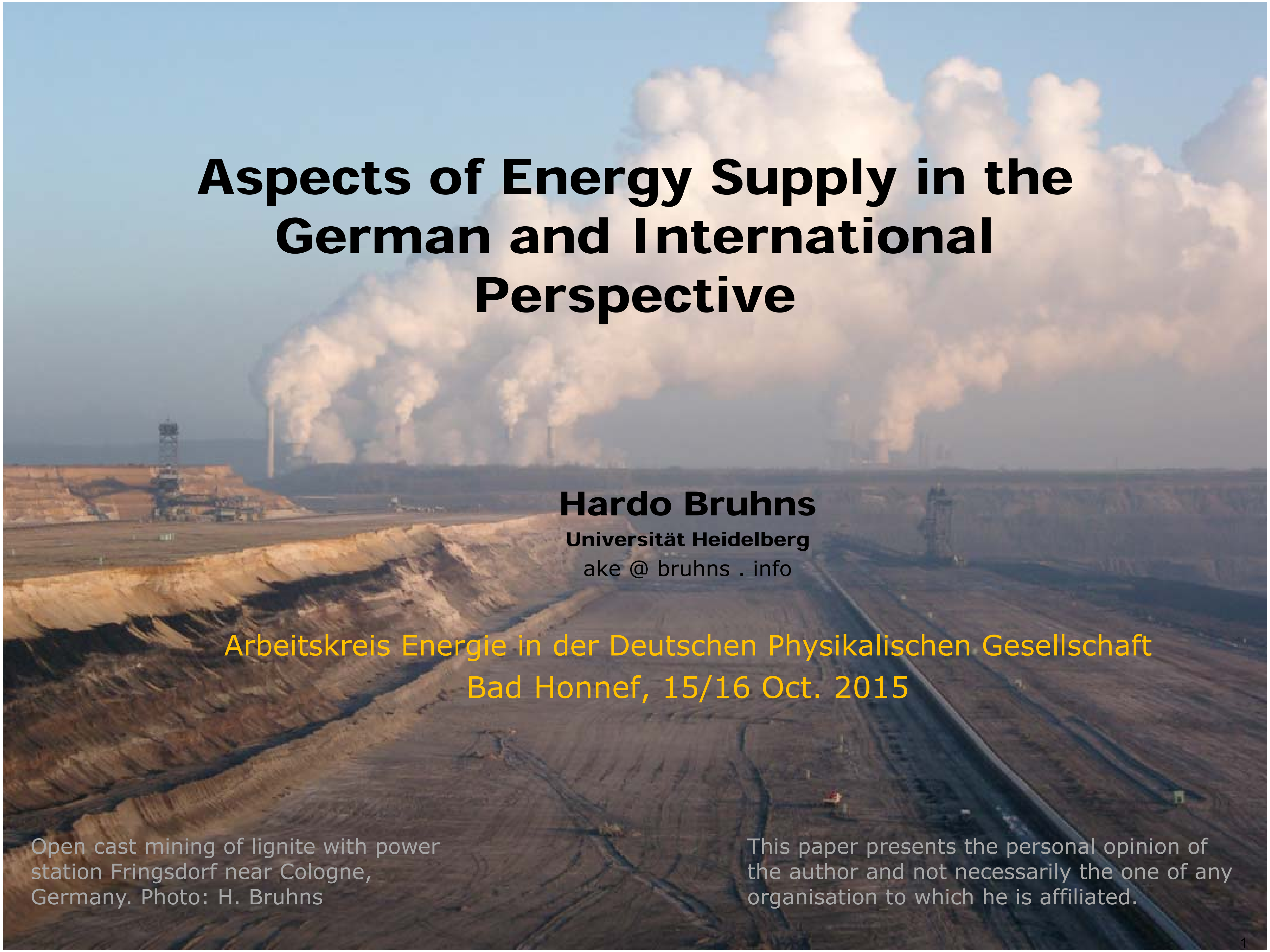
Aspects of Energy Supply in the German and International Perspective



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Arbeitskreis Energie in der Deutschen Physikalischen Gesellschaft
Bad Honnef, 15/16 Oct. 2015

Open cast mining of lignite with power station Fringsdorf near Cologne, Germany. Photo: H. Bruhns

This paper presents the personal opinion of the author and not necessarily the one of any organisation to which he is affiliated.

Overview

Energy production and use is dependent on

- Societal framework
  - Global population
  - Political development
  - Economic development
- Environmental framework
  - Global warming
  - Pollution
  - Other (e.g. Protection of Resources)
- Scientific-technical framework
  - New developments for the energy systems
    - Energy sources
    - **Energy distribution**
    - Energy use

    Smart use of energy
- Germany in the world
- Interaction Germany → Europe / World
- Interaction World / Europe → Germany

COP21: The UN Paris Climate Conference

Requirements for a „2° (450ppm) trajectory"

There are models which promise that there are scenarios to stay in the vicinity of a 2° warming if within ~20-40 years:

- Build up Renewables fast enough so that <GHG emission> from the energy system is < 120 g CO2/kWh - for every kWh on the world!

- burn only some 440 Gt coal corresponding to 1200 Gt CO_2 (other figures exist as well) while resources are 17,000 Gt (~500,000 EJ)

i.e. the vast majority of coal, oil, gas must remain untapped.

COP21: The UN Paris Climate Conference Commitments for CO_2 reduction

* Source WEC 2015, INDC: indicative nationally determined commitments

Possible Agreements	Commitment	Control
Weak	Voluntary targets nonbinding	national
Moderate	binding targets	national
Robust	binding targets	international monitoring mechanism
Strong	binding targets	international monitoring and enforcement mechamism

Recent Bad News (FAZ, 13. 10. 2015):

- EU to abandon plans for binding targets on
  27% implementation of RES and 27% increase in energy efficiency
  - Start of initial action plans delayed from 2017 to 2020
  - Only „neighbouring nations" to monitor action plans
  - 40% CO_2-target remains
- MSCI to include carbon footprint information in its share index

The energy trilemma*

climate change is not the only issue

- **Equity** (Accessibility & Affordability)

  Access to electricity and fuels outside the developed world (infrastructure)

  Energy prices affordable to the low-income population
- **Security**

  Mitigation of dependence from supply from abroad

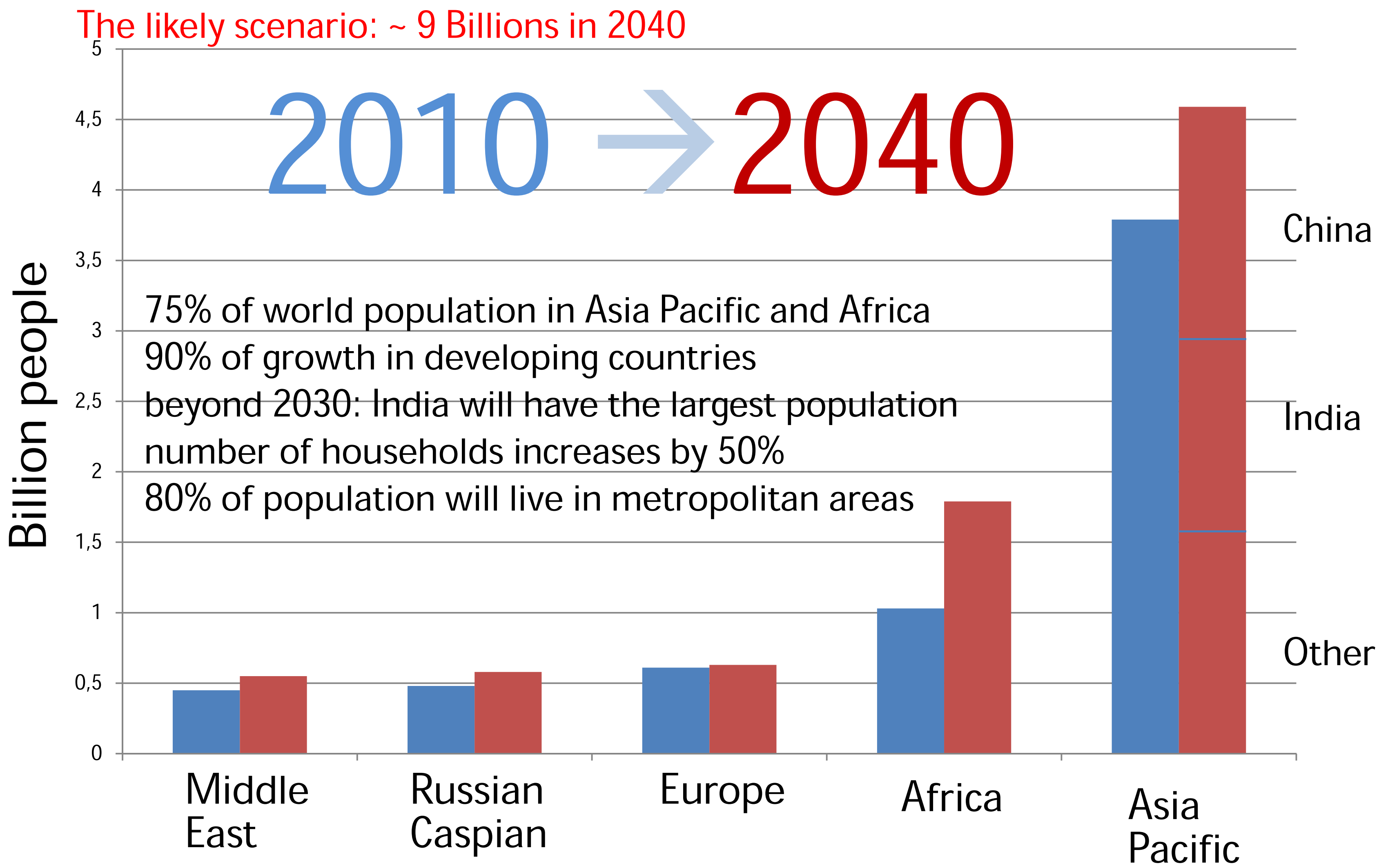
  Risk of unsecure supply from indigenous resources (also renewables)
- **Sustainability**

  Compatibility with GHG targets

  Avoidance / Minimization of damage to the environment and living conditions

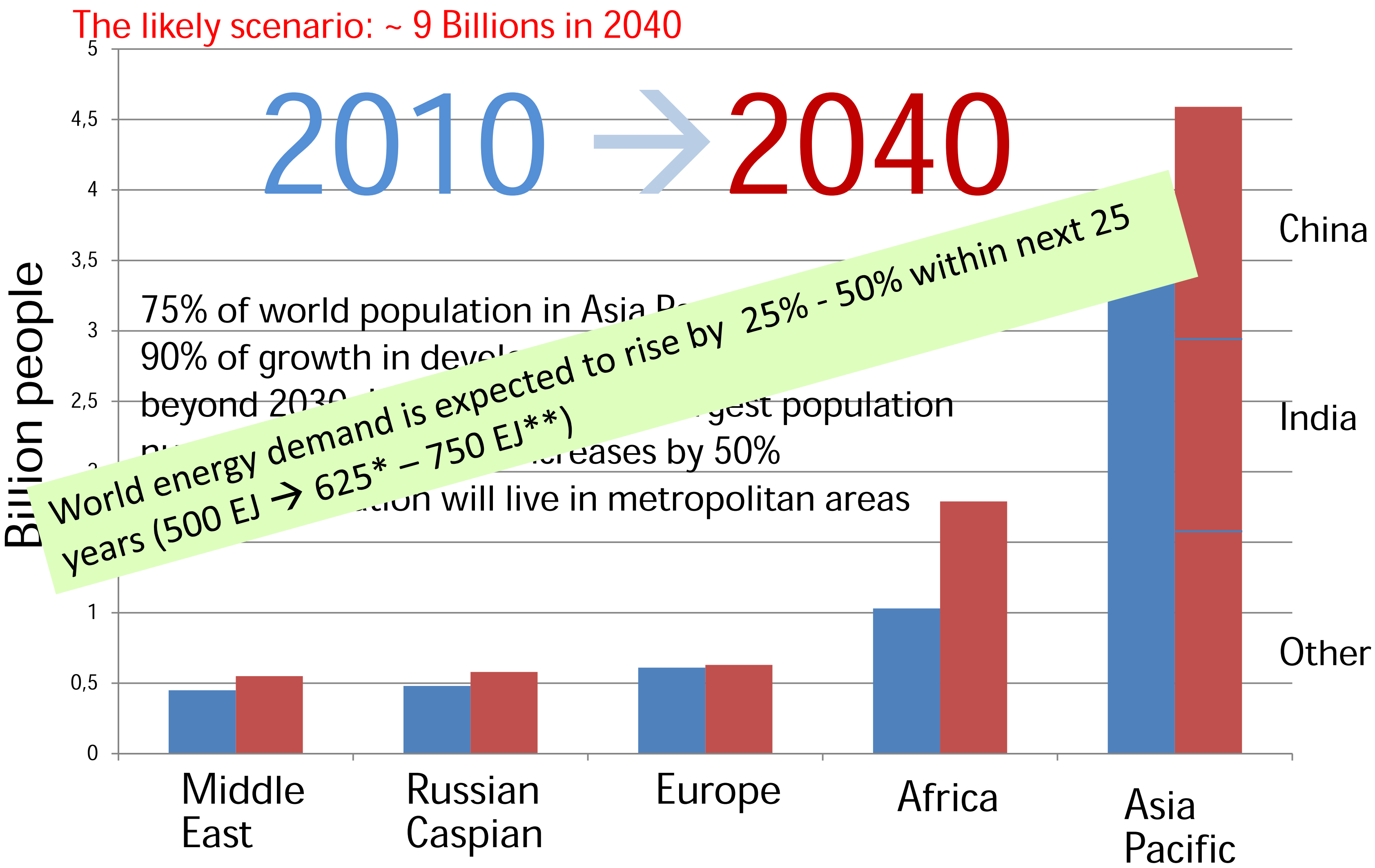
*World Energy Council 2012, 2015

World Population: towards 9 Bio in 2040



data source: exxonmobile energyoutlook 2013

World Population: towards 9 Bio in 2040



data source: exxonmobile energyoutlook 2013

Economic/political perspectives 2010 → 2100: major shifts

- New powers are expected to dominate the development
- --> 2050: **BRICS** = Brasil, Russia, India, China, South Africa
    - dominate the use of resources
    - dominate energy production and
    - govern (energy) trade?
- Wealth generation of „Old economies“ on decline? Probably not for all.
    - US and Canada may become major fossil energy producer
    - European energy resources (UK, NO, …) in strong decline
- beyond 2050: Further shift of economic weigths?
  - India, Africa, South America?
    - Will Europe, the US or others accept their dwindling roles?

- **China** (~+10% GDP_{2010}) **will overtake the US economy** in 2026 (World Bank) or in 2019 (Economist). Even with present uncertainties (2015) China will become soon the world‘s largest economy.

  India and Africa may follow later.

Economic development 2010 → 2100 (smooth development)

- GDP: a continuing increase*
  - World real GDP grew on average +3.6%/a between 1961 and 2012 (per capita +1,9%/a)+
  - World real GDP growth in 2011 and 2012 was 4.7% and 4.1%
  - With <+3.5%> it would grow by **360%** till 2050 and by 2000% till 2100
- Energy intensity**: a continuing reduction
  - Structural changes (changes in sectoral composition of industries)
  - Intensity demand of individual industries
- Increase of Energy demand: even with the expected reduction of energy intensity:
  - → still **a factor >3.5 …6 in total primary energy against today**. (we will assume 2-3)
- ?? Energy prices are expected to stay high or to rise further: this will support expansion of renewable and nonconventional fossil sources.
  - US natural gas ($2010/Mio BTU): 1990: 2.5, 2010: 4#, 2035: 6 …8 (source: EIA EAO 2012)

\+ Source: World Bank.

