Part 1: Sustainability in the Electricity Sector

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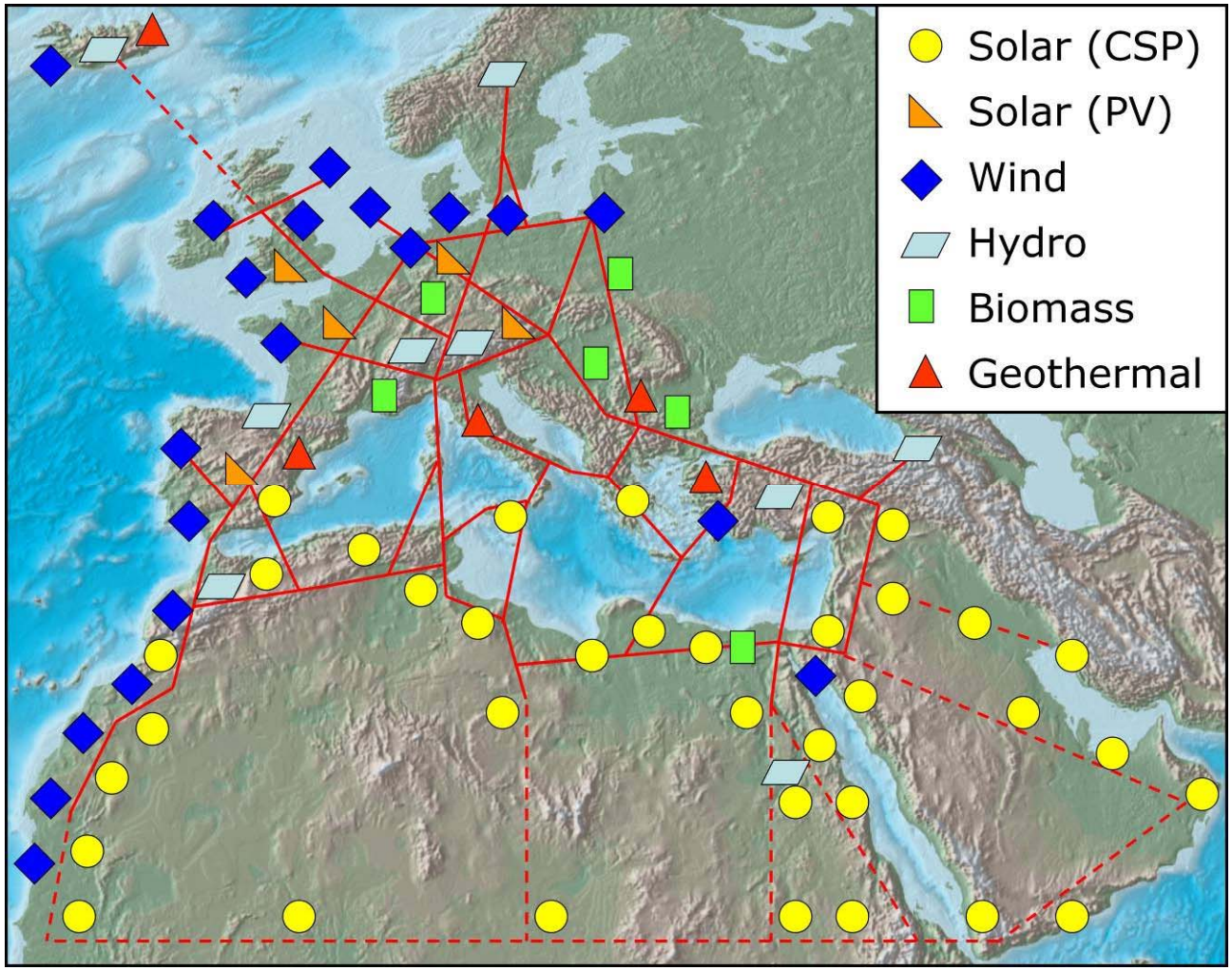
MBA Energy Management, Vienna, September 12-13, 2012

EUMENA Scenario for Sustainable Electricity and Water

Trans-Mediterranean High Voltage Direct Current Electricity Grid: Interstate Highways for Renewable Electricity in EUMENA

TREC
Clean Power from the Deserts
Trans-Mediterranean
Renewable Energy Cooperation
In conjunction with The Club of Rome

THE CLUB OF ROME



EUMENA:
Europe
Middle East
North Africa

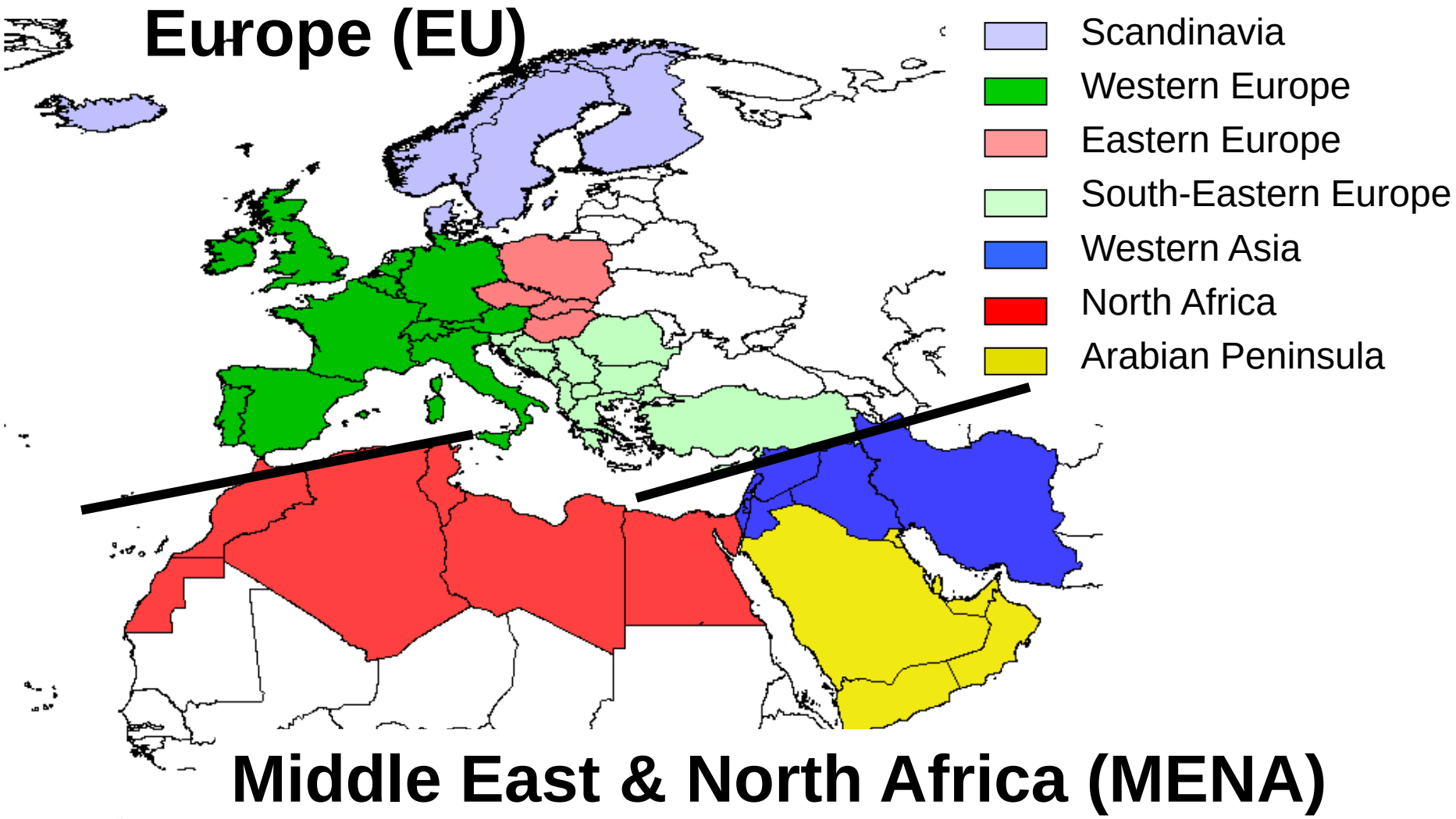
Studies:

Assessment of the renewable energy potential for the sustainable supply of electricity and water in 50 countries of Europe, the Middle East and North Africa taking into consideration the option of Concentrating Solar Thermal Power Plants (CSP).

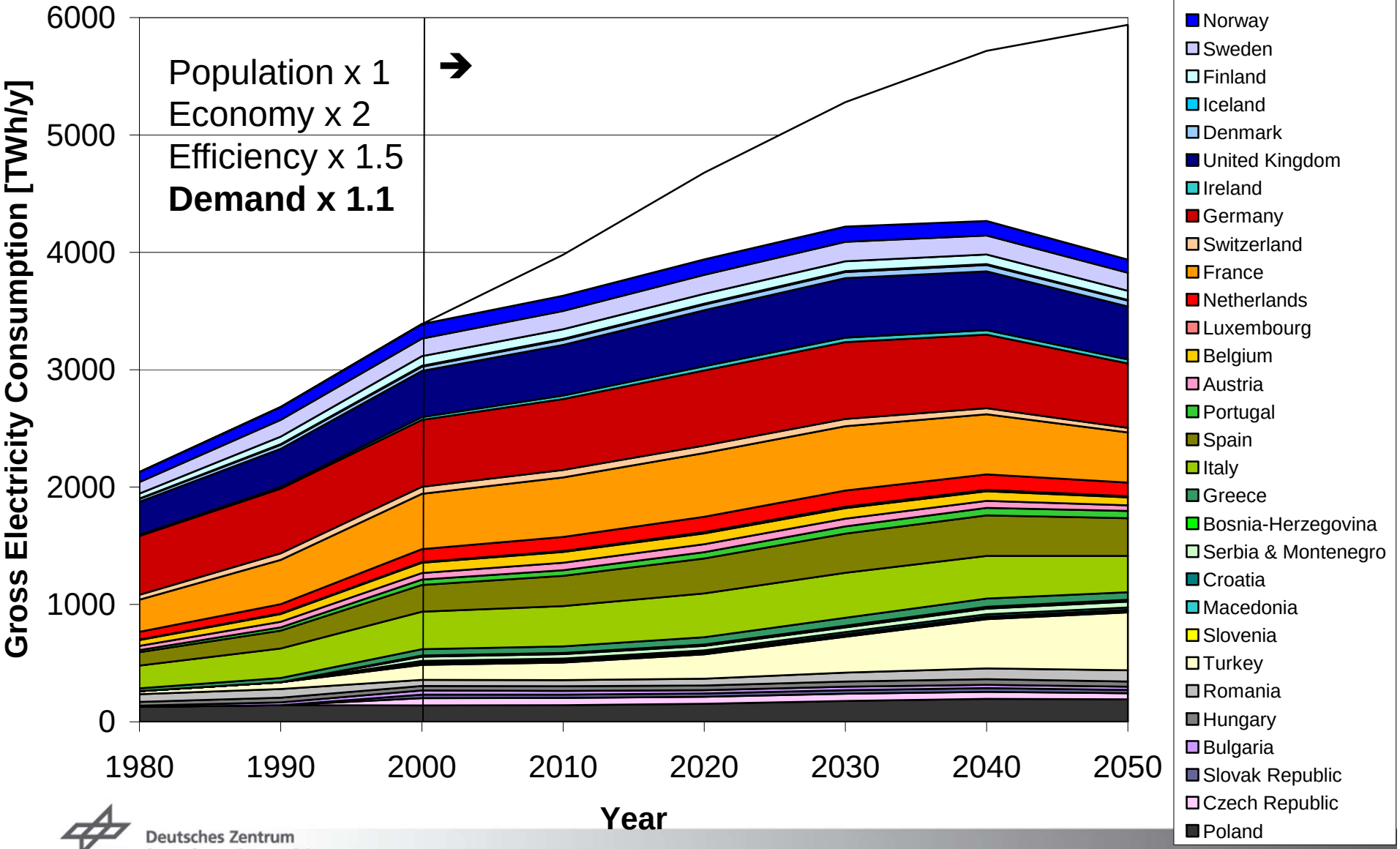
www.dlr.de/tt/med-csp
www.dlr.de/tt/trans-csp
www.dlr.de/tt/aqua-csp

Bundesministerium
für Umwelt, Naturschutz
und Reaktorsicherheit

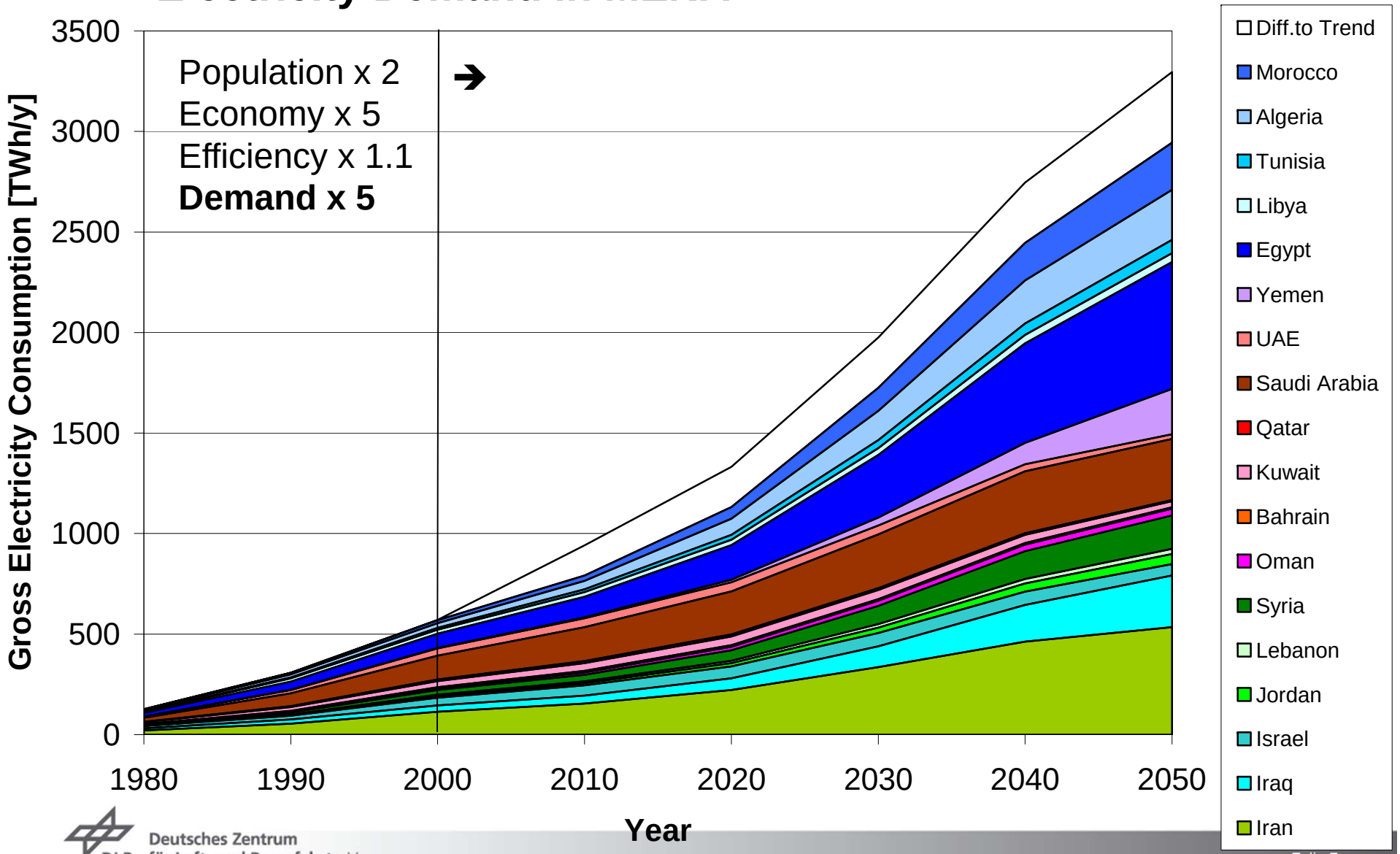
50 Countries in EUMENA analysed



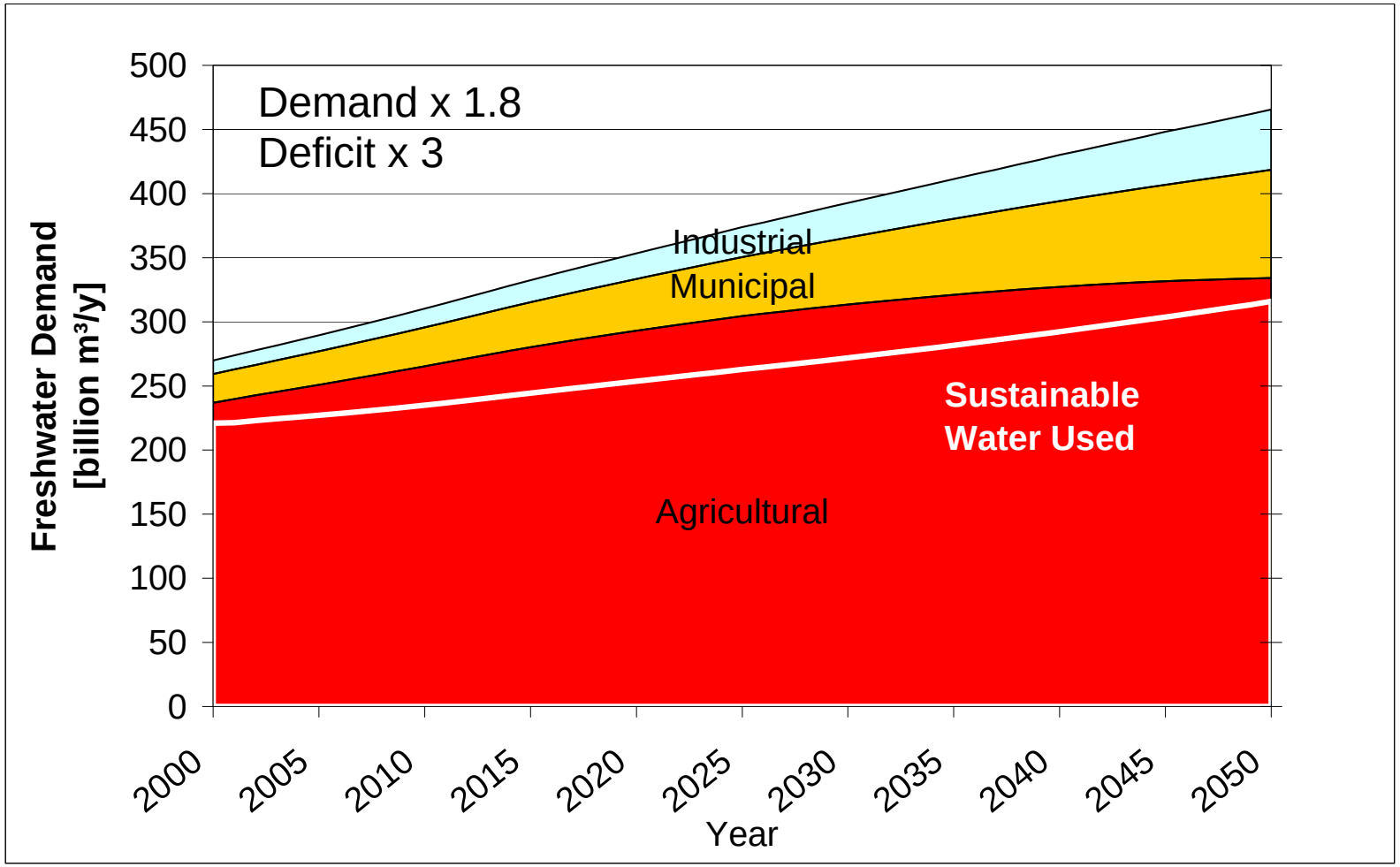
Electricity Demand in Europe



Electricity Demand in MENA



Water Demand in MENA



Criteria for Sustainable Electricity Supply:

✓ **Inexpensive**

low electricity cost
no long term subsidies

✓ **Secure**

diversified and redundant supply
power on demand
based on inexhaustible resources
available or at least visible technology
capacities expandable in time

✓ **Compatible**

low pollution
climate protection
low risks for health and environment
fair access

Renewable Energy Technologies

Geothermal

Hydropower

Concentrating Solar Power

Biomass

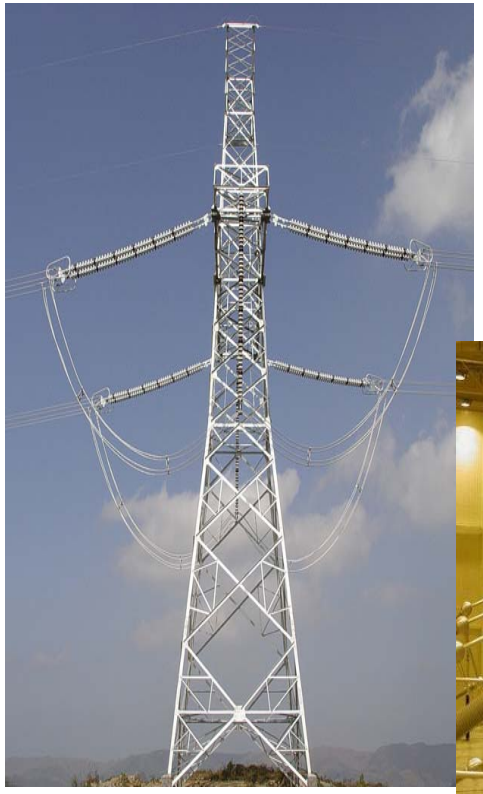
Tides

Waves

Photovoltaic

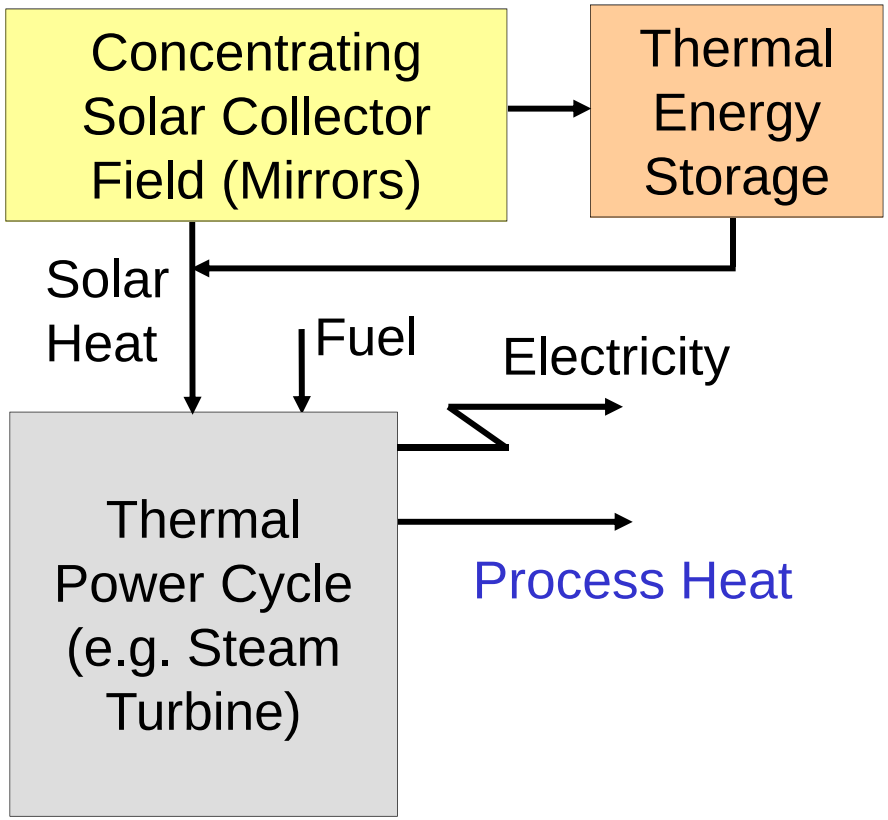
Wind Power

High Voltage Direct Current Transmission



Voltage:	± 800.000 Volt
Power:	6400 Megawatt
Length:	2070 km
Source:	Hydropower
Losses:	7-8%
Construction:	2 years
Cost:	2.5 bn €

Principle of a Concentrating Solar Thermal Power Plant



- concentrated, easily storable solar thermal energy as fuel saver

- spinning reserve
- firm capacity, power on demand
- combined generation of process heat for cooling, industry, desalination, etc.

Portfolio of Energy Sources for Electricity:

- ✓ Coal, Lignite
- ✓ Oil, Gas
- ✓ Nuclear Fission, Fusion

} ideally stored primary energy

- ✓ Concentrating Solar Power (CSP)
- ✓ Geothermal Power (Hot Dry Rock)
- ✓ Biomass
- ✓ Hydropower

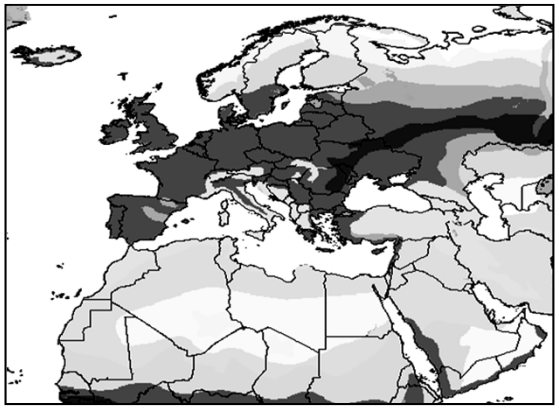
} storable primary energy

- ✓ Wind Power
- ✓ Photovoltaic
- ✓ Wave / Tidal

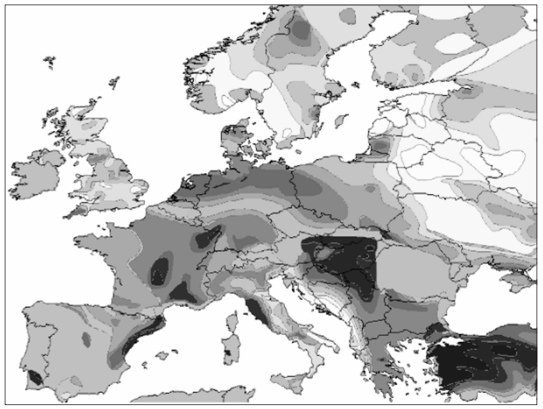
} fluctuating primary energy

Renewable Electricity Potential in Europe, Middle East & North Africa

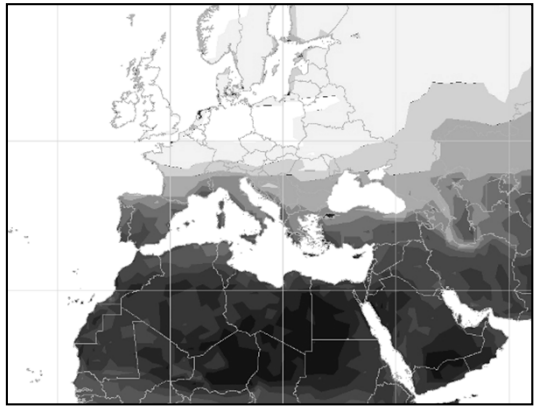
Biomass (0-1)

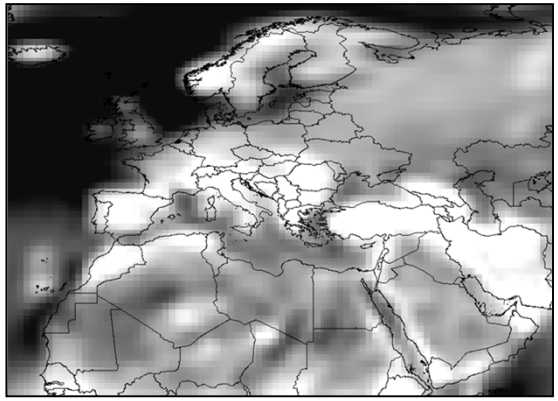


Geothermal (0-1)

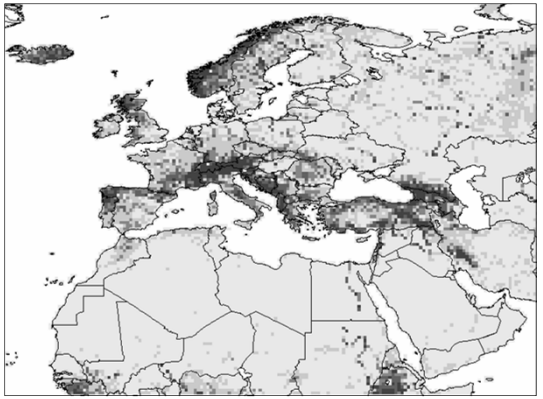


Solar (10-250)





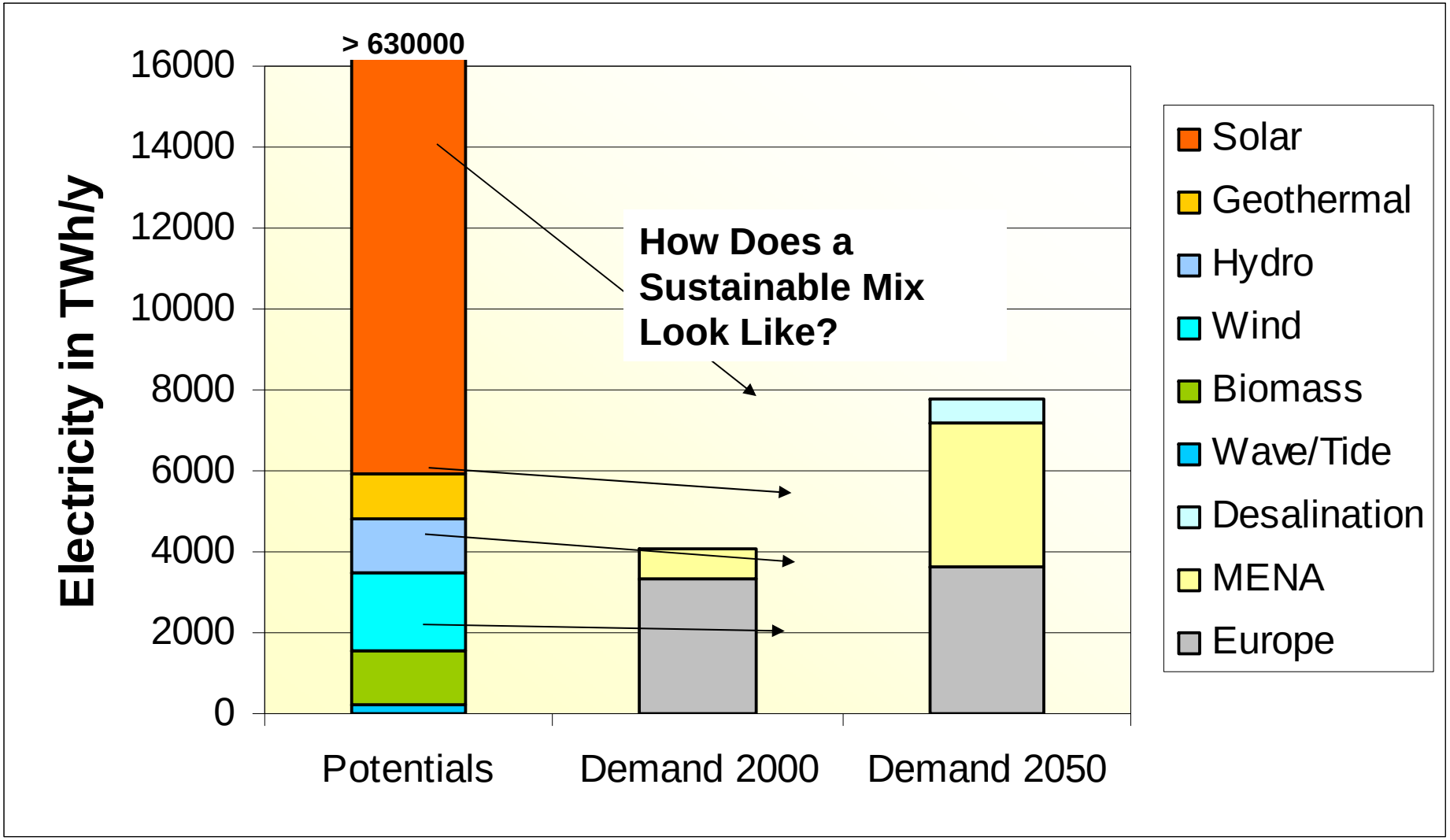
Wind Energy (5-50)



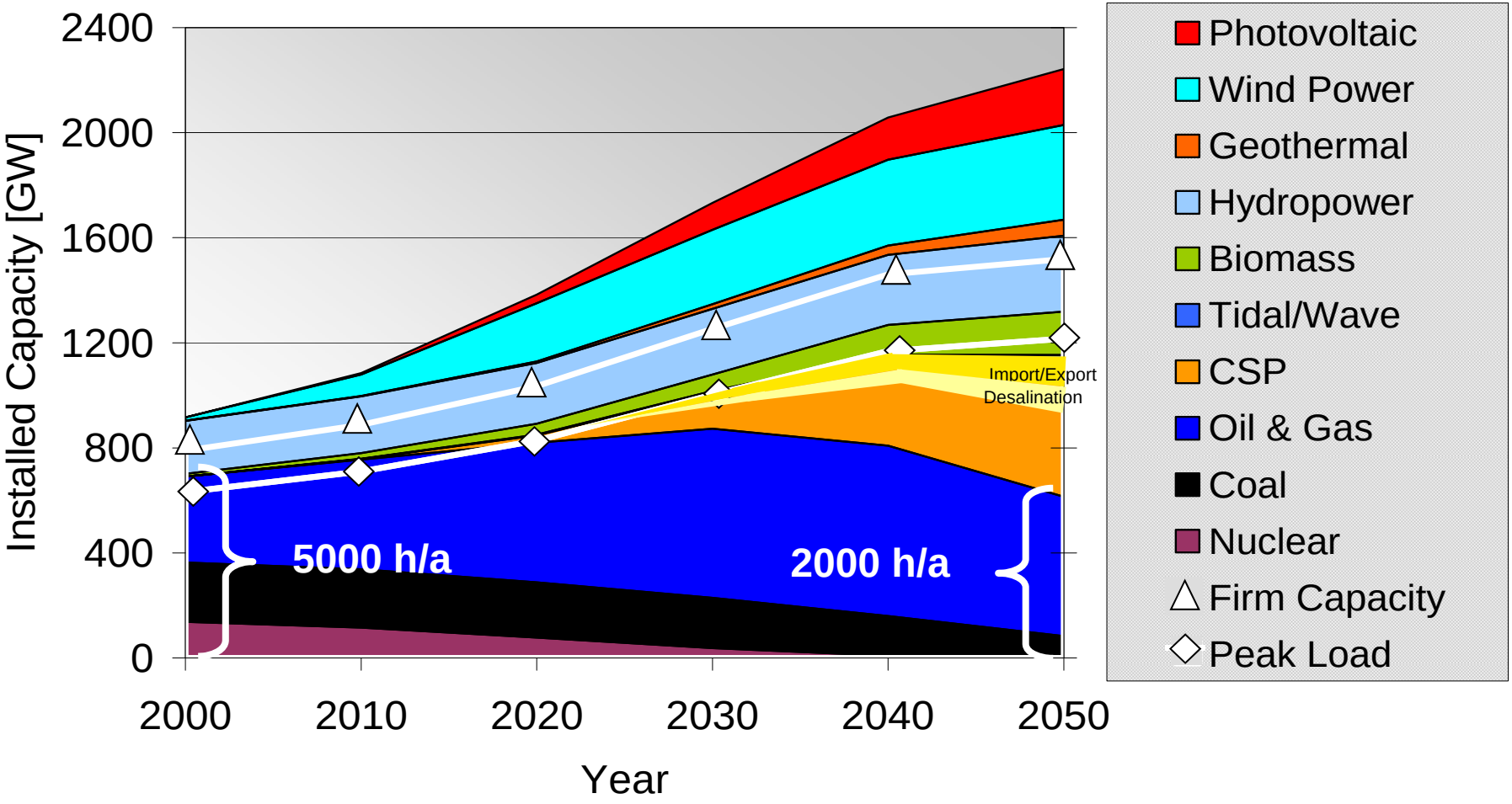
Hydropower (0-50)

