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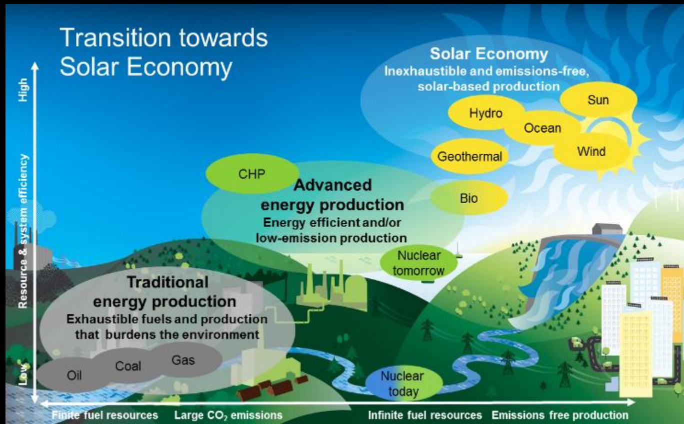

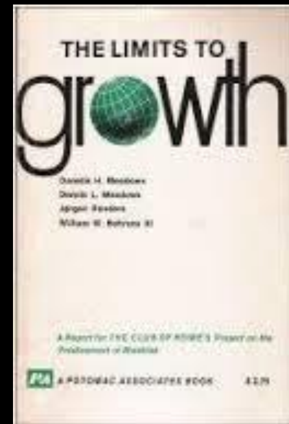

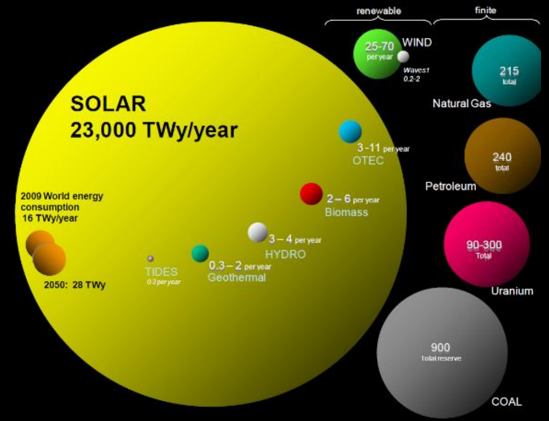

Are there real limits to growth in the ‘Neo-Carbon Energy’ world?

Christian Breyer
Professor for Solar Economy, LUT
The Finnish Association for the Club of Rome
Helsinki, November 3, 2014

How I got personally involved …

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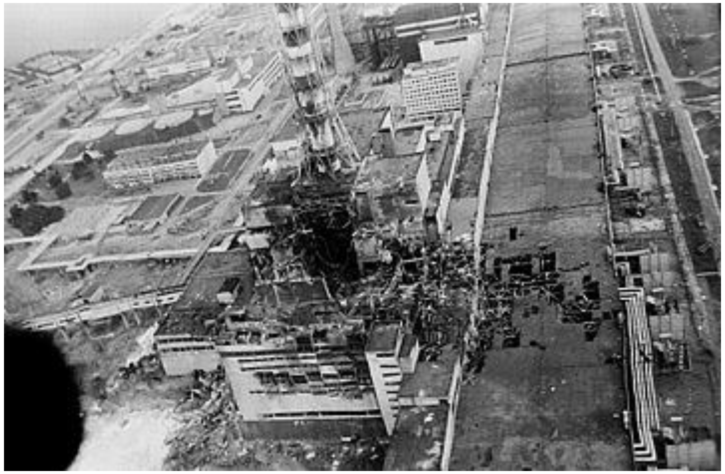
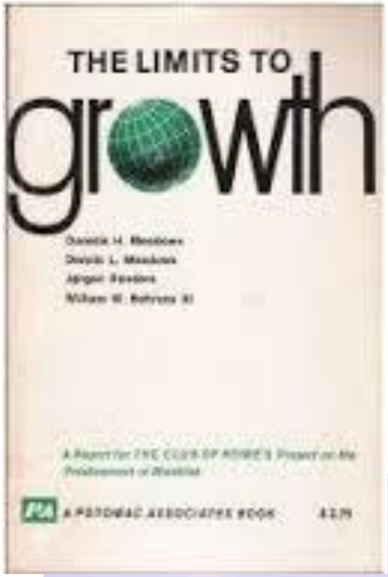




Short Answer

What is ‘Neo-Carbon Energy’ ?

- There is nothing wrong with carbon …
- … except the fact that the planet is distroyed for the current status of life, IF fossil carbon is used
- Learning 1: substitute fossil carbon
- Learning 2: sustainable carbon (not necessarily bioenergy) is ok

- This is meant by ’Neo-Carbon Energy’

Short Answer

Are there real limits to growth in the 'Neo-Carbon Energy' world?

NO

BUT

- solar PV and wind energy are available on quantities MUCH higher than ever needed
- fossil fuels and nuclear to be phased-out fast due to sustainability requirements
- populations growth is slowed down as a function of wealth (in reality access to health services, electricity and higher income)
- there are at least two major limits
  - availability of arable land
  - stability of the ecosphere

Focus today mainly on the energy system and the respective limits

Summary

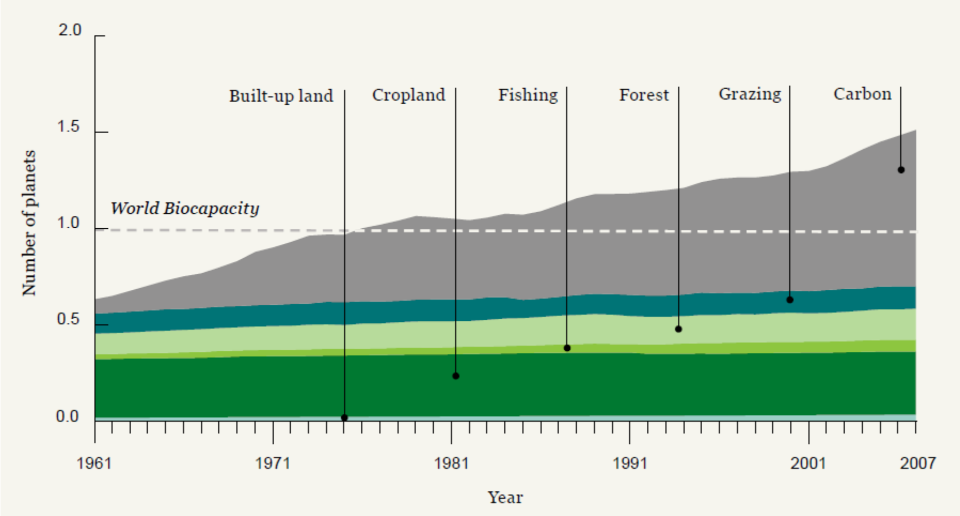
- solar PV diffusion trend is stable for decades (leaning rate, growth rate, cost reduction)
- more and more market segments are becoming profitable
- PV and Wind emerge to the backbone of global energy supply
- 100% RE system is feasible: technical, economical, ecological
- highest risk for RE is not economics it is politics
- opportunities are huge – but only for the ones who act (the rest will [have to] follow [for economic reasons])
- power business is/ will be radically transformed due to system impact of (decentralised, low scale) PV and storage

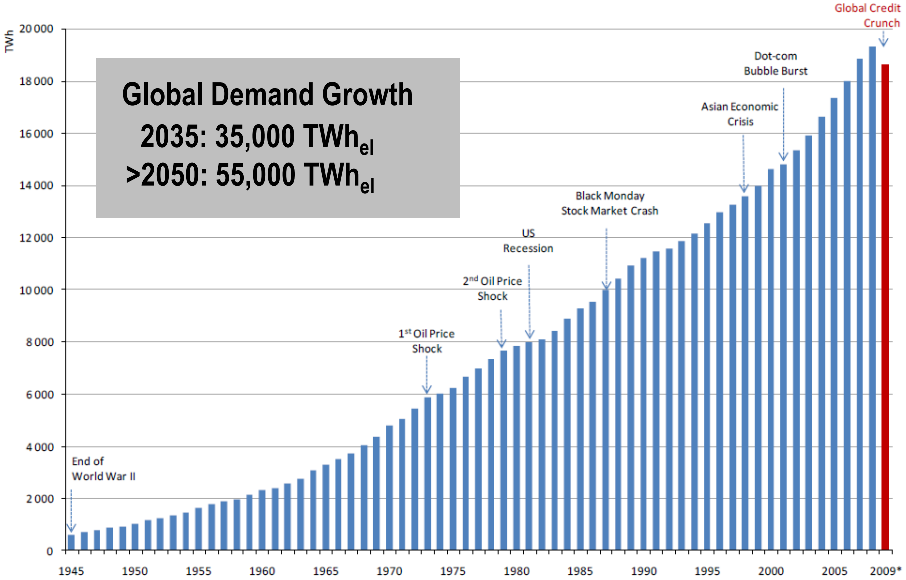
Agenda

- Motivation
- Status and Dynamics of solar PV Diffusion
- High shares of RE in the System (case of IE)
- Some insights for the RE transition (case of DE)
- What else is on the Horizon?
- Summary

Motivation

- Ecologic balance on planet earth in crash mode
- Climate Change might destroy our modern global civilization
- Global energy demand will triple in coming decades – at least





„Climate Change presents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen.“ Lord Nicholas Stern (fromer Chief Economist World Bank), 2006

sources: Wackernagel, 2010; Stern N., 2006; IEA, 2009

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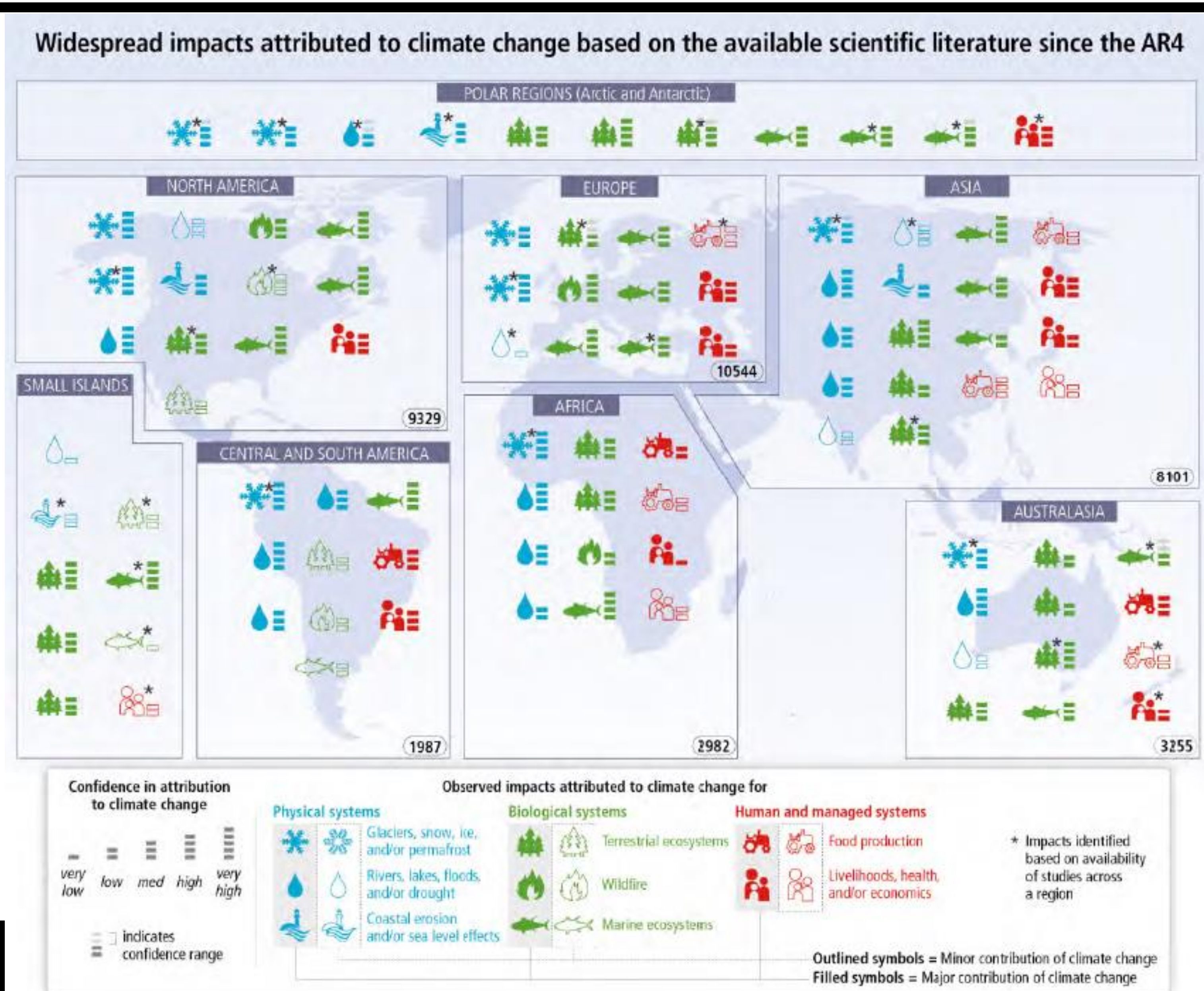
Impact of Climate Change worldwide



source:
IPCC, 2014. 5th AR – Synthesis Report

IPCC mitigation in energy sectors

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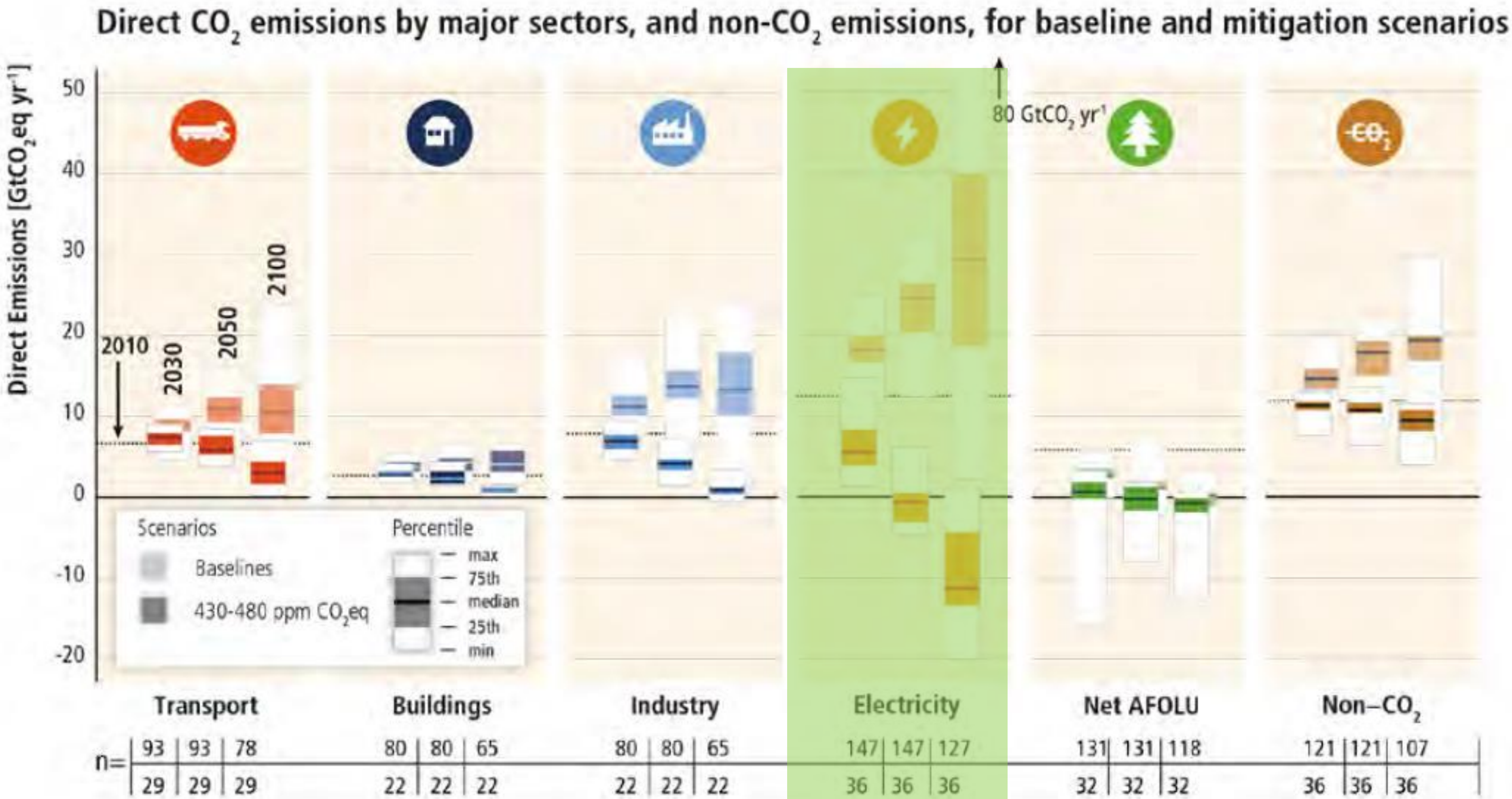
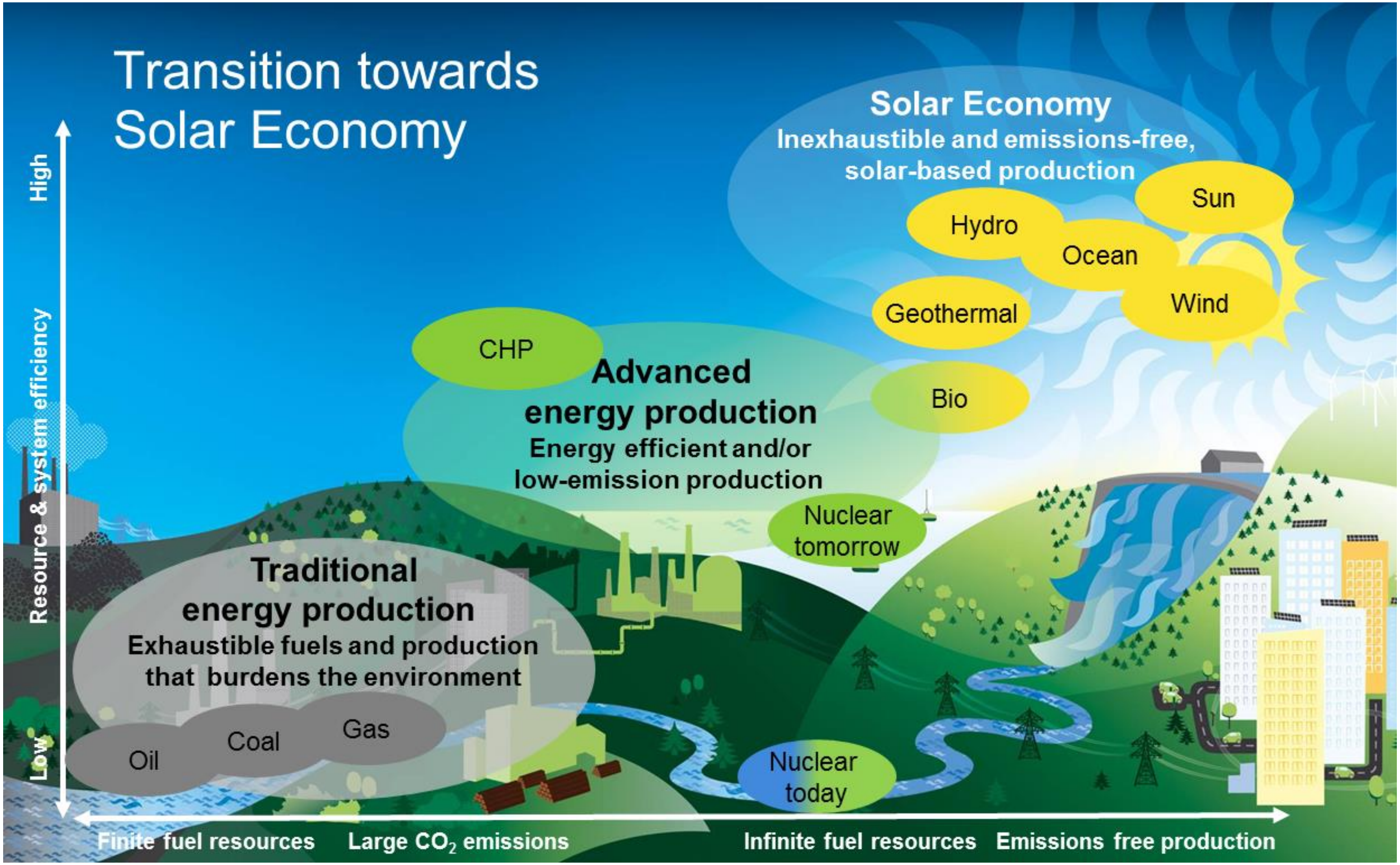


source:
IPCC, 2014. 5th AR – Synthesis Report

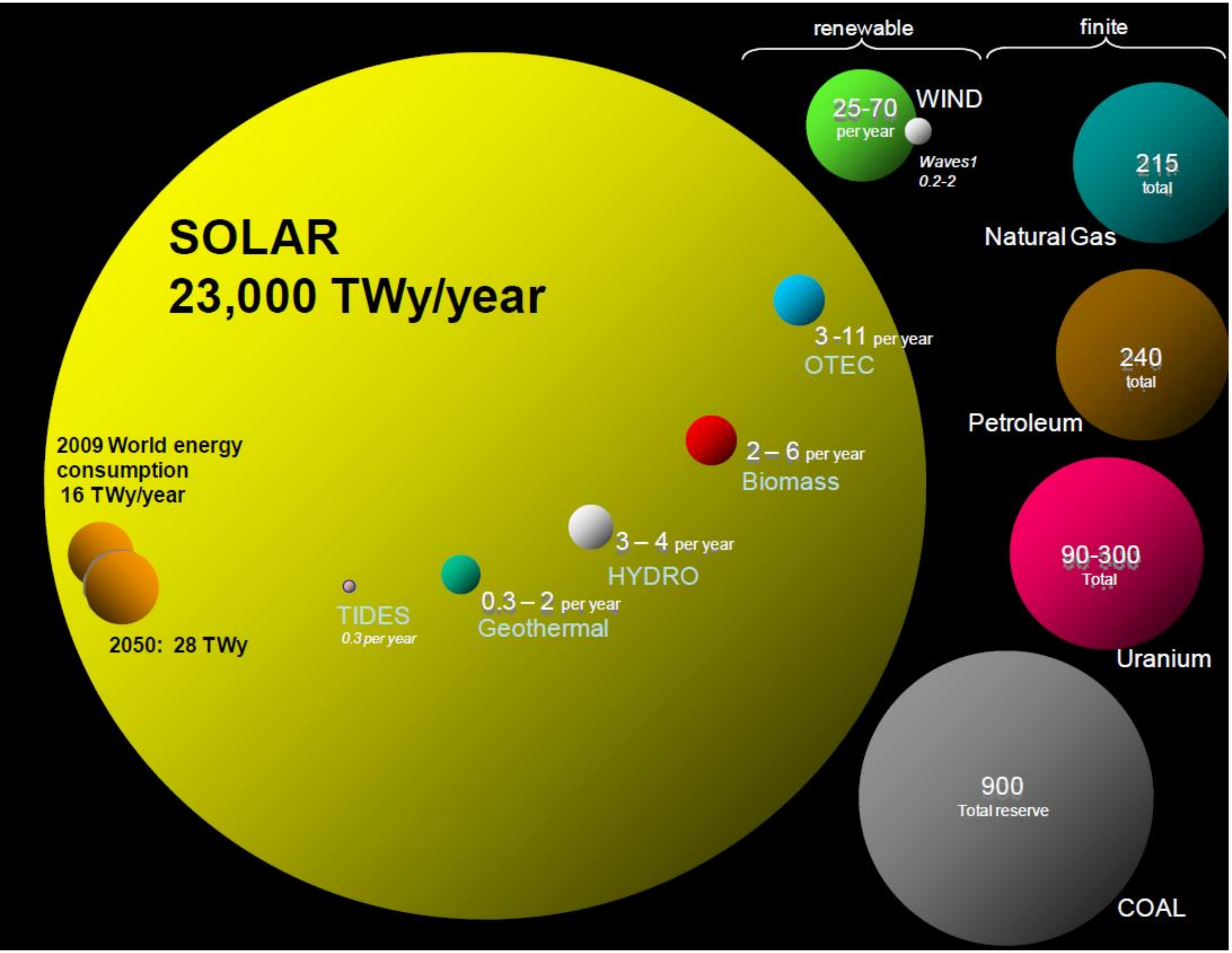
Key insights:
- **GHG emissions in the power sector to be zero by 2050**
- **ALL new investments MUST fulfill this requirement**

Solar Economy (as defined by Fortum)



source: Brunila A., 2012. Fortum – Power and heat company in the Nordic countries, Russia, Poland and the Baltics

Resources and Energy Demand



Key insights:

- no lack of energy resouces
- limited conventional resources
- solar and wind resources need to be the major pillars of a sustainable energy supply

Remark:

- conventional resources might be lower than depicted by Perez

source: Perez R. and Perez M., 2009. A fundamental look on energy reserves for the planet. The IEA SHC Solar Update, Volume 50

Key steps for reaching Sustainable Energy supply

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1. Public actions for investments in sustainable RE investments (mainly PV and wind energy)
2. Bio-energy production to be favoured – BUT ONLY if sustainability criteria are fulfilled
3. Offshore wind energy is important but not top priority
4. Decentralised RE deployment including strong involvement of citizens to be preferred
5. RE electricity will gain also high contribution in the heat and mobility sector
6. Do not forget low cost energy efficiency measures and improvement in the building sector
7. Grid enforcement wherever necessary
8. Storage investments have to be taken into account
9. No new coal fired power plants
10. No new nuclear power plants
11. Internalization of external costs for reducing the high level of subsidies
12. RE industrial policy need to be redefined in Europe

Sustainable Energy system is feasible: technical, economical, ecological
but also political?

