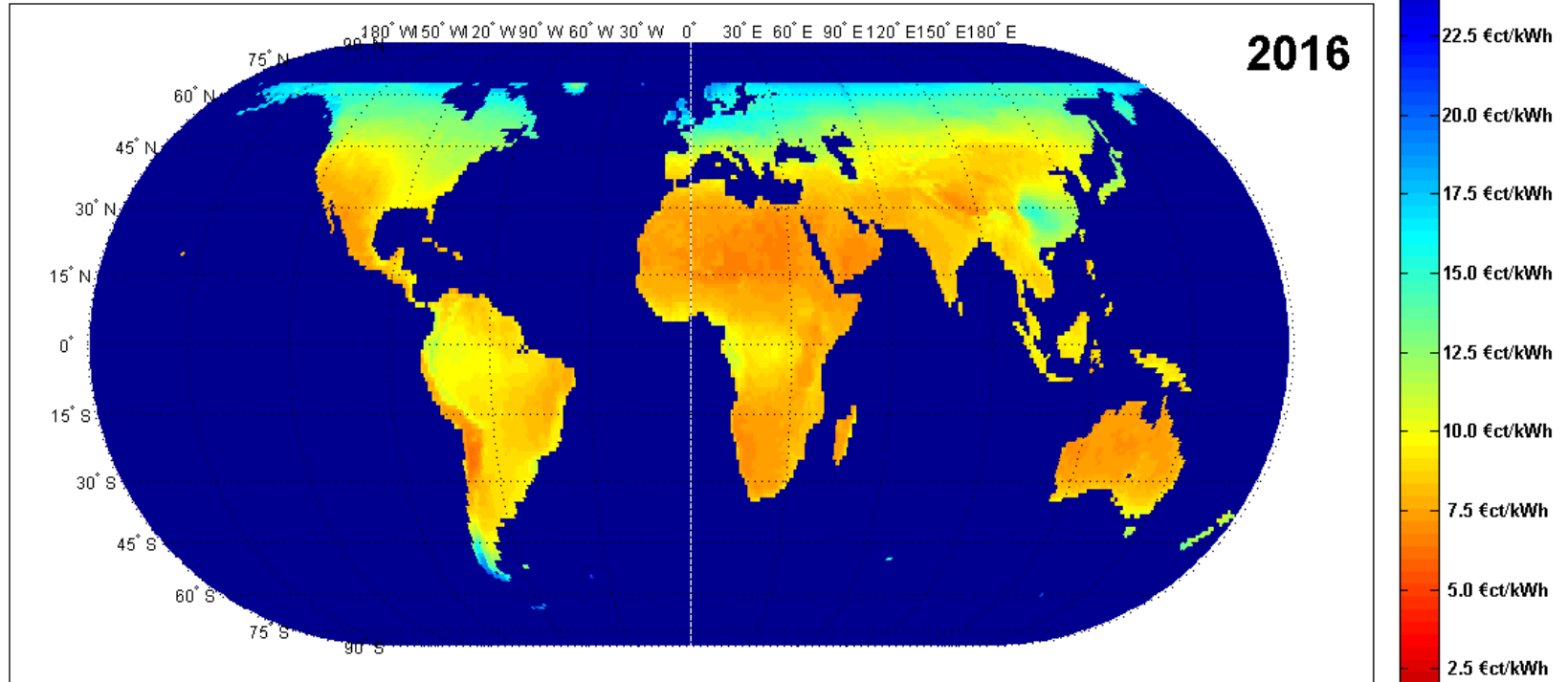
0-axis fixed tilted local LCOE in year 2013, scenario: realistic



PV power plant installations in >50 MW, 6.8% WACC, 1.4 \$/€, system adapted to local conditions, 30% industry growth rate, 15-20% learning rate

source: Breyer Ch. et al., 2010. Fuel-Parity: New Very Large and Sustainable Market Segments for PV Systems, IEEE EnergyCon, Manama, December 18–22

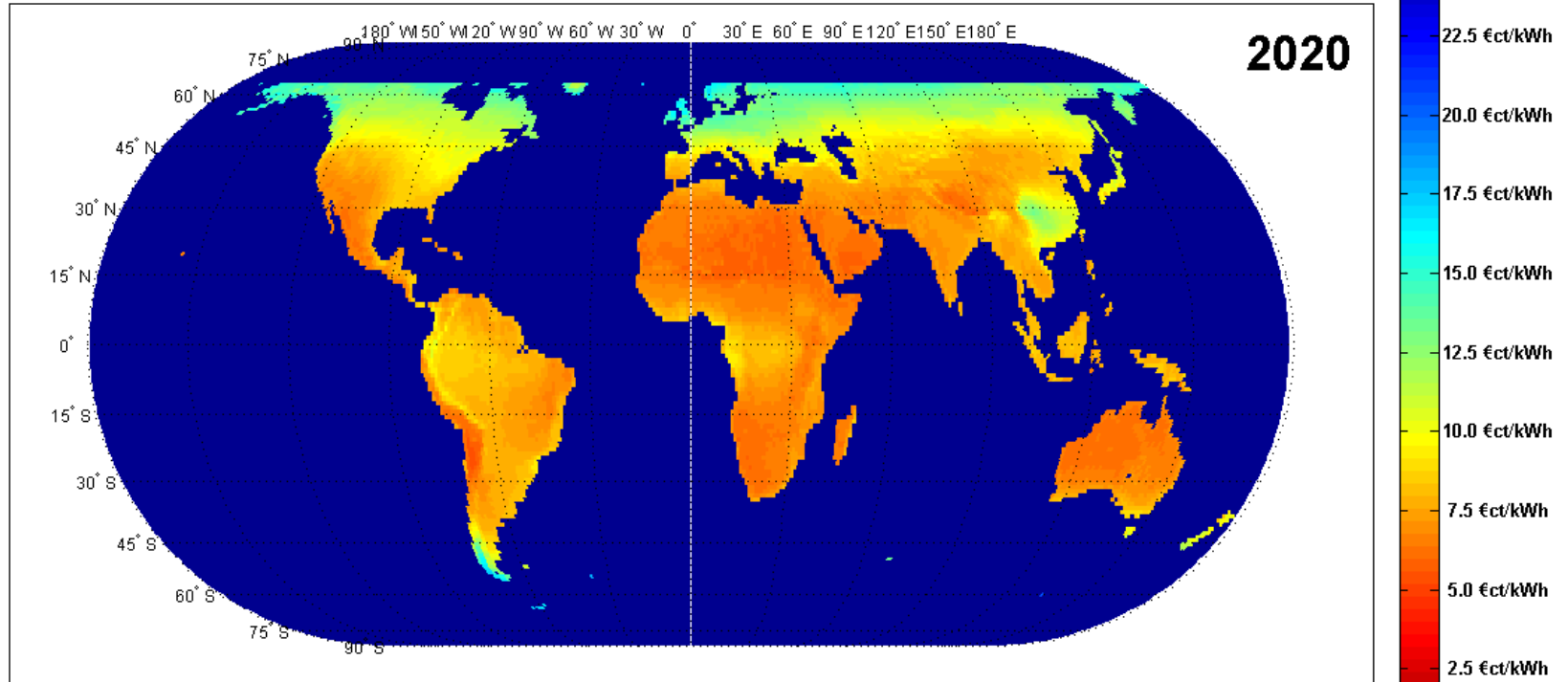
0-axis fixed tilted local LCOE in year 2016, scenario: realistic