Electricity Yield
in GWh/km²/y

Economic Renewable Electricity Potentials vs. Demand in EUMENA

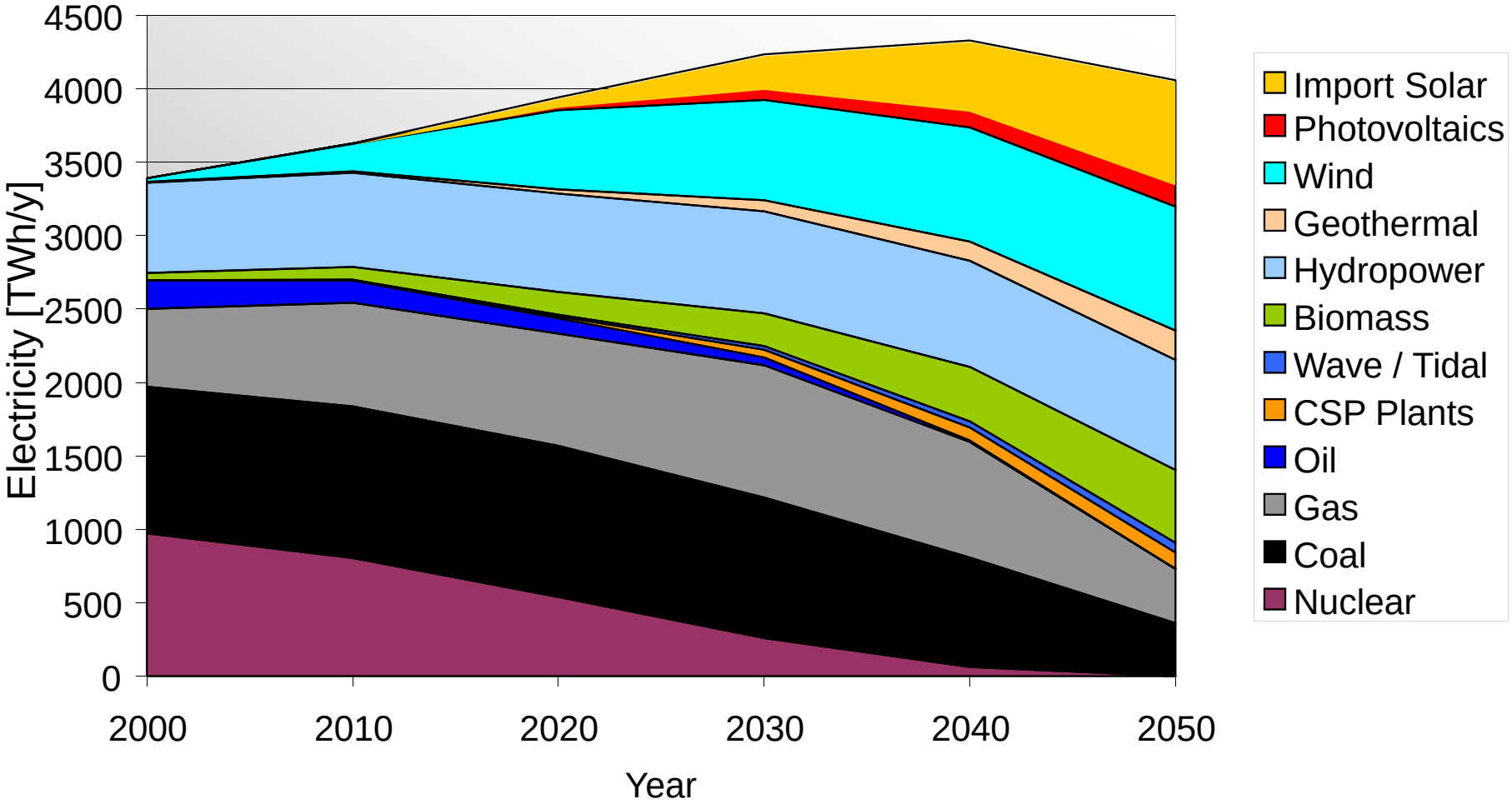


Installed Capacity vs. Peak Load in EUMENA

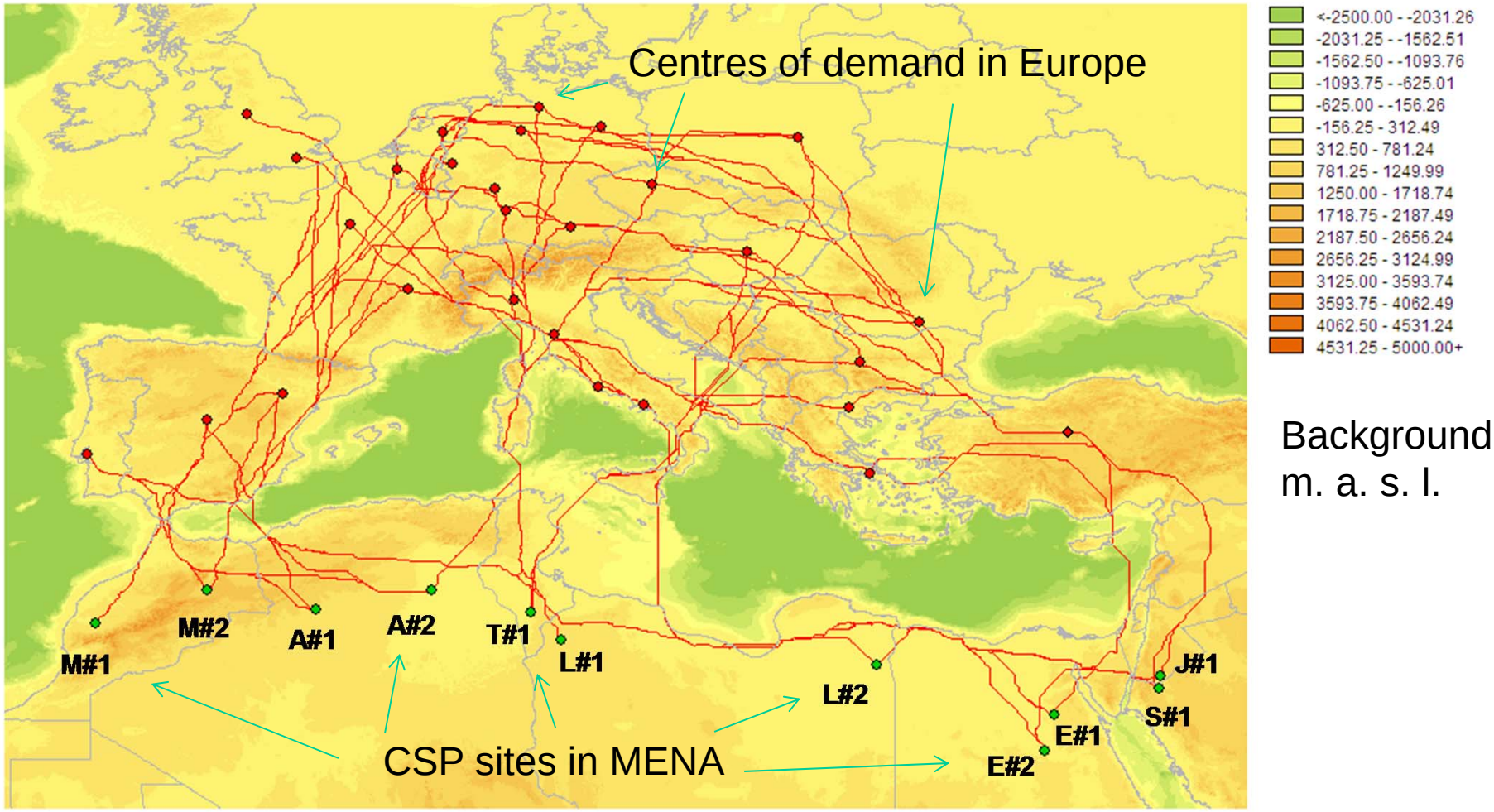


➔ 100 % availability plus 25 % reserve capacity

Electricity Supply in Europe (TRANS-CSP Scenario)



33 new additional energy supply corridors for Europe



Background:
m. a. s. l.

33 new additional energy supply corridors for Europe

Import Country	Start Point	End Point	Overhead Line Length	Underground Cable Length	Sea Cable Length	Start Year	Full Load Production	Net Import Capacity	Net Import Electricity	Total Investment	Import Electricity Cost	Solar Multiple	Total Length
			km	km	km	a	h/a	MW	TWh/a	M€	€/kWh		km
Germany /	Morocco #1	Karlsruhe, Germany	2,506	278	132	2020	6,679	3,440	23.0	32,005	0.116	3.5	2,917
Denmark	Morocco #2	Jülich, Germany	2,075	231	149	2030	6,943	3,522	24.5	25,355	0.086	3.5	2,455
	Tunisia #1	Mainz, Germany	1,634	182	344	2040	6,584	3,587	23.6	23,048	0.081	3.5	2,160
	Algeria #1	Hannover, Germany	2,384	265	202	2045	6,967	3,456	24.1	22,370	0.077	3.5	2,851
	Algeria #2	Munich, Germany	1,427	159	413	2050	6,883	3,620	24.9	21,813	0.073	3.5	1,998
France	Morocco #1	Paris, France	1,957	217	132	2020	5,284	3,547	18.7	23,055	0.102	2.5	2,306
	Morocco #2	Paris, France	1,611	179	149	2030	5,492	3,613	19.8	18,560	0.078	2.5	1,939
	Tunisia #1	Paris, France	1,666	185	344	2040	5,962	3,581	21.3	20,221	0.079	3.0	2,195
	Algeria #1	Lion, France	1,480	164	202	2045	6,967	3,633	25.3	21,655	0.071	3.5	1,847
	Algeria #2	Lion, France	1,805	201	202	2050	6,883	3,569	24.6	21,416	0.073	3.5	2,208
United	Morocco #1	London, UK	2,125	236	282	2030	5,284	3,498	18.5	19,481	0.088	2.5	2,643
Kingdom	Morocco #2	London, UK	1,835	204	265	2040	6,287	3,557	22.4	20,089	0.075	3.0	2,304
	Algeria #1	Newcastle, UK	2,196	244	308	2050	6,967	3,481	24.3	22,075	0.068	3.5	2,748
Spain	Morocco #2	Madrid, Spain	853	95	16	2040	5,492	3,775	20.7	15,698	0.063	2.5	964
	Algeria #1	Zaragoza, Spain	879	98	202	2050	6,451	3,750	24.2	18,545	0.064	3.1	1,178
Italy	Algeria #2	Milano, Italy	1,057	117	413	2030	5,454	3,693	20.1	19,034	0.079	2.5	1,587
	Tunisia #1	Firence, Italy	980	109	344	2040	5,208	3,715	19.3	16,935	0.073	2.5	1,432
	Libya #1	Roma, Italy	1,305	145	312	2050	5,626	3,655	20.6	17,189	0.070	2.7	1,761
Poland	Egypt #1	Warszaw	2,574	286	665	2030	5,625	3,369	18.9	21,246	0.093	2.5	3,525
	Jordan #1	Warszaw	3,053	339	108	2040	5,435	3,335	18.1	17,833	0.082	2.5	3,500
	Egypt #2	Warszaw	2,837	315	665	2045	6,655	3,317	22.1	21,589	0.081	3.0	3,817
	Saudi Arabia #1	Warszaw	3,130	348	108	2050	7,158	3,320	23.8	22,154	0.078	3.5	3,586
Turkey	Jordan #1	Ankara, Turkey	2,050	205	0	2030	5,435	3,546	19.3	18,332	0.079	2.5	2,255
	Saudi Arabia #1	Ankara, Turkey	2,100	210	0	2040	5,663	3,537	20.0	16,604	0.069	2.5	2,310
	Saudi Arabia #1	Ankara, Turkey	2,100	210	0	2050	5,838	3,537	20.6	16,221	0.065	2.6	2,310
Czech	Algeria #2	Prague, Czech Republic	1,635	182	413	2040	5,445	3,580	19.5	17,714	0.076	2.5	2,230
Republic	Libya #1	Prague, Czech Republic	1,629	181	344	2050	5,303	3,588	19.0	16,552	0.072	2.5	2,154
Belgium	Morocco #1	Brussels, Belgium	2,232	248	132	2030	5,447	3,493	19.0	19,646	0.086	2.6	2,612
Netherlands	Morocco #2	Appledorn, Netherlands	2,082	231	149	2040	6,287	3,521	22.1	19,892	0.075	3.0	2,462
Romania	Jordan #1	Bukarest, Romania	2,154	239	108	2030	4,512	3,511	15.8	15,900	0.084	2.0	2,502
	Algeria #2	Bukarest, Romania	2,255	251	413	2040	5,445	3,458	18.8	18,226	0.081	2.5	2,918
Greece / Bulgaria	Egypt #2	Sophia, Bulgaria	1,974	219	655	2030	6,168	3,487	21.5	21,925	0.085	2.7	2,849
Hungary / Slovakia	Libya #1	Budapest, Hungary	1,388	154	712	2040	6,883	3,596	24.7	24,115	0.081	3.5	2,254

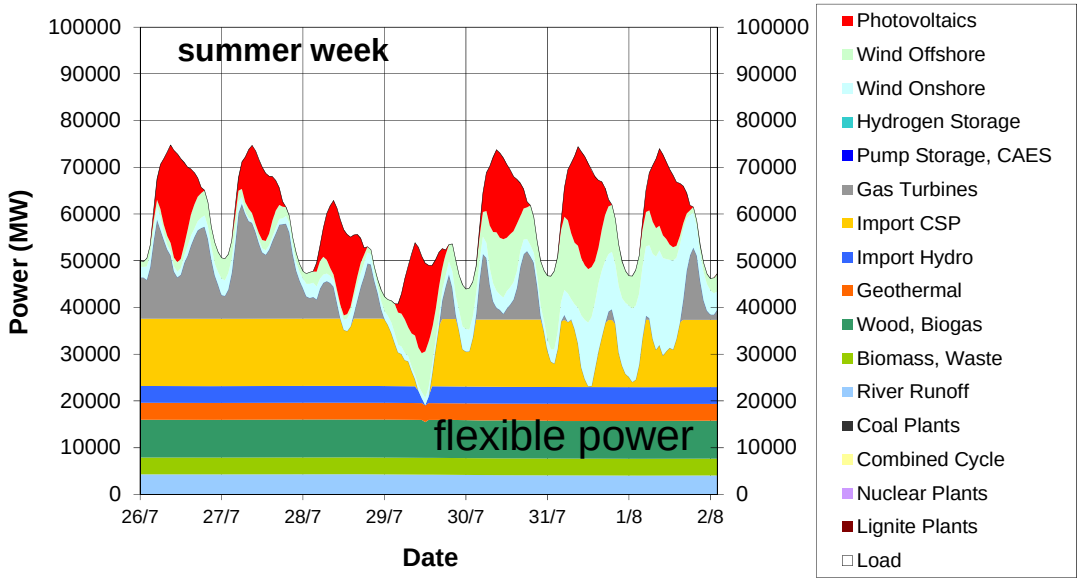
Source: Trieb et al., Energy Policy 42 (2012) 341-353

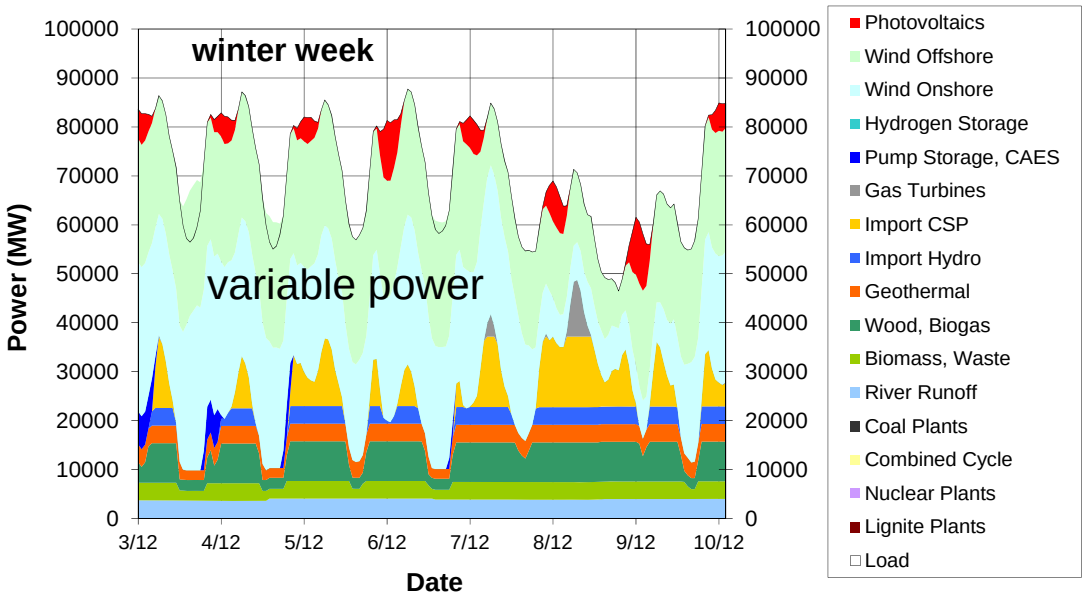
Case study Germany 2050

The role of variable and flexible renewable power sources in a 90% renewable electricity scenario for the year 2050 for Germany.

Installed Capacities:

Photovoltaics:	45 GW	50% var. RE
Wind Onshore:	40 GW	
Wind Offshore:	27 GW	
Runoff Hydropower:	6 GW	40% flex. RE
Import CSP:	16 GW	
Import Hydro:	4 GW	
Geothermal:	4 GW	
Biomass:	9 GW	
Biomass Waste:	4 GW	
Natural Gas:	63 GW	10% flex. Fuel





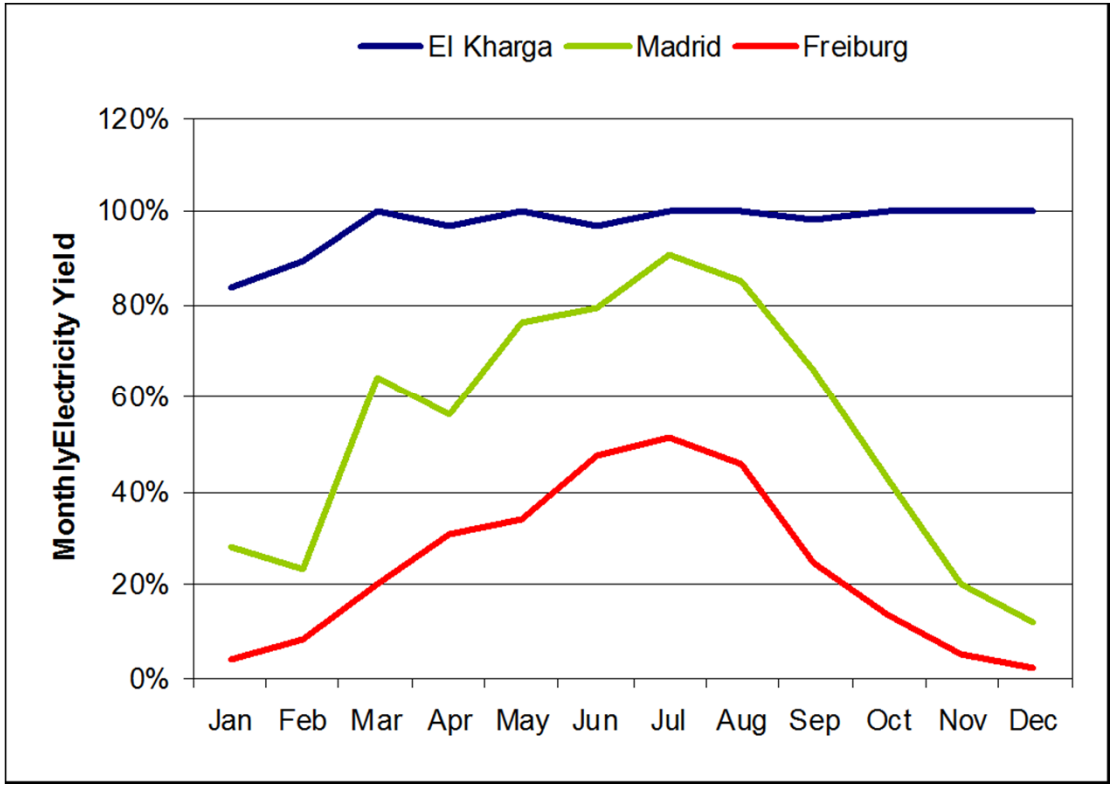
Why CSP imports from MENA?