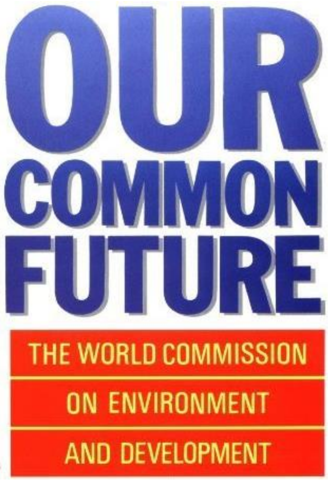
source: Breyer Ch., 2014. 100% RE supply in Europe, European Energy Security Forum, Brussels, September 26, invited for the topic

Criteria for Sustainable Energy Scenarios

Definition of Sustainability:

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

World Commission on Environment and Development, 1987



Major criteria for sustainable energy scenarios

- Energy resource base
- Climate change impact
- Societal cost
- Coverage of energy sectors
- Energy access for all

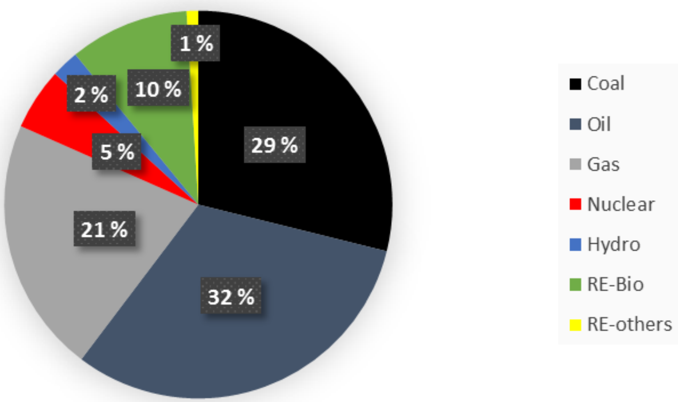
Current Global Energy Supply in 2011

source:
IEA, WEO 2013

Total	[TWhth]	161 023
- Power	[TWhth]	61 359
- Industry	[TWhth]	21 574
- Transport	[TWhth]	28 930
- Buildings	[TWhth]	23 385
- others	[TWhth]	17 989

	Sustainability
Energy resource base	
Climate change impact	
Societal cost	
Energy access for all	
Coverage of energy sectors	

TPED, 2011

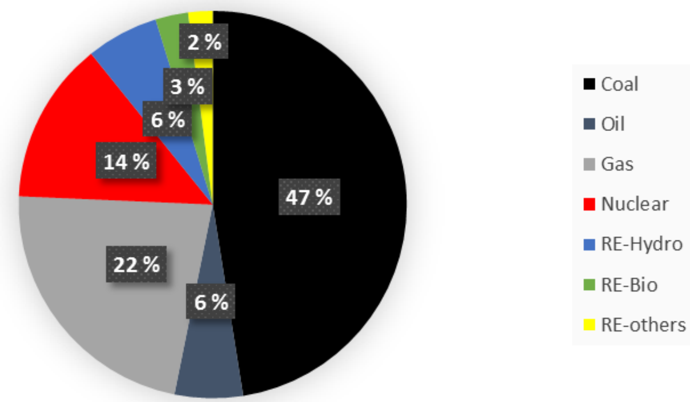


Efficiency of current power plant fleet

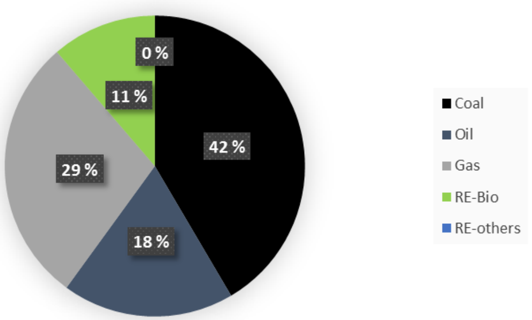
all, including RE
61360 TWh_{th} - Input
22110 TWh_{el} - Output
36% efficiency

Coal, oil, gas, nuclear
32% efficiency

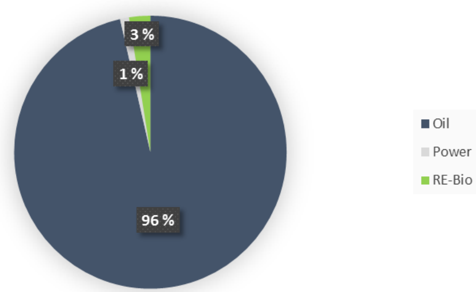
Power, 2011



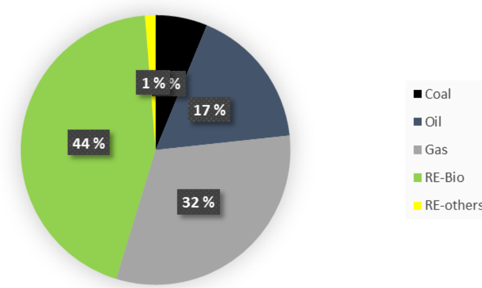
Industry, 2011



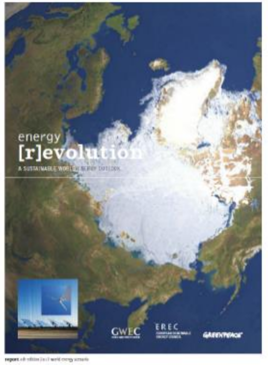
Transport, 2011



Building, 2011



Greenpeace energy [r]evolution, 2100

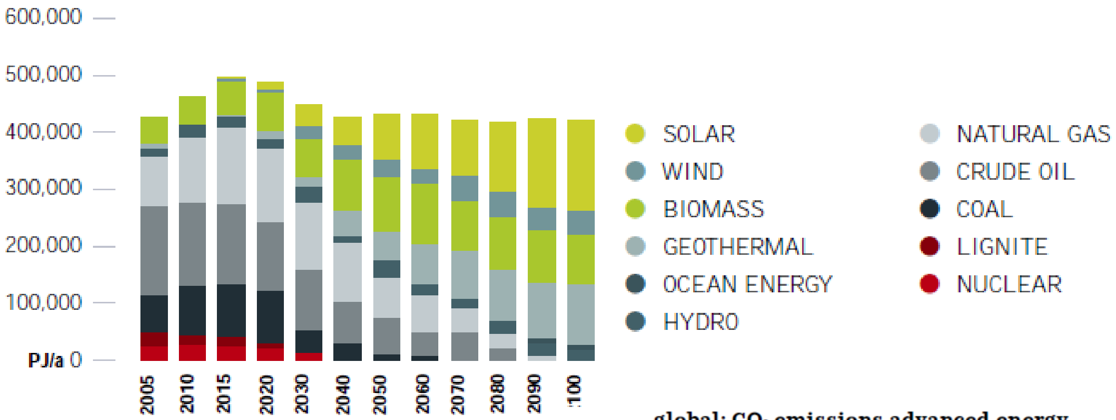


Maybe, the transition should be faster!

	Sustainability
Energy resource base	
Climate change impact	
Societal cost	
Energy access for all	
Coverage of energy sectors	

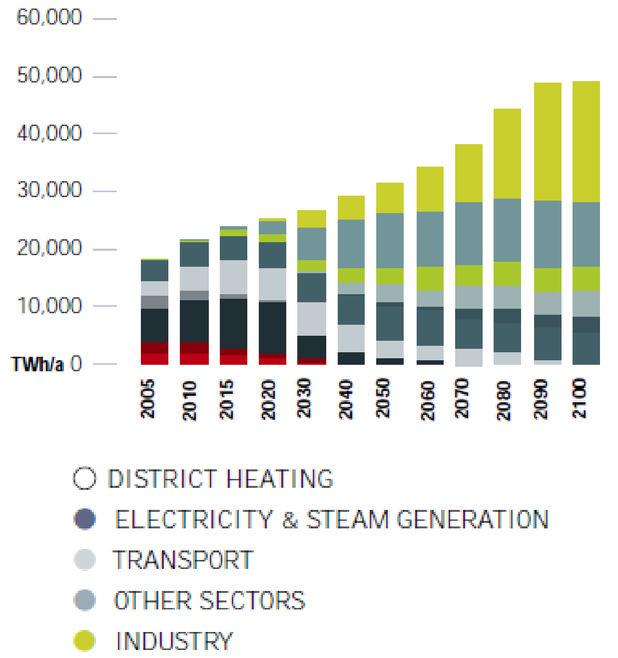
global: primary energy demand in the advanced energy [r]evolution scenario until 2100

COAL POWER PLANTS PHASED OUT BY 2050



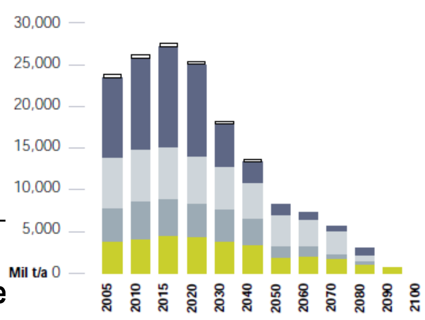
global: electricity generation advanced energy [r]evolution scenario until 2100

COAL POWER PLANTS PHASED OUT BY 2050 (20 YEARS LIFETIME)



global: CO_2 emissions advanced energy [r]evolution scenario until 2100

80% GLOBAL CO_2 REDUCTION BY 2075



Overview, Global Energy Scenarios

	Current Status	IEA	Exxon	Greenpeace	WWF	Shell	IEA-PVPS	Greenpeace
	today	2035	2040	2050	2050	2060	2100	2100
Energy resource base								
Climate change impact								
Societal cost								
Energy access for all								
Coverage of energy sectors								

Key insights and general remarks:

- climate change as a major challenge accepted by all energy scenarios (lacking behind: Exxon)
- increasing share of RE is accepted by all scenarios (lacking behind: Exxon)
- assumptions on future energy demand and energy efficiency efforts differ widely
- NO scenario discusses impact of peak-oil, -gas, -coal and -uranium and respective price impacts
- dominance of power sector in future only understood by WWF and Greenpeace
- cost advantage of solar PV vs CSP reflected only by IEA-PVPS
- role of storage and long distance grids reflected by NO scenario
- power-to-gas technology as storage and bridging technology reflected by NO scenario
- coupling of energy sectors reflected by WWF, Greenpeace, IEA-PVPS but no cost transparency

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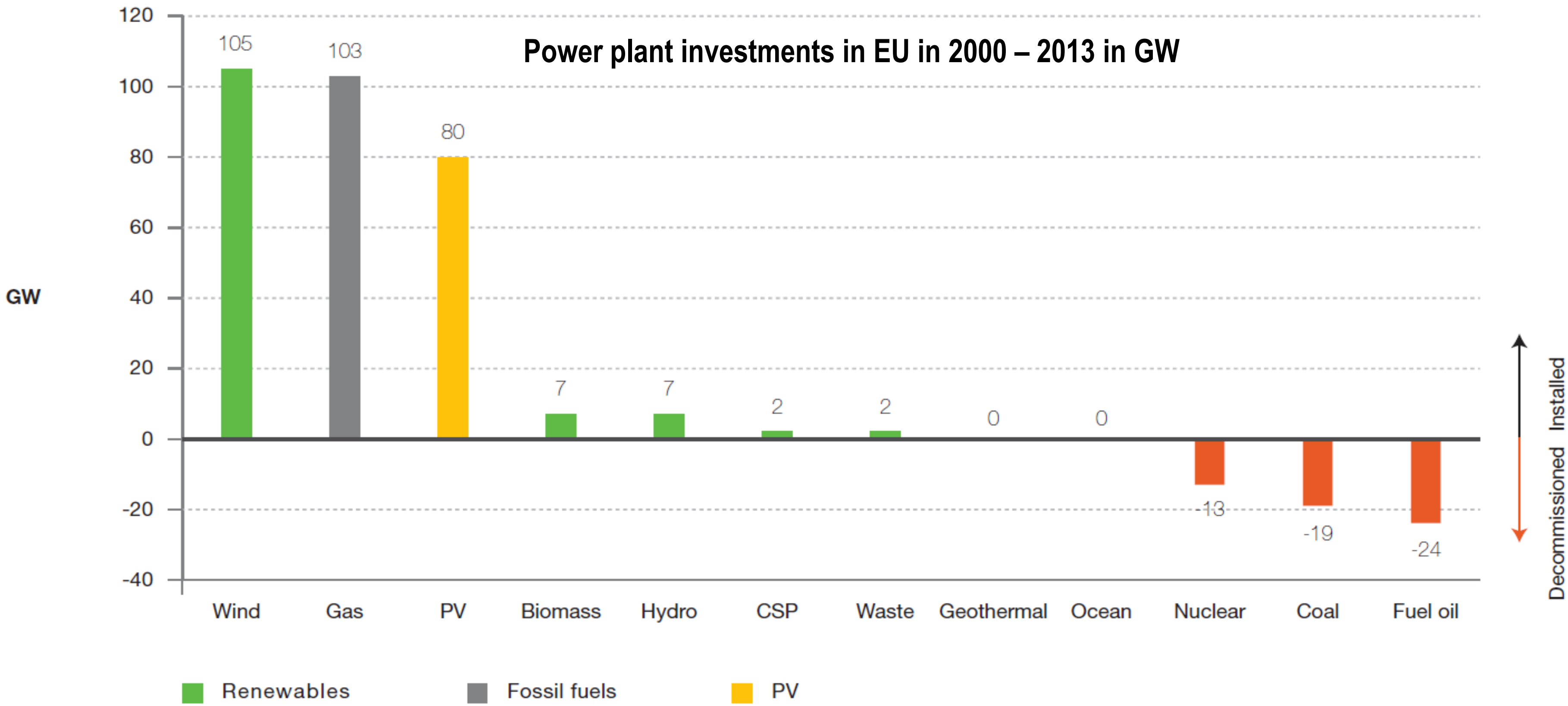
Power plant investments in EU (2000 – 2013)



- PV and wind power will become the core pillars of a sustainable power supply
- gas fired power plants are the bridging technology towards a 100% RE power supply
- investments in gas infrastructure are NO stranded investments (unlike coal and nuclear)

source: EPIA, 2014

Global installed capacity: solar PV and Wind

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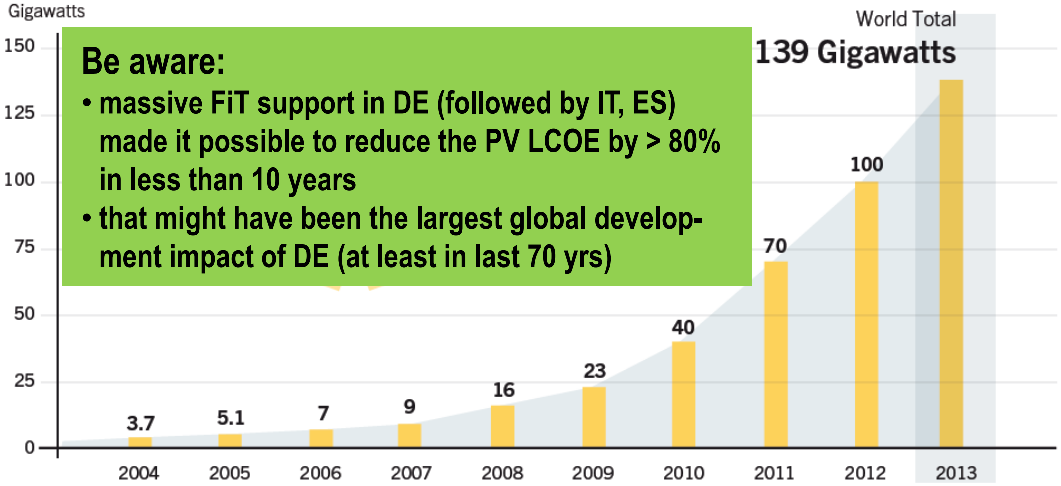
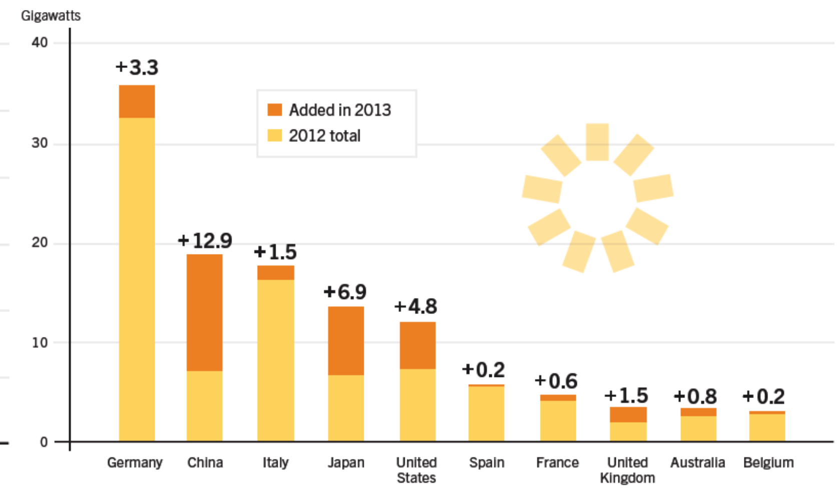
Solar PV Total Global Capacity, 2004–2013

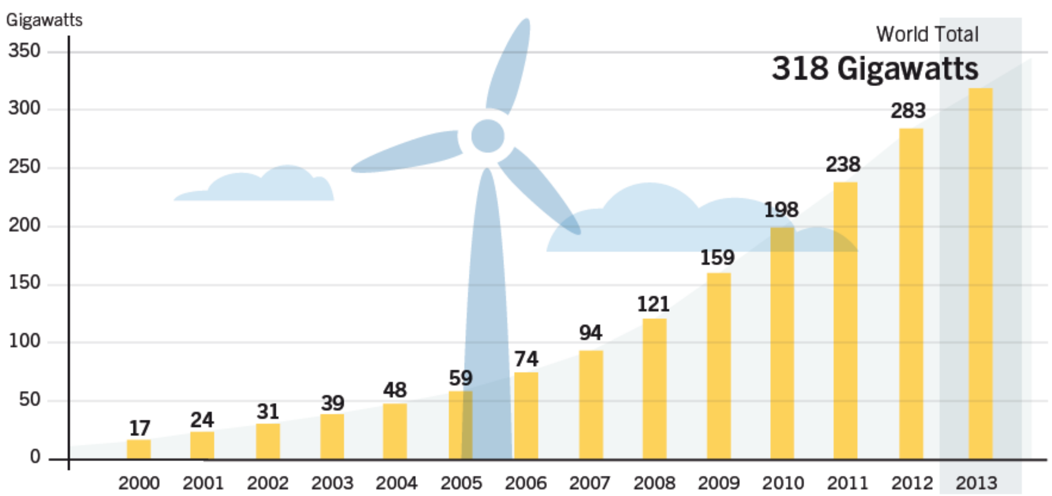
Be aware:
- massive FiT support in DE (followed by IT, ES) made it possible to reduce the PV LCOE by > 80% in less than 10 years
- that might have been the largest global development impact of DE (at least in last 70 yrs)



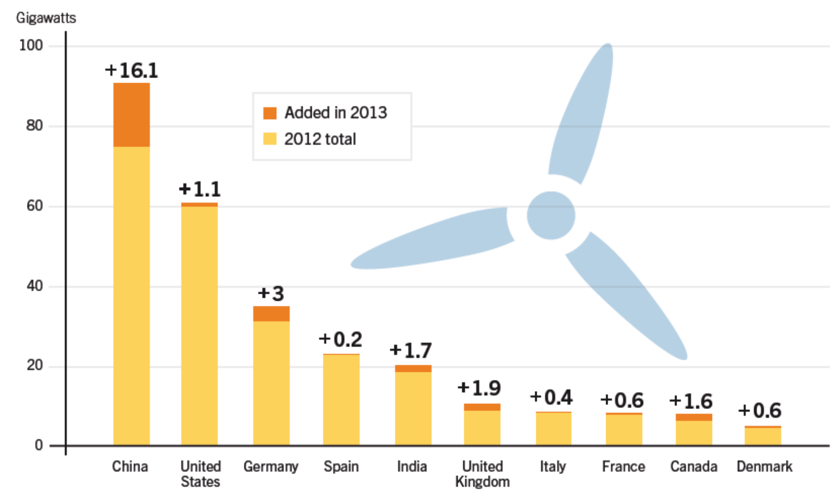
Solar PV Capacity and Additions, Top 10 Countries, 2013



Wind Power Total World Capacity, 2000–2013



Wind Power Capacity and Additions, Top 10 Countries, 2013



source: REN21, 2014. Renewables 2014 – Global Status Report

Global PV Market till 2020

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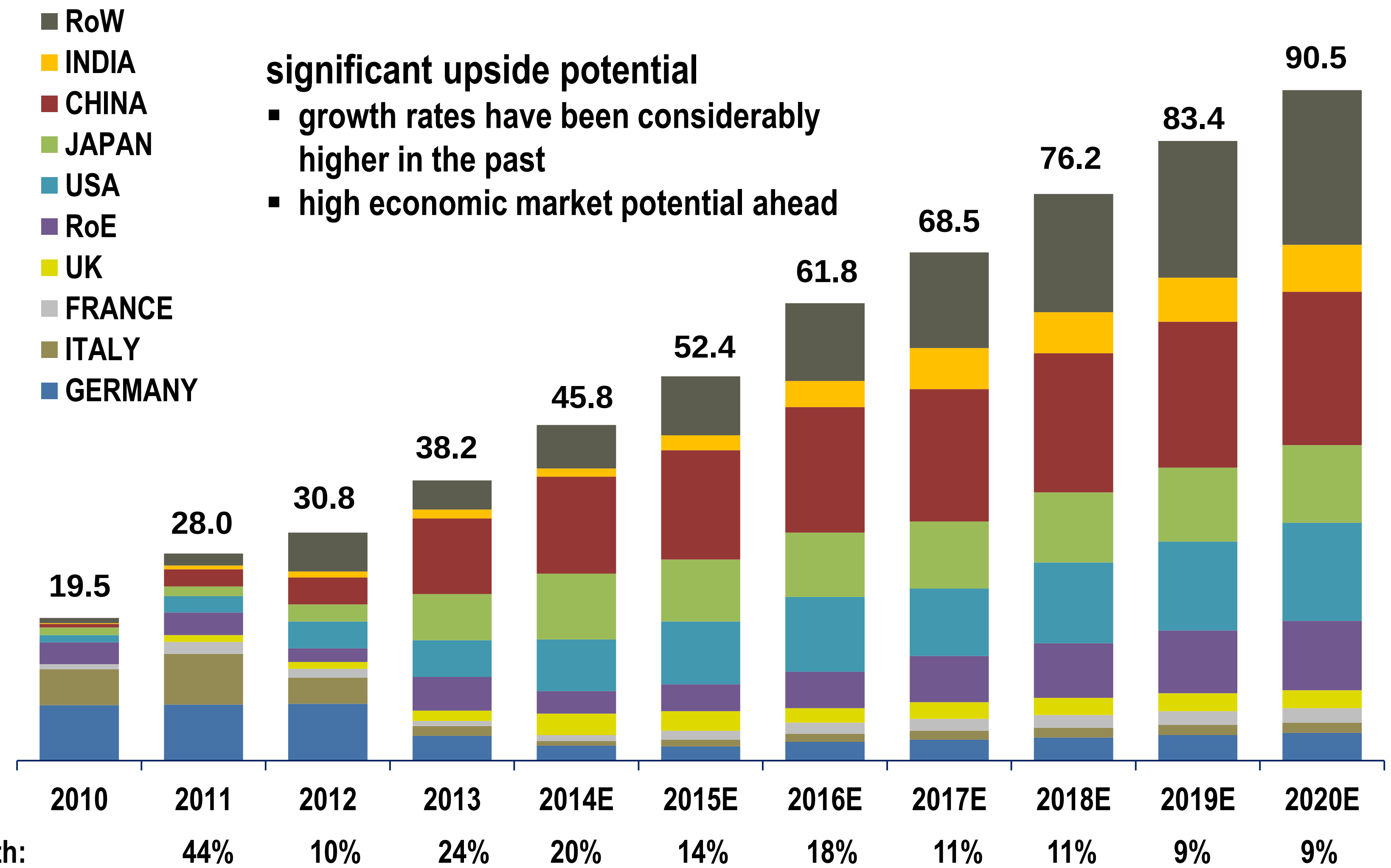
significant upside potential

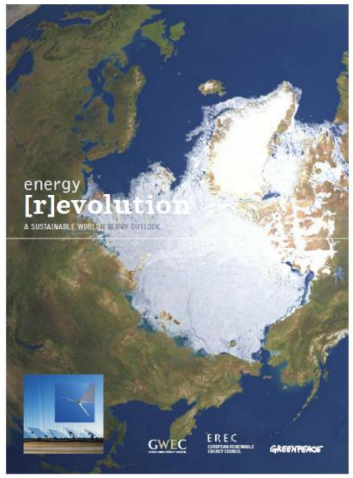
- growth rates have been considerably higher in the past
- high economic market potential ahead

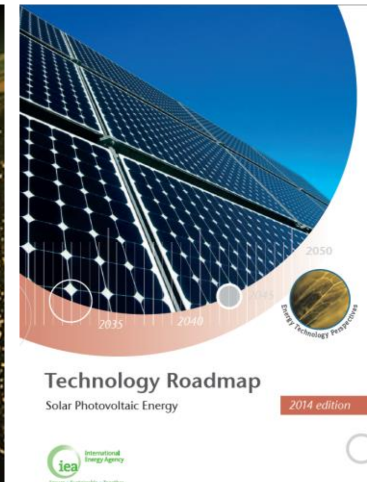


Sources: Hanwha Q CELLS Market Intelligence, IHS, BSW, EuPD, Bank analysts

source: Breyer Ch., Gerlach A., Werner Ch., Breyer Ch., 2014. Impact of Financing Cost on Global Grid-Parity Dynamics till 2030, 29th EU PVSEC, Amsterdam, September 22-26

