MENA Regional Water Outlook
Desalination Using Renewable Energy

Overview of DLR work within the MENA Regional Water Outlook study

Franz Trieb, Massimo Moser, Tobias Fichter

Muscat, February 22-23, 2011

Presentation overview

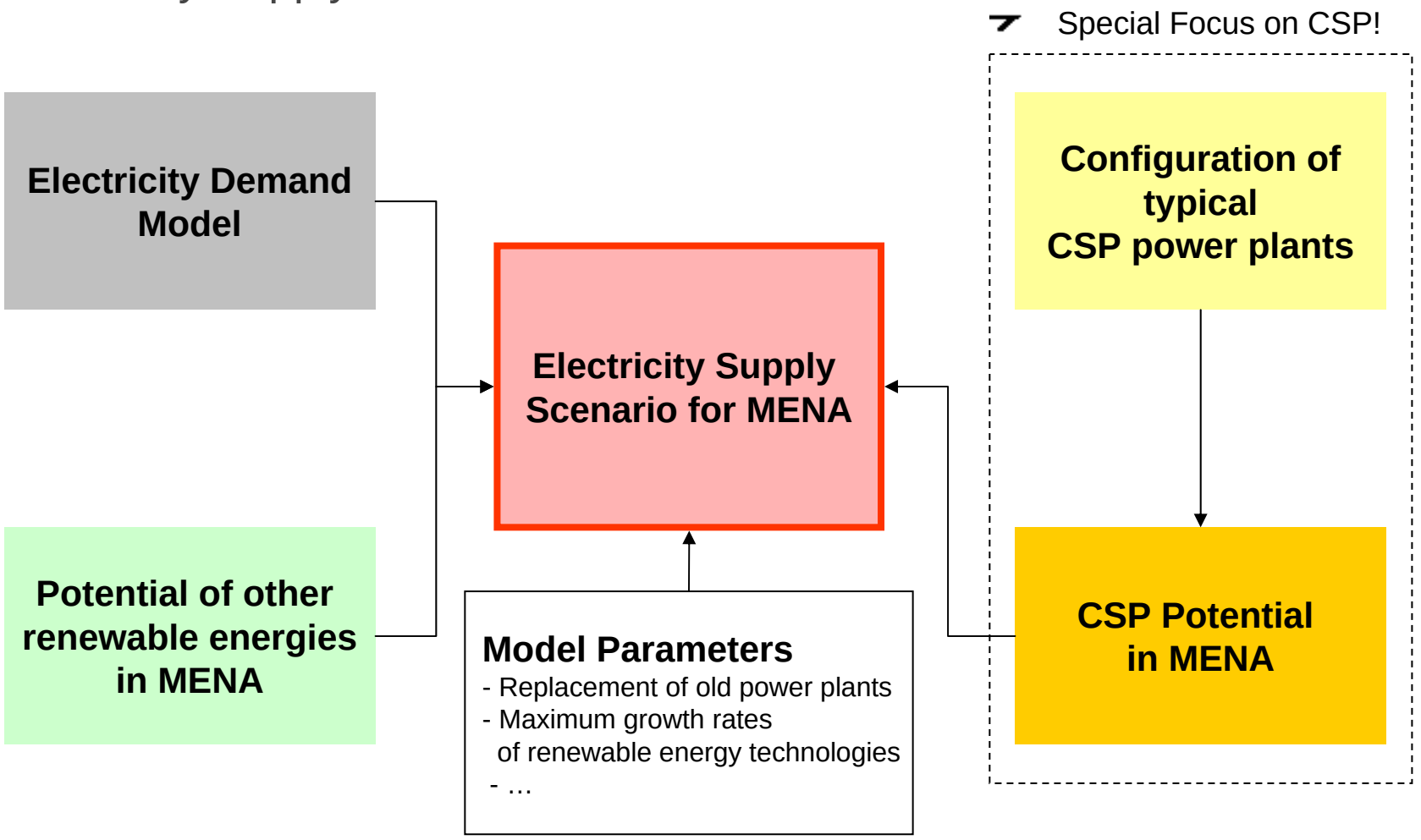
1. Applied Methodology

2. Desalination and renewable energy: The case of CSP
    - CSP and Desalination: Introduction and Preliminary Considerations
        - Description of Typical Plant Configurations
        - Results Overview
    - CSP Potential Assessment
        - Methodology
        - Results

3. The Scope of CSP in the MENA Region
    - Electricity Supply Scenario
    - Water Supply Scenario

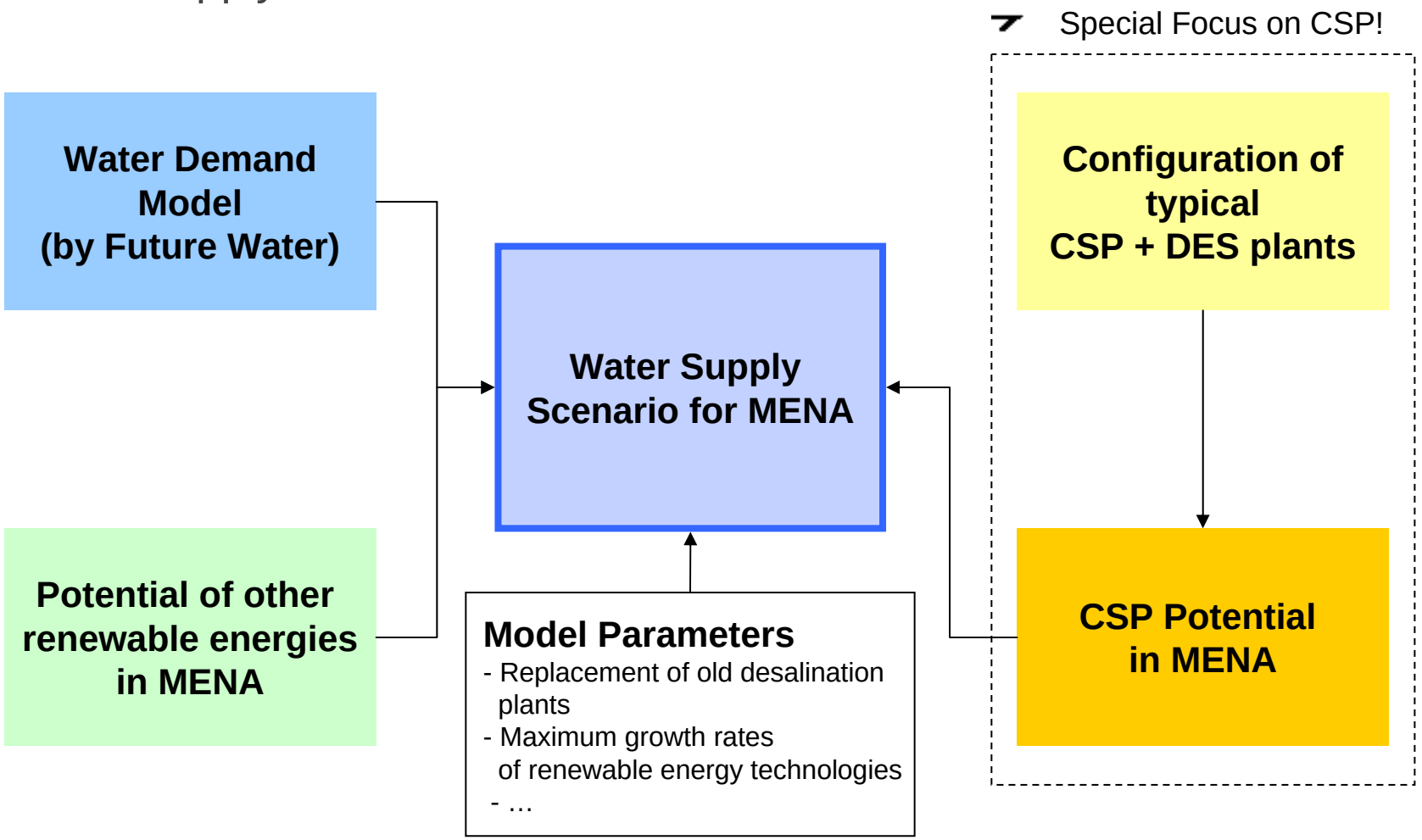
Methodology

Electricity Supply Scenario



Methodology

Water Supply Scenario



Desalination and renewable energy: The case of CSP

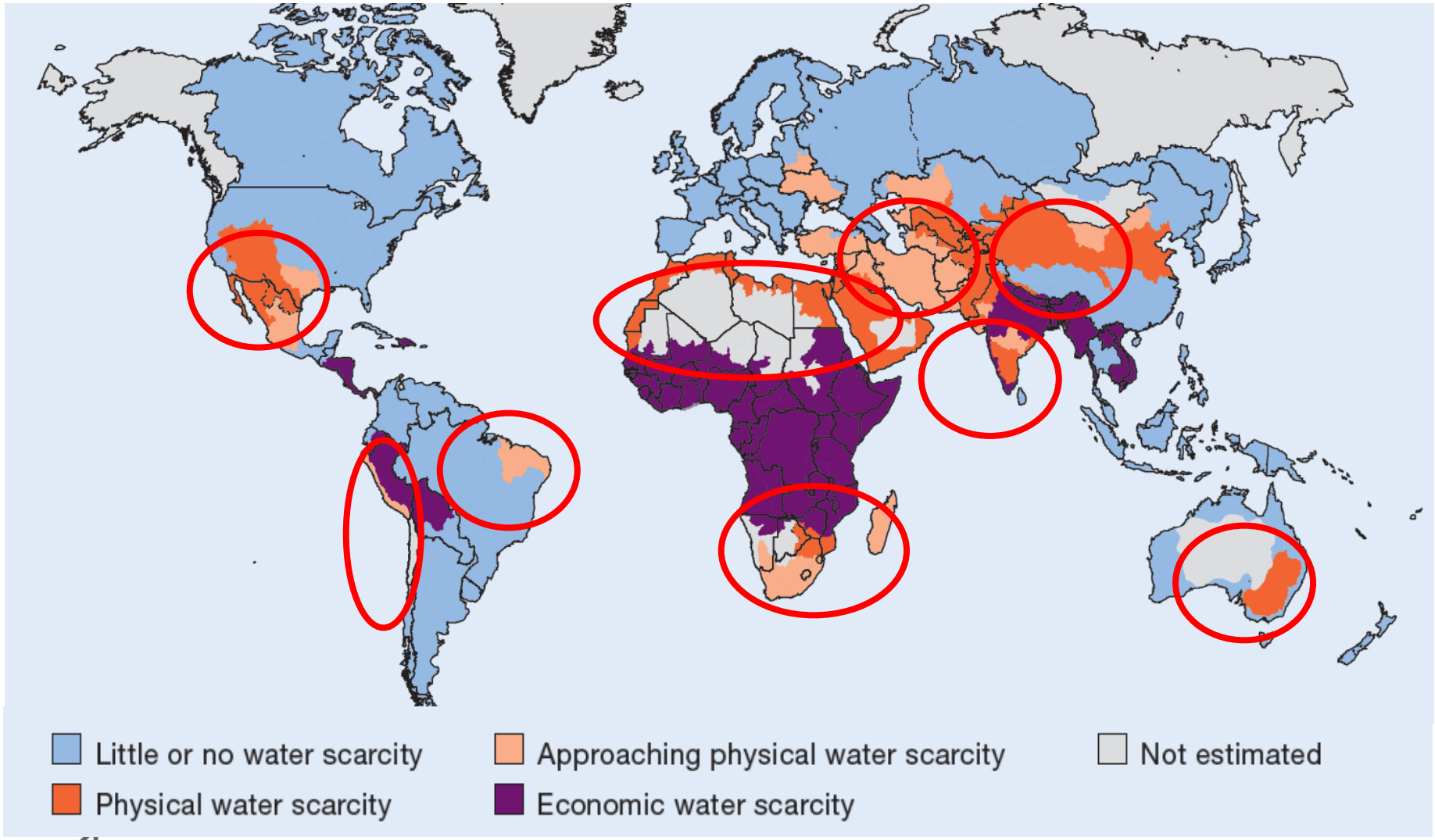
CSP and Desalination: Introduction and Preliminary Considerations