PV power plant installations in >50 MW, 6.8% WACC, 1.4 \$/€, system adapted to local conditions, 30% industry growth rate, 15-20% learning rate

source: Breyer Ch. et al., 2010. Fuel-Parity: New Very Large and Sustainable Market Segments for PV Systems, IEEE EnergyCon, Manama, December 18–22

0-axis fixed tilted local LCOE in year 2020, scenario: realistic

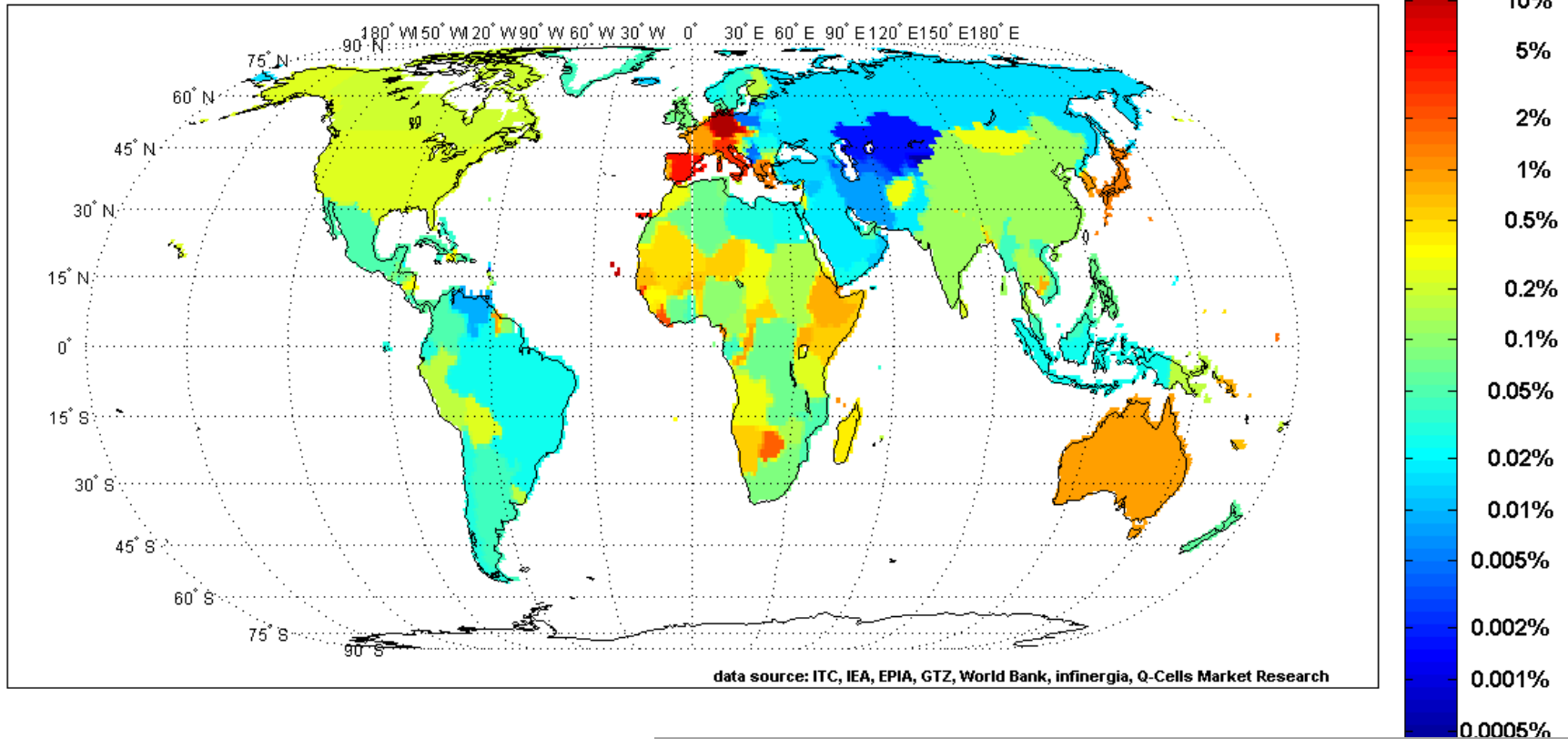


PV power plant installations in >50 MW, 6.8% WACC, 1.4 \$/€, system adapted to local conditions, 30% industry growth rate, 15-20% learning rate

source: Breyer Ch. et al., 2010. Fuel-Parity: New Very Large and Sustainable Market Segments for PV Systems, IEEE EnergyCon, Manama, December 18–22