Global PV Market till 2030

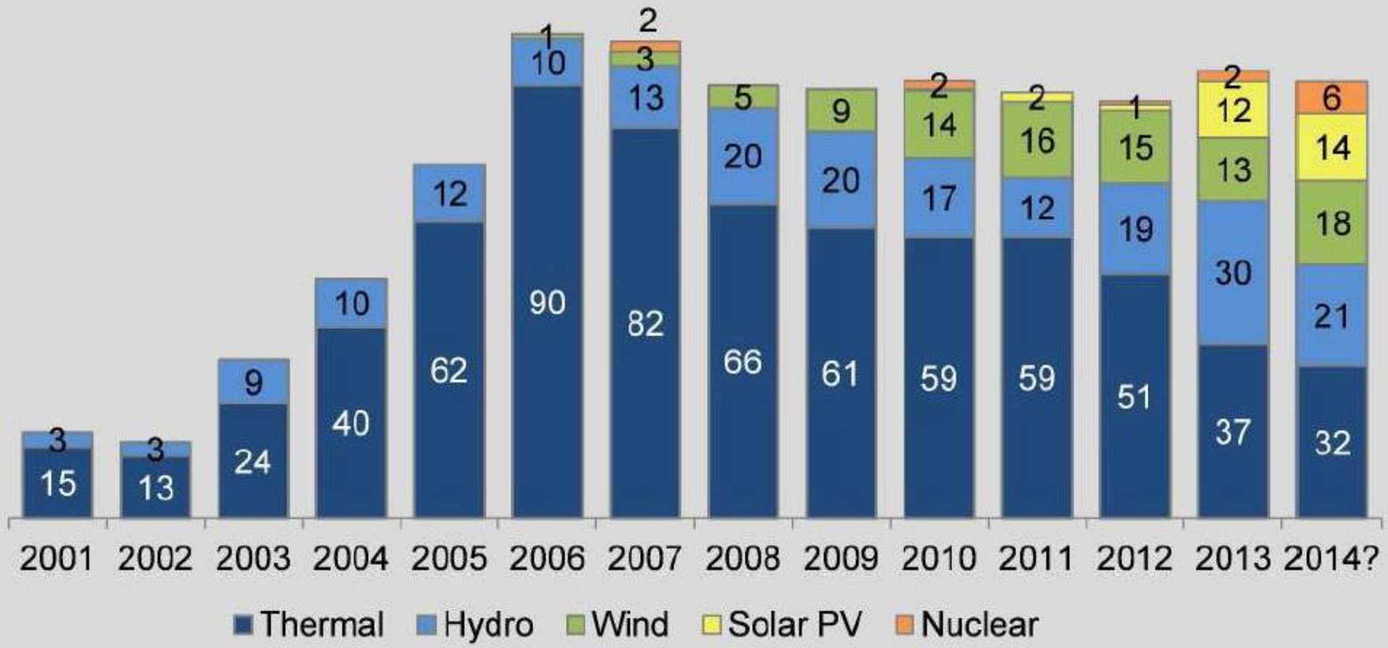




Solar PV	1764 GW	1840 GW	1721 GW
CSP	714 GW	20 GW	261 GW
Wind	2908 GW	1318 GW	960 GW

source: Greenpeace, Bloomberg New Energy Finance, IEA

China's Power Capacity Investments



Note: 2014 is CEC projection. Thermal figures are mostly coal but also include a small amount of gas and biomass-fired power plants; Source: China Electricity Council, Global Wind Energy Council

- we witness a historic turning point, since no 1 power investor structurally changes the investment strategy (reason: reduction of total societal costs of energy generation)
- this will have a dramatic impact on the global investment trends since many countries accept China leading many fields
- it should be no surprise if international climate change policy will be pushed by China (obvious reason: China is the largest manufacturer of the products needed …)

Global Installed PV Capacity: Growth Rates

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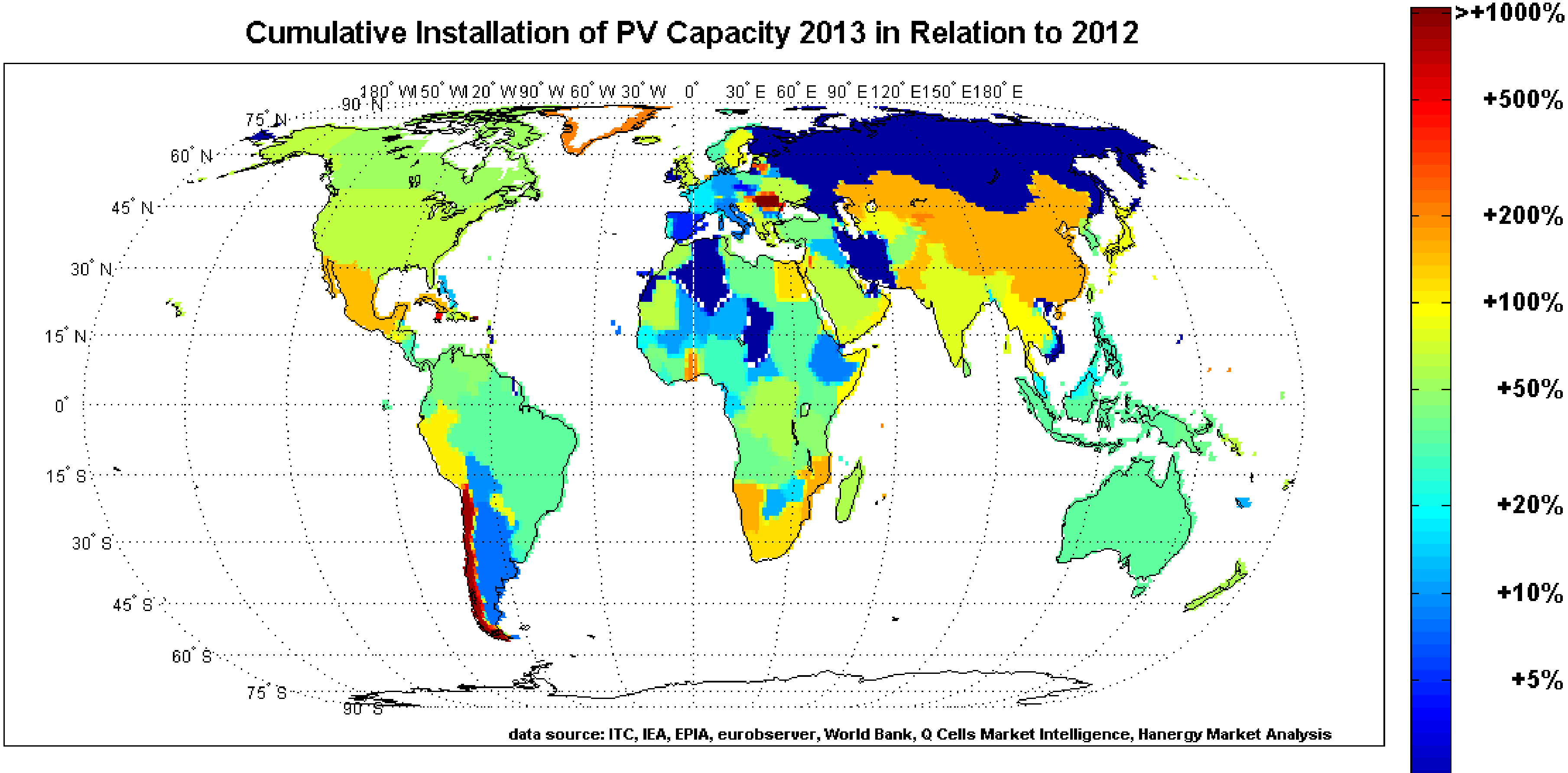
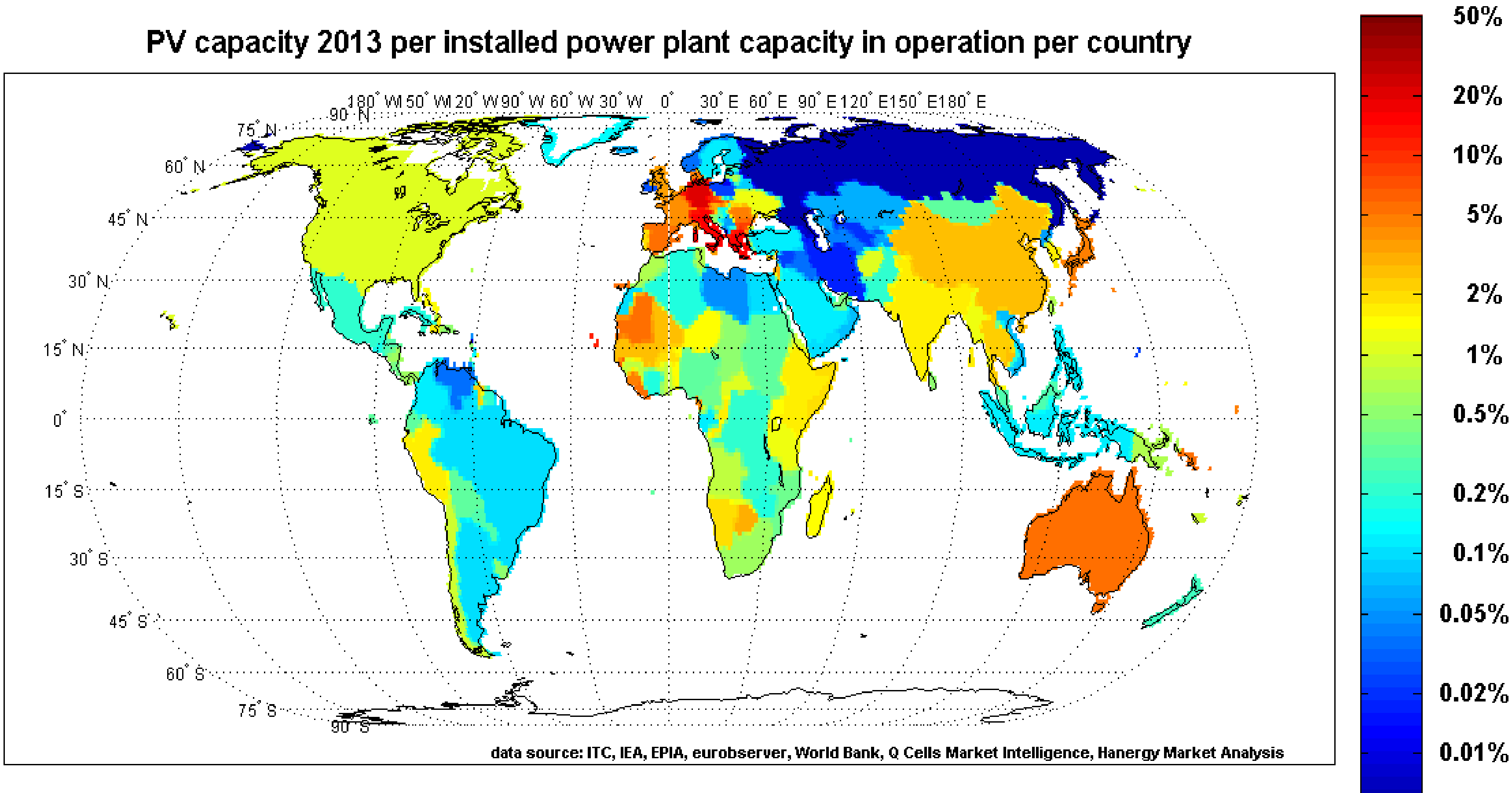


source: Werner C., Gerlach A., Breyer Ch., 2014. Global Installed Photovoltaic Capacity and Identification of Hidden Growth Markets, 29th EU PVSEC, Amsterdam, September 22-26
Gerlach A.-K., Breyer Ch., et al., 2011. PV and Wind Power – Complementary Technologies, ISES Solar World Congress, Kassel

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

Global Installed PV Capacity: Relative



source: Werner C., Gerlach A., Breyer Ch., 2014. Global Installed Photovoltaic Capacity and Identification of Hidden Growth Markets, 29th EU PVSEC, Amsterdam, September 22-26
Gerlach A.-K., Breyer Ch., et al., 2011. PV and Wind Power – Complementary Technologies, ISES Solar World Congress, Kassel

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

Experience Curve: driven by growth and learning

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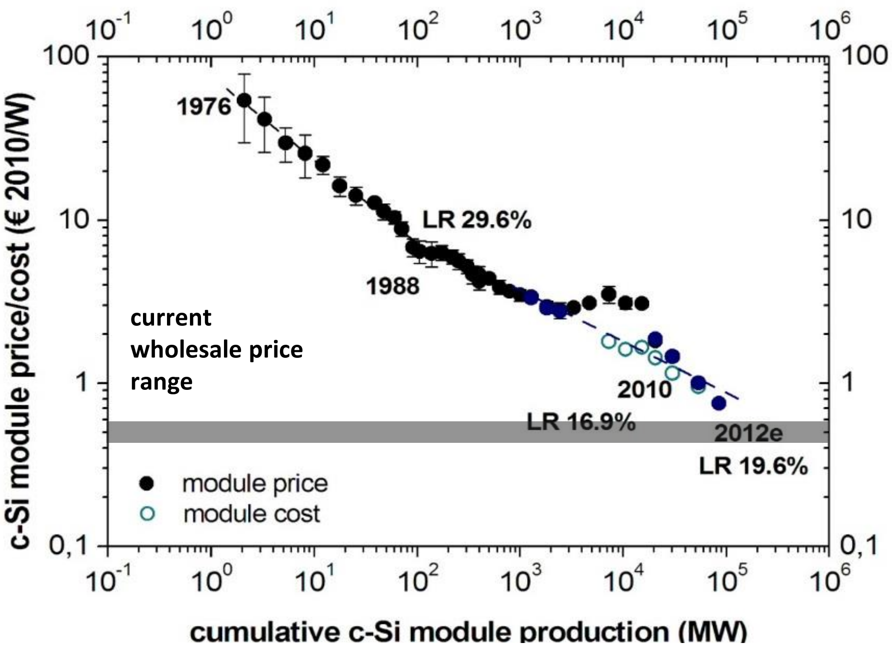
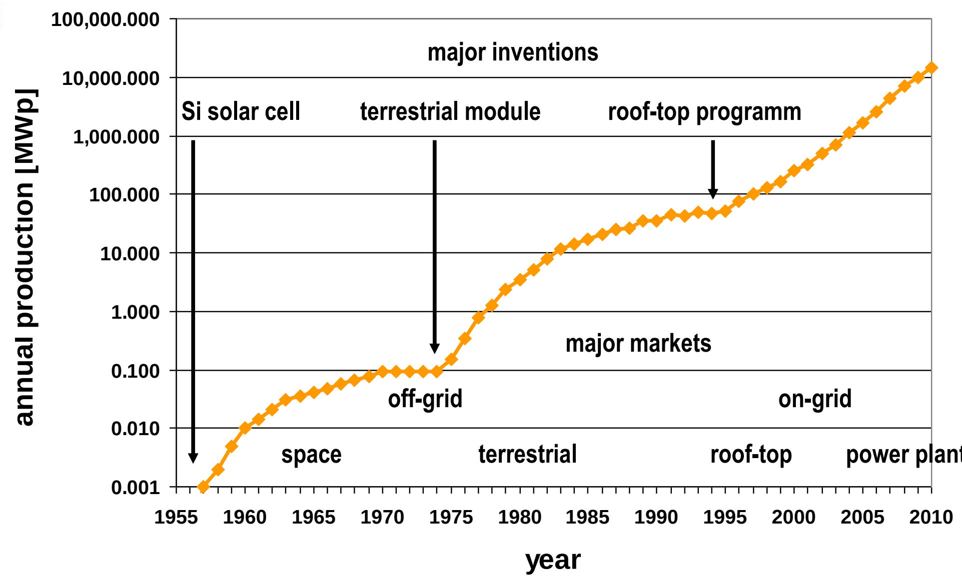
cost reduction by x% per each doubling of cumulated historic capacity (PV modules: ~20%, PV systems: ~16%)





source: Breyer Ch., et al., 2011. Research and Development Investments in PV – A limiting Factor for a fast PV Diffusion?, 25th EU PVSEC/ WCPEC-5, Valencia 2010, September 6–10 ; Breyer Ch., et al., 2013. Global current and historic photovoltaic research and development investments from the public and private sector, Energy Policy, 62, 1570-1580

Solar Resource and current and projected cost

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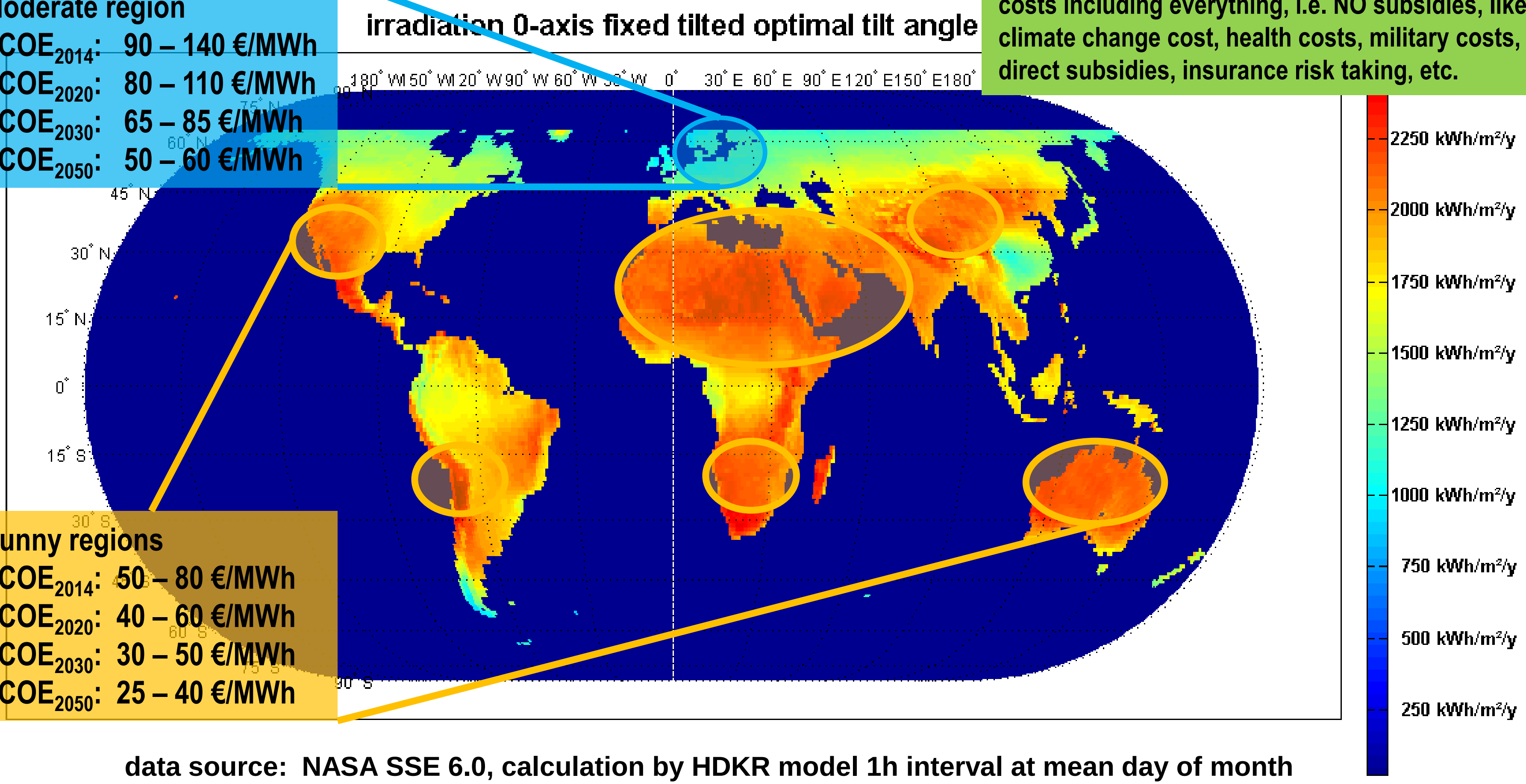
Moderate region
LCOE$_{2014}$: 90 – 140 €/MWh
LCOE$_{2020}$: 80 – 110 €/MWh
LCOE$_{2030}$: 65 – 85 €/MWh
LCOE$_{2050}$: 50 – 60 €/MWh

Be aware:
costs including everything, i.e. NO subsidies, like climate change cost, health costs, military costs, direct subsidies, insurance risk taking, etc.

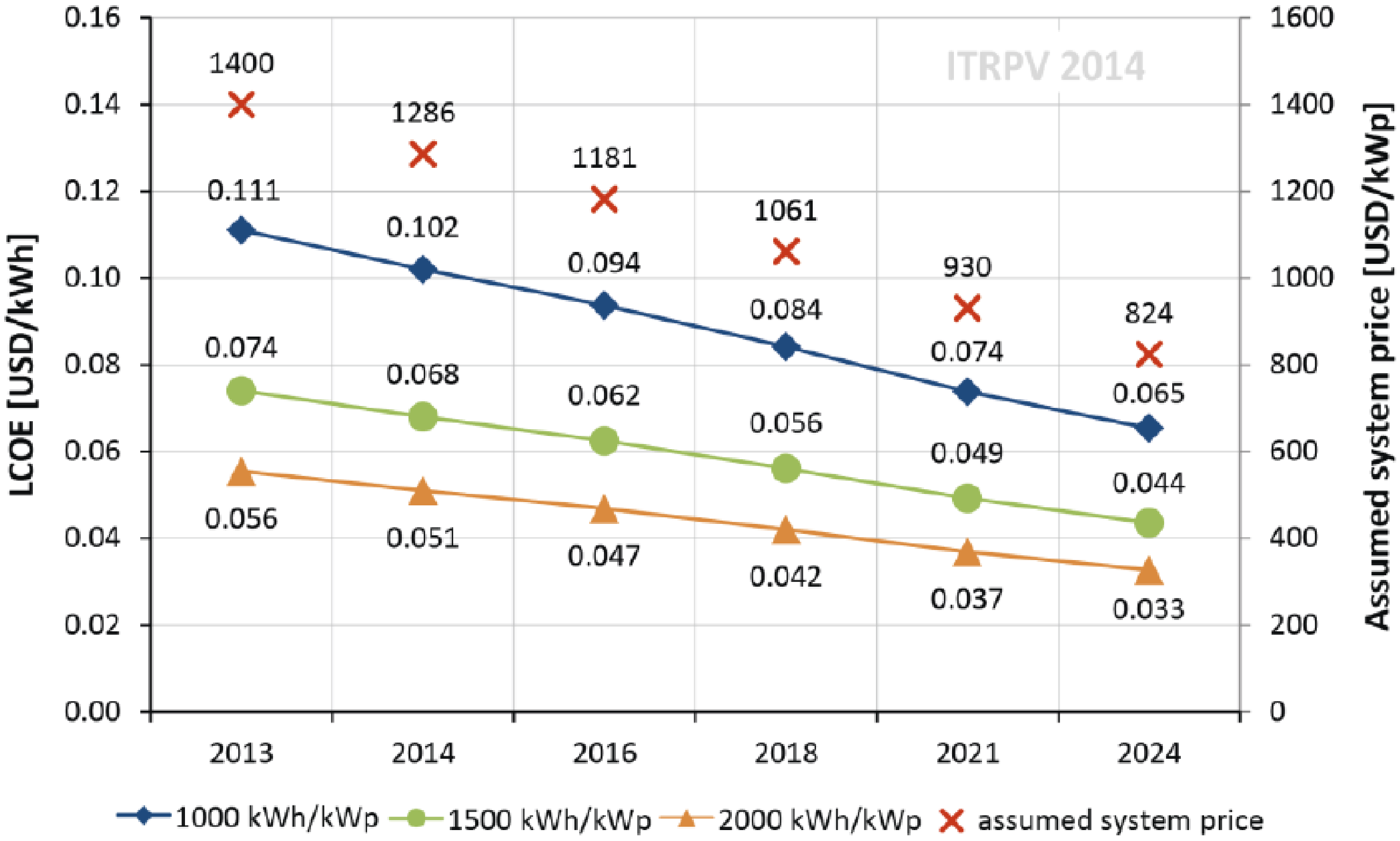


Sunny regions
LCOE$_{2014}$: 50 – 80 €/MWh
LCOE$_{2020}$: 40 – 60 €/MWh
LCOE$_{2030}$: 30 – 50 €/MWh
LCOE$_{2050}$: 25 – 40 €/MWh

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

Solar emerges to least cost energy source



ITRPV 2014: Calculated LCOE values for different insolation conditions. Financial conditions: 80% debt, 5%/a interest rate, 20 years loan tenor, 2%/a inflation rate, 25 years usable system life.

source: ITRPV, 2014. International Technology Roadmap for Photovoltaic – 2013 Results, ITRPV supported by semi