* BP energy outlook 2030 (2013) expects 3,5% average increase around 2025 - 2030.

** Contains generally two aspects: intensity change in individual industries and structural change in industries.

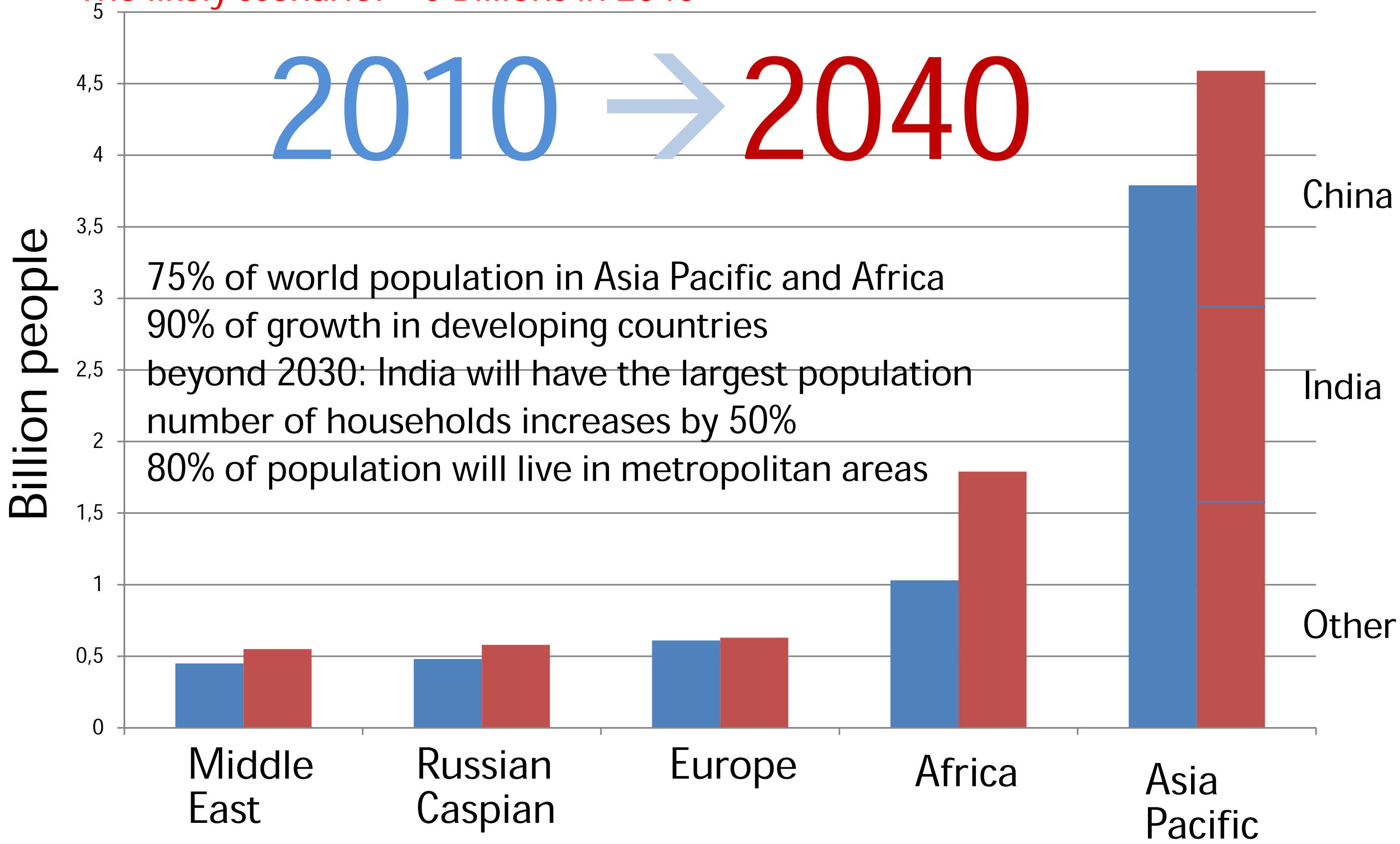
See e.g. for the US: Ian Sue Wing and Richard S. Eckaus, Energy Policy 35, 5267 (2007)

*** own estimate, BP estimates 31% decrease till 2030 (-1.9% p.a.) although it was 1% between 2000 and 2010. If we assume <-1.3% p.a.> until 2100 this gives 0.5 kWh/€ , <-1.9% p.a.> gives 0.28 kWh/€ which corresponds to an increase of total primary energy by a factor of about 3.5 till 2100.

#: after much higher prices in the recent past this reflects already the shale gas opportunities

World Population: towards 9 Bio in 2040

The likely scenario: ~ 9 Billions in 2040



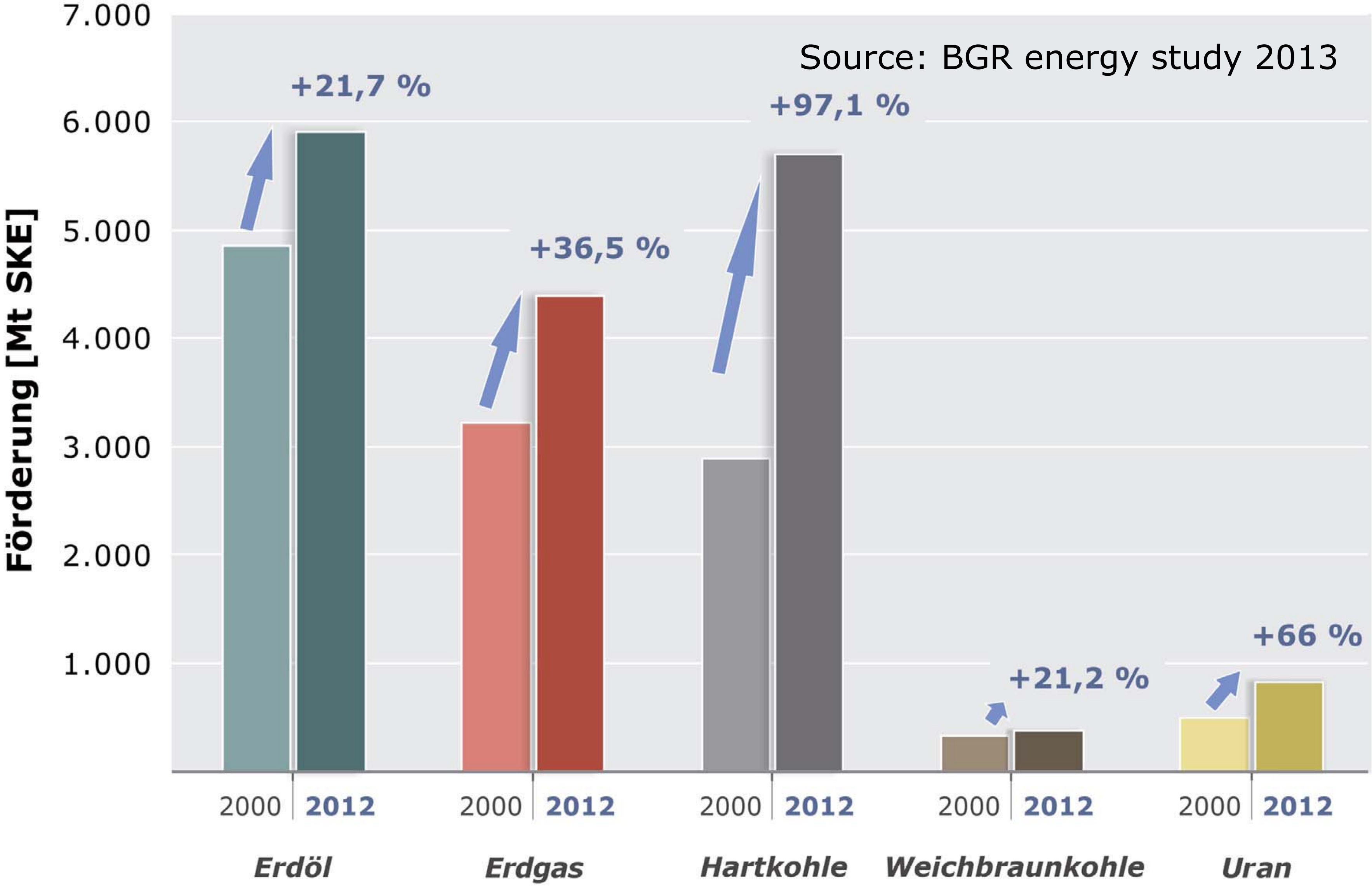
data source: exxonmobile energyoutlook 2013

Population and Energy

2011	World	USA	German y	China	India	Bangladesh
Population (Mio)	7,000	319	81	1,364 2014: 1,391	1,295	159
toe/cap	1.87	7.0 2014: 6.9	3.8	2.0 2014: 2.2	0.6	0.21
distance to 2 toe/cap	+7%	-71%	-47%	0 2014: -10%	+333%	+952%
Prim. Energy consumption (Mtoe)	13,100	2,233	308	2,728 2014: 3,034	777	33
change in consump-tion per decade	+29.9% (2001-2011)	+1.3% (2001-2011)	-1.68% (2000-2010)	+239% (2000-2010)	+71.4% (2000-2010)	+92% (2000-2010)

data sources: World Bank, http://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE
U.S. Energy Information Administration (EIA) 2015

Fossil fuels – world production 2000 → 2012



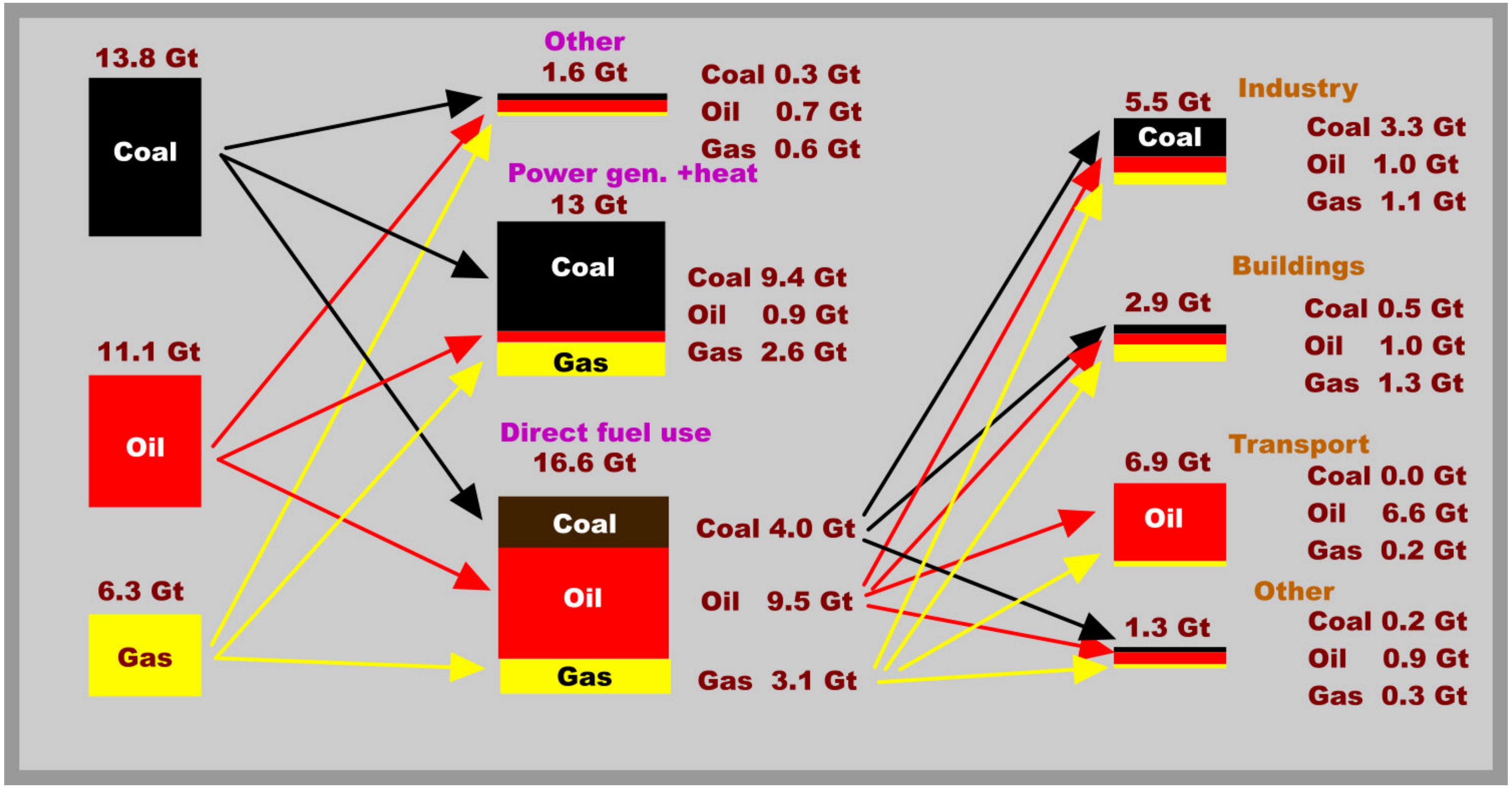
Fossil fuels

World	Consum-ption (EJ 2012)	Reserves (EJ)	Ressources (EJ)	Range (years)
Oil (conventional)	172	7050	6732	53 /
Oil (unconv.)	incl.	2001	11191	/ 104
Gas (conventional)	125	7244	11779	60 /
Gas (unconv.)	incl.	211	20021	/ 254
Total Hydrocarbons	*297*	*16507*	*49723*	*75 / 167*
Hard Coal		22320	474655	
Lignite		3259	49500	
Total Coal	*156*	*22320**	*474655**	*143 / 3042*
Total Coal+Oil+Gas	**453**	**38826**	**524378**	**86 / 1158**
Uranium+Thorium	21	1084	9116	52 / 434

* 762 Gt Coal, 16200 Gt Coal, respectively

World fossil CO_2 emissions by fuel and sector

- **31.2 Gt CO_2 (2011)**



* Data: World Energy Outlook Special Report 2013

China*

- Remarkable Energy supply capability and security. In 2011, the output of primary energy equaled 3.18 Gtons of standard coal (93.2 EJ), ranking first in the world.
- From 1981-2011 China's energy consumption increased by 5.82% annually, underpinning the 10 percent annual growth of the national economy.
- From 2006 to 2011, the energy consumption for every 10,000 yuan of GDP dropped by 20.7 percent, saving energy equivalent to 0.7 Gtons of standard coal.
- Rapid development in non-fossil energy.
  - hydropower reached 230 GW in 2011, ranking first in the world.
  - Fifteen nuclear power plants went into operation, with 12.54 GW. Another 26 units under construction with a total installed capacity of 29.24 GW, leading the world.
  - The installed capacity of wind power reached 47 GW ranking top in the world.
  - Photovoltaic power reported speedy growth, with a total installed capacity of 3 GW.
  - Solar water heating covered a total area of 200 million sq m.
  - The state also expedites the use of biogas, geothermal energy, tidal energy and other renewable energy resources.
- Non-fossil energy accounted (2011) for 8 percent of the total primary energy consumption, which means an annual reduction of more than 0.6 Gtons CO_2 emission.