Relative Global Installed PV Capacity

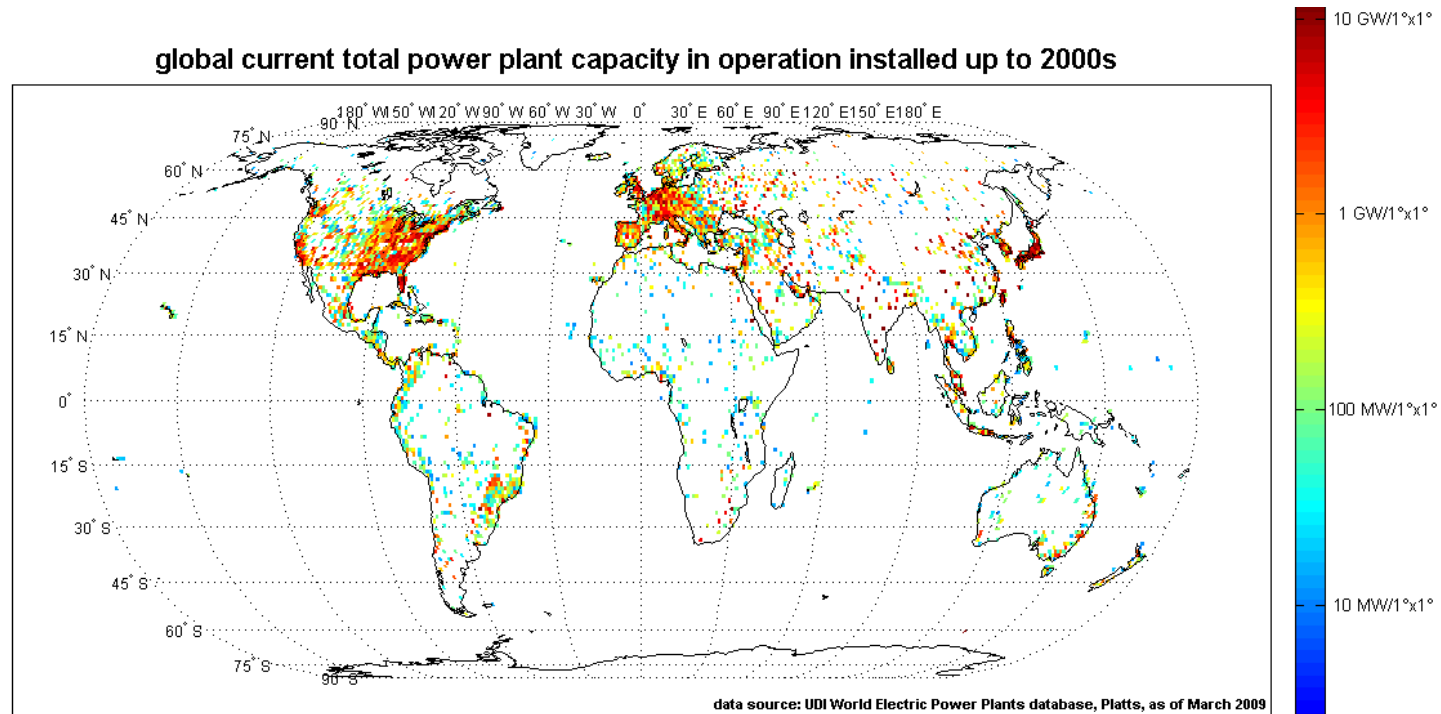
PV installations 2010 per installed power plant capacity in operation per country



source: Werner C., Breyer Ch., et al., 2011. Global Overview on cumulative installed Photovoltaic Power, 26th PVSEC, Hamburg, September 5–9
 Gerlach A.-K., Breyer Ch., et al., 2011. PV and Wind Power – Complementary Technologies, 26th PVSEC, Hamburg, September 5–9

enormous market growth ahead,
 since ~50%+ of conventional power capacity base could be supplemented
 by PV (there is NO competition to wind power)