The Main PV Market Segments

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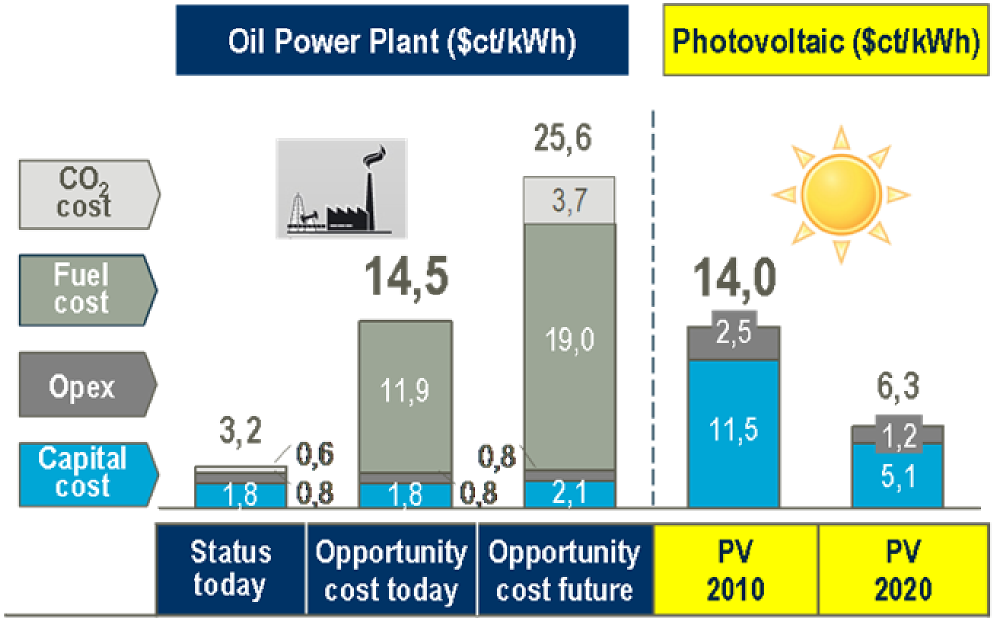
Utility	Commercial / Industrial	Residential	Off-Grid
			
▪ large power plants (> 1 MW) ▪ Utility or electricity wholesale market as customer	▪ Often > 100 kW installations ▪ Professional customers	▪ Small and very small installations (< 10 kW) ▪ Mainly homeowners	▪ Varying system sizes ▪ Varying customer types

PV can be used in all regions in the world, by the poorest to the richest, in decentral and central applications
- highly modular and flexibly adaptable to respective needs -

Do not forget Fuel-Parity



* 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

Breyer Ch. and Reiß A., 2014. Hybrid PV Power Plants: Least Cost Power Options for the MENA Region, 29th EU PVSEC, Amsterdam, September 22-26

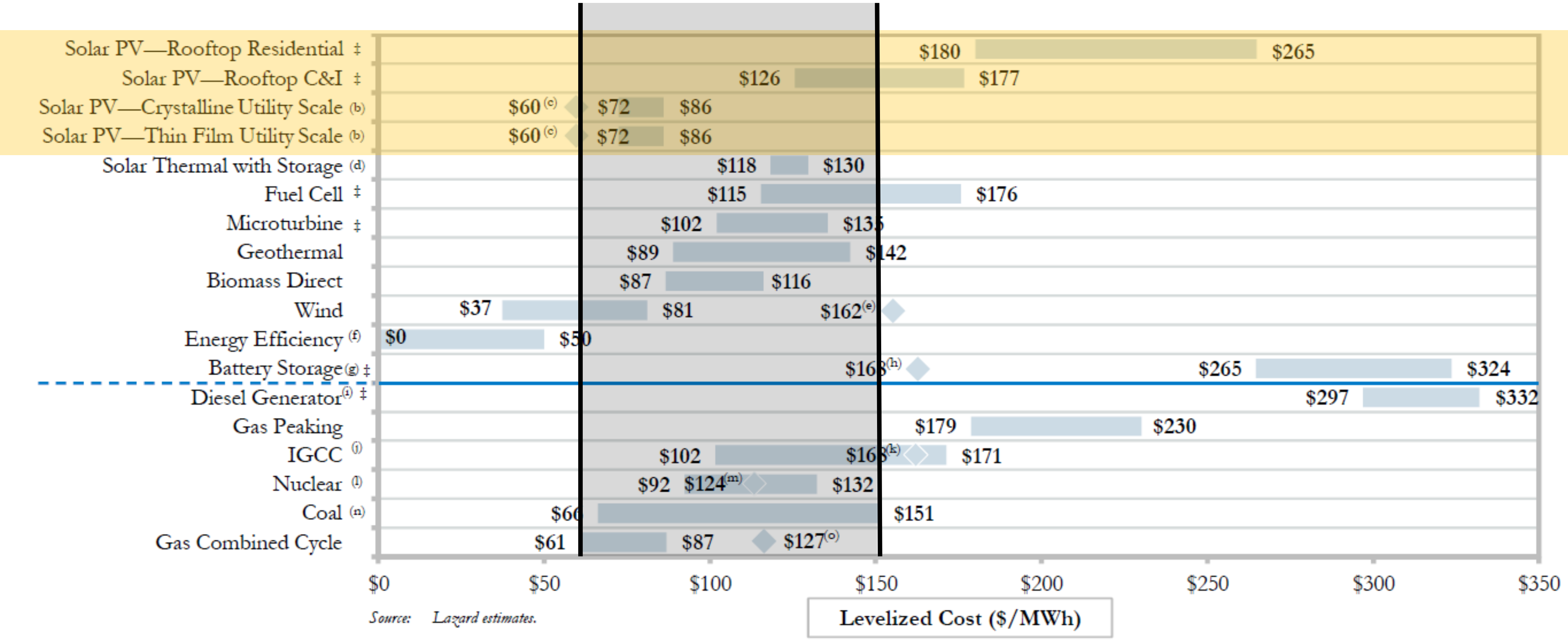
Macroeconomic implications for MENA

- MENA among first fuel-parity markets in the world
- 1 GW PV saves 2.0 - 2.5m bbl oil per year
- Investment in PV results in 20% IRR for MENA region due to higher oil export revenues

Reality in the year 2014

- Oil LCOE about 19 $ct/kWh
- PV LCOE about 8 $ct/kWh

Cost comparison to other power technologies



- utility PV already competitive to new gas and coal fired power plants
- solar PV lower in cost than gas and coal from about 2015 onwards
- solar PV and wind are the least cost power sources from about 2015 onwards
- STEG significantly higher in cost than solar PV
- new nuclear already higher in cost than solar PV (despite of nuclear subsidies)

Solar PV and End-user Economics

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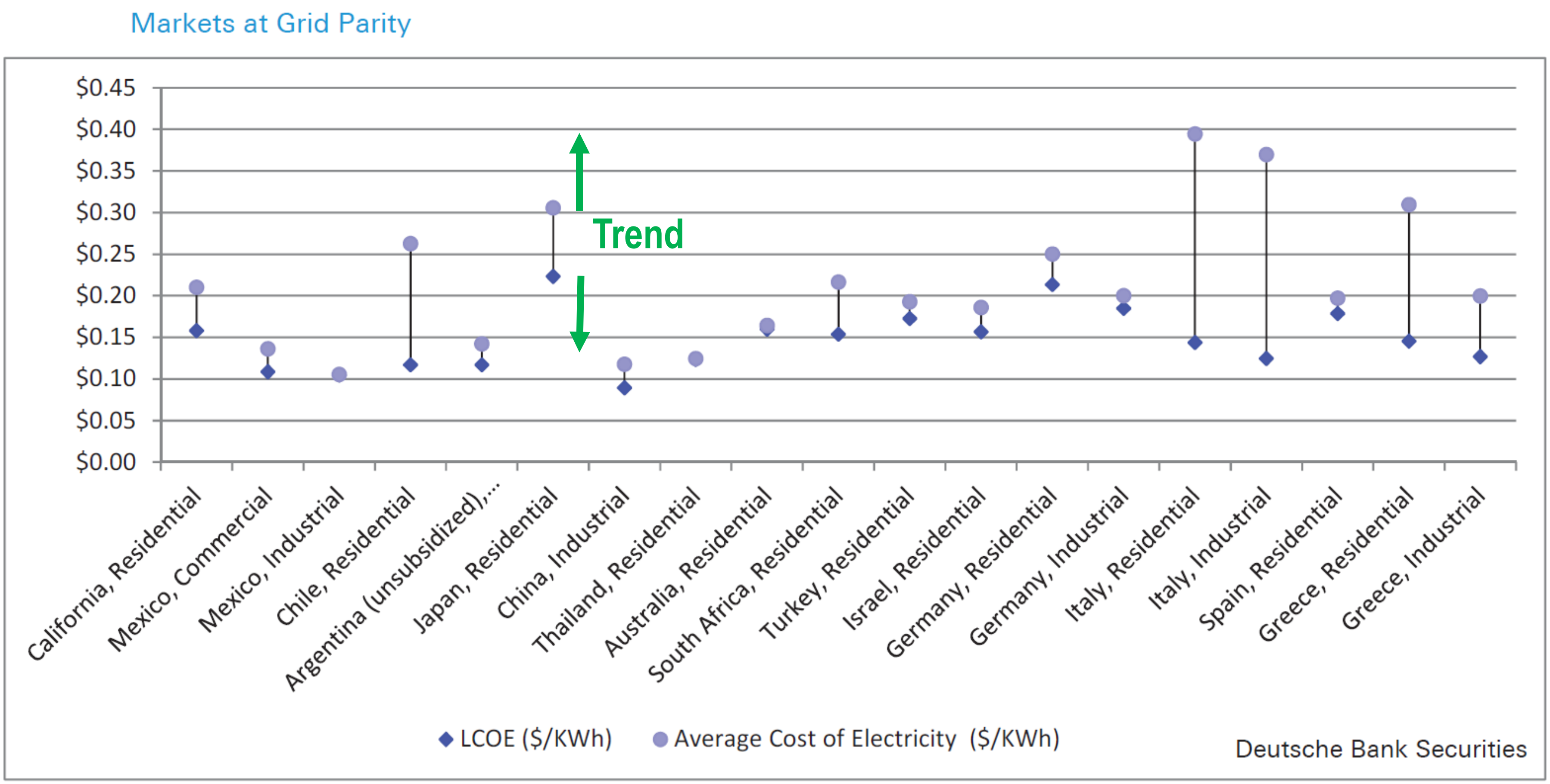

Source: DB, BLS, Ontario Energy Board, Mexican Ministry of Energy, Chile Energy Group, Argentinean Secretary of Energy, NASA, Tepco, Chinese Economic Observer, Beijing International, Indian Central Regulatory Commission, Australia Power and Gas, Saudi Electric Company, Eksom, EuroStat

source: Deutsche Bank Securities, 2014. 2014 Outlook: Let the Second Gold Rush Begin, New York

Impression for (Commercial) End-User Profitability

Retail			
(high taxes and duties) South-facing solar installation			
Energy requirement [MWh/year]	254		
Installation size [kWp]	95		
Solar installation investment costs [EUR]	114,000		
Solar installation investment costs [EUR/kWp]	1,200		
Locations	Hamburg	Bonn	Nuremberg
Self-consumption ratio [%]	83.7	80.5	79.6
Net present value of self-consumption [EUR]	40,429	57,795	76,492
Net present value of self-consumption [EUR/kWp]	426	609	806
Internal rate of return [%]	8.95	10.49	12.09
Payback period [years]	9.0	8.2	7.4
Return on equity	20.01	24.42	28.98

Produzierendes Gewerbe		
(mittlere Belastung durch Abgaben und Steuern) Solaranlage mit Südausrichtung		
Energiebedarf [MWh/a]	7.953	
Anlagengröße [kWp]	190	
Investitionskosten Solar-anlage [€]	208.725	
Investitionskosten Solar-anlage [€/kWp]	1.100	
Standorte	Ankara	Izmir
Eigenverbrauchsrate [%]	99,9	99,9
Nettobarwert Eigenver-brauch [€]	133.418	232.614
Nettobarwert Eigenver-brauch [€/kWp]	703	1.226
Interner Zinsfuß [%]	13,99	18,6
Amortisationsdauer [a]	6,9	5,4
Eigenkapitalrendite	33,29	46,46

source: REC Solar, 2014. Study on the Profitability of Commercial Self-Consumption Solar Installations in Germany; Italy and Turkey (only in German available)

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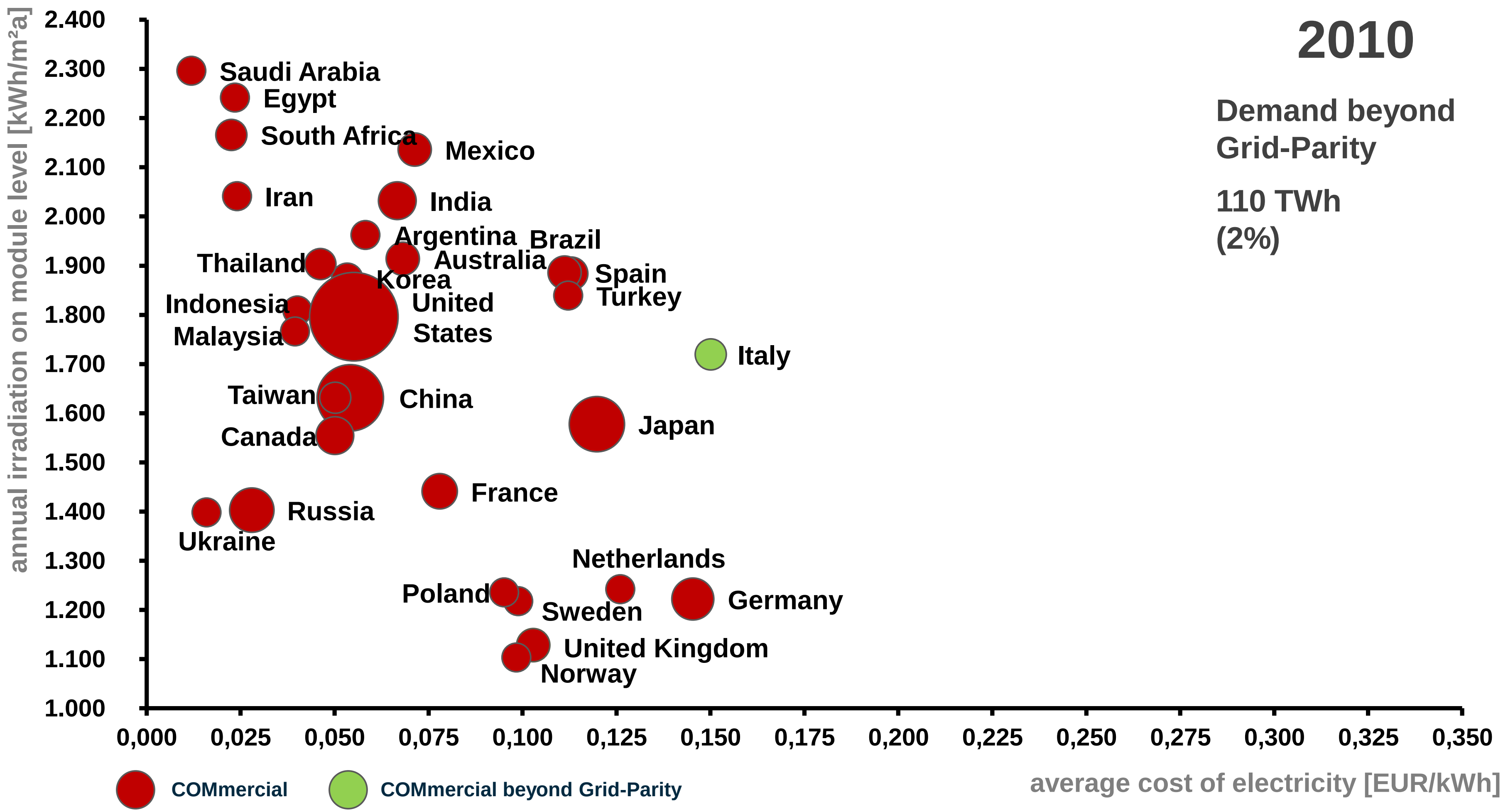
- **both systems on the right are part of a 220 kWp commercial solar PV system**
- **it is financially beneficial for the university**

source: Kosonen A., Ahola J., Breyer Ch., Albó A., 2014. Large Scale Solar Power Plant in Nordic Conditions, 16th EU Conference on Power Electronics and Applications, August 26-28

Commercial – Grid-Parity – top 30 Countries



sources raw data: Hanwha Q CELLS Market Intelligence, Eurostat, EIA, utility feedback

source: Gerlach A., Werner C., Breyer Ch., 2014. Impact of Financing Cost on Global Grid-Parity Dynamics till 2030, 29th EU PVSEC, Amsterdam

Commercial – Grid-Parity – top 30 Countries

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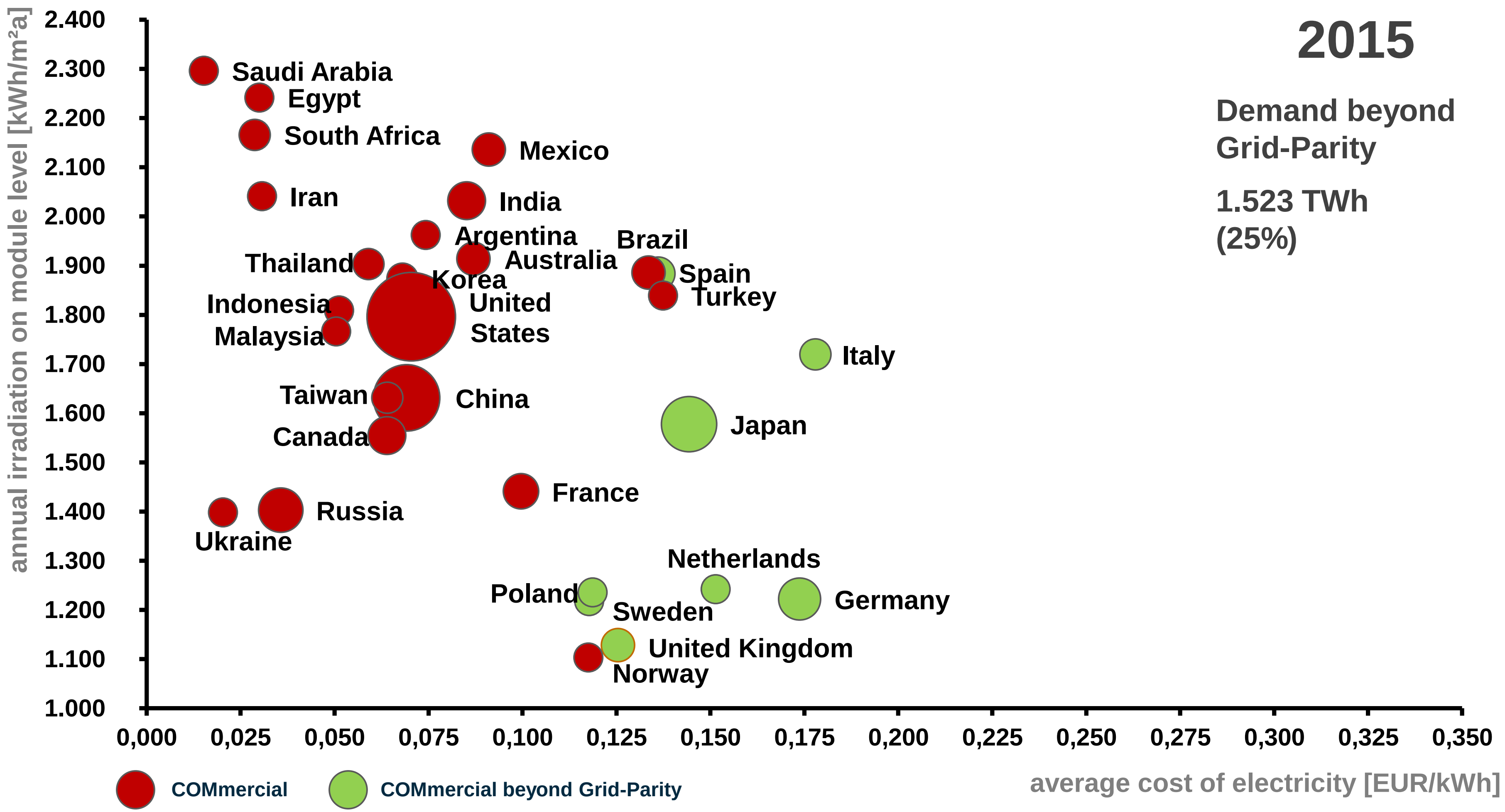

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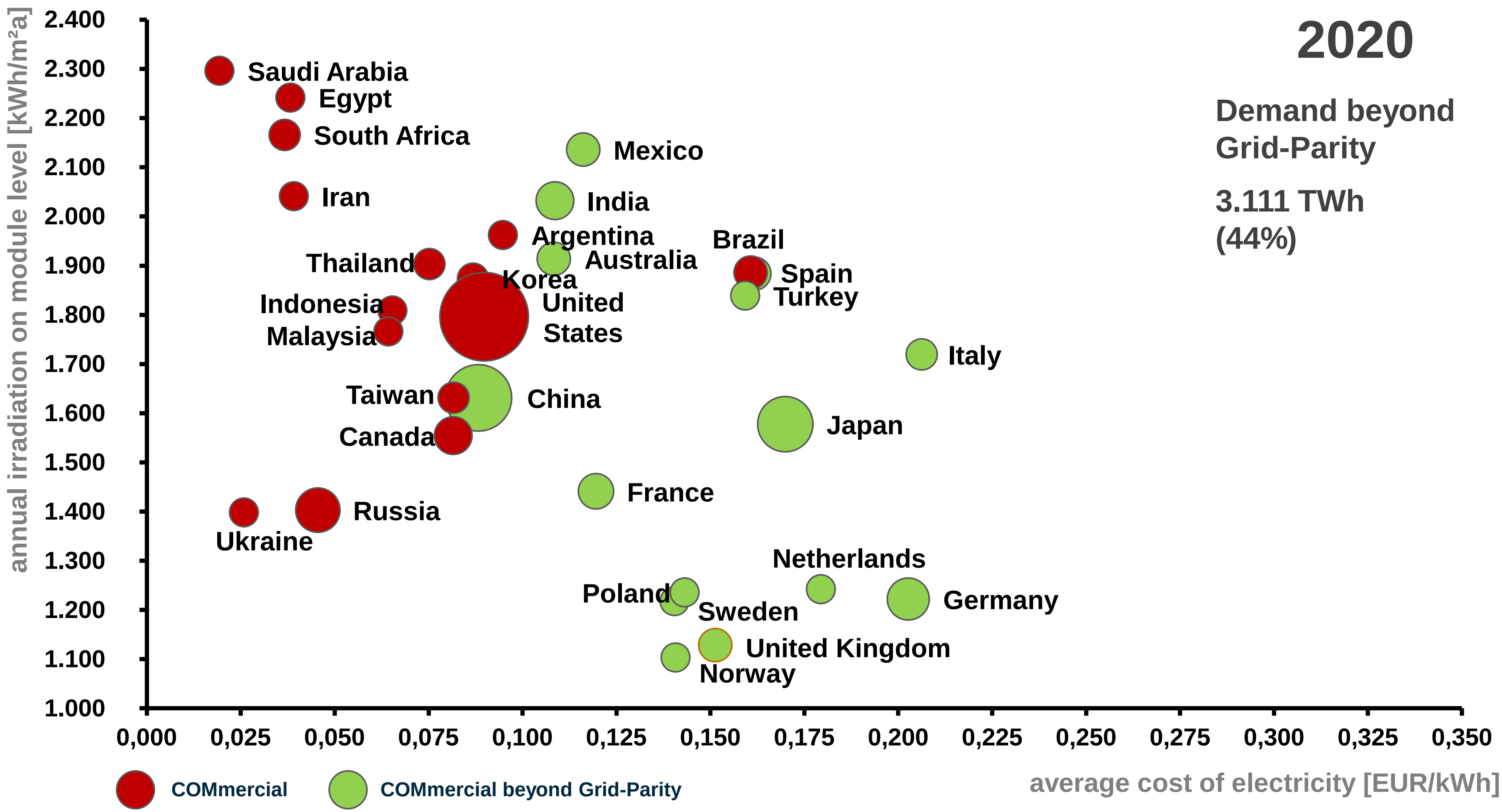