Higher availability than in EU → flexible renewable power

CSP with large solar field and storage (SM4) at three sites:

MENA advantages:

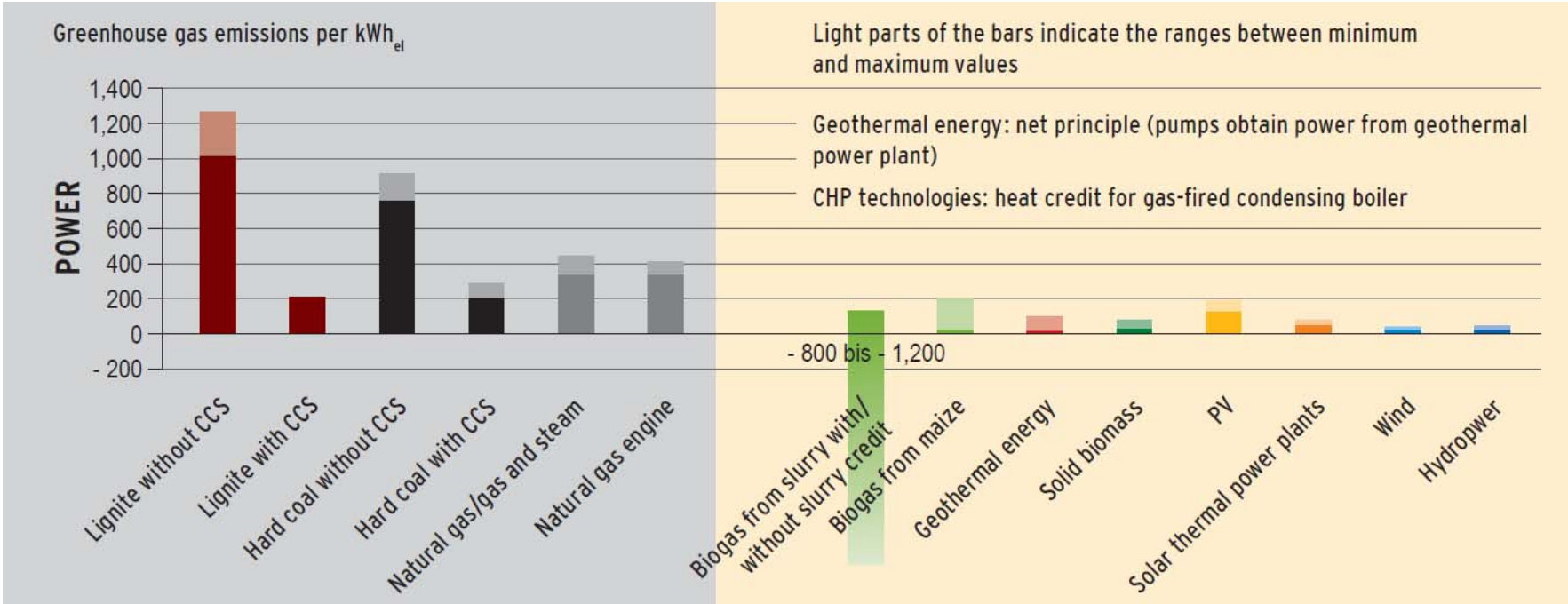
- more sunny days
- lower latitude
- ➔ lower seasonal variation of electricity yield



Availability and Redundancy

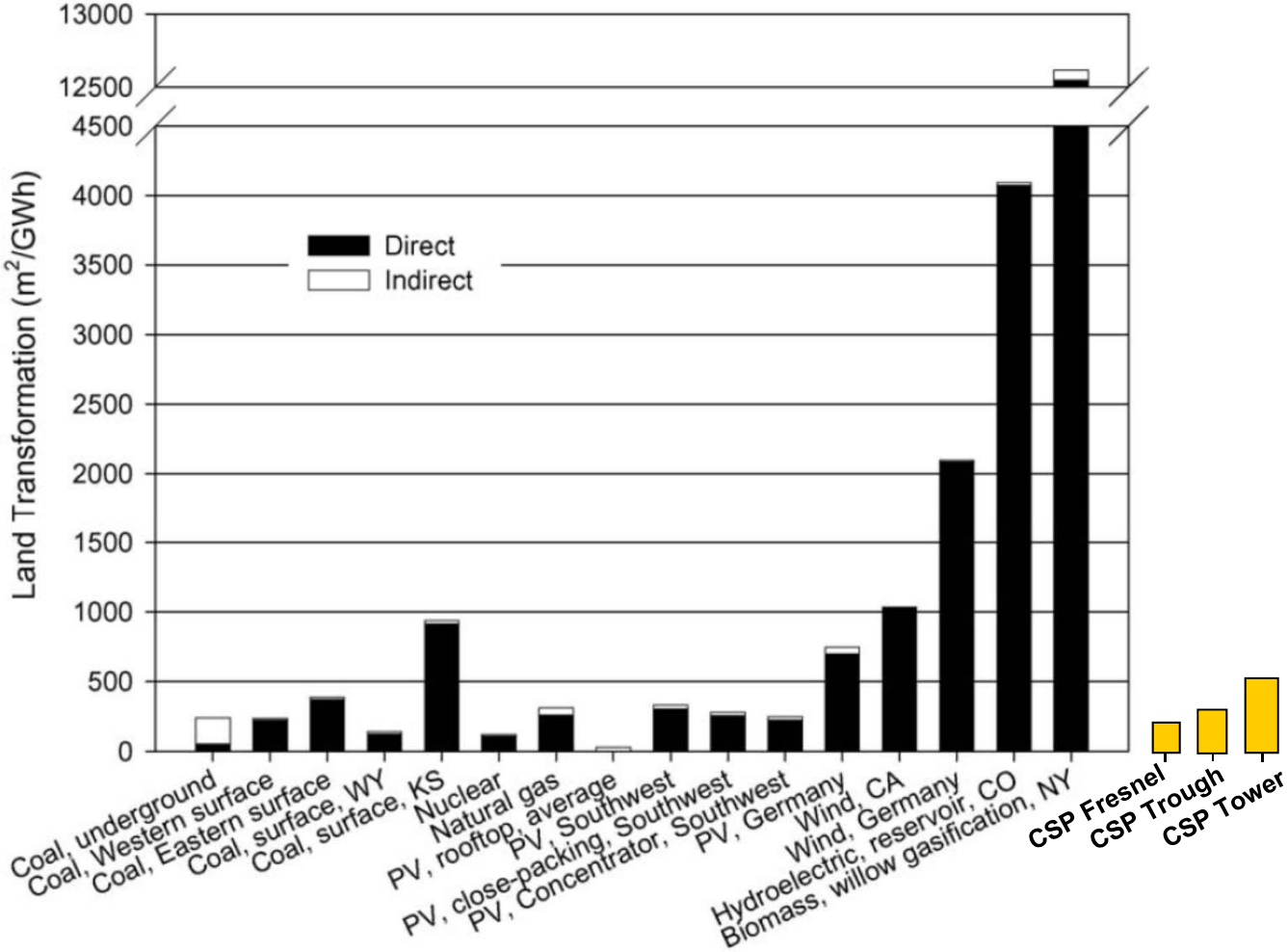
- Power on demand by a mix of fluctuating and balancing sources
- Increased number of non-correlated energy sources
- Increased number and reduced average size of power plants
- Increased number of supply regions
- Additional HVDC grid infrastructure for long-distance transfer
- Domestic sources dominate the electricity mix
- Non-depletable sources dominate the electricity mix
- Strategy is based on proven technologies

Life Cycle Carbon Emissions



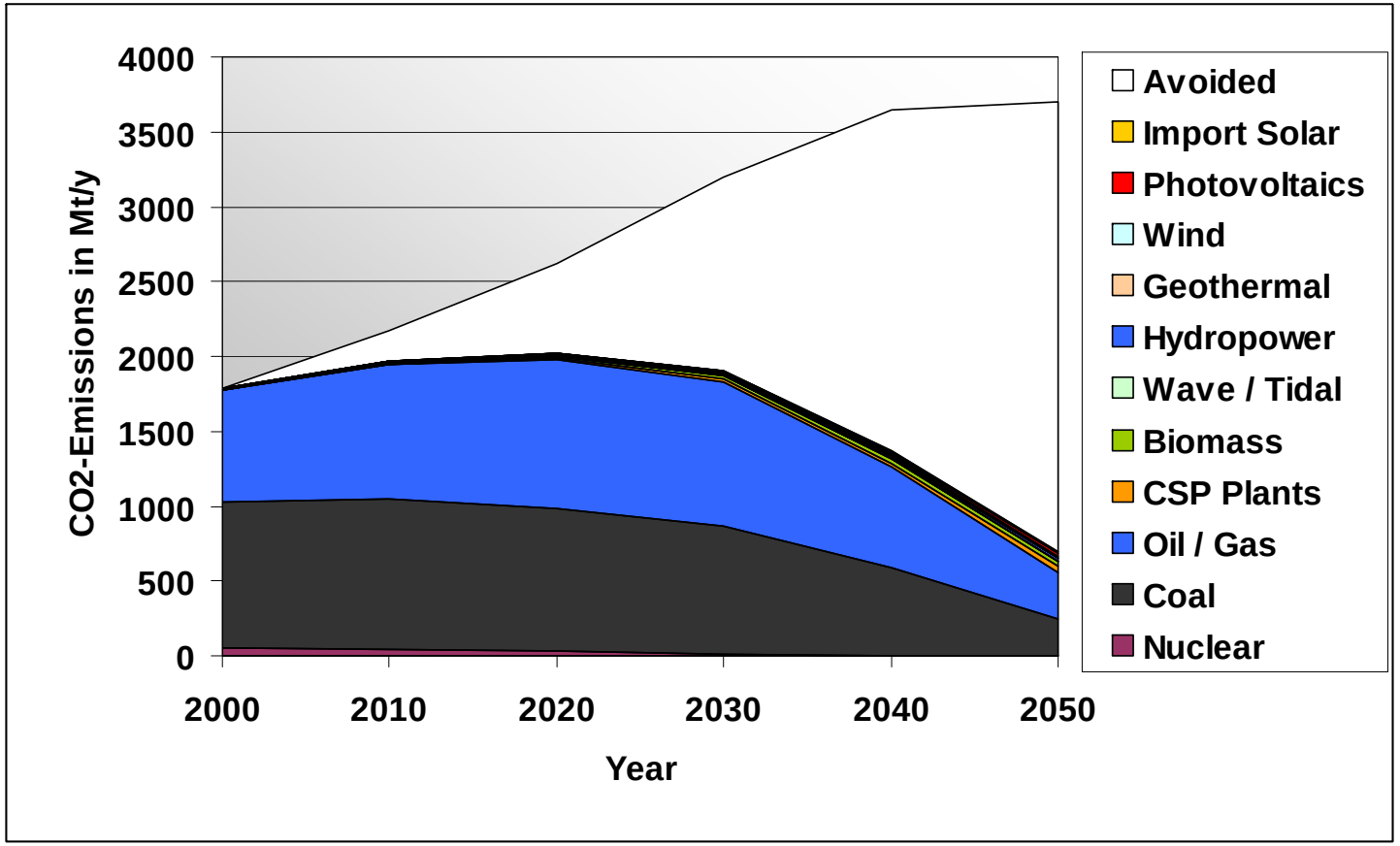
http://www.erneuerbare-energien.de/english/renewable_energy/downloads/doc/44744.php

Life Cycle Land Use



V. Fthenakis, H.C. Kim / Renewable and Sustainable Energy Reviews 13 (2009) 1465–1474

Carbon emissions of EUMENA power sector are reduced to 38 % until 2050 in spite of a quickly growing demand

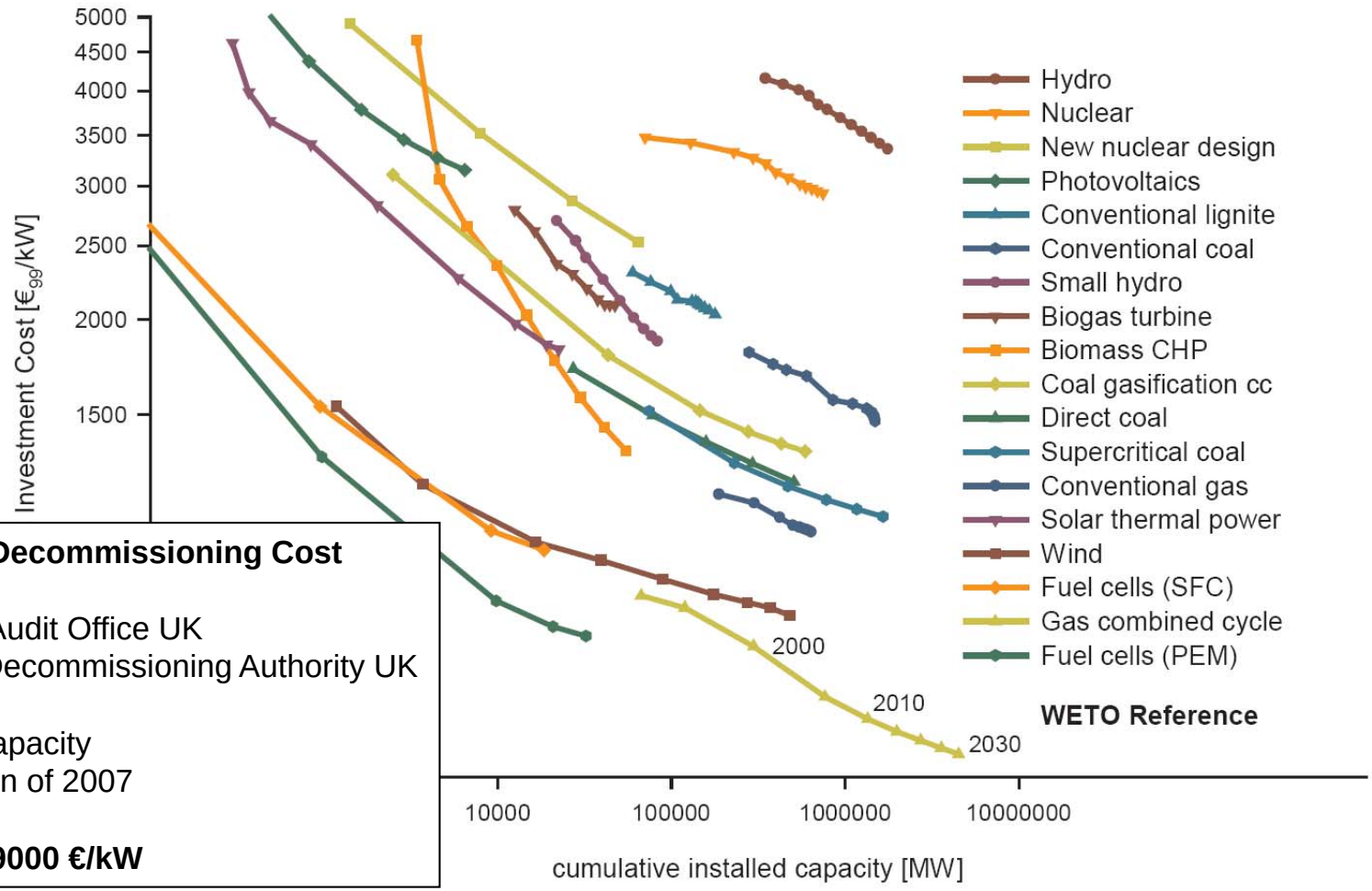


1% of Land Area Required

Environmental Security

- Reduced life cycle greenhouse gas emissions from power generation
- Reduced risks of nuclear contamination and proliferation
- Reduced local pollution by combustion products
- Optimal land use (1%) through diversified mix
- Technology based on recyclable materials

Equipment Cost Learning Curves



Nuclear Decommissioning Cost

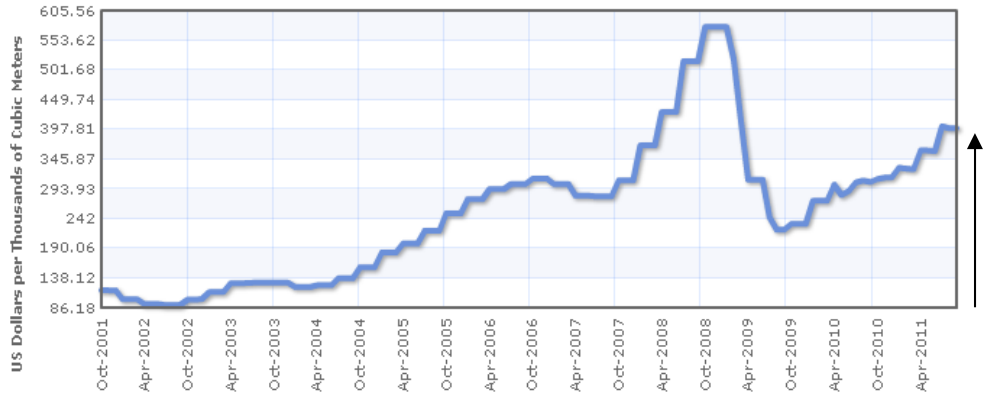
National Audit Office UK
Nuclear Decommissioning Authority UK

11 GW Capacity
61 £ Billion of 2007

= 6000 - 9000 €/kW

Fuel Prices 2001 - 2011

Natural Gas
Russia



x 4.6

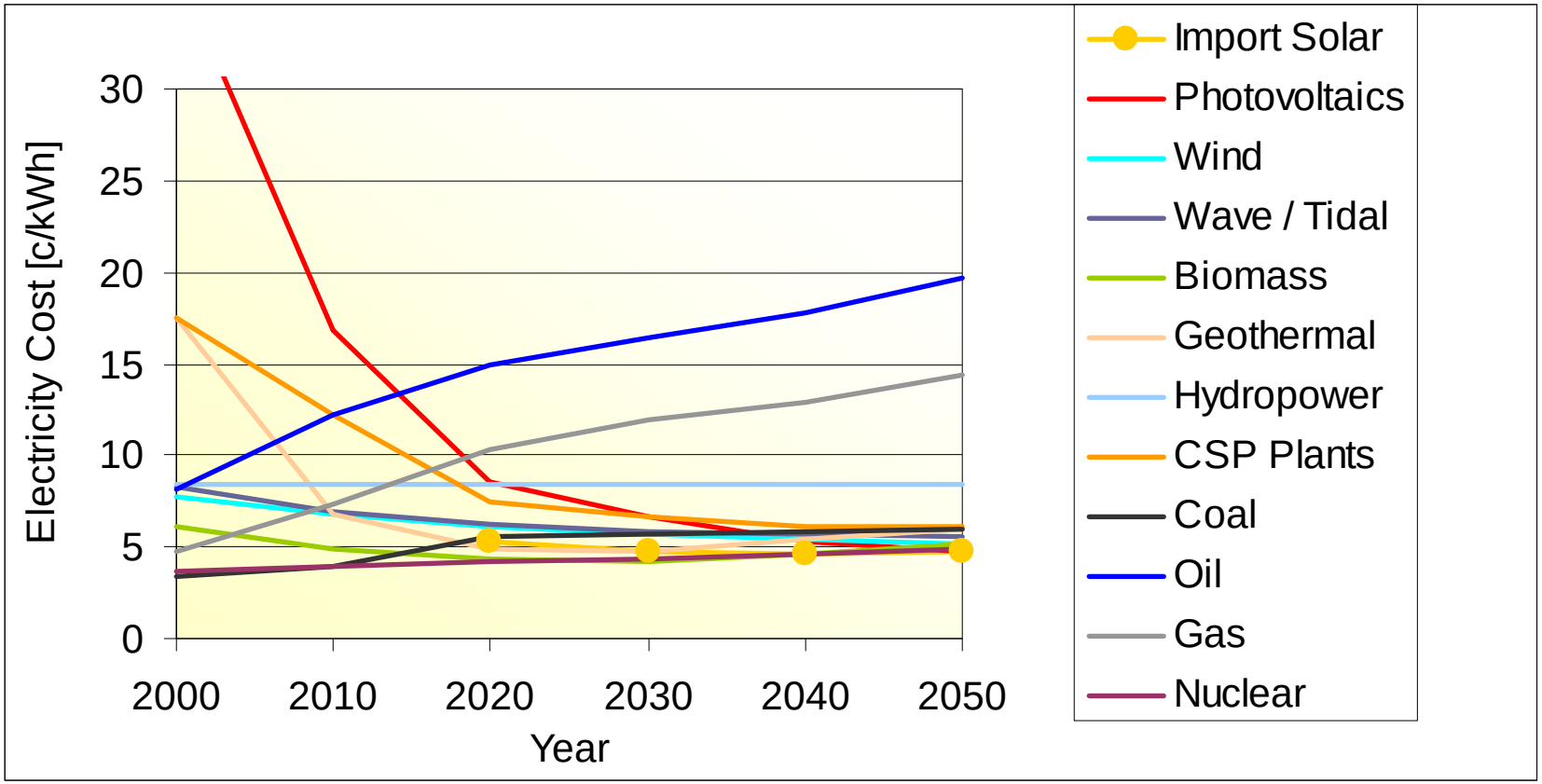
Crude Oil

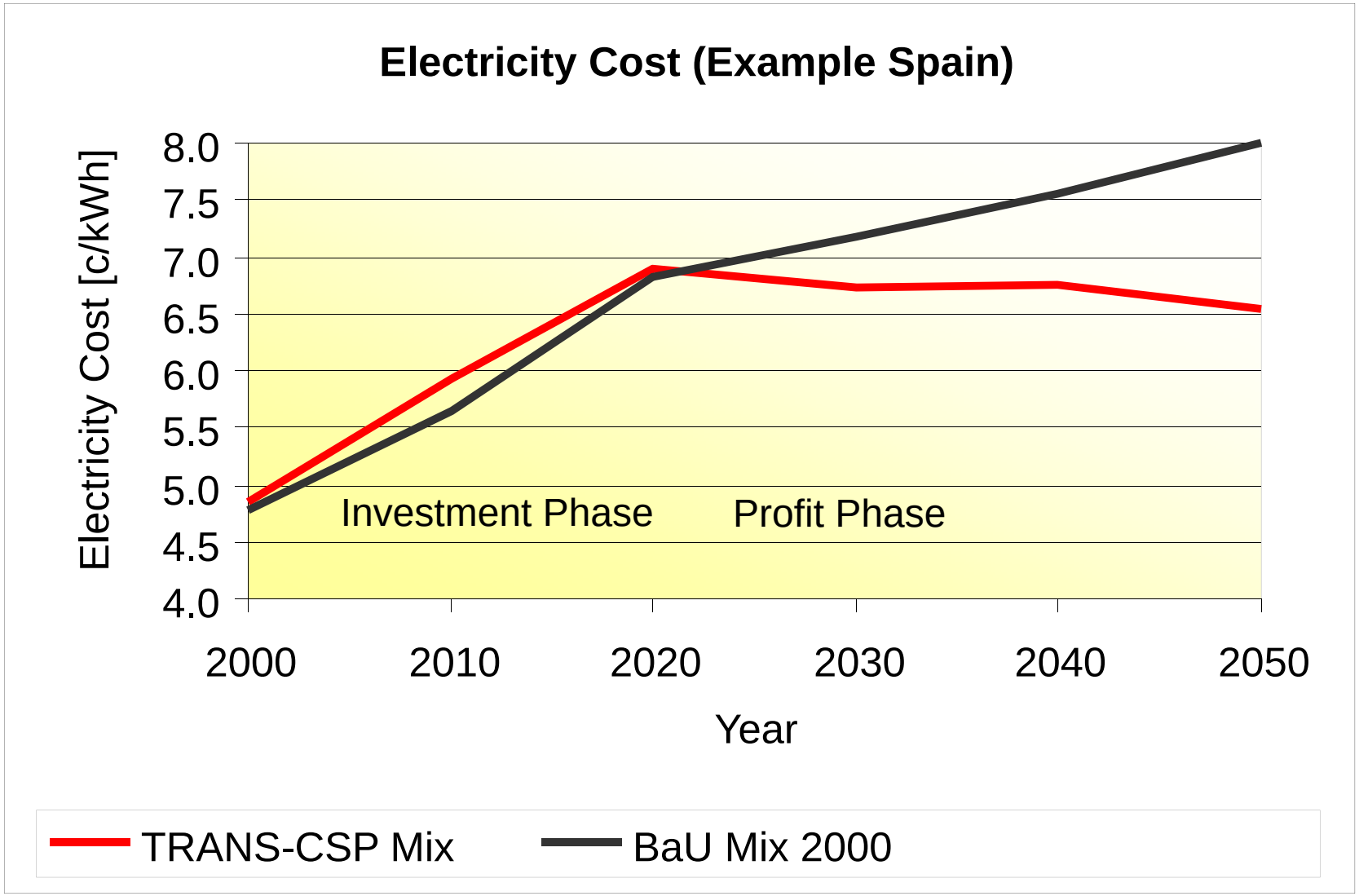
x 5.9

Coal (thermal)
Australia

x 5.6

Electricity Cost Learning Curves (example Spain)