PV Potential and Power Plants of the World

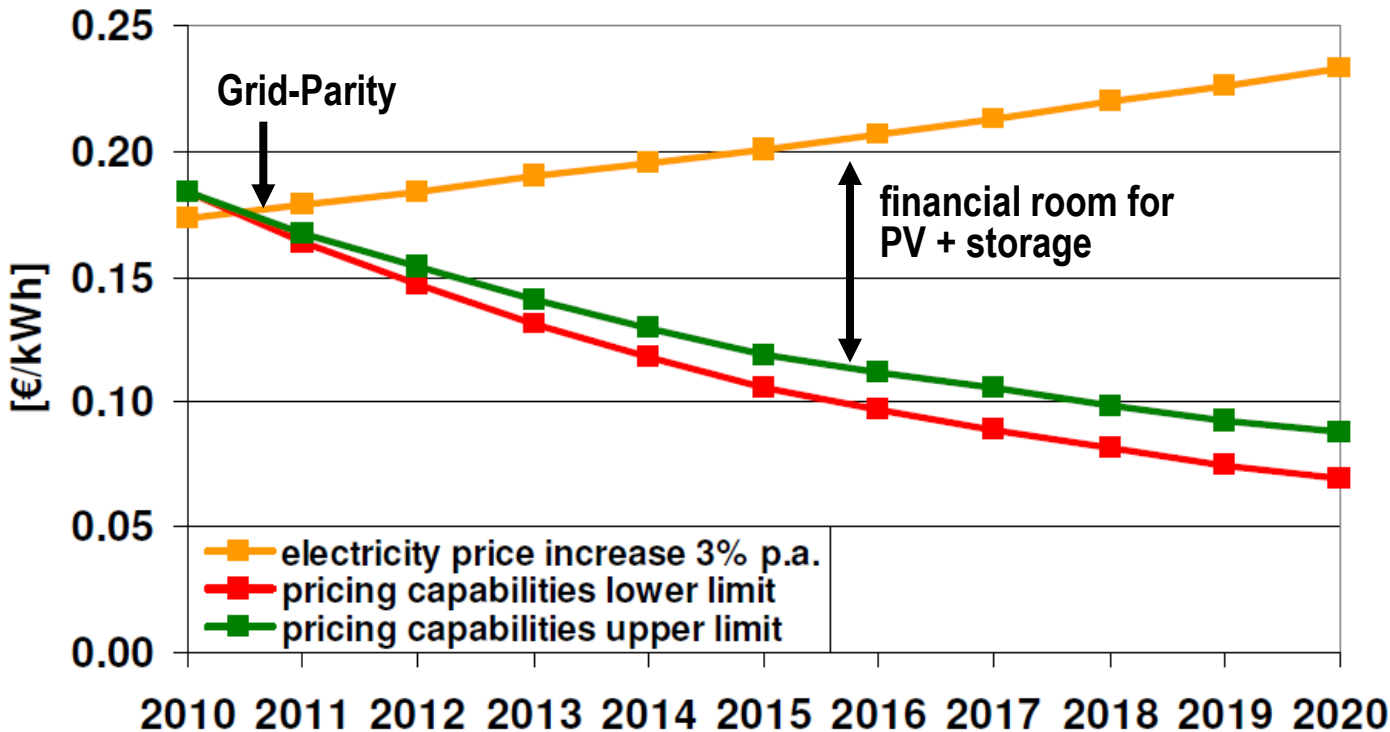


note: plotted category represents 4570 GW of current total 4570 GW (100 %)

Power plant capacity 2009: ~4,600 GW	PV capacity total 2011: ~67 GW (~ 1.3% of capacity)
Power plant capacity additions: ~150 GW/y	PV capacity additions 2011: ~27 GW (~ 18% of all conv. additions)
Electricity generation 2009: ~20,000 TWh	PV supply potential <u>without</u> storage ~10%: ~2,000 TWh
	Electricity generation weighted fixed tilted irradiation: 1,700 kWh/m ² /y
	PV capacity potential at least: ~1,500 GW (@ 0.77 PR)

Grid-Parity: Concept

Example of Spain, residential market segment

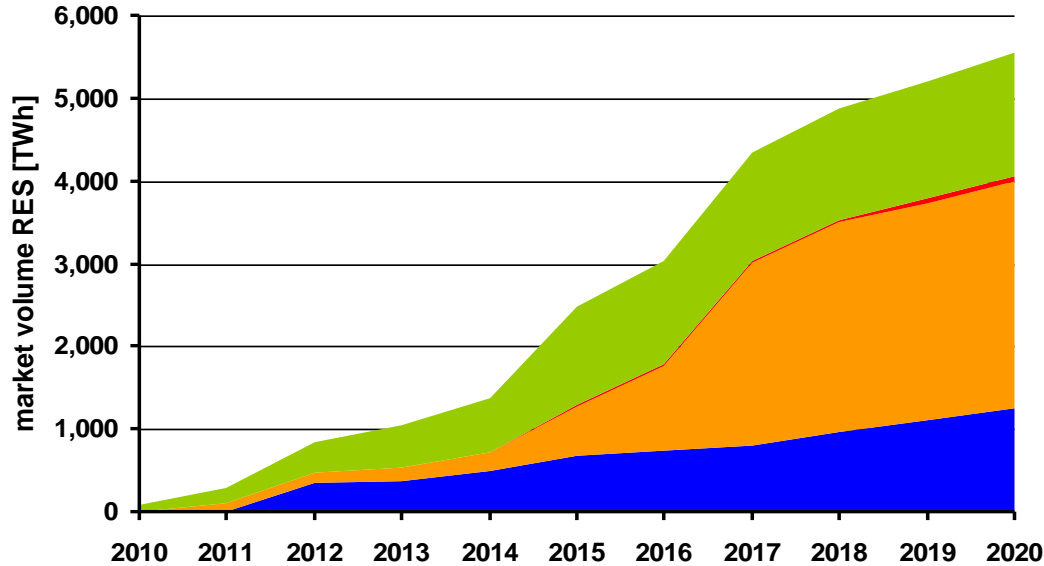


Assumptions:
 Capex 2010: ~2.7 €/Wp residential, ~2.4 €/Wp industrial; Opex: 1.5% of Capex; system lifetime 25 years; performance ratio 80%; WACC 6.4%; growth rate: ~30%/y; learning rate: 15-20%

source: Breyer Ch. and Gerlach A., 2010. Global Overview on Grid-Parity Event Dynamics, 25th EU PVSEC/ WCPEC-5, Valencia, September 6–10

Breyer Ch. and Gerlach A., 2012. Global Overview on Grid-Parity, Progress in Photovoltaics: Research and Applications, DOI: 10.1002/pip.1254

Grid-Parity: Global Trends



■ Asia ■ Americas ■ Africa ■ Europe

regarded countries for residential markets represent:
 98.0% of world population
 99.7% of global GDP
 99.2% of global energy related CO₂ emissions
 99.5% of global residential electricity consumption

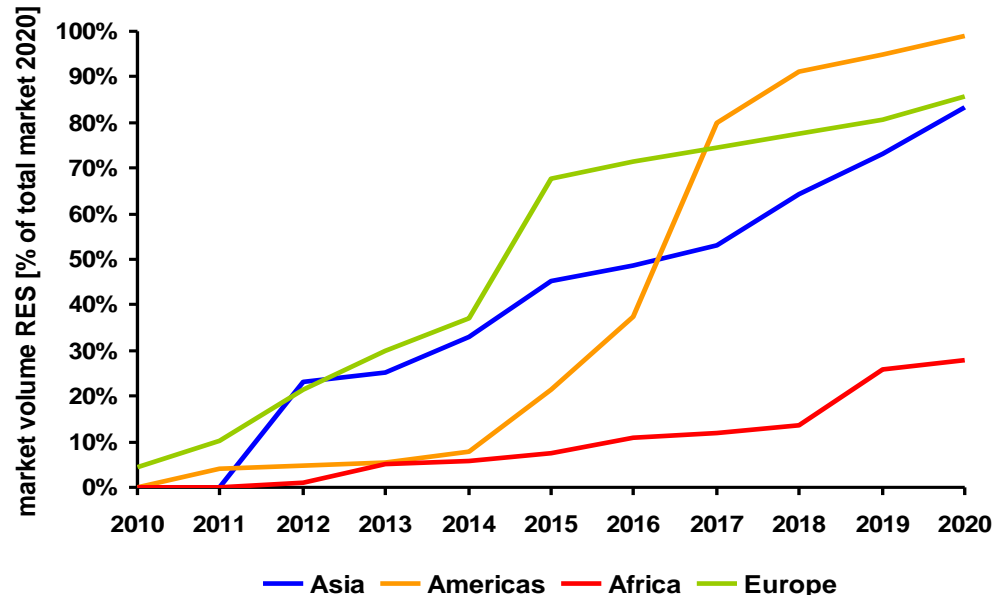
total Grid-Parity translates to
 2,000 - 3,900 GWp Market Potential in 2020

