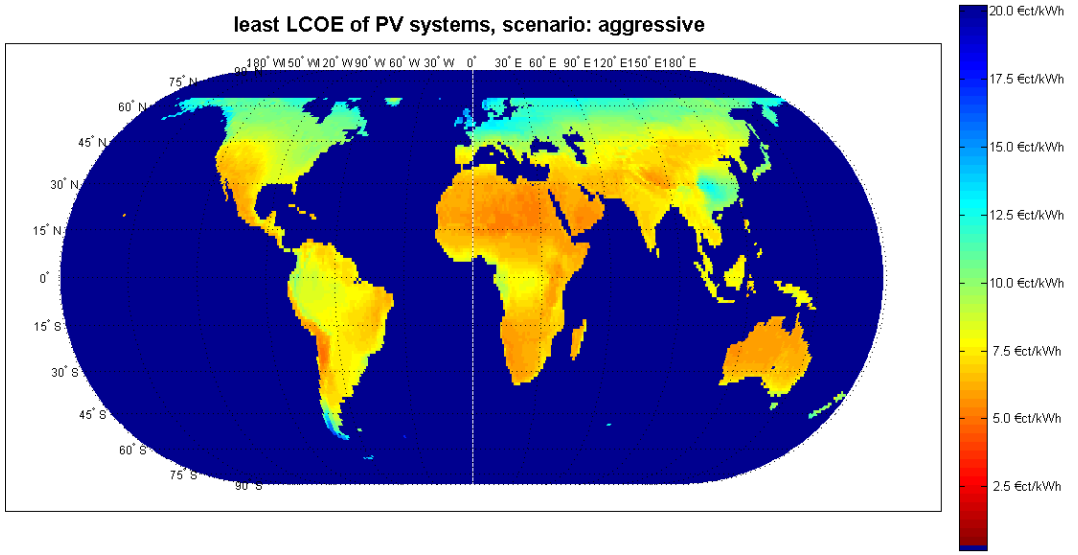

How favourable is Photovoltaic?

DPG-AKE Frühjahrssitzung

Christian Breyer, Bad Honnef, 6. Mai 2010

UNIKASSEL VERSITÄT

IEE Rationelle Energiewandlung

Q.CELLS

Outline

- Motivation
- Learning Curve
- PV R&D Investments
- 2nd milestone – Off-Grid PV
- 3rd milestone – Grid-Parity
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- Conclusions

Need for restructuring global power sector

Peak-oil/ gas/ coal

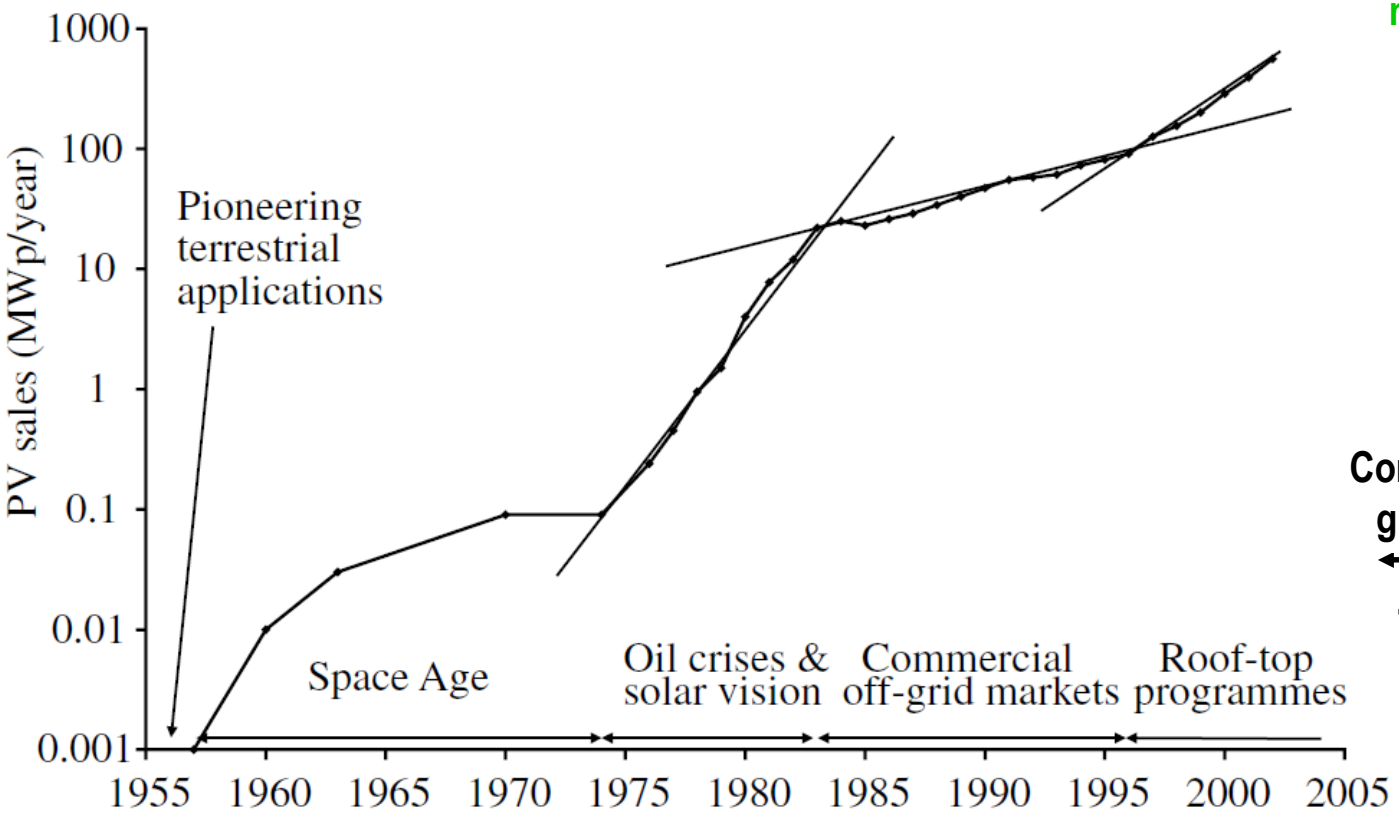
- "The world production [of oil] is estimated to peak in 2014."
  I.S. Nashawi et al, Energy Fuels, 2010, 10, 1788-1800
  (Kuwait Oil Company)
- "Peak oil is now."
  Energy Watch Group, EWG Series No 3/2007
- "The peak in the rate of world production would be reached about the year 2000."
  M.K. Hubbert, Energy and Power, 1971
- "The date of culmination [of US oil production] should be approximately 1970."
  M.K. Hubbert, Spring Meeting API, 1956
  (Shell, Research Division)
- "China's coal peak [in production] will be between late 2020s and early 2030s."
  B. Lin and J. Liu, Energy Policy, 2010, 38, 512-519
  (China Center for Energy Economics, Xiamen)

Climate Change

- "Climate Change presents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen."
  N. Stern, Economics of Climate Change, 2006
- "Without resolute counteraction, climate change will overstretch many societies' adaptive capacities. This could result in destabilization and violence, jeopardizing national and international security to a new degree."
  WBGU, Climate Change as a Security Risk, 2007
- "There is a scientific consensus on the reality of anthropogenic climate change."
  N. Oreskes, Science, 2004, 306, 1686
- "The increase in mean temperature, due to the artificial production of carbon dioxide is estimated to 0.003 ℃ per year at present."
  G.S. Callendar, Qtly J Royal Meteorol Soc, 1938, 64, 223-240

Major PV diffusion milestones: A short history

PV diffusion milestones	1st	2nd	3rd	4th
least cost option	✓	✓	starting now	starting now



Commercial utility-scale power plants

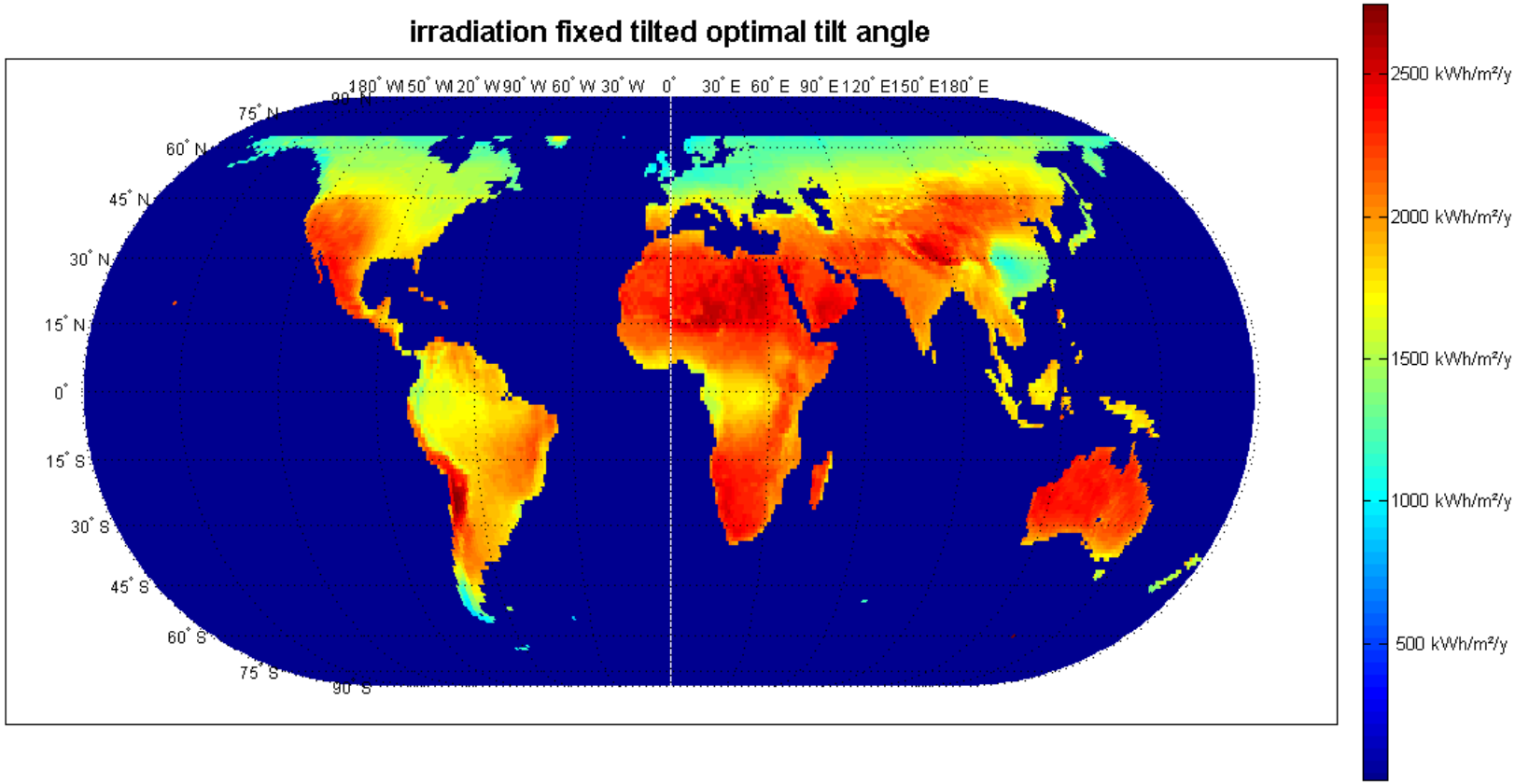
~ 2010

Commercial on-grid markets

~ 2010

diagram source: B.A. Sandén, Solar Energy, 2005, 78, 137-146

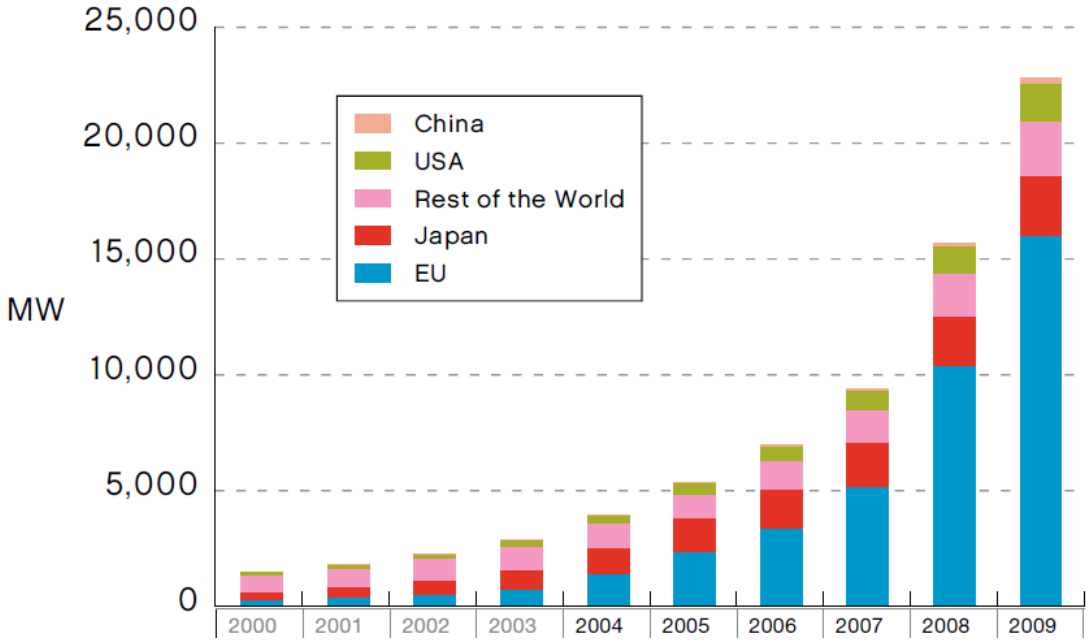
Solar Resource



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

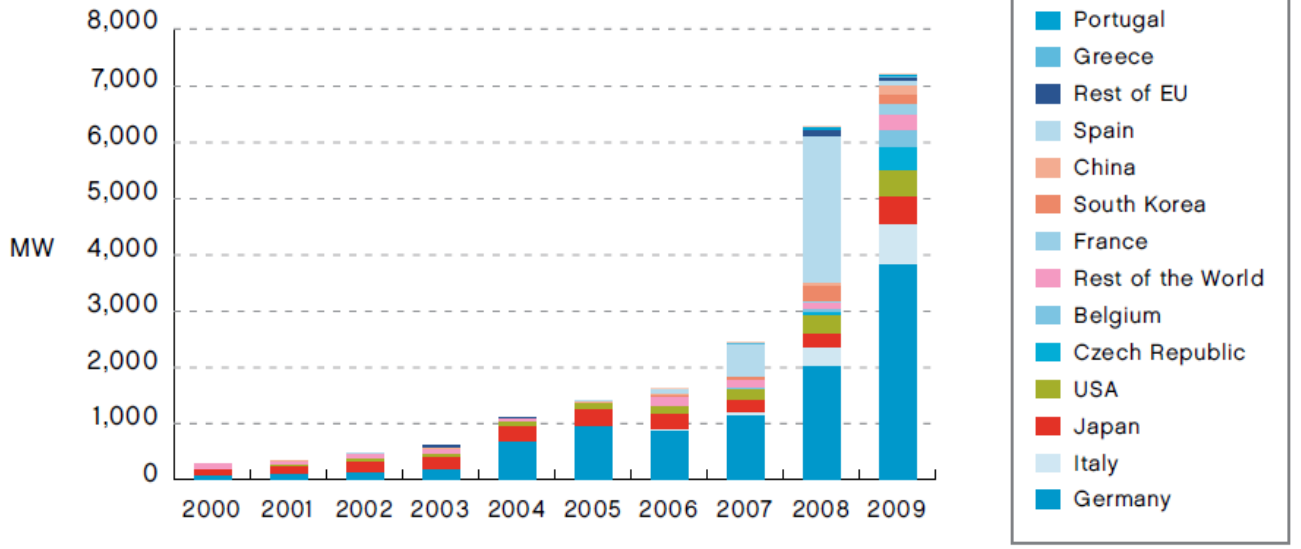
source: **Ch. Breyer, J. Schmid, Global Distribution of optimal Tilt Angles for fixed tilted PV Systems, 25th PVSEC Valencia, 2010, accepted**

