PAUL SCHERRER INSTITUT

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ORCHESTRATING OR IMPROVISING THE GLOBAL ENERGY TRANSITION: SCENARIO MODELLING WITH THE WORLD ENERGY COUNCIL

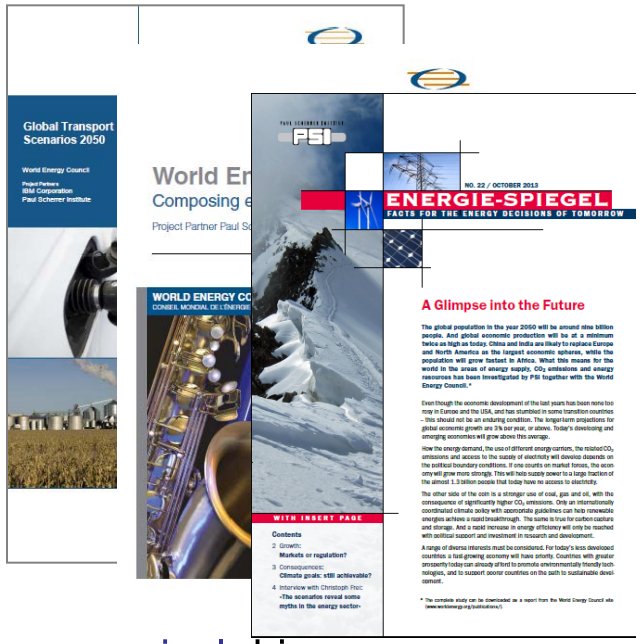
Paul Scherrer Institute

IEW 2014, Beijing

PSI Modelling Team: M. Densing, H. Turton, E. Panos, K. Volkart

Overview: Energy Scenarios of PSI and WEC

- 2011: Global Transport Scenarios 2050
- 2012: Pilot study for whole energy system
- 2013: World Energy Scenarios 2050
  - launched at World Energy Congress (Oct. 2013)
- 2014+: New methodologies and extensions (with WEC)
  - New scenarios, deep dives and methods
  - Open-source model; third-party projects

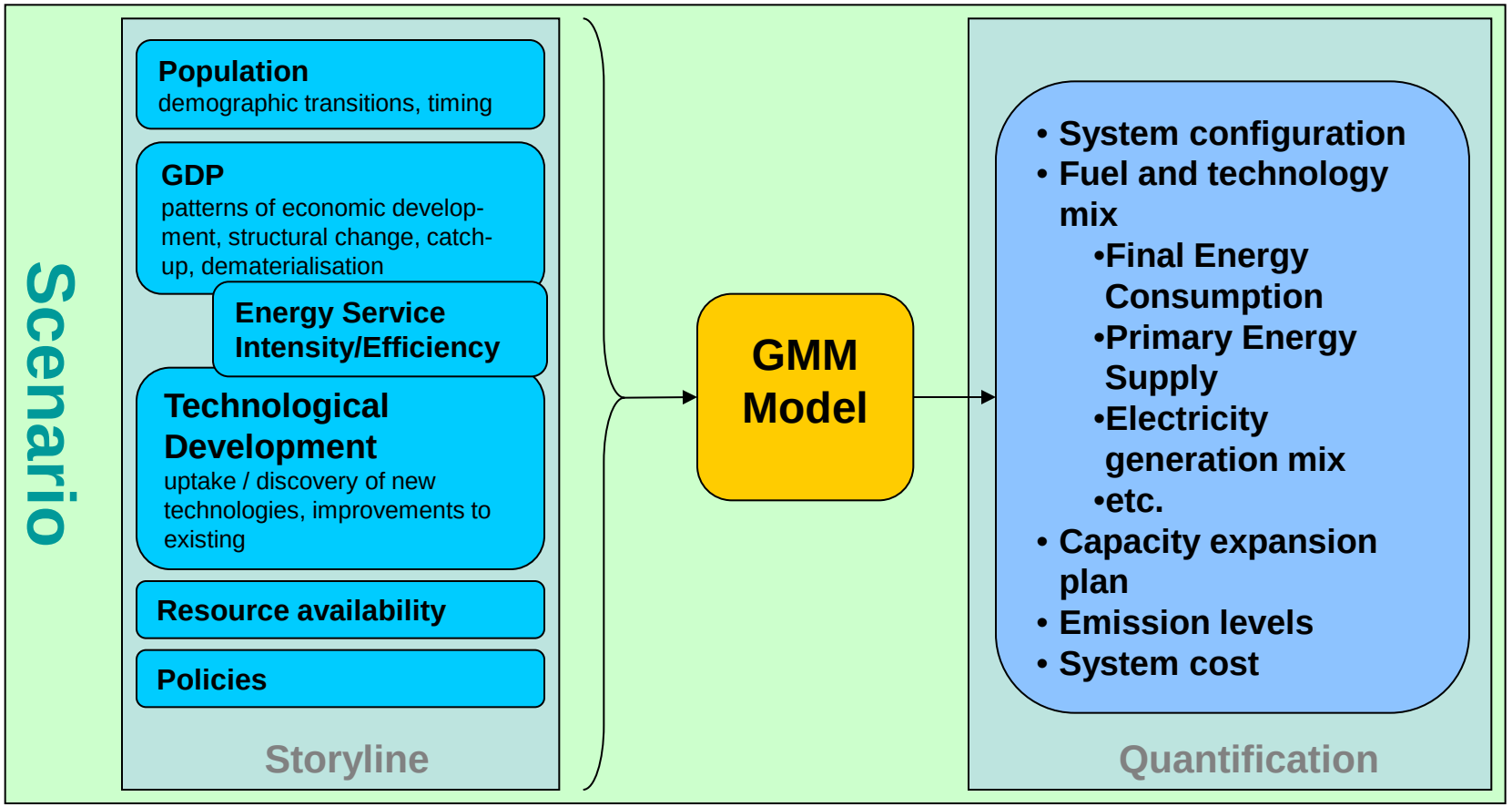


Methodology for World Energy Scenarios 2050

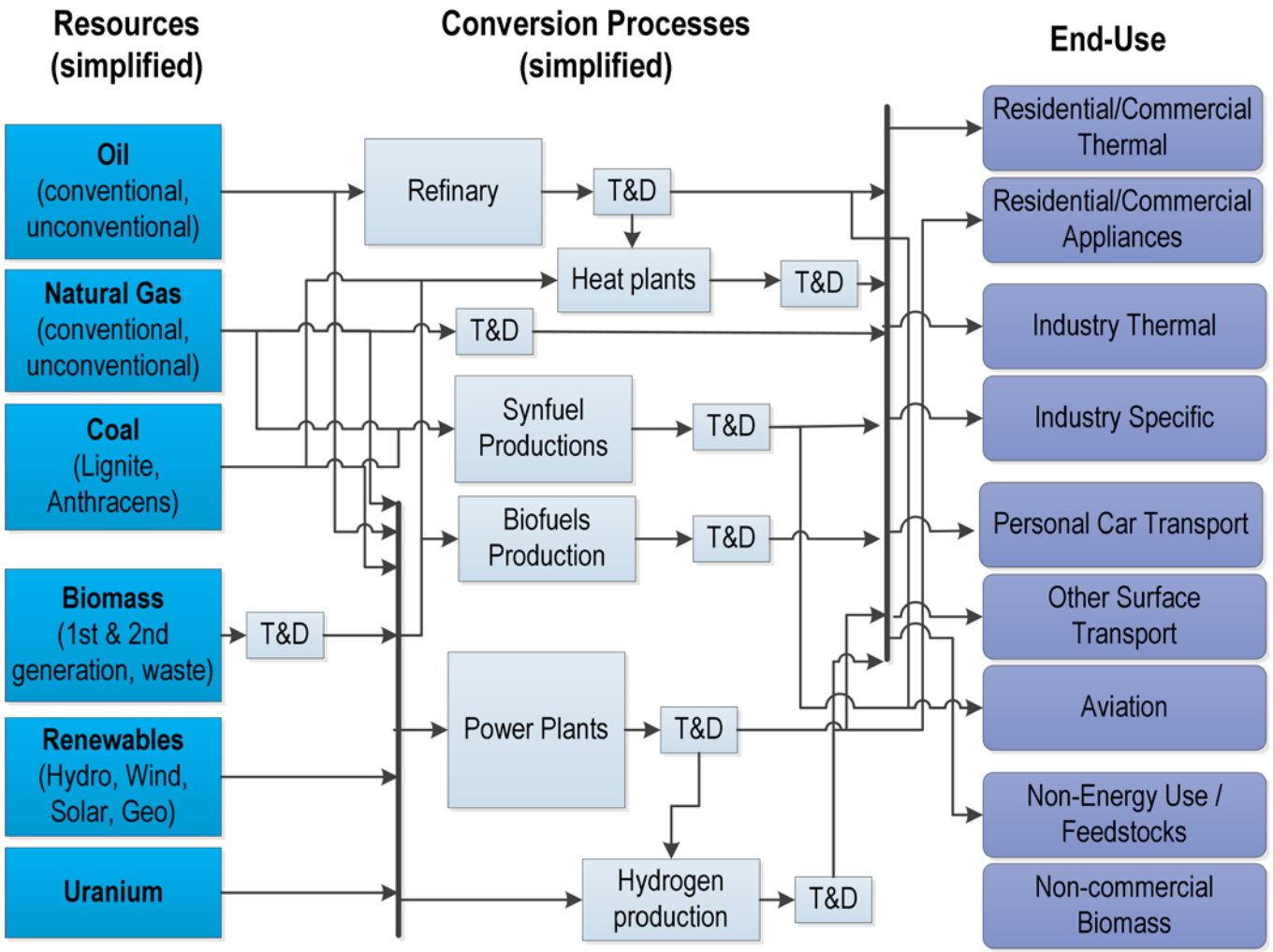
- 2 scenarios with coherent storylines of social, political and economical drivers
  - Drivers developed in regional workshops in last 2 years (international practitioners' & academics' view)
  - e.g., markets/trade/liberalization/innovation → GDP → energy intensity → demand
- Quantified and analysed with energy system model GMM (Global Multi-regional MARKAL):
  - Bottom-up supply-side model with a detailed representation of resources, technologies, energy flows, and technological change [Barreto 2001; Gül 2007; Densing & Turton 2012]
  - Cost-optimization of the energy system (market allocation = competitive equilibrium)
  - Non-cost and behavioural factors are modelled by additional assumptions