Assumptions: Capex 2010: ~2.7 €/Wp residential, ~2.4 €/Wp industrial; Opex: 1.5% of Capex; system lifetime 25 years; performance ratio 80%; WACC 6.4%; growth rate: ~30%/y; learning rate: 15-20%

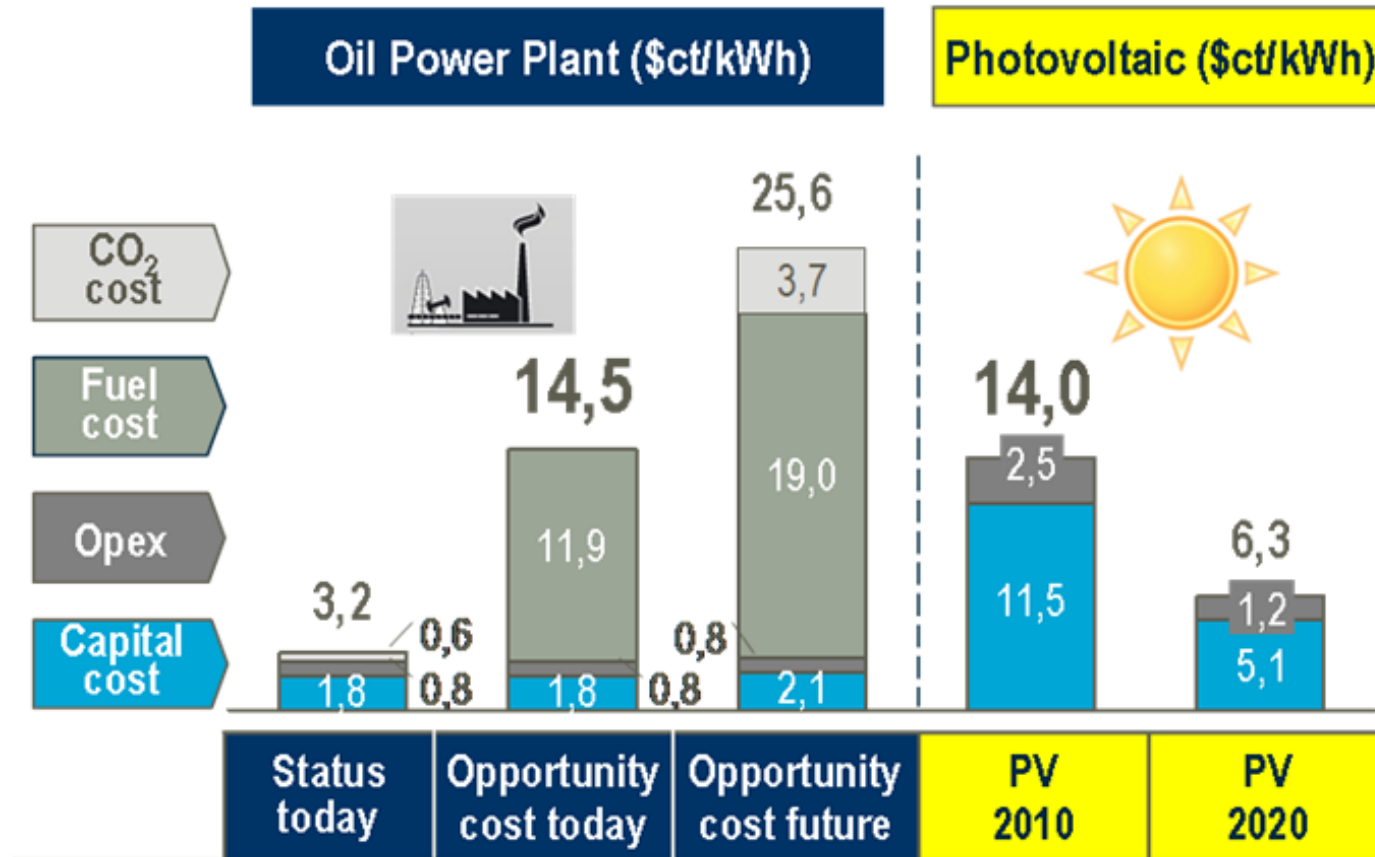
source:

Breyer Ch. and Gerlach A., 2010. Global Overview on Grid-Parity Event Dynamics, 25th EU PVSEC/ WCPEC-5, Valencia, September 6–10

Breyer Ch. et al., 2011. Fuel-Parity: Impact of Photovoltaic on Global Fossil Fuel Fired Power Plant Business, 26. Symposium Photovoltaische Solarenergie, Bad Staffelstein, March 2–4