Global PV Market



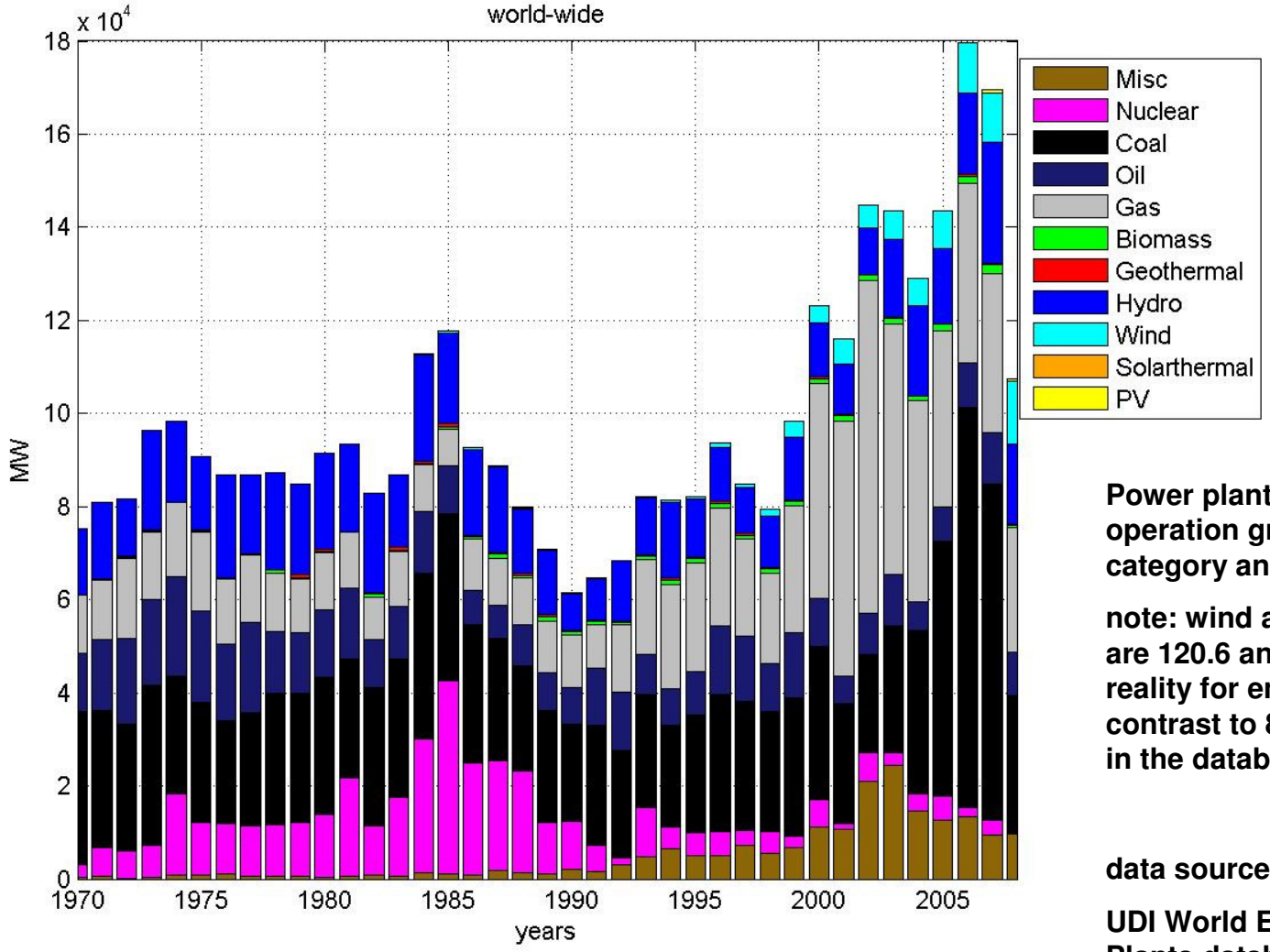
Global installed PV capacity

annual PV capacity addings



source: **EPIA, Global Market Outlook for PV, 2010**

Global Power Plant Capacity Addings



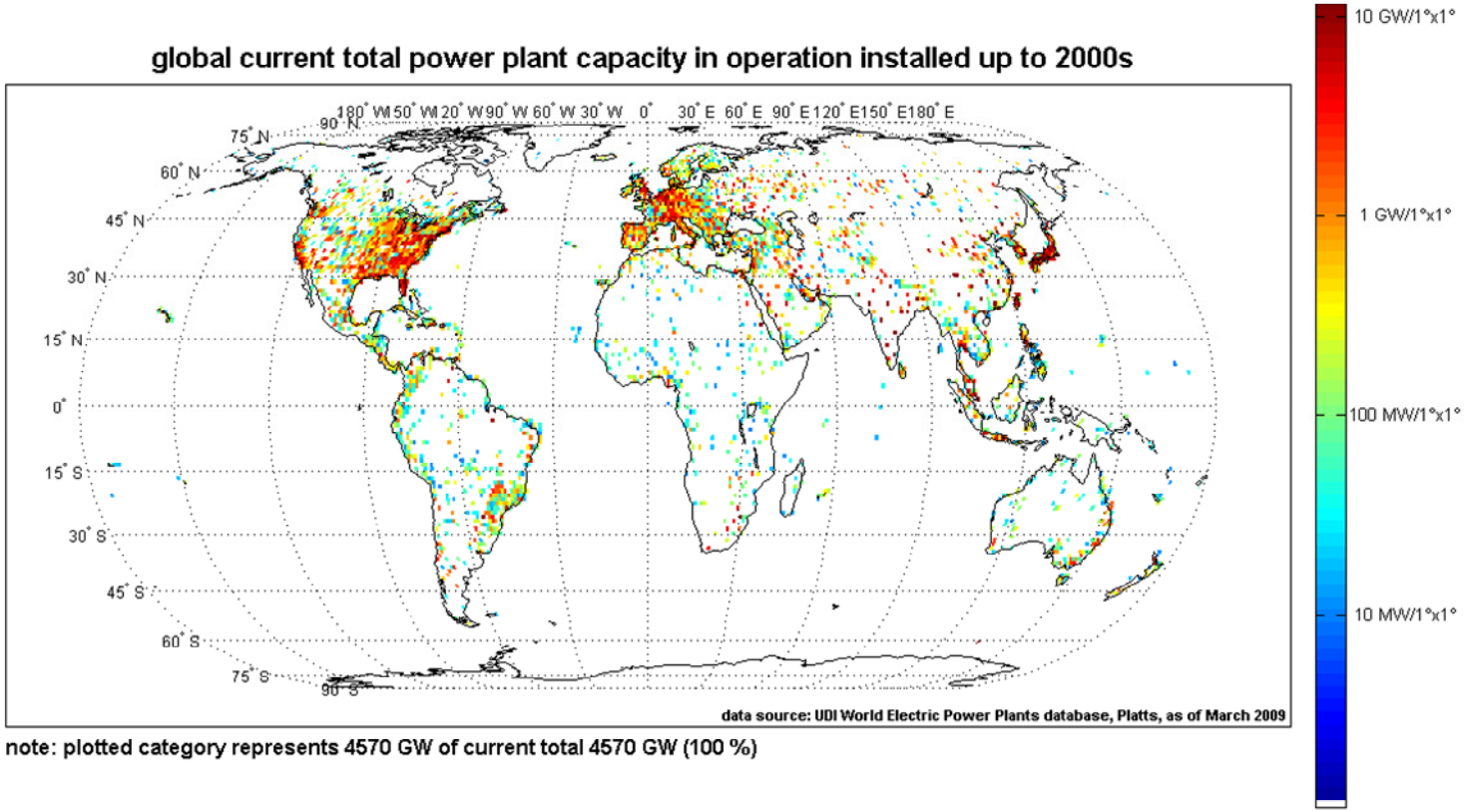
Power plants today in operation grouped by fuel category and geography

note: wind and PV capacities are 120.6 and 14.7 GW in reality for end of 2008 in contrast to 84.8 and 1.6 GW in the database

data source:

UDI World Electric Power Plants database, March 2009

Power Plants of the world



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

Power plant capacity 2009: ~4,600 GW
Power plant capacity addings: ~150 GW/y
Electricity generation 2009: ~20,000 TWh

PV capacity total 2009: ~22 GW (~0.5% of capacity)
PV capacity addings 2009: ~7 GW (~5% of all addings)
PV supply potential without storage ~10%: ~2,000 TWh
Electricity generation weighted fixed tilted irradiation: 1,700 kWh/m²/y
PV capacity potential: ~1,500 GW (@ 0.77 PR)

source: Ch. Breyer, results to be published, 2010

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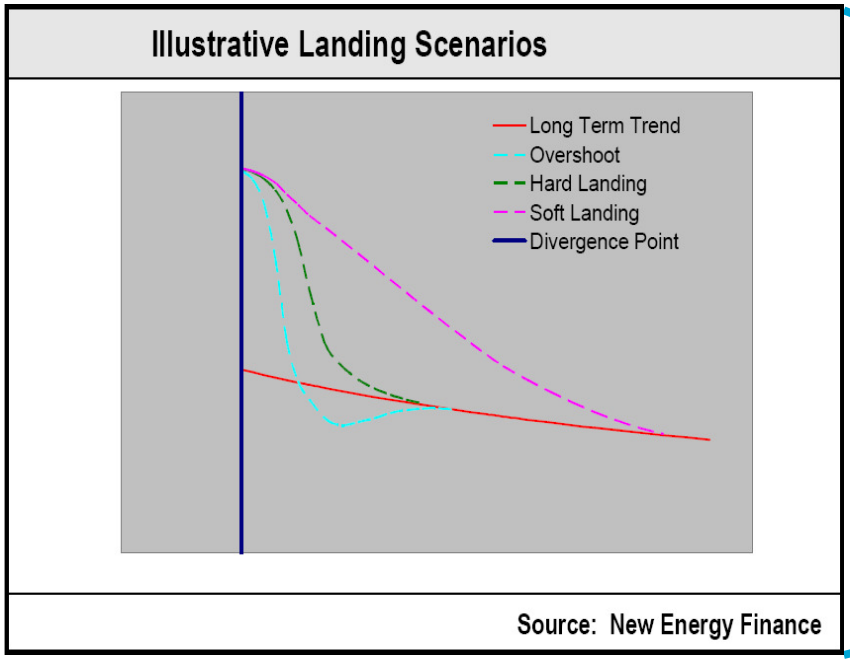
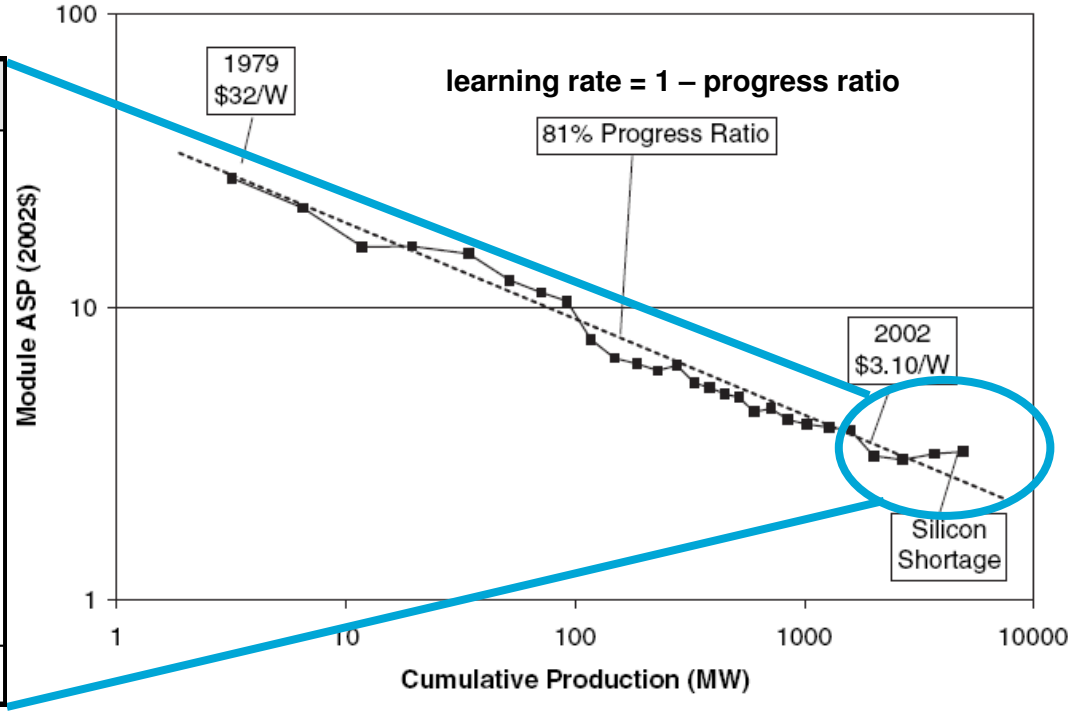
Experience curve: the key for understanding PV cost dynamics





learning rates in comparable industries:

~40% DRAMs (by getting smaller)

~35% flat panels (by getting larger)

source: W. Hoffmann et al, 24th PVSEC Hamburg, 2009

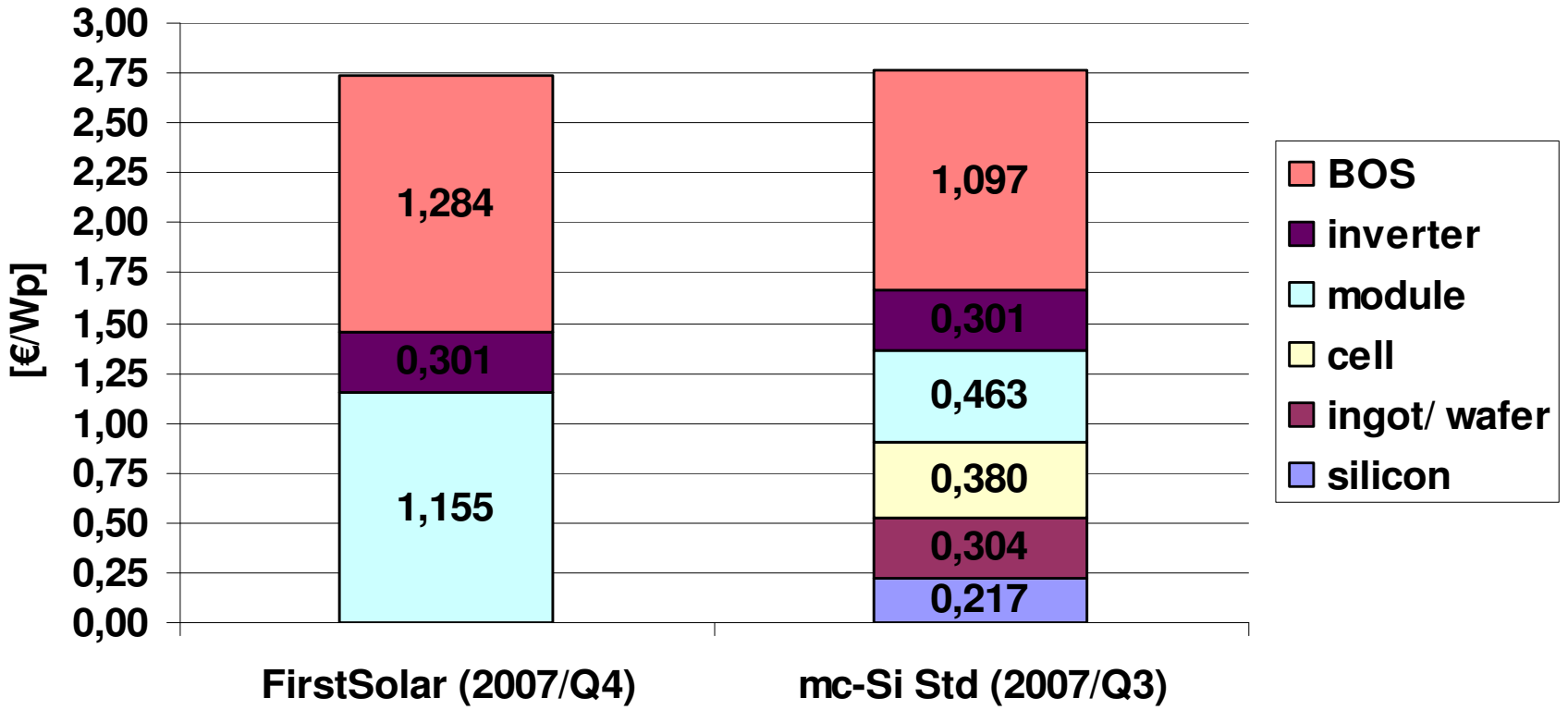
learning rates of PV are likely to remain at ~20%

source:
R.M. Swanson, Prog in PV, 2006, 14, 443-453

Investment cost of major PV technologies: CdTe vs mc-Si Std

fully-integrated (inverter prices) cost over the PV value chain

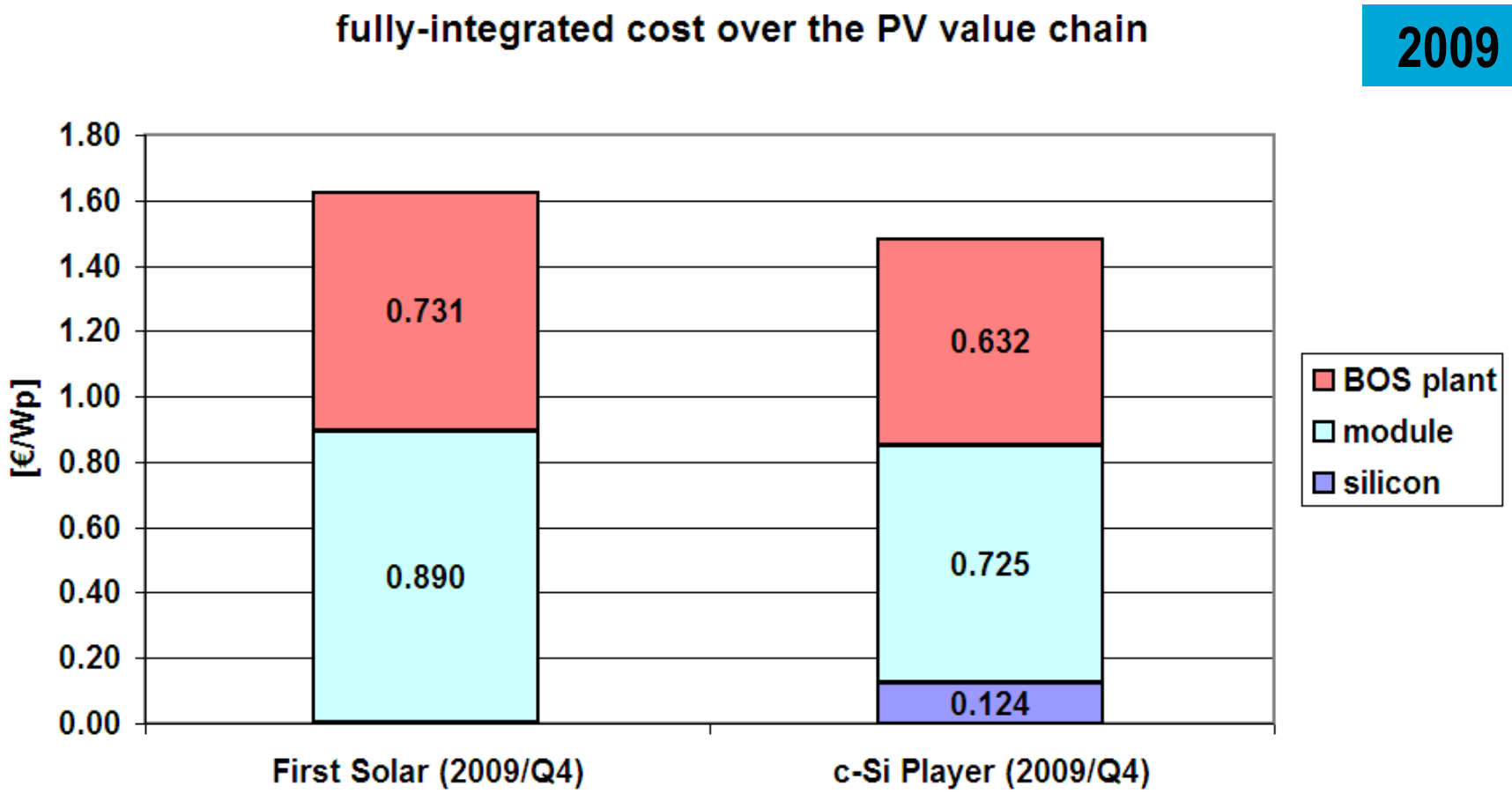
2007



data source: Photon Int. Jan/2008; First Solar, company reports, 2007; Q-Cells Research
note: cost of dept/ equity and value chain inefficiencies are not included

Investment cost of major PV technologies: CdTe vs mc-Si Std

2009



data source: company reports, 2009; Q-Cells Research
note: cost of dept/ equity and value chain inefficiencies are not included

40-45% cost reduction within 24 months!!

equal to a learning rate of ~35% (>> 20%)!