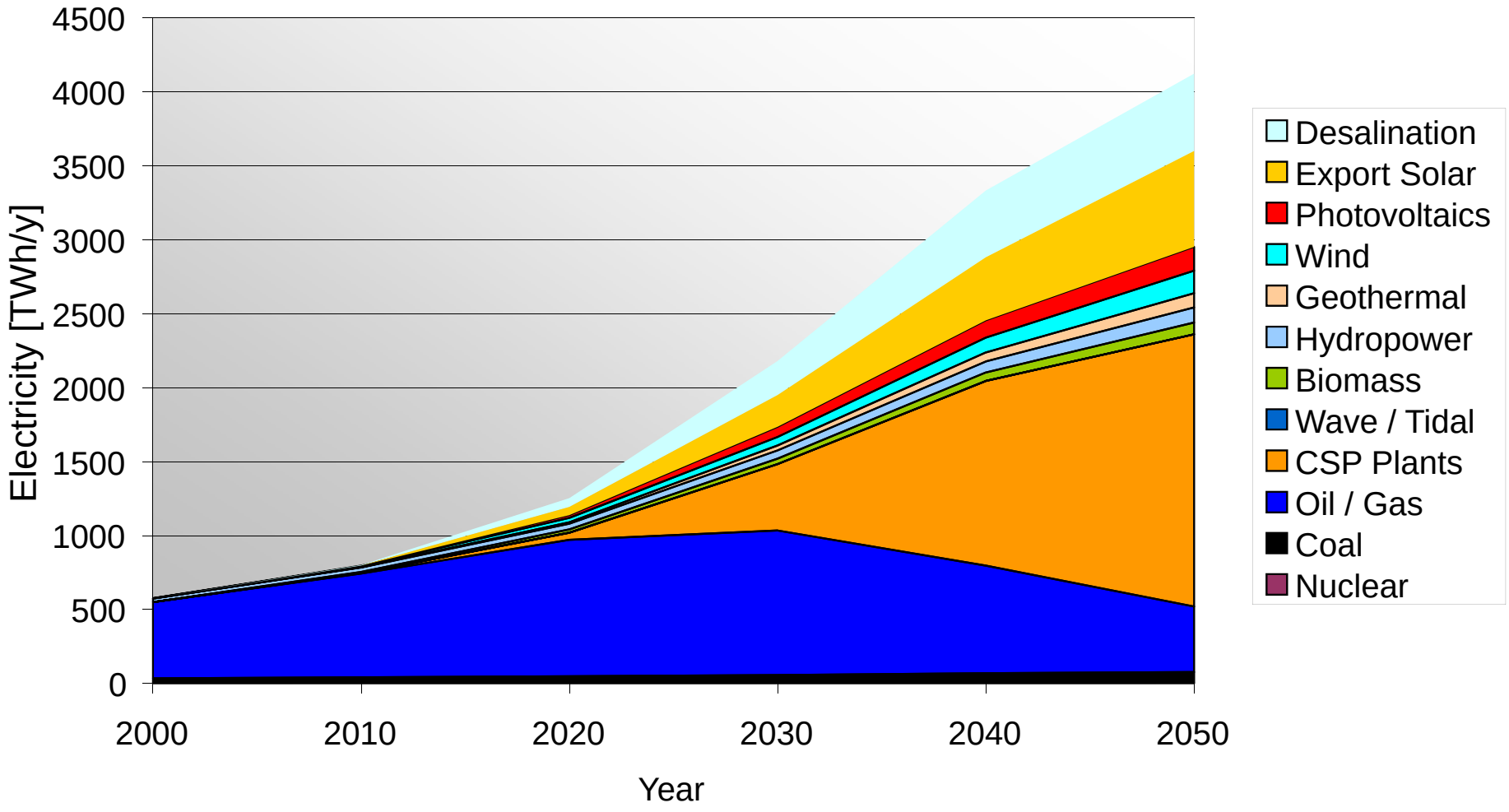


$€_{2000}$, Fuel Cost: IEA / WEO 2005, after 2020 CCS

Economic Security

- Economic risk hedged by increased portfolio
- Intrinsic trend to lower cost and lower price volatility
- Energy cost stabilization through investment in new sources
- Prevention of cost escalation due to environmental constraints
- Prevention of cost escalation due to scarcity
- Prevention of cost explosion due to nuclear decommissioning
- Reduction of energy subsidies in Europe and MENA

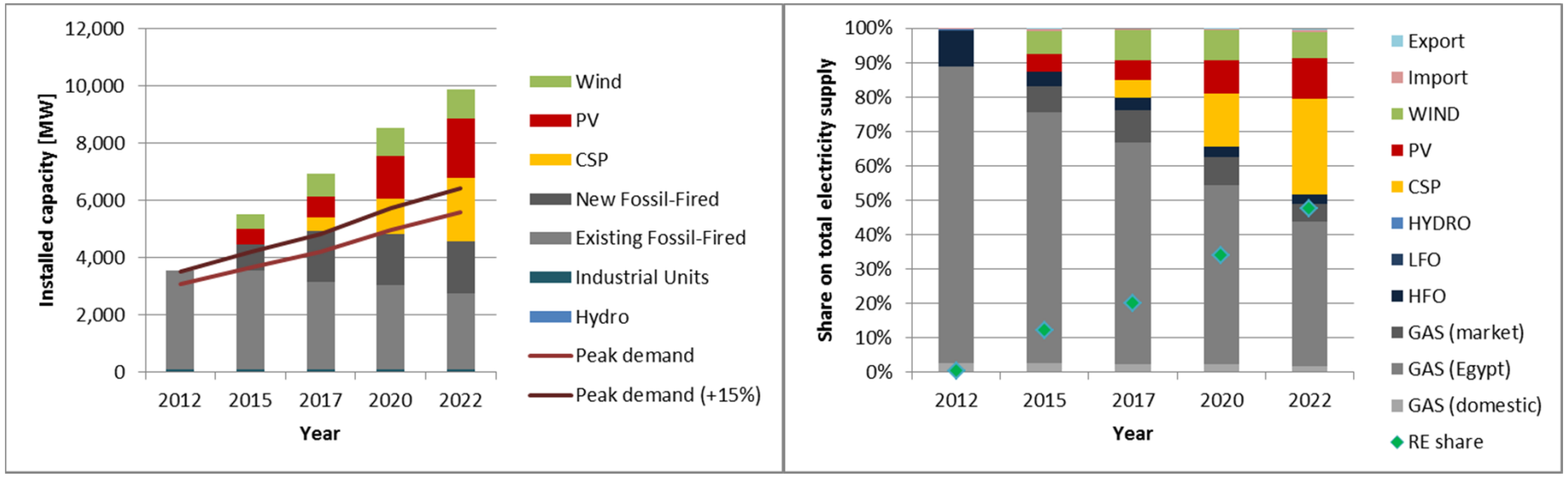
Electricity Supply in the Middle East & North Africa



Prospects for RES-E expansion in North Africa

ReMix-MENA cost optimization model for capacity expansion

- Example: Case study for Jordan
- Jordan's situation:
  - Strongly increasing electricity demand
  - High dependency on fossil fuel imports
  - Peak- and upper mid-merit load by expensive H.F.O. and L.F.O



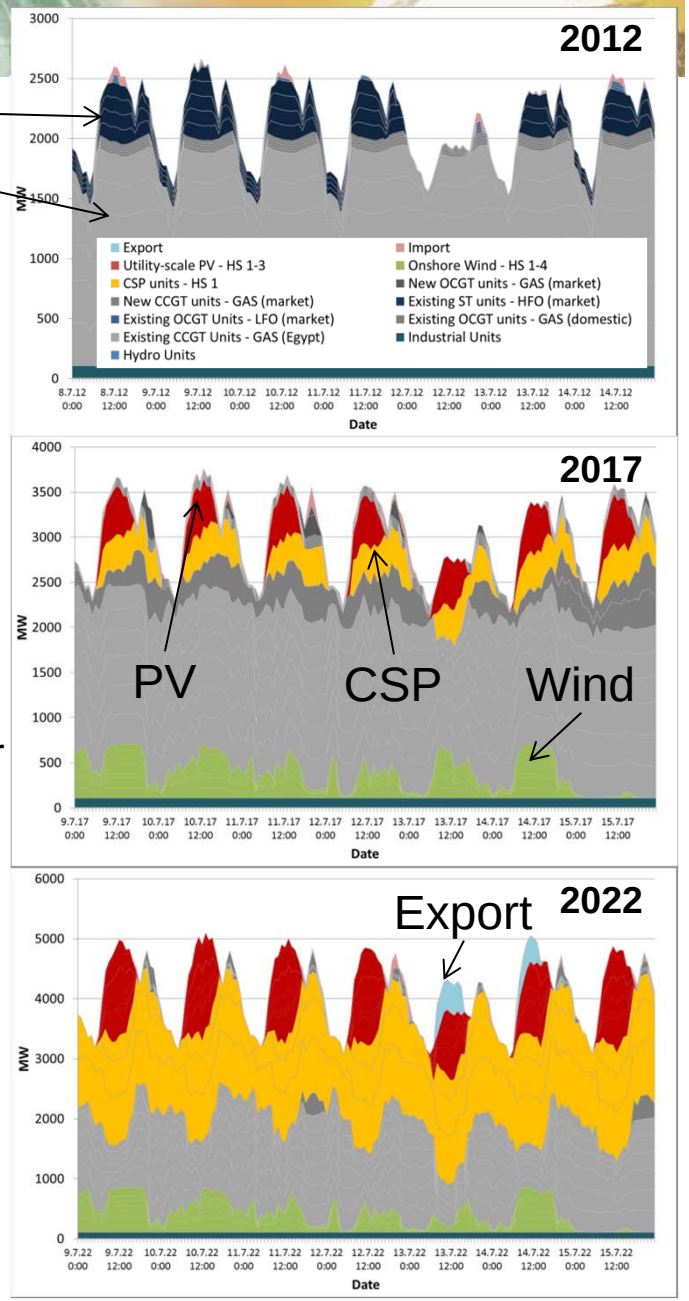
Scenario: „base case"

Source: Fichter (DLR) 2012, ReMix-MENA optimization tool

Business case NA

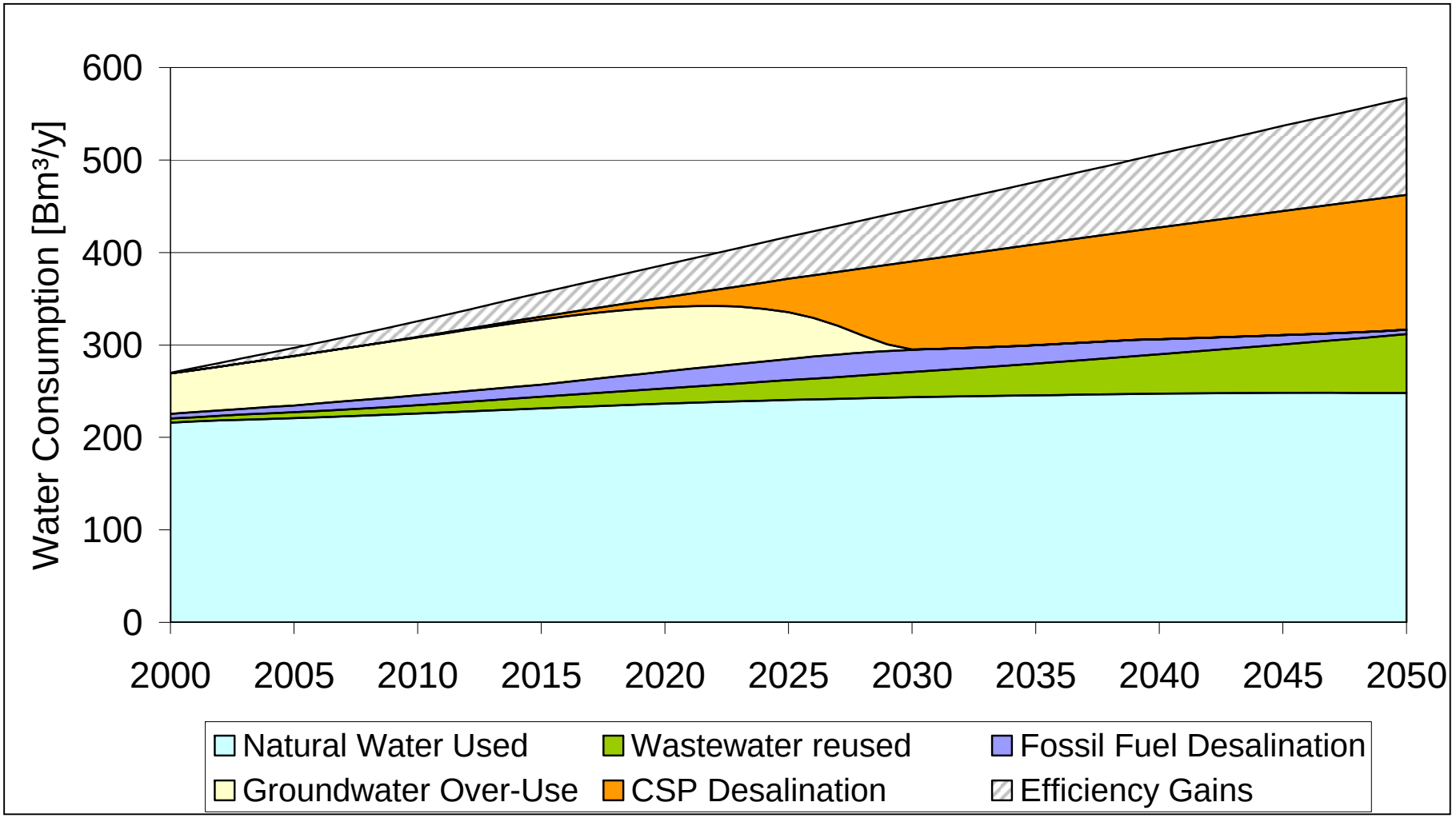
Strongly required firm and flexible renewable power capacity

- CSP competitive in the peak and upper-mid merit segment in the short-term.
- CSP providing strongly required firm and flexible power capacity.
- First CSP plants with rather small solar field and storage.
- Very limited availability of electricity storage and of other flexible and firm RES-E.
- PV as “fuel saver” in the peak load segment (noon-peak).
- Wind as “fuel saver” in the base load segment.
- In the medium-term CSP competitive in mid-merit and base load segment. SM and storage capacity is increased.
- CSP in long-term as back-bone of electricity supply.



Source: Fichter (DLR) 2012, ReMix-MENA optimization tool

AQUA-CSP Scenario for Middle East & North Africa



Solar Power & Desalination Plants

Energy,
Water,
Food,
Labor and
Income

for further
300 Million
People
in MENA ?