* Han Wenke, Yang Yufeng: Chinas 12th Five Year Energy Plan period 2011-2015 (China-Energy Outlook Exec. Summary) ERI Chinese Energy Research Institute National Development and Reform Commission (downloaded 24.2.2013)

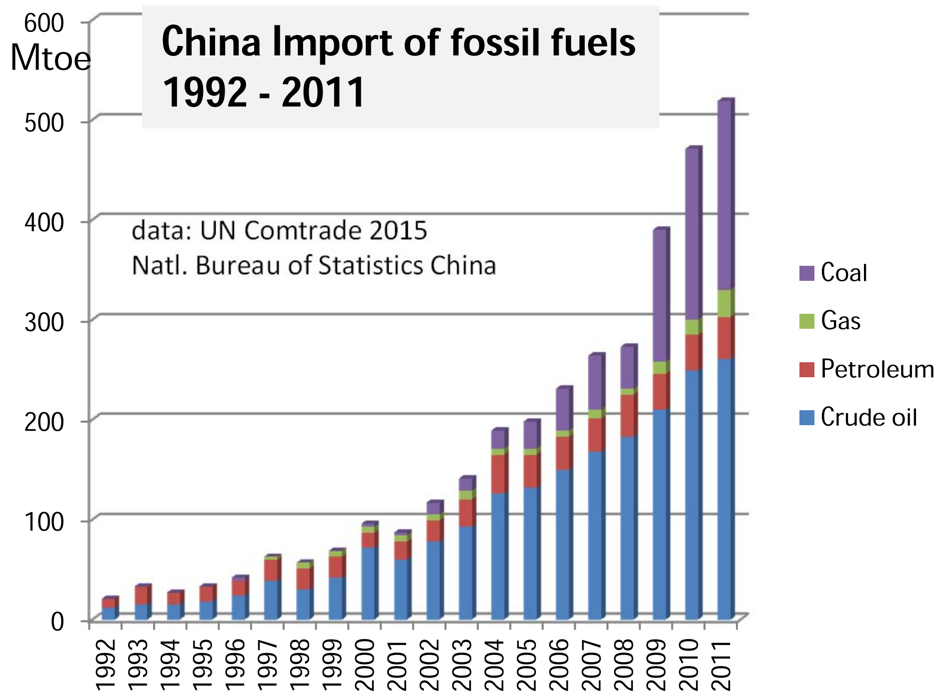
China

New Climate Action Plan 2015 with Target 2030:

- reduce CO_2/GDP by 60-65% against 2005 (target was 40-45% by 2020)
- non-fossil primary energy share → ~20% (target was 15% by 2020)
  - Renewables
  - Nuclear
- emissions will peak around 2030

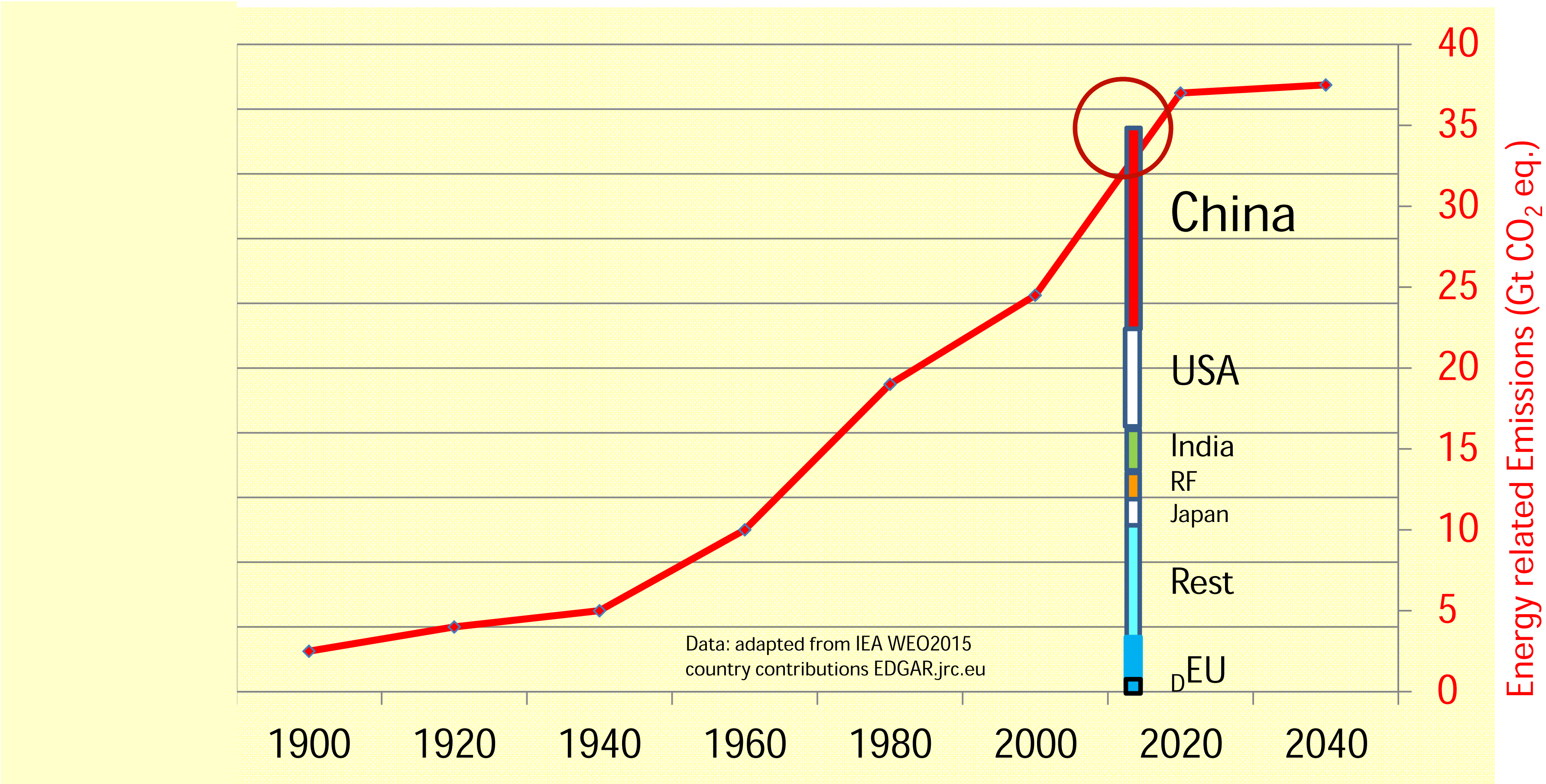
Current developments:

- rising domestic oil production, substantial potential of conventional and tight oil
- expansion of fossil fuel imports from Russia, Indonesia and other countries
- active policy for securing and gaining access to oil&gas potential in south chinese sea



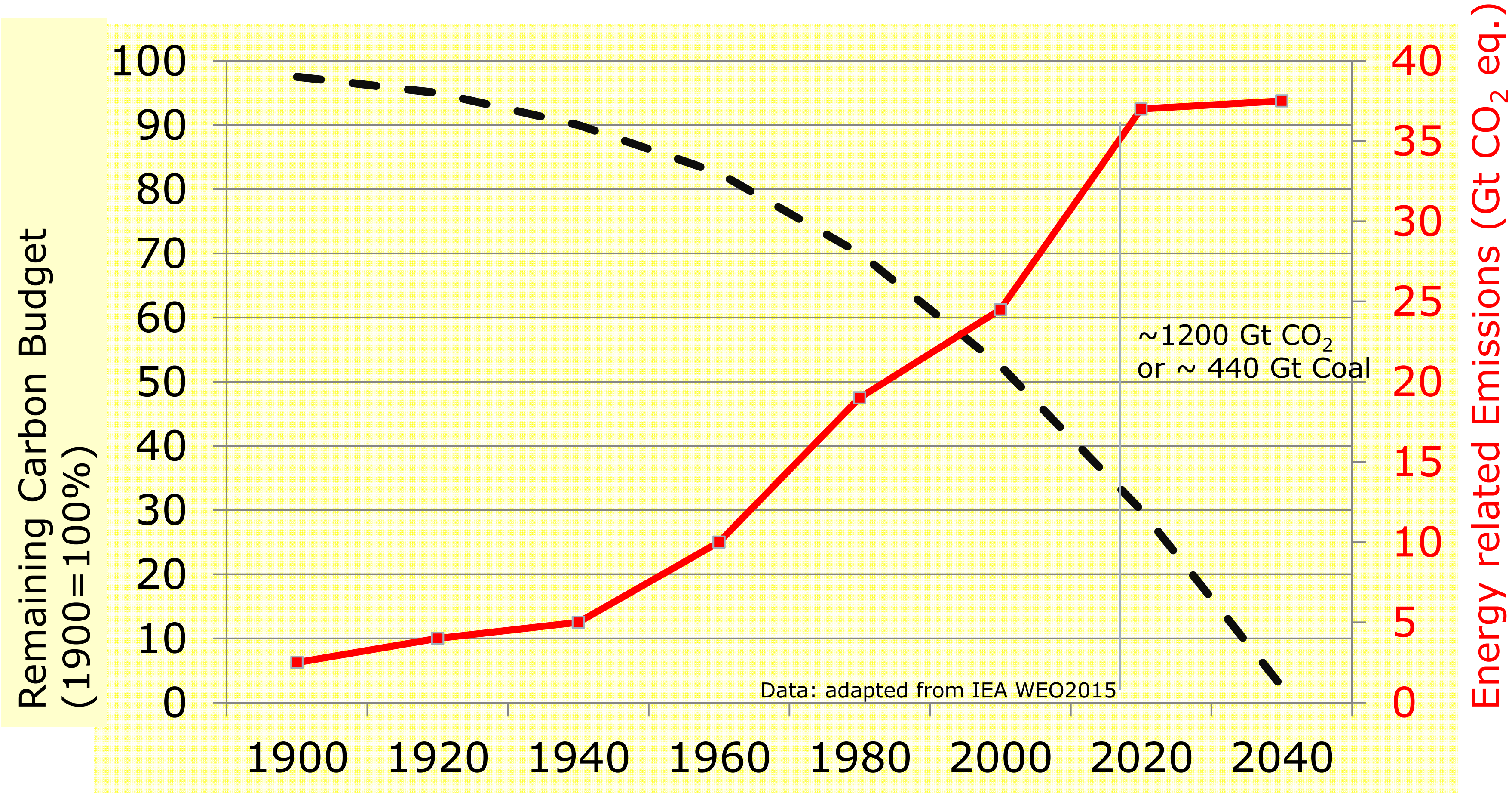
Global annual CO_2 emissions

(IEA INDC Scenario with 50% chance of reaching 2° goal)



Annual CO_2 emissions and remaining carbon budget for 2° scenario

(IEA INDC Scenario with 50% chance of reaching 2° goal)



Positive Trends

- Use of low-carbon energy sources is expanding rapidly
  - Renewables account for nearly 50% of all global new generation capacity
- Signs that growth in the global economy and energy-related emissions may be starting to decouple
  - 2014 first time since 40 years (outside economic crisis) that global economy grew (by 3%) and energy related CO2 stayed flat
  - World energy intensity dropped by 2.3% due to
    - Improved energy efficiency
    - Structural changes in some economies
- Mobilized climate financing of developed to developing countries reached 62bn$ in 2014*, on a good path towards the agreed green fund of 100 bn$/a by 2020.

*source: OECD/CPI report 2015

How to reduce GHG emissions?

Local action does not help – world wide action needed

- **Subvention of CO2-lean Technologies (this is no market concept)**
- **Energy Market: make CO2 expensive (inclusion of external cost): The way to go worldwide in order to achieve**
  - **Reduction of fossil energy demand by change of consumer habits**
  - **New CO2-lean technologies by Research and Development and their implementation**

*World Energy Council 2012, 2015

Reduction of GHG emission by market mechanisms

- ETS (Emission Trading System): Certificates allow units of emission and can be traded so that the most economic approach for GHG avoidance will develop. The total number of Certificates will be reduced (cap) thereby progressively limiting the permitted overall emission in a region.
  - any reduction which is not reflected in the cap will have no impact
- Carbon Tax: GHG emissions are made expensive by taxation thereby providing an incentive for their avoidance.
  - no direct control over total emissions

Emission trading systems – Carbon taxes

- Examples (mainlgy for electricity and industry sectors)
  - **EU:** covers ~45% of EU-GHG. Certificates 3.5€/tCO2 (2013) due to excess provision of certificates.
  - **US RGGI** (East Cost from Delaware to Vermont): carbon budget down by 45% reflecting lower actual emissions partly due to shale gas replacing oil&coal.
  - **China** pilot system in cities and provinces covering >25% GDP and population of 250 million. To be expanded nation-wide after 2015.
  - **World Bank**: scheme for carbon market in 16 developing and emerging economies. Links to California, Quebec, Australia (and the EU in 2018)
  - UNFCCC: *non-Annex I* countries: **clean development mechanism** (2/3 of projects in China and India) close to failure, price at 0.3€/t

International climate protection (EU-vision)

- **2015 international agreement**
  (Adoption at the Paris climate conference COP21, Dec. 2015 ?)

  - 2050: Reduce global emissions by 60% (basis 2010)
  - Create a common legal framework applying to all countries
  - Fair and ambitious targets based on global economic and national circumstances
  - Regularly review and strengthen countries' targets in light of <2° goal
  - Hold all countries accountable … for meeting their targets
  - Negotiation text for the agreement was agreed in Feb. 2015
  - So far, countries representing ~60% of global ghg-emission presented their intended nationally determined contributions (INDC)
  - Preparatory meeting in Bonn (Sept. 2015): some progress at slow pace but also frustration
  - WEC Energy Outlook Special Report (June 2015) analyses voluntary national committments → INSUFFICIENT

European climate protection aims (reductions per basis 1990)

- **Horizon 2020** European Council 2007[1]
  - 20% (or even 30% [2]) greenhouse gas reductions
  - 20% more renewable energy
  - 20% energy savings

20-20-20% goal

- **Framework 2030** European Council 2014, goals[3]
  - > 40% greenhouse gas reductions (binding)
  - > 27% renewable energy (binding)
  - > 27% energy savings
  - Emission trading reform

>40-27-27% goal

- **Horizon 2050** European Targets 2007[4]
  - 80% green house gas reductions by
    - improving energy efficiency
    - „low carbon" fuels, biomass
    - electricity from „close to zero emission sources"

80% goal

[1] A Strategy for Competitive Sustainable and Secure Energy, EU-Commission (2010)
[2] Commitment of the EU in case other industrial nations would commit themselves as well to reach this target and v developing nations would undertake appropriate efforts.
[3] A policy framework for climate and energy in the period from 2020 to 2030 [COM(2014) 15
[4] Energy Roadmap 2050 [COM/2011/885]

Technical aspects: likely developments

- Electricity (+400% from 1971-2010*) will become the prime energy vector: 1971: 8%*, 2010 15%*, 2050: 25%?, 2100: 40%? * source for present and past figures: IEA World Energy Statistics 2012
- Non-thermal electricity production will reduce primary energy demand.
- Smart grid, new paradigm for balancing production and consumption?
- Improve energy efficiency (40% by 2030? IIASA GEA 2013)
- High temperature supra conductivity?
- Electrical transportation (not for trucks, not for airplanes)
- Fully automated processes
- Robotics – what does mankind?

- Until 2100 there are only two to three generations of energy equipment, 2050 only one or two.