Scenario quantification framework

- Evolutions of key scenario drivers are expressed in a **coherent storyline** of future economic and social developments
- Scenario storylines quantified with GMM



Energy system model: flow of energy carriers

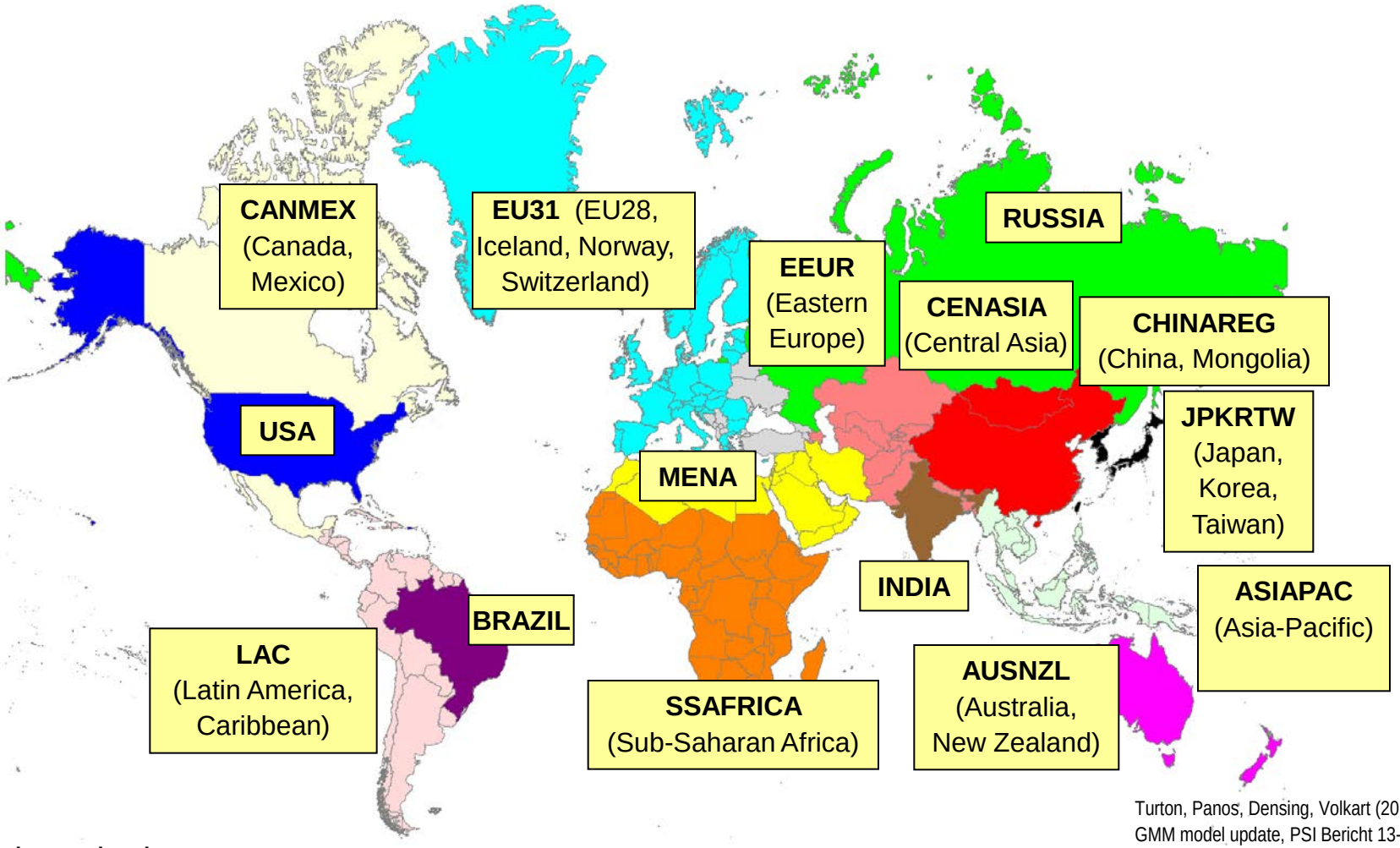


T&D: Transport and Distribution

GMM has approx. 400 technologies per region

PSI (2013): Energie-Spiegel

World regions (15 modelled, aggregated to 8 WEC regions)



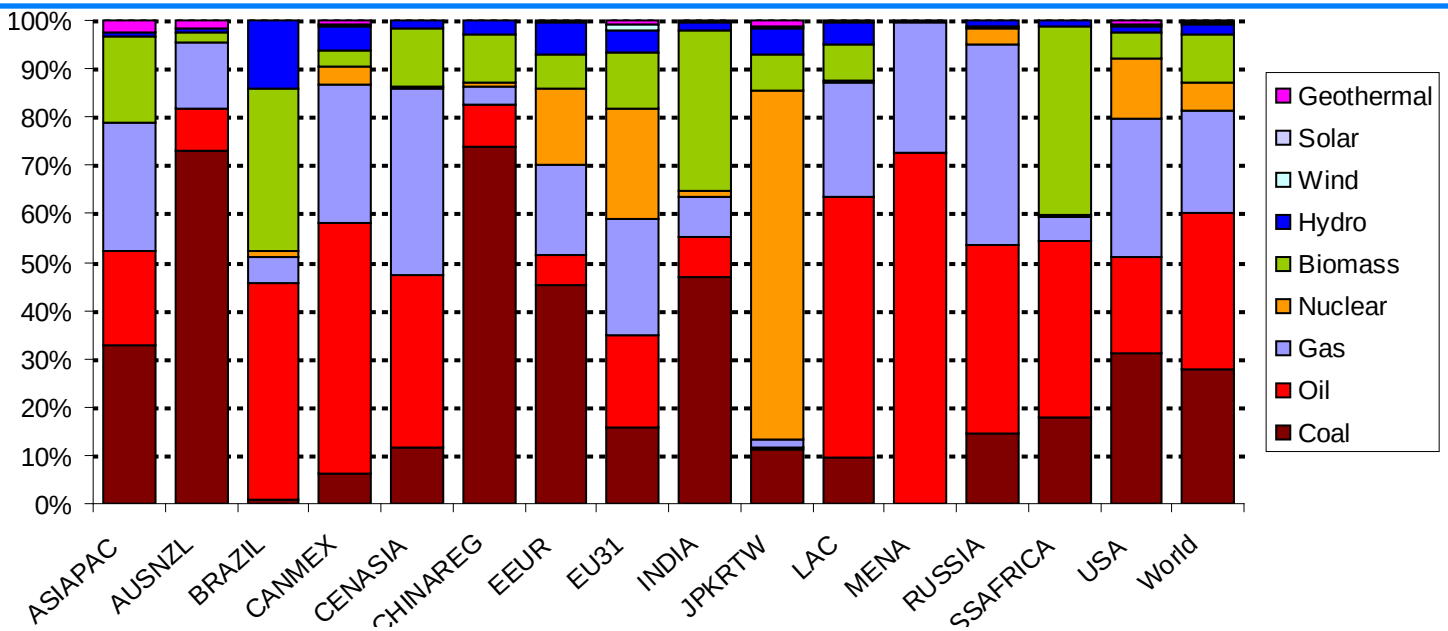
Turton, Panos, Densing, Volkart (2013): GMM model update, PSI Bericht 13-03

Separation criteria:

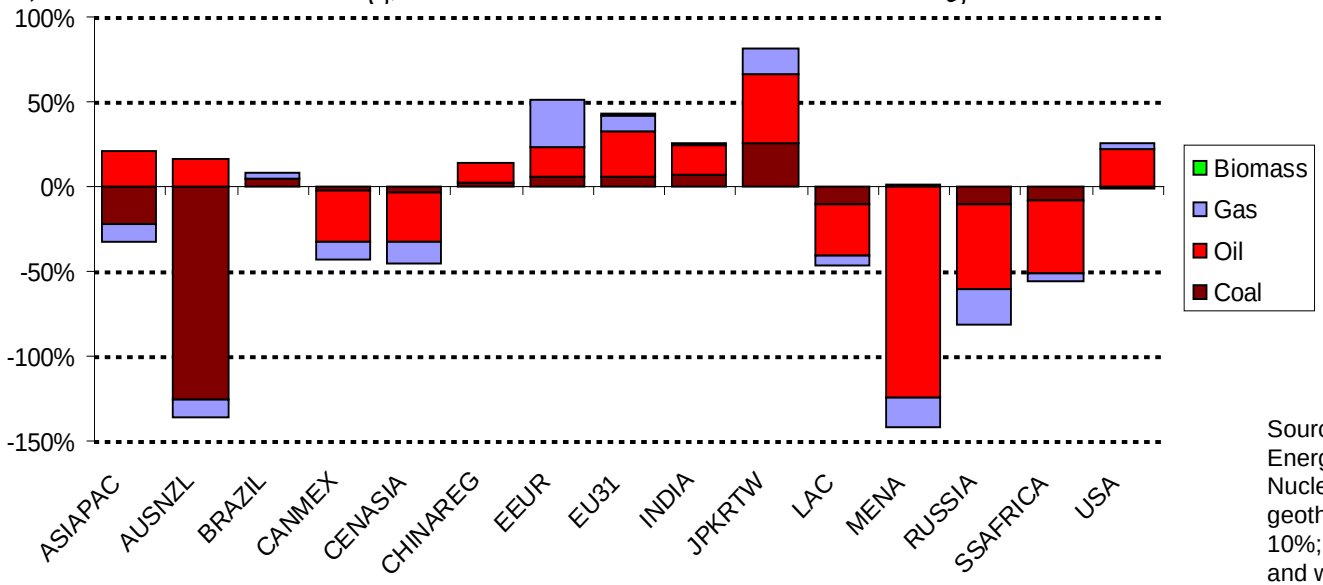
- Current economic size & expected development (e.g. , single countries: USA, China, India, Brazil)
- Fossil resources (e.g. large amounts of coal in AUSNZL, small in JPKRTW)
- Possibility to combine to WEC's 8 regions

Regional partition: Diversity of primary energy and trade

Domestic production of primary energy (year 2010)



Net import (% of total primary energy supply)



BRAZIL: Bio -0.4%, Oil: 0.1%; CHINAREG: Gas 0.5%; INDIA: Gas 1.5%; LAC: Bio -0.4%; EU31: Bio: 0.3%

Source: IEA (2012), Energy Balances. Nuclear eff. = 33%; geothermal eff. = 10%; solar, hydro and wind: produced energy.

Storylines

Jazz	Symphony
World where there is a consumer focus on achieving energy access, affordability, and individual energy security with the use of best available energy sources	World where there is a voter consensus on driving environmental sustainability and national energy security through corresponding practices and policies
Main players are multi-national companies, banks, venture capitalists, and price-conscious consumers	Main players are private and public-sector companies, local govts, NGOs, and environmentally-minded voters
Technologies are chosen in competitive markets	Governments pick technology winners
Energy sources compete on basis of price & availability	Select energy sources are subsidised and incentivized by governments
Higher GDP growth due to optimised (efficient) market practices.	Lower GDP due to non-optimal economic policies
Free-trade strategies lead to increased exports	Nationalistic strategies result in reduced exports/imports
Renewable and low carbon energy grows in line with market selection	Certain types of renewable and low carbon energy actively promoted by governments in the first part of the scenario period
In the absence of international agreed commitments carbon market grows more slowly from bottom-up based on regional, national and local initiatives.	Carbon market is top down based on an international agreement, with commitments and allocations.

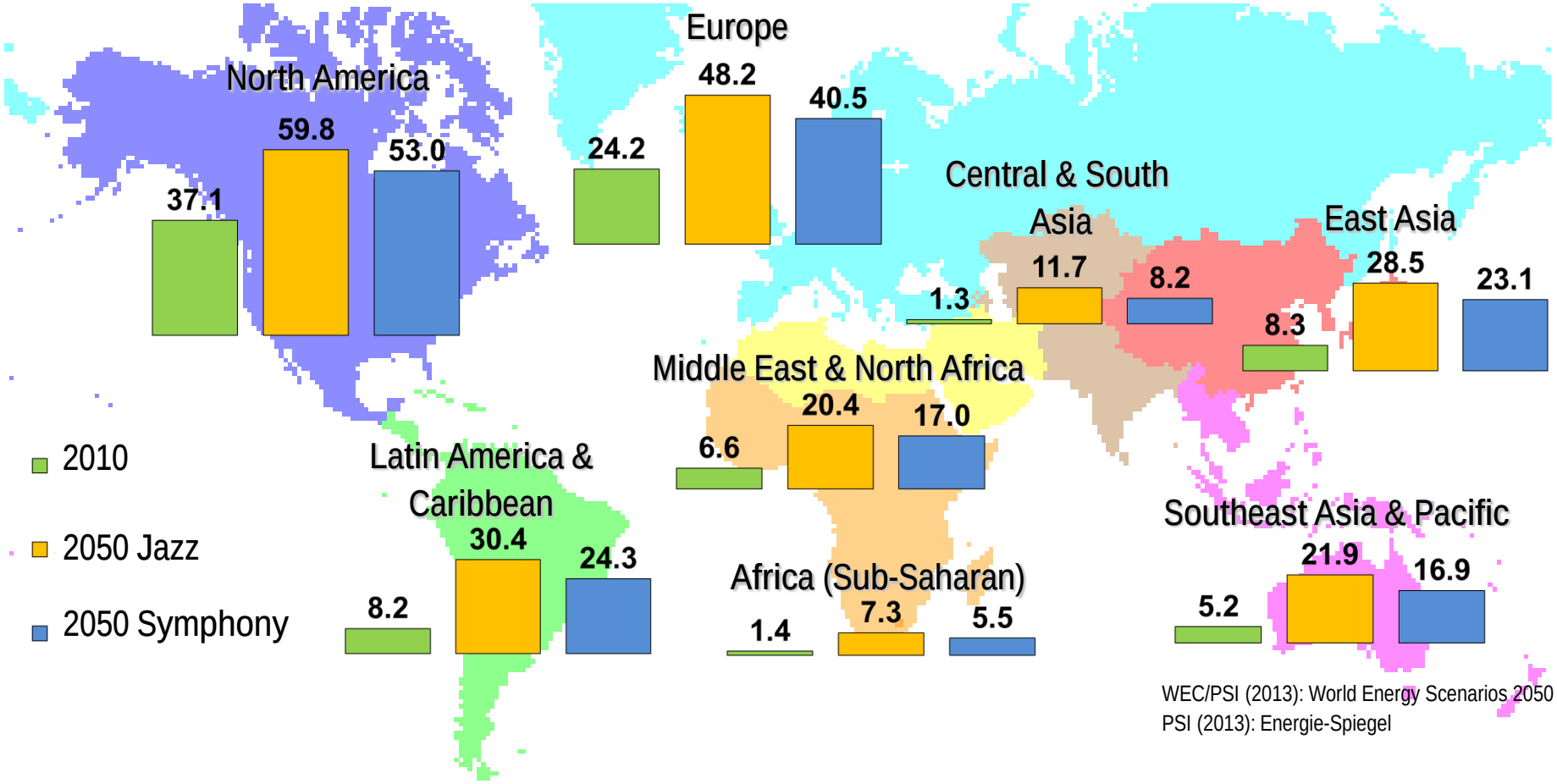
Storylines (quantification)

	Jazz: Market-oriented Future	Symphony: Regulation-oriented Future
Goals	• Affordable energy access through free markets • High income ➔ Mainly adaption to environmental damages	• Secure energy access • Targeted regulation through states and international organizations ➔ Mainly avoidance of environmental damages
Economic Growth	GDP growth has priority (3.5% annual average to 2050, PPP)	Less GDP growth (3.1% annual average to 2050, PPP)
Population	Increase (8.7 billion in 2050)	Stronger Increase (less income) (9.3 billion in 2050)
Climate Policy	CO_2-markets develop slowly (CO_2 price in 2050: 23-45 \$/tCO_2)	Stronger coordinated state action, global convergence (CO_2 price in 2050: 70-80 \$/tCO_2)
Energy Efficiency / Intensity	Efficiency increases based on market criteria	State promotion of efficiency measures and energy savings
Unconventional Resources (e.g. shale gas/oil, oil sands)	Expanded opening of markets. High incentive because high energy demands.	Regulation (for water use, market access). Fewer incentives because less demand.
Renewable Energy	Limited promotion. „The market“ selects the technologies.	Selected state promotion.
Non-renewable Energy	Limited Support: •CCS market-driven (pilot in 2030) •Nuclear plants under construction partially not in operation	State support: •CCS available from 2020 •Nuclear, large hydro power

PSI (2013): Energie-Spiegel

Future income (GDP/capita) in Jazz and Symphony

GDP/capita (1'000 USD per inhabitant, GDP in $\$_{2010}$ MER):