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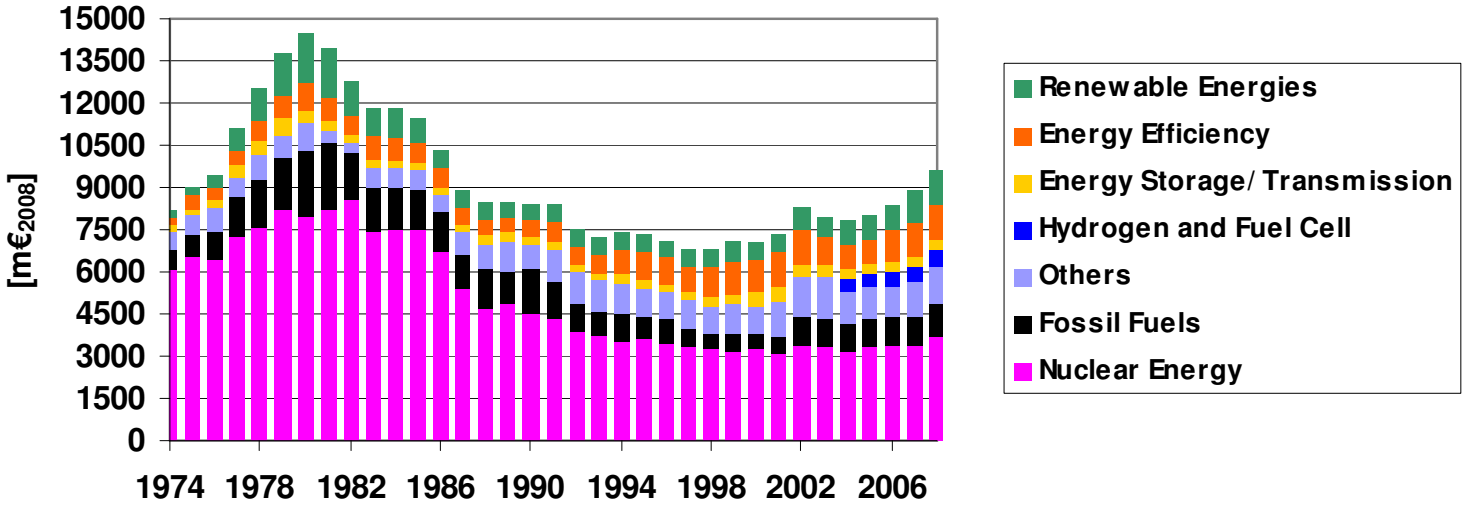
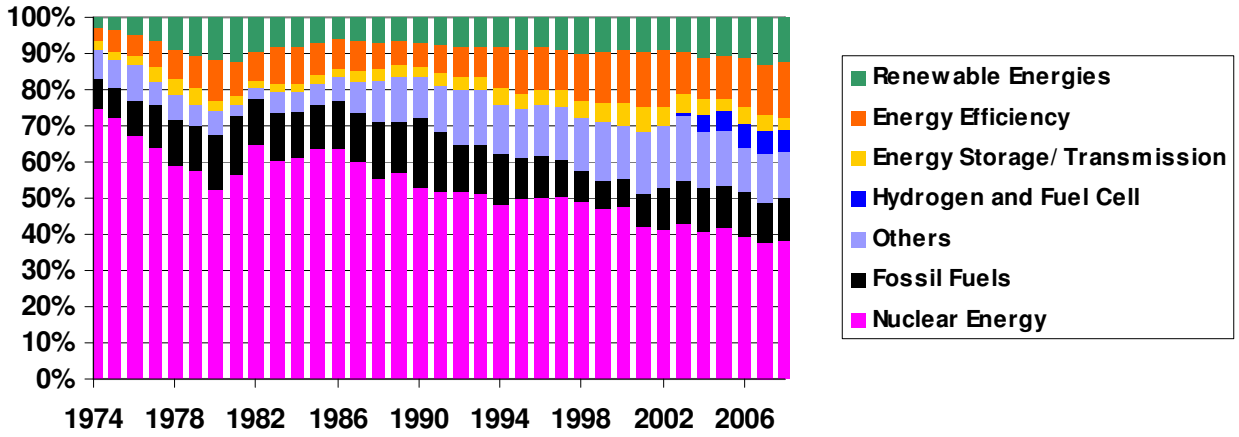
Public Energy R&D in OECD

public Energy R&D in OECD



relativ public Energy R&D in OECD



public energy R&D subcritical

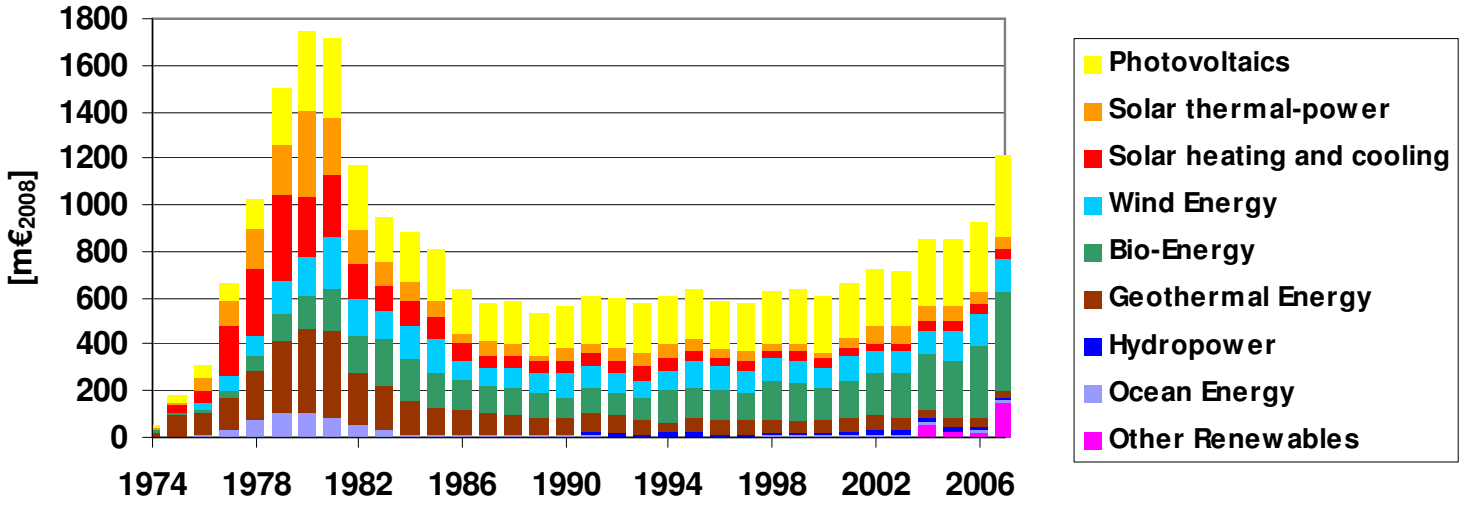
renewables R&D extremely low

data source: IEA, 2009

source: Ch. Breyer et al, Research and Development Investments in PV – A limiting Factor for a fast PV Diffusion?, 25th PVSEC Valencia, 2010, accepted

Public Renewable Energy R&D in OECD

public Renewable Energy R&D in OECD



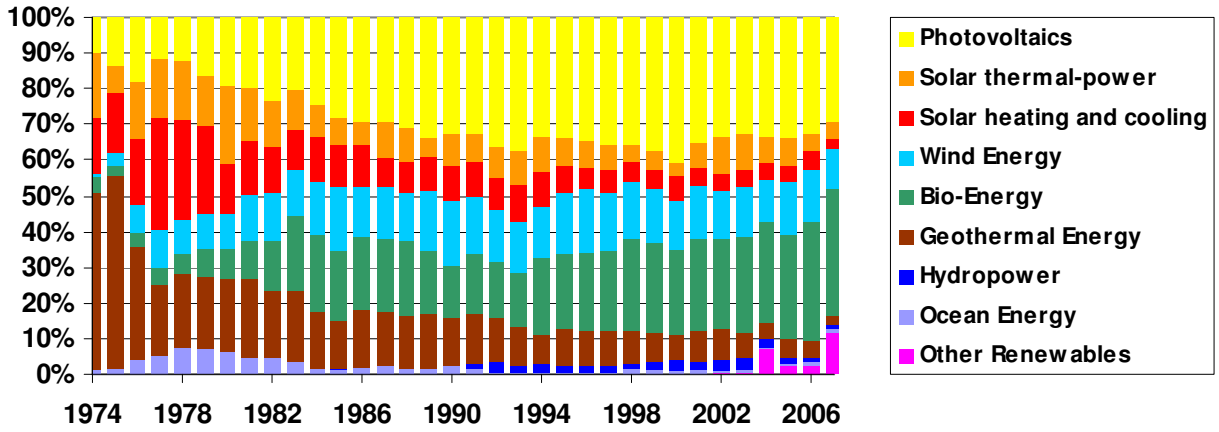
renewables R&D extremely low

STEG and Wind relative too low

data source: IEA, 2009

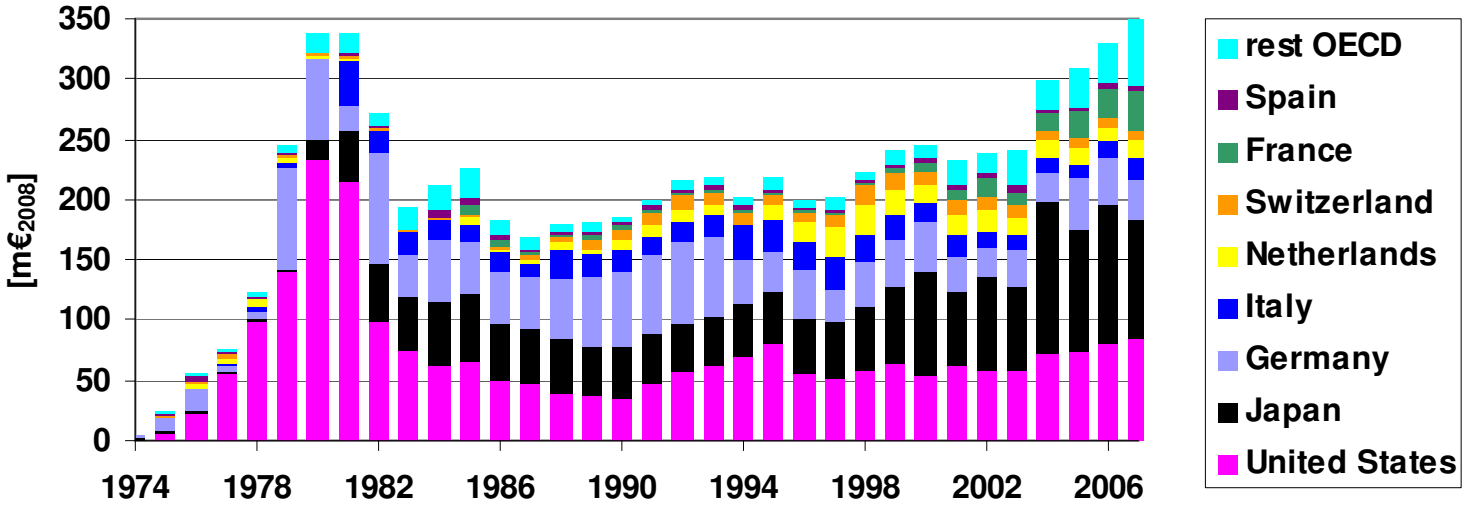
source: Ch. Breyer et al, Research and Development Investments in PV – A limiting Factor for a fast PV Diffusion?, 25th PVSEC Valencia, 2010, accepted

relativ public Renewable Energy R&D in OECD



Public R&D Investments in PV in OECD

Historic annual public R&D Investments in PV



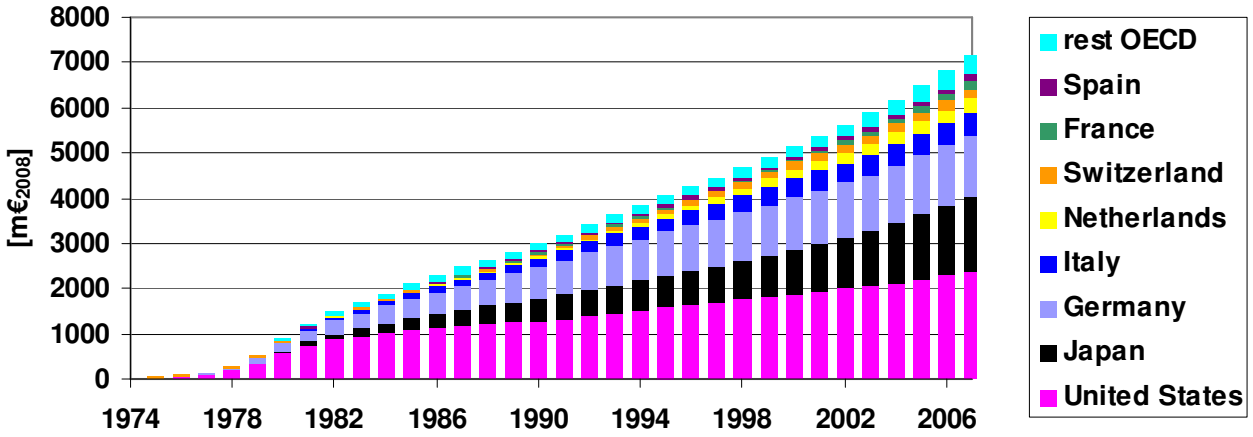
Nuclear Energy

1982: 8.6 bn€ x 31 PV
2007: 3.4 bn€ x 11 PV
74-07: 174 bn€ x 24 PV

data source: IEA, 2009

source: Ch. Breyer et al, Research and Development Investments in PV – A limiting Factor for a fast PV Diffusion?, 25th PVSEC Valencia, 2010, accepted

Historic cumulated public R&D Investments in PV



Corporate R&D Investments in PV

		2009 R&D/sales	2009 [m€]	2008 [m€]	2007 [m€]
Solyndra	US	84.2%	58.7	90.2	58.4
SMA Solar Technology	DE	6.0%	56.3	34.7	19.7
First Solar	US	3.8%	54.3	24.1	10.3
oerlikon Solar	CH	13.9%	42.5	33.7	12.7
REC	NO	3.3%	36.6	21.7	20.9
centrotherm PV	DE	5.6%	28.4	16.8	7.4
MEMC Electronic Materials	US	3.5%	28.0	29.3	26.7
Q-Cells	DE	3.3%	26.5	33.1	21.9
SunPower	US	2.1%	21.9	15.4	9.2
Suntech Power	CN	1.7%	20.1	11.0	10.2
Yingli Green	CN	2.5%	18.7	6.0	1.6
Roth&Rau	DE	8.3%	16.5	4.9	2.5
Meyer Burger	CH	5.3%	15.2	14.6	
GT Solar	US	4.4%	15.0	11.9	6.8
Schott Solar	DE	4.0%	13.5	13.5	13.3
EvergreenSolar	US	6.7%	12.6	15.8	14.0
Manz automation	DE	14.1%	12.1	10.3	
SolarWorld	DE	1.2%	12.0	13.0	10.8
Wacker BU Polysilicon	DE	1.0%	11.3	5.4	6.3
ReneSola	CN	2.8%	10.1	7.0	0.7
ECD_Ovonic Solar	US	4.8%	7.1	6.3	5.3
PV Crystalox Solar	DE	2.2%	6.2	6.2	4.4
Satcon Technology	CA	16.0%	5.8	3.7	1.6
LDK Solar	CN	0.8%	5.8	5.5	2.2
Arise Technologies	CA	22.4%	4.7	3.8	2.7
total top25*		3.8%	539.9	437.8	269.5
annual growth			23.3%	62.5%	63.2%

no data available:

AMAT, Abound Solar, Avencis, Azur, Bosch Solar (Ersol), BP Solar, Concentrix, Elkem Solar, Emcore Solar, E-Ton Solar, Fronius, G24i, Gintech, Heliatek, Hemlock, Innovalight, Isofoton, KACO, Kaneka, Komax, Konarka, Kyocera, Miasole, Mitsubishi Electric, Motech, Nanosolar, Phocos, Photowatt, Plextronics, Primestar Solar, Samsung, Sanyo, Sharp, Showa-Shell, Solamer, Solfocus, Solland, Spectrolab, Tokuyama, Würth Solar

annual R&D Investments in PV

Public: ~ 400 m€

Corporate: ~ 900 m€

total: ~ 1300 m€

compare (2008):

Microsoft	**6.5 bn€**	**Semiconductor**	
Nokia	**5.3 bn€**	**Industry**	**30.8 bn€**
Intel	**4.1 bn€**		
Samsung	**3.5 bn€**		

data source: **company reports, 2009 – 2006; *estimated 60% of industry; 2009 EU industrial R&D investment SCOREBOARD**

source: **Ch. Breyer et al, Research and Development Investments in PV – A limiting Factor for a fast PV Diffusion?, 25th PVSEC Valencia, 2010, accepted**