(artist view created with
Google Earth)

Political Security

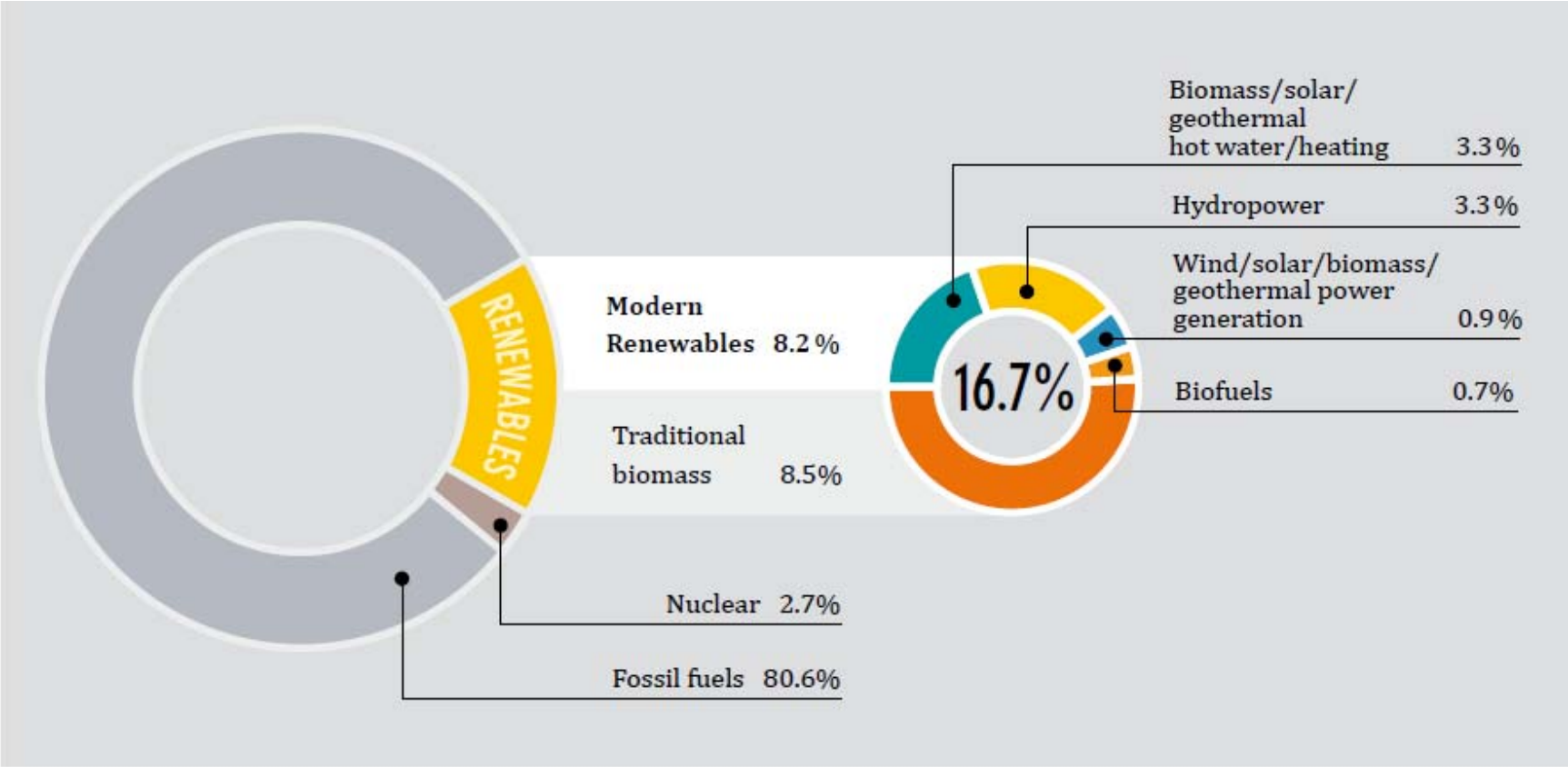
- Conflict prevention between EU and MENA reducing pressure on fuels
- Conflict prevention in MENA solving energy and water scarcity
- Conflict prevention in Europe increasing energy diversity
- Reduction of European energy import dependency
- Addition of energy corridors for European supply
- Initiating EU-MENA (Energy) Partnership

Challenges

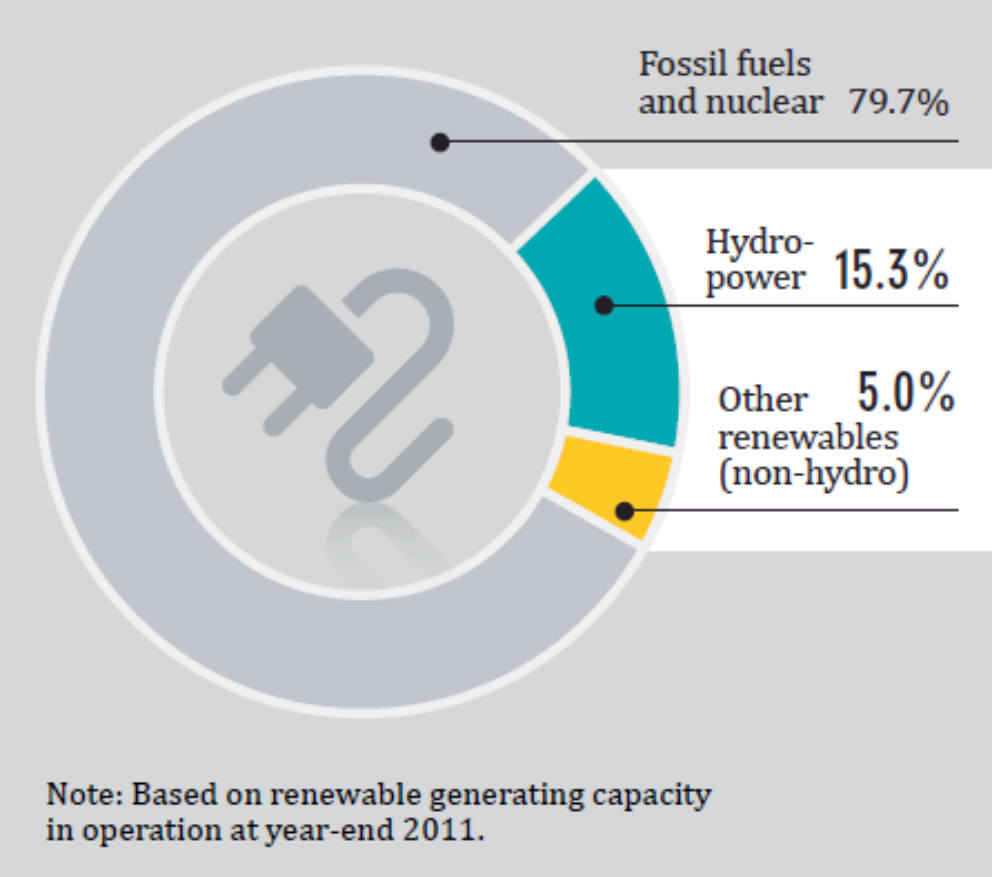
- Requires new structures and new thinking (change of paradigm)
- Requires long-term financing schemes due to long-term investments
- Based on international cooperation and interdependencies
- Higher complexity than using ideally stored fossil energy sources
- More stakeholders involved due to decentralized generation
- Cultural and political differences in EUMENA
- Lobby groups acting against each other
- Speed of environmental change and conflict potentials

Global Achievements

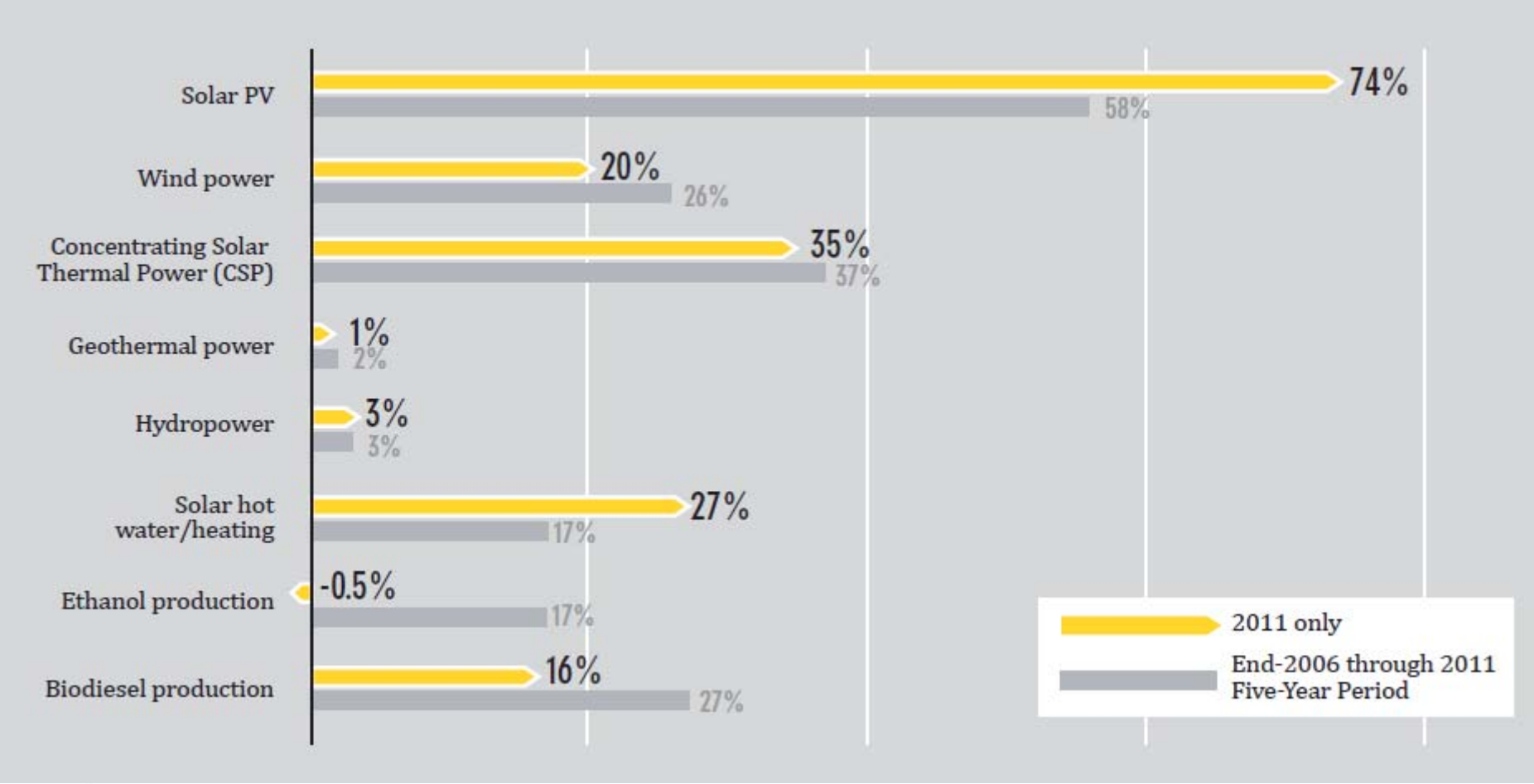
Renewable Share of Global Final Energy Consumption in 2010



Renewable Energy Share of Global Electricity Production, 2011



Average Annual Growth Rates of Renewable Energy Capacity and Biofuels Production, 2006–2011



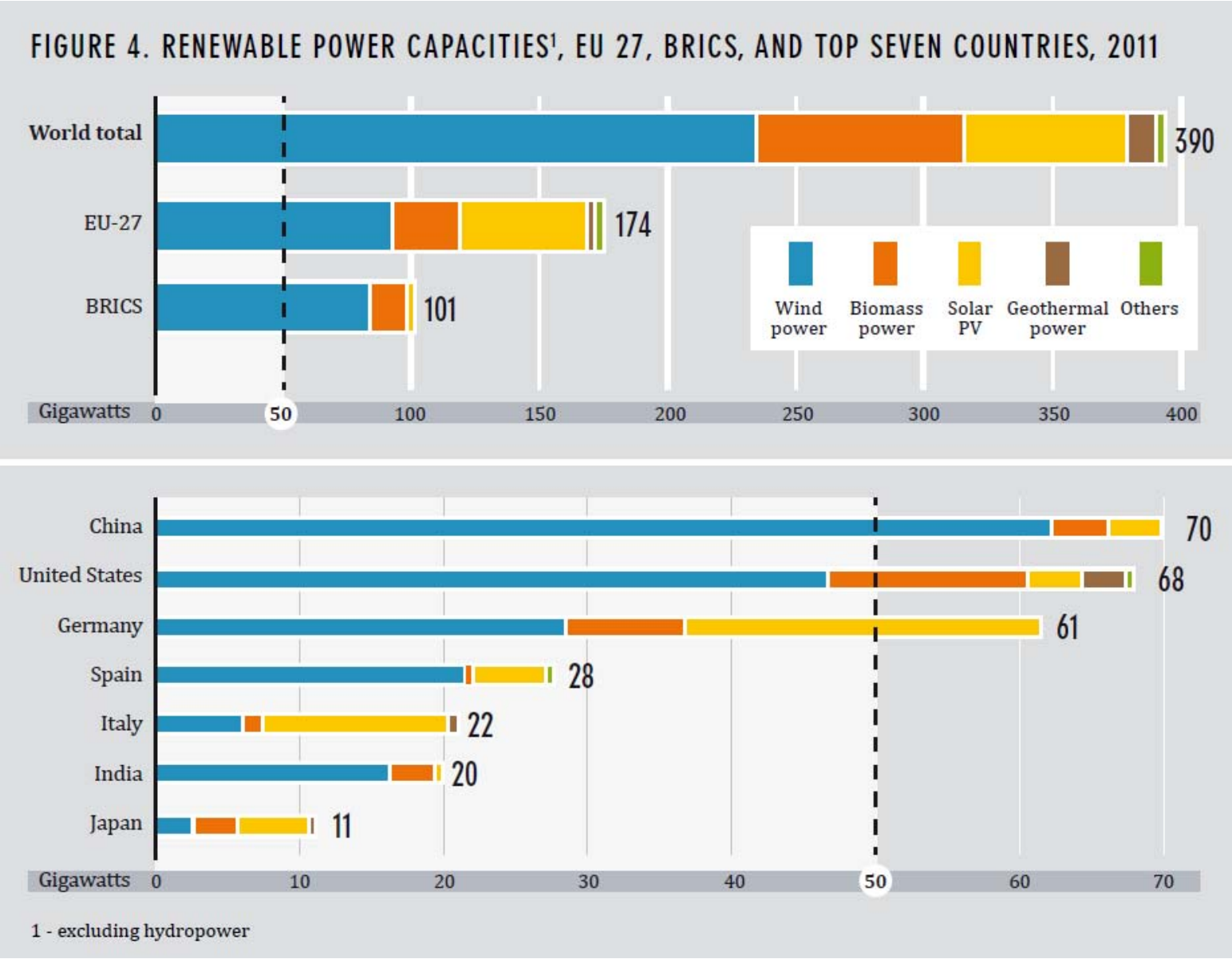
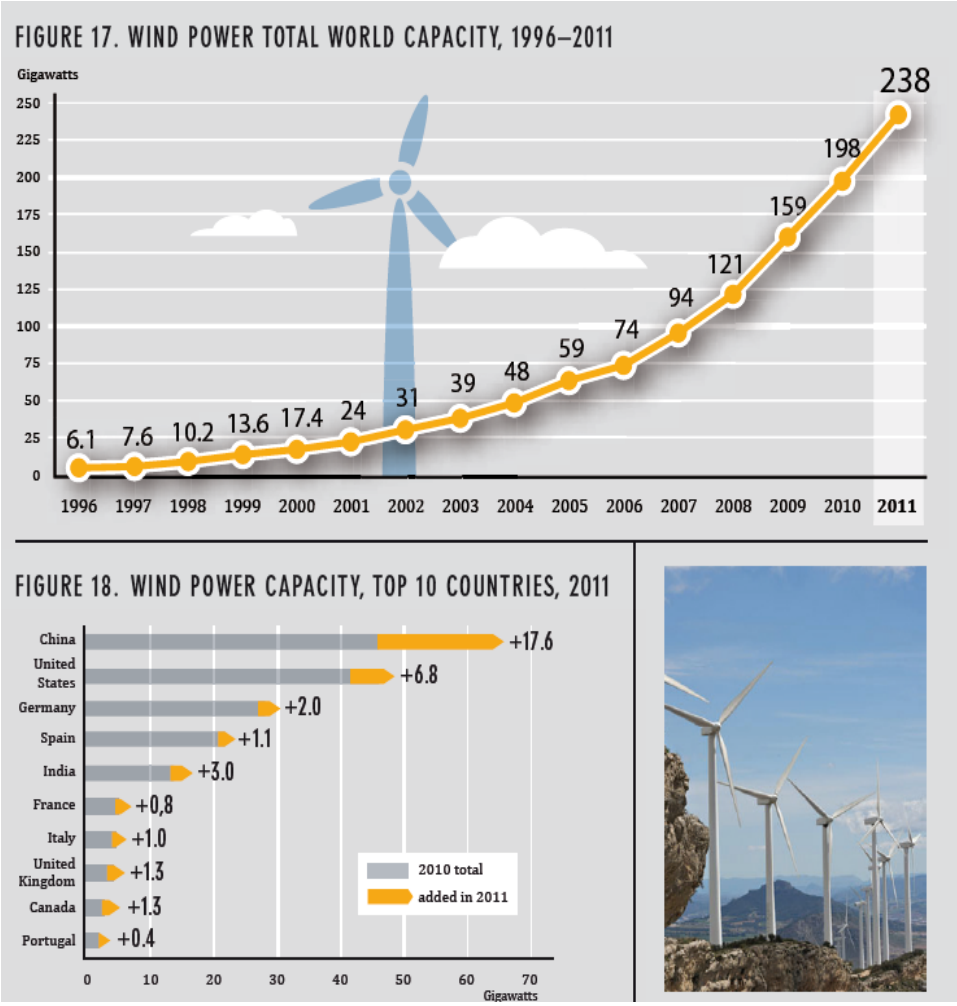


FIGURE 4. RENEWABLE POWER CAPACITIES[1], EU 27, BRICS, AND TOP SEVEN COUNTRIES, 2011
World total
EU-27
BRICS
390
174
101
Wind power
Biomass power
Solar PV
Geothermal power
Others
Gigawatts
0
50
100
150
200
250
300
350
400
China
United States
Germany
Spain
Italy
India
Japan
70
68
61
28
22
20
11
Gigawatts
0
10
20
30
40
50
60
70
1 - excluding hydropower

TABLE R2. RENEWABLE ELECTRIC POWER CAPACITY, WORLD AND TOP REGIONS/COUNTRIES, TOTAL YEAR-END 2011

TECHNOLOGY	World Total	EU-27	BRICS	China	United States	Germany	Spain	Italy	India	Japan
	(GW)									
Biomass power	72	26	17.5	4.4	13.7	7.2	0.8	2.1	3.8	3.3
Geothermal power	11.2	0.9	0.1	~ 0	3.1	~ 0	0	0.8	0	0.5
Ocean (tidal) power	0.5	0.2	~ 0	~ 0	~ 0	0	~ 0	0	0	0
Solar PV	70	51	3.7	3.1	4	25	4.5	13	0.5	4.9
Concentrating solar thermal power (CSP)	1.8	1.1	~ 0	0	0.5	0	1.1	~ 0	~ 0	0
Wind power	238	94	80	62	47	29	22	6.7	16	2.5
Total renewable power capacity (not including hydropower)	**390**	**174**	**101**	**70**	**68**	**61**	**28**	**22**	**20**	**11**
Per capita capacity (kW/inhabitant, not including hydropower)	0.06	0.35	0.03	0.05	0.22	0.75	0.60	0.37	0.02	0.09
Hydropower	970	120	383	212	79	4.4	20	18	42	28
Total renewable power capacity (including hydropower)	**1,360**	**294**	**484**	**282**	**147**	**65**	**48**	**40**	**62**	**39**

Global Wind Power Capacity Expansion 1996 to 2011

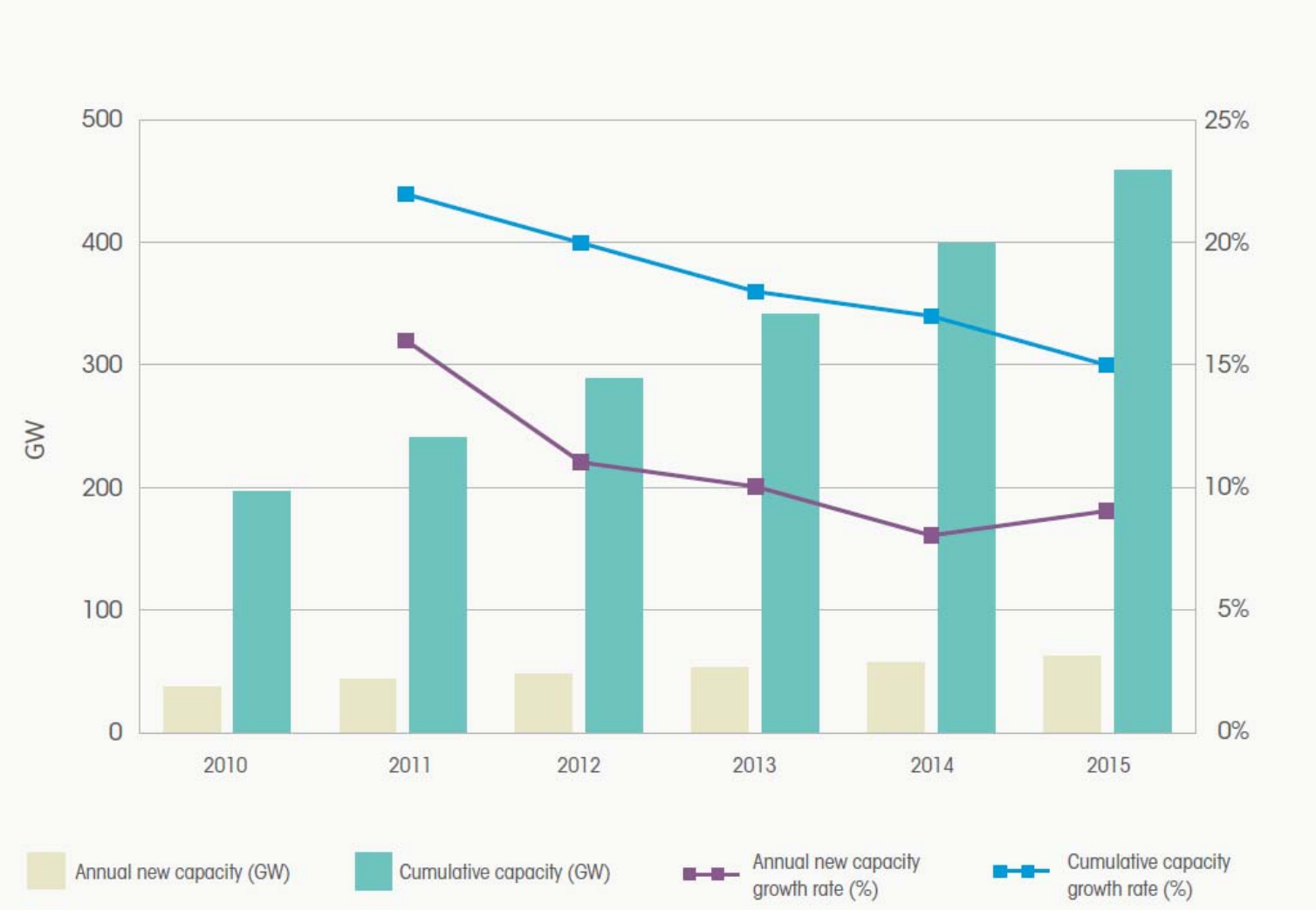


In 2011, 40GW of wind power capacity was installed, increasing the total to 238GW.