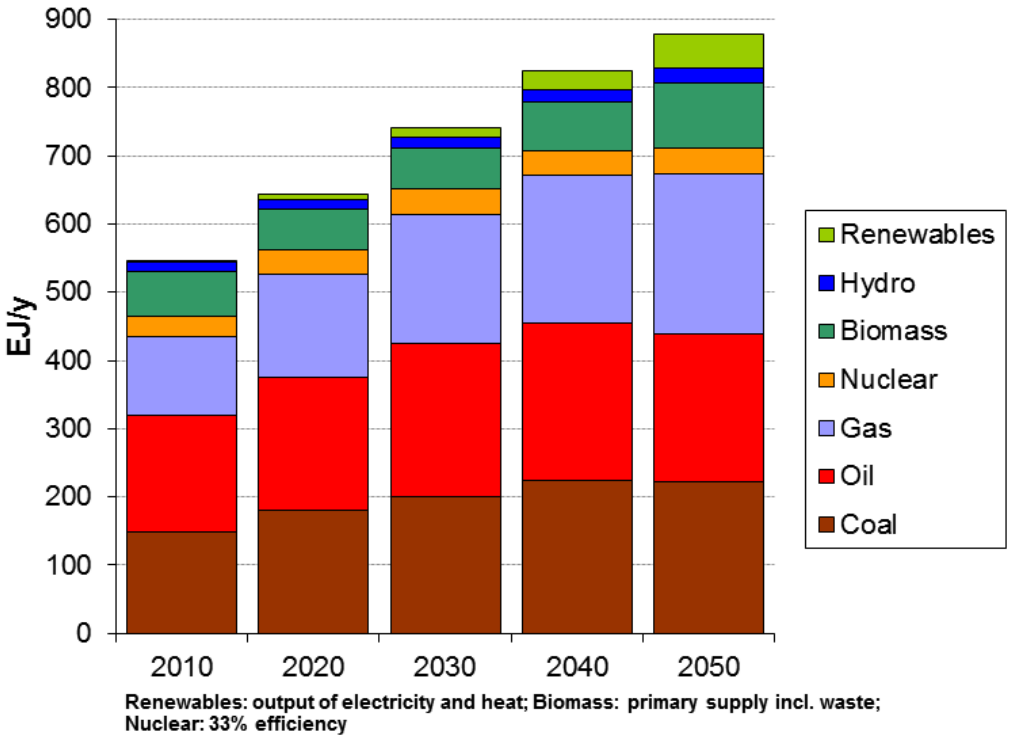
WEC/PSI (2013): World Energy Scenarios 2050
PSI (2013): Energie-Spiegel

GDP growth is partially offset by population growth in some developing countries.
E.g., Sub-Saharan: 860 Mio. people in 2010, 1.6 Bio. (Jazz) and 2 Bio. (Symphony) in 2050

Primary energy supply (by energy carrier)

Jazz

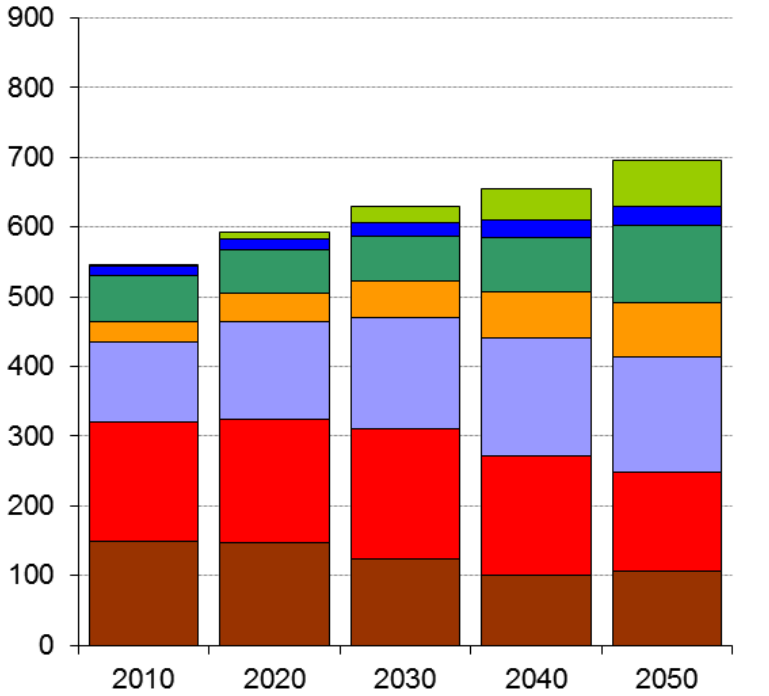
(consumer driven and market-oriented)



Renewables: output of electricity and heat; Biomass: primary supply incl. waste; Nuclear: 33% efficiency

Symphony

(voter driven and more regulation)



Renewables: output of electricity and heat; Biomass: primary supply in
Nuclear: 33% efficiency

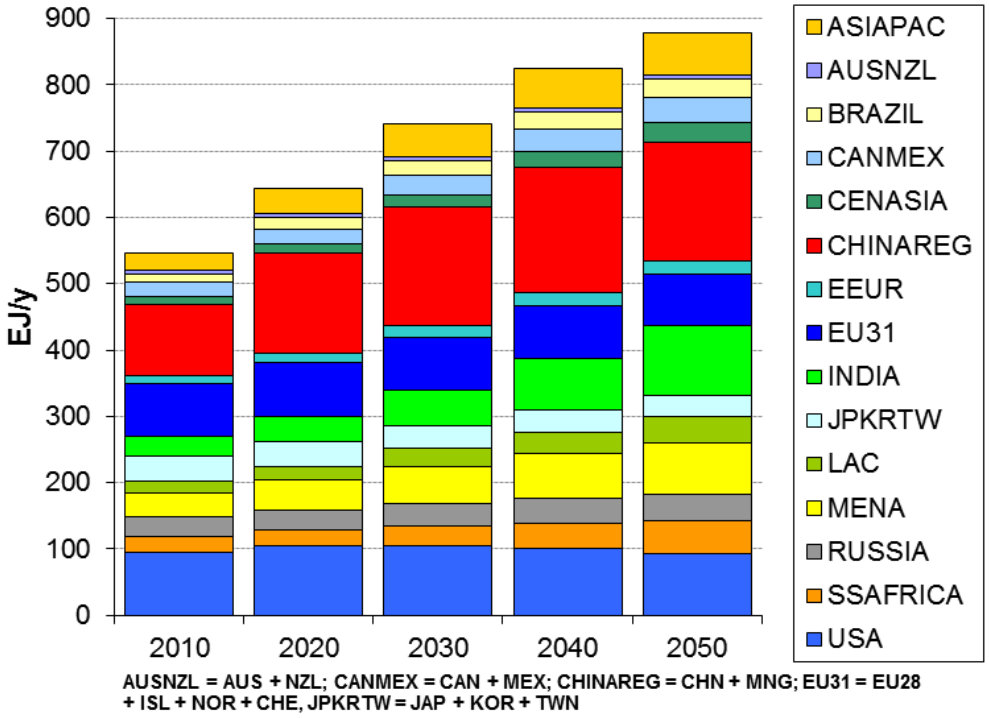
Shale gas: 32% of global gas resources [EIA 2013]

WEC/PSI (2013): World Energy Scenarios 2050

Primary energy supply (by world region)

Jazz

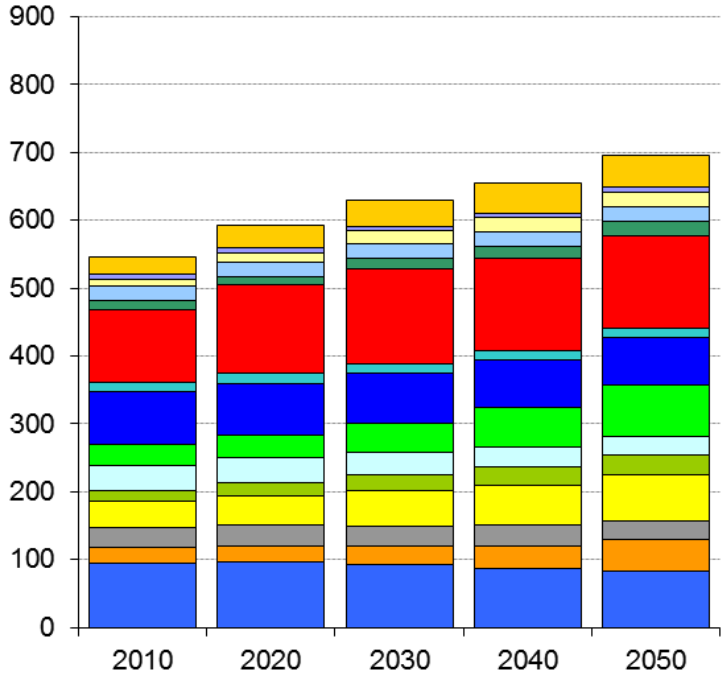
(consumer driven and market-oriented)