Technical solutions for energy related CO_2 reduction

Wind and PV generation → huge success story

but a system massively dominated by intermittent RES creates serious inherent problems

- Excessive capacity needed
- Surplus energy must be used
- Large backup generation or huge energy storage required

Controllable RES (biomass, water, geothermal)

Nuclear power – in the long-run fusion power

Complementing measures (examples)

- Reduction of consumption and improvement of energy intensity
- Improvement of efficiency of thermal fossil power plants
- Use of steerable power
  - nuclear power
  - controllable RES (Biomass, Water, Geothermal)
- Storage
  - Electrochemical, mechanical … storage
  - Power-to-x chemical storage
  - CO_2 capture and chemical conversion
- CO_2 capture and storage (CCS), CO_2 -Chemistry

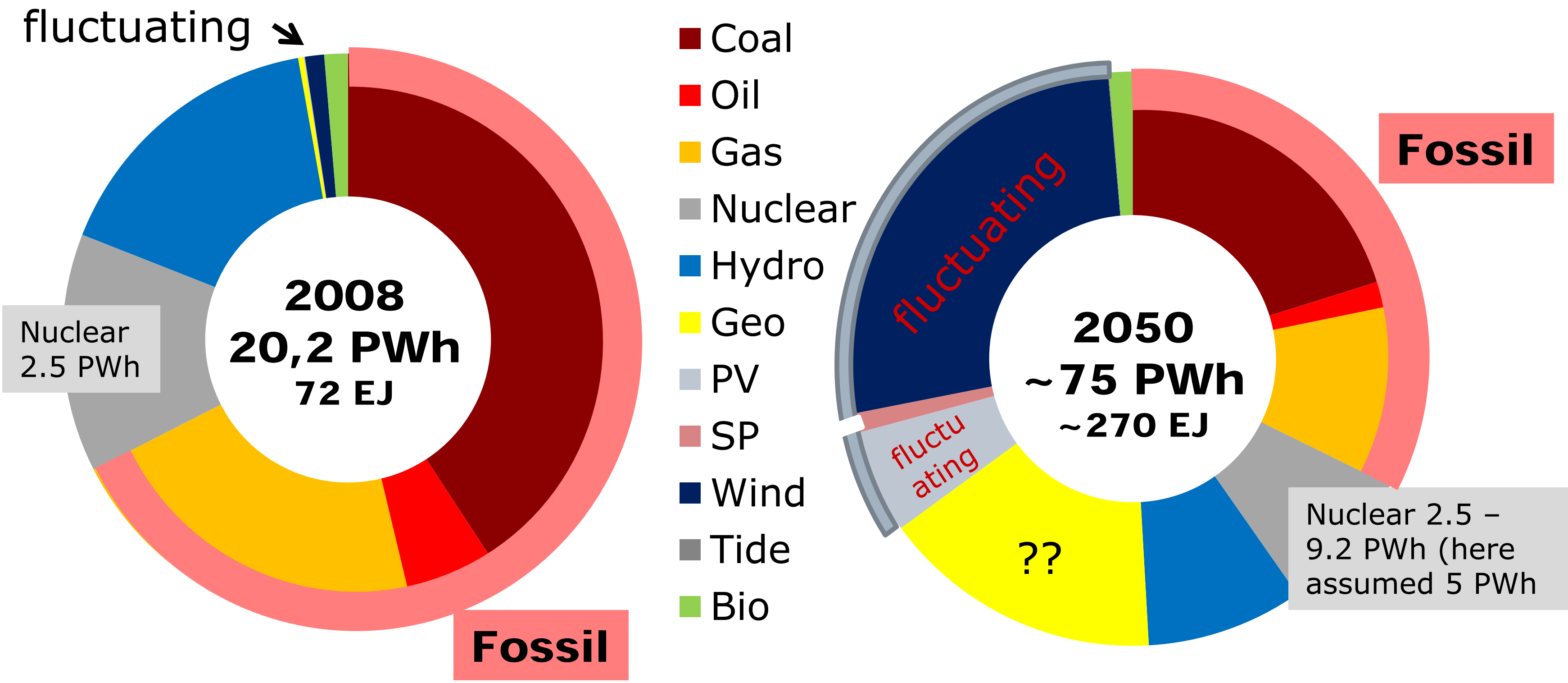
Gross electricity generation in Germany 2000 - 2014

	2014	2000
Total	589.8 TWh	579.6 TWh
Lignite	24,9%	25.7%
Hard coal	18.9%	24.8%
Natural Gas	9.6%	8.5%
Total fossil	53,4%	59%
Nuclear	15,5%	29.5%
RES	25.8%	6.6%
- Wind onshore	8.9%	1.6%
- Wind offshore	0.2%	-
- PV	5.6%	0%
- Biomass+Waste	6.6%	7.8%
- Water	4.3%	3.1%
Other	+- 5%	+-5%

Efficiency
of thermal
power stations
2000: 38.9%
2014: 45.2%
--> 16% CO_2
reduction

Electricity generation now and in 40 years. A possible scenario

Electricity, in the long-term, will become the major energy vector.
World electricity market is expected to grow by a factor 3.8 till 2050,
Nuclear by a factor 1 … **2** …3.8, Fossil could grow by a factor 1.8, renewables (without hydro) by a factor >40



Source: 2008: IEA/OECD; 2050: global value and nuclear: IAEA-RDS-1-32_web.pdf p. 18, contributions of other energy sources (2050): own estimate

Efficiency of fossil power stations

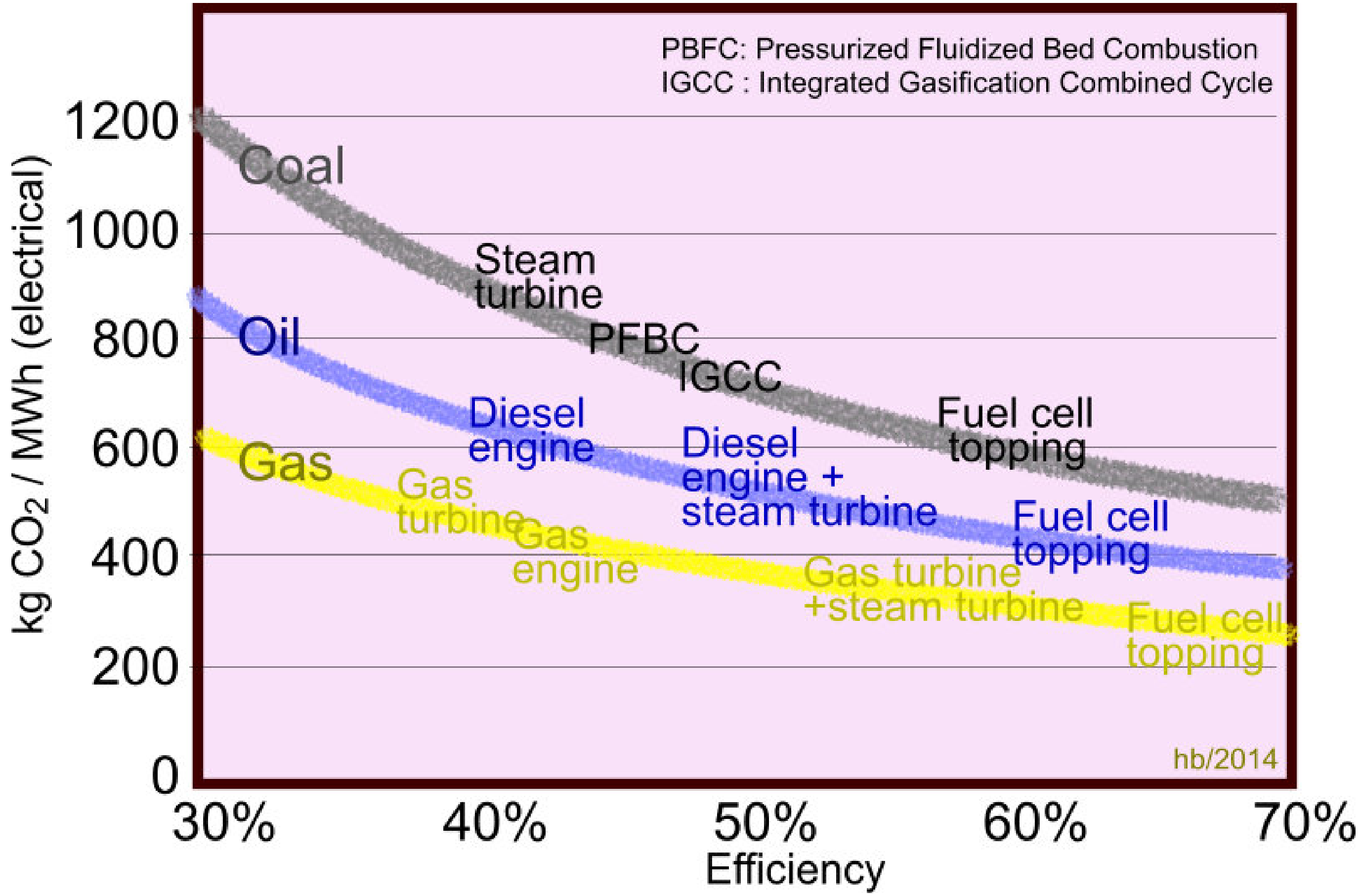
strong near-term impact on CO2 emission reduction

Highly relevant at world level.

Export of novel technology for fossil power stations could provide an important contribution for reducing world CO_2 emissions.

However, this not encouraged by the German government (except for KWK).

Source: Forum für Zukunftsenergien, MinDir Schafhausen, 6. 10. 2015



*source: AGEB

CCS: CO_2 Abscheidung, Speicherung und Verbringung (CCS)

Verbringung des CO_2 in

- Entleerte Öl- und Gasfelder,
- Enhanced Oil recovery
- Tiefe Kohleflöze (adsorbiert an Kohle)
- Aquifere
- ~~Tiefsee~~ –Umweltzerstörung par excellence

- Deutschland: geologischen Speichermöglichkeiten eher gering (30 – 60 Jahre für den aktuellen energetisch bedingten Ausstoß).
- Umwandlung in z.B. $CaCO_3$ (Kalkstein)
  - per Abbau und anschl. Lagerung
  - in situ
- Austausch mit Methanhydrat

- Abscheidung gewaltige Mengen (Welt: Gigatonnen/a).
- Nachweis der Sicherheit für die ganze Verfahrenskette erforderlich
- Wirtschaftlichkeit der Verfahren (bestimmt durch CO2-Zertifikate-Preis)

Photovoltaic cell R&D: continuing progress and still much potential

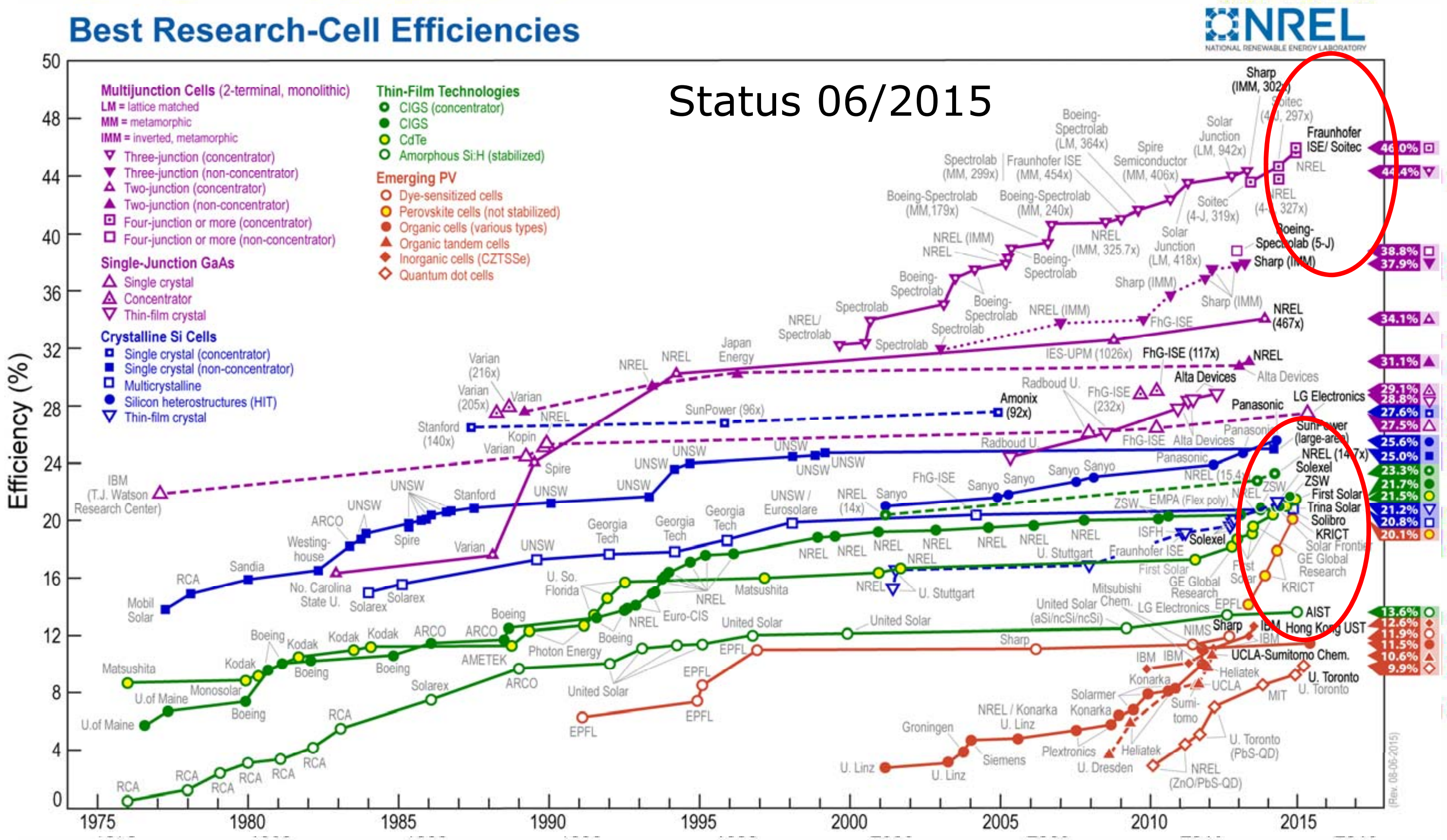
Wirkungsgrad: Rekorde (Labor)

Status 06/2015

Photovoltaic cell R&D: continuing progress and still much potential

TECHNISCHE UNIVERSITÄT DRESDEN

Wirkungsgrad: Rekorde (Labor)