Massimo Moser, DLR

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

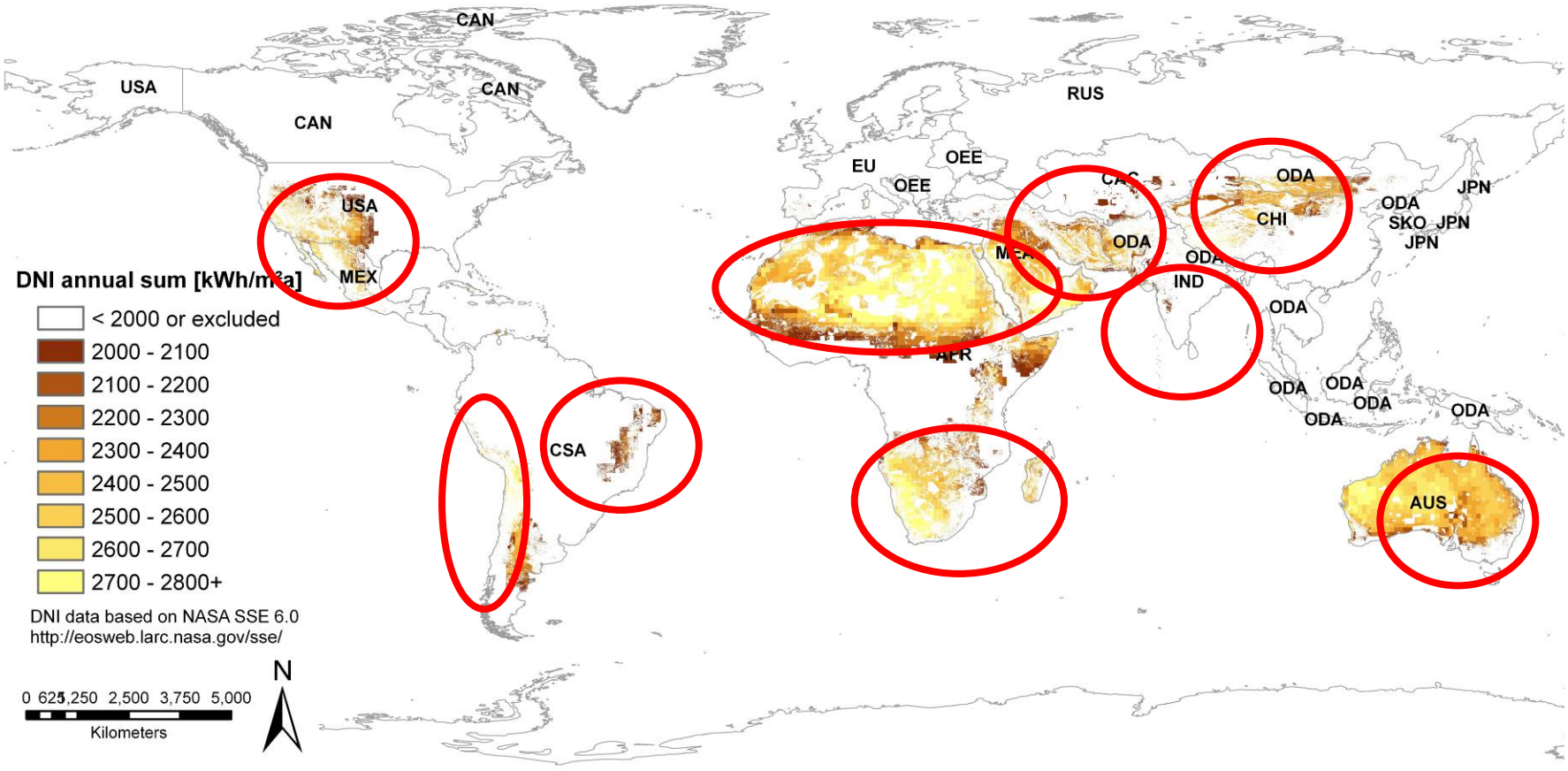
CSP Technology Overview

Global Water Scarcity



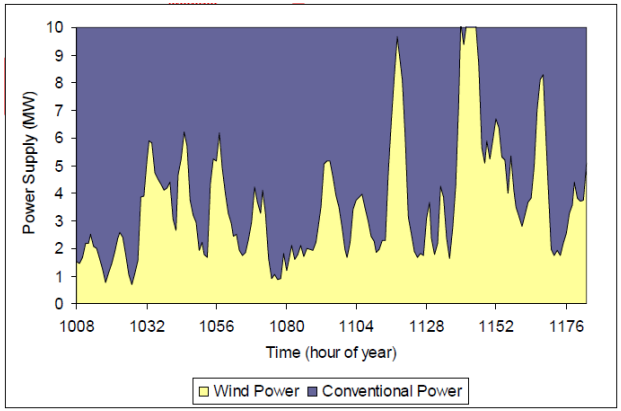
Source: IWMI 2006

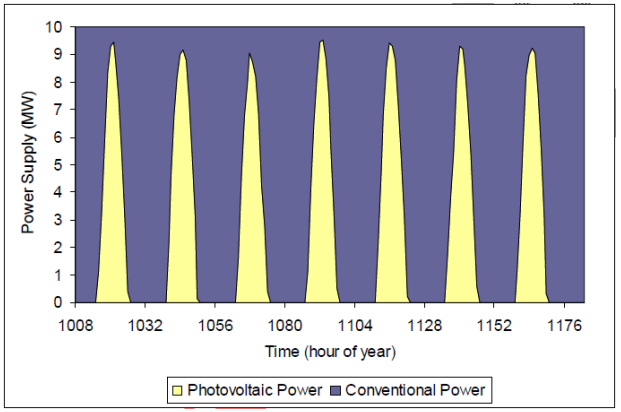
Global Potential for Concentrating Solar Power

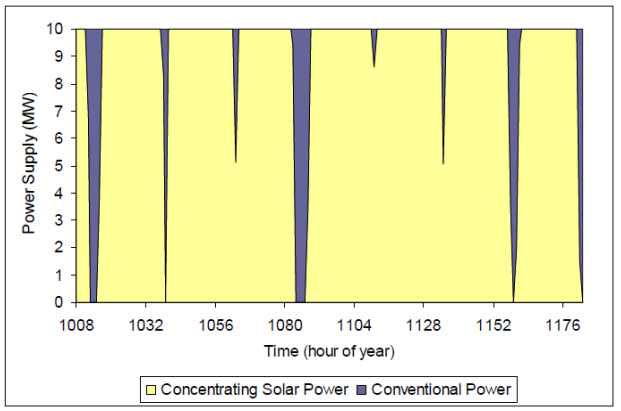


Data provided by DLR (2008) for EU-project REACCESS

Renewable energies for desalination: why CSP?







Desalination plants require continuous operation

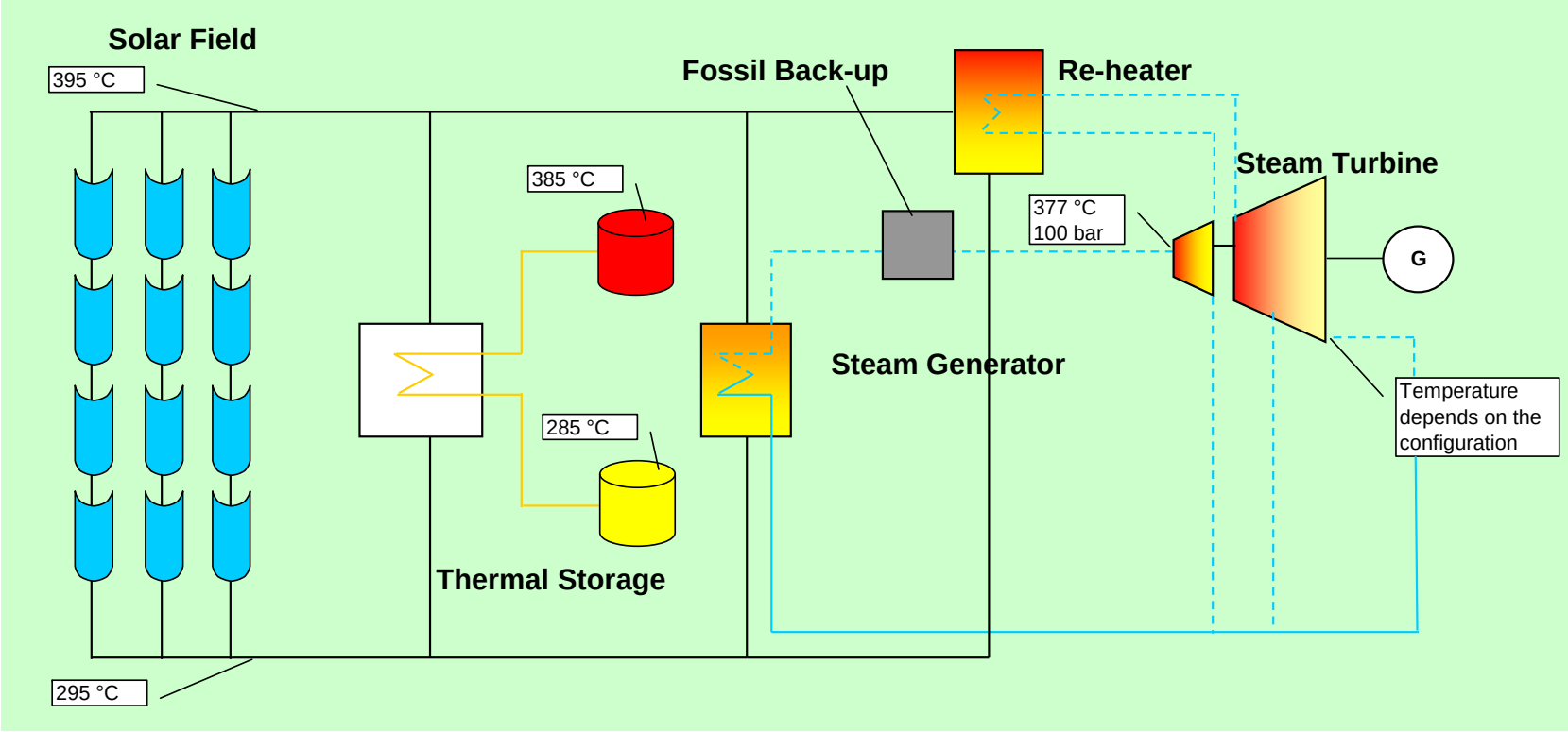
→ This conflicts with the intermittent nature of renewable energies

→ Storage of electricity is expensive

→ CSP offers the option of thermal energy storage

→ Hybrid operation is possible in the same power block (no “shadow power plant” required)

CSP Scheme


Solar Field
395 °C
Fossil Back-up
Re-heater
385 °C
Steam Turbine
377 °C
100 bar
G
Steam Generator
285 °C
Temperature depends on the configuration
Thermal Storage
295 °C

Methodology

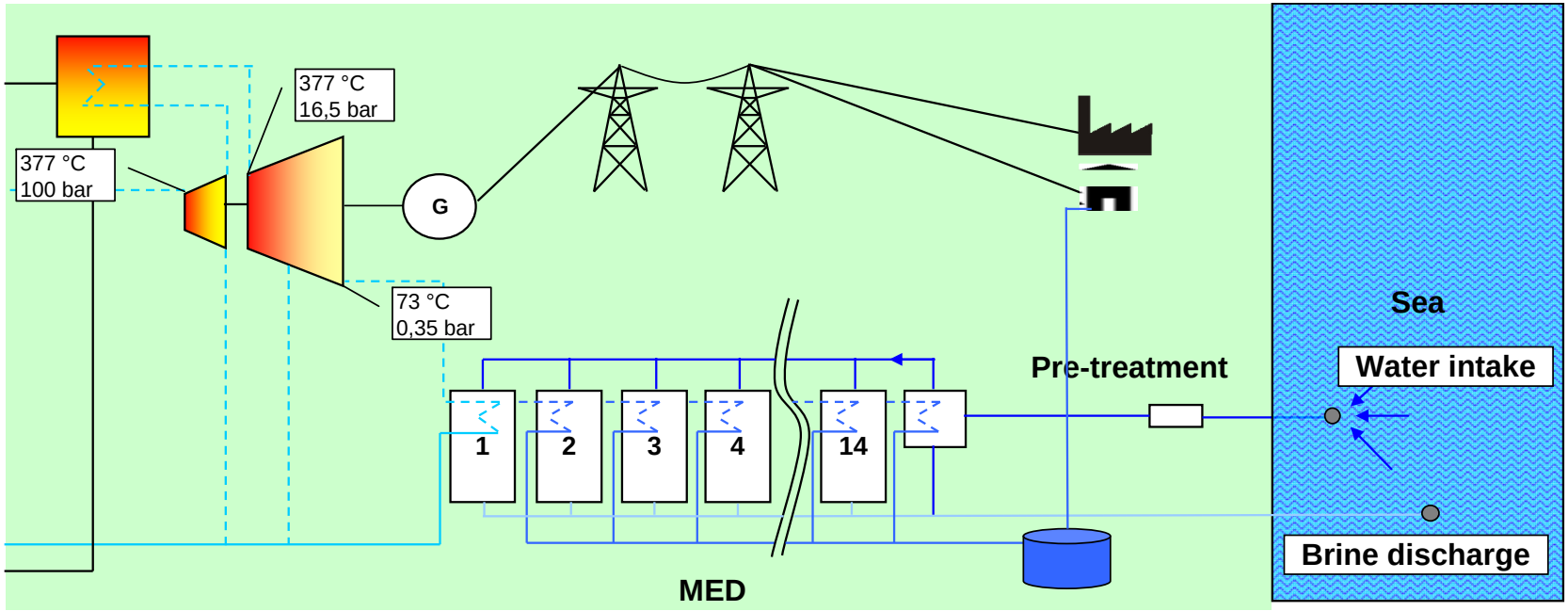
1. Objective: preliminary analysis and comparison of different concentrating solar power and desalination plants