PV Oil Fuel-Parity in Sunny Regions

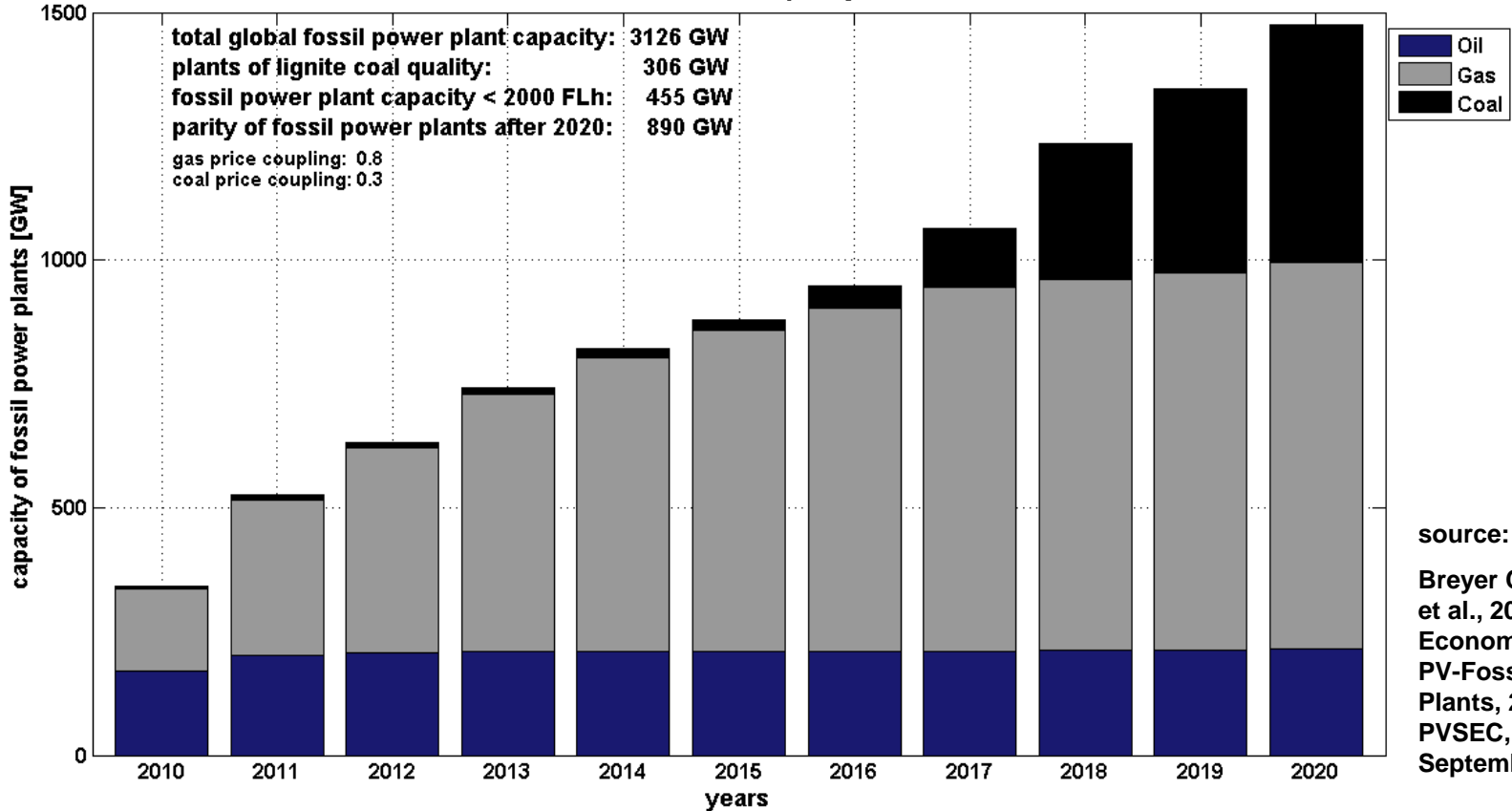


* oil production cost 4 \$/barrel, world market price for opportunity cost today 80 \$/barrel and in future 160 \$/barrel, PV Capex 2000 €/kWp (2010) and 1000 €/kWp (2020), 5% WACC

source: Breyer Ch., Görig M., et al., 2011. Economics of Hybrid PV-Fossil Power Plants, 26th EU PVSEC, Hamburg, September 5–9

Hybrid PV-Fossil: Global Demand for the 2010s

Demand Curve of PV-Fossil Power Plants for total LCOE parity for local FLh >2000 h and scenario: realistic



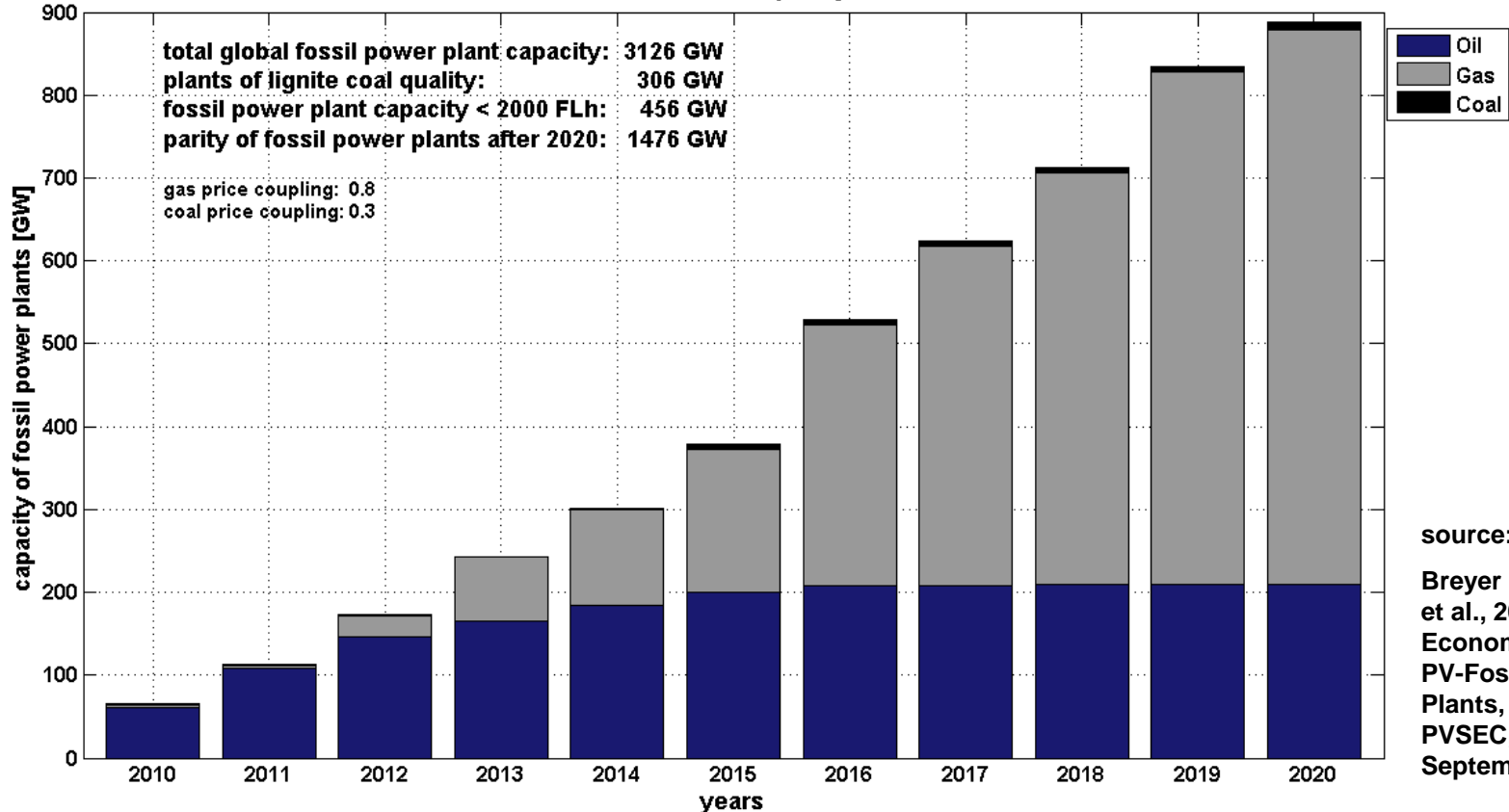
source:
Breyer Ch., Görig M.,
et al., 2011.
Economics of Hybrid
PV-Fossil Power
Plants, 26th EU
PVSEC, Hamburg,
September 5–9