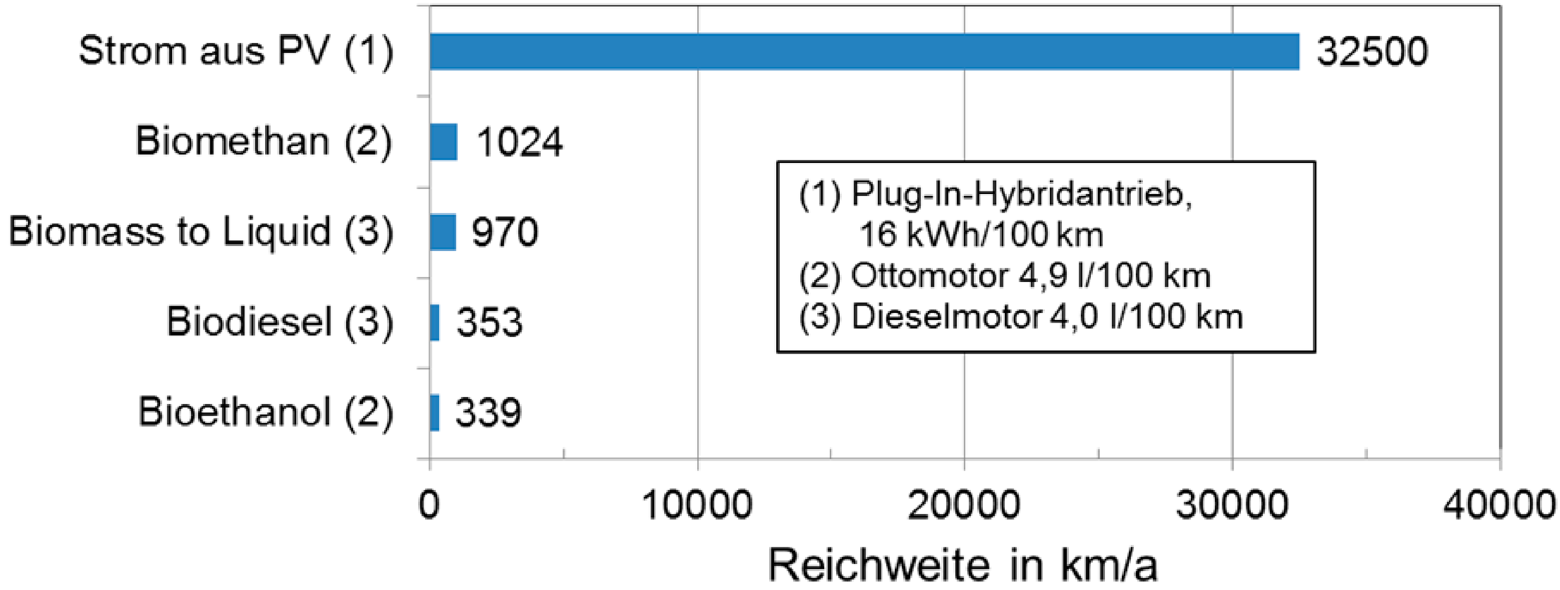
Solution Bioenergy – besides resource competition: Energetic Return of Investment and Energetic Area Efficiency

Biomass may be able to supply 10-20% of global energy demand

	EROI	Area efficiency ($W\ m^{-2}$) (year's average) [e]
Firewood (Germany)	10 [a]	< 0.2
Biodiesel from rapeseed (Germany)	< 2 [a]	< 0.2
Bioethanol from maize (USA)	1.5 [a]	< 0.3
Bioethanol from sugar beet (Germany)	3.5 [a]	< 0.4
Bioethanol from sugar cane (Brazil)	8 [a,b]	< 0.5
Bioethanol from Triticale/maize (Germany) (combined production)(Chapter 2.11)	8 [a]	< 0.3
Bioethanol[a] methane[a] and electricity from lignocellulose (Chapter 2.11)	3	< 0.5
Bioethanol from switch grass (USA)	5.4 [a]	< 0.2
Bio-butanol	< 1 [a]	
Biodiesel from algae (Chapter 1.17)	< 1 [a]	
Biogas from maize silage (Germany)	4.8 [a]	< 1.1
Biogas from maize silage (Germany) (electricity)	1.4	< 0.4
Photovoltaic (Germany) (electricity)	7	> 5
Photovoltaic (Brazil) (electricity)		> 10
Wind turbine (Germany) (electricity)	18	(2 – 3 [c])
Nuclear power (electricity)	10 – 20 [d]	
Hydropower (electricity)	100	

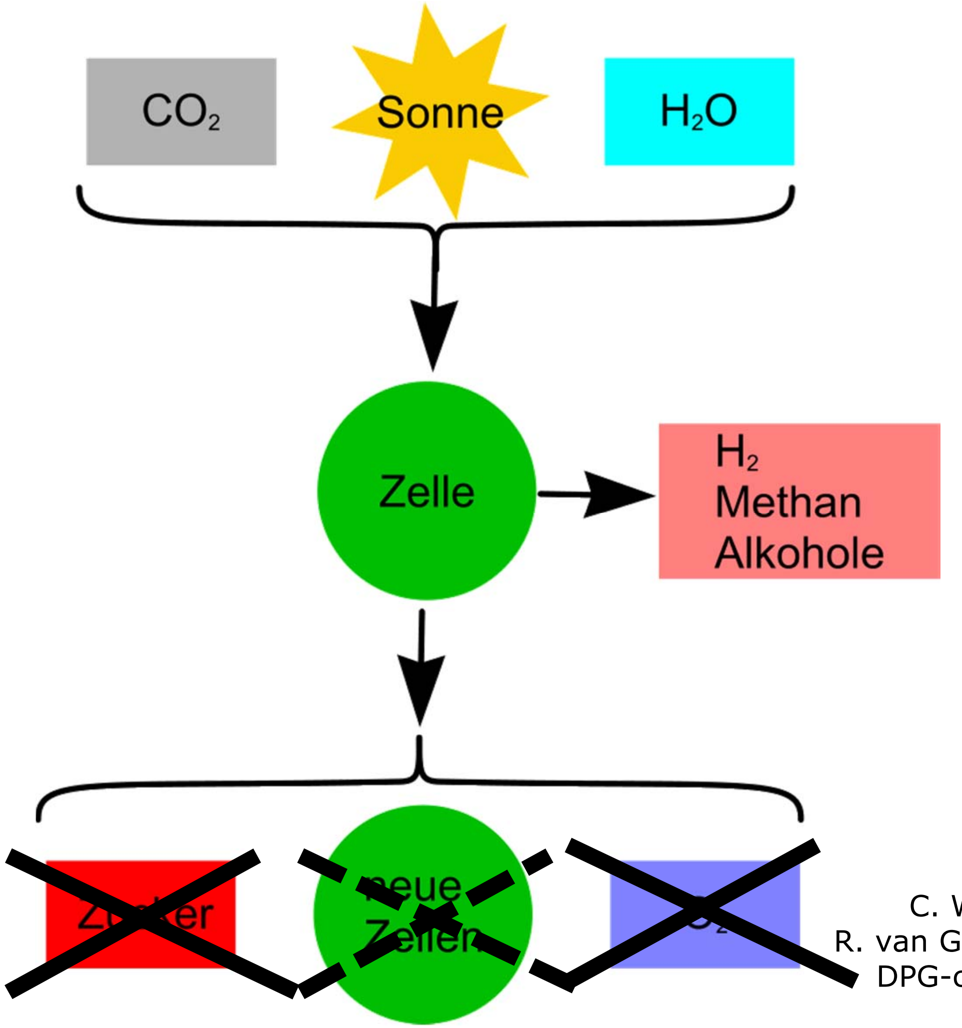
Source: Leopoldina Bioenergy Study 2013

Land use: comparing PV with biofuels



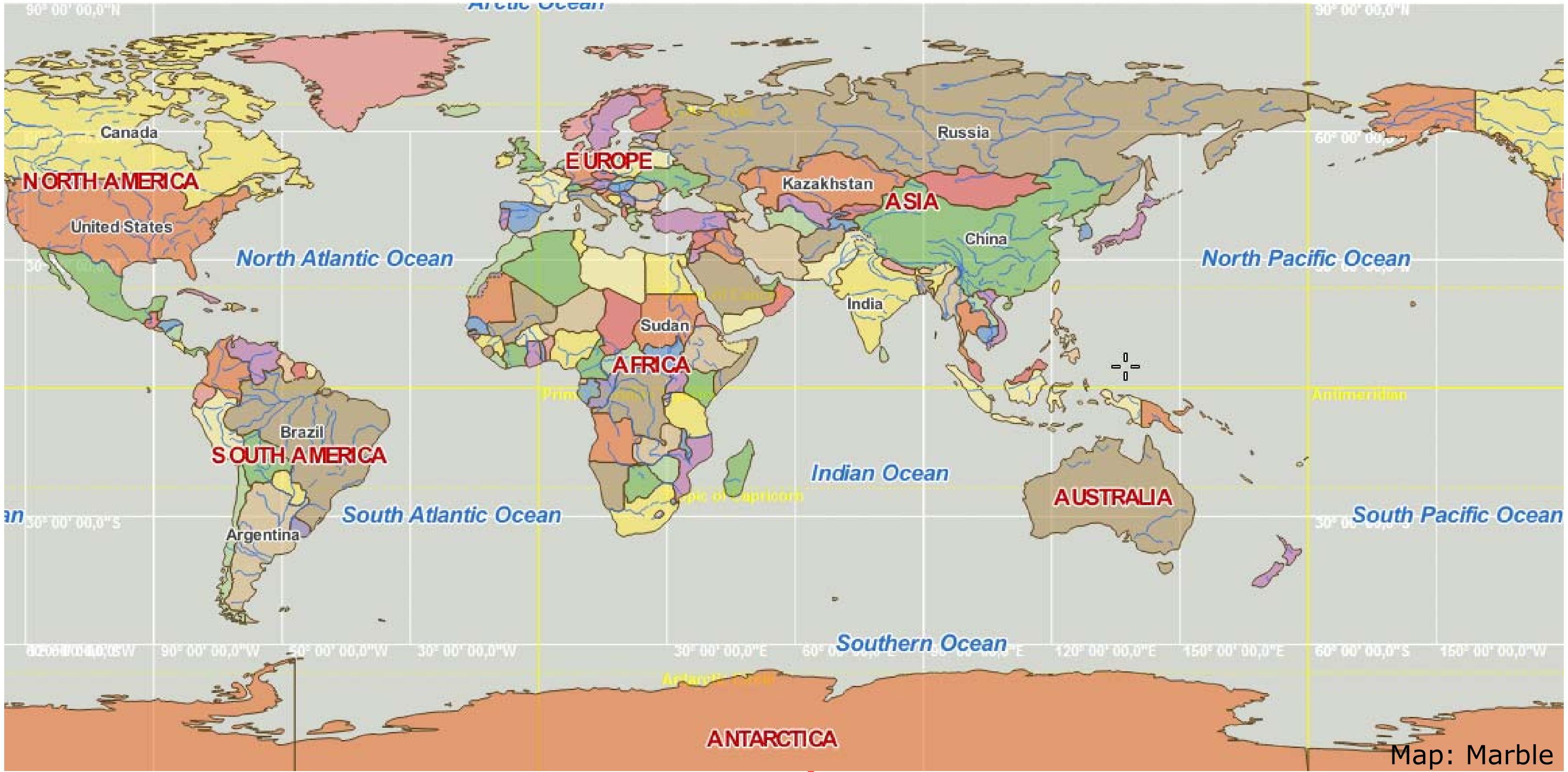
Vehicle range for an annual yield of 1 a = 100 m2 of energy crops (2,3) or 40 m2 of elevated PV modules constructed on 100 m2 of flat open ground, Sources: ISE FHG after (Photon, April 2007 (data 1) and Fachagentur Nachwachsende Rohstoffe (data 2, 3).

Neue Wege: Biotreibstoffe ohne Biomasse?



C. Wilhelm, (U. Leipzig),
R. van Grondelle (FU Amsterdam),
DPG-conference Berlin 2014

German Energy: the 2% model country?

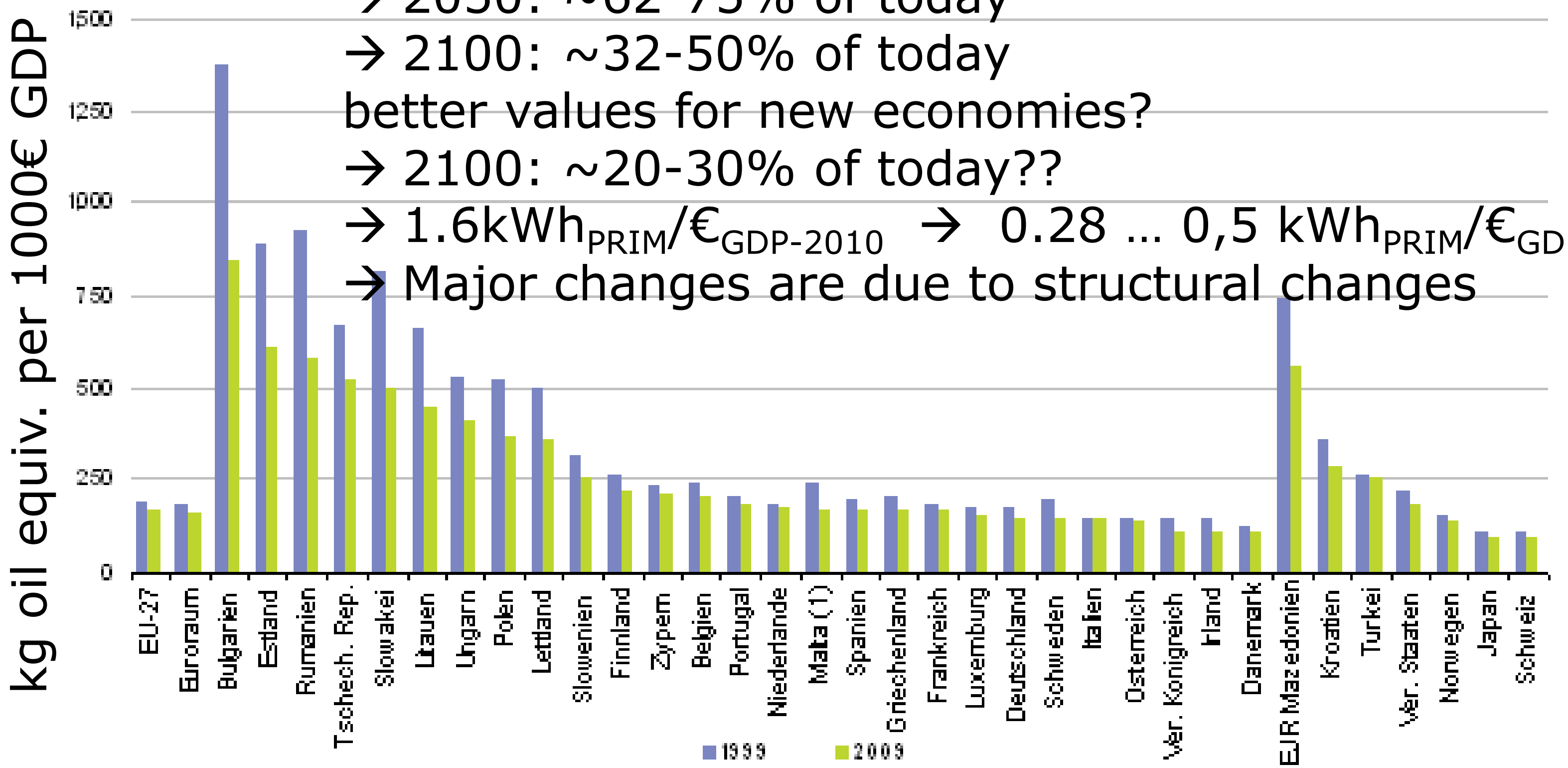


Jahr: 2013	Deutschland	% Welt
Energieverbrauch:	332 Mtoe (~14 EJ)	2,6%
CO_2-Emission:	748 Mt_{CO2eq}	2,4%

Quelle: IWR Münster, eia USA, status 03/2014

Energy intensity changes: intrinsic and structural causes

Overall improvement ~-0.7%/a (EU), -1.3% (US)
→ 2050: ~62-75% of today
→ 2100: ~32-50% of today
better values for new economies?
→ 2100: ~20-30% of today??
→ 1.6kWh$_{PRIM}$/€$_{GDP-2010}$ → 0.28 … 0,5 kWh$_{PRIM}$/€$_{GDP-2100}$?
→ Major changes are due to structural changes