AUSNZL = AUS + NZL; CANMEX = CAN + MEX; CHINAREG = CHN + MNG; EU31 = EU28 + ISL + NOR + CHE, JPKRTW = JAP + KOR + TWN

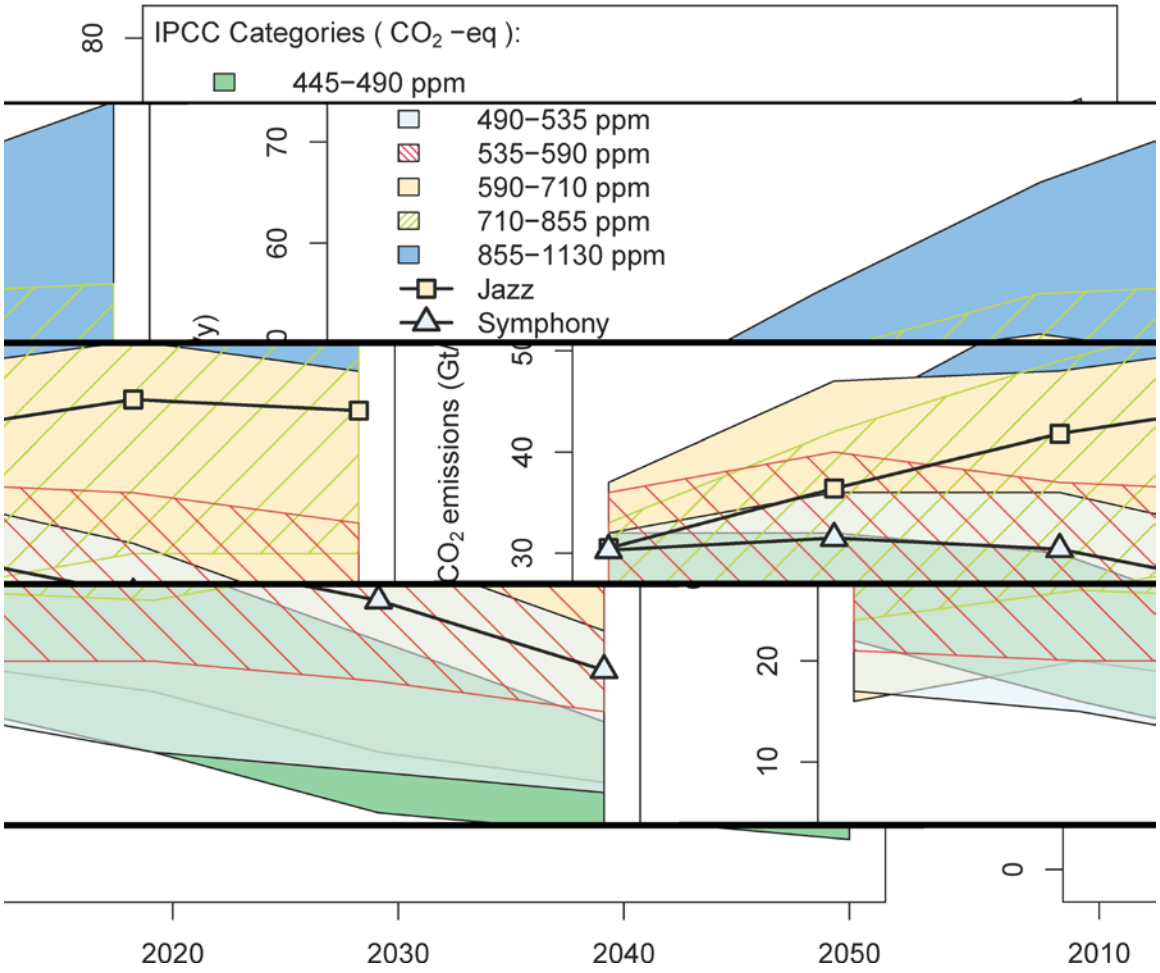
Symphony

(voter driven and more regulation)



WEC/PSI (2013): World Energy Scenarios 2050

Energy-related CO_2 emissions

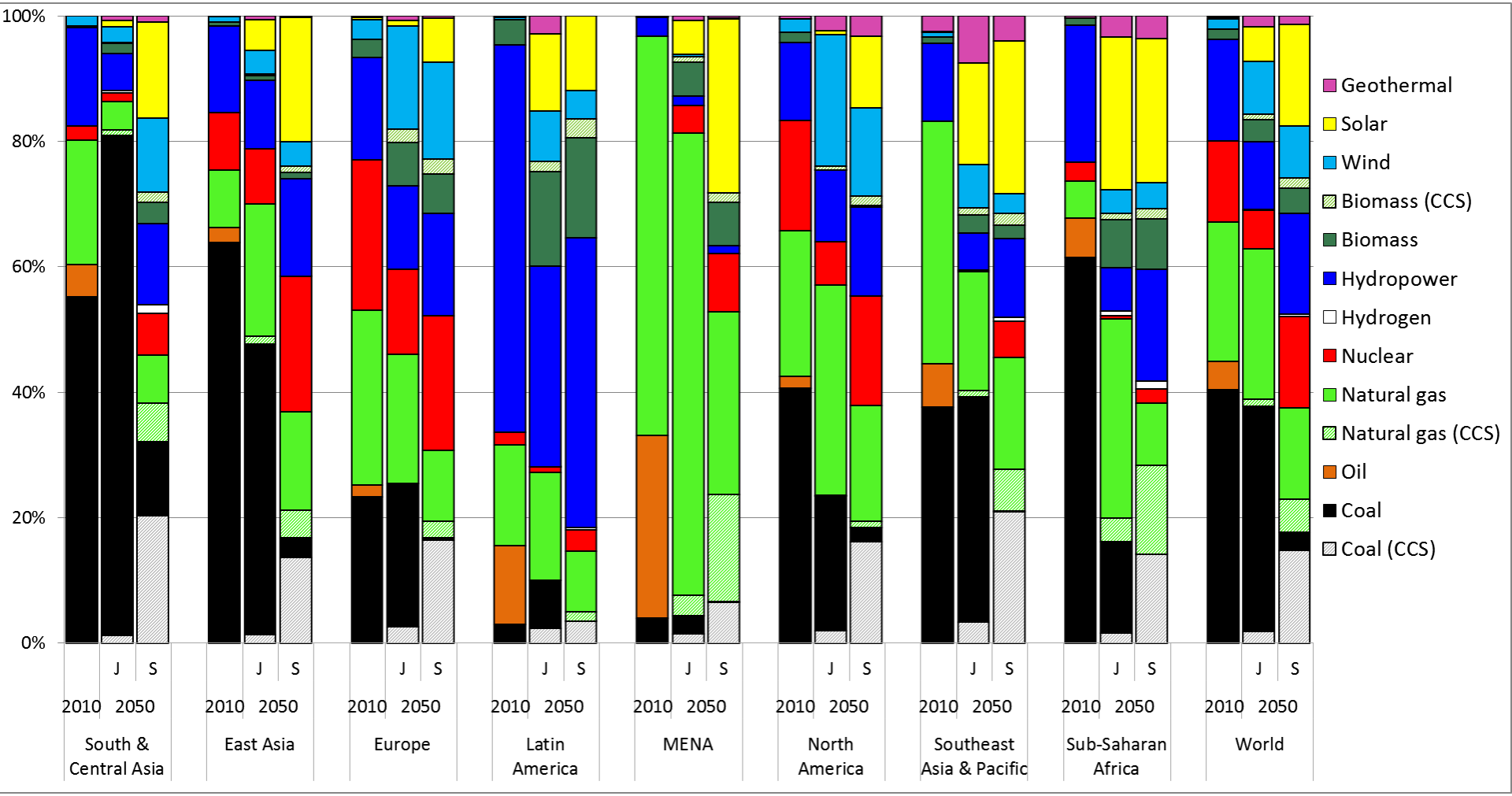


WEC/PSI (2013): World Energy Scenarios 2050

Focus of climate policy

- in Jazz (market-driven): Adaptation (mitigation comes later, 2030+)
- in Symphony (regulation): Mitigation (also after 2050); +2° degree may be achieved

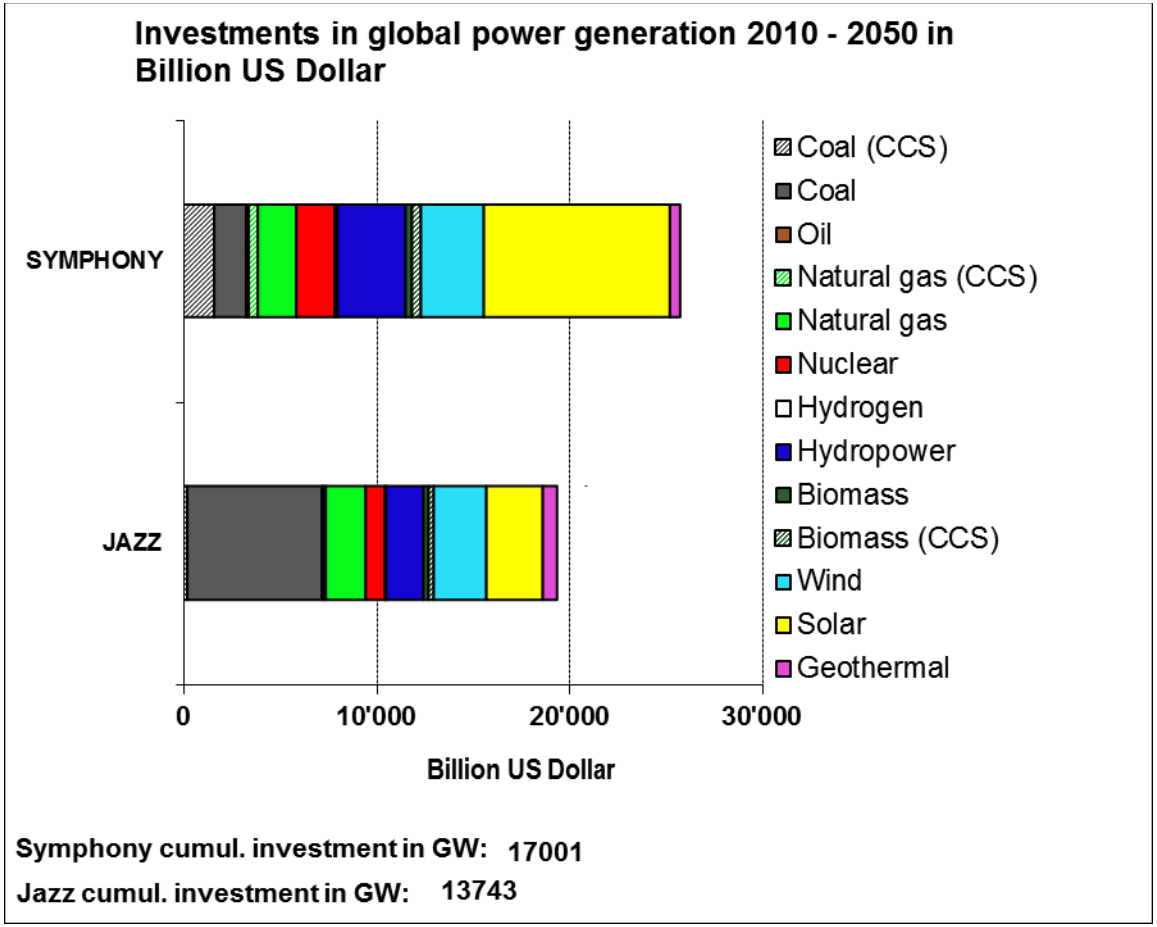
Electricity production (by world region)