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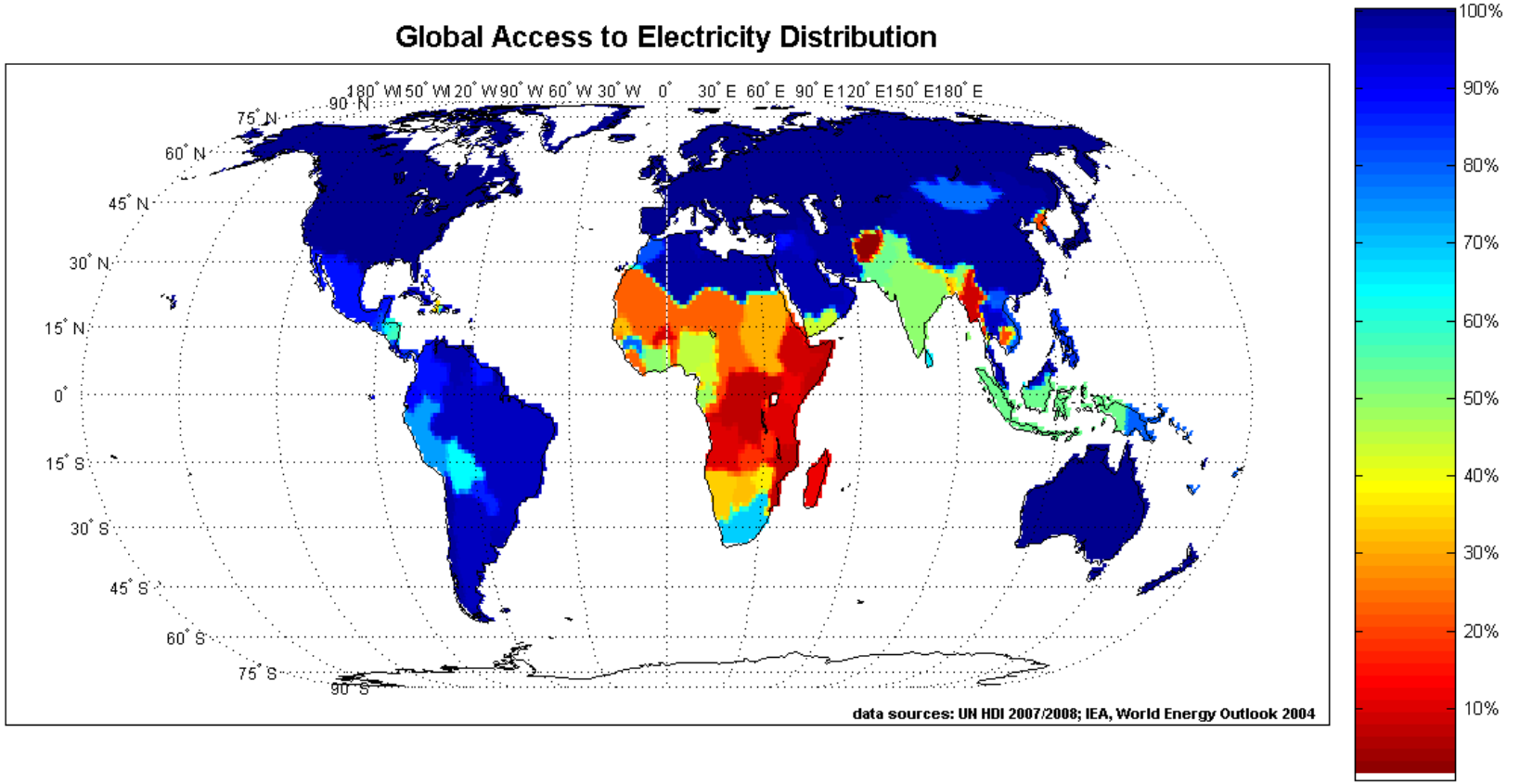
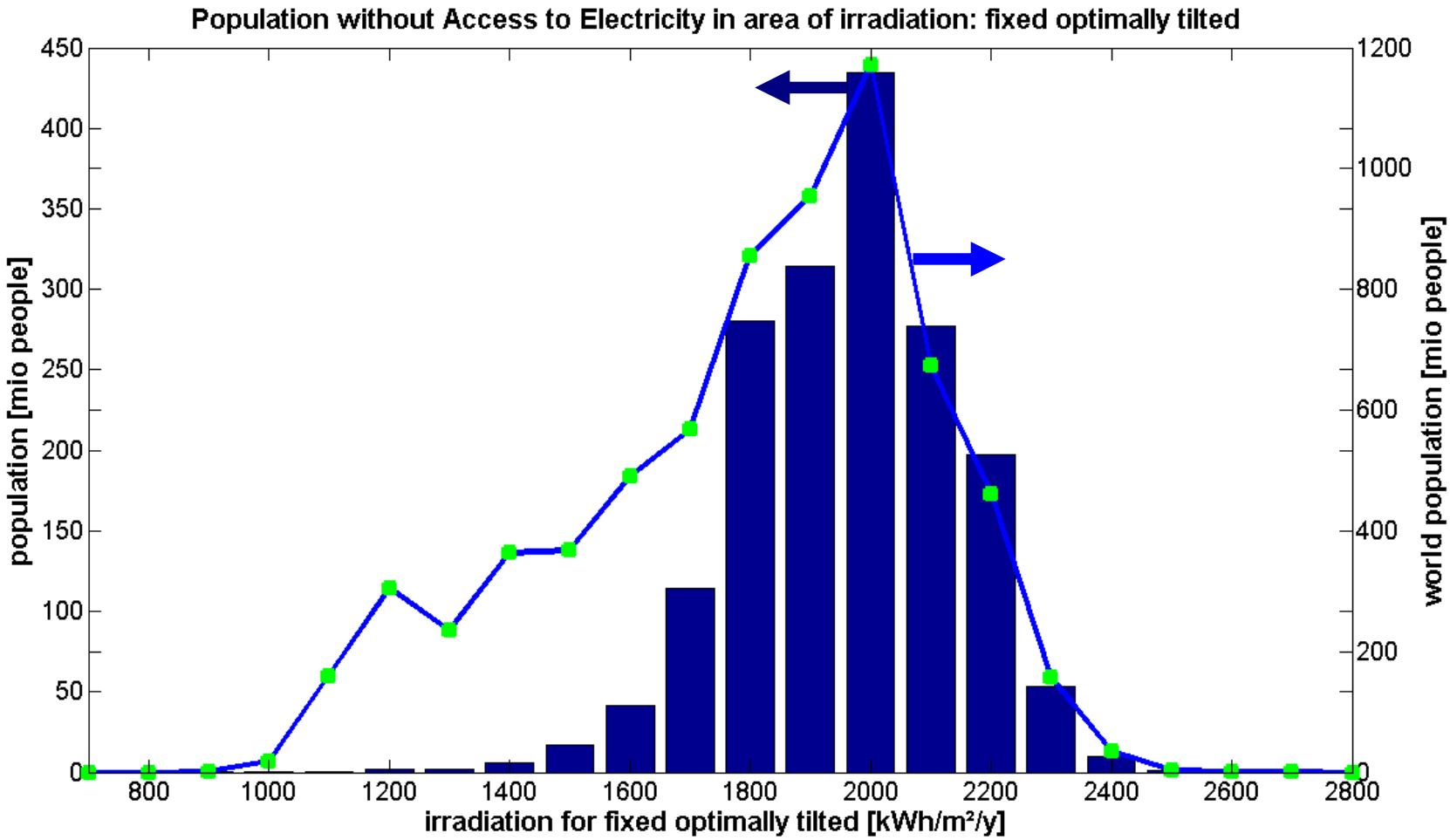
1.6 bn People without Access to Electricity



source: Ch. Breyer, results to be published, 2010

No Electricity Access and Irradiation

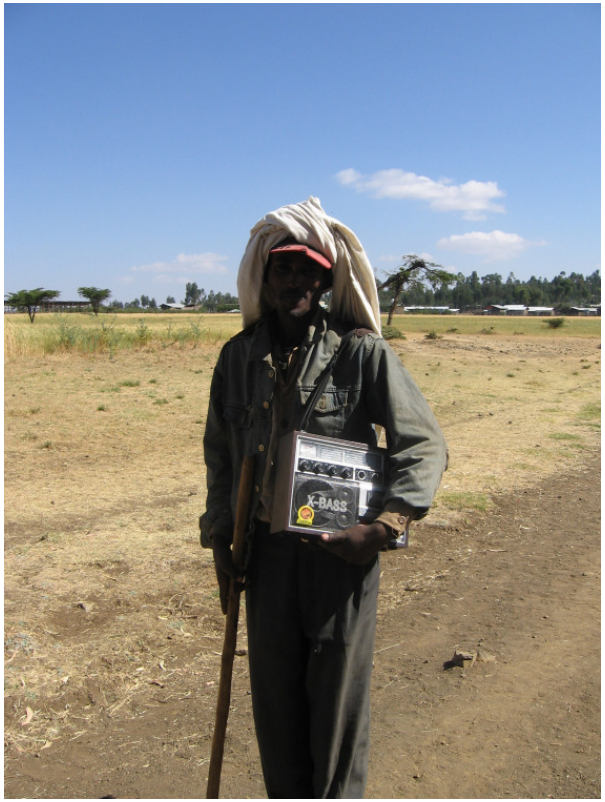


source: Ch. Breyer, results to be published, 2010

Conventional Energy Use in Rural Areas

Light

Music

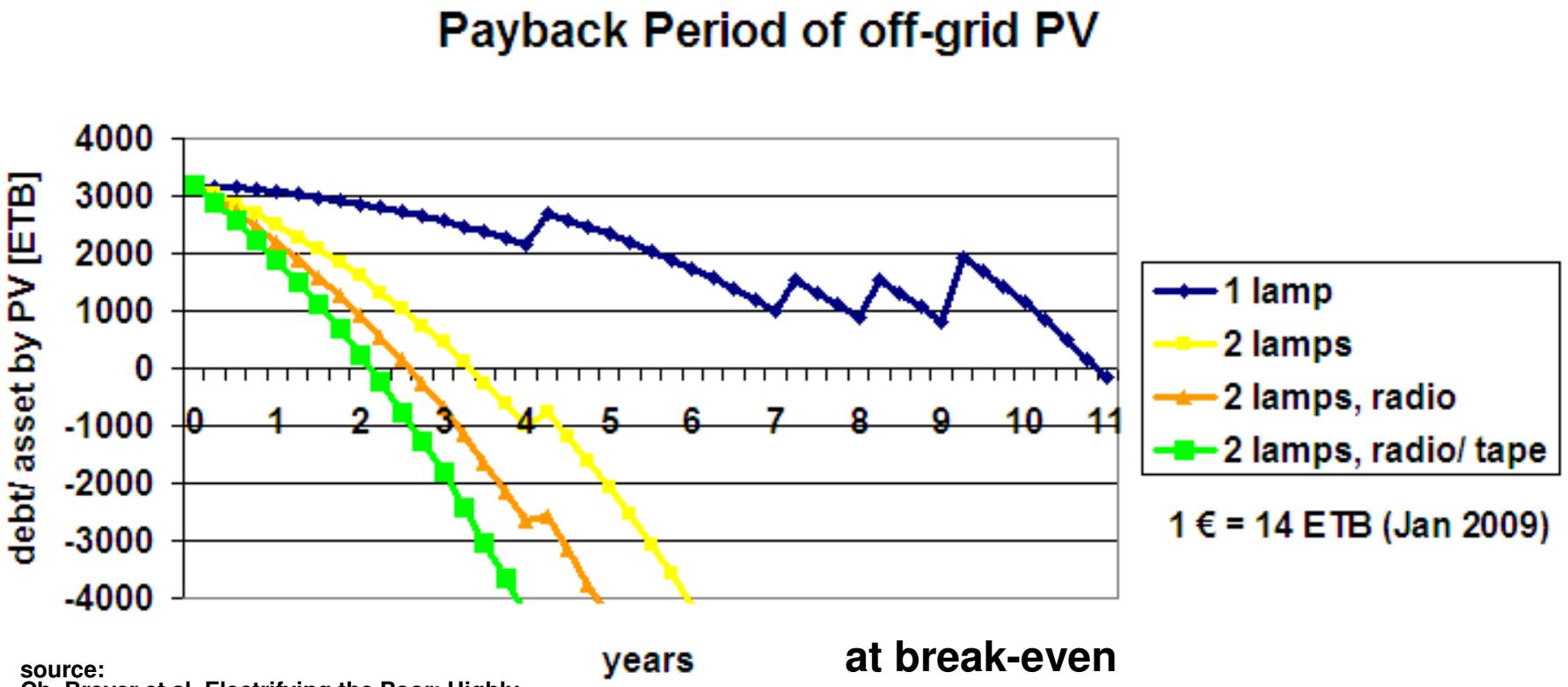


source: Ch. Breyer et al, Electrifying the Poor: Highly Economic Off-Grid PV Systems in Ethiopia, 24th PVSEC, 2009

Solar Home System (SHS) in Ethiopia

source: Ch. Breyer et al, Electrifying the Poor: Highly Economic Off-Grid PV Systems in Ethiopia, 24th PVSEC, 2009

Economics of SHS in Ethiopia



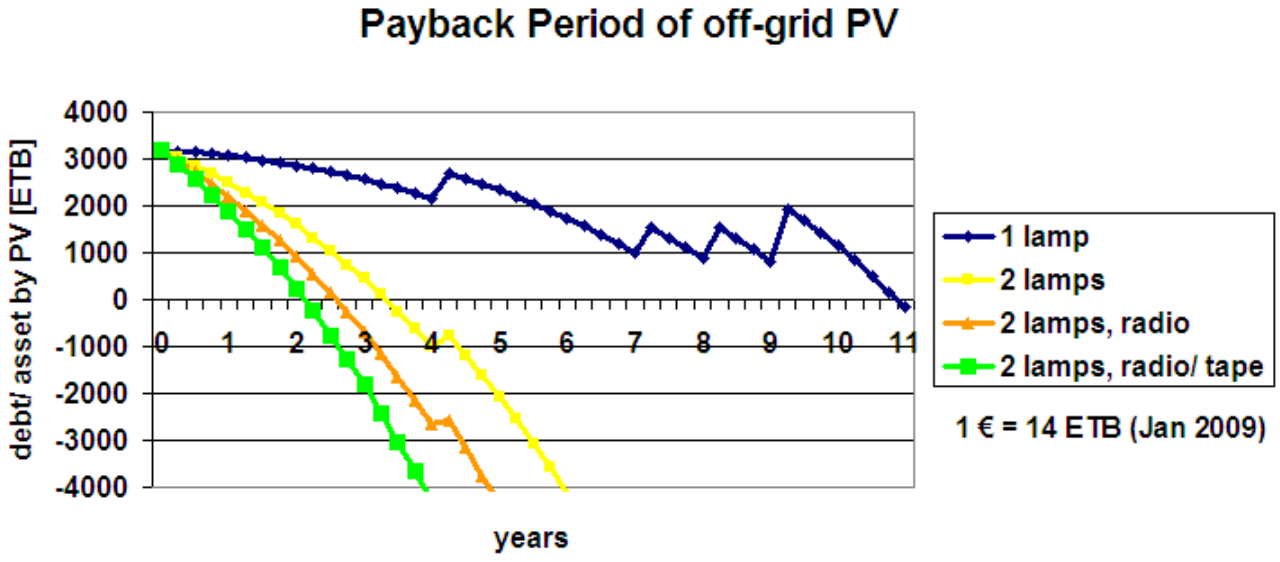
source:
Ch. Breyer et al, Electrifying the Poor: Highly Economic Off-Grid PV Systems in Ethiopia, 24th PVSEC, 2009

at break-even

cost reduction: 80 - 90%
NPV: 16 - 32 kETB
9 - 18 GDP/capita
IRR: 28 - 45%

SHS is least cost option

Economics of SHS in Ethiopia



at break-even

cost reduction: 80 - 90%
NPV: 16 - 32 kETB
9 - 18 GDP/capita
IRR: 28 - 45%

SHS is least cost option

3200	ETB	capex	cost of PV system 10W and 18 Ah gel Pb battery
440	ETB	capex	cost of new battery (every 4 years)
600	ETB	capex	cost of new charge controller & remote controller (every 10 years)
400	ETB	capex	cost of 4 new LED lamps (every 7 years)
45	ETB	month/lamp	cost for paraffin lamps, on average 2 lamps per family
24	ETB	month/radio	cost for battery (2 birr/ dry battery and 3 batteries per radio and 4 sets of batteries/ month)
48	ETB	month/tape rec	cost for battery (3 times the cost for radio, but less in use)
10%	overall price increase per year		
3%	credit spread		

source:
Ch. Breyer et al, Electrifying the Poor: Highly Economic Off-Grid PV Systems in Ethiopia, 24th PVSEC, 2009