   → Base idea for the comparison: all plants are designed to produce the same amount of electricity and water (100,000 m^3/d water – ca. 115 MW electricity)

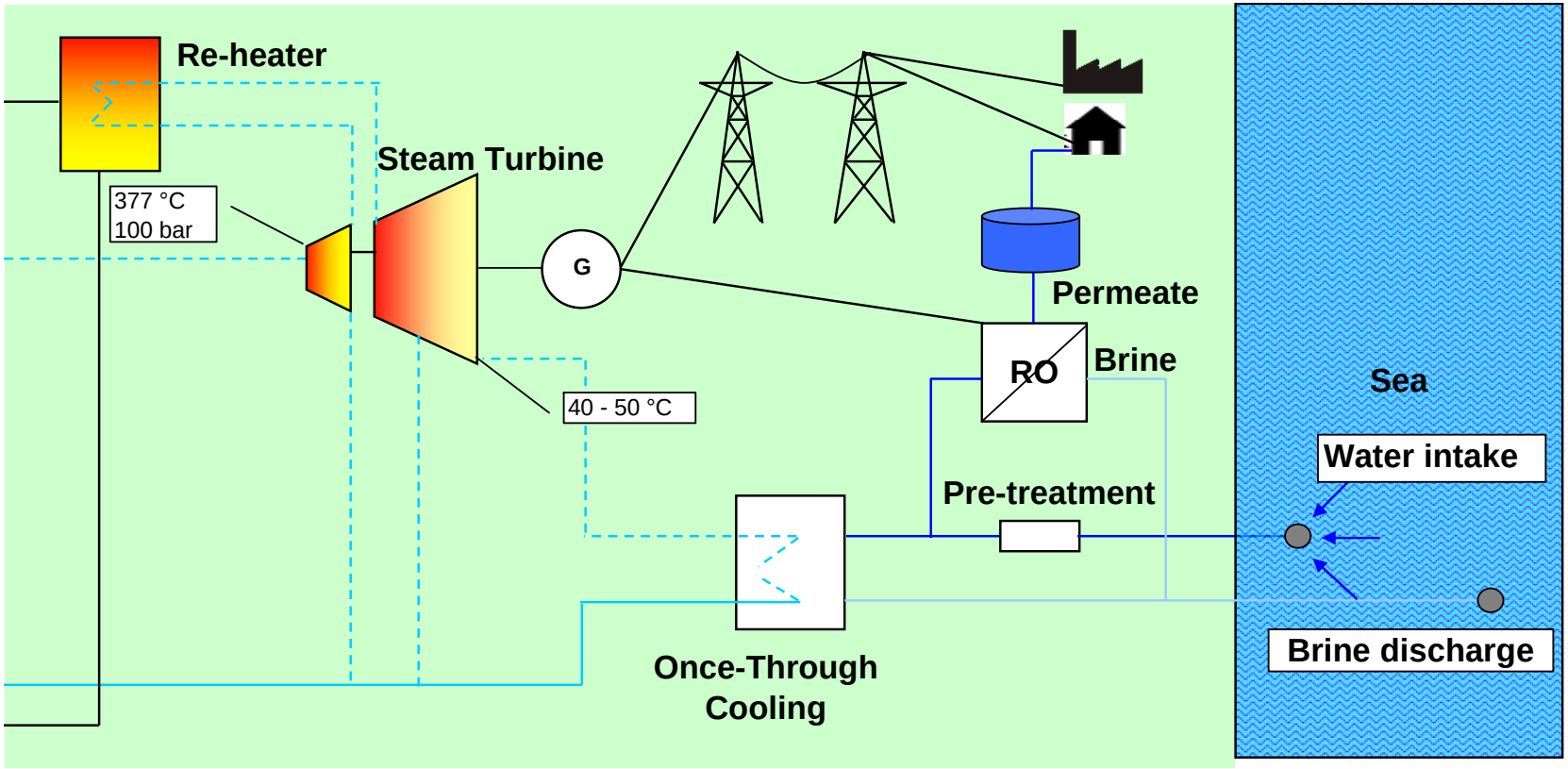
2. Land requirement assessment (input for potential assessment)

3. Preliminary plant design and LEC calculation (input for Desalination model)

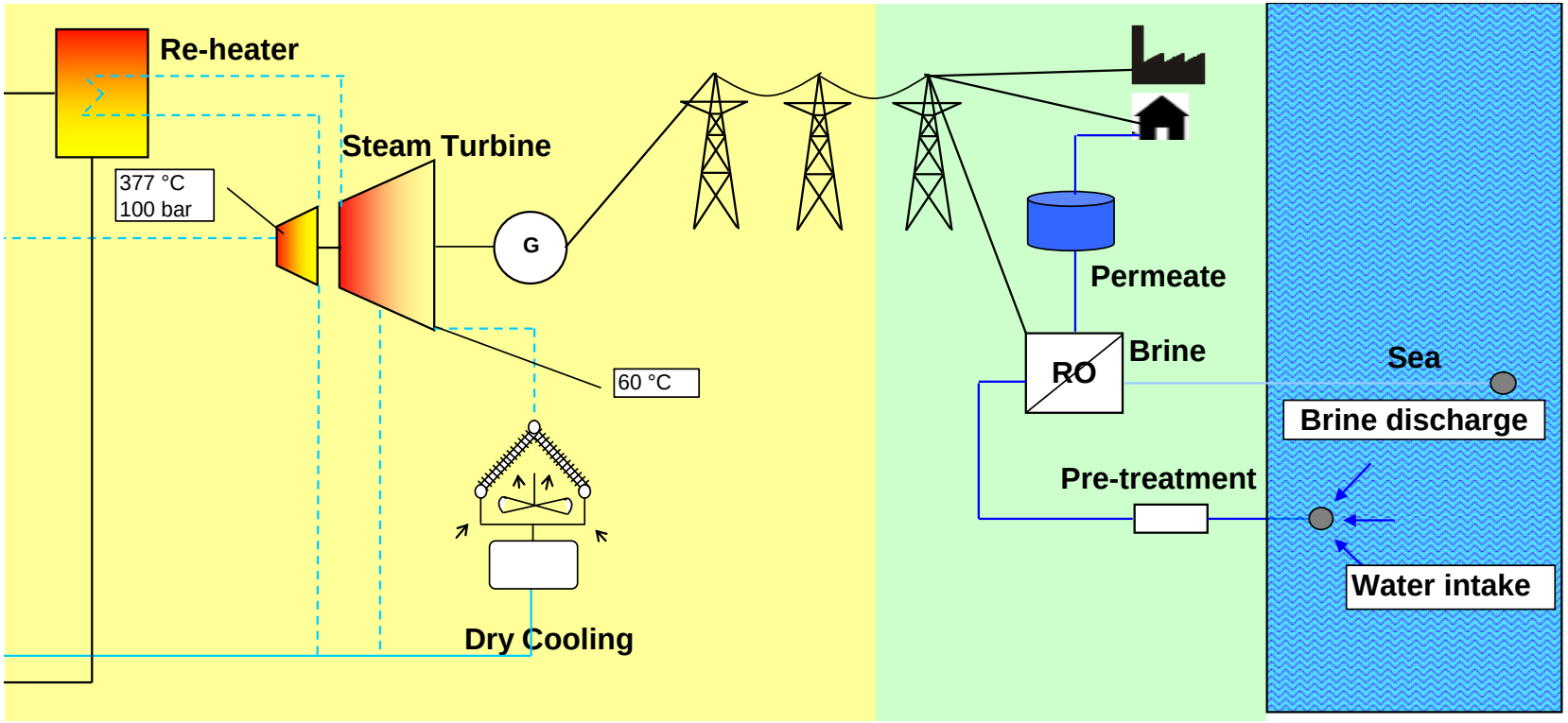
CSP - MED


377 °C
16,5 bar
377 °C
100 bar
G
73 °C
0,35 bar
1
2
3
4
14
Pre-treatment
Sea
Water intake
Brine discharge
MED

CSP coast - RO


Re-heater
377 °C
100 bar
Steam Turbine
G
40 - 50 °C
Permeate
RO
Brine
Sea
Water intake
Pre-treatment
Brine discharge
Once-Through
Cooling

CSP inland - RO

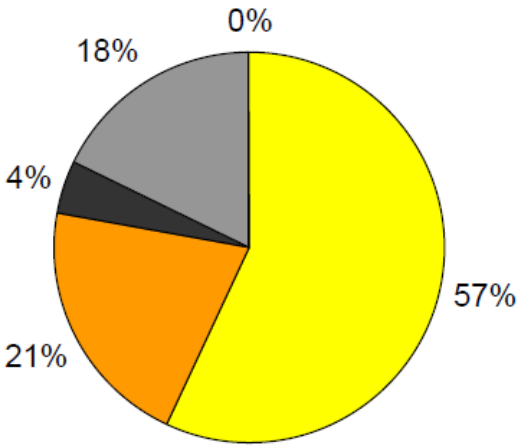


Analyzed Configurations

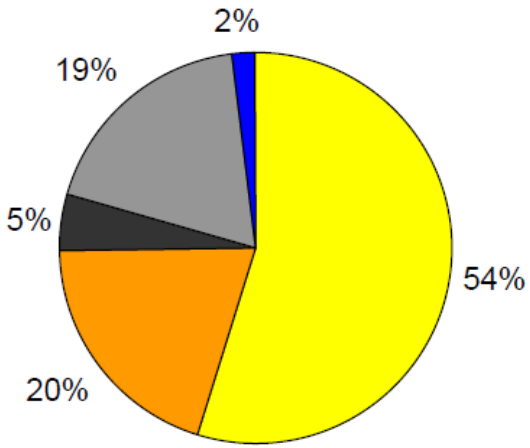
Desalination	100,000 m^3/day
Gross Power	110 – 120 MW
Operation	Base load (8,000 hours/y)
Thermal Storage	SM 2 (7.5 hours full load operation)
Locations	1) Mediterranean Sea / Atlantic Ocean 2) Red Sea / Indian Ocean 3) Arabian Gulf
Back-up fuel	1) Natural gas (NG): fuel factor 0.85 (Reference: crude oil price) 2) Heavy Fuel Oil (HFO): fuel factor 0.8
DNI	1) 2,000 kWh/m^2/year coast site + 2,400 kWh/m^2/year inland site 2) 2,400 kWh/m^2/year coast site + 2,800 kWh/m^2/year inland site