(1) 1999: vorläufig.
Quelle: Eurostat (Online-Datencode: t2020_32)

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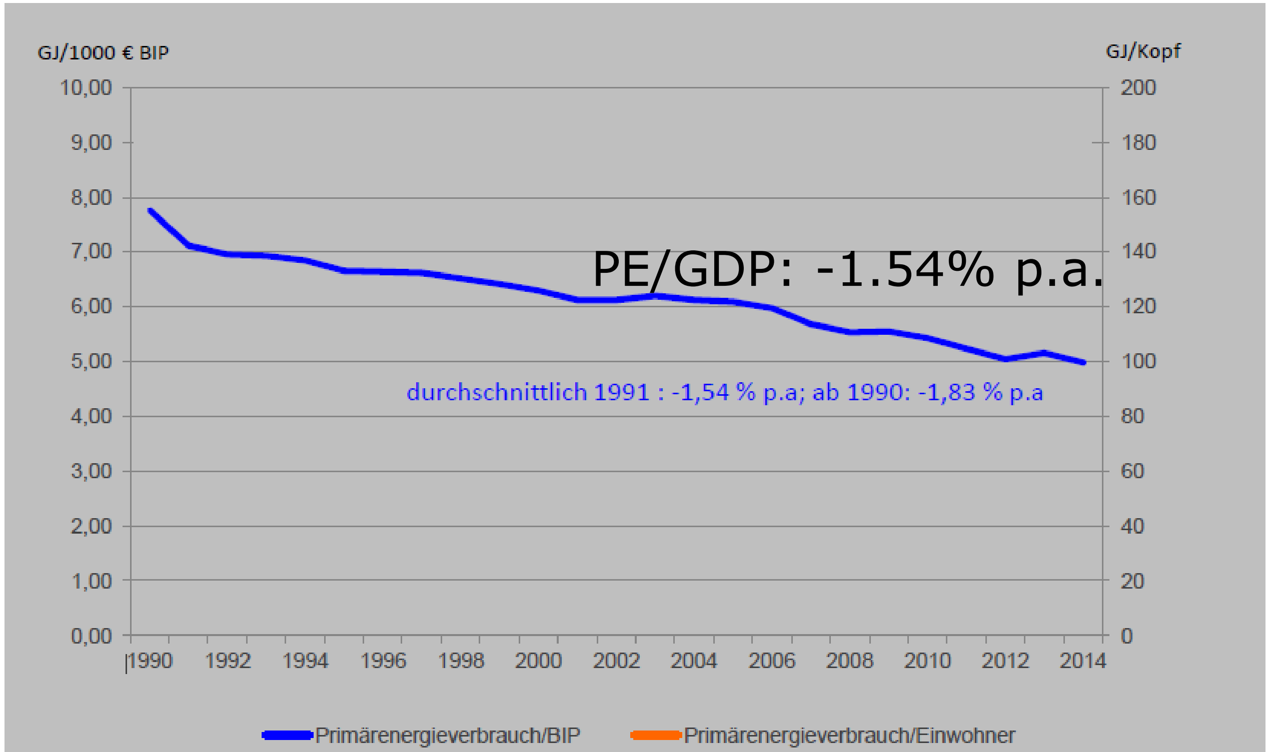
Energy intensity in Germany 1990-2014 (Source AGEB)



Primärenergieverbrauch (PEV) je Einheit realen Bruttoinlandsprodukts (BIP) und je Einwohner

Bereinigt um Temperatureffekte und Bilanz der Lagerbestände

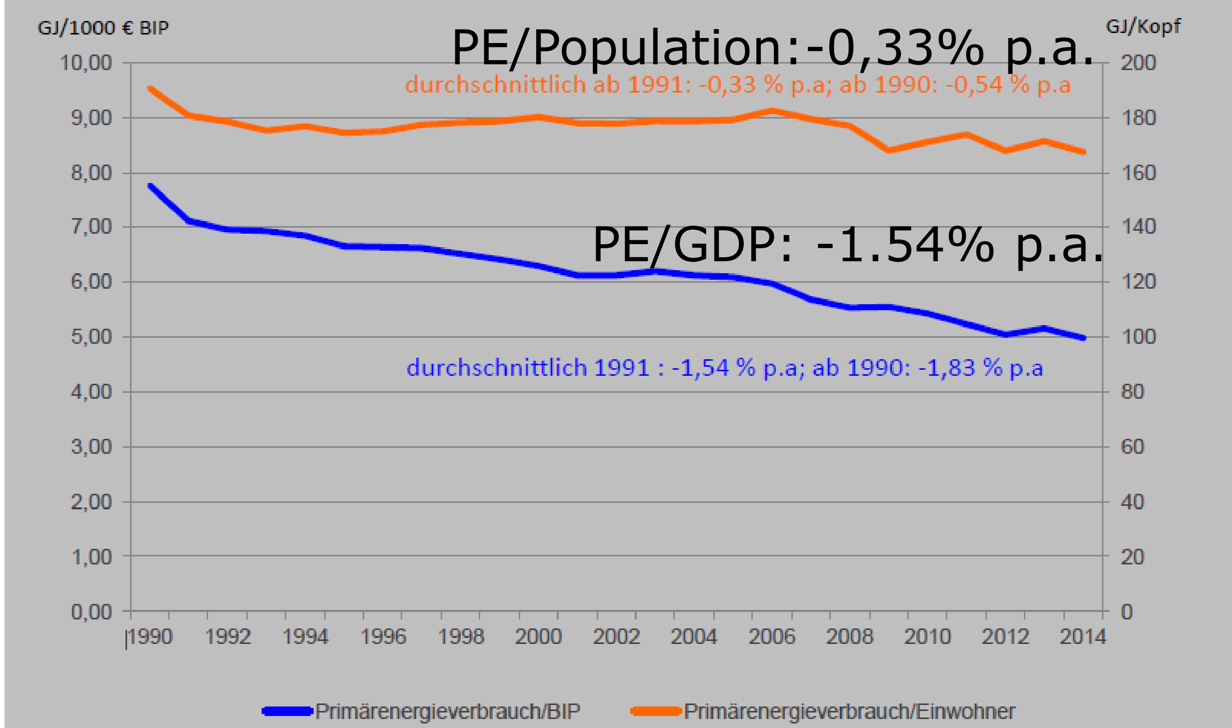
	'90	'95	'00	'05	'10	'13	'14
PEV/BIP	7,7	6,7	6,3	6,1	5,4	5,1	5,0
PEV/Kopf	190,6	174,3	180,1	179,1	171,0	167,9	171,3

[1)] Ergebnisse der VGR-Generalrevision 2014 (dem Niveau der Zeitreihe des realen BIP, liegt der Nominalwert in Preisen des Jahres 2010 zugrunde)

Quelle: Arbeitsgemeinschaft Energiebilanzen u. Statistisches Bundesamt

Structural change: reduction of energy intensity

Energy intensity in Germany 1990-2014 (Source AGEB)



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PEV/BIP	7,7	6,7	6,3	6,1	5,4	5,1	5,0
PEV/Kopf	190,6	174,3	180,1	179,1	171,0	167,9	171,3

[1)] Ergebnisse der VGR-Generalrevision 2014 (dem Niveau der Zeitreihe des realen BIP, liegt der Nominalwert in Preisen des Jahres 2010 zugrunde)

Quelle: Arbeitsgemeinschaft Energiebilanzen u. Statistisches Bundesamt

Structural change: heavy industry in Germany decreases → reduction of energy intensity

Large industries have reduced investment in Germany (and Europe) but strongly expanded in the US and Asia

Carbon leakage – international trade

- Traditional statistics counts CO_2 produced on the territory of a nation.
- Due to shift of industries to e.g. Asia it is more adequate to include CO_2 implied in the production of goods which are consumed by a nation*

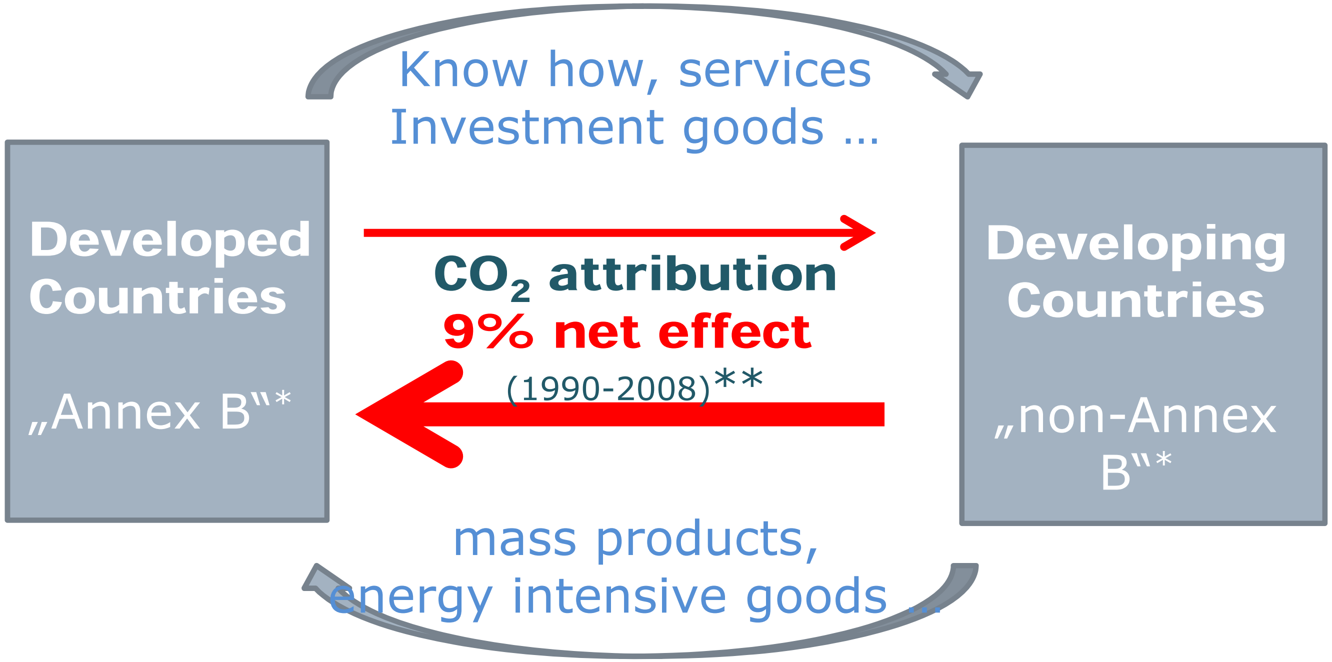
→ Virtual CO_2 reduction in OECD countries

* Peters, G.P. et al. Proc. Natl. Acad Sci (USA) 108, 8903-8908 (2011) DOI 10.1073/pnas.1006388108

Energy intensity

Carbon leakage – international trade

Excluding carbon leakage: German primary energy intensity: -0.33%/cap*year and -1.54%/GDP*year since 1991***. However, Carbon Leakage should be considered:



* Referring to the signatory states of the Kyoto Protocol
** Percentage of „Annex B" Countries' CO2-Attribution. Peters, G.P. et al. Proc. Natl. Acad Sci (USA) 108, 8903-8908 (2011) DOI 10.1073/pnas.1006388108
*** data source: AGEB and Statistisches Bundesamnt (2015)

Energy in Germany
Common critics

- Strategy is expensive, not efficient and, as long as a consisten storage scenario is at hand, risky.
- EEG
  - The EEG-route is likely to require order of 1000 bn€ from the electricity customers*.
  - The EEG withdraws annually order 20 bn€ mainly from tenants and small-income citizens to houseowners and rich investors
  - Merit order: trading prices are fictitious due to the absence of common market boundary conditions for all generation systems.
- German energy policy is supposed to
  - Have established a new industry
    - No major solar player is in Germany
      but major wind manufacturer is in Germany
  - Have created numerous new jobs: net efffect is seen by many economists as negative**.

Some figures for 2012:
German GNP ~ 2700 bn€, wages and salaries ~1120 bn€ (net 750 bn€), federal governments household ~306 bn€ (income)

- BM Peter Altmeier 2012, ** e.g. Sinn, Weimann, Bettzüge, Frondel

Energy: Germany and Europe critics

- ETS – Scheme
  - Due to the colliding ETS and EEG mechanisms there is no net reduction of CO_2 emissions.
    - if one ignores the ETS and only considers the intra-German reduction of GHG, then there is an effect. For the world, however, it always will remain below noticeability.
  - Germany counteracts the ETS by having objected to certificate reduction (Target price was 40€/t CO_2, current price (2015) is 5€/t CO_2)
- Market relations to the neighbours
  - Only by a deficiency of EU subvention rules the EEG appears to be formally compatible with European law. De facto and with regard to the spirit of these rules the feed-in tariff system is inacceptable as it destroys fair European competition.
  - Europe providing fudge factors for overcoming German problems (e.g. market for surplus energy, providing energy storage, interconnector capacity between the north and Bavaria through Poland, Czech Republic, Slowakia, Austria)

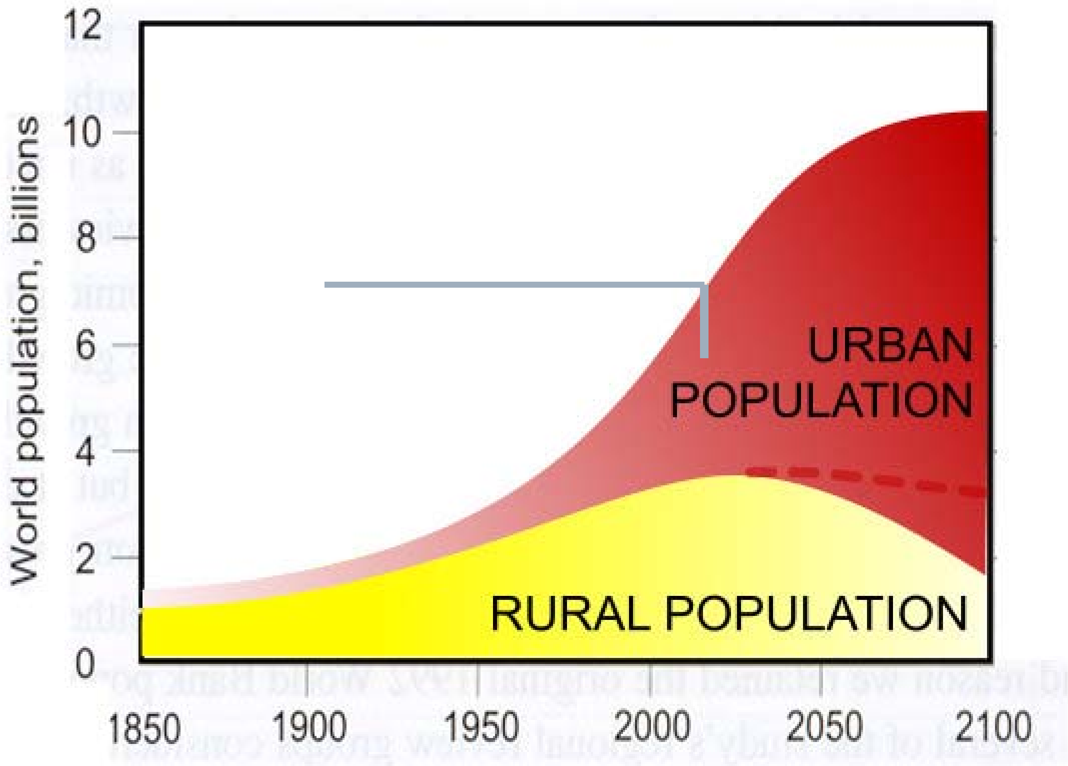
Energy: Germany and the World
critics

- Common Critics
  - German Energy Policy is focused on the national scene. Even if CO_2 would be reduced, the German contribution is negligible in the world-wide context.