$$\text{total LCOE}_{\text{fossil}} > \text{total LCOE}_{\text{PV}} + \text{FLh-effect}_{\text{fossil}}$$

more optimistic assumptions would lead to
up to 2,300 GW economic upgrading potential

Hybrid PV-Fossil: Global Demand for the 2010s

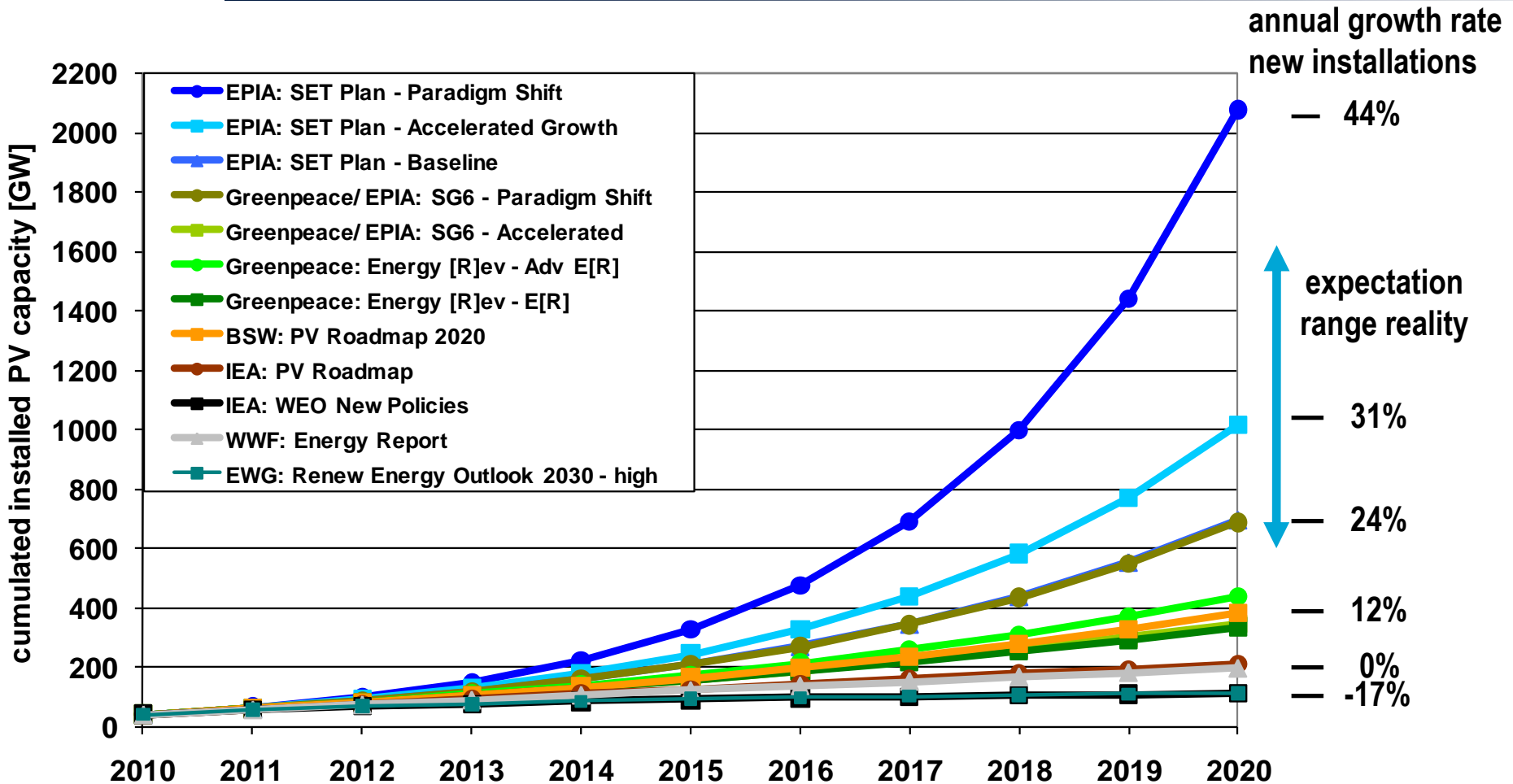
Demand Curve of PV-Fossil Power Plants for fuel LCOE parity for local FLh >2000 h and scenario: realistic



$$\text{fuel LCOE}_{\text{fossil}} > \text{total LCOE}_{\text{PV}} + \text{FLh-effect}_{\text{fossil}}$$

more pessimistic assumptions would lead to at least 700 GW economic upgrading potential