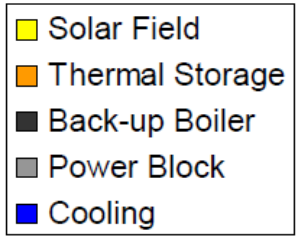
Results 1 – Investment Cost

MED/CSP



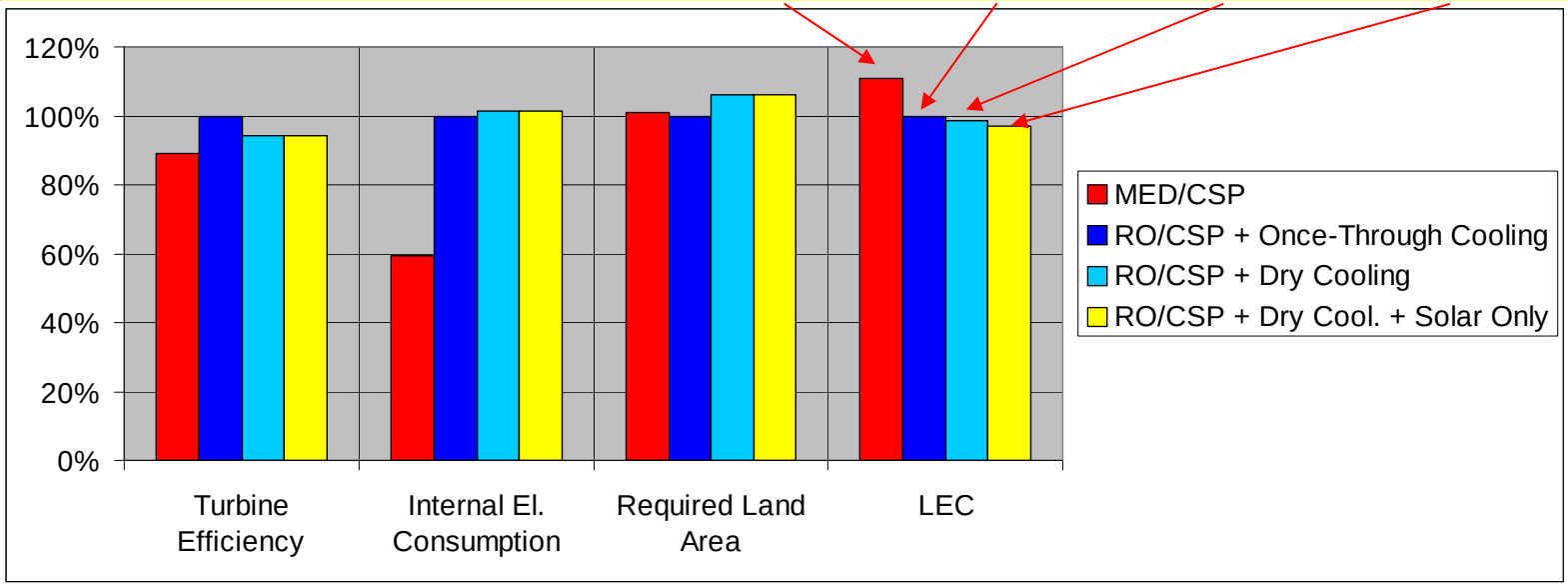
RO/CSP + Once-Through Cooling





Results 2 – Comparison of Configurations

	Unit	MED/CSP	RO/CSP + Once-Through Cooling	RO/CSP + Dry Cooling	RO/CSP + Dry Cool. + Solar Only
Turbine Efficiency (Gross)	%	32.9	37.0	35.0	
Gross Power Production	MW	107.8	120.0	120.4	
Internal El. Consumption	MW	17.8	30.0	30.4	
Mirror area	km^2	1.26	1.25	1.32	
Required Land Area	km^2	4.78	4.73	5.03	
Solar Full Load Hours	h/year	3,652		4,344	
Total Full Load Hours	h/year	8,000			4,344
Solar Share	%	45.7%		54.3%	100.0%
Total Net Power Production	GWh el/year	719.8			390.8
Total Water Production	Mio. m^3/year	33.3			
LEC	US$cent/kWh	24.43	22.04	21.76	21.37



Assumptions: Location: Arabian Gulf; DNI: 2,400 kWh/m²/y; Fuel: NG

Desalination and renewable energy: The case of CSP

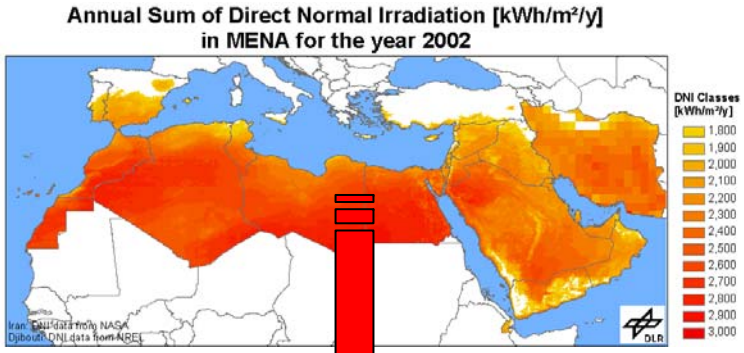
CSP Potential Assessment

Prepared by Tobias Fichter, DLR

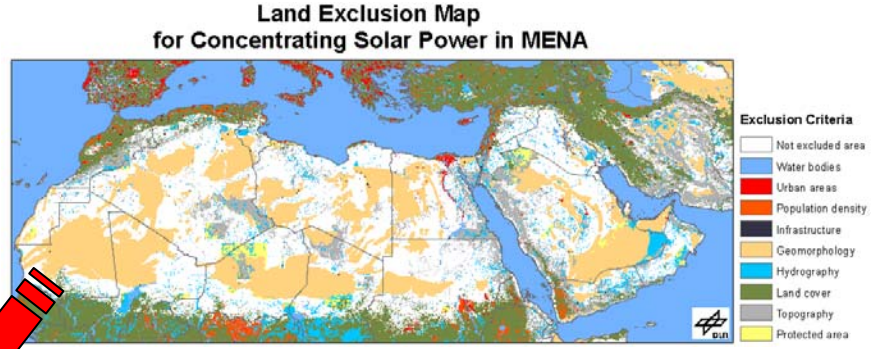
CSP Potential in MENA

Methodology:

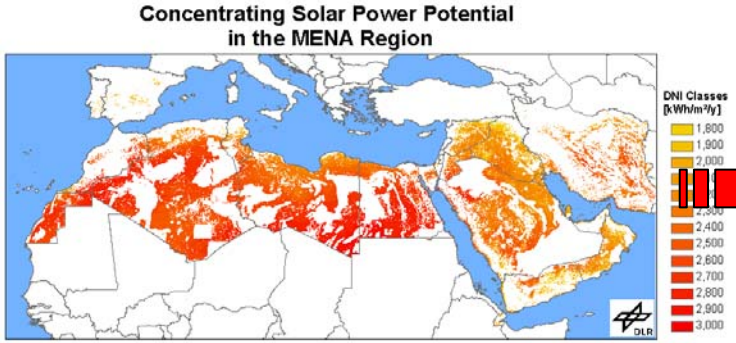
I. Solar Resource Assessment



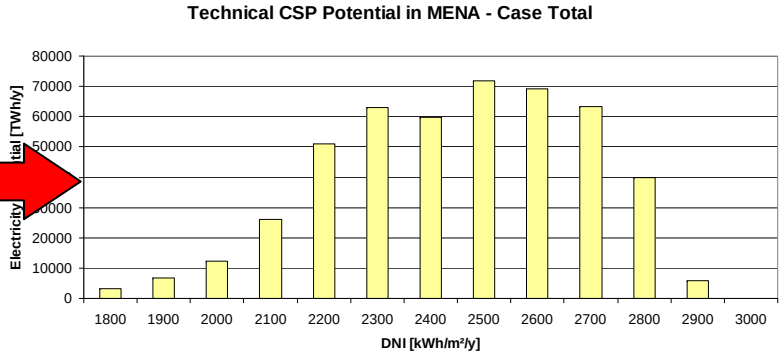
II. Land Resource Assessment



III. CSP Potential



IV. Statistical Evaluation

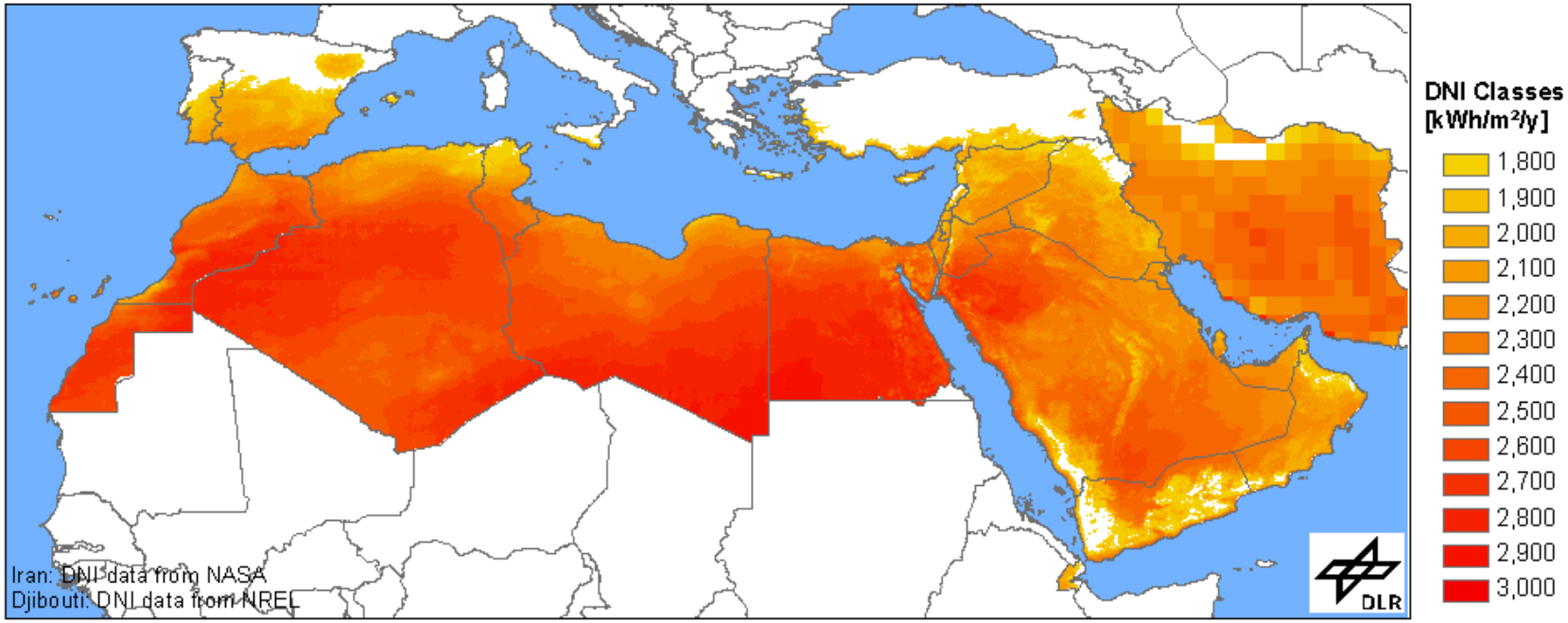


CSP Potential MENA

Solar Resource Assessment:

- Direct Normal Irradiation (DNI) is the energy resource for CSP power plants
- DLR method models the optical transparency of the atmosphere to calculate the DNI

Annual Sum of Direct Normal Irradiation [kWh/m²/y]
in MENA for the year 2002



CSP Potential in MENA

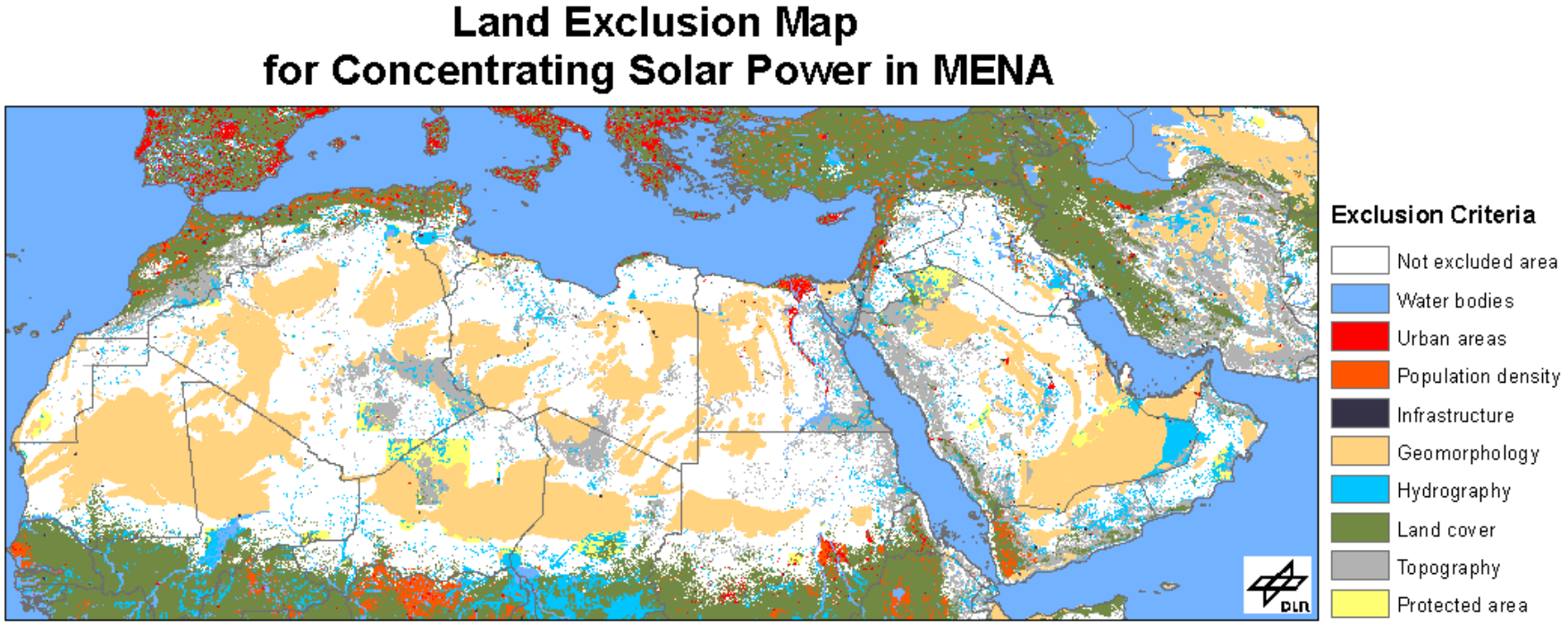
Land Ressource Assessment:

Exclusion Criteria for CSP Plants	Compulsive	Optional	Cases	
			Total	Coast
Terrain				
Slope > 2,1%	x		x	x
Land Cover				
Post-flooding or irrigated croplands (or aquatic)	x		x	x
Rainfed croplands		x	x	
Mosaic cropland / vegetation		x	x	
Forest (>5m)		x	x	x
...				
Population Density				
Population density > 50 persons per km²		x	x	x
Hydrology				
Lake	x		x	x
Reservoir	x		x	x
River	x		x	x
Freshwater Marsh, Floodplain	x		x	x
...				
Geomorphology				
Shifting Sand, Dunes	x		x	x
Security Zone for Shifting Sands 10km		x	x	x
Salt Pans		x	x	x
...				
Protected Area				
IUCN Ia		x	x	x
IUCN Ib		x	x	x
IUCN II		x	x	x
...				
Infrastructure				
Airports		x	x	x
Security Zone for Airports 5km		x	x	x
Desalination plants (capacity > 50,000 m³/day)		x	x	x
Security Zone for Desalination Plants 0.5 km		x	x	x
Project related exclusion criteria				
Suitable area < 4km²		x	x	x
Distance from shore (onshore) > 5km		x		x
...				

- Definition of land exclusion criteria
- Two Cases:
  - Total & Coast
- Different land exclusion criteria for the cases
- Main exclusion criteria categories:
  - Terrain
  - Land cover
  - Hydrology
  - Geomorphology
  - Protected areas
  - Infrastructure
  - Project related criteria

CSP Potential in MENA

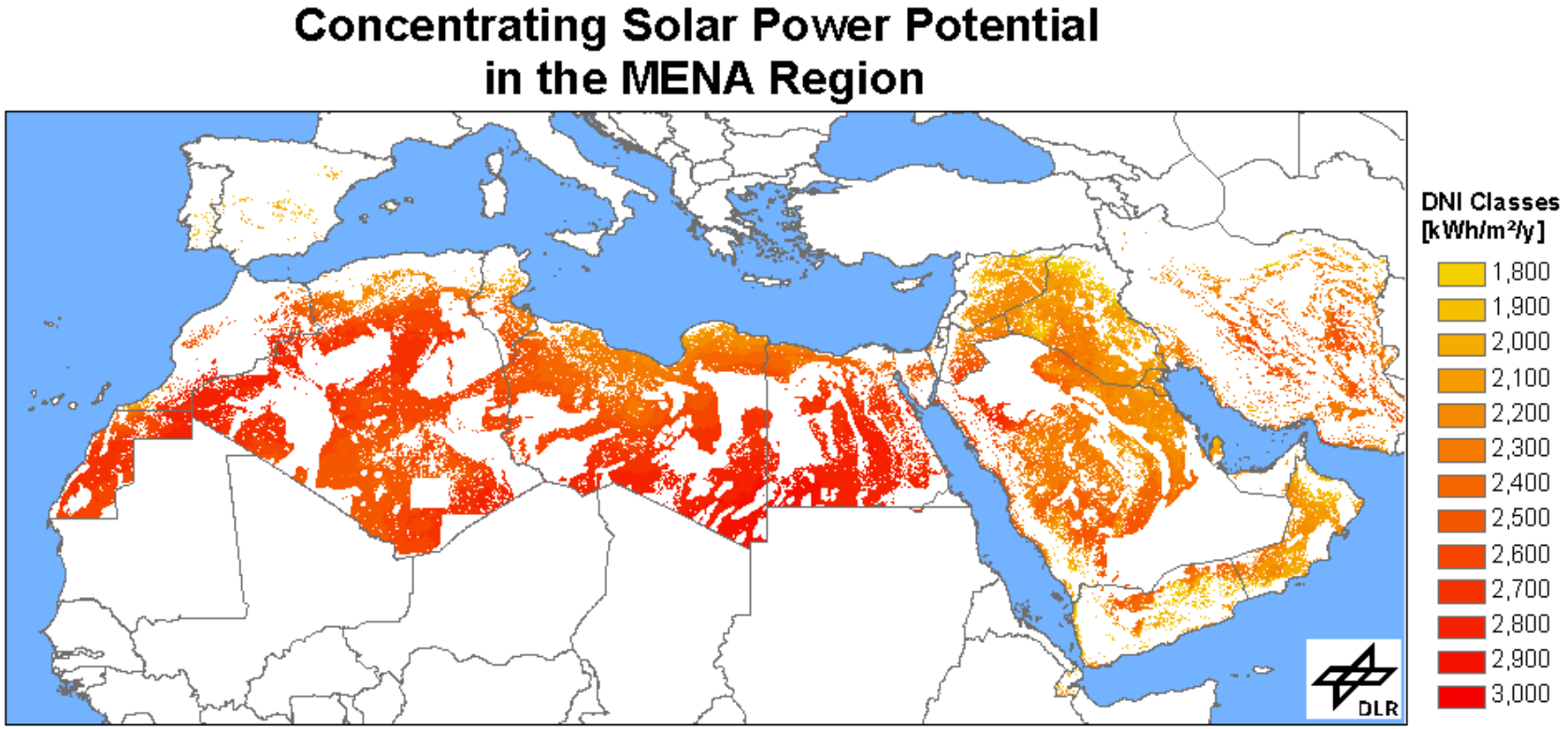
Land Resource Assessment:



CSP Potential in MENA

CSP Potential Map

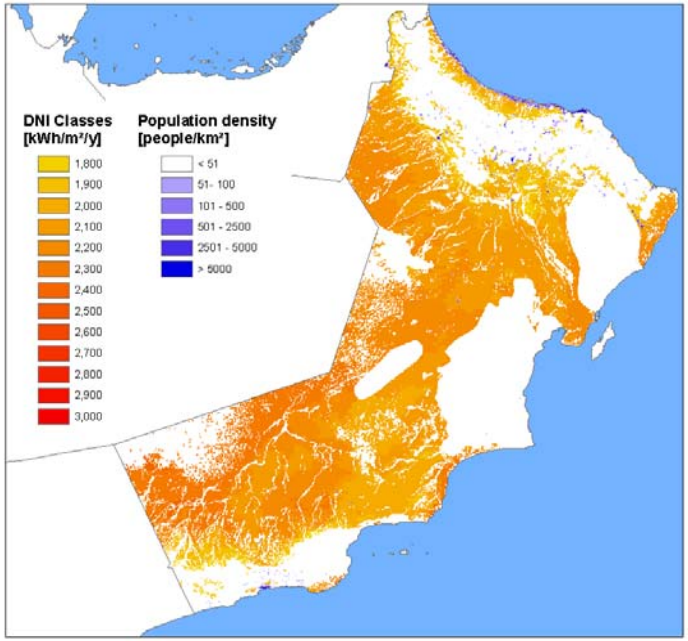
- Combining data from solar resource assessment and land resource assessment
- Results: Annual sum of DNI on areas which are suitable for CSP power plants

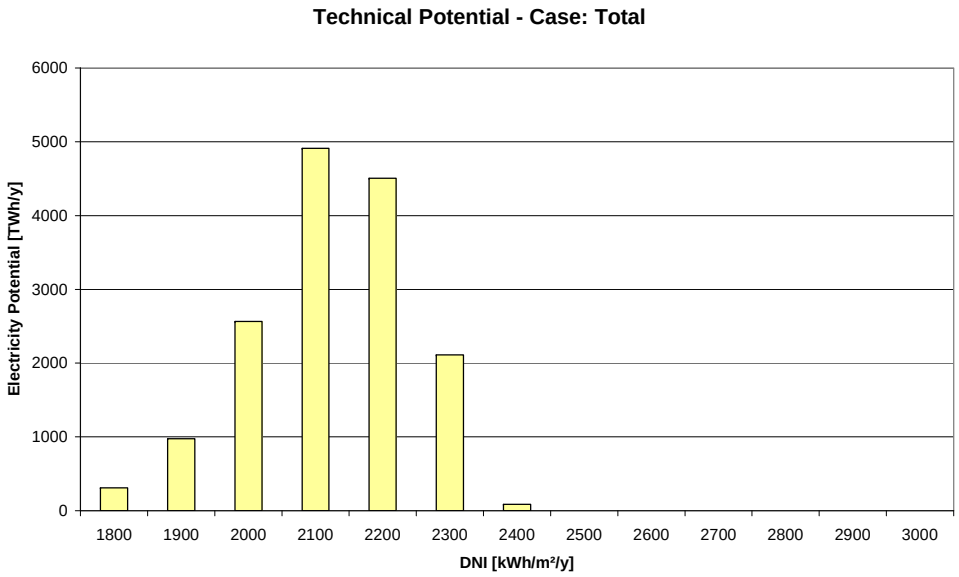


CSP Potential in MENA

Results:

- Detailed CSP potential maps for each country
- Statistical evaluation for each country
- Example: Oman (case Total)

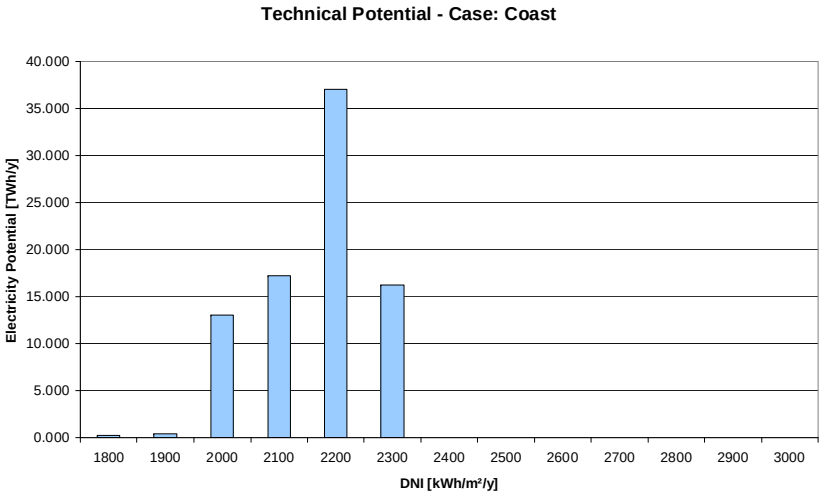


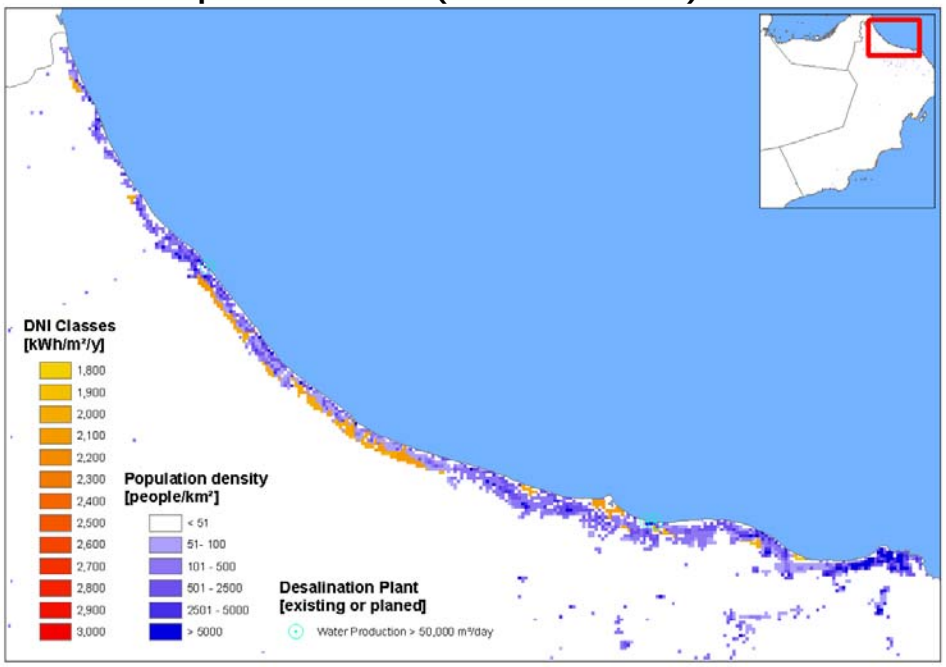


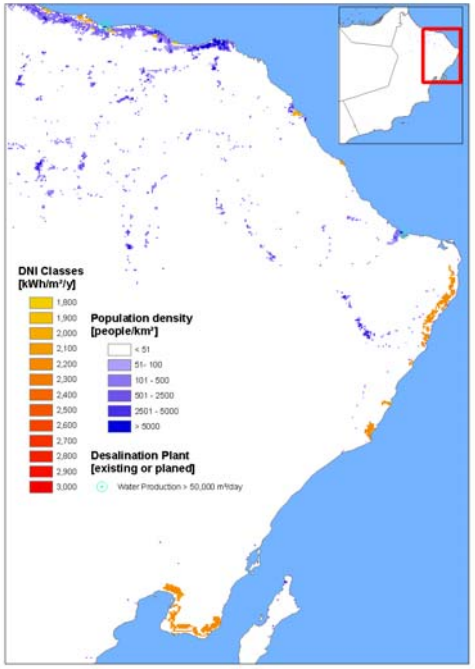
CSP Potential in MENA

Results:

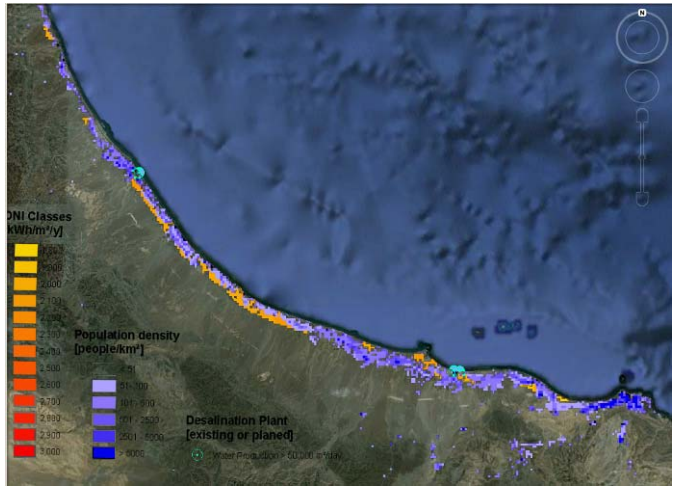
- Detailed near-shore CSP potential maps for each country
- Statistical evaluation for each country
- Example: Oman (case Coast)

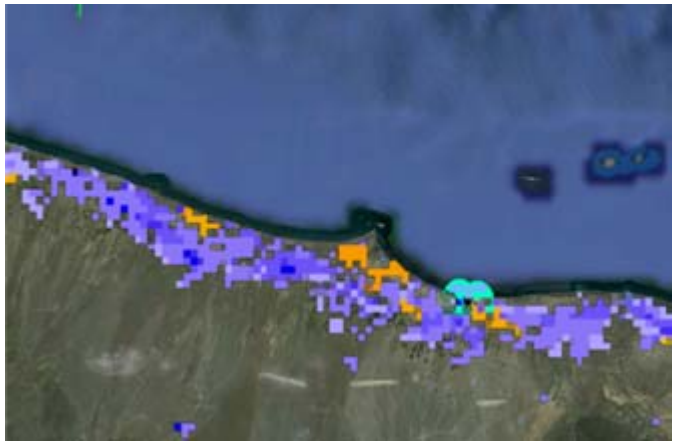


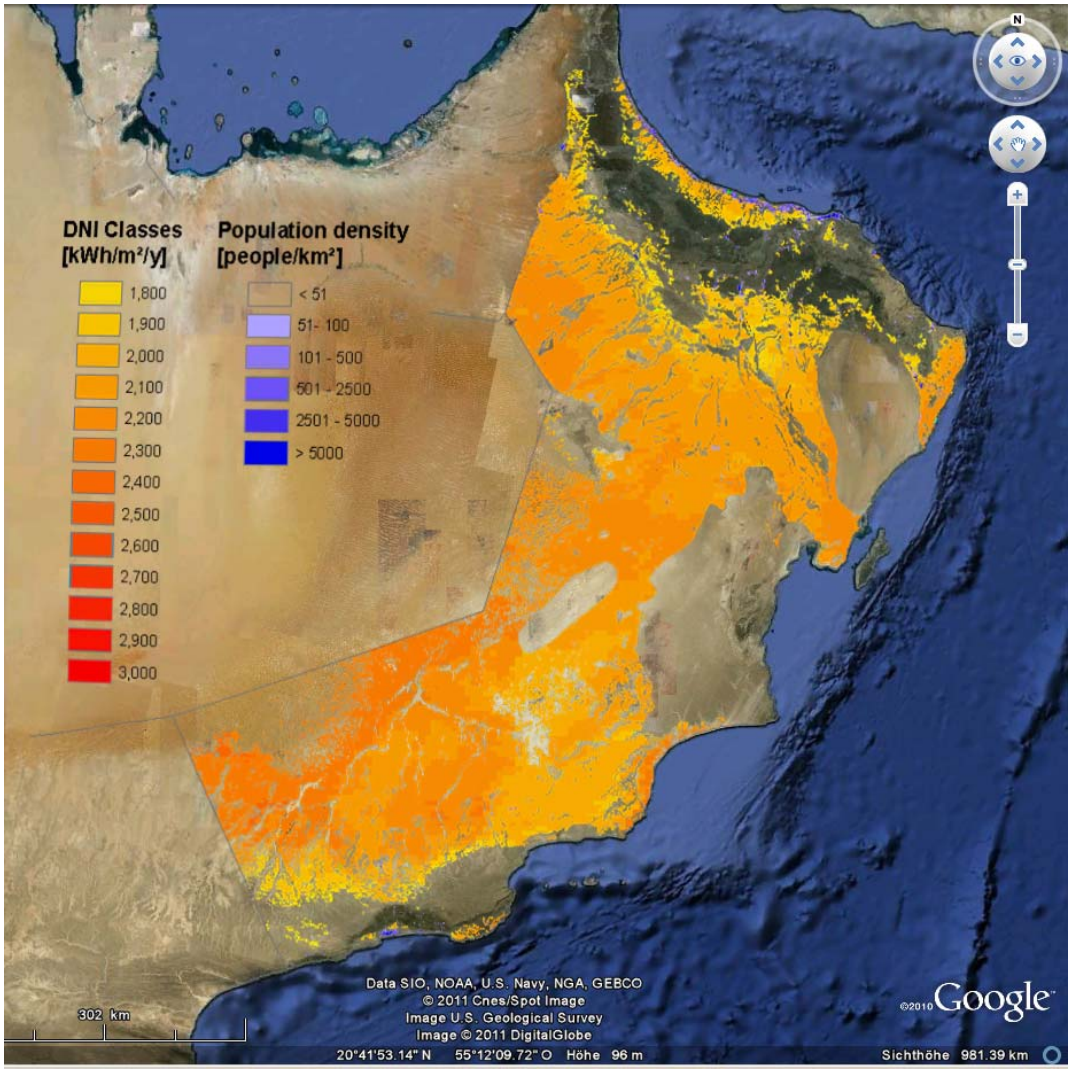




Google Earth overlay for site assessment







CSP Potential in MENA

Input for Electricity and Water Supply Scenarios

- CSP potential for electricity generation of each MENA country

	Total		Coast	
	Technical Potential [TWh/y]	Economical Potential [TWh/y]	Technical Potential [TWh/y]	Economical Potential [TWh/y]
	[DNI > 1800 kWh/m²/y]	[DNI > 2000 kWh/m²/y]	[DNI > 1800 kWh/m²/y]	[DNI > 2000 kWh/m²/y]
Algeria	135823	135771	0.3	0
Bahrain	16	16	9	9
Djibouti*	372	300	0	0
Egypt	57143	57140	74	74
Gaza Strip & Westbanks	8	8	0	0
Iran*	32597	32134	267	267
Iraq	27719	24657	0	0
Israel	151	151	2	2
Jordan	5885	5884	0	0
Kuwait	1372	1372	18	18
Lebanon	5	5	0	0
Libya	82727	82714	135	132
Malta	0	0	0	0
Morocco	8463	8428	15	15
Oman	15460	14174	84	84
Qatar	696	555	56	43
Saudi Arabia	76318	75832	152	152
Syria	9616	8449	1	1
Tunisia	5762	5673	58	49
United Arab Emirates	493	447	15	15
Yemen	11432	8486	108	104
Total	**472057**	**462196**	**995**	**964**

The Scope of CSP in the MENA Region

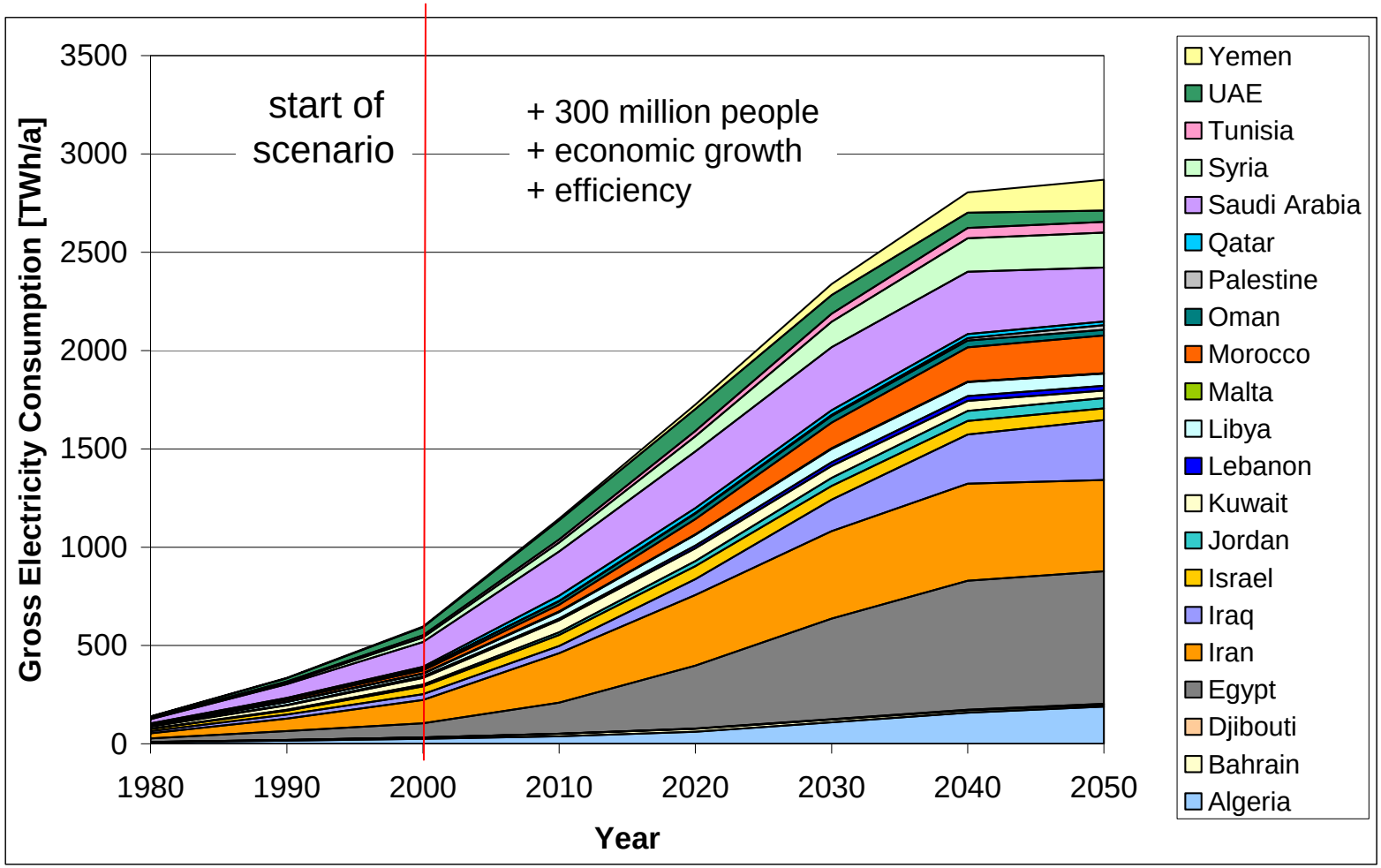
Electricity and Water Supply Scenarios

Franz Trieb, DLR

Power Scenario Methodology

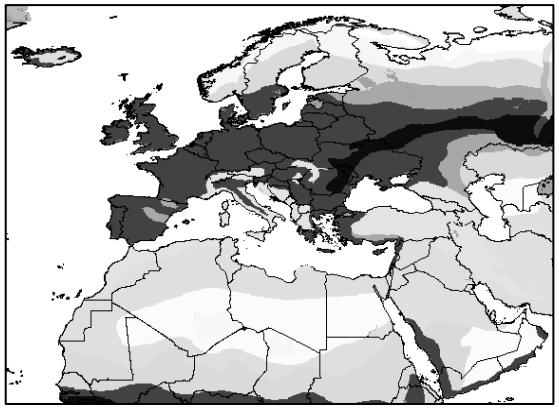
1. power demand from 2000 to 2050
2. economic renewable energy potential for power generation
3. life cycle of old power plants opens opportunity for replacement
4. share of power technologies on firm capacity ➔ 125% availability
5. performance (load factor) of each technology
6. sustainable: secure, inexpensive, compatible
7. well balanced mix of fluctuating and storable sources
8. no technical break through required