As a model, the Energiewende should be

- Applicable to the world
- Demonstrate a convincing energy transition perspective
- Prove to be affordable

Urban population will become the vast majority



Today ~3.5 billion people live in urban environment. 6,5 billion of urban population will exist by 2050 (GEA, IIASA 2013)

Everybody his own energy master?

2050 >6 billion people
2100 >8 billion people
will live in densely populated cities

The German emphasis on decentralised energy production by an „autonomous“ individual is ideologic and clearly no model for the future world.

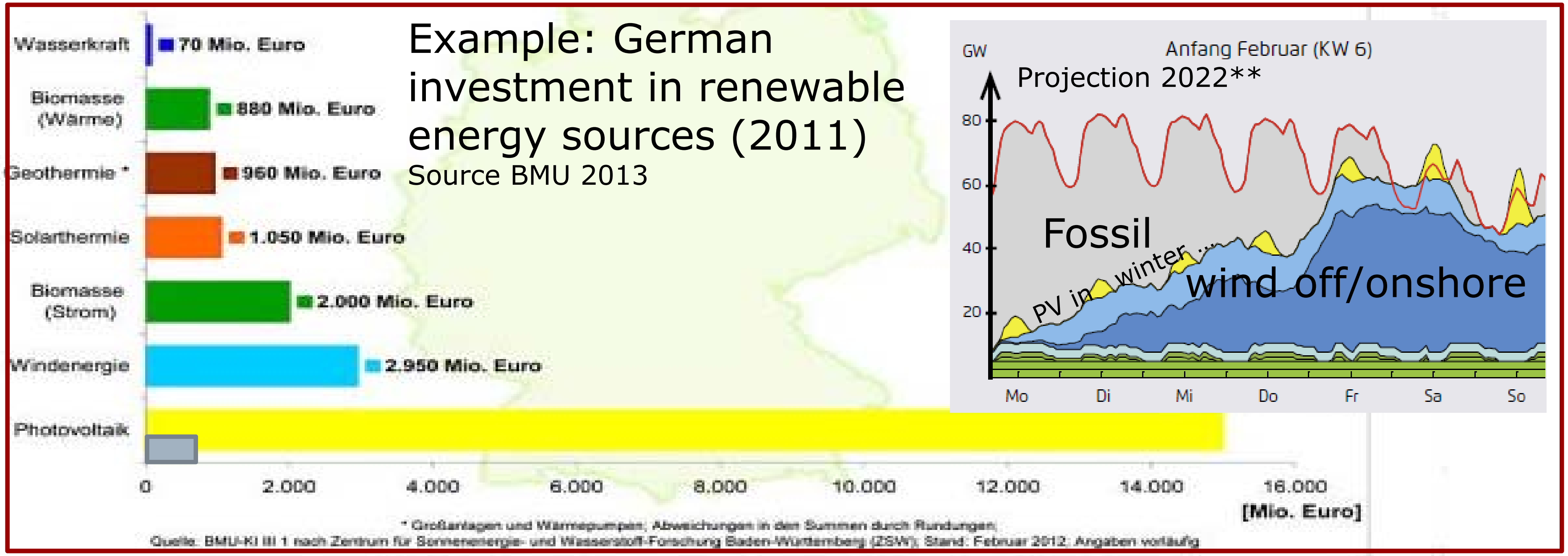
Fotos: H. Bruhns

A strong change in the world‘s Electricity generation installed capacity

- ~ 50% of world added new capacity for electricity generation during 2008-2010 was renewable
- Global added renewable capacity 2010 was ~ 66 GW*#
- EU: since 2006 >40% of annual new capacity# is renewable
  China: 2010: 38% of net added capacity# was renewable

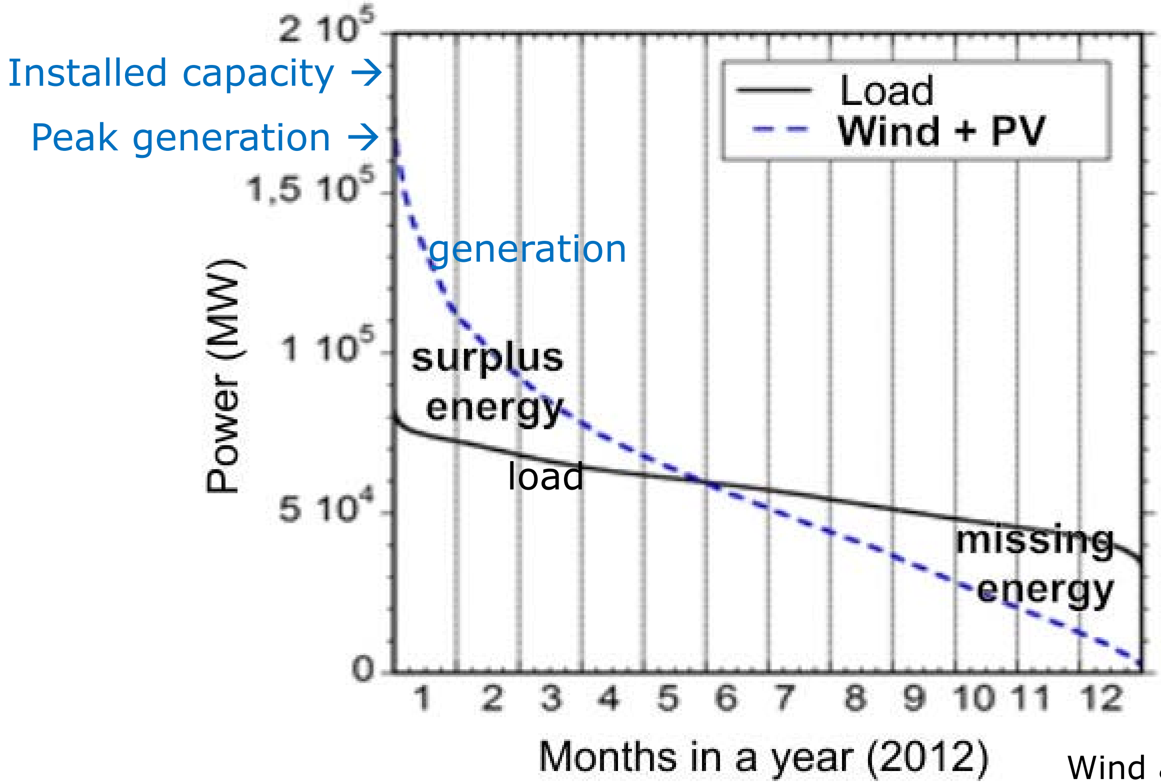
* Source Global Energy Assessment – IIASA 2010, installed nominal capacity

Example: German investment in renewable energy sources (2011)
Source BMU 2013



**Source: Agora Energiewende :12 Thesen zur Energiewende (2013)
http://www.agora-energiewende.de/zwoelf-thesen-zur-energiewende

Load curve 500 TWh: surplus and backup (100% scenario)



Surplus power: up to 90 GW

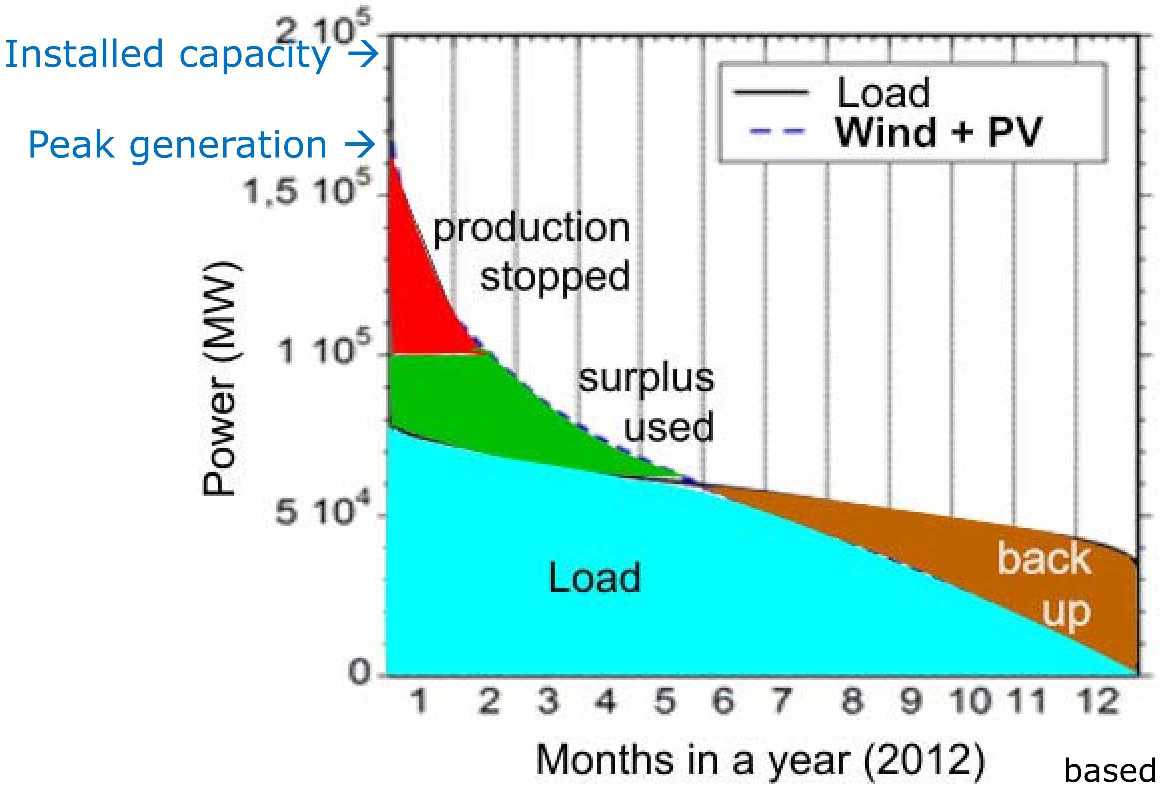
Missing power up to35 GW

Surplus/Missing energy: 110 TWh

Wind and PV data of 2012 extrapolated to 100% average coverage of the annual load

Adapted from: F. Wagner in AKE-Tagungsband 2015 (DPG Bad Honnef 2015)

Load curve 500 TWh: surplus and backup (100% renewable energy scenario)



500 TWh annual load

Peak load power
79 GW ←→ required
Installed capacity
> 190 GW

Surplus power:
up to 90 GW,
needed backup power
up to35 GW

Surplus = backup
energy: 110 TWh

based on Wind and PV data of 2012 extrapolated to 100% average coverage of the annual load

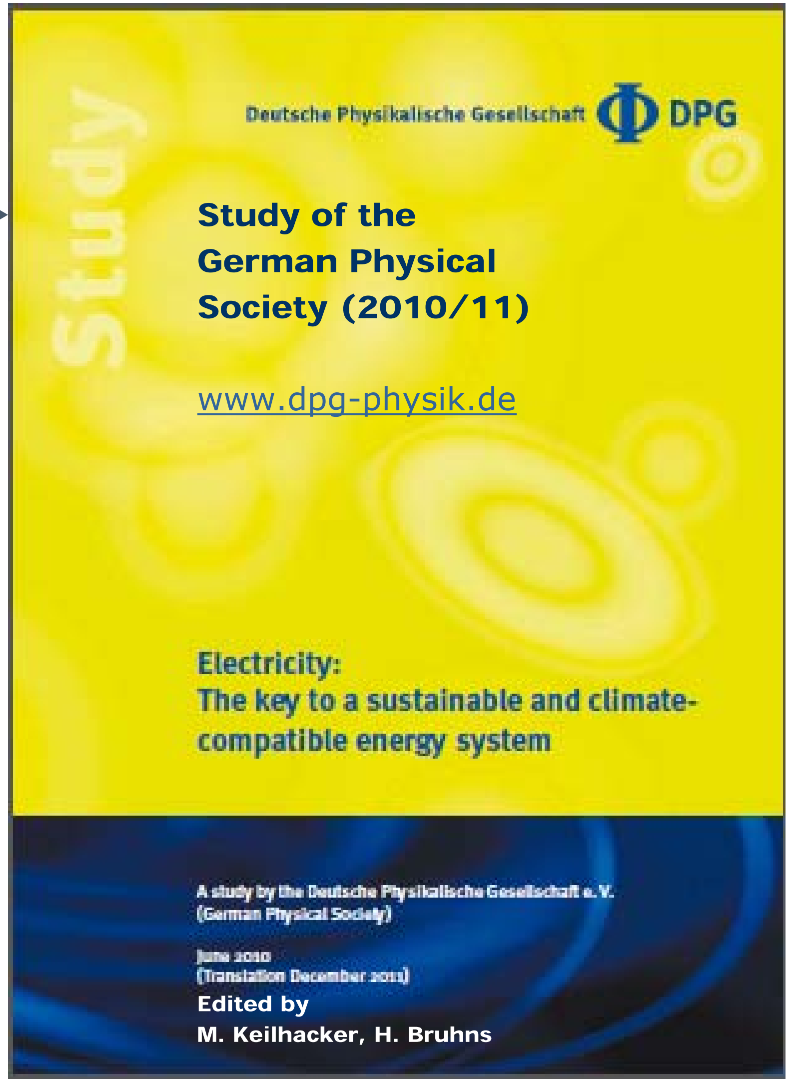
Adapted from: F. Wagner in AKE-Tagungsband 2015 (DPG Bad Honnef 2015)

undesired effects of fluctuating renewables

fluctuating renewable energy systems tend to perpetuate the use of fossil fuels.

with a high fraction of fluctuating power from wind and sun, the marginal price will be very low – wind and PV cannot refinance themselves → perpetual subvention.

due to few operational hours and few cycles, respectively, backup and storage systems will not earn the money needed for their capital investment and maintenance.



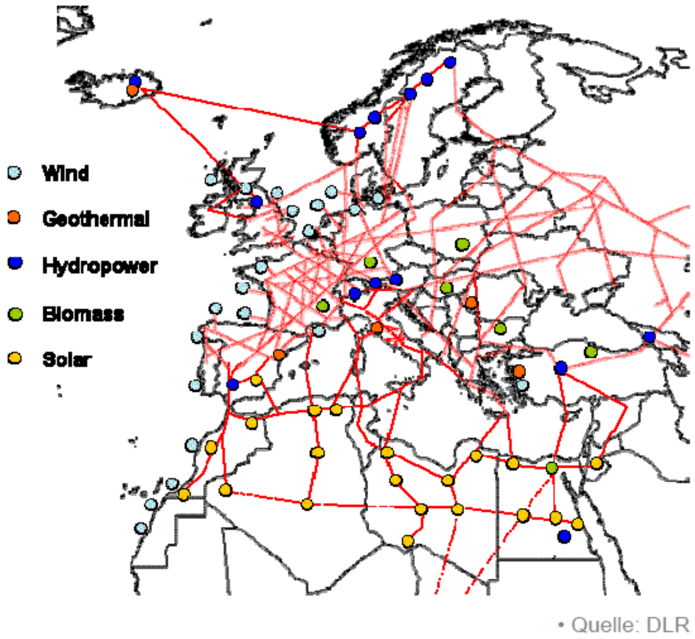
Erforderlich: Verteil- und Übertragungsnetze regional – überregional - europaweit

Obwohl die Netz-Technologien grundsätzlich verfügbar sind, erfordert der neuartige Ausbau intensive Forschung und Entwicklung:

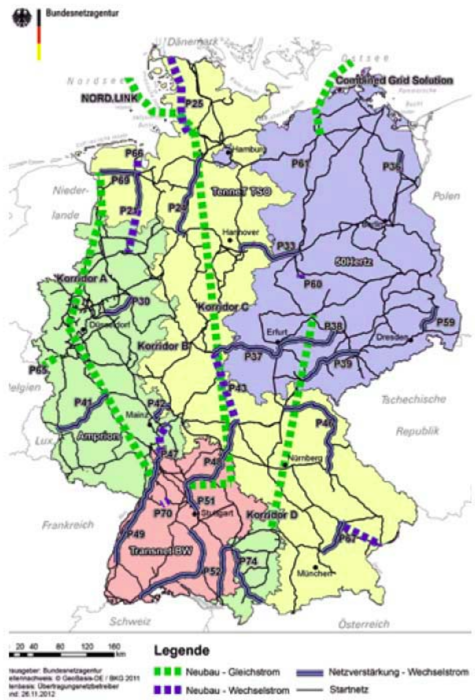
- Multi-Terminal-Fähigkeit
- Stabilität, Systemanalyse
- Optimierung der Wirtschaftlichkeit
- Steuerungs- und Schutzsysteme, "Active Grid", flexibles Verbraucherverhalten.