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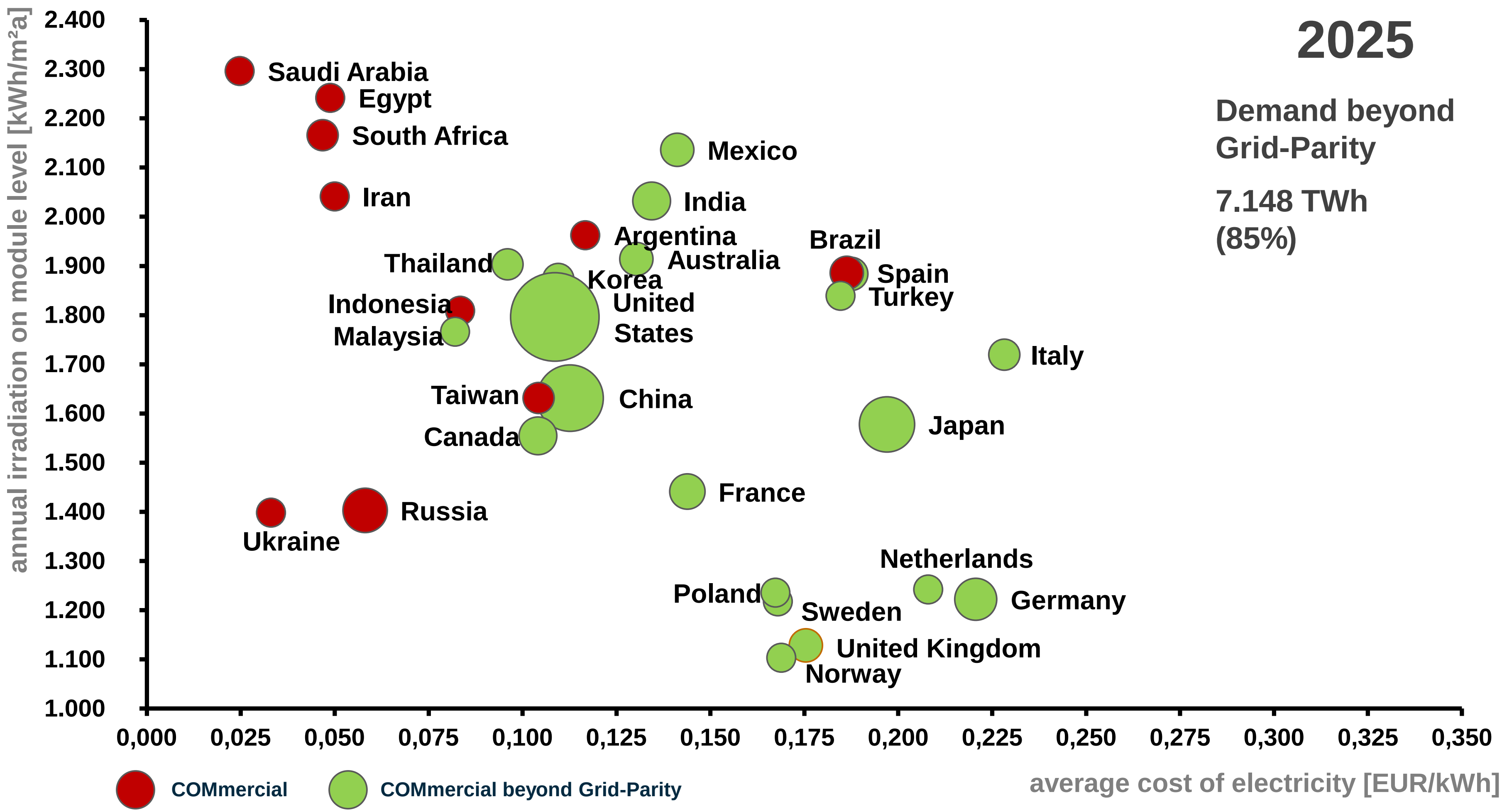
Commercial – Grid-Parity – top 30 Countries



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source: Gerlach A., Werner C., Breyer Ch., 2014. Impact of Financing Cost on Global Grid-Parity Dynamics till 2030, 29th EU PVSEC, Amsterdam

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Commercial – Grid-Parity – top 30 Countries

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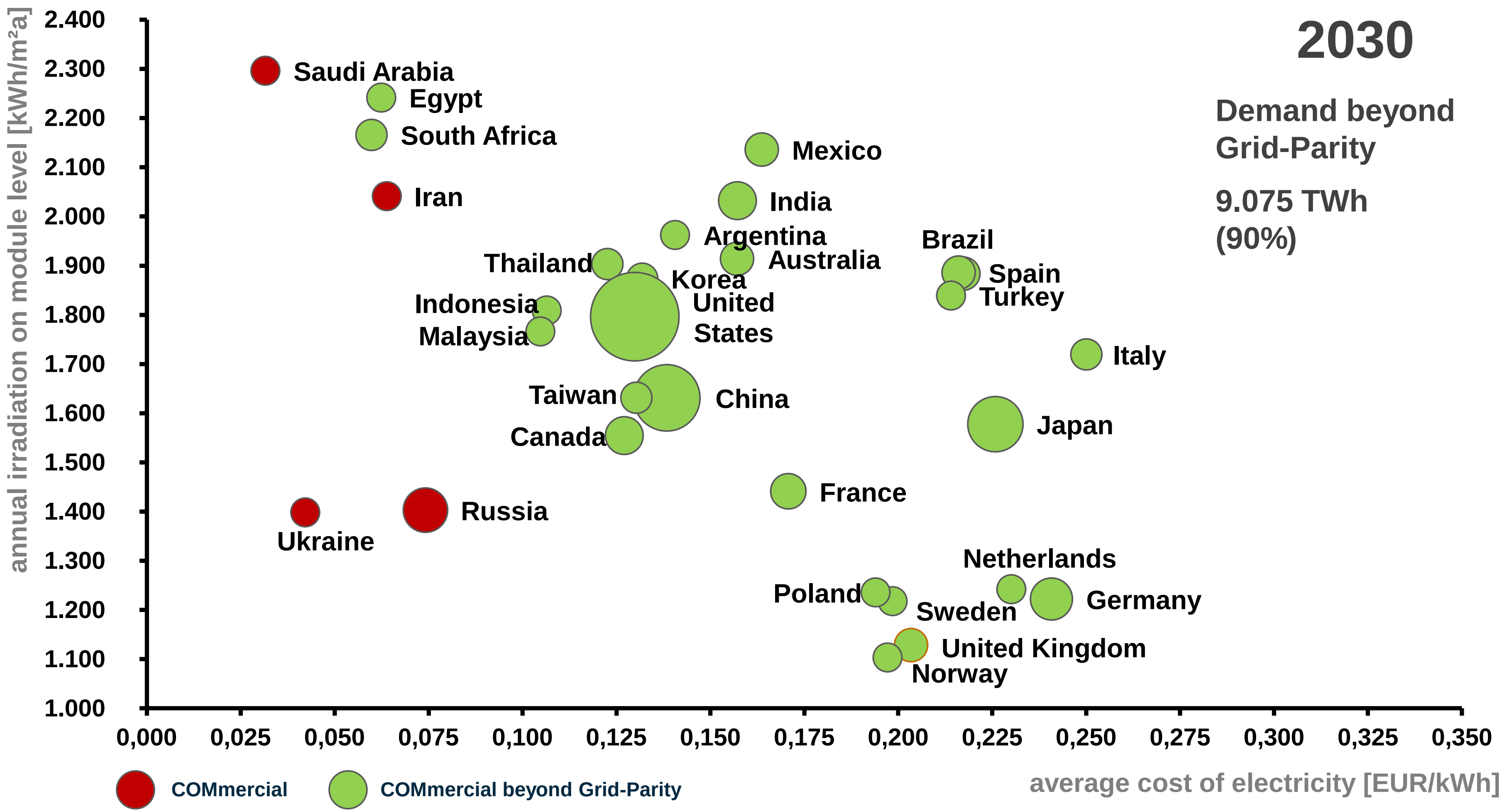

sources raw data: Hanwha Q CELLS Market Intelligence, Eurostat, EIA, utility feedback

source: Gerlach A., Werner C., Breyer Ch., 2014. Impact of Financing Cost on Global Grid-Parity Dynamics till 2030, 29th EU PVSEC, Amsterdam

RES – Grid-Parity – top 30 Countries

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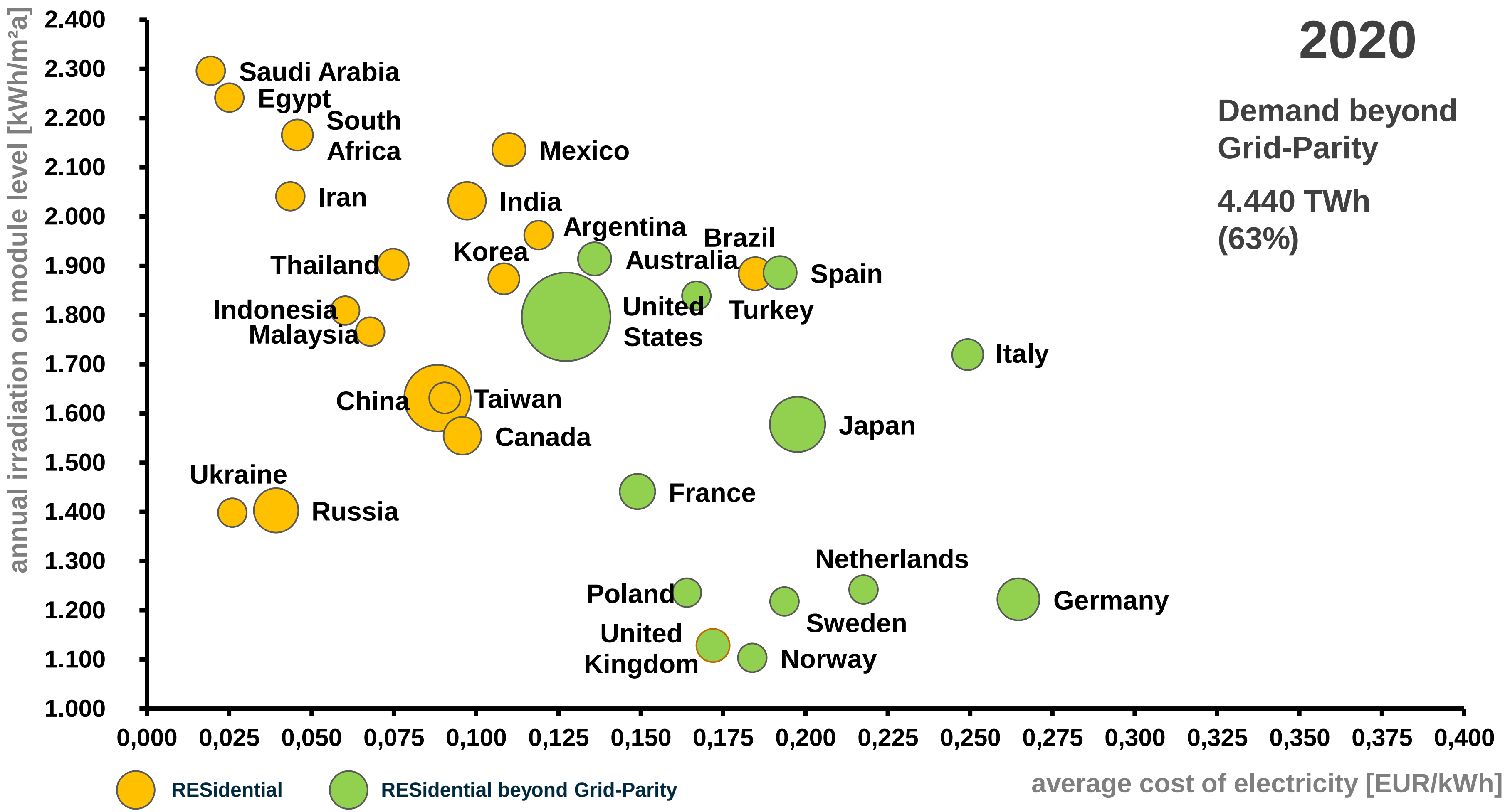
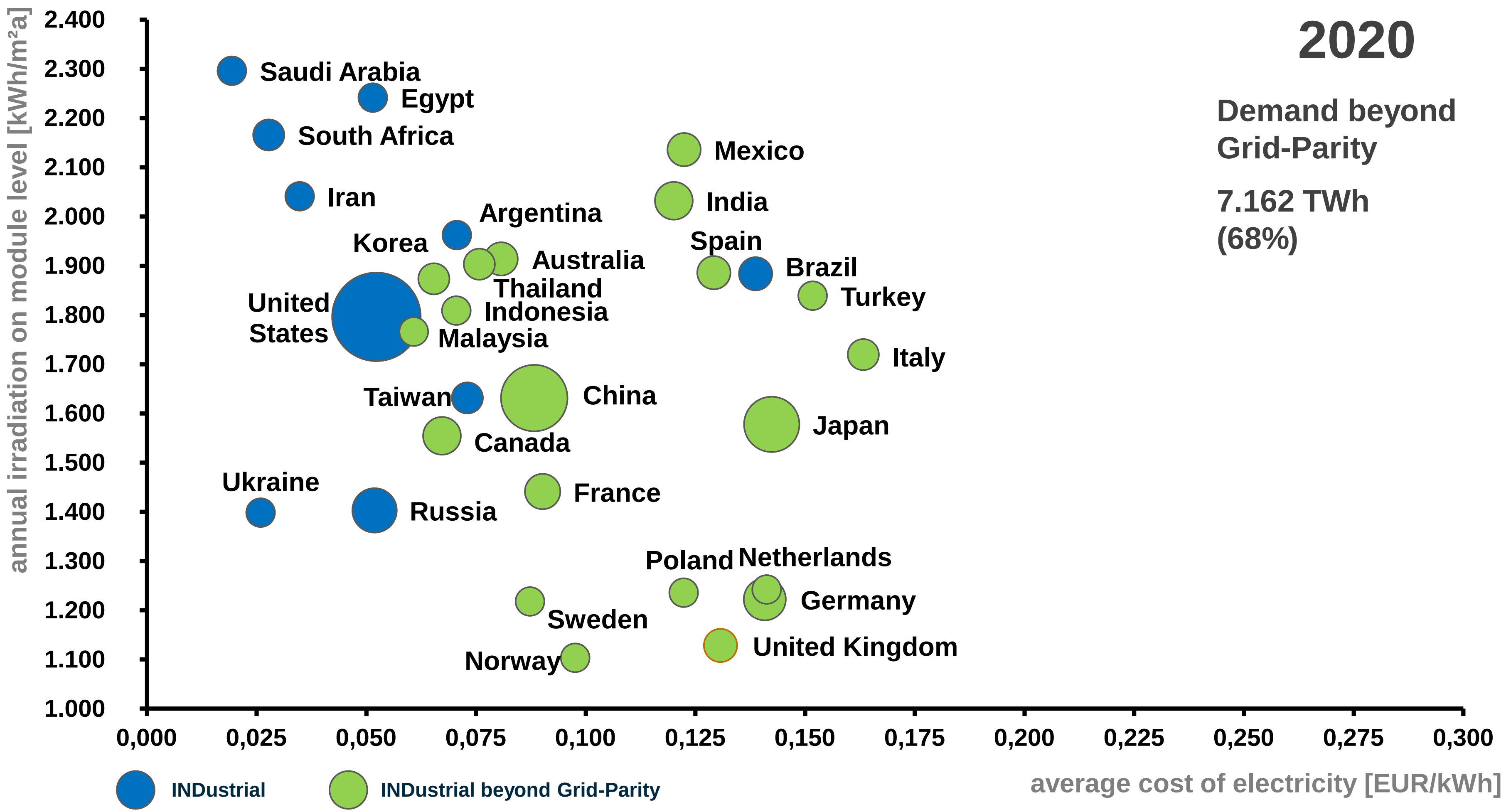


Sources: Hanwha Q CELLS Market Intelligence, Eurostat, EIA, utility feedback

source: Breyer Ch., Gerlach A., Werner Ch., Breyer Ch., 2014. Impact of Financing Cost on Global Grid-Parity Dynamics till 2030, 29th EU PVSEC, Amsterdam, September 22-26

IND – Grid-Parity – top 30 Countries

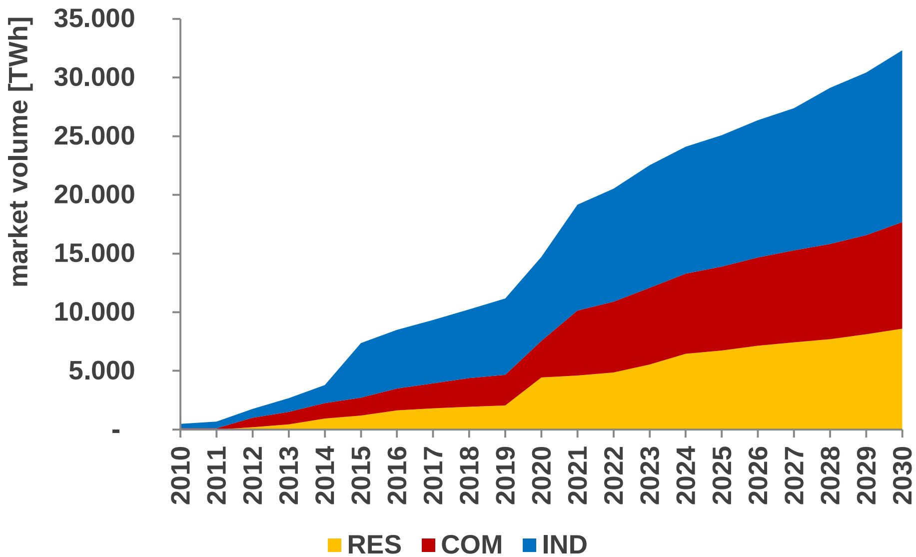


Sources: Hanwha Q CELLS Market Intelligence, Eurostat, EIA, utility feedback

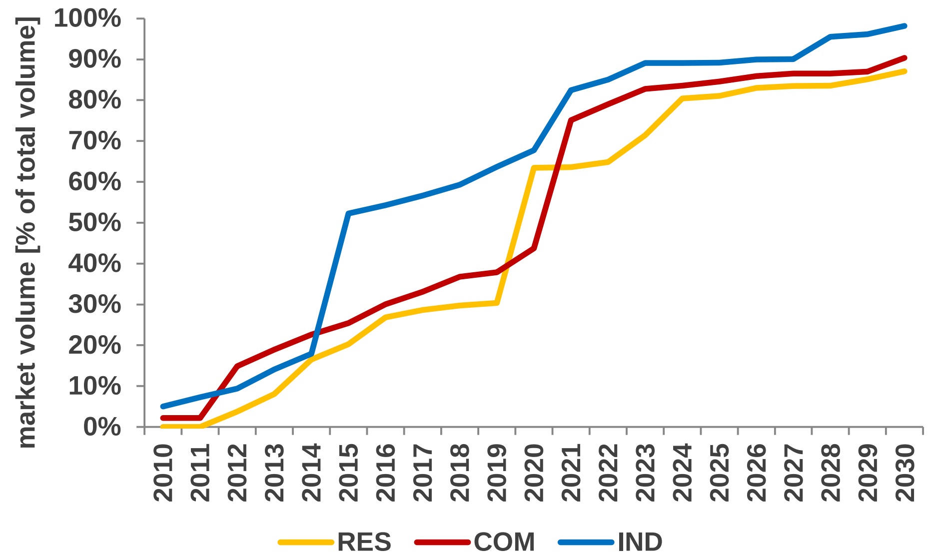
source: Breyer Ch., Gerlach A., Werner Ch., Breyer Ch., 2014. Impact of Financing Cost on Global Grid-Parity Dynamics till 2030, 29th EU PVSEC, Amsterdam, September 22-26

Global Grid-Parity Volume

GLOBAL MARKET VOLUME [TWh]



GLOBAL MARKET VOLUME [% of total volume]



NUMBER OF MARKETS BEYOND GRID-PARITY BY SEGMENT

Years	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
RES	2	3	15	24	34	44	54	66	71	79	94	100	106	116	120	121	128	131	133	138	141
COM	11	11	26	31	40	49	64	80	85	99	105	113	122	127	134	138	142	143	144	148	150
IND	17	19	31	38	56	71	89	99	104	110	117	126	133	141	143	145	147	149	150	154	157

sources raw data: Hanwha Q CELLS Market Intelligence, Eurostat, EIA, utility feedback

source: Gerlach A., Werner C., Breyer Ch., 2014. Impact of Financing Cost on Global Grid-Parity Dynamics till 2030, 29th EU PVSEC, Amsterdam

Agenda

- Motivation
- Status and Dynamics of solar PV Diffusion
- High shares of RE in the System (case of IE)
- Some insights for the RE transition (case of DE)
- What else is on the Horizon?
- Summary

100% RE in Ireland – Aalborg University, DK

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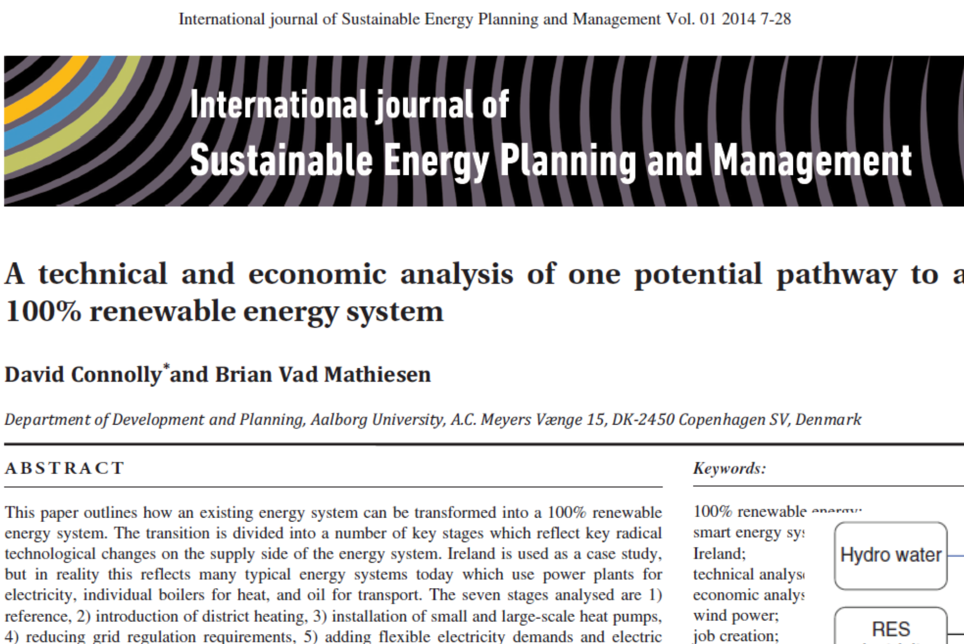

International journal of Sustainable Energy Planning and Management Vol. 01 2014 7-28

International journal of
Sustainable Energy Planning and Management

A technical and economic analysis of one potential pathway to a 100% renewable energy system

David Connolly* and Brian Vad Mathiesen

Department of Development and Planning, Aalborg University, A.C. Meyers Vænge 15, DK-2450 Copenhagen SV, Denmark

ABSTRACT

This paper outlines how an existing energy system can be transformed into a 100% renewable energy system. The transition is divided into a number of key stages which reflect key radical technological changes on the supply side of the energy system. Ireland is used as a case study, but in reality this reflects many typical energy systems today which use power plants for electricity, individual boilers for heat, and oil for transport. The seven stages analysed are 1) reference, 2) introduction of district heating, 3) installation of small and large-scale heat pumps, 4) reducing grid regulation requirements, 5) adding flexible electricity demands and electric

Keywords:

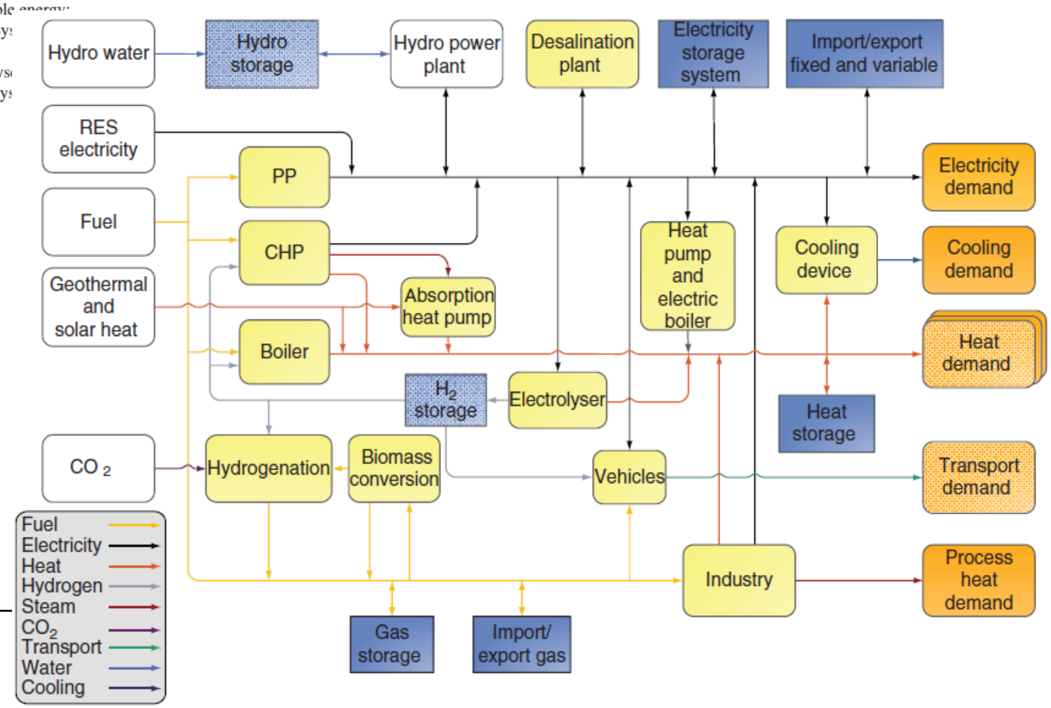
100% renewable
smart energy sy
Ireland;
technical analys
economic analys
wind power;
job creation;

source:

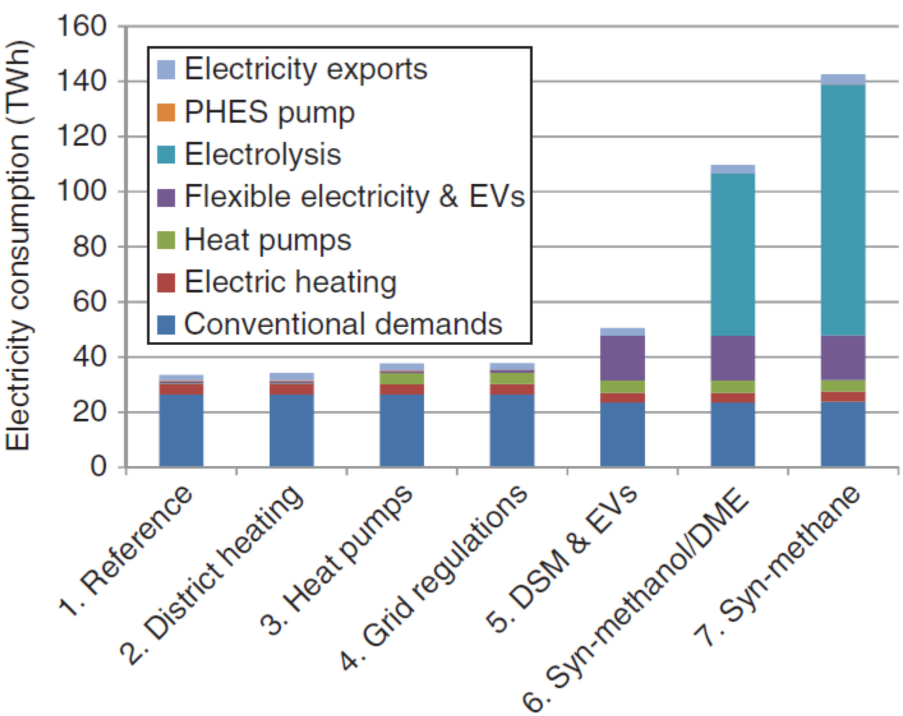
Connolly D. and Mathiesen V., 2014. A technical and economic analysis of one potential pathway to a 100% renewable energy system, Int. J. Sustain Energy Planning and Mgm