Electricity / Total Final Consumption =
17% (2010), 32% (Symphony 2050), 27% (Jazz 2050), 24% (CH 2010)

PSI (2013): Energie-Spiegel
TFC: includes non-energy use

Cumulative investment in electricity generation

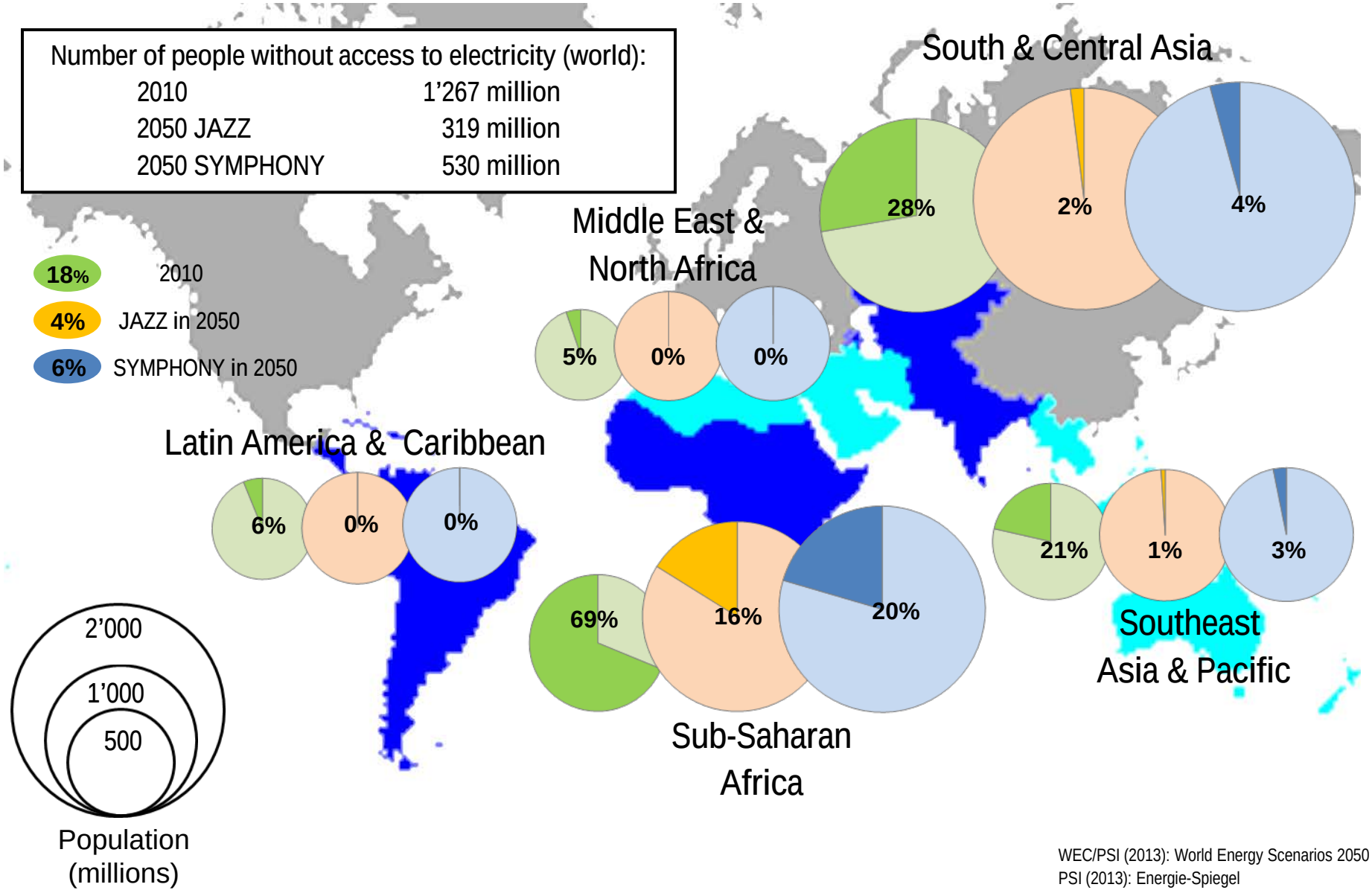


PSI (2013): Energiespiegel

- Electricity production 2050: 54 PWh in Jazz, only 48 PWh in Symphony
- Solar 2050: new 2'000 GW in Jazz, 5'900 GW in Symphony (2008→2012: 15→97 GW)

IEA, PVPS 2012

Population without access to electricity



WEC/PSI (2013): World Energy Scenarios 2050
PSI (2013): Energie-Spiegel

Summary of selected results


Energiespiegel No. 22, Titlepage

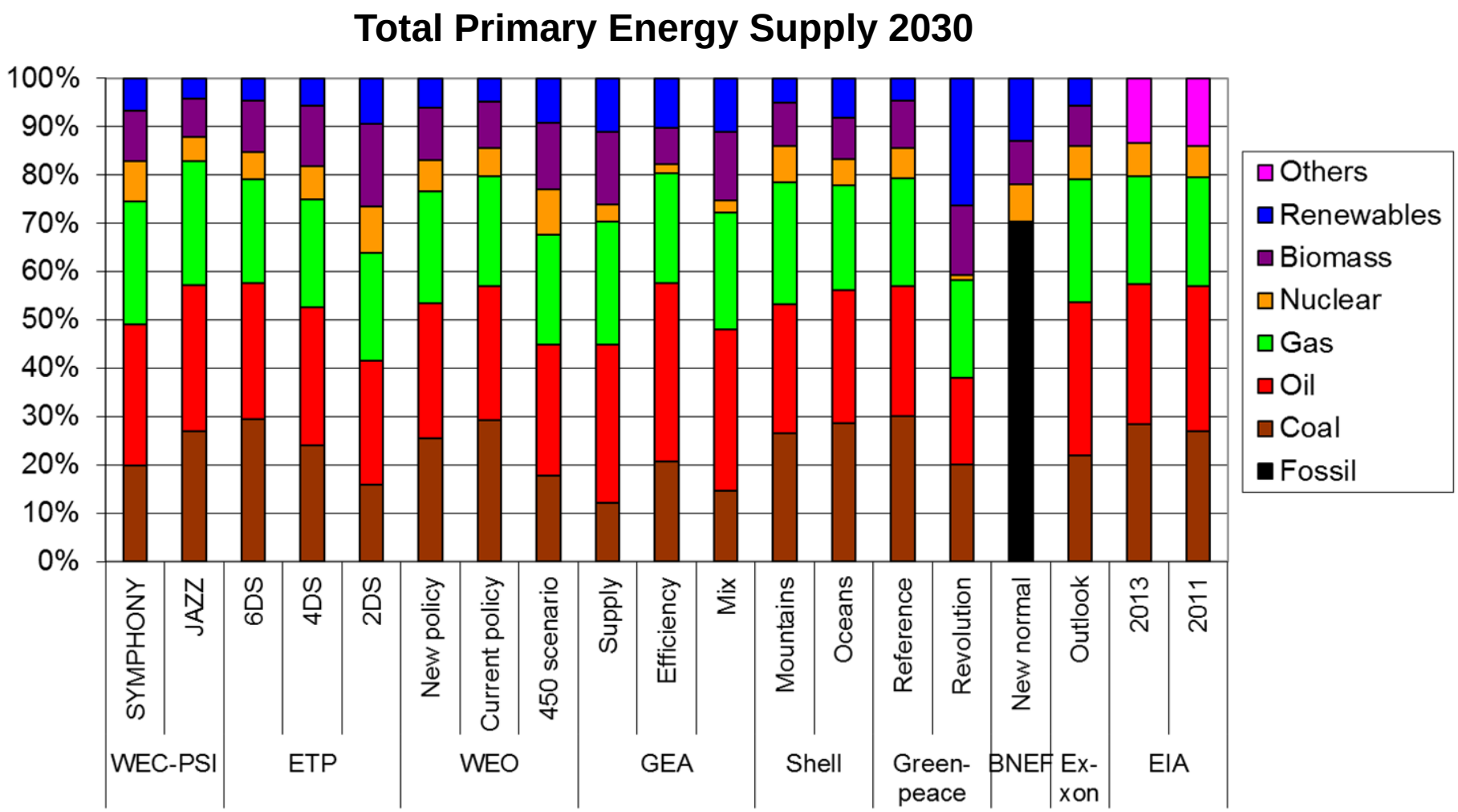
Scenario outcomes (and implied decisions) lead only partially to sustainability:

- Symphony (stronger government role; voters' viewpoint):
  - reduced burden on global climate (less CO_2) and less depletion of fossil resources
  - more energy security (more renewables, more large hydro)
  - more CCS and more nuclear (esp. non-Europe)
  - higher investments, especially in electricity sector (e.g., more capacity and more backup for intermittent renewables)

- Jazz (opening of markets; consumers' viewpoint):
  - improved energy access and increases average income
  - greater climate burden (more CO_2, but less CCS); more unconventional gas/oil