Electricity Consumption of all MENA Countries

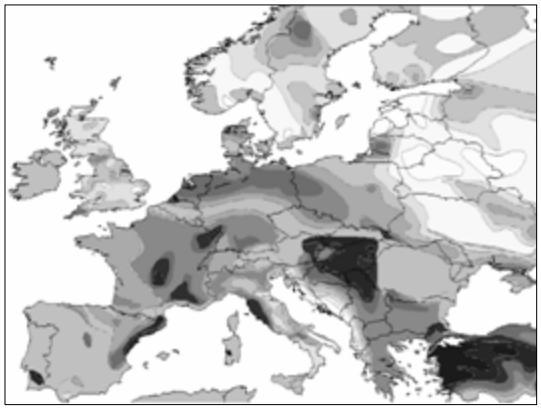


Renewable Electricity Potential in Europe, Middle East & North Africa

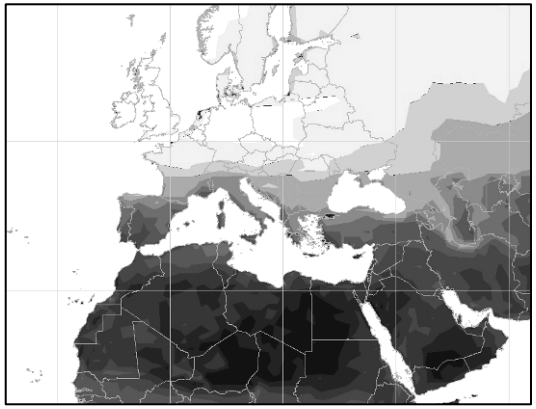
Biomass (0-1)

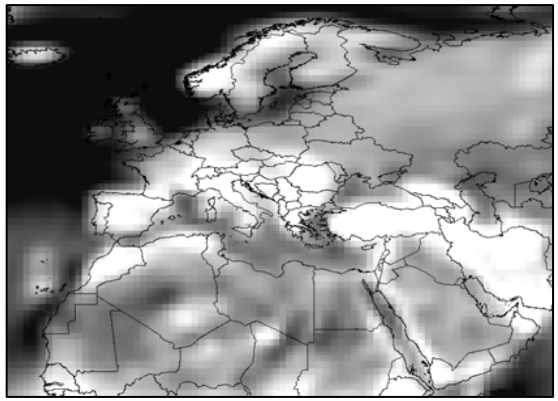


Geothermal (0-1)

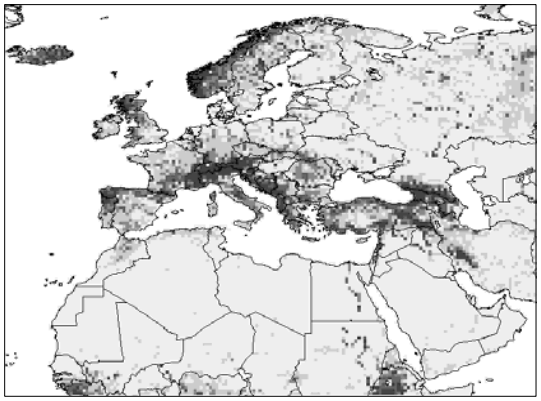


Solar (10-250)





Wind Energy (5-50)



Hydropower (0-50)

Electricity Yield
in GWh/km²/y

Renewable Power Generation Potential by Sources in TWh/y

	Hydro	Geo	Bio	CSP	Wind	PV *
Algeria	0.5	4.7	12.3	135771	35.0	20.9
Bahrain	0.0	0.0	0.2	16	0.1	0.5
Djibouti	0.0	0.0	0.0	300	1.0	50.0
Egypt	50.0	25.7	14.1	57140	125.0	54.0
Gaza & WB	0.0	0.0	1.7	8	0.5	20.0
Iran	48.0	11.3	23.7	32134	12.0	54.0
Iraq	67.0	0.0	8.8	24657	20.0	34.6
Israel	7.0	0.0	2.3	151	0.5	6.0
Jordan	0.1	0.0	1.6	5884	5.0	6.7
Kuwait	0.0	0.0	0.8	1372	n.a.	3.8
Lebanon	1.0	0.0	0.9	5	1.0	5.0
Libya	0.0	0.0	1.8	82714	15.0	7.8
Malta	0.0	0.0	0.1	0	0.2	0.2
Morocco	4.0	10.0	14.3	8428	35.0	17.0
Oman	0.0	0.0	1.1	14174	8.0	4.1
Qatar	0.0	0.0	0.2	555	n.a.	1.5
Saudi Arabia	0.0	70.9	10.0	75832	20.0	20.8
Syria	4.0	0.0	4.7	8449	15.0	17.3
Tunisia	0.5	3.2	3.2	5673	8.0	3.7
UAE	0.0	0.0	0.7	447	n.a.	9.0
Yemen	0.0	107.0	9.1	8486	3.0	19.3
Total	**182**	**233**	**111**	**462196**	**304**	**356**

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

Portfolio of Energy Sources for Electricity:

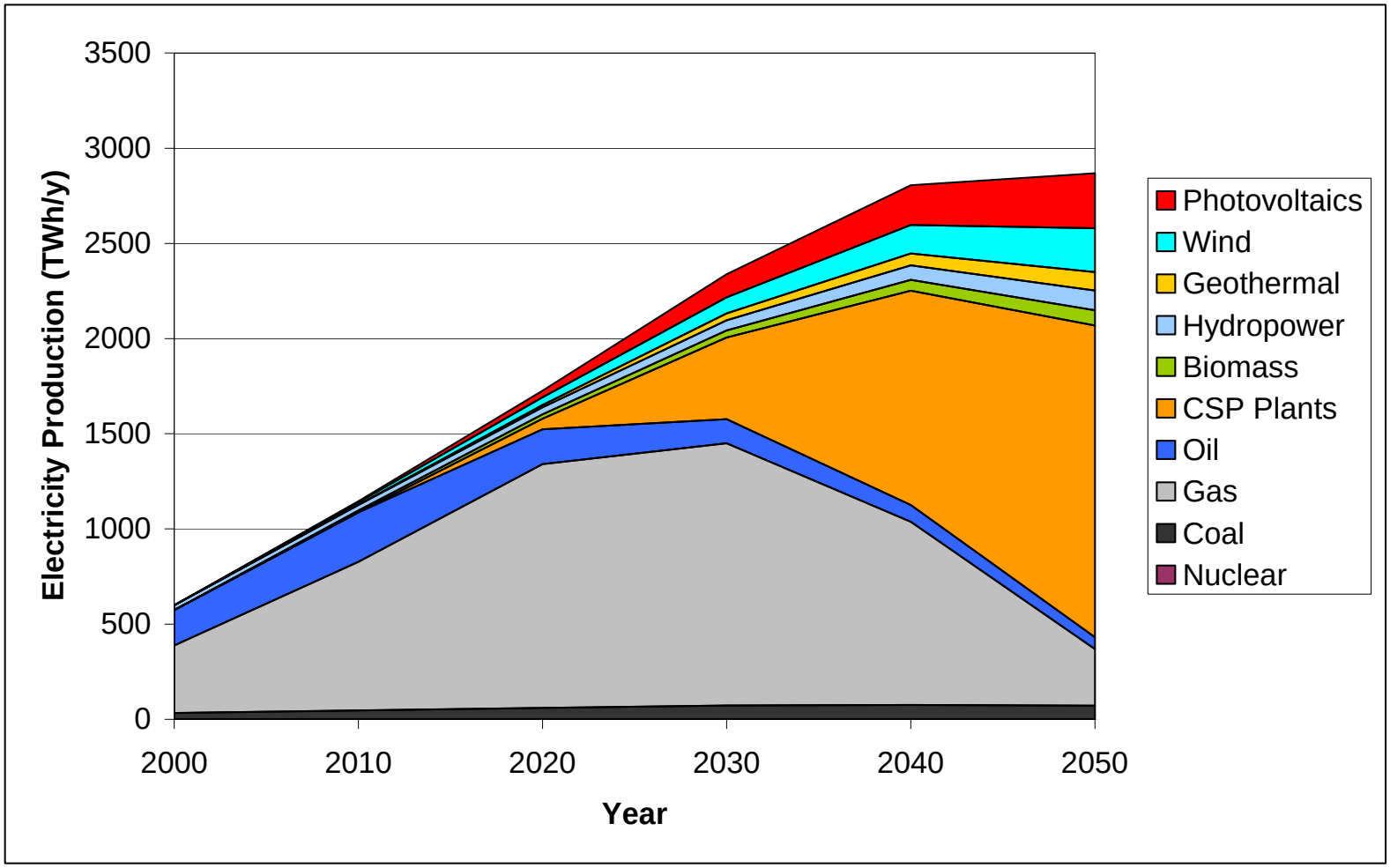
- ✓ Coal, Lignite
- ✓ Oil, Gas
- ✓ Nuclear Fission, Fusion
- ✓ Concentrating Solar Power (CSP)
- ✓ Geothermal Power (Hot Dry Rock)
- ✓ Biomass
- ✓ Hydropower
- ✓ Wind Power
- ✓ Photovoltaic
- ✓ Wave / Tidal