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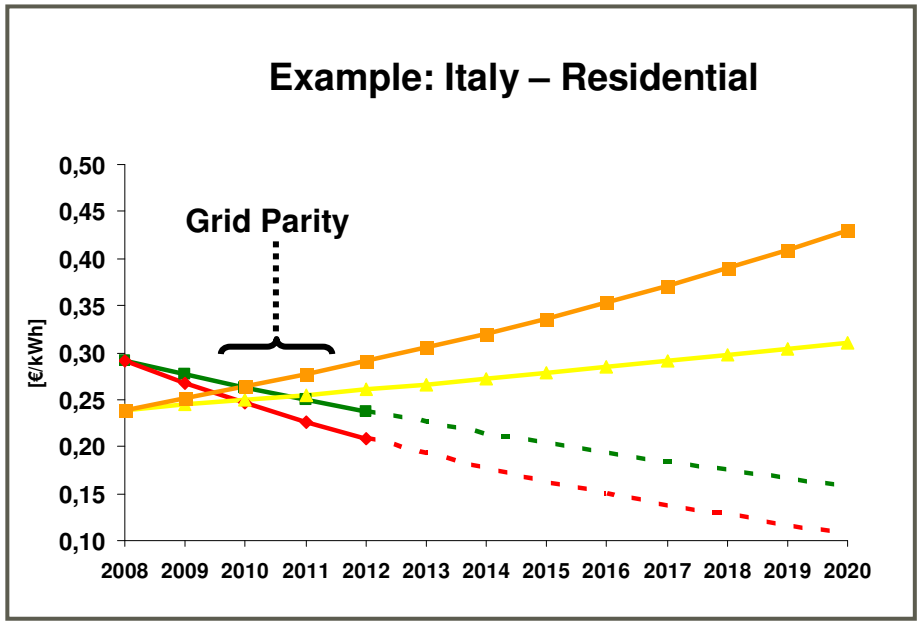
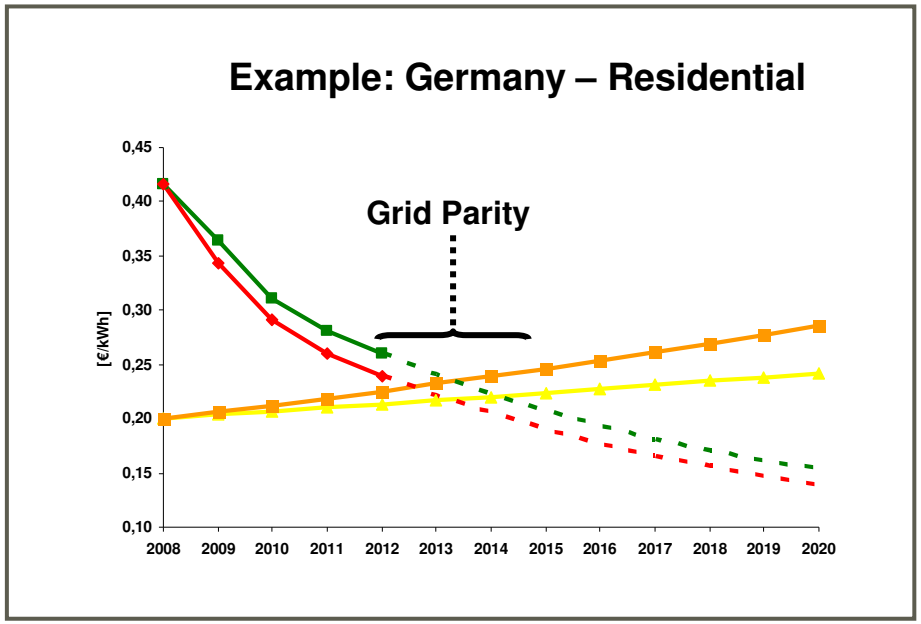
Cost Reduction: Key to Grid-Parity



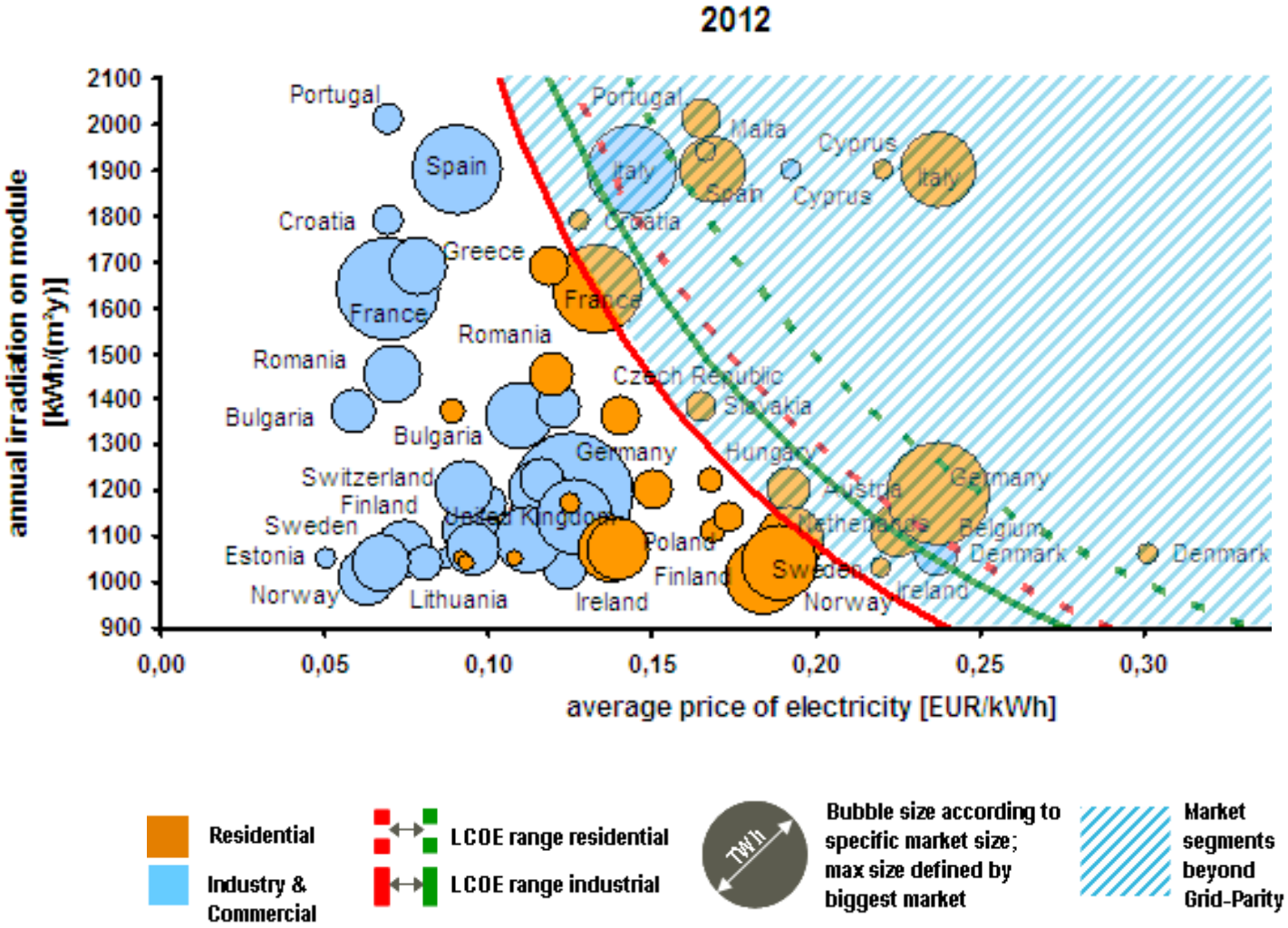


Pricing Capabilities upper Limit
Pricing Capabilities lower Limit
Historic Electricity Price Increase
Electricity Price Increase 3% p.a.

LCOE = Levelized Cost of Electricity Generation based on PV system (starting price 2008: 4.00 EUR/Wp) and electricity price; source: eurostat, 2008

source: Ch. Breyer and A. Gerlach et al, Grid-Parity Analysis for EU and US Regions, 24th PVSEC Hamburg, 2009

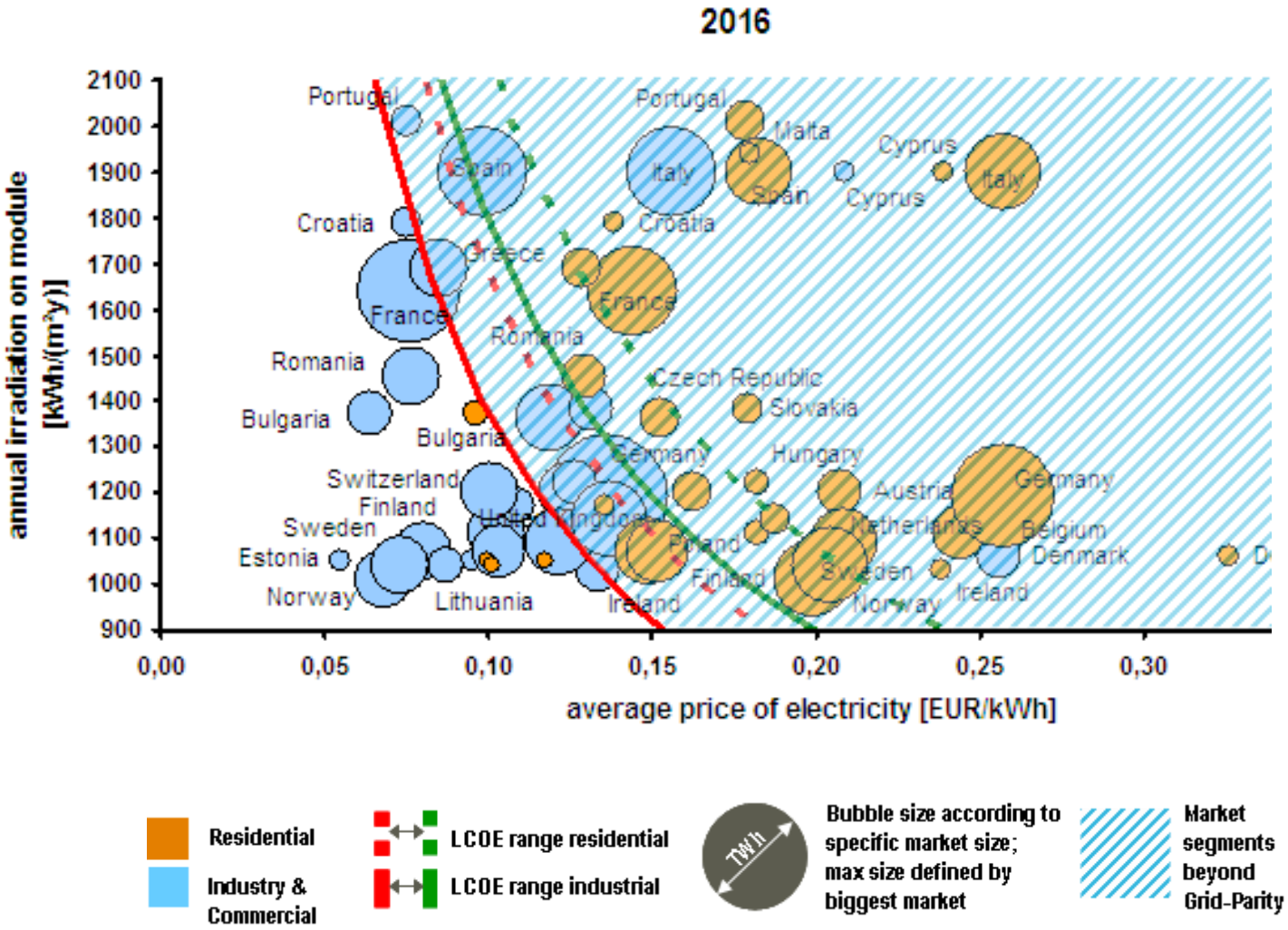
Europe - 2012



Assumptions:
Capex 2010: ~2.9 €/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:
Ch. Breyer and A. Gerlach, Global Overview on Grid-Parity Event Dynamics, 25th PVSEC Valencia, 2010, accepted

Europe - 2016



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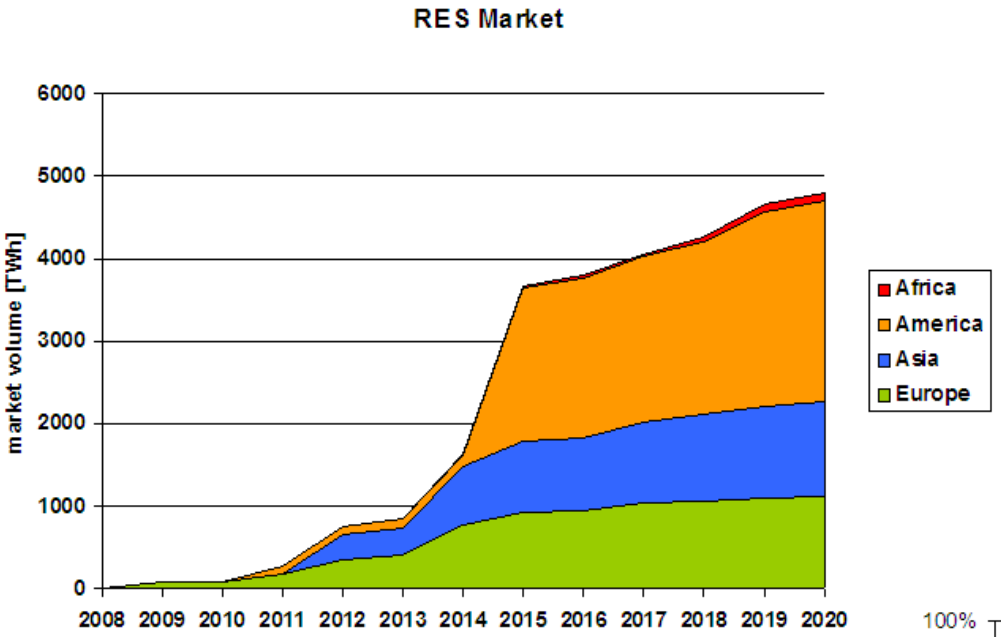
Addressable Market Volume Residential



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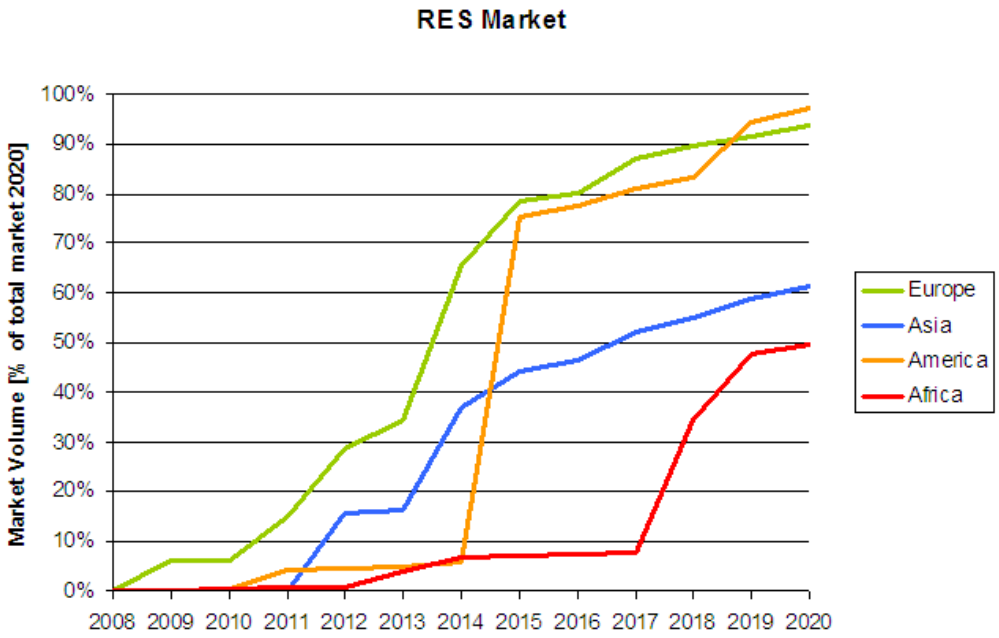
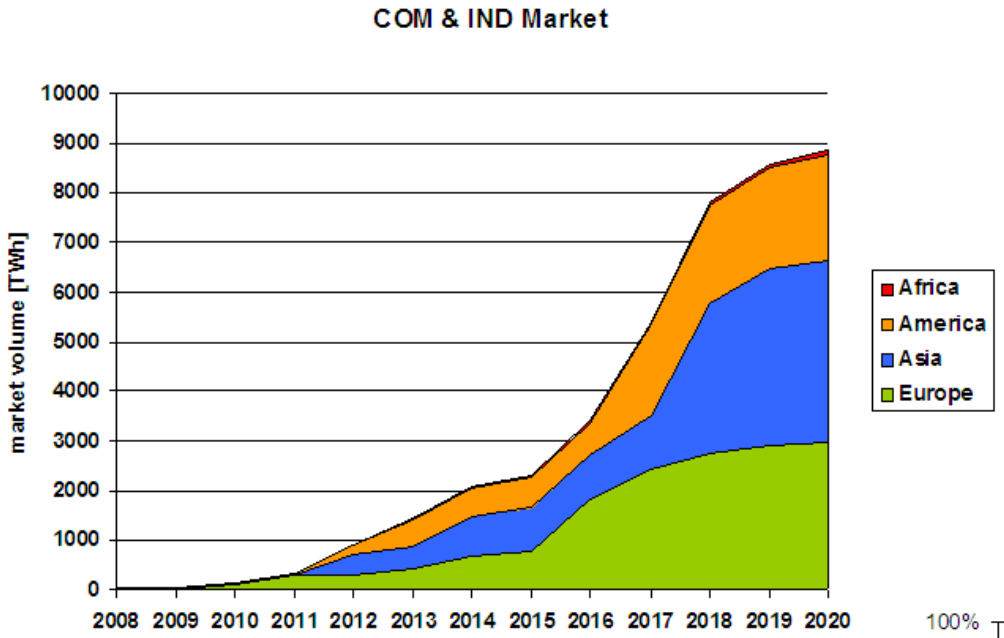
source:
Ch. Breyer and A. Gerlach, Global Overview on Grid-Parity Event Dynamics, 25th PVSEC Valencia, 2010, accepted

regarded countries for residential markets represent:

- **86% of world population**
- **98% of global GDP**
- **95% of global energy related CO_2 emissions**
- **96% of global residential electricity consumption**