Ein großes Problem ist gesellschaftliche Akzeptanz neuer Stromtrassen mit hohen Masten …

→ Erdkabel nach Bayern!



Europa



Deutschland

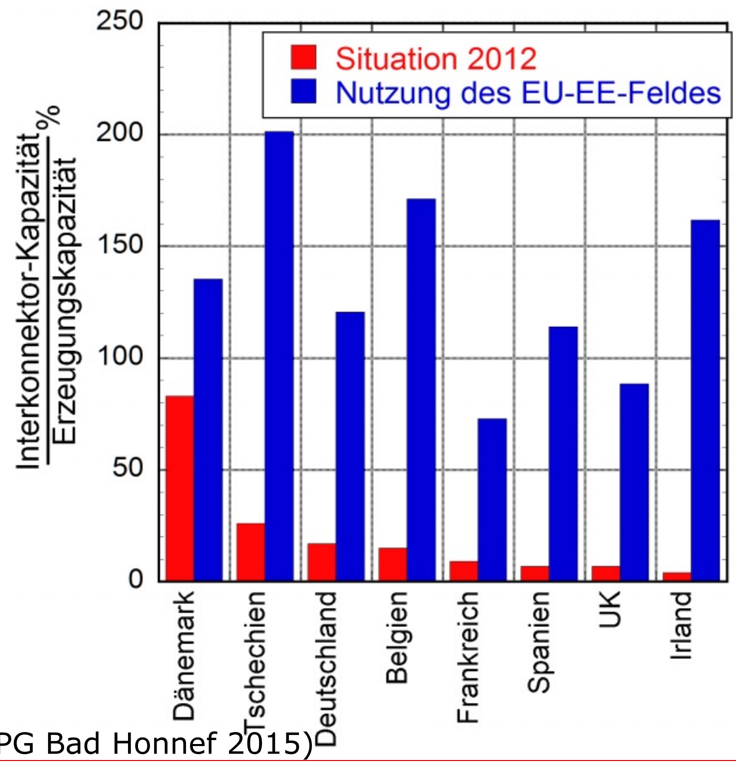
Deutschland: Hin zu einem hohen Anteil fluktuierender Stromerzeugung $P_{(wind+PV)\ nominal} > P_{Last}$

- Wind und Sonne können allein nicht die bisherige Stromerzeugung ersetzten.
- Eigenschaften von Wind und ganz besonders Photovoltaik:
  - Zeiten mit Überschuss-Stromerzeugung bis hin zur vollen Leistungskapazität
  - Zeiten mit viel zu wenig Stromerzeugung überwiegen bei weitem
- Statt bisher einem sind drei Systeme erforderlich:
  1. Wind und Sonne (→ $P_{(wind+PV)\ nominal}$ ca. 140 GW?)
  2. Back-up Kraftwerke / Speicher bis nahe zur Netzlast (ca. 50 – 60 GW)
  3. Eine Industrie, die den überschüssigen Strom in Wasserstoff, Methan, Methanol umwandelt, speichert und etwa für Mobilitätsanwendungen nutzt. Rückverwandlung in Strom hat sehr geringen Wirkungsgrad (Strom → Strom ~ 20 – 40%)
- Im- und -export von Strom helfen Deutschland, verlagern aber das Problem nach Europa.
  - Voraussetzung: Ein massiv ausgebautes europäisches Stromnetz.

Wind power:
Correlation between D and other EU countries

Correlation lengths of wind and solar generation are such that insufficient or surplus generation of Germany and its neighbour typically will happen with high correllation. Only Spain, the UK and Ireland show less similar patterns.

Actual and required power capacity of interconnectors from other European countries to Germany (and vice versa)



Source: F. Wagner in AKE-Tagungsband 2015 (DPG Bad Honnef 2015)

Fluktuierende Energie: Anforderungen Netze, Speicher, Backup- und Regelenergie

- Optimierungen:
  - Fluktuierende RES: 40% PV, 60% Wind
  - offshore Wind hat wesentlich günstigeren Lastfaktor
  - Europäischer Ausgleich – aber: wenn ohnhin massives europäisches Netz, warum dann nicht z.B. PV im Süden aufstellen?

  Wichtige Elemente, aber keine qualitativen Lösungen
- Speicher erforderlich:
  - Tagesspeicher
  - saisonale Speicher
  - Langfrist-Speicher?!

  Je kleiner der Backup-Kraftwerkspark sein soll, in desto größerem Maß und umso langfristiger muss Strom gespeichert werden können.
- Regelenergie
  - Dezentrale, fluktuierende Erzeuger werden ihren Beitrag liefern müssen
    - Phasenregelung
    - Abregelungen
- Zeitliche Anpassung der Last an Erzeugung: begrenzter Effekt.

Wohin mit dem Strom (60 – 100 TWh/a)? Stromspeicher

- Anforderung: großtechnisches Potential (TWh/a) bei niedrigen Verlusten und hoher Zyklenzahl
- Wasser-, Luftspeicher (Pumpen ← → Turbinen)
  - Hydro-Pumpspeicher (z.Zt. 30 Anlagen, 7000 MW, 45 GWh, η>75% →>80%), Bergwerksspeicher? Tiefbohrungsspeicher?
  - Advanced adiabatic Compressed Air Energy Storage (AA-CAES), in Entwicklung,Speichervermögen: groß/noch unklar, η>70%?, Kosten?)
- Elektrochemische Speicher (Batterien, Akkus) eignen sich nur für Regelleistung
  - geringe Zyklenzahl (Akkus: 1000 – 2000) → Lebensdauer
  - hohe Entladeraten (Supraleiter, Supercaps: 10%/Tag) → nur Kurzzeitspeicher
  - z.T. niedrige Effizienz (NiMH, Zink-Luft: <70%)
  - hohe Kosten (Supraleiter, Supercaps, NiMH, Li-Ionen)
  - Elektroautomobil-Batterien: Speicherkapazität (1 Mio Fahrzeuge): ~10 – 20 GWh pro Zyklus* → bei täglich 1 Zyklus: 7.7 TWh im Jahr, Lebensdauer?
- Chemische Konversion (u.a. „Power to Gas") → Wasserstoff, Methan, Methanol

  \+ Energiedichte - Effizienz bei Rückwandlung in Strom
  - Große Speicher vorhanden (ETG Taskforce „Grundsätzliche Auslegung neuer Netze" (2015))
    - Methan 121 TWh (106 TWh) in Kavernen (Porenspeicher)
    - H2: 42 TWh (27 TWh) in Kavernen (Porenspeicher)
- Wärmespeicher (water, salt, phase change materials, neben Chem. Konversion einzige Option für saisonale Speicherung)
- Anpassung der Stromnutzung (smart grid): verringert den Speicherbedarf.

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- Elektrochemische Speicher (… …ung
  - geringe Zyklenzahl …
  - hohe Entlad…
  - z.T. n…
  - …

…TWh im Jahr

- …, Methan, Methanol

… Strom

  - …e „Grundsätzliche Auslegung neuer Netze" (2015))

… in Kavernen (Porenspeicher)

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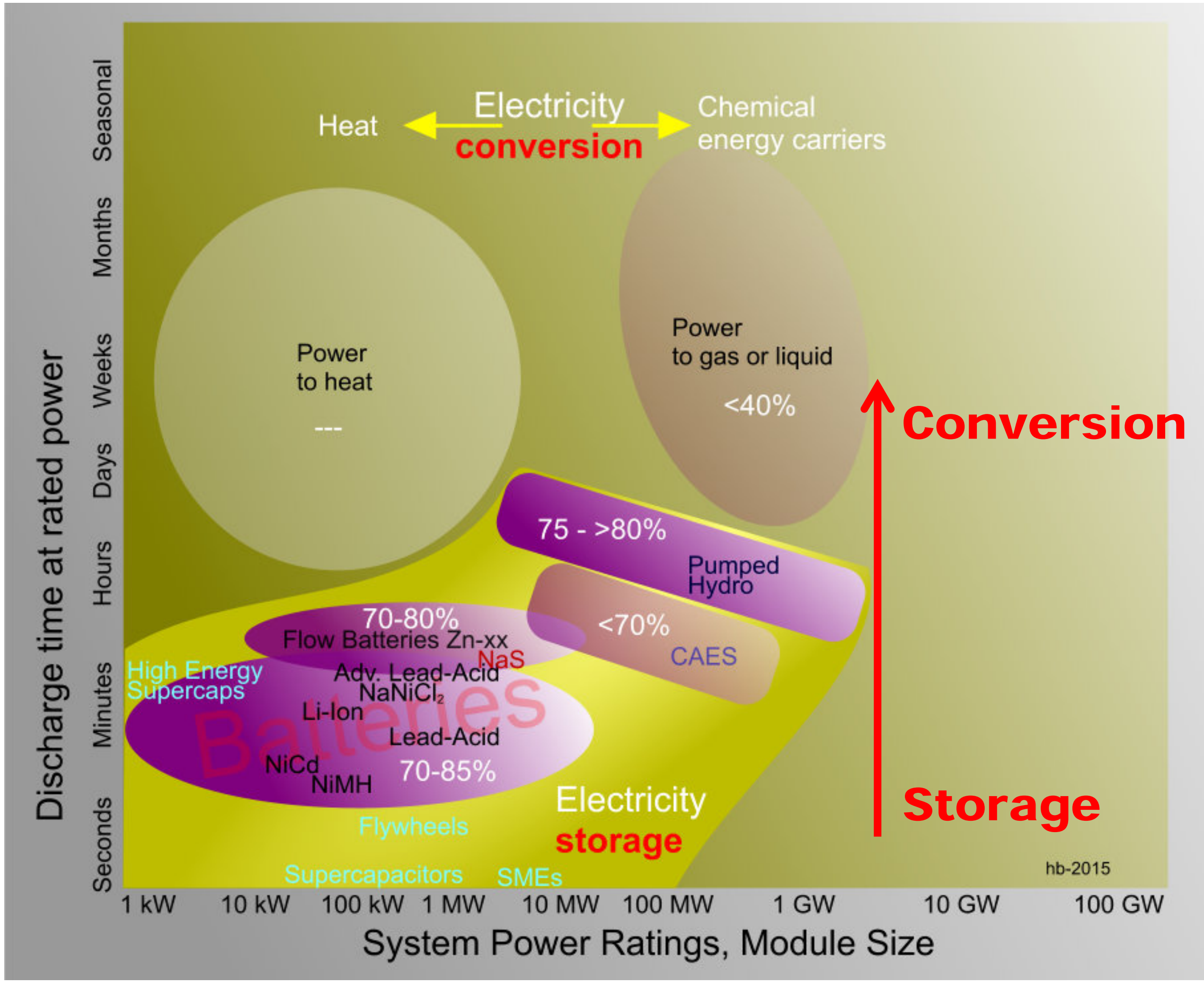
Chemische Energiekonversion:
Vieles geht im Labor, wenig ist bisher technisch machbar, nichts ist preiswert genug für den praktischen Einsatz.
Derzeit: 1000€/kW (PV) gegen 4000€/kW Investition in Speicher, die nur geringe jährl. Nutzungsdauer haben.
- Es fehlt an grundsätzlichen Fortschritten, eine rein inkrementelle Verbesserung wird nicht ausreichen.

(nach R. Schlögl)

Electricity storage and conversion



percentages: electricity to electricity full cycle conversion efficiencies

Forschungsförderung in Deutschland

- FuE Bruttoinlandsausgaben (2011): 2,9% (2013)
  - Wirtschaft: 44,3 Mrd €
  - Staat: 19,9 Mrd €
  - Ausland, Privat: 2,8 Mrd €
- Energieforschung (Staat)*:
  - 2010 618 Mio €
  - 2014 soll: 1,007 Mrd €
  - ca. 70 Ministerien befassen sich in Deutschland derzeit mit Energieforschungspolitik → wahrscheinlich ein Weltrekord.

Zum Vergleich:

- Nettokosten EEG (2013): ~ 16,2 Mrd. €***

  (31,1 Mrd € Umlage minus Verkaufswert des erzeugten Stroms)
- EEG für Energieforschung kontraproduktiv? Forschungsintensität der deutschen Solarindustrie 2004-2009: <2% (zum Vergleich: andere Hi-Tec Bereiche investieren typisch 5 – 15% des Umsatzes in FuE

*Quelle: Eurostat, für 2010 , 2,8% lt. Bundesbericht Forschung und Innovation 2012, Bundesforschungsministerium 2013, Energieforschung laut Tab. 17 Internationaler Vergleich 883 Mio € oder 3,8% gegen 4,2% EU27 ohne D
** Quelle: 6. Energieforschungsprogramm der Bundesregierung (2014)
*** Quelle: IWR, Die FAZ 9.1.2014 zitiert die Umlage mit 31,1 Mrd € entspr. 240 € /Kopf

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- Im- und -export von Strom helfen (begrenzt), erfordern massiven europäischen Netzausbau.

Conclusions

- Although an in-principle political agreement for a carbon-lean energy supply is emerging (COP 21), **fossil fuels are unlikely to be phased out** at the pace and scale needed for the 2° goal.
- Growing energy demand in **Asia, in particular China and India, will dominate the global energy supply development with**, besides **a growing contribution by RES,** a **further increase of nuclear and (cleaner) fossil energy supply**.
- **A global ETS or Carbon Tax mechanism would** assist the implementation of clean(er) energy supply strategies and **generate** corresponding **incentives to R&D and industry**. Key areas are improved RES, clean mobility solutions,(energy / electricity) storage systems, CCS and nuclear research.
- Electricity from renewable sources increasingly **will become a major clean energy carrier** of the future which would benefit from sufficient non-intermittent generation.
- **Within** the European energy market **a European electricity system** should develop with an optimized deployment of fluctuating RES and minimization of back-up and storage requirements. However, **required grid and interconnector capacities are substantial**. National energy policies would have to adapt.
- **Only global CO_2 emission reduction will help**. Germany therefore should develop a global role in clean technologies by enhanced investment in corresponding R&D.
- Combatting global warming with **a ~2° perspective proves to be challenging**. **Adaptation** scenarios **may become progressively a relevant part of the debate***. This will not affect the need for a carbon-lean and clean energy supply and corresponding R&D.