- Moreover:
  - very stringent global climate change mitigation targets (e.g., <2 degrees) are challenging without additional ambitious policy action
  - CCS may be a competitor and complement to deployment of renewables
  - disruptive technology breakthroughs could change the picture

Comparison with other global energy scenarios



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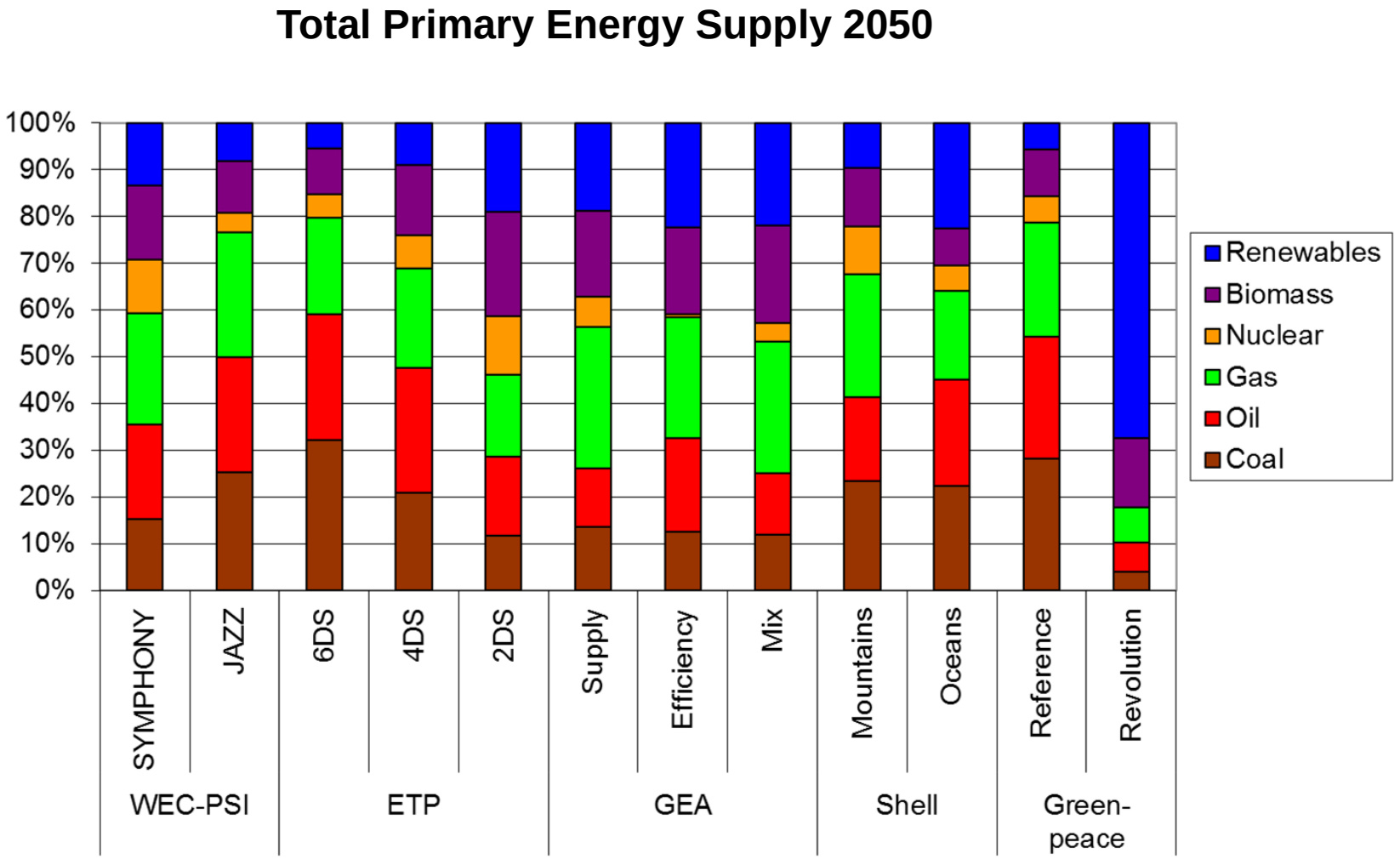
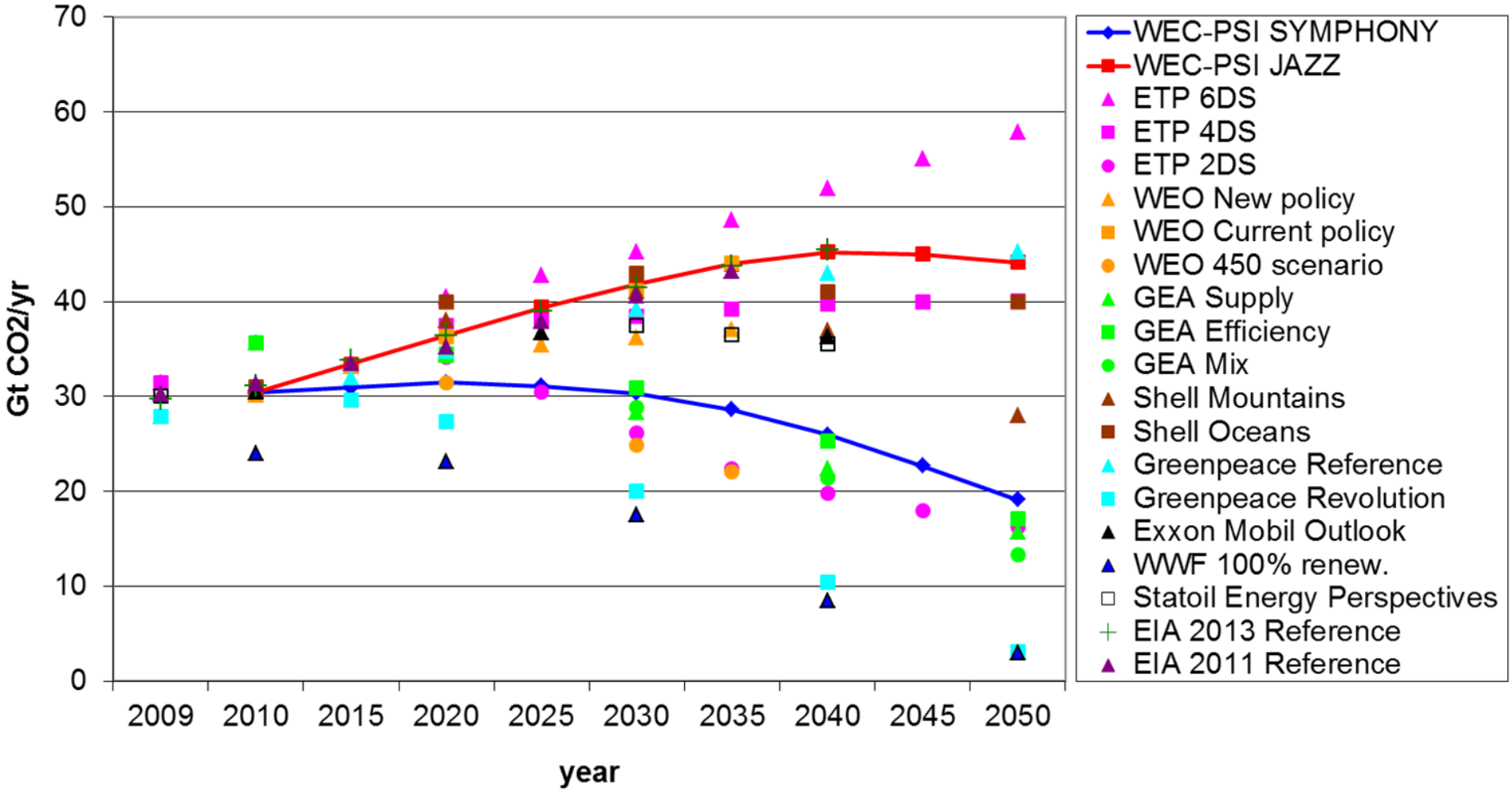


Comparison with other scenarios – CO2 Emissions



Conclusions: World Energy Scenarios 2050 Report


Energiespiegel No. 22, Titlepage

1. Energy system complexity will increase by 2050 (e.g. by renewables)
2. Energy efficiency is crucial in dealing with demand outstripping supply
3. Still a mainly fossil-based energy mix in 2050 (e.g. in transport sectors)
4. Regional priorities: No 'one-size-fits-all' solution to energy trilemma (affordability / access, environmental sustainability, security)
5. 450ppm-CO_2eq target difficult with economically-acceptable carbon prices
6. CCUS (carbon capture, utilisation and storage) can challenge renewables for a low-carbon future; changing consumer behaviour may also help
7. Key technological uncertainties up to 2050 are CCUS, solar energy and energy storage
8. Balancing of energy trilemma implies difficult trade-offs
9. Energy markets require investments and regional integration to deliver benefits to all consumers
10. Energy policy should ensure that energy and carbon markets deliver

Outlook: Future of WEC/PSI Partnership


Energiespiegel No. 22, Titlepage

Possible methodological enhancements of WEC/PSI-model

- Energy “trilemma”: Exploring additional impacts of scenarios (e.g., water, human toxicity, land use, etc.), using new methods
- Deep dives on regions, sectors, technologies, resources: **for example**, electricity sector, storage, short-term dispatch (by using experience from PSI’s modelling of Switzerland)
- Open-source paradigm: additional transparency, distribution
- 3rd party projects

Thank you very much for your attention! Questions?