Addressable Market Volume Industrial



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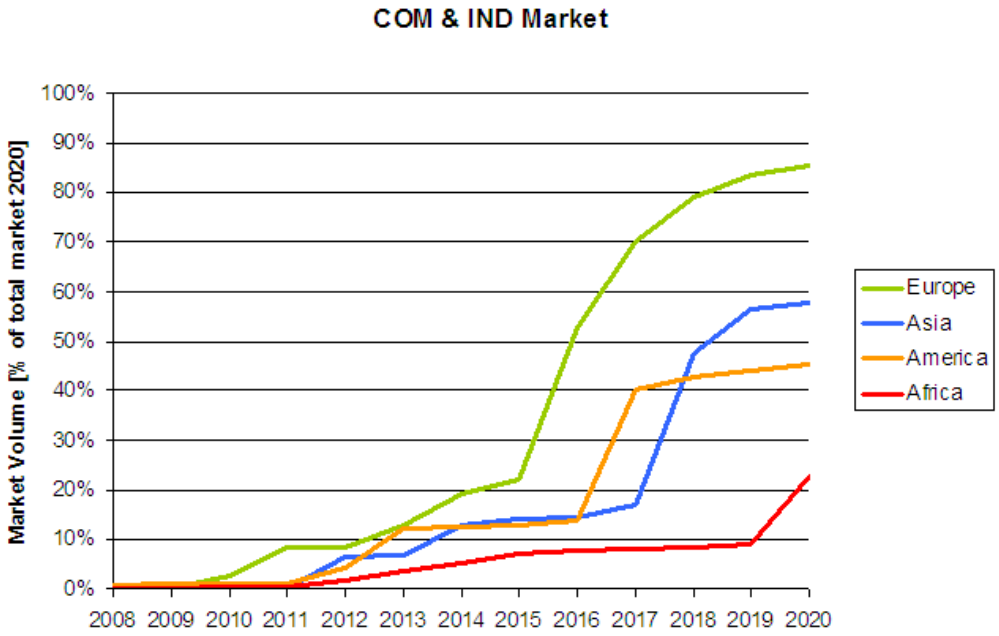
source:
Ch. Breyer and A. Gerlach, Global Overview on Grid-Parity Event Dynamics, 25th PVSEC Valencia, 2010, accepted

regarded countries for industrial markets represent:
- **82% of world population**
- **92% of global GDP**
- **93% of global energy related CO_2 emissions**
- **96% of global industrial electricity consumption**

numbers for commerical markets are ~33%



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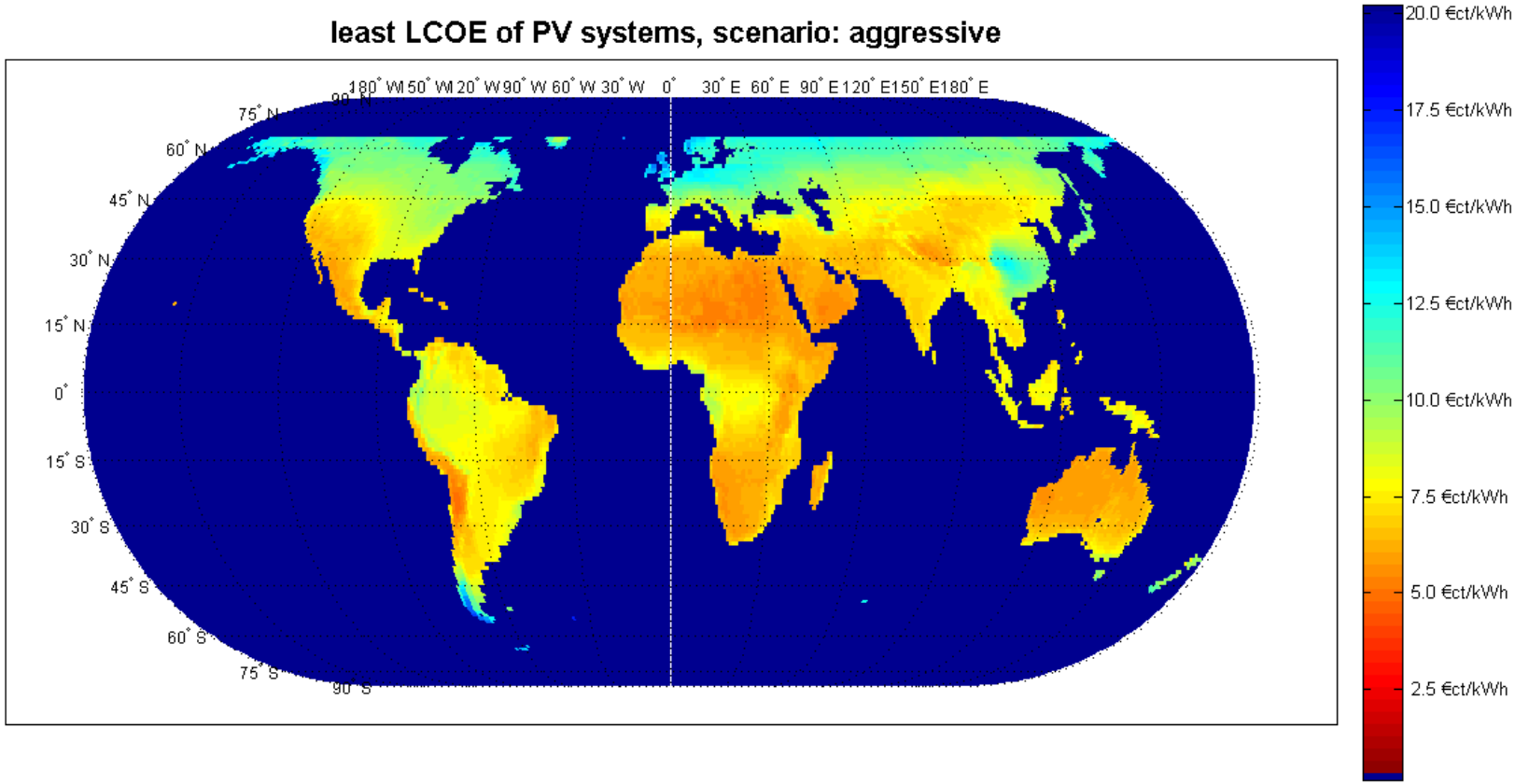
Utility-scale PV

Finsterwalde, Germany

44 MW, 2009, grid-connected

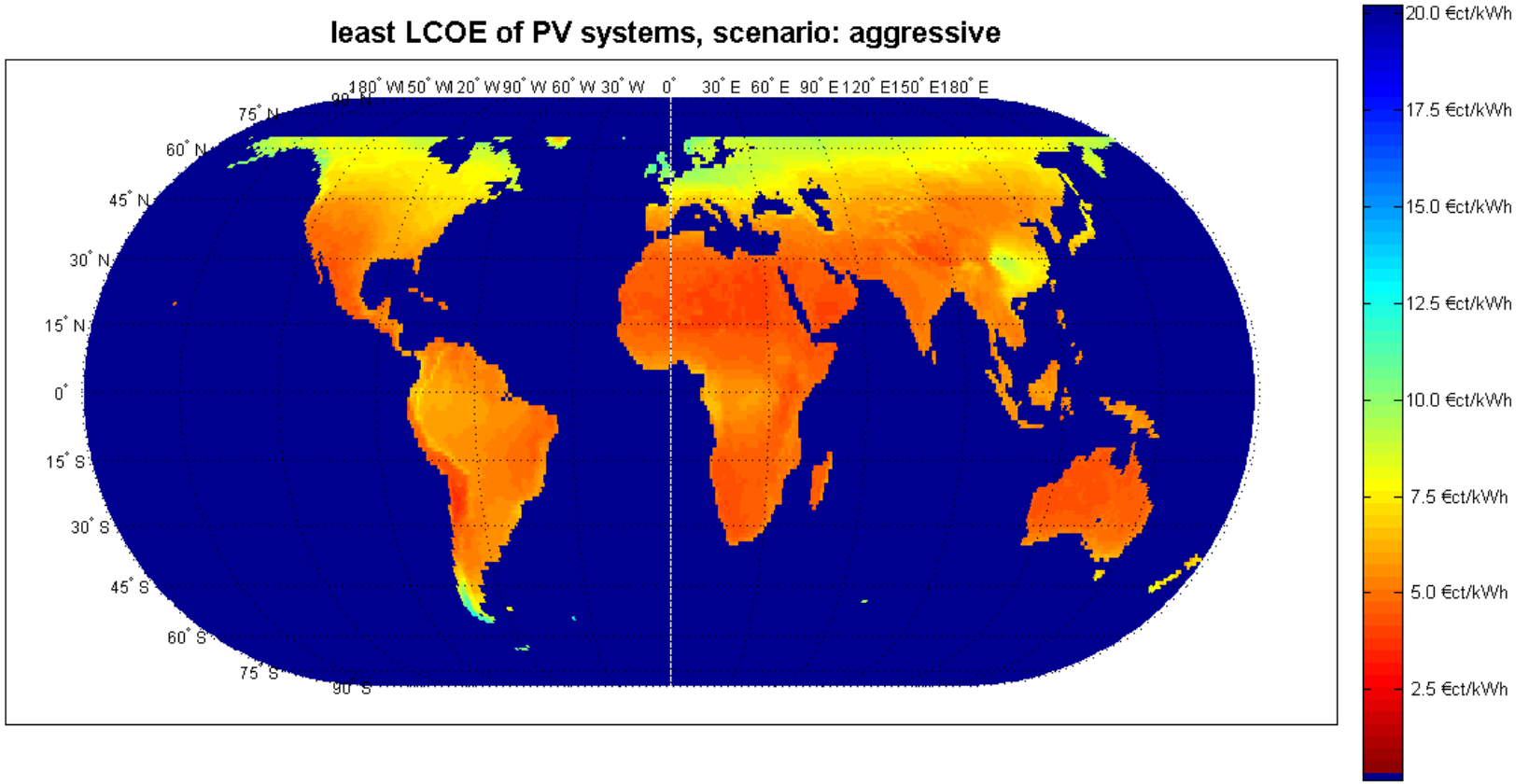
source: Q-Cells Systems

LCOE PV: (significantly) before 2015



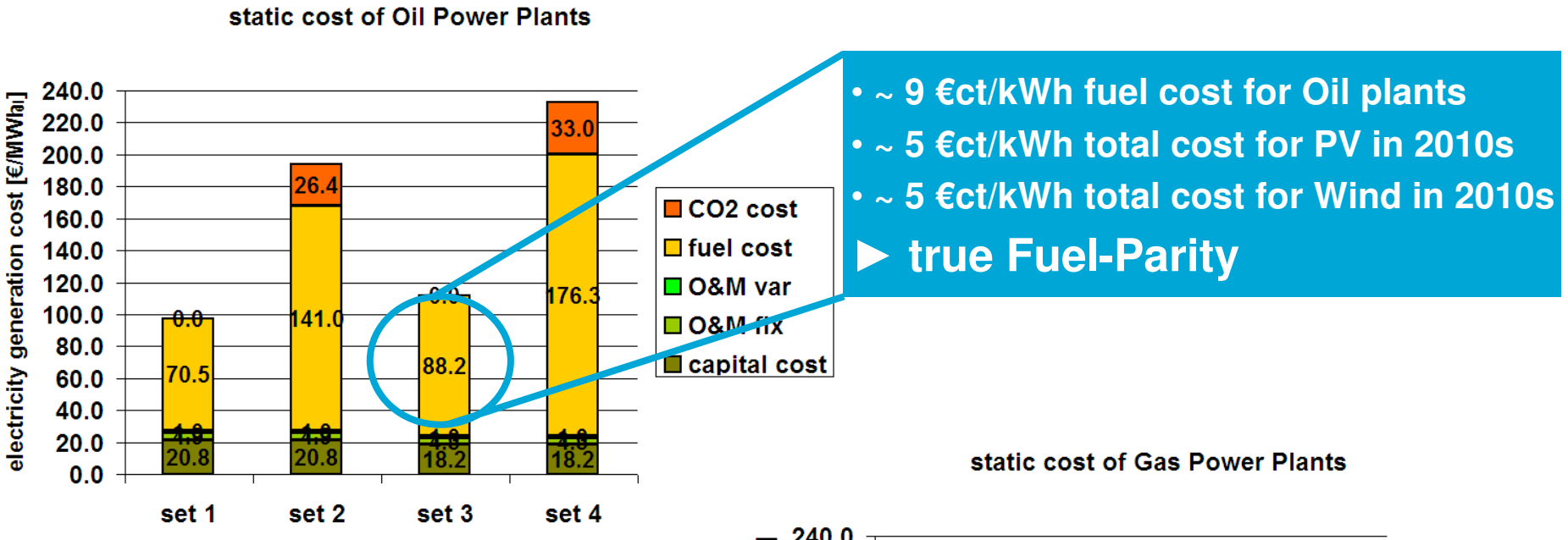
source: Ch. Breyer, results to be published, 2010

LCOE PV: (significantly) before 2020



source: Ch. Breyer, results to be published, 2010

Cost of fossil fuel powered plants



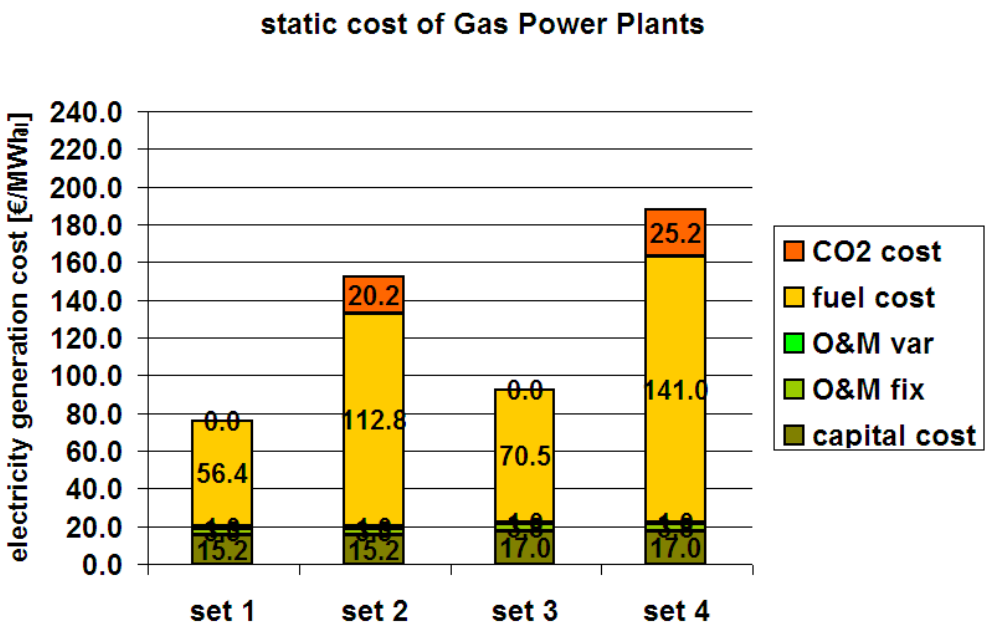
- ~ 9 €ct/kWh fuel cost for Oil plants
- ~ 5 €ct/kWh total cost for PV in 2010s
- ~ 5 €ct/kWh total cost for Wind in 2010s

► true Fuel-Parity

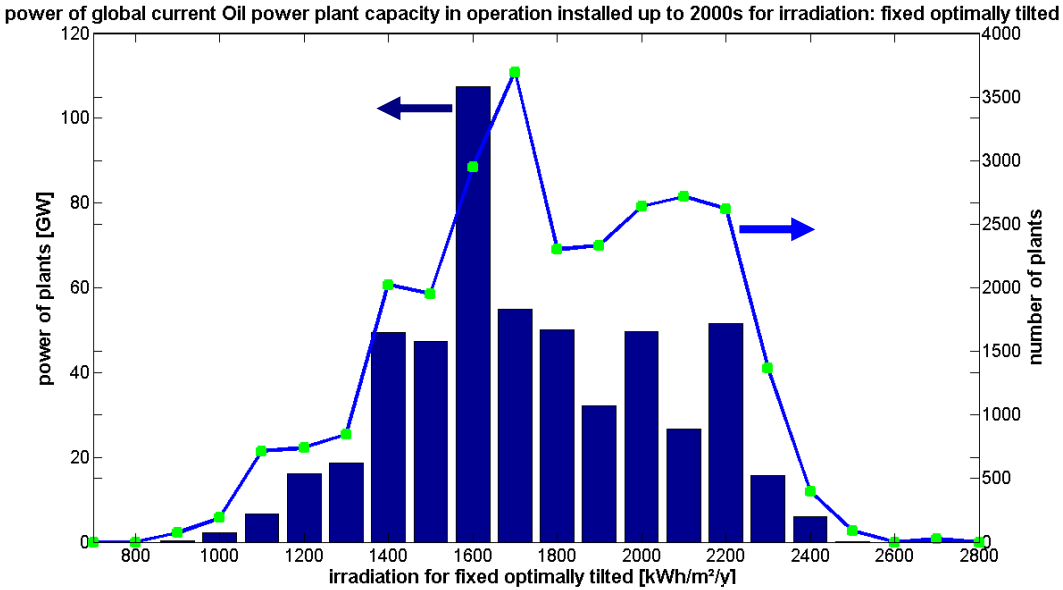
		set 1	set 2	set 3	set 4
load hours - gas	[h/y]	4500	4500	4000	4000
load hours - oil	[h/y]	3500	3500	4000	4000
efficiency - gas	[%]	50%	50%	40%	40%
efficiency - oil	[%]	50%	50%	40%	40%
CO2 cost	[€/tCO2]	0	50	0	50
oil price	[USD/bbl]	80	160	80	160

data sources: IEA WEO, 2005; ECF, 2010; Q-Cells

source: Ch. Breyer, results to be published, 2010



Solar Location of Oil and Gas Power Plants



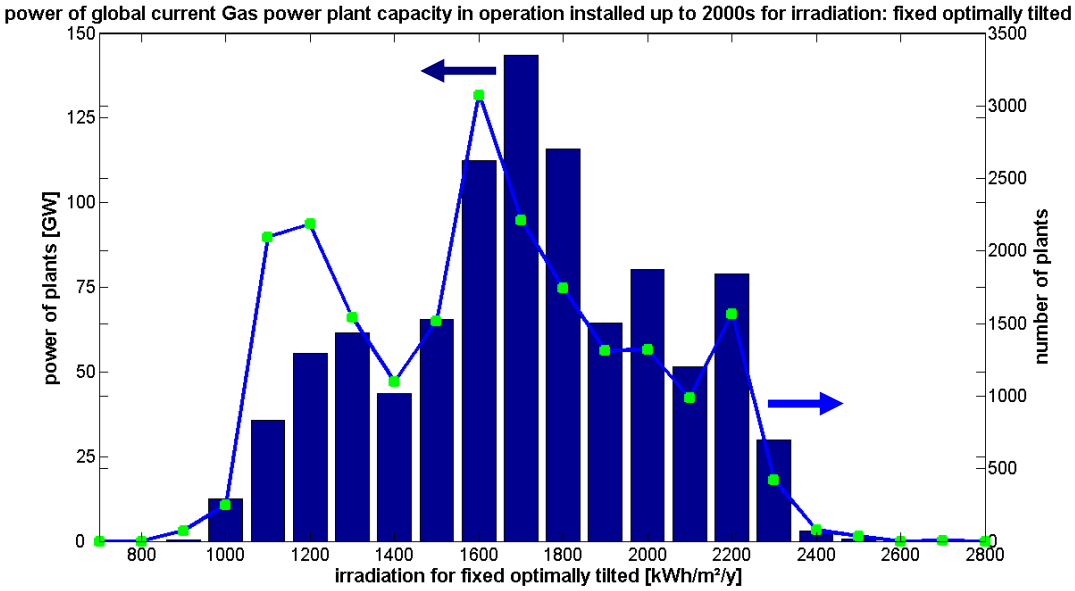
~150 GW Oil Power Plants @ ≥ 2000 kWh/m²/y