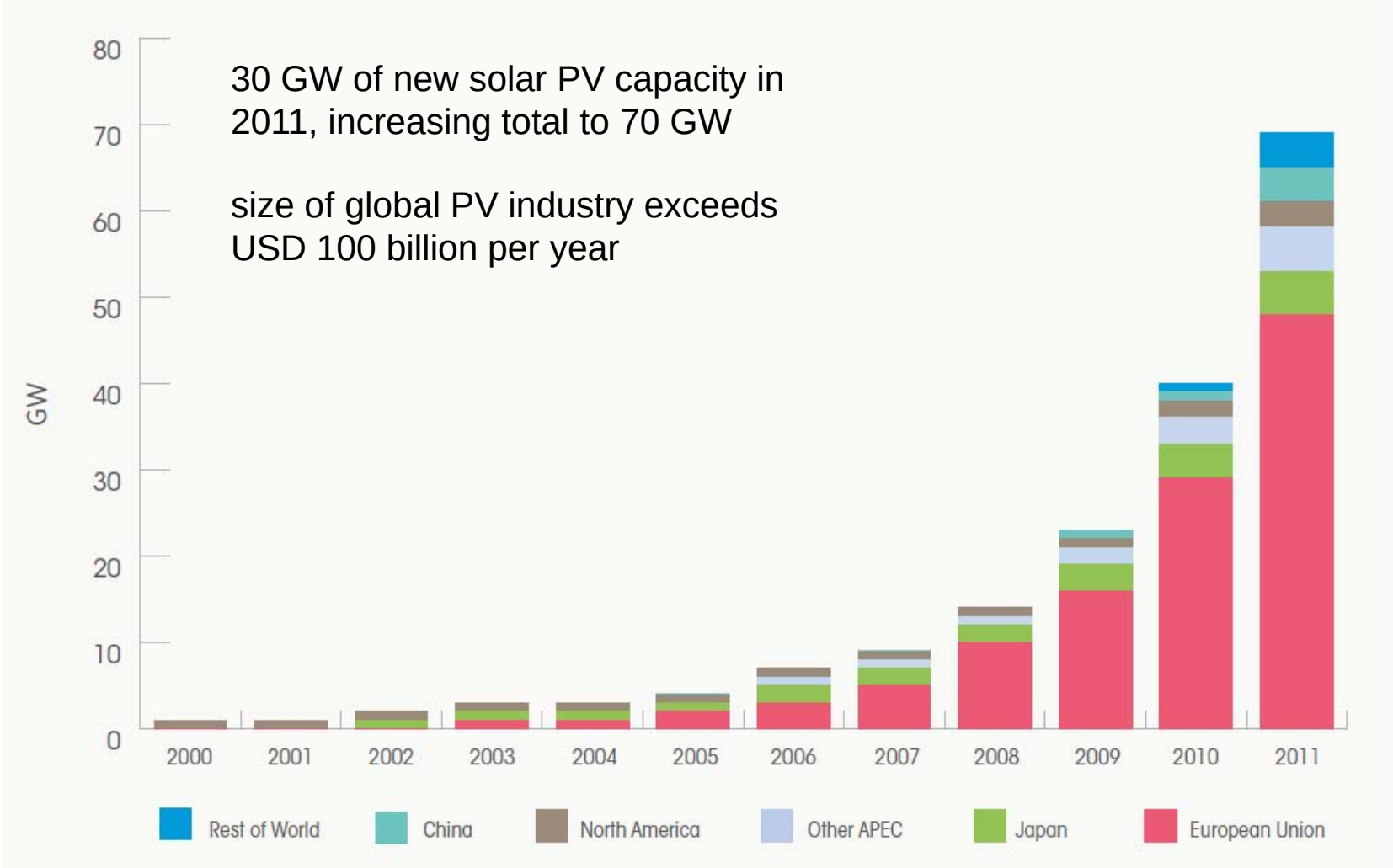
Annual growth rate of cumulative wind power capacity between 2006-2010 averaged at 26%

Latin America saw the most significant growth in wind power. Brazil, Argentina, Chile, Dominican Republic, Honduras and Mexico; all added capacity during 2011

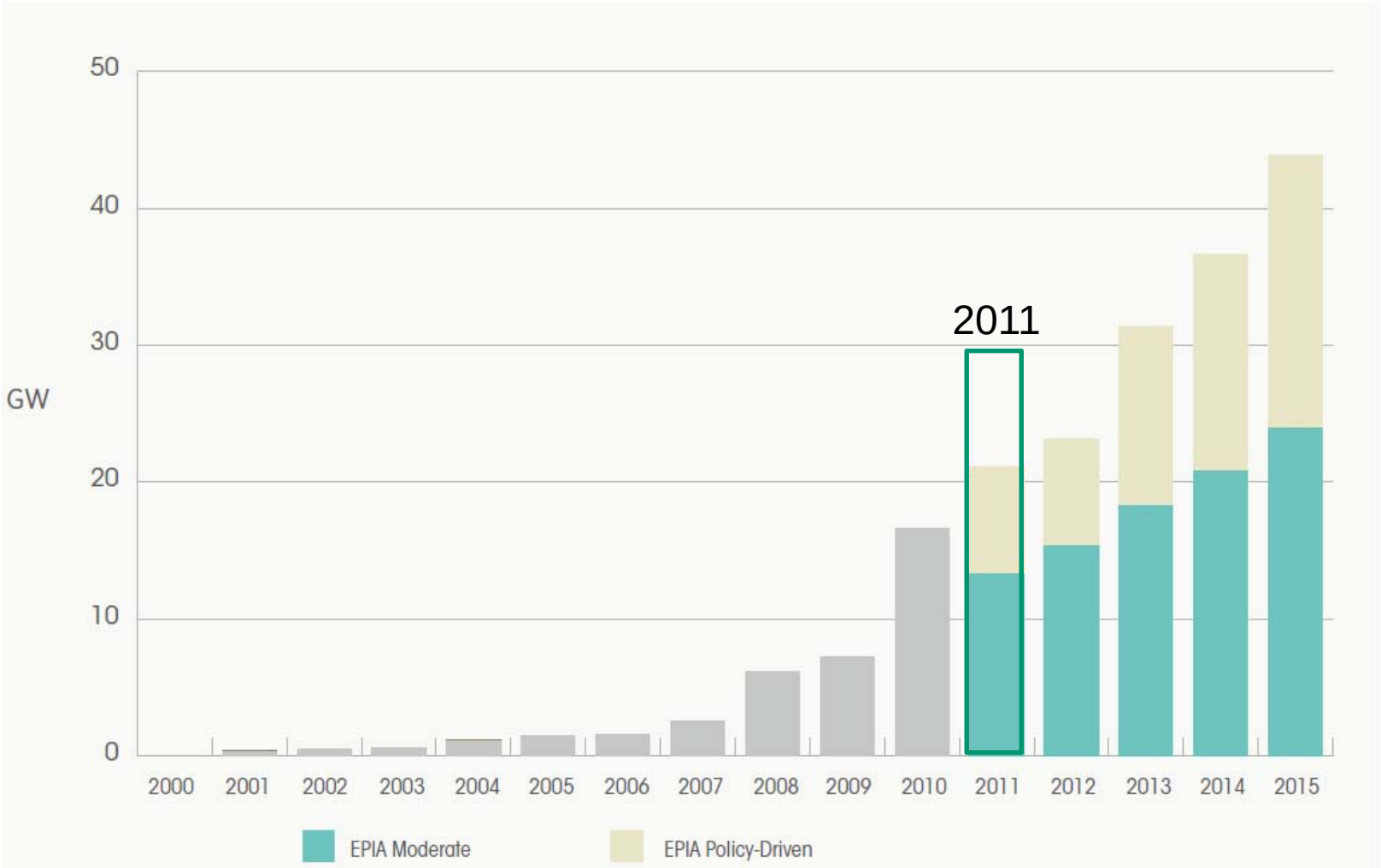
Global Wind Power Expansion Perspectives until 2015



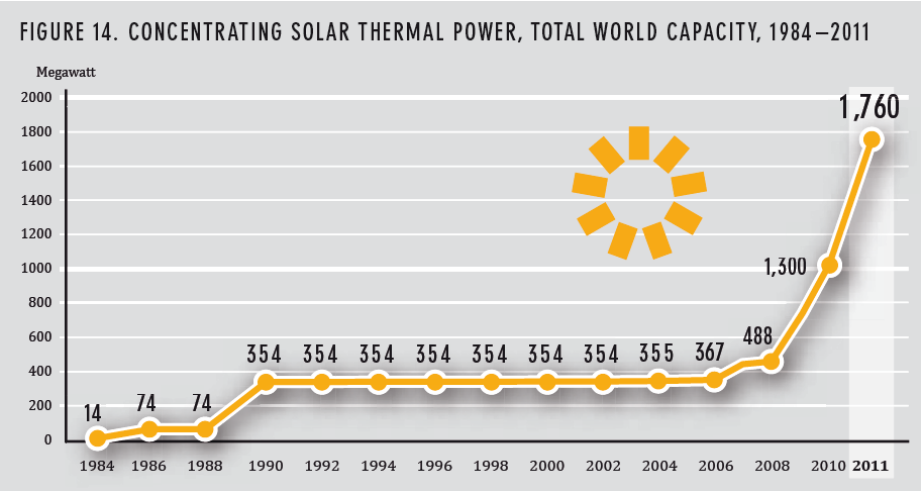
Global Photovoltaic Power Capacity Expansion 1995 to 2011

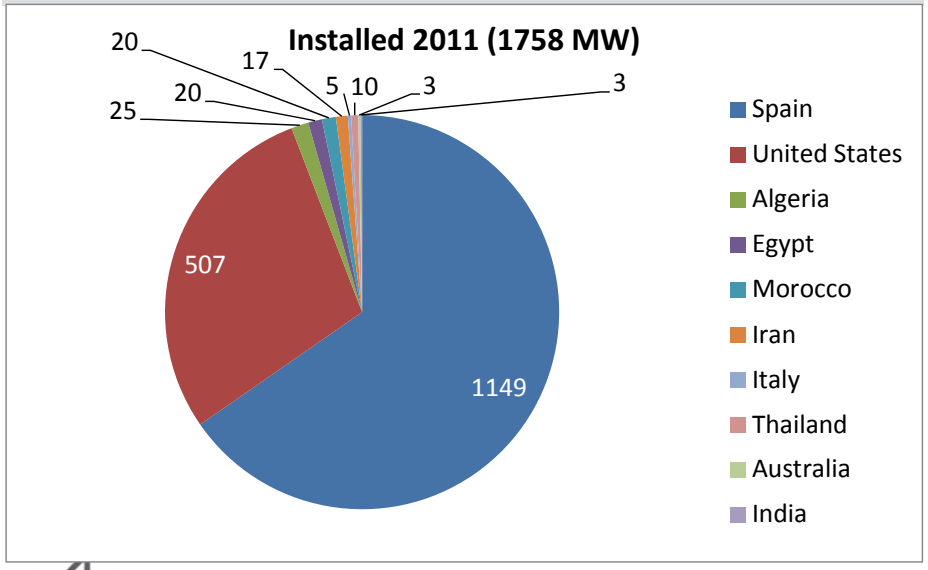


EPIA scenarios for global annual new installed pv capacity until 2015



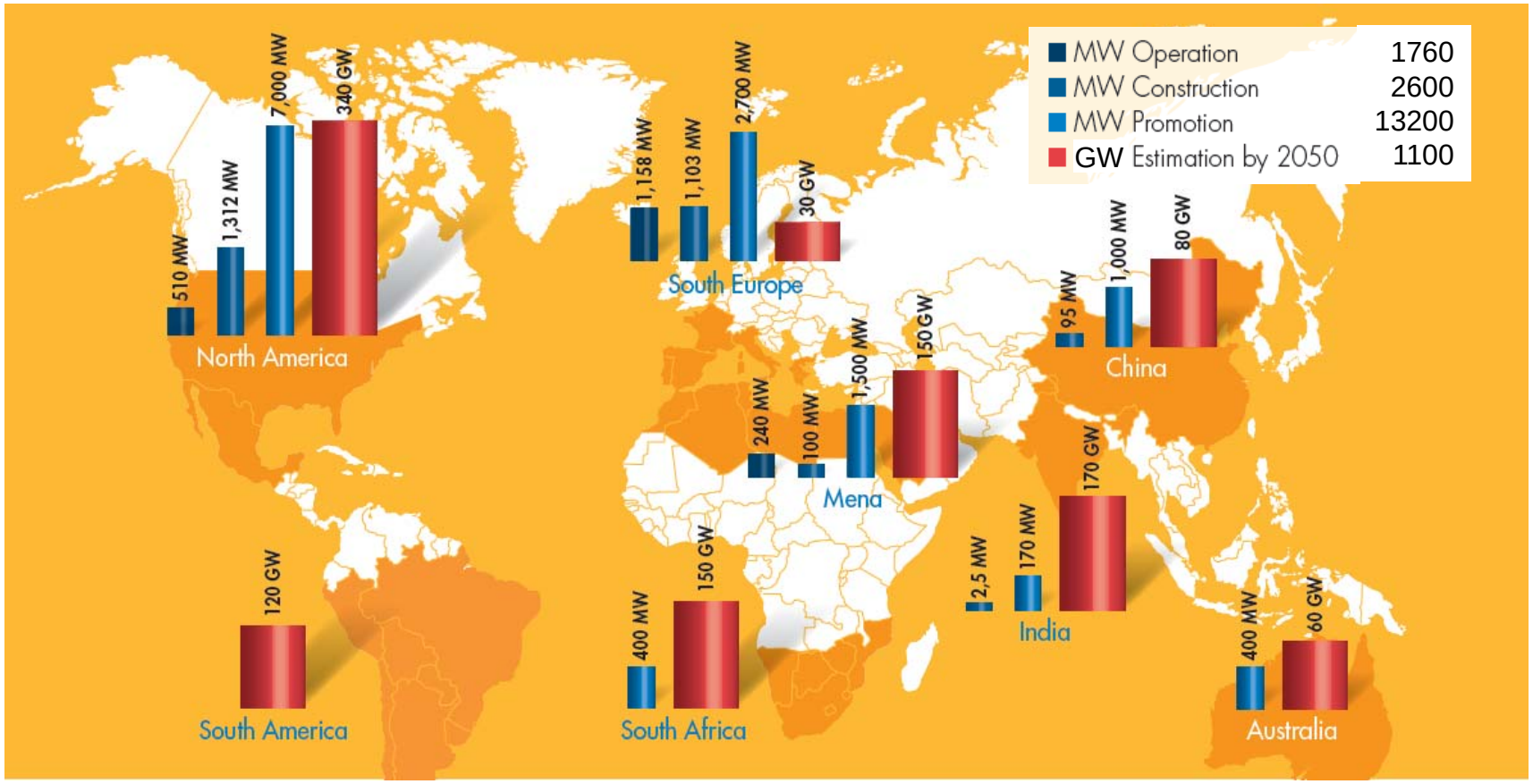
Global Concentrating Solar Thermal Power Expansion 1984 to 2011



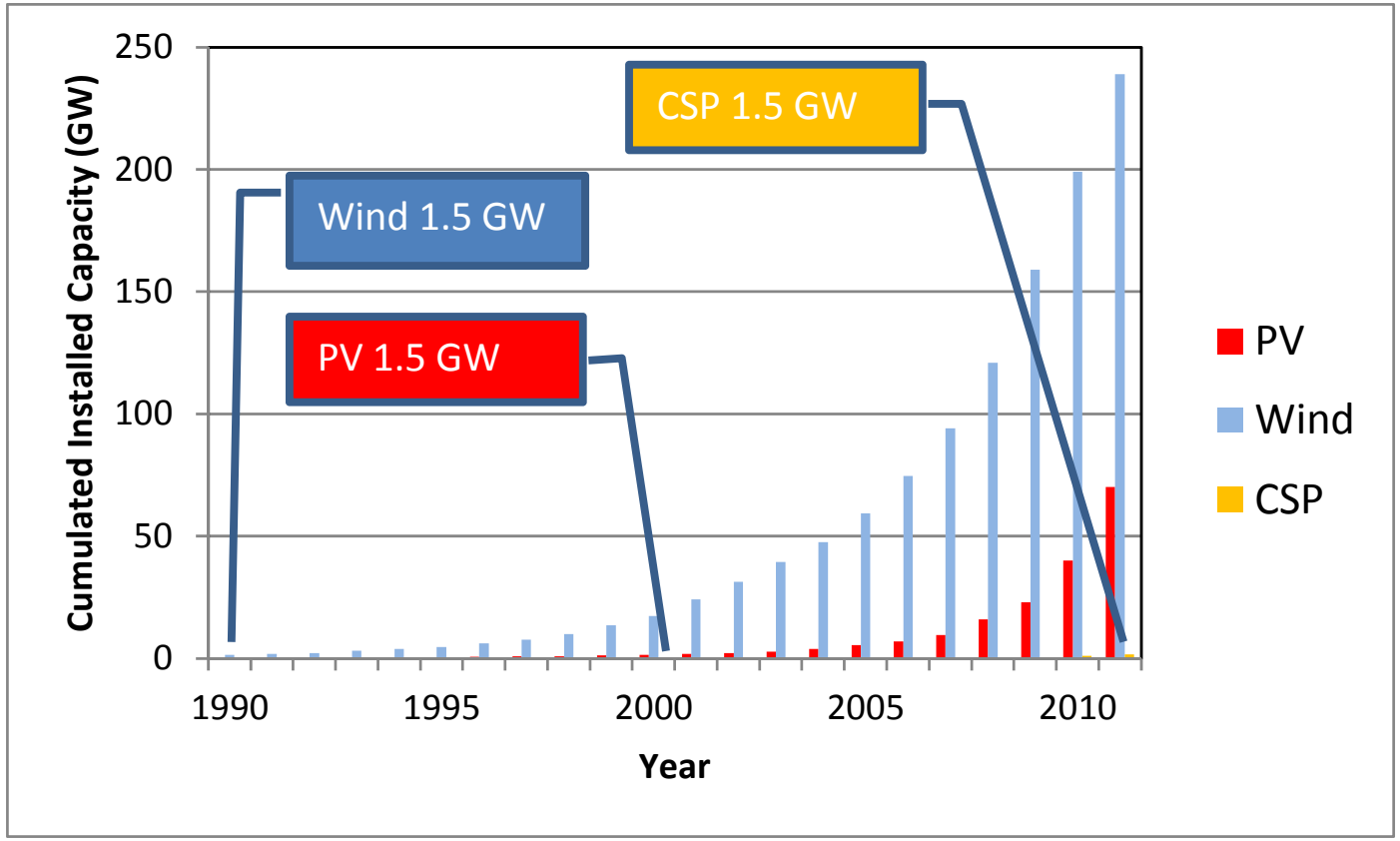


Spain is the leading CSP country but recently has stopped its FIT system due to financial crisis