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Selected key scenario indicators

		1990	2010	2050	
				Jazz	Symphony
CO_2	Gigatons / year	21.0	30.5	44.1	19.1
CO_2 China & India	% world	14%	31%	40%	35%
Primary energy	Exajoule	367	546	879	696
Primary energy China & India	% world	14%	25%	33%	30%
Final consumption	Exajoule	252	373	629	491
Final consumption China & India	% world	15%	24%	33%	31%
GDP	Trillion $\$_{2010}$	34	63	201	172
GDP China & India	% world	3%	12%	26%	24%
Population	Billion	5.3	6.9	8.7	9.4
Population China & India	% world	38%	37%	33%	32%
GDP / capita (income)	$\$_{2010}$	6'814	9'162	23'139	18'317
CO_2 / capita	ton / year	4.0	4.4	5.1	2.0
CO_2 / GDP (CO_2-intensity)	kg / $\$_{2010}$	0.62	0.48	0.22	0.11
Final consumption / capita	Gigajoule / year	47	54	72	52
Renewables / Primary energy	%	13%	15%	19%	29%
Renewables / Electr. production	%	19%	20%	31%	48%
Electricity / Final consumption	%	14%	17%	27%	32%

Key Numbers of Scenarios (German)

		1990	2010	2050	
				Jazz	Symphonie
CO_2	Gigatonnen/Jahr	21.0	30.5	44.1	19.1
CO_2 China+Indien	%	14%	31%	40%	35%
Primärenergie	Exajoule	367	546	879	696
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Erneuerbare / Primärenergie	%	13%	15%	19%	29%
Erneuerbare / Stromproduktion	%	19%	20%	31%	48%
Elektrizität / Endverbrauch	%	14%	17%	27%	32%

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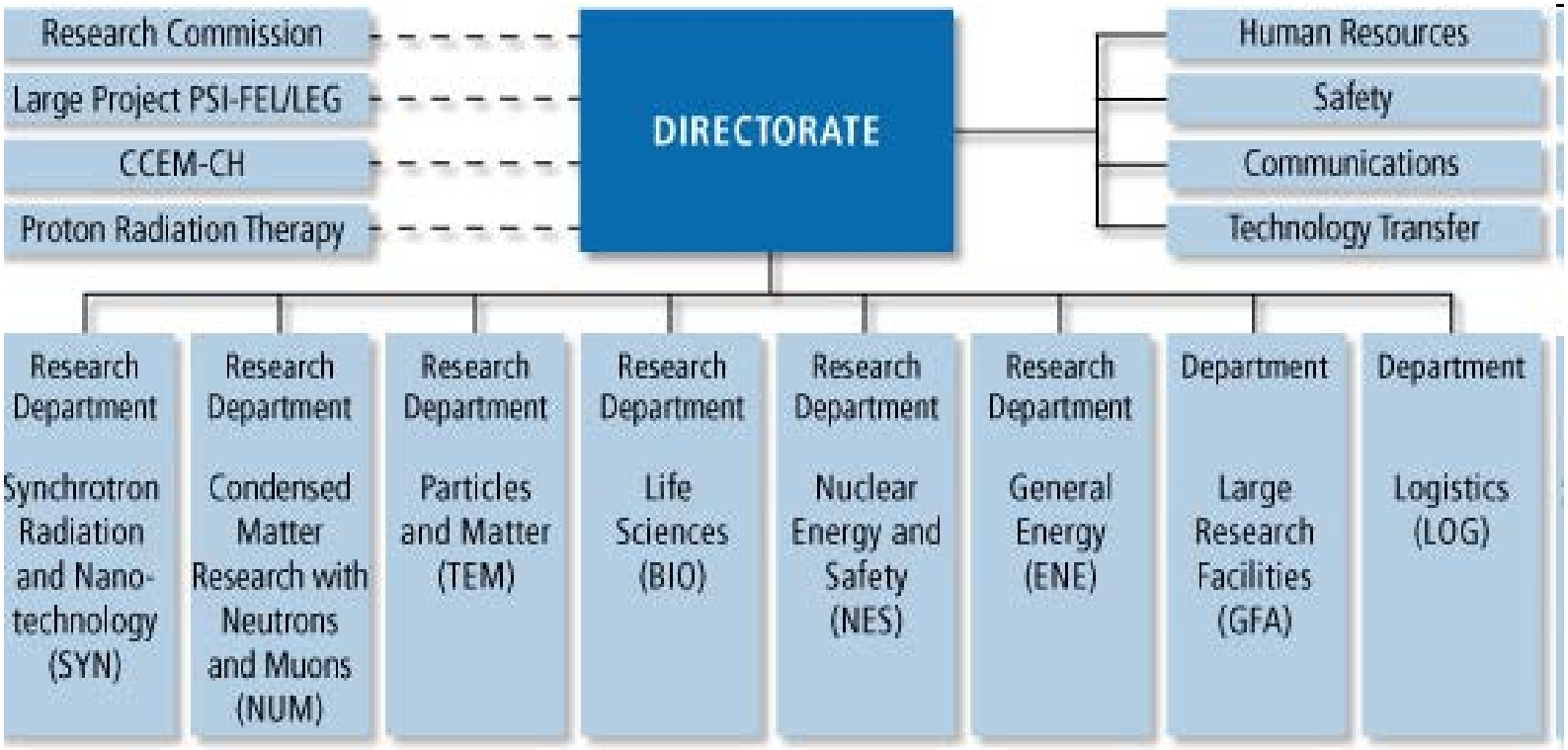
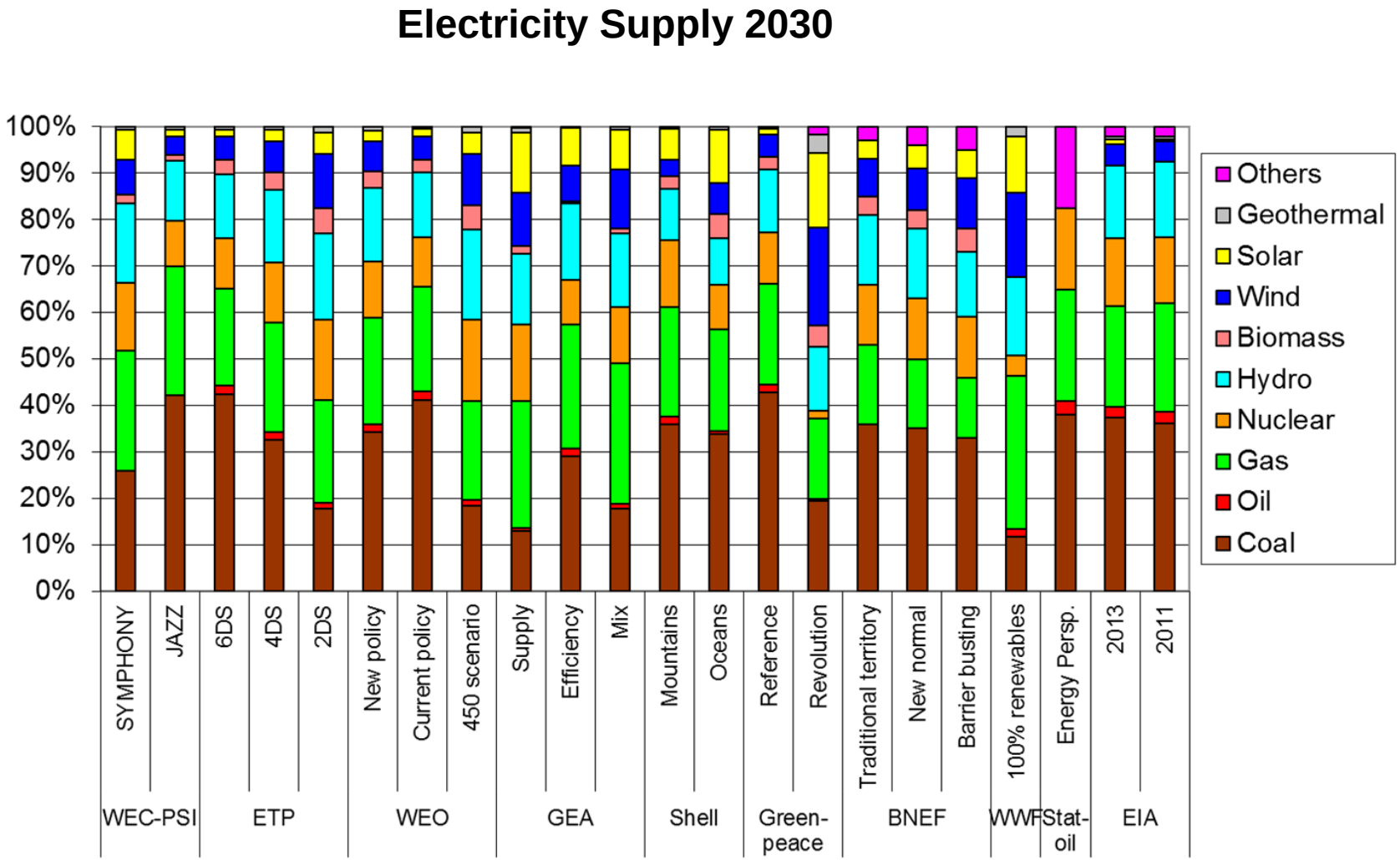


Energy Economics
Technology Assessment
Risk and Human Reliability

Laboratory for Energy Systems Analysis (LEA)

Comparison with other global energy scenarios



Comparison with other global energy scenarios

Electricity Supply 2050