~250 GW Gas Power Plants @ ≥ 2000 kWh/m²/y

7 – 9 €ct/kWh LCOE Gas/ Oil (fuel only)

7.5 – 10.5 €ct/kWh LCOE PV @ 2000-2400 kWh/m²/y, 2.0 €/Wp, 0.77 PR, 5% WACC

CO_2 reduction benefits



data source: UDI World Electric Power Plants database, March 2009

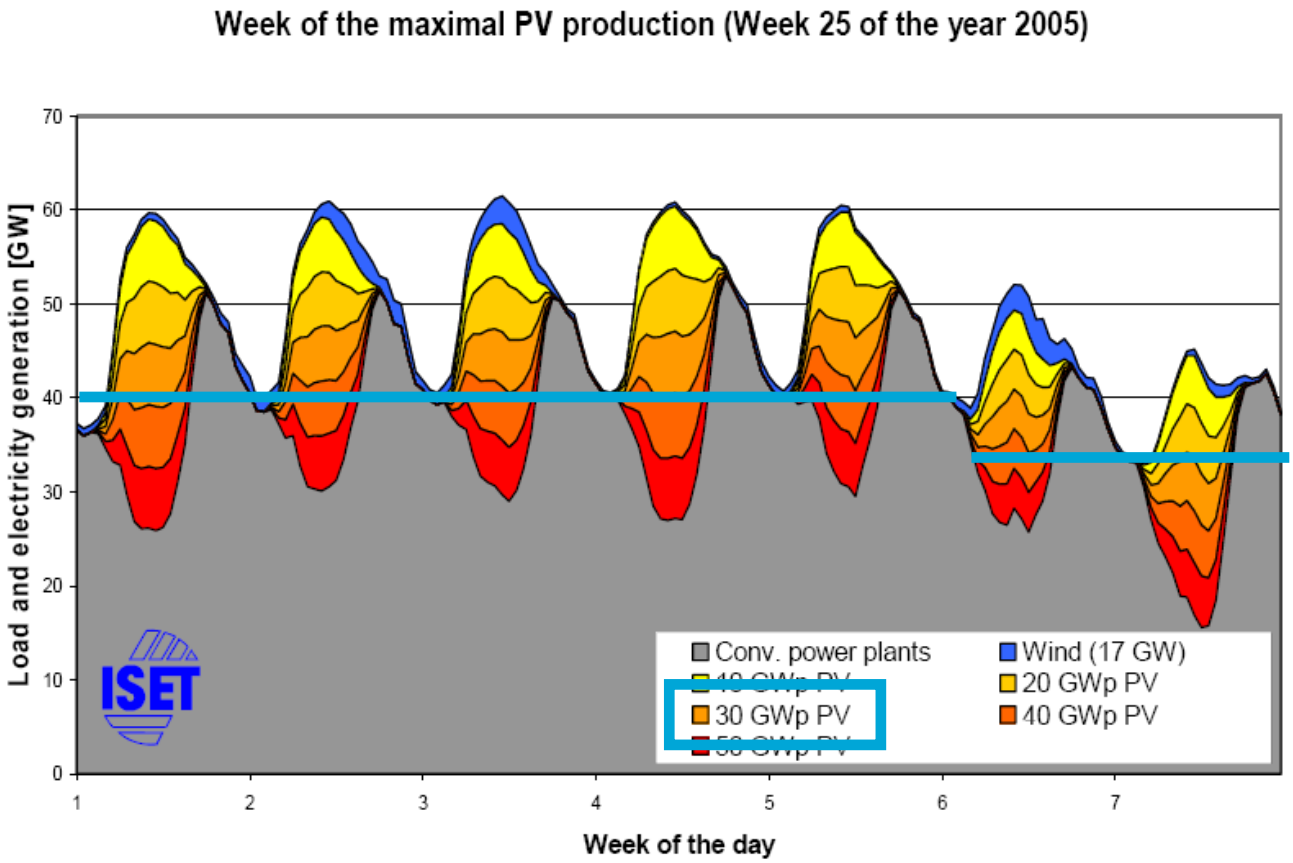
source: Ch. Breyer, results to be published, 2010

Outline

- Motivation
- Learning Curve
- PV R&D Investments
- 2nd milestone – Off-Grid PV
- 3rd milestone – Grid-Parity
- 4th milestone – Utility-scale PV
- Germany 2020
- Beyond SET 2020 Plan
- Conclusions

Germany: Growth limits for PV

PV growth limit assuming low impact on today's electricity structure



PV installed

30 GWp

annual yield

950 kWh/kWp

PV electricity generation

28.5 TWh

total electricity used

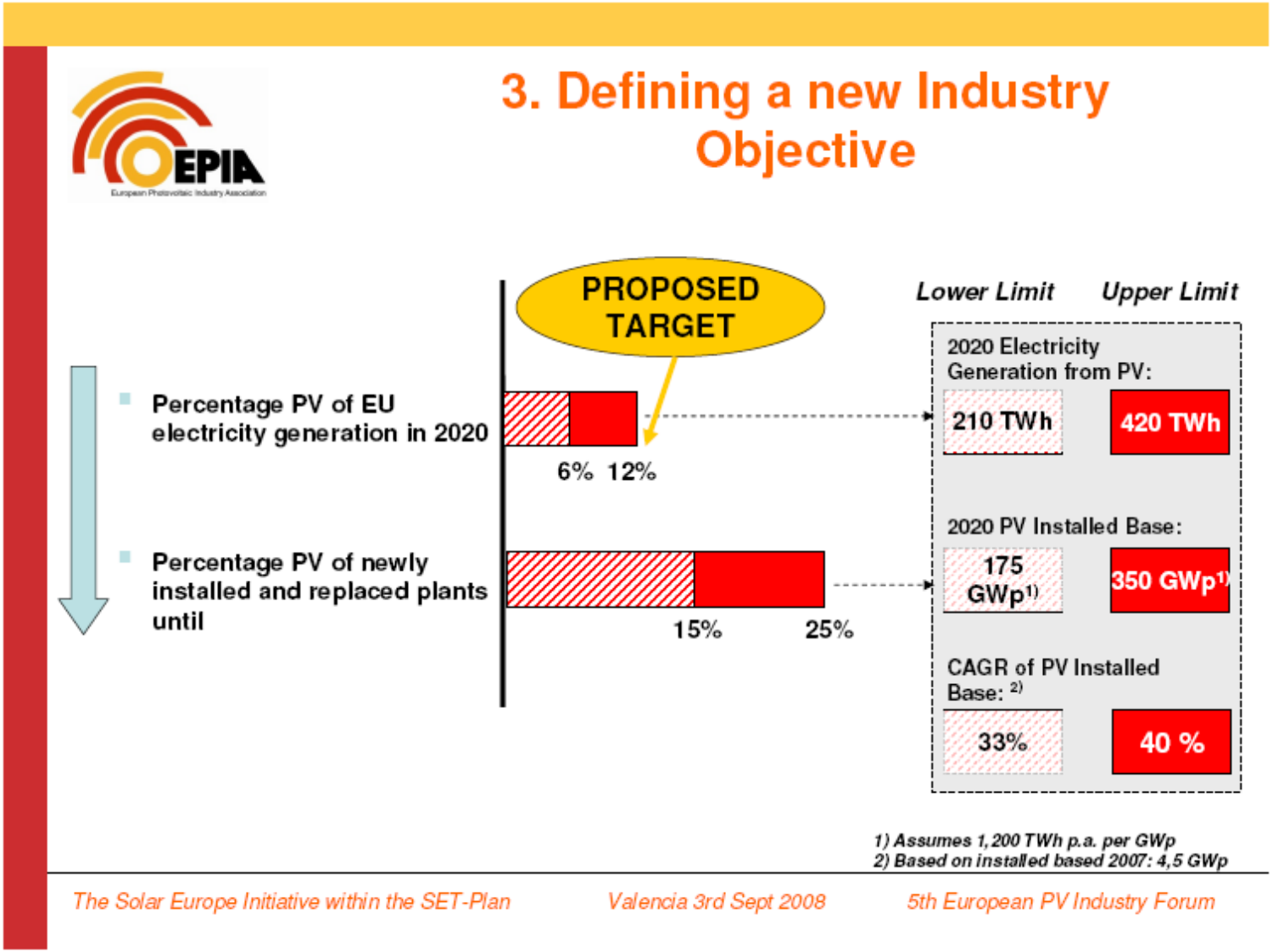
517 TWh

PV market share

~6%

source: M. Braun, PV Value study, ISET (now FhG-IWES), 2008

SET Plan 2020: EU PV Industry Targets



source: A. Milner, 5th EU PV Industry Forum, 2008

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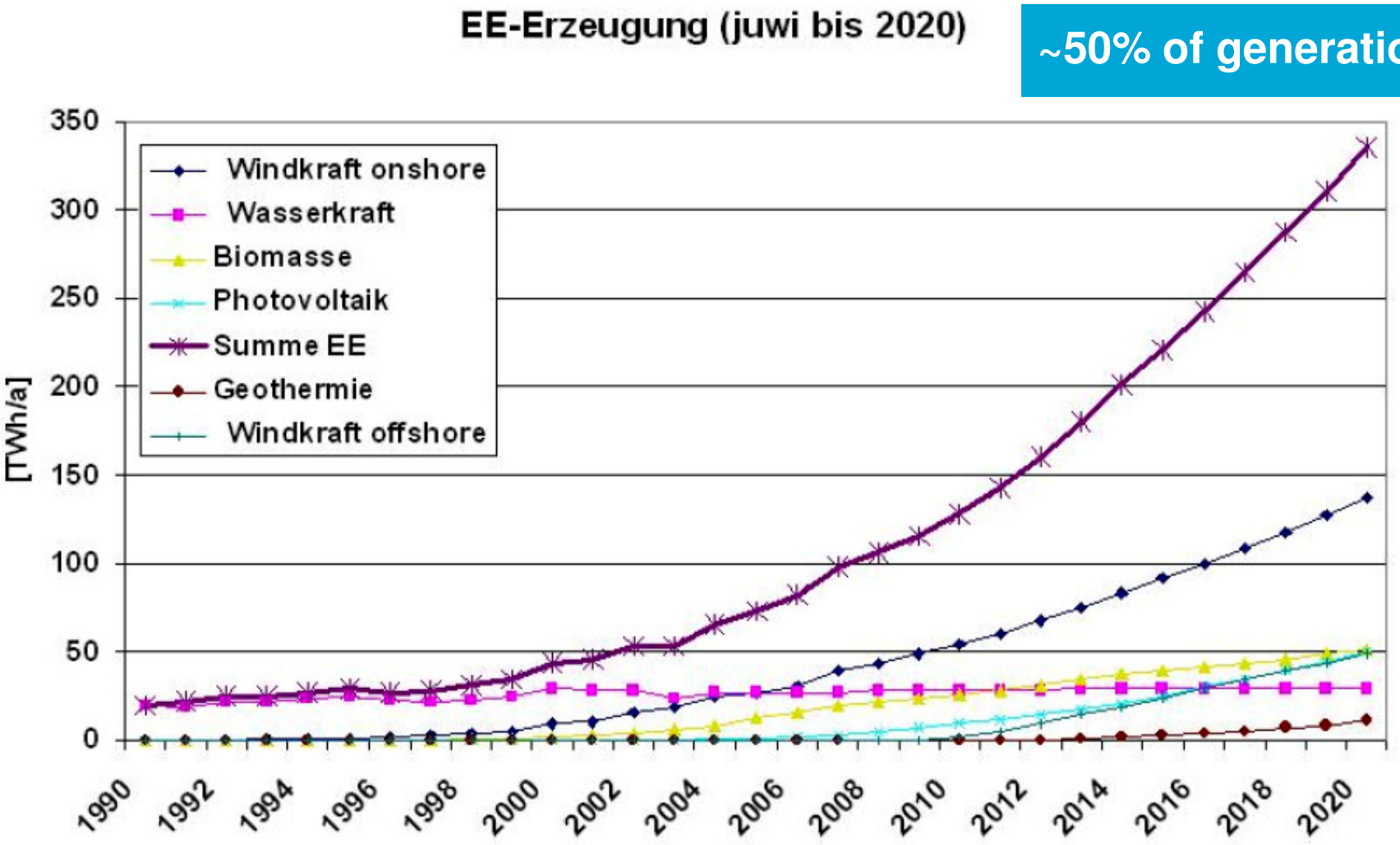
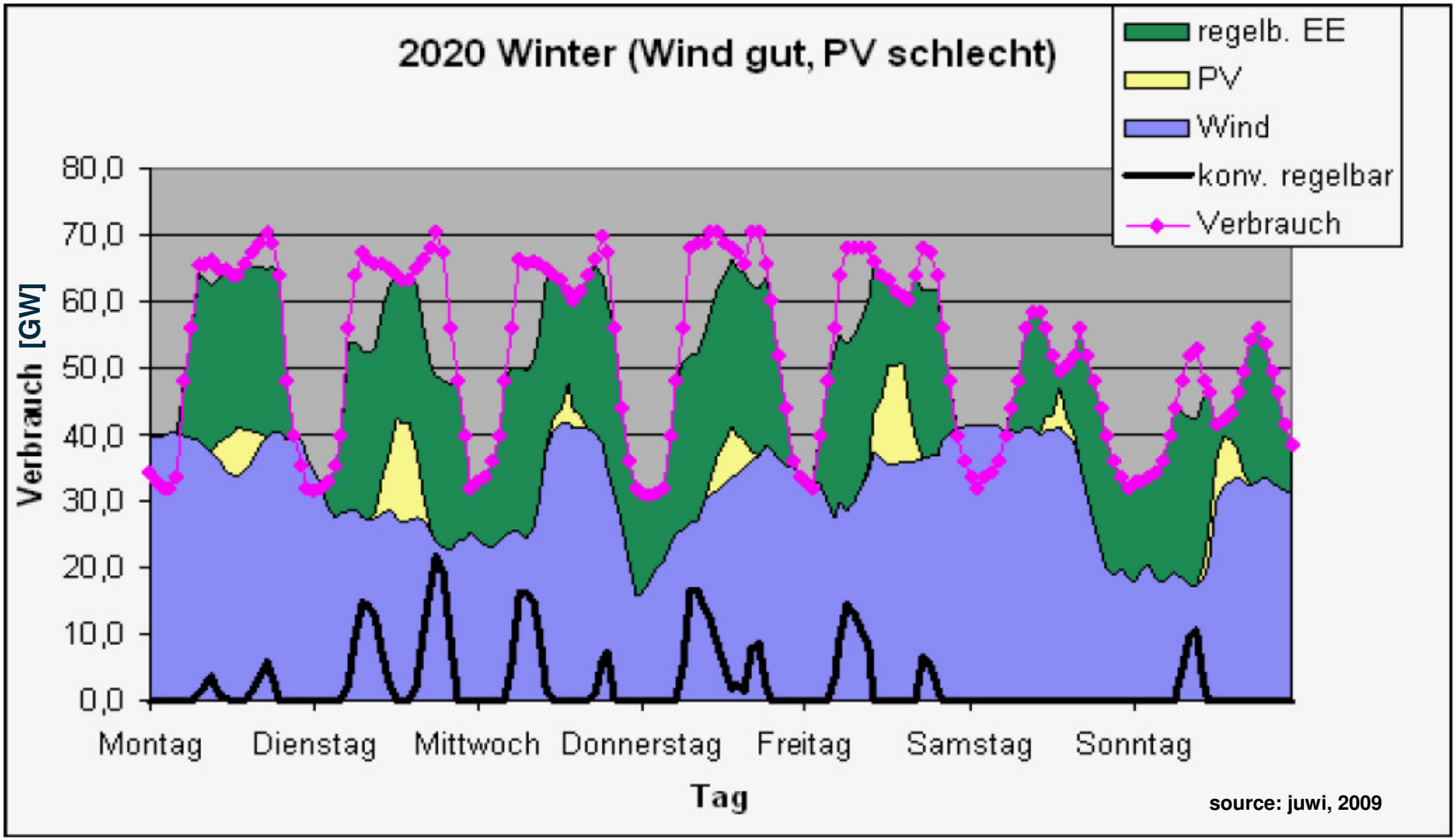
Grundversorgungskraftwerk