Global Concentrating Solar Thermal Power Outlook 2011

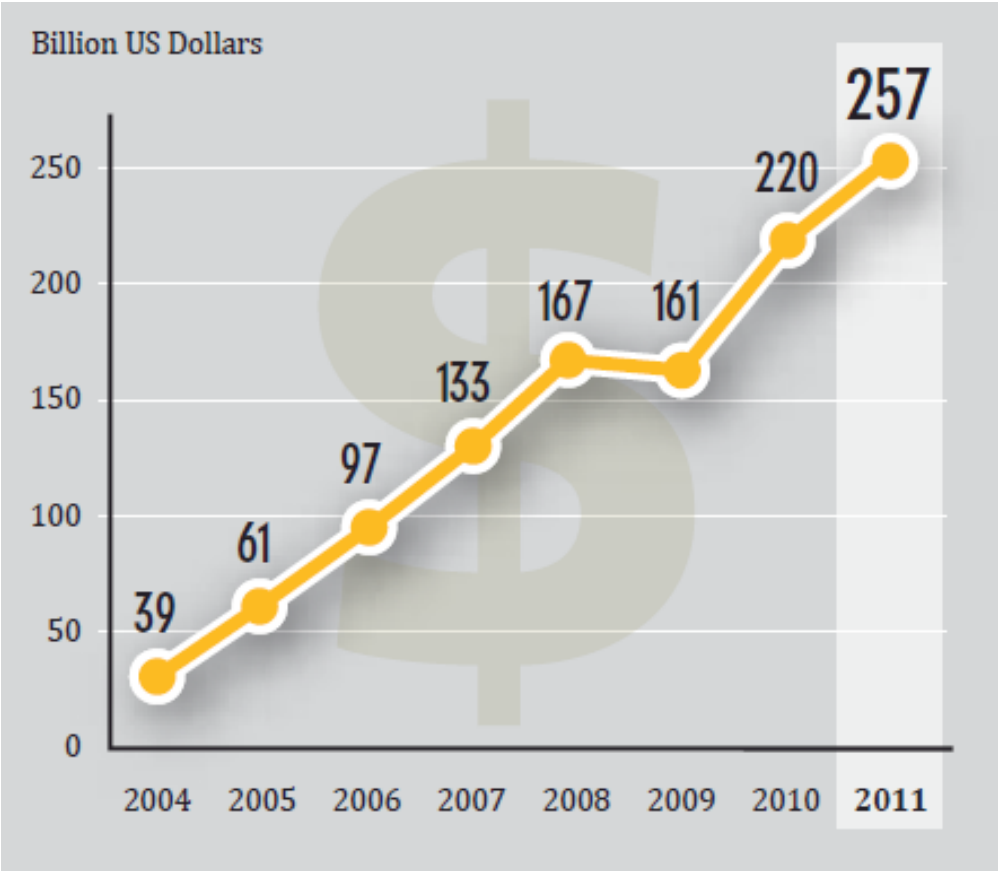


Global Cumulated Wind, PV and CSP Capacity in 2011



Source: WWEA 2012, EPIA 2012, ESTELA 2012, REN21 2011

Global New Investment in Renewable Energy, 2004–2011



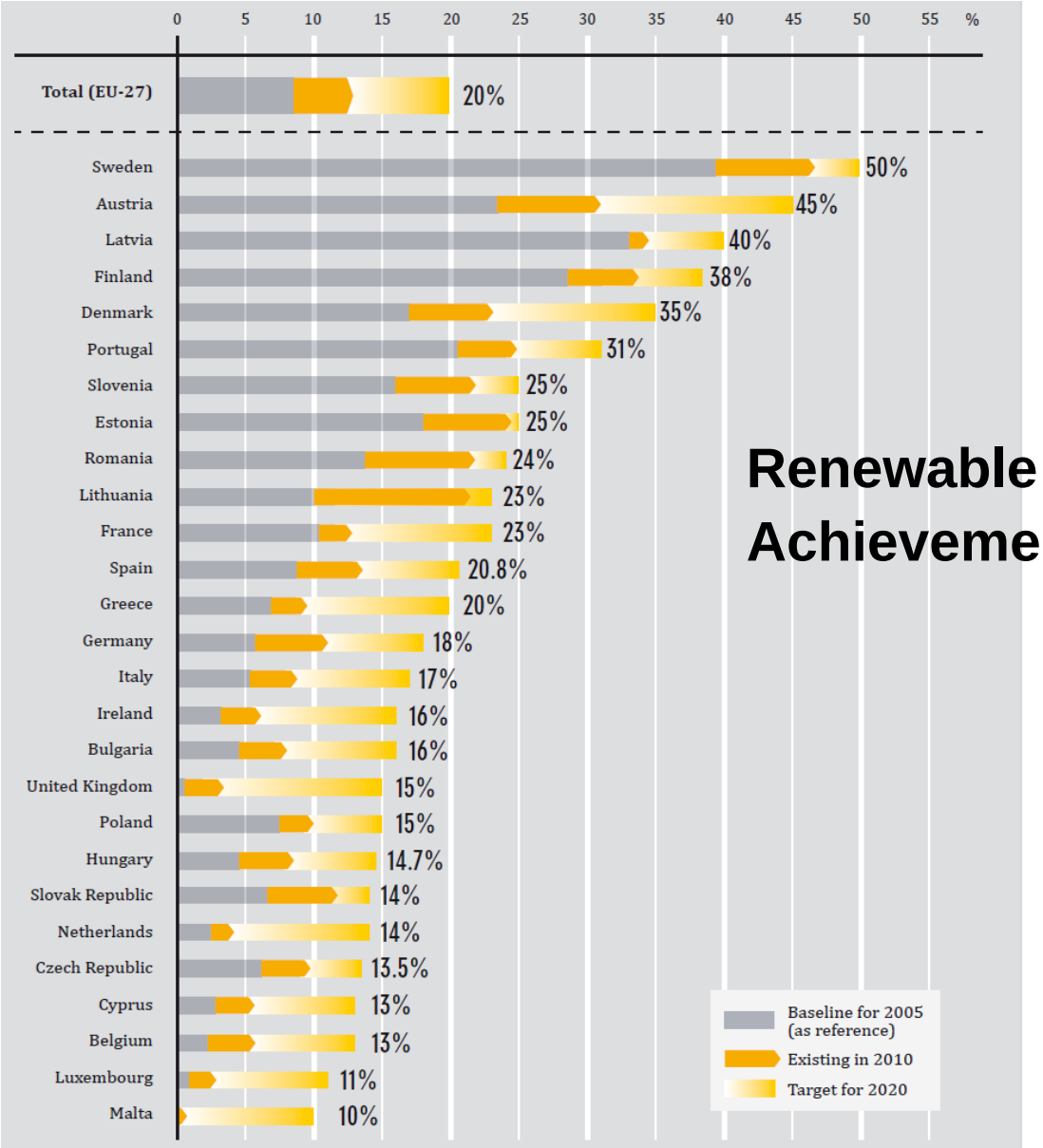
$257 billion invested in RE in 2011 (up 16% from 2010)

To this adds:

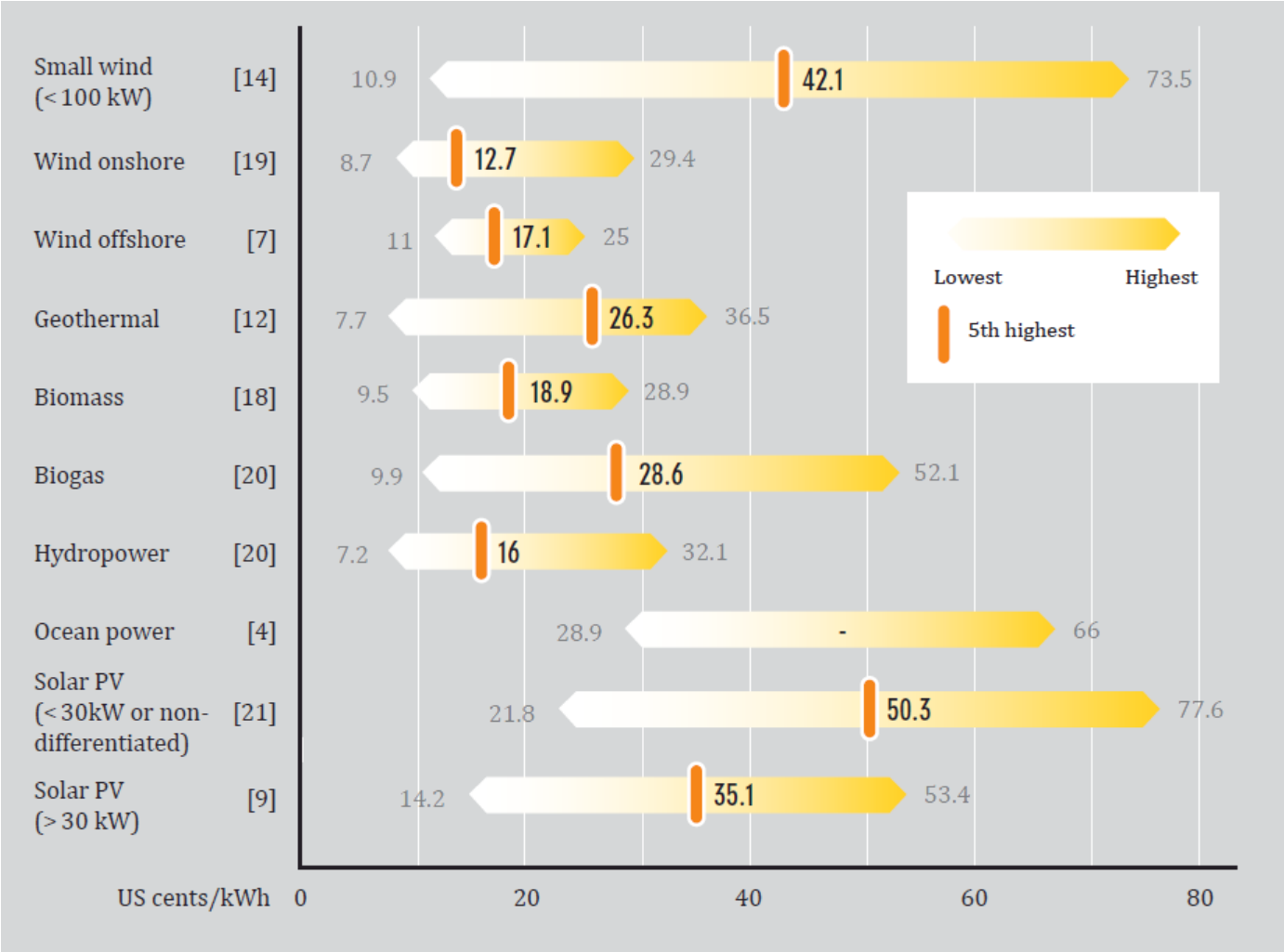
- estimated $10 billion (unreported) invested in solar hot water
- $25 billion invested in large hydropower (>50 MW)

Global New Investment in Renewable Energy in 2011

Renewable Energy Targets and Achievements in the EU27



FIT payments for renewable energy technologies, selected countries, 2011/2012



Jobs in Renewable Energy Industry in 2011 (up 1.5 million from 2010)

TECHNOLOGIES	Global	China	India	Brazil	USA	EU[7]	Germany	Spain	Others
	Thousand jobs								
Biomass[1]	750	266	58		152	273	51	14	2[8]
Biofuels	1,500			889[6]	47–160	151	23	2	194[9]
Biogas	230	90	85			53	51	1.4	
Geothermal[1]	90				10	53	14	0.6	
Hydropower (Small[2])	40		12		8	16	7	1.6	1[8]
Solar PV	820[4]	300[5]	112		82	268	111	28	60[10]
CSP	40				9		2	24	
Solar Heating/ Cooling	900	800	41		9	50	12	10	1[8]
Wind Power	670[4]	150	42	14	75	253	101	55	33[11]
Total[3]	**5,000**	**1,606**	**350**	**889**	**392-505**	**1,117**	**372**	**137**	**291**

Selected Renewable Energy Indicators 2009 - 2011

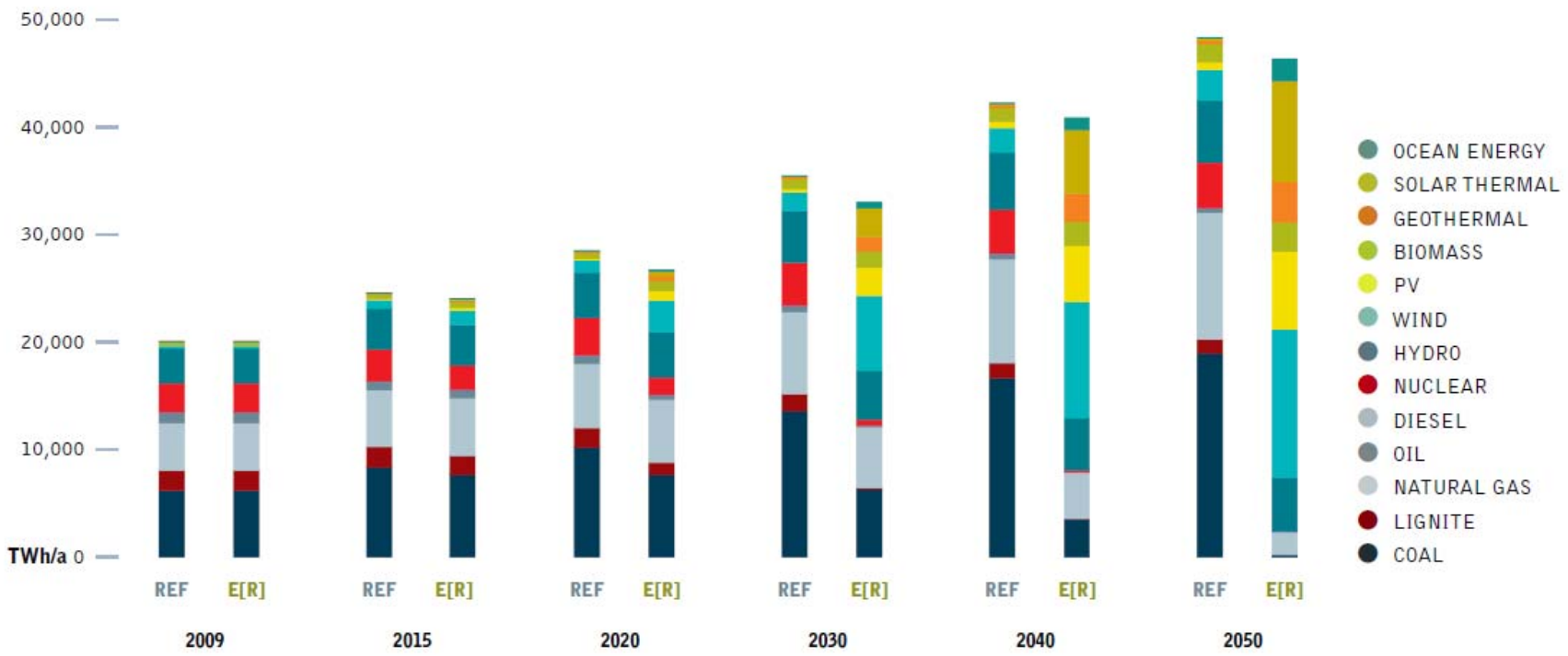
		2009	→	2010	→	2011
Investment in new renewable capacity (annual)[1]	billion USD	161	→	220	→	257
Renewable power capacity (total, not including hydro)	GW	250	→	315	→	390
Renewable power capacity (total, including hydro)[2]	GW	1,170	→	1,260	→	1,360
Hydropower capacity (total)[2]	GW	915	→	945	→	970
Solar PV capacity (total)	GW	23	→	40	→	70
Concentrating solar thermal power (total)	GW	0.7	→	1.3	→	1.8
Wind power capacity (total)	GW	159	→	198	→	238
Solar hot water/heat capacity (total)[3]	GW_{th}	153	→	182	→	232
Ethanol production (annual)	billion litres	73.1	→	86.5	→	86.1
Biodiesel production (annual)	billion litres	17.8	→	18.5	→	21.4
Countries with policy targets	#	89	→	109	→	118
States/provinces/countries with feed-in policies[4]	#	82	→	86	→	92
States/provinces/countries with RPS/quota policies[4]	#	66	→	69	→	71
States/provinces/countries with biofuels mandates[5]	#	57	→	71	→	72

Renewable Energy Characteristics 2011

POWER GENERATION	Typical Characteristics	Capital Costs (USD/kW)	Typical Energy Costs (US cents/kWh)
Biomass Power Stoker boiler/steam turbine Circulating fluidised bed	Plant size: 25–100 MW Conversion efficiency: 27% Capacity factor: 70–80%	3,030–4,660	7.9–17.6
Geothermal Power	Plant size: 1–100 MW Types: binary cycle, single-and double-flash, natural steam Capacity factor: 60–90%	condensing flash: 2,100–4,200 binary: 2,470–6,100	condensing flash: 5.7–8.4 binary: 6.2–10.7
Hydropower (grid-based)	Plant size: 1 MW–18,000+ MW Plant type: reservoir, run-of-river Capacity factor: 30–60%	Projects >300 MW: <2,000 Projects <300 MW: 2,000–4,000	5–10
Hydropower (off-grid/rural)	Plant capacity: 0.1–1,000 kW Plant type: run-of-river, hydrokinetic, diurnal storage	1,175–3,500	5–40
Ocean Power (tidal range)	Plant size: <1 to >250 MW Capacity factor: 23–29%	5,290–5,870	21–28
Solar PV (rooftop)	Peak capacity: 3–5 kW (residential); 100 kW (commercial); 500 kW (industrial) Conversion efficiency: 12–20%	2,480–3,270	22–44 (Europe)
Solar PV (ground-mounted utility-scale)	Peak capacity: 2.5–100 MW Conversion efficiency: 15–27%	1,830–2,350	20–37 (Europe)
Concentrating Solar Thermal Power (CSP)	Types: trough, tower, dish Plant size: 50–500 MW (trough), 50–300 MW (tower); Capacity factor: 20–25% (trough); 40–50% (trough with six hours storage); 40–80% (solar tower with 6–15 hours storage)	Trough without storage: 4,500; Trough with six hours storage: 7,100–9,000; Solar tower with 6–18 hours storage: 6,300–10,500	18.8–29
Wind Power (onshore)	Turbine size: 1.5–3.5 MW Rotor diameter: 60–110+ meters Capacity factor: 20–40%	1,410–2,475	5.2–16.5
Wind Power (offshore)	Turbine size: 1.5–7.5 MW Rotor diameter: 70–125 meters Capacity factor: 35–45%	3,760–5,870	11.4–22.4
Wind Power (small-scale)	Turbine size: up to 100 kW	3,000–6,000 (USA); 1,580 (China)	15–20 (USA)

Greenpeace Energy (R)evolution Scenario 2012

figure 5.6: global: electricity generation structure under the reference scenario and the energy [r]evolution scenario (INCLUDING ELECTRICITY FOR ELECTROMOBILITY, HEAT PUMPS AND HYDROGEN GENERATION)



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