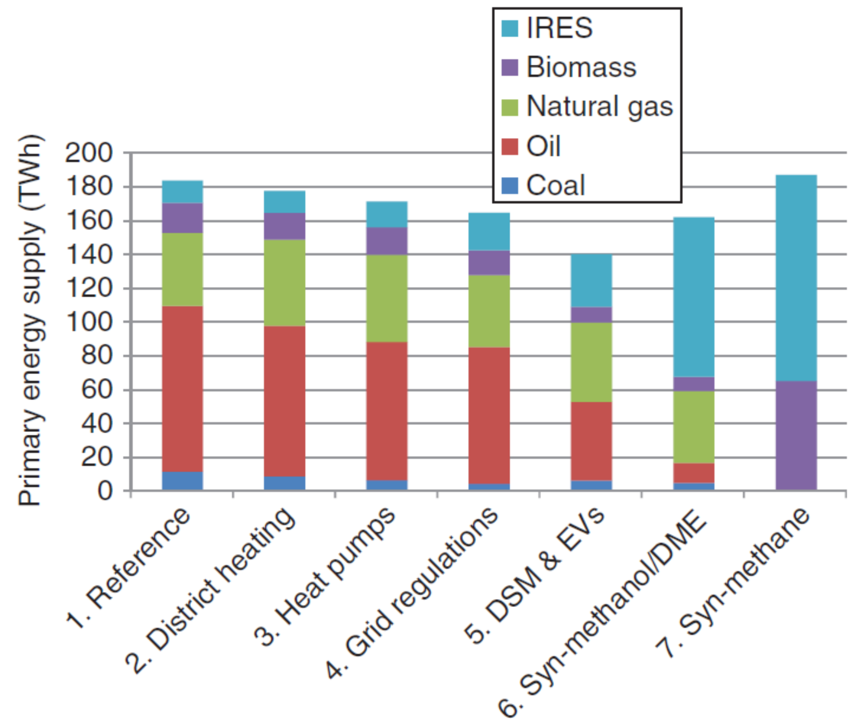
Key characteristics:

- 100% RE system for all sector
- hourly resolved simulation
- solar PV ‚forgotten'
- well balanced RE-heat and RE-mobility
- focus on energy flows and system costs
- no grid, no import/ export, not fully optimised



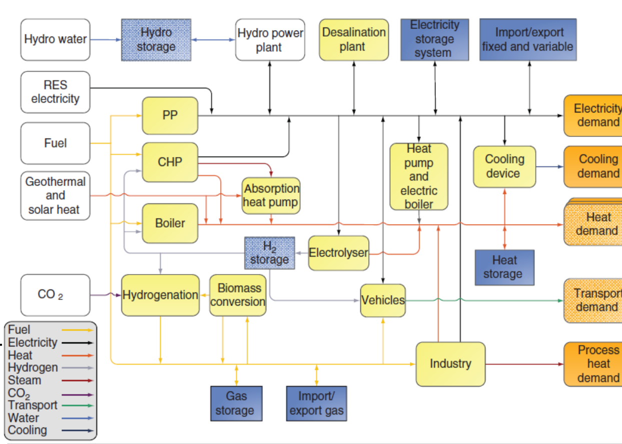
100% RE in Ireland – Aalborg University, DK



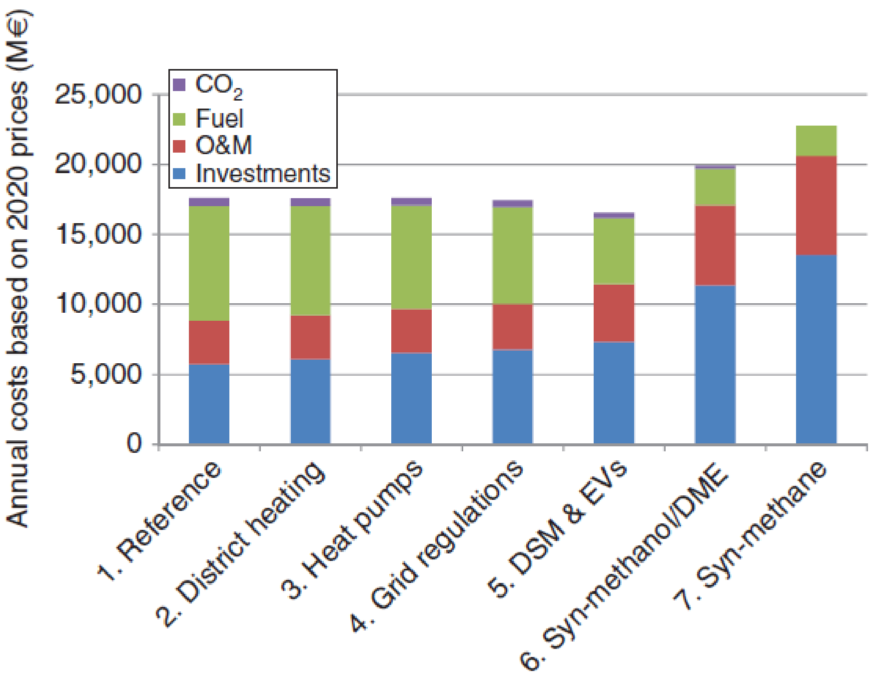


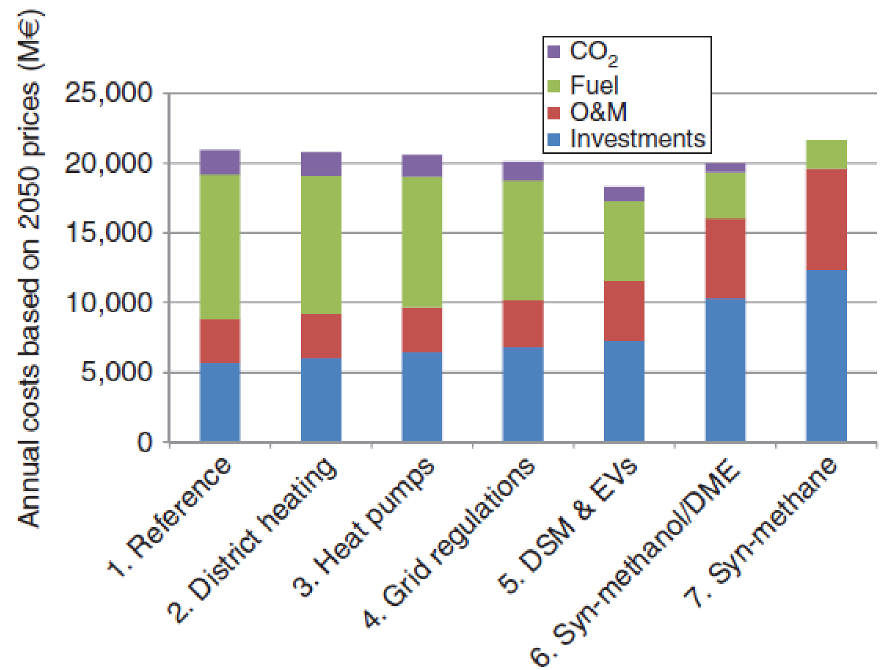
Key insights:

- 7 step approach feasible
- significant increase in power demand (~ +350%)
- BUT, no change in total primary energy demand (TPED)
- highly efficient power-based RE system enables power-to-gas/liquid pathways



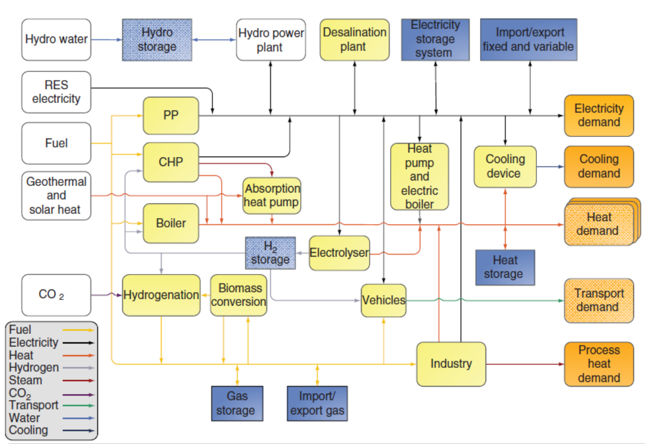
100% RE in Ireland – Aalborg University, DK





Key insights:

- 2020 system cost only 30% higher than reference (neglecting: cost of climate change, cancer deaths, negative trade balance effects, lower level of employment in energy sector, less tax income)
- 2050 system cost identical to reference
- simplified standard economic consideration, neglecting the full view on total societal cost
- otherwise, maybe 30% less in cost (personal estimate)
- significant increase in employment (> 100 000 jobs)



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System consequences of PV in Germany

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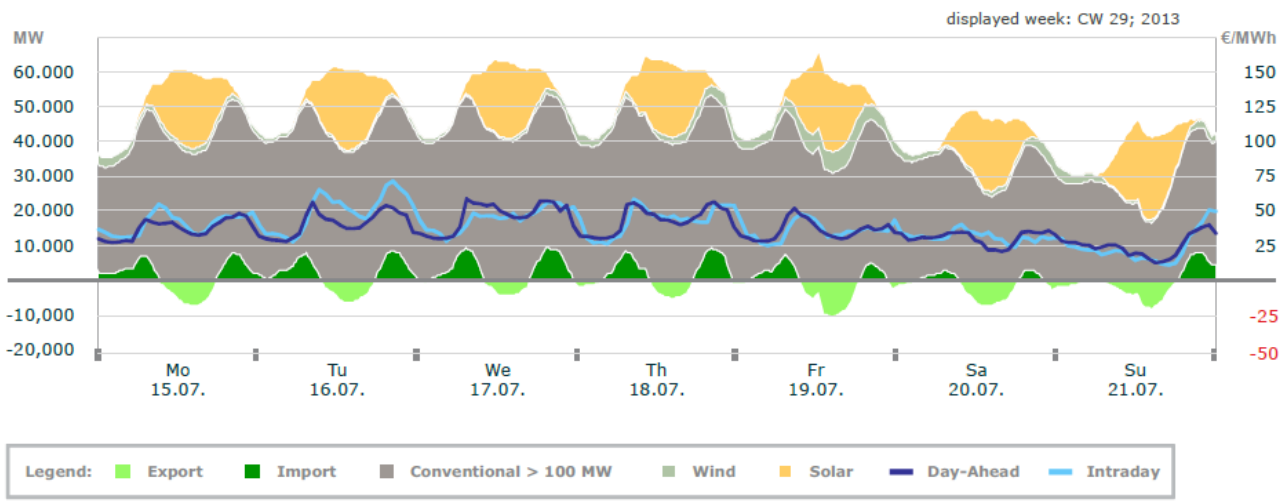
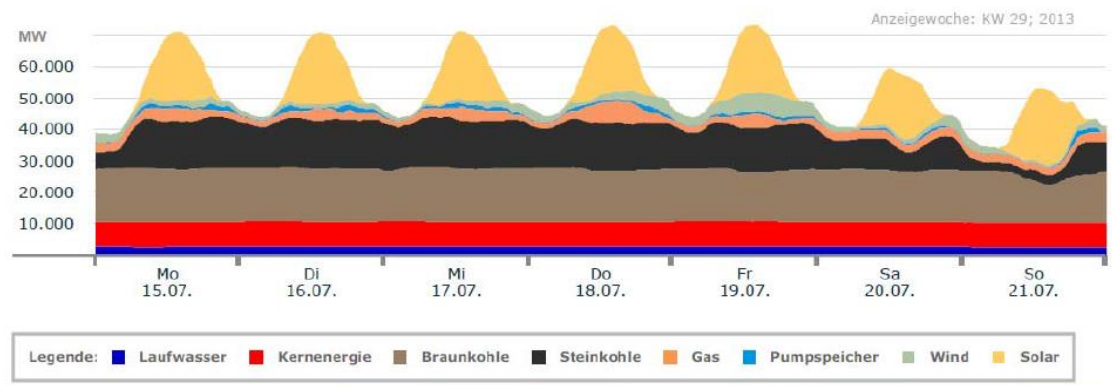
Electricity Production and Spot-Prices: CW 29 2013

source: Fraunhofer ISE



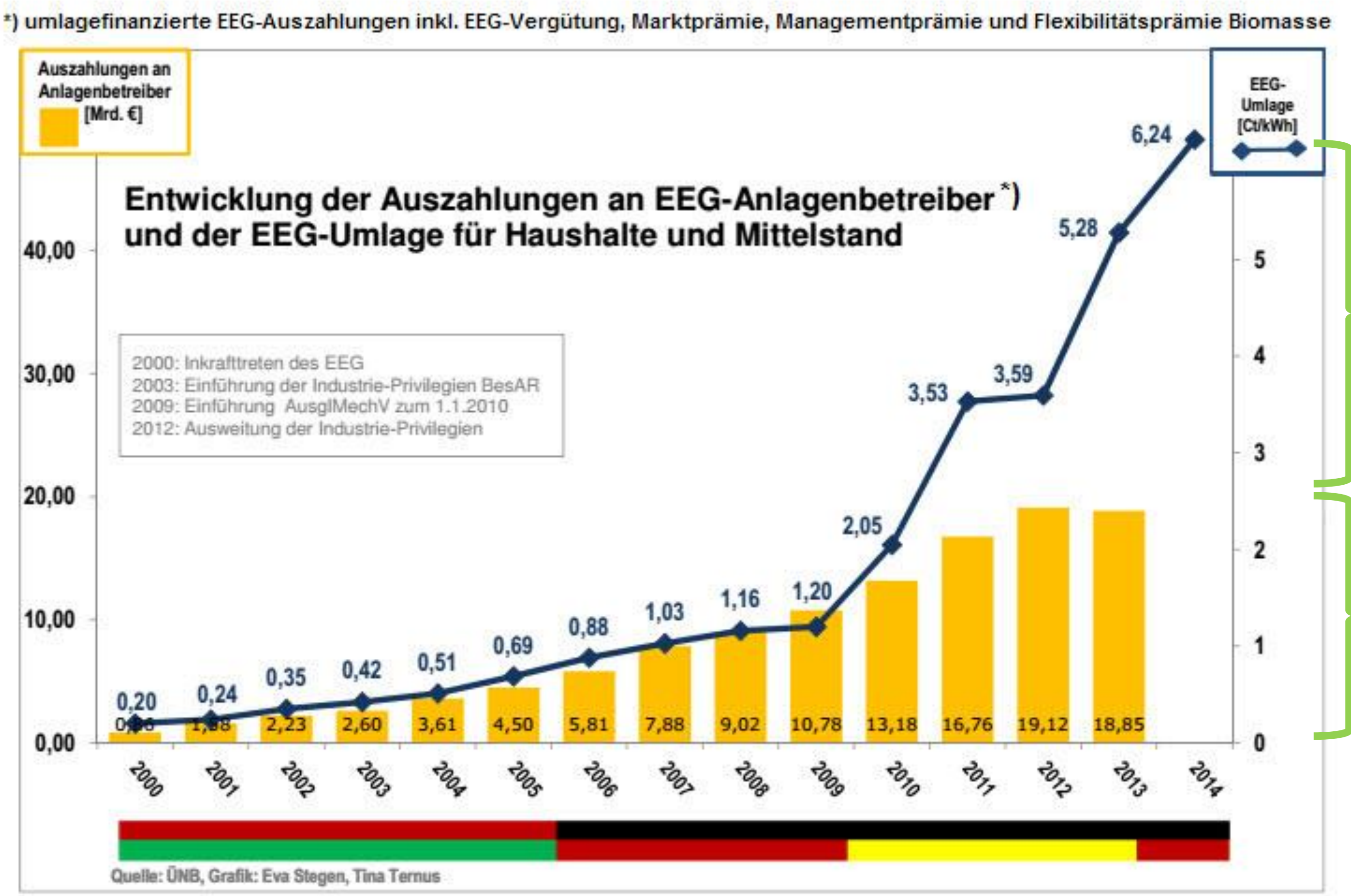
Key insights:

- PV induces pressure on wholesale price
- gas is substituted first
- hard coal starts to be substituted
- lignite coal/ nuclear not adapted but exported in times of PV feed-in
- highest electricity exports of Germany in its history



	LW	AKW	BK	SK	Gas	PSp	Wind	Solar
min. Leistung (GW)	2,4	7,4	12,1	2,7	1,5	0	0,2	0
max. Leistung (GW)	2,8	7,9	17,5	16,1	6,9	2,2	6,7	24
Wochenenergie (TWh)	0,4	1,3	2,8	2,1	0,5	0,1	0,3	1,3

Cost of the Energiewende – Negative Politics

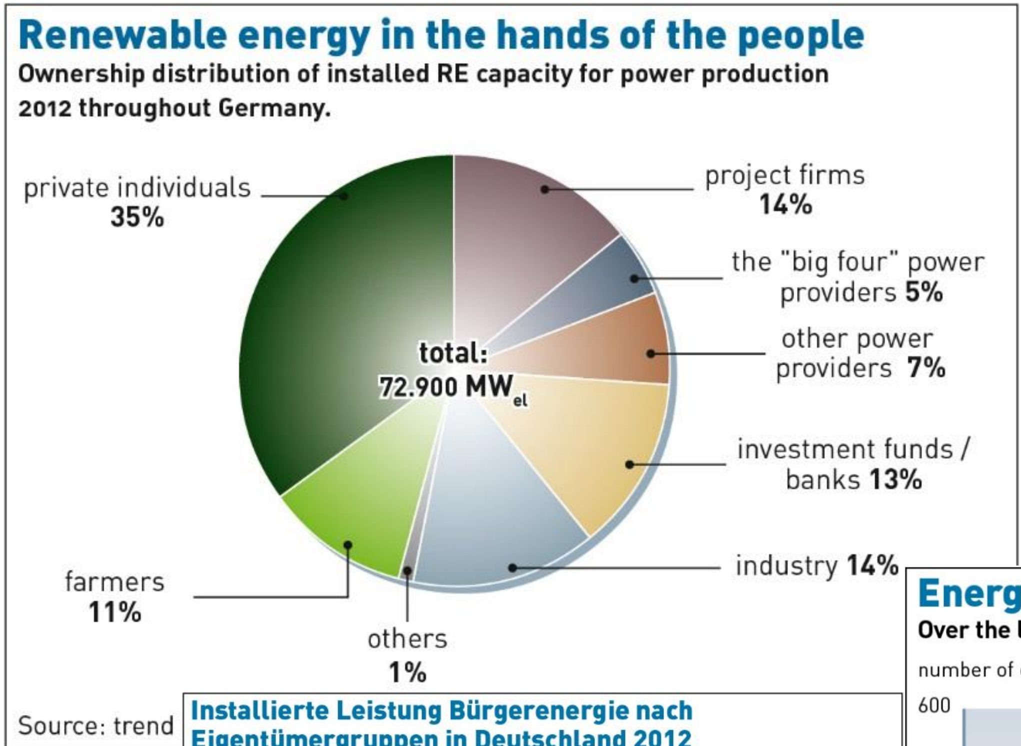


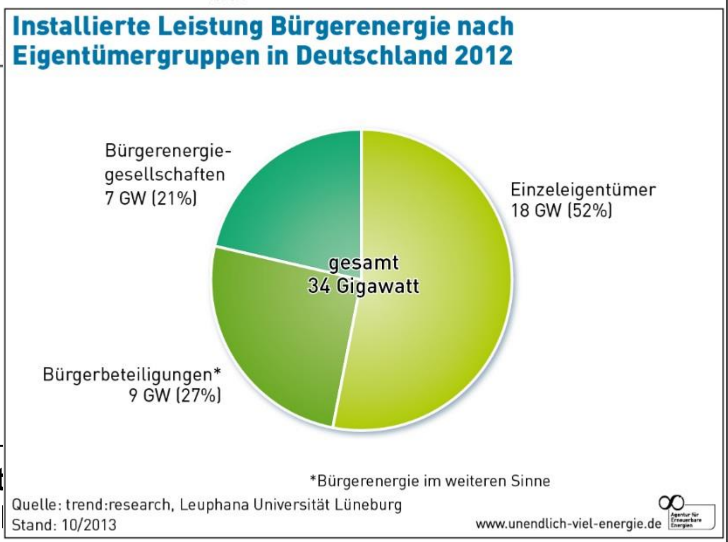
payment of end-users 'not priveledged'

(virtual) 'cost increase' by a factor of 2 due to policy changes (mainly subsidies to industry and failed market design)

payment to RE operators

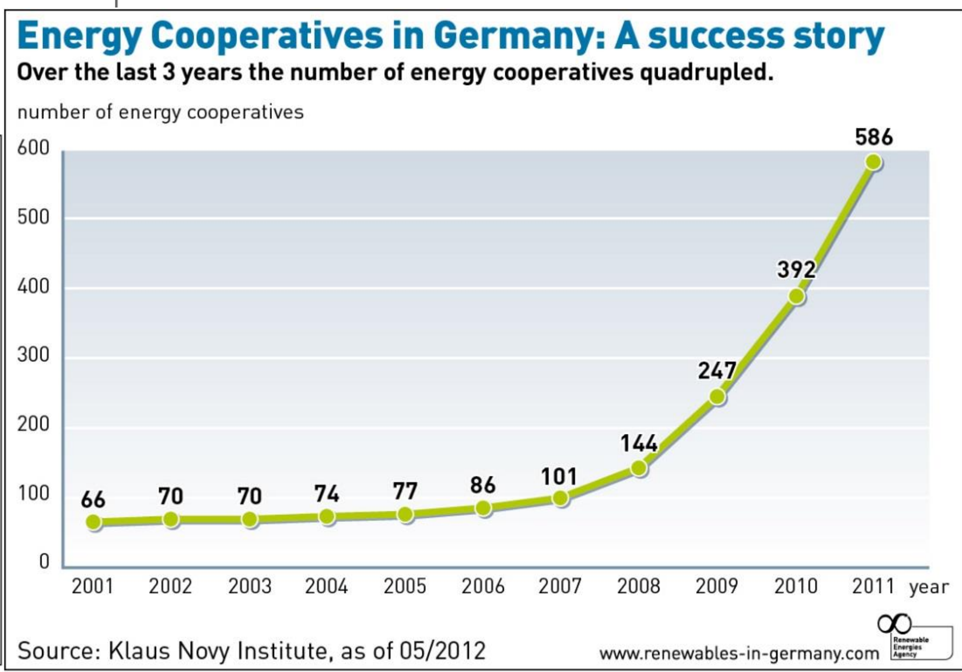
Investors in Renewable Energy in Germany





Key insights:

- citizens finance the Energiewende
- farmers benefit substantially
- new boom years for (energy) cooperatives
- high value creation in rural areas
- important pre-condition: feed-in tariffs (no broad benefits with tendering, investment support unclear)
- large utilites are NO help (in Germany)



50% RE in Germany – Agora Energiewende

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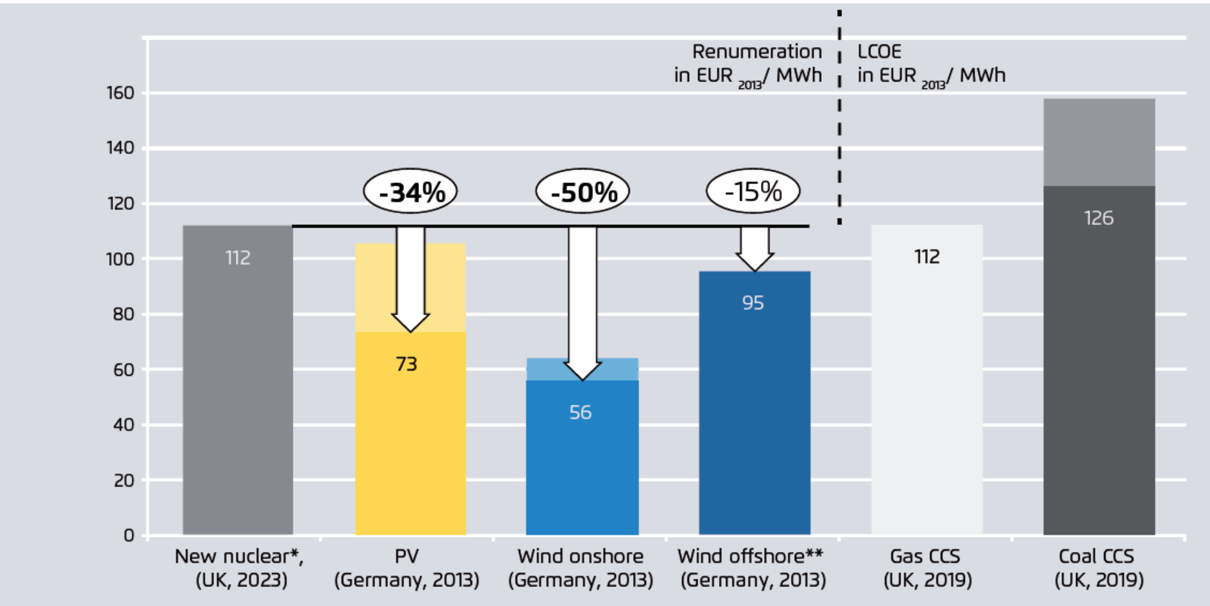
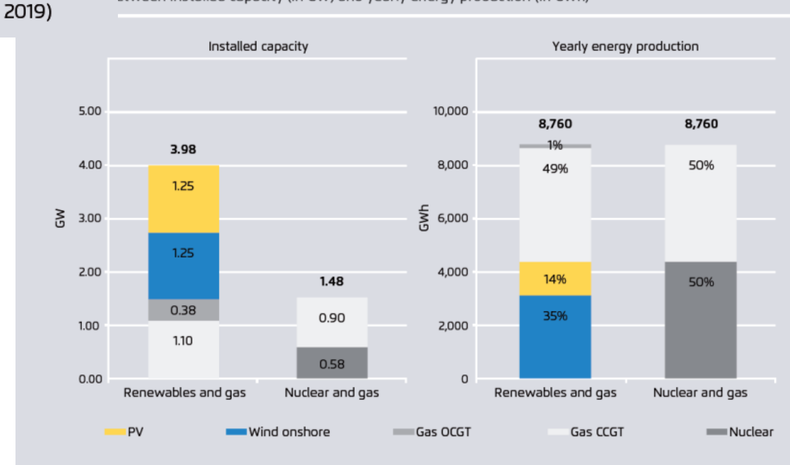
Comparison of average remuneration for new nuclear power, PV, wind and the levelized cost of electricity for gas/coal CCS



etween installed capacity (in GW) and yearly energy production (in GWh)