Cumulated Installed PV Capacity - World

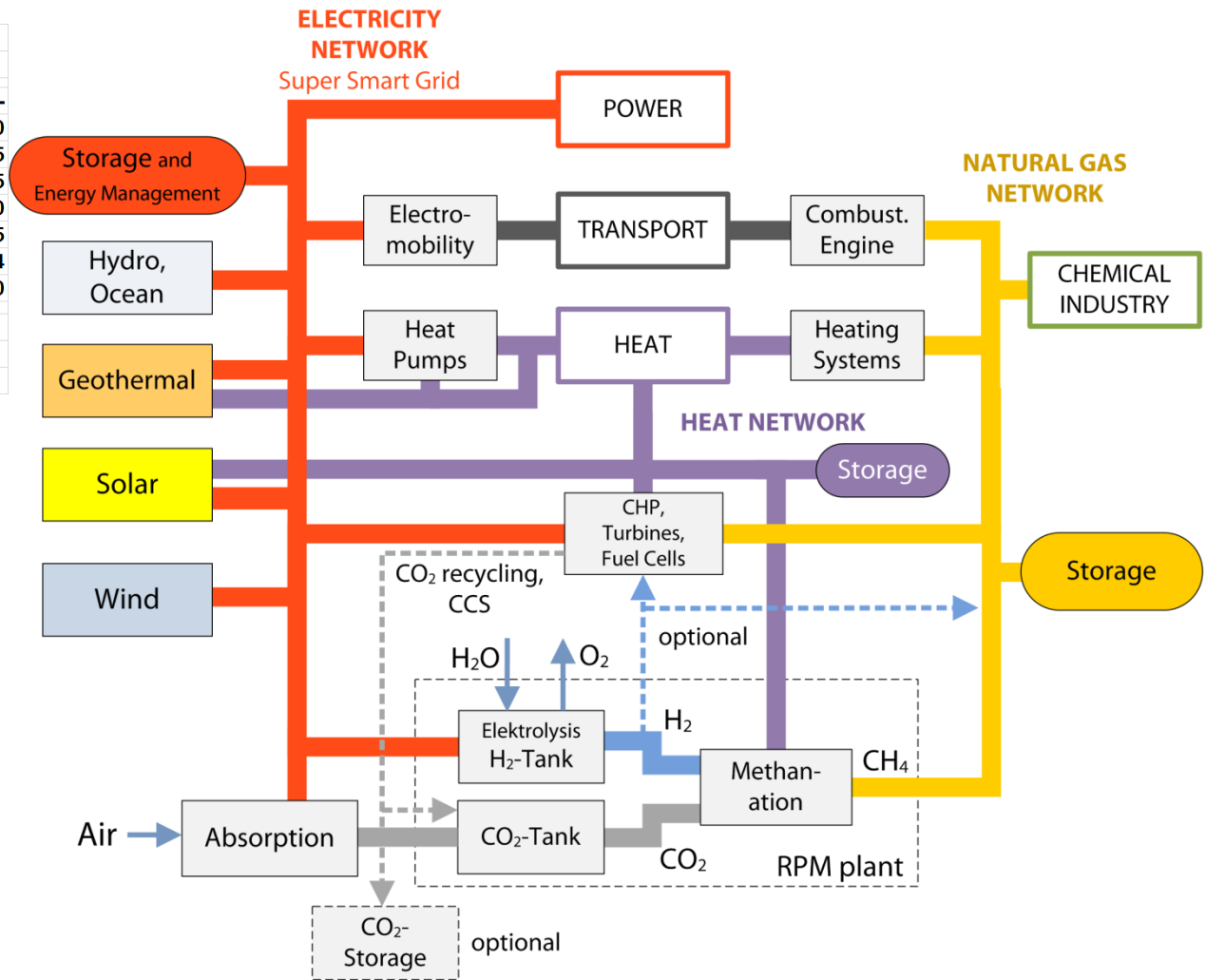


source: Breyer Ch., 2011. The Photovoltaic Reality Ahead: Terawatt Scale Market Potential Powered by Pico to Gigawatt PV Systems and Enabled by High Learning and Growth Rates, 26th EU PVSEC, Hamburg, September 5–9

Grid-Parity Analysis	2,000 – 3,900 GWp
Fuel-Parity Analysis	1,200 – 2,000 GWp
Economic Market Potential (on-grid)	2,700 – 4,200 GWp
Economic Market Potential (off-grid)	100 GWp
Pessimistic Case	~20% of Potential: ~600 GWp
Realistic Case	~35% of Potential: ~1,000 GWp
Optimistic Case	~50% of Potential: ~1,600 GWp

PV and Wind as backbone of global 100% RE

Technical Potential		PV [TW]	Wind [TW]
Weingart	1978	> 100	-
WBGU	2003	infinite	90
Greenpeace	2008	150	35
Sawin and Moomaw	2008	145	55
Lu et al.	2009	-	80 - 150
Jacobson and Delucchi	2009	580	40 - 85
WBGU	2011	8900	54
IPCC SRREN	2011	120000	190
Current Global Energy Demand			
including waste of heat	[TW]	17.0	
direct energy demand	[TW]	11.5	



Legend

- █ Electrical Energy
- █ Thermal Energy
- █ Mechanical Energy
- █ Chemical Energy (Methane)
- █ Chemical Energy (Hydrogen)
- █ CO₂
- RPM Renewable Power Methane
- CHP Combined Heat and Power
- CCS Carbon Capture and Storage

- **ongoing fast PV cost reduction is very likely**
- **PV is still negligible in terms of currently cumulative installed capacities**
- **PV enters three markets in parallel: off-grid, on-grid decentral (residential) and on-grid central (upgrade of flexible fossil plants)**
- **economic PV market potential by 2020 roughly 2,800 – 4,300 GWp**
- **cumulative installed capacity by 2020 roughly 600 – 1,600 GWp**
- **most institutions cannot imagine a fast PV diffusion (except EPIA, Greenpeace)**
- **PV and Wind emerge to the backbone of global energy supply**

Thanks for your attention.

... and in particular to Alexander Gerlach, Marzella Görig, Ann-Katrin Gerlach, Chris Werner and Oliver Beckel for contribution and support.



all referenced papers can be found at www.reiner-lemoine-institut.de or www.q-cells.com