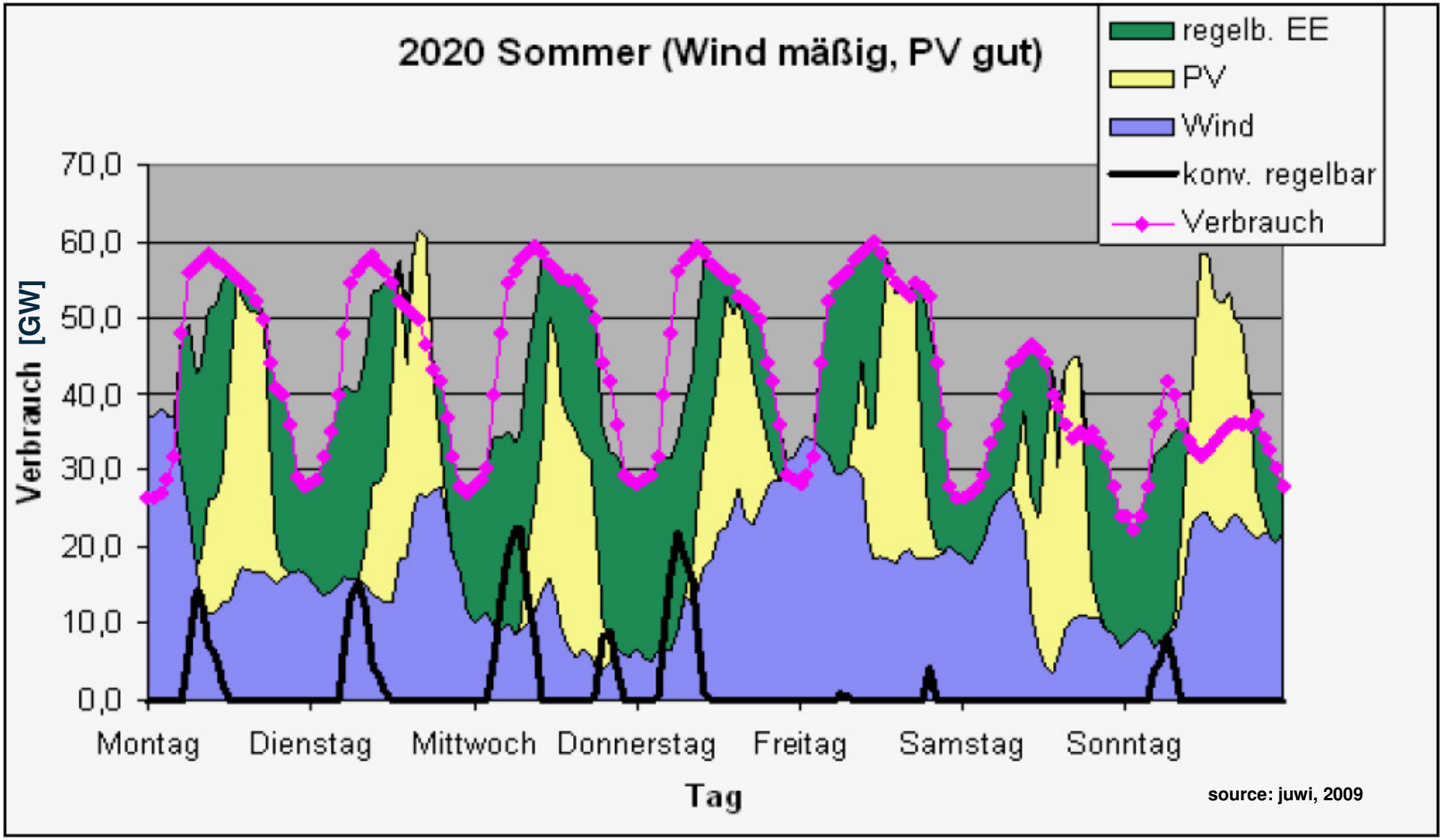
~50% of generation

source: juwi, 2009

Grundversorgungskraftwerk



Grundversorgungskraftwerk



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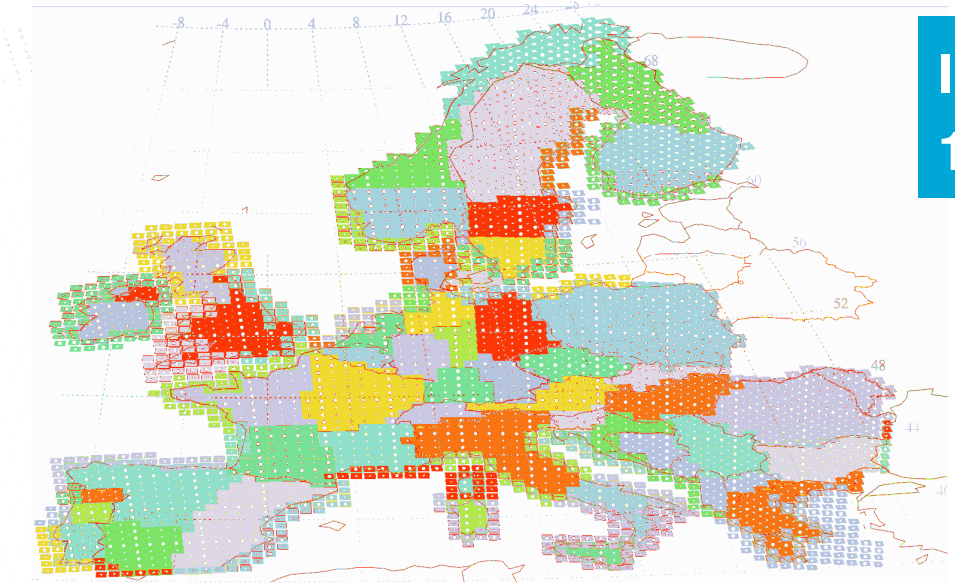
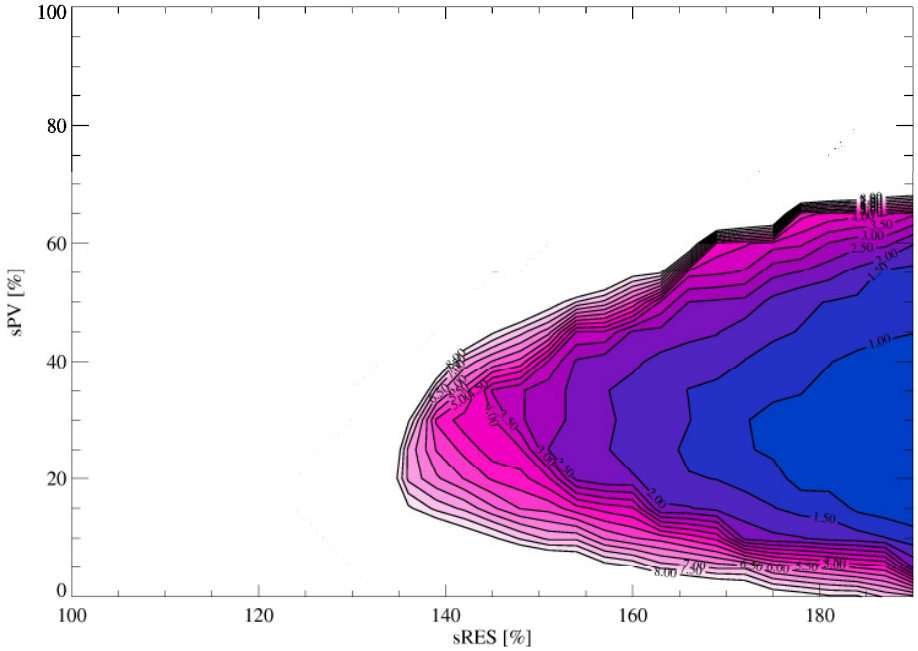
Europe: Growth limits for PV

PV potential in Europe assuming excellent grids and substantial storage



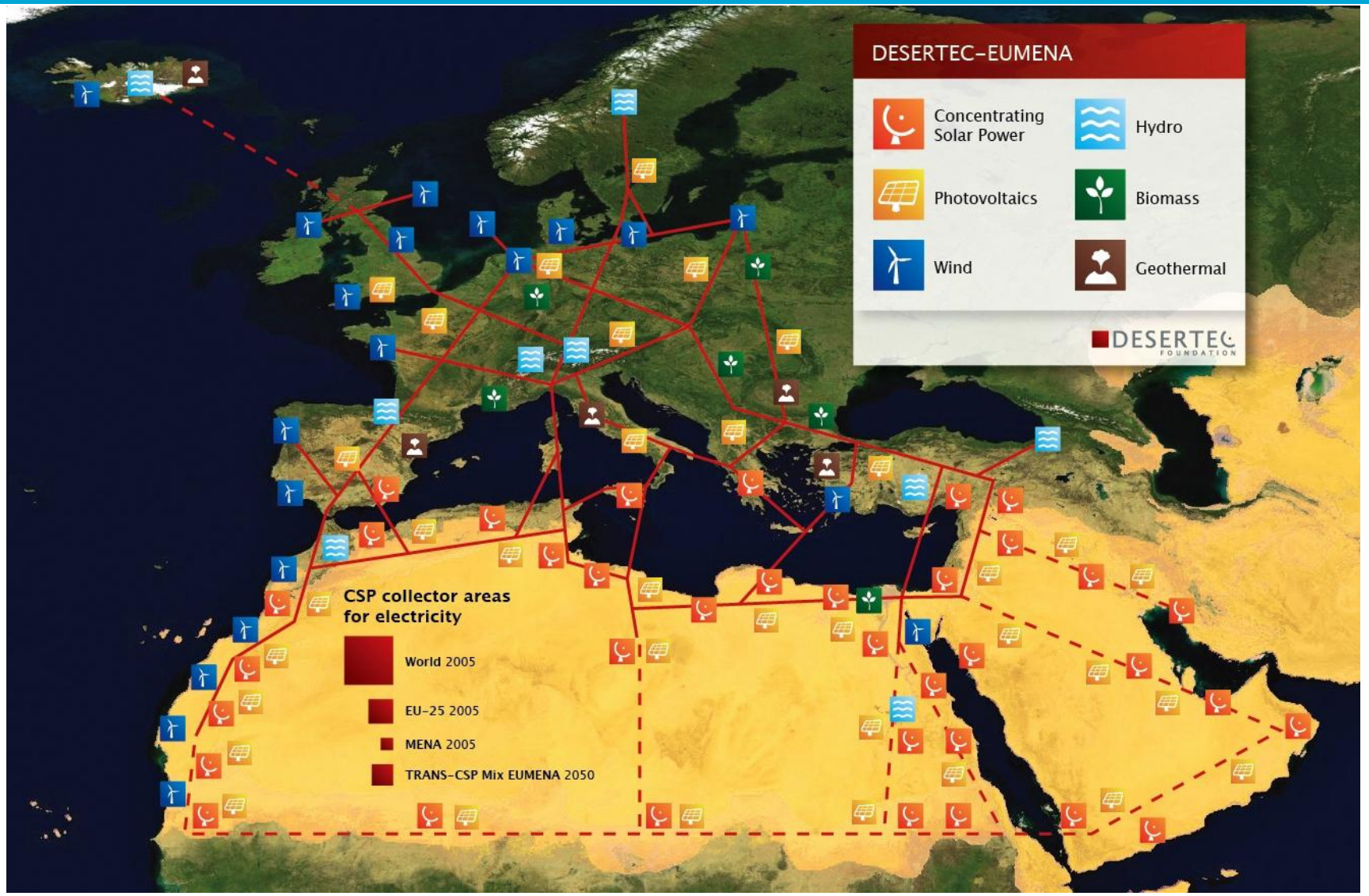
In reality:
12% SET Plan target is conservative!

20 - 50% PV supply in the European electricity system might be possible



source: C. Hoffmann, IRES-III Berlin, 2008
(study by Siemens and FhG-IWES)

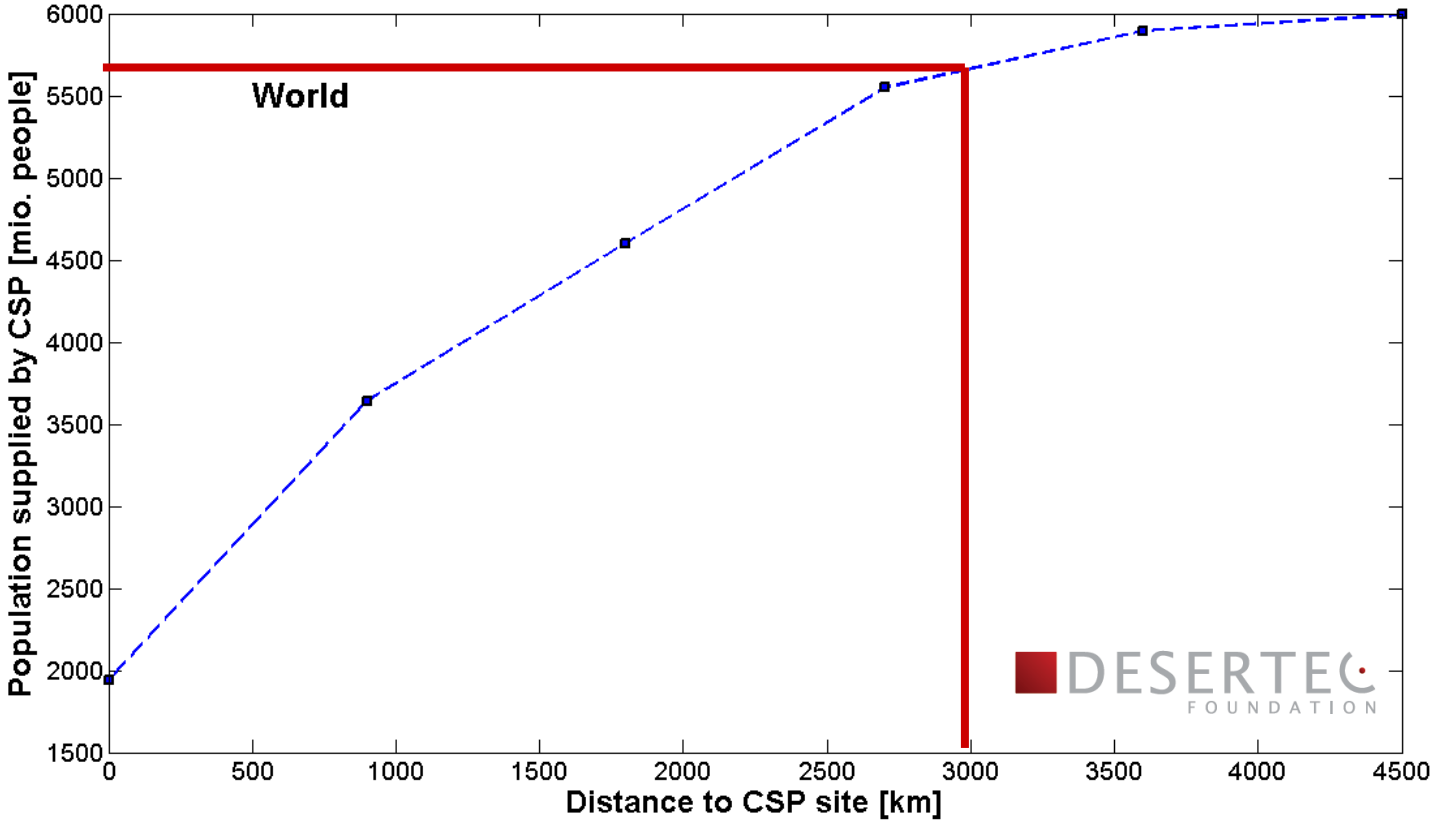
DESERTEC concept: EU-MENA – PV expansion



source: Q-Cells/ DESERTEC, 2009

Global energy supply potential of solar energy

> 90% of world population could be supplied by solar power (PV and/or CSP) via HVDC power lines not longer than 3,000 km



source: Ch. Breyer and G. Knies, Global Energy Supply Potential of CSP, SolarPACES Berlin, 2009

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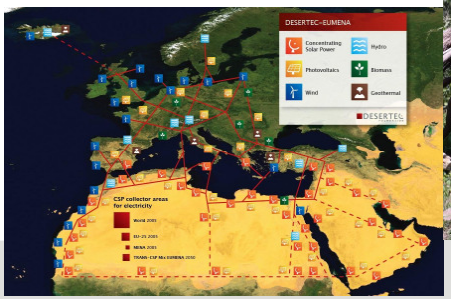
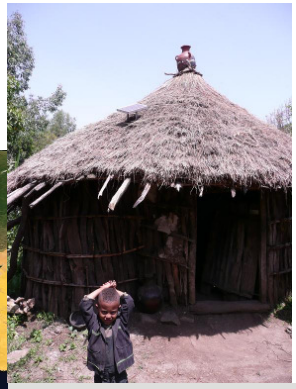
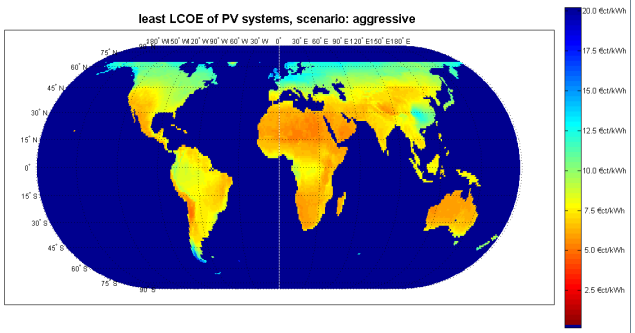
Conclusions

- peak-oil and climate change powers renewables
- high PV learning rates enable fast cost reduction
- public energy R&D spendings are subcritical low
- off-grid PV is highly economic
- grid-parity largely occurs in 2010s
- fuel-parity is already reached in very sunny regions
- PV penetration on ~10% level at end of 2010s possible
- no conventional baseload power plants needed anymore







Feel free to disseminate the key messages of this presentation ☺!

THANK YOU.

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IEE Rationelle Energiewandlung

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BACKUP

List of Abbreviations

ASP	average selling price
BOS	balance of system
Capex	capital expenditure
CdTe	cadmium telluride
COM	commercial
c-Si	crystalline silicon
CSP	concentrating solar thermal power
ECF	European Climate Foundation
EE	erneuerbare Energien
EPIA	European Photovoltaic Industry Association
ETB	Ethiopian Birr
GDP	gross domestic product
HDI	human development index
HDKR	Hay-Davis-Klucher-Reindl
HVDC	high voltage direct current
IEA	International Energy Agency
IND	industrial
IRR	internal rate of return
LCOE	levelized cost of electricity
mc-Si	multi-crystalline silicon
MENA	Middle East North Africa
NPV	net present value
O&M	operation & maintenance (Opex)
OECD	Organisation for Economic Co-operation and Development
Opex	operational expenditure
PEF	price experience function
PR	performance ratio
PV	photovoltaic
PVSEC	Photovoltaic Solar Energy Conference
R&D	research & devlopment
RES	renewable energy sources
RES	residential
SET	Strategic Energy Technologies
SHS	solar home system
STEG	solar thermal electricity generation
UN	United Nations
WACC	weighted average cost of capital
WEO	World Energy Outlook