Key insights:

- PV-Wind-Gas is the least cost option
- nuclear and coal-CCS is too expensive
- nuclear and coal-CCS are high risk technologies
- high value added for PV-Wind due to higher capacities needed

source: Agora Energiewende, 2014. Comparing the Cost of Low-Carbon Technologies: What is the Cheapest option, Berlin

100% RE in Germany – Fraunhofer ISE

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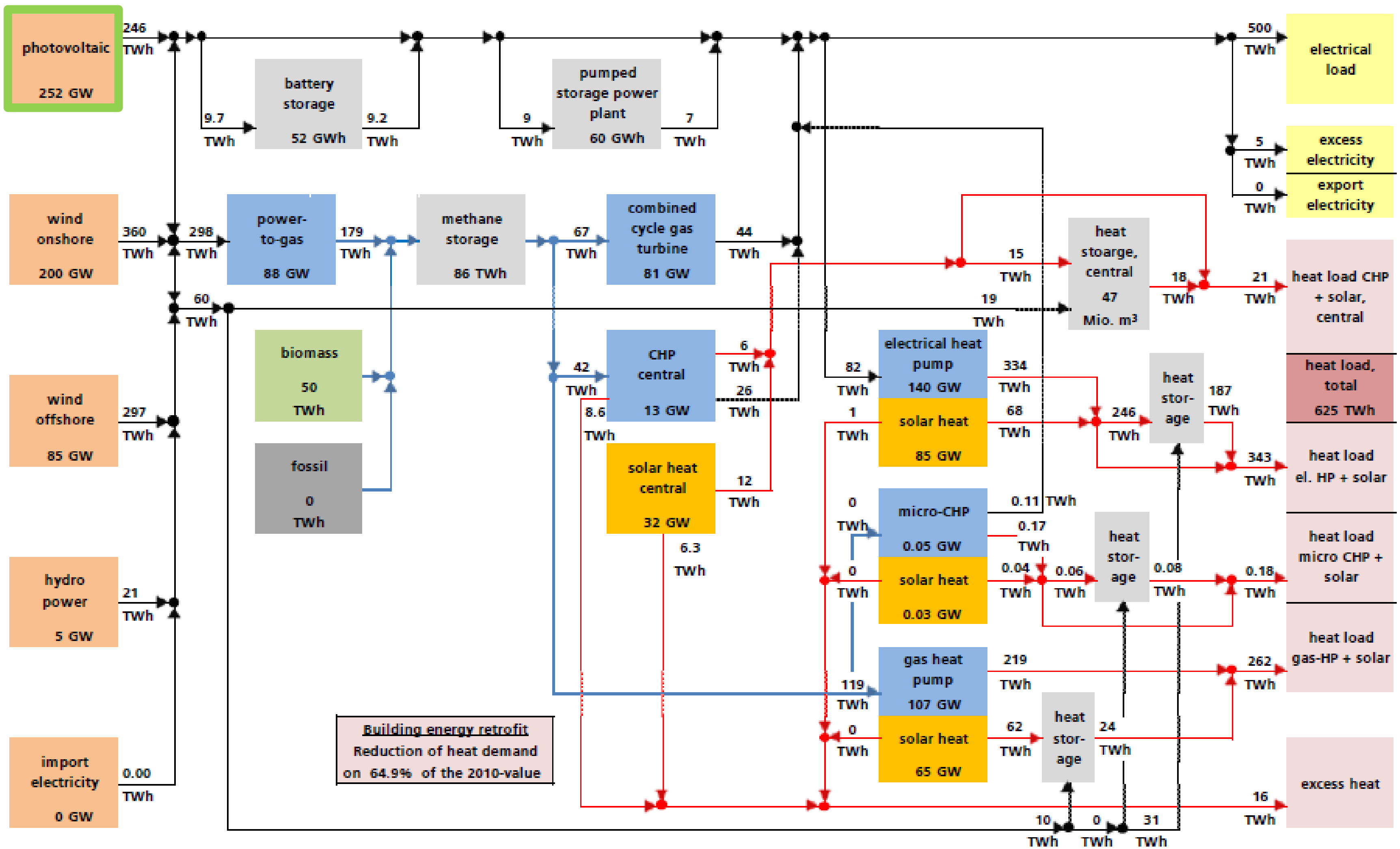
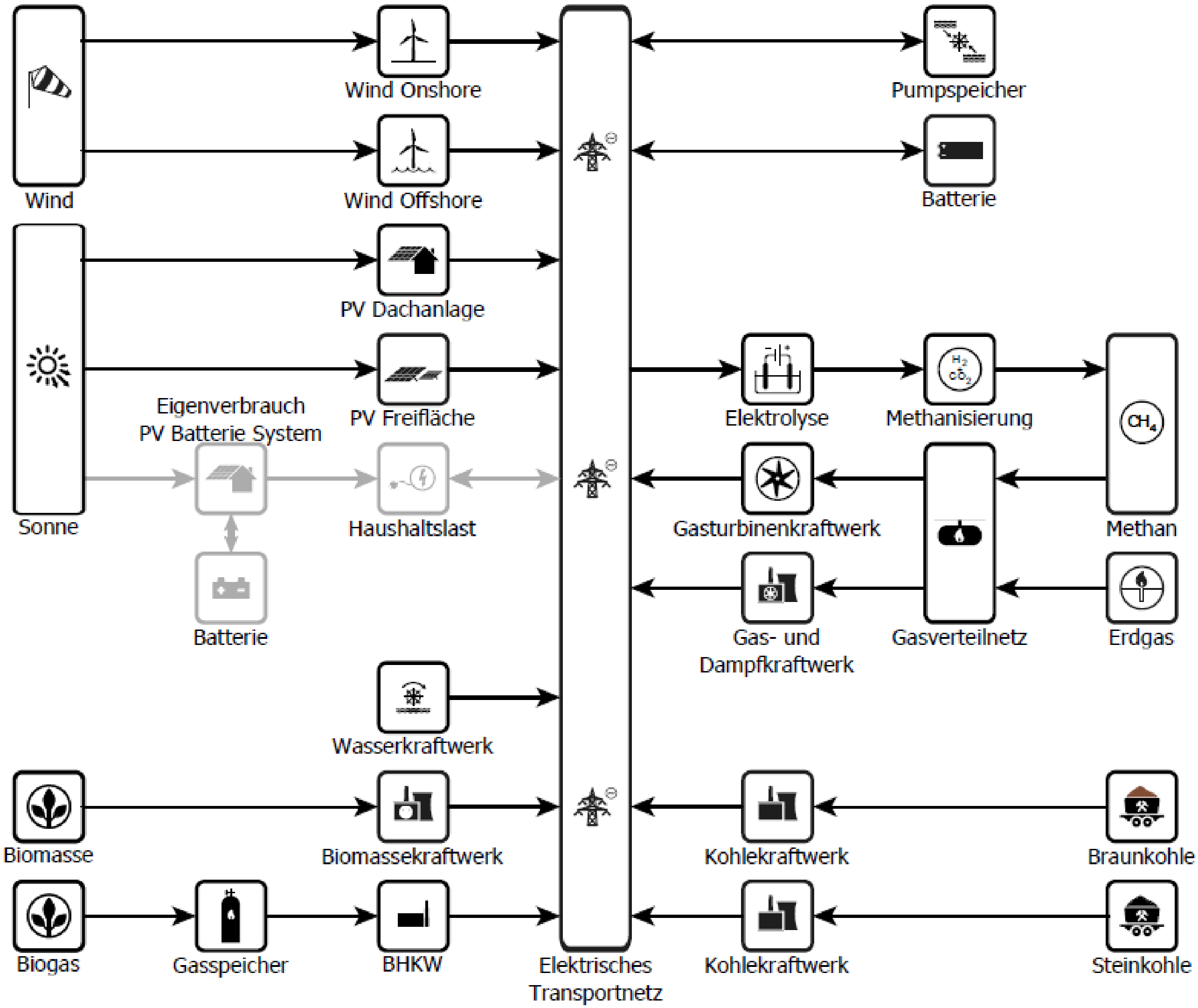


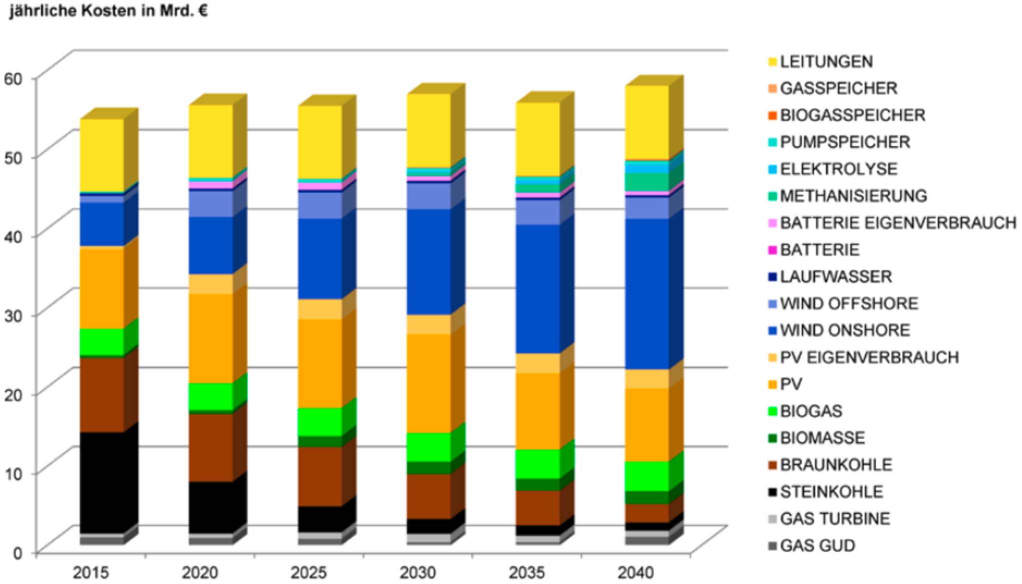
source: Henning H.-M. and Palzer A., 2012. 100 % Renewables for Electricity and Heat – a Holistic Model for a Future German Energy System , 7th IRES, Berlin

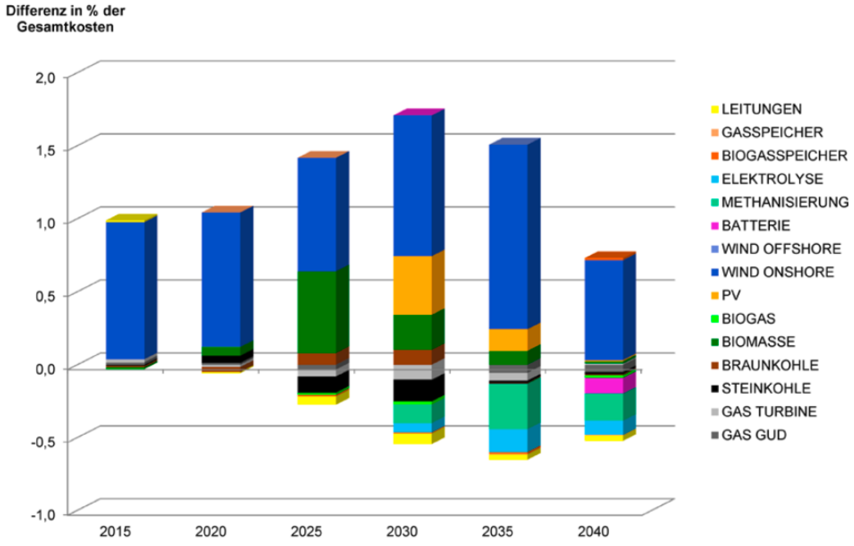
100% RE in Germany – Reiner Lemoine Institut



source: Breyer Ch., Müller B., et al., 2013. Vergleich und Optimierung vonn zentral und dezentral orientierten Ausbaupfaden zu einer Stromversorgung aus EE in DE, RLI, Berlin

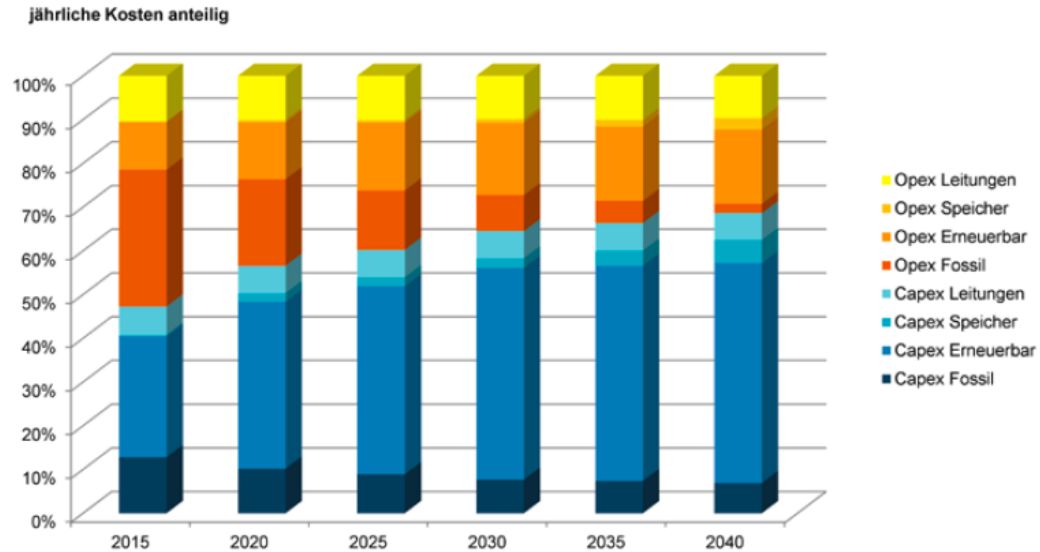
100% RE in Germany – Reiner Lemoine Institut





Key insights:

- cost of 100% RE similar to today's cost
- decentral and central option cost are more or less the same
- system is switching from operational to capital expenditures and fuel is squeezed out
- BUT, operational fraction still one third – equivalent to more jobs than today



Agora Energiewende – Role of Electricity

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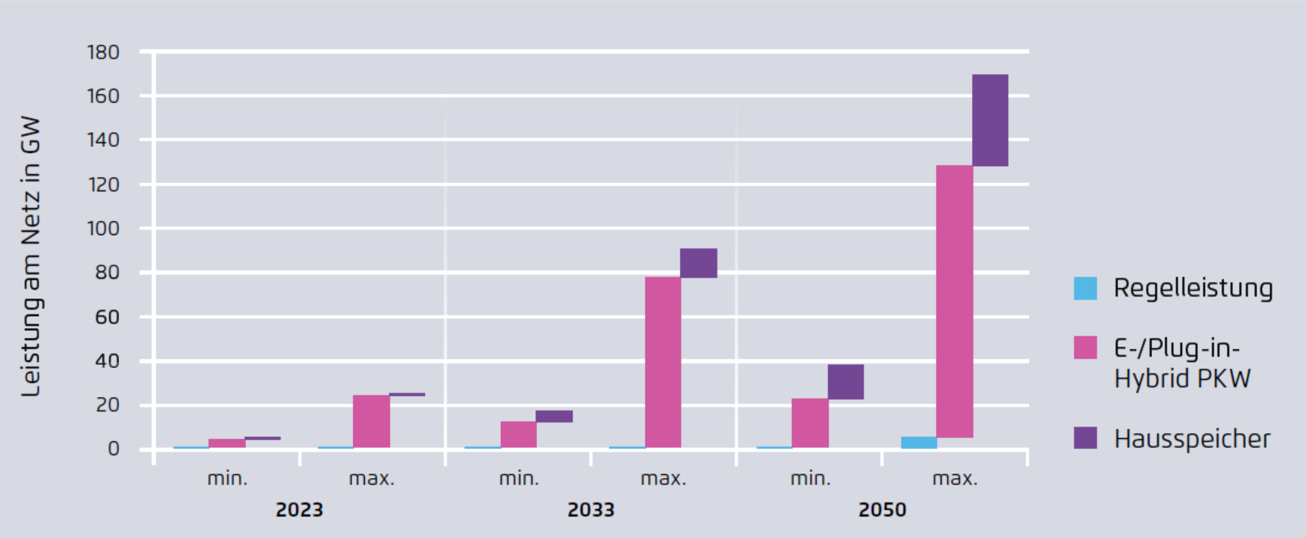
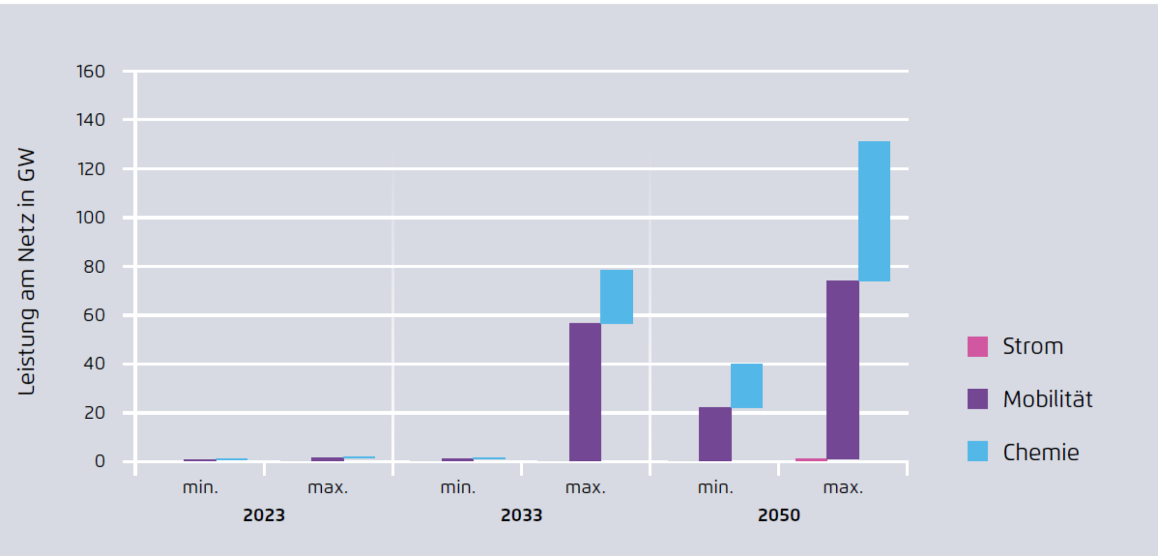
Bandbreite der installierten Leistung an Batteriespeichern (Märkte für Batteriespeicher) Abbildung 1-6



Bandbreite der installierten Leistung von *Power-to-Gas/-Liquid/-Chemicals* (Märkte für *Power-to-X*) Abbildung 1-7



Key insights:

- **mobility will be powered by electricity (batteries and PtG)**
- **chemistry will change the resource basis towards ‚electricity'**

source:

Agora Energiewende, 2014. Stromspeicher in der Energiewende

Agenda

Storage Options in General and PtG

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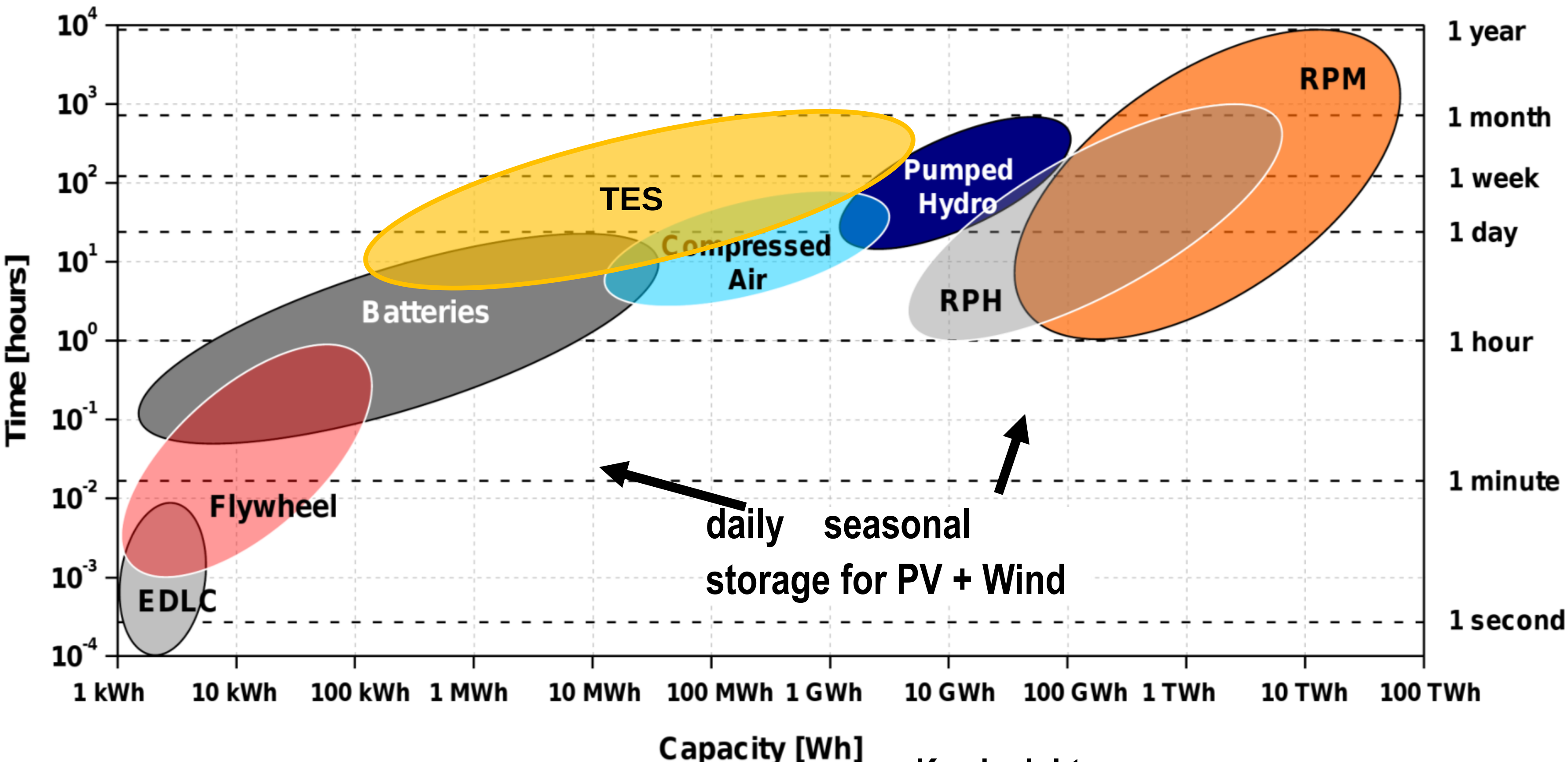
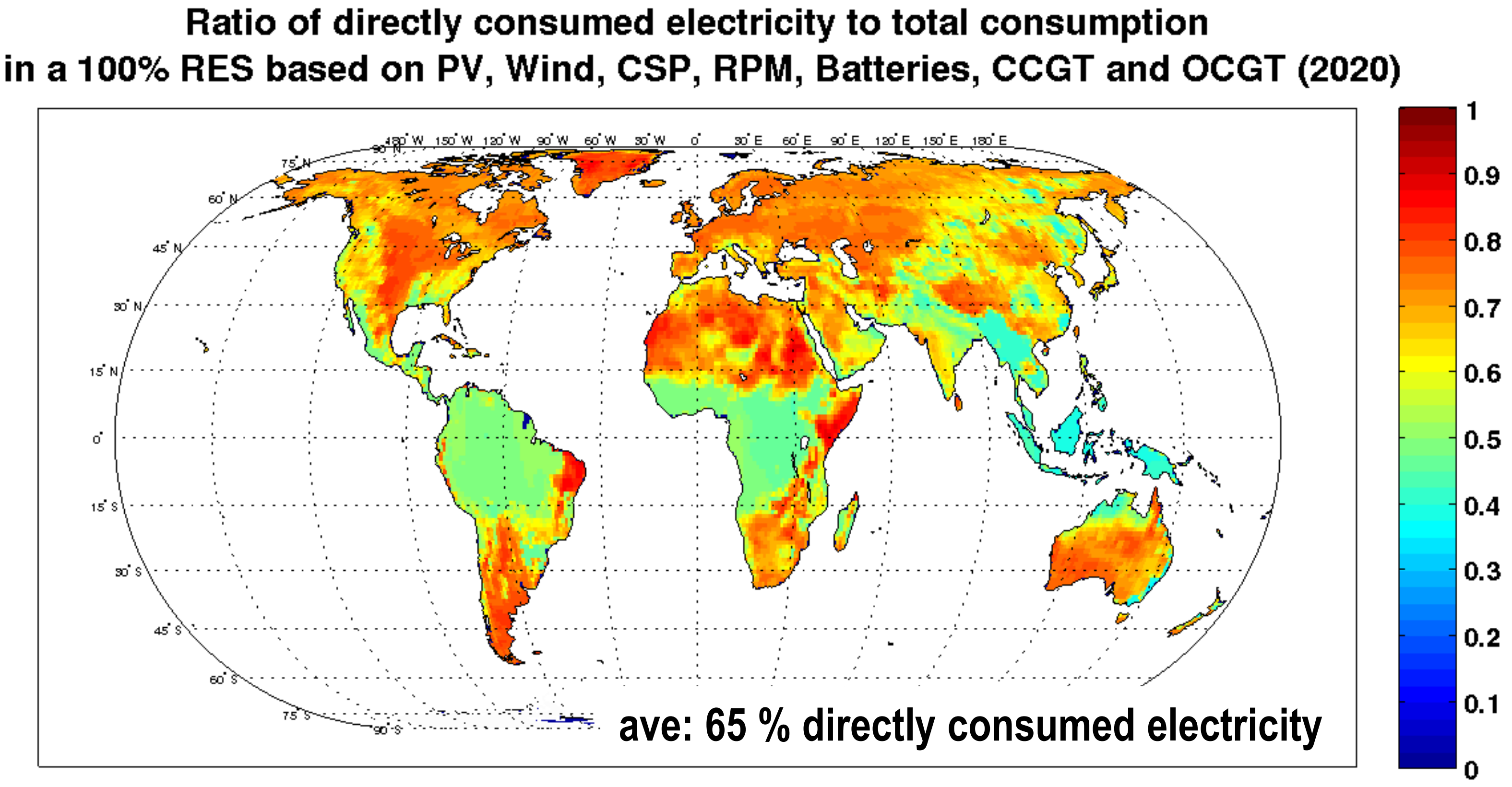


Key insights:

- gas is the only long term energy storage
- RPM might be favoured due to an evolutionary transition process

source: Breyer Ch., Rieke S., et al., 2011. Hybrid PV-Wind-Renewable Methane Power Plants – A Potential Cornerstone of Global Energy Supply, 26th EU PVSEC, Hamburg, September 5-9

How much energy is to be stored?

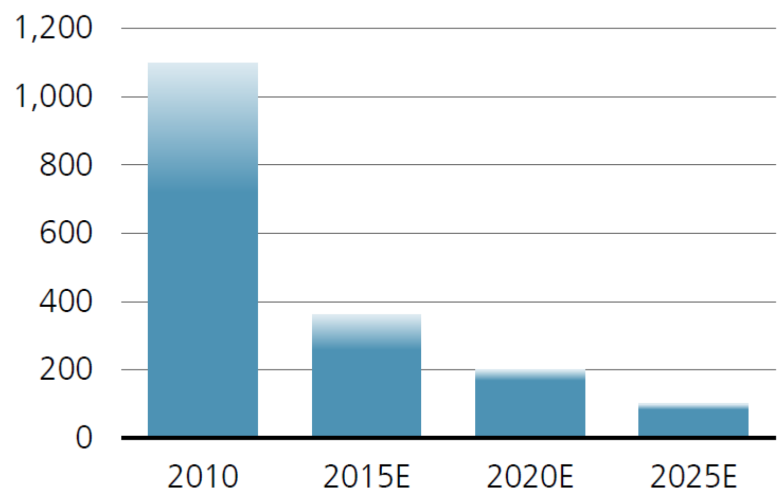


- on average, one third of the consumed energy comes from storage
- the regionally optimal amount of stored energy depends on the type of RE source used
- in particular tropical regions have lower ratio of immediatly consumed RE electricity

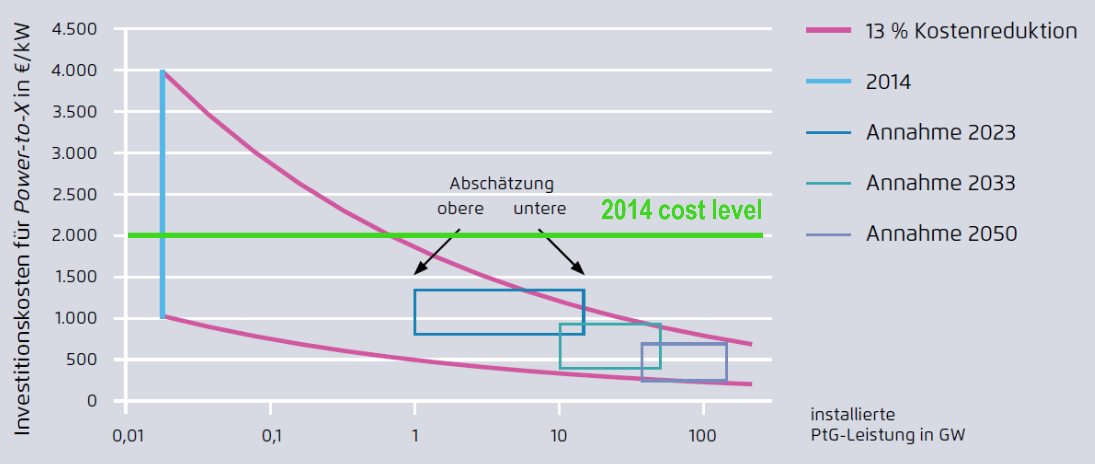
source: Pleßmann G., Breyer Ch. et al., 2014. Global Energy Storage Demand for a 100% Renewable Electricity Supply, Energy Procedia, 46, 22-31

Storage: The story of PV reloaded?

Lithium battery cost to decline >50% by 2020



Source: Tesla, Umicore, UBSe. Cost estimates are for the battery pack (€/kWh).



Key insights (Battery):

- 100 €/kWh battery pack capex translates roughly into 200 €/kWh battery system capex
- tremendous boost for decentral PV-battery applications (on-grid)
- cost for storing a kWh then <10 €ct/kWh
- stored 30-50% of generation, LCOS are 3-5 €ct/kWh
- PV LCOE might be 3-6 €ct/kWh
- 6-11 €ct/kWh for very high self-supply shares

Key insights (PtG):

- first 1 GW very important for cost scaling
- 500 – 1000 €/kW capex will trigger continuous growth for PtG
- PtG is one of the most valuable technologies in 21st century
- Neo-Carbon Energy (LUT, VTT, UTU) launched in July by Tekes
- Finland could catch up with leading Germany, but industrial will needed

source: UBS, 2014. Will solar, batteries and electric cars re-shape the electricity system?, August 20; Agora Energiewende, 2014. Stromspeicher in der Energiewende, September 16

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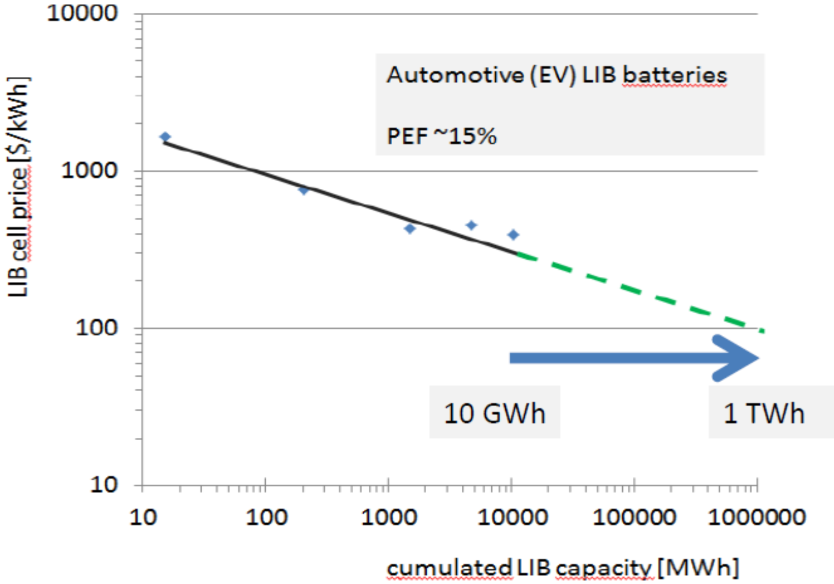
LIB Learning Rate

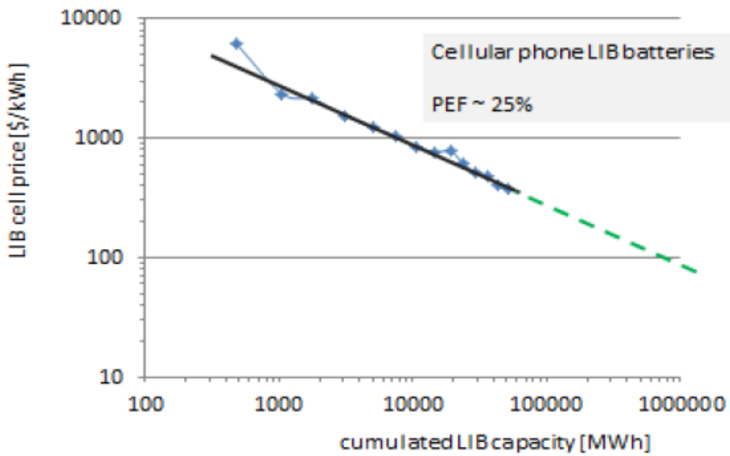


For comparison: PV between 2000 and 2010 had CAGR (cum) of 41%

CAGR (cum. Vol.) = 31 p.a. for 2030

Key insights:

- LIB learning rate between 15-25%
- Stationary applications might have about 20%
- Impact of LIB in coming 8 years might be about the same as that of solar PV in the last 8 years



green dotted line is extrapolation of past PEC

source: Hoffmann W., 2014. Importance and Evidence for Cost Effective Electricity Storage, 29th EU PVSEC, Amsterdam, September 22-26

Learning from Nature

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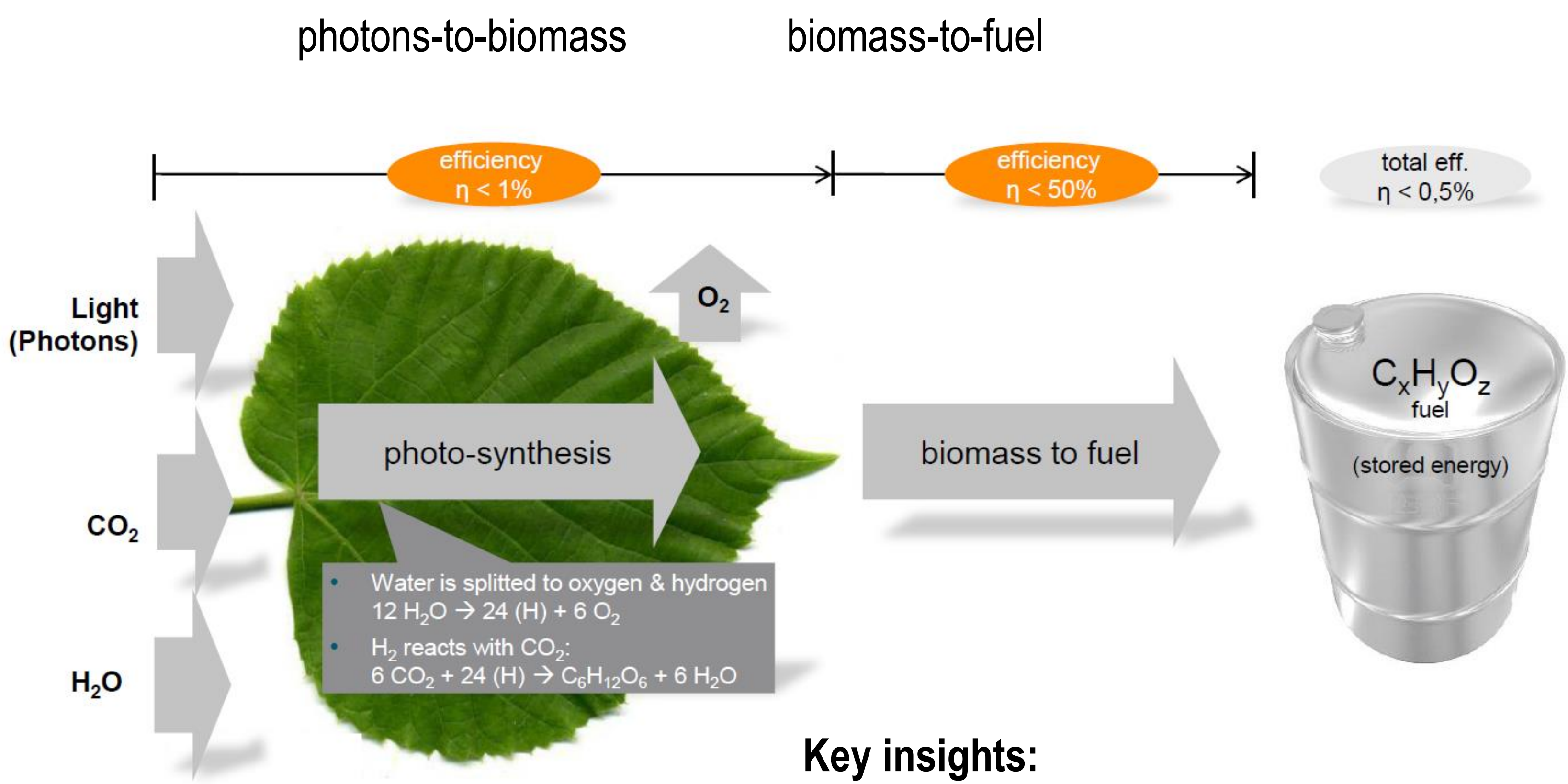


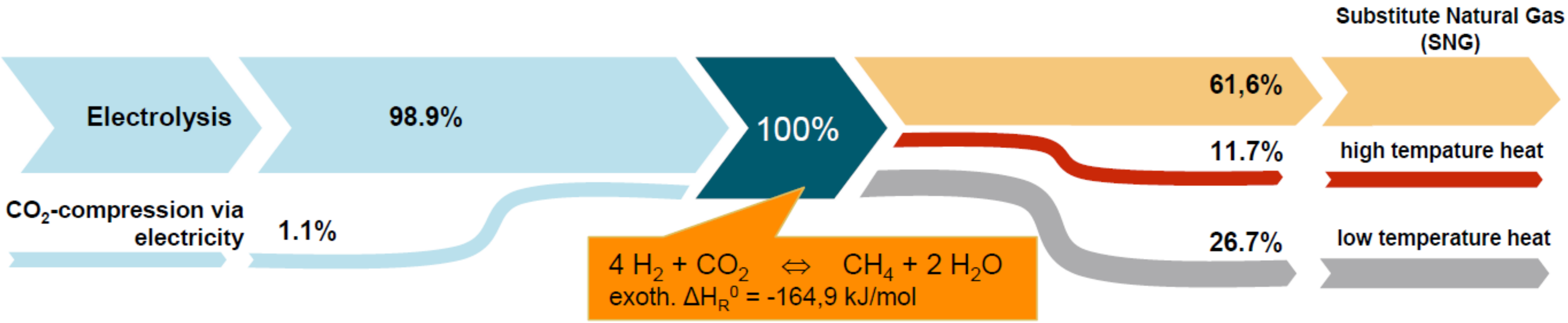
Key insights:

- processes well established
- efficiency of photons-to-biomass is quite low
- efficiency of photons-to-biomass-to fuel is even lower

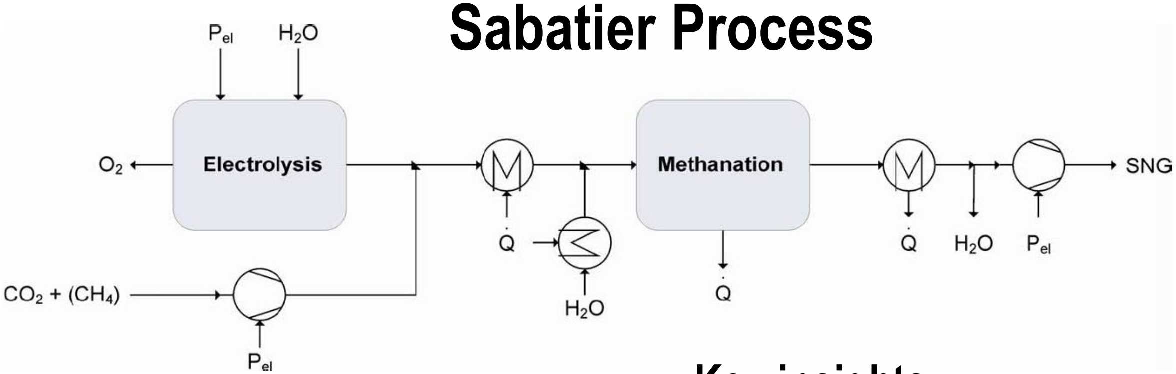
source:

ETOGAS, 2013

Power-to-Gas (PtG, or P2G/ RPM/ …)



Sabatier Process



Key insights:

- 2 step process: electrolysis + methanation
- input: electricity, H_2O, CO_2
- output: CH_4, H_2O, H_2 (optionally), O_2
- power-to-gas efficiency: ~60% (>80% with use of waste heat)

source: ETOGAS, ZSW, 2010

Spotlight on Storage

Insights:

- up to 50% RE (PV and wind) nearly NO storage is needed, but a flexible power system
- intermittent solar PV and wind will be the major energy sources in future
- societal cost of RE energy is 40 – 60 €/MWh (for some today, for the rest in next decade)
- ALL conventional energy sources are higher in societal costs

Question:

Role and impact of storage technologies?

Expectation I (case of chemical batteries):

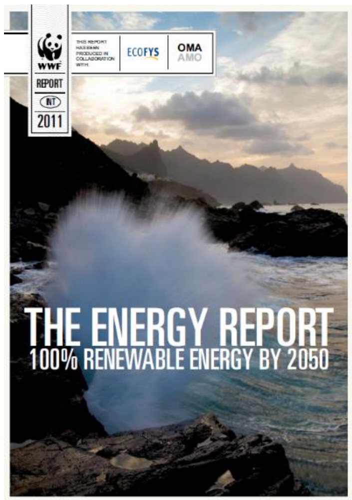
- current cost of storage attractive in mobile IT, emerging in transport, niche in power
- growth in mobile IT and i.p. transport could reduce cost of storage to < 20 €/MWh stored elec
- every generation and demand within days would cost 50 – 80 €/MWh
- NO OECD country has such low tariffs for end-users!!
- todays investments have to take that into account for avoiding stranded investments
- JP, KR, CN in the industrial lead

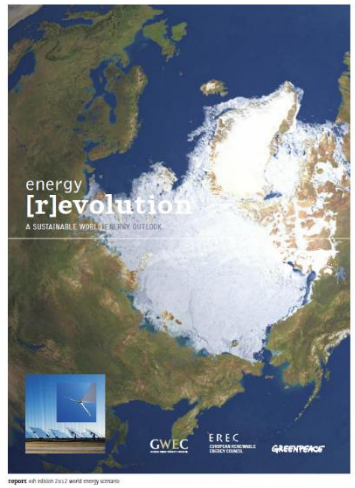
Expectation II (case of power-to-gas)

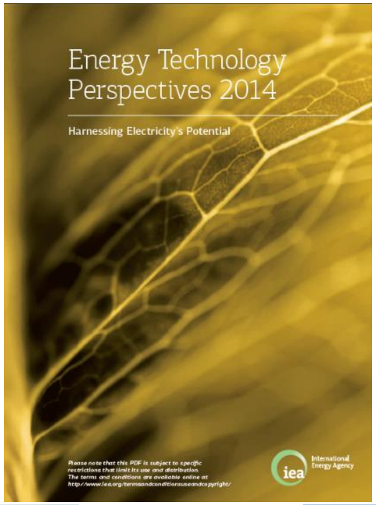
- bridging technology: coupling of gas and mobility sector to power sector
- the only substantial seasonal power storage we know today
- DE in the lead, FI could catch up (if FI industrial players are willing to do)

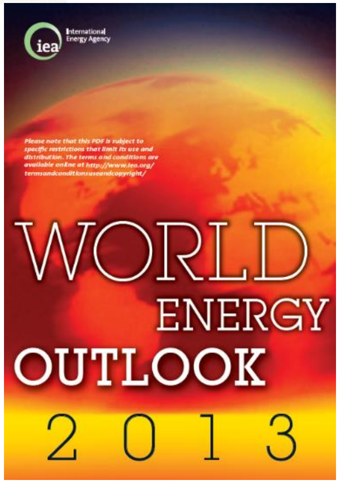
Do we know the long-term PV demand?

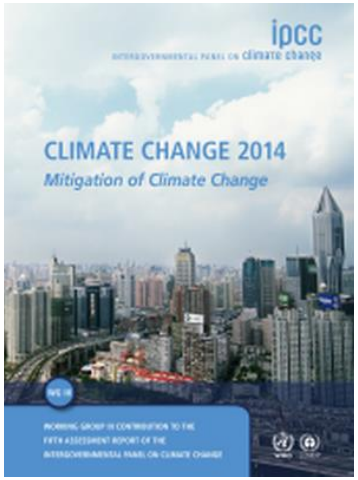
The results of some recent studies might help …

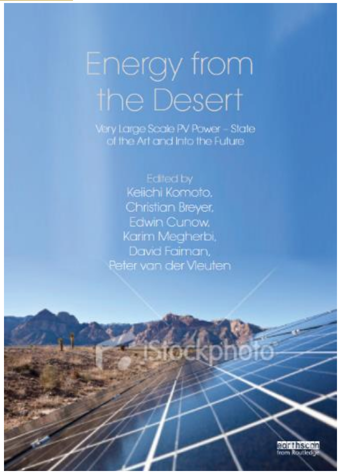




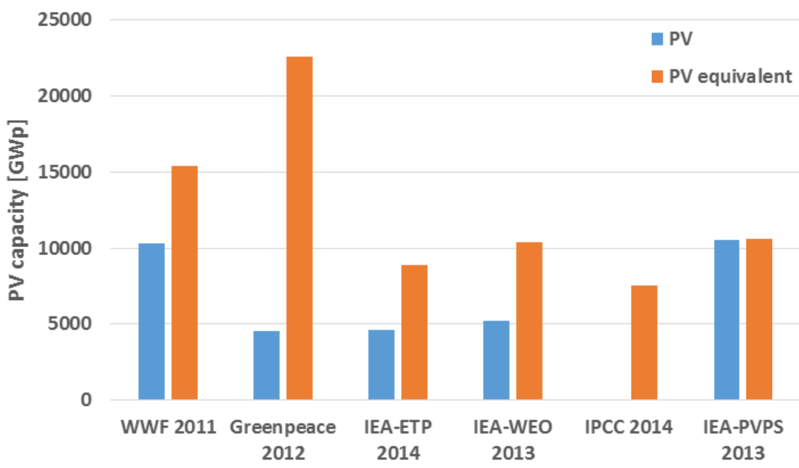


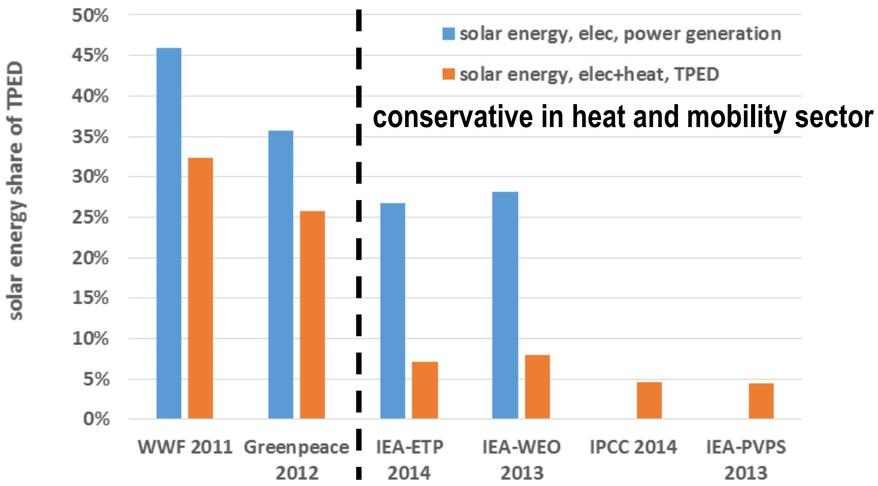






Focus on PV for the year 2050





- all reports acknowledge significant relevance of PV (≥ 5 TW)
- BUT, the variation in results (input) is high, despite of progressive/ RE-based scenarios
- closer view to the key numbers might provide a valuable guideline
- my view I: own published numbers would be 7.5 – 12 TW for about 2050
- my view II: updated insights in 2014 lead to ~25 TW (2050) and 65-100 TW (2050 – 2100)

Agenda

- Motivation
- Status and Dynamics of solar PV Diffusion
- High shares of RE in the System (case of IE)
- Some insights for the RE transition (case of DE)
- What else is on the Horizon?
- Summary

Summary

- solar PV diffusion trend is stable for decades (leaning rate, growth rate, cost reduction)
- more and more market segments are becoming profitable
- PV and Wind emerge to the backbone of global energy supply
- 100% RE system is feasible: technical, economical, ecological
- highest risk for RE is not economics it is politics
- opportunities are huge – but only for the ones who act (the rest will [have to] follow [for economic reasons])
- power business is/ will be radically transformed due to system impact of (decentralised, low scale) PV and storage

Thanks for your attention!

Open your mind. LUT.

Lappeenranta University of Technology