ideally stored primary energy

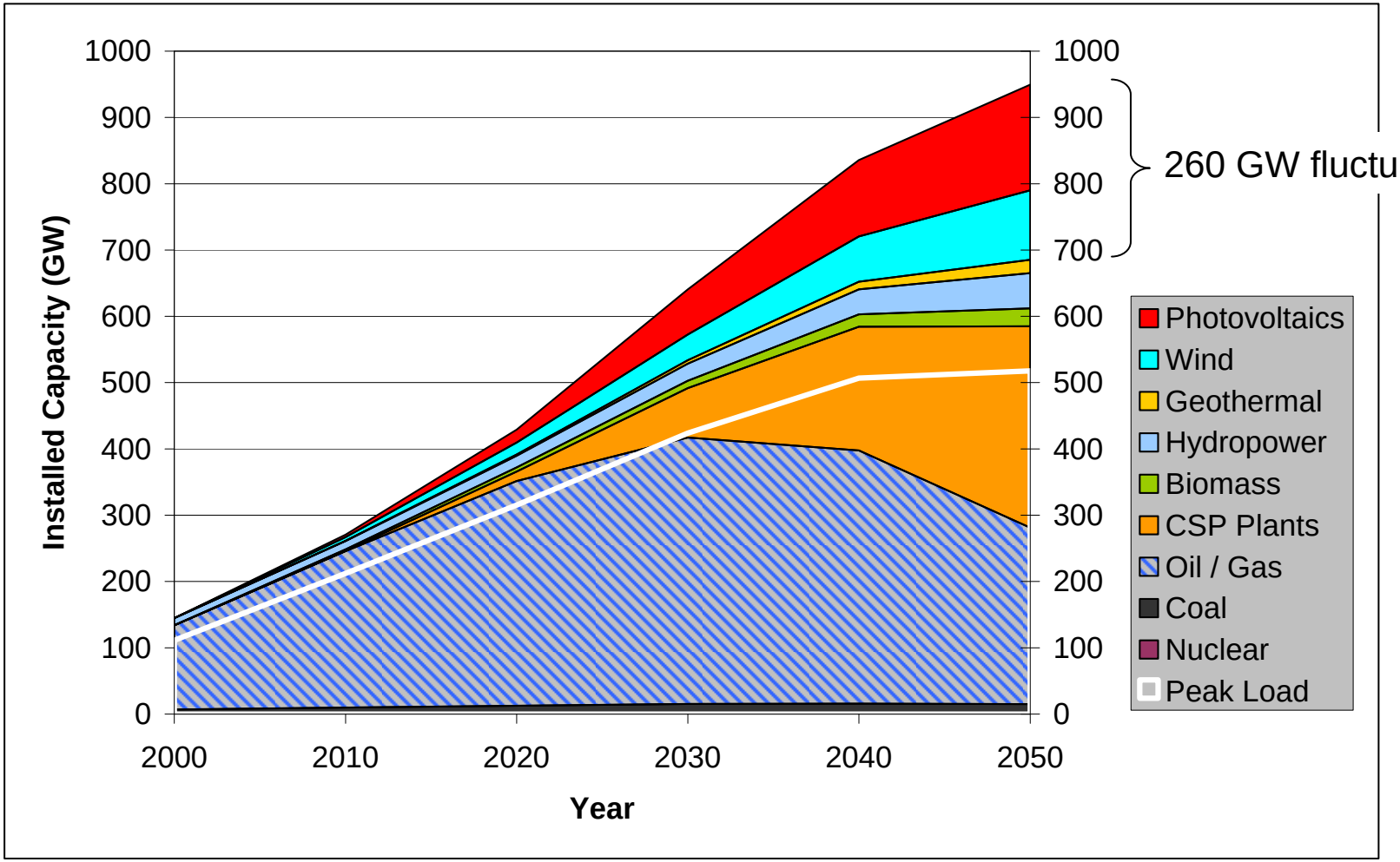
storable primary energy

fluctuating primary energy

Electricity Production of all MENA Countries by Sources

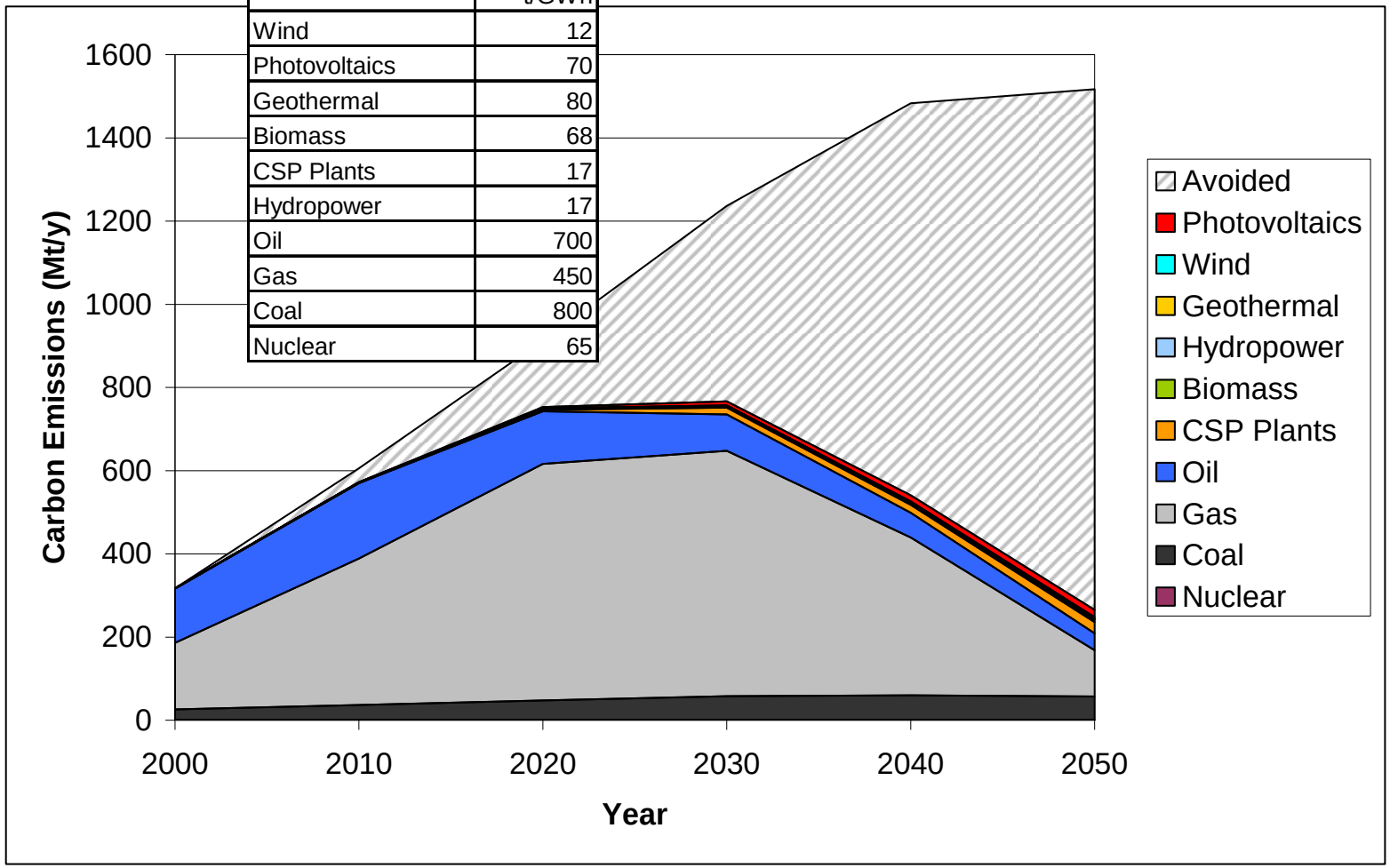


Installed Capacity in all MENA Countries by Sources



CO_2- Emissions from Power Generation by Sources

	t/GWh
Wind	12
Photovoltaics	70
Geothermal	80
Biomass	68
CSP Plants	17
Hydropower	17
Oil	700
Gas	450
Coal	800
Nuclear	65



Why CSP for Power in MENA?

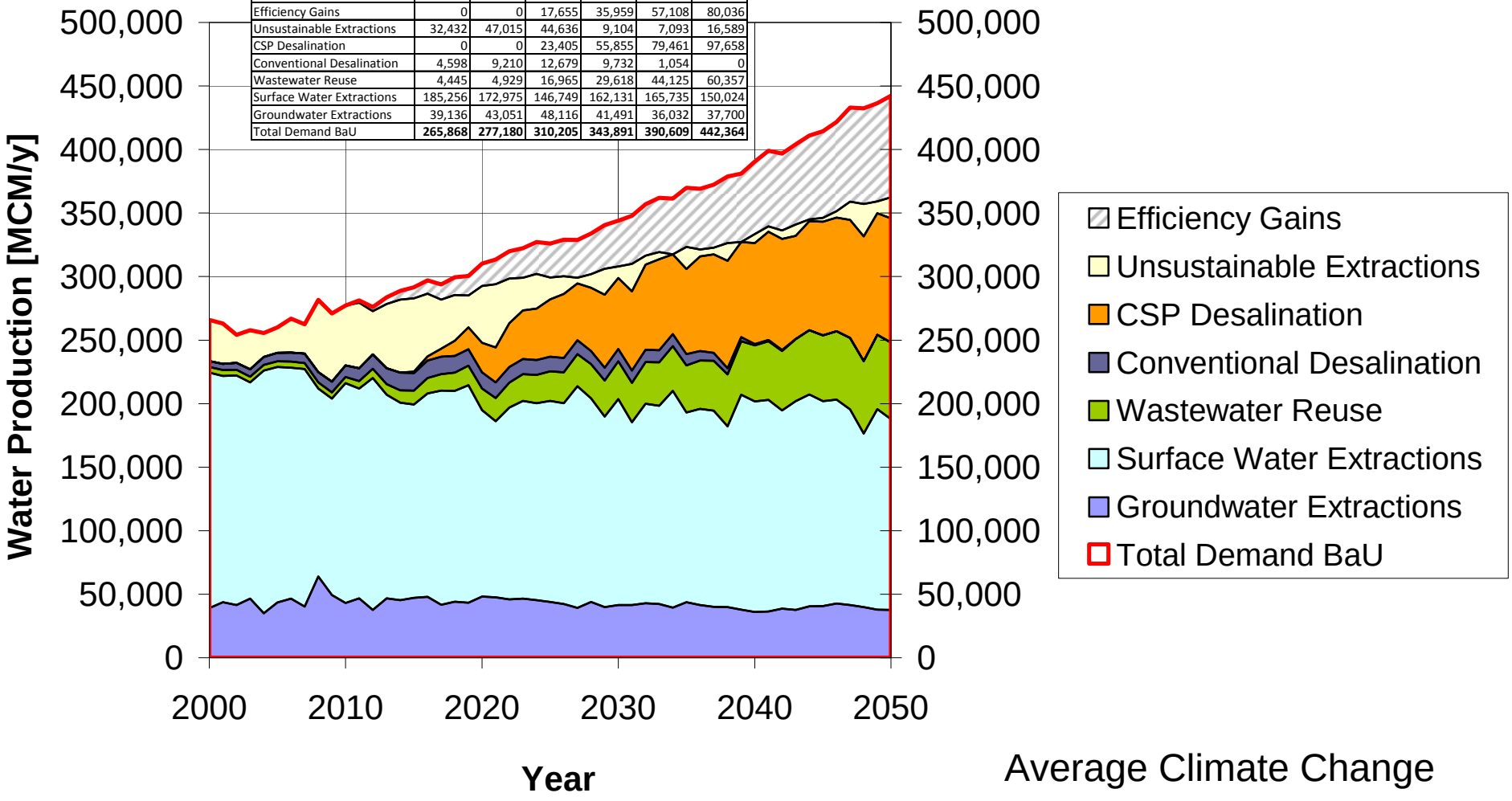
1. CSP provides balancing power on demand for base, medium or peak load
2. MENA has no potential for pump storage like Europe to compensate fluctuations from wind and PV
3. storable hydropower, biomass and geothermal are very limited in MENA
4. CSP potential in MENA is extremely large and domestic
5. CSP combines ideally with natural gas and fuel oil

Water Scenario Methodology

1. water demand from 2000 to 2050
2. total and coastal CSP potential for desalination
3. life cycle of old desal plants opens opportunity for replacement
4. top priority for efficiency gains
5. second priority for reuse of waste water
6. third priority for sustainable surface and ground water extractions
7. fourth priority for existing and planned conventional desal plants
8. last priority for CSP desalination after 2015
9. no priority for unsustainable water extractions

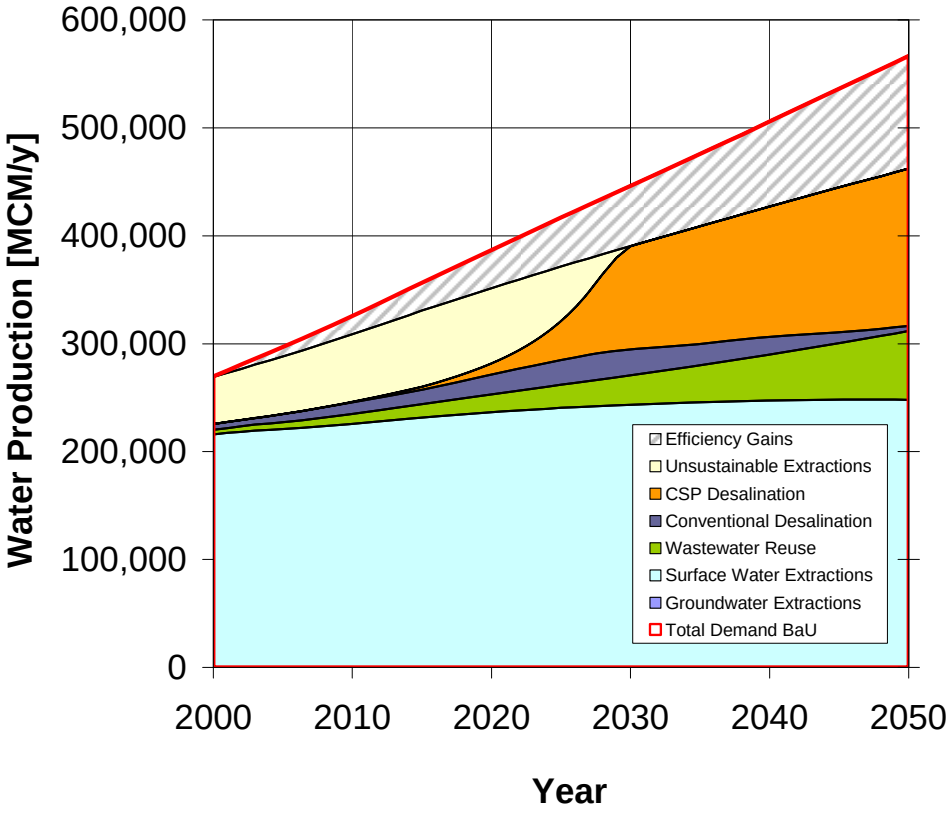
Middle East & North Africa (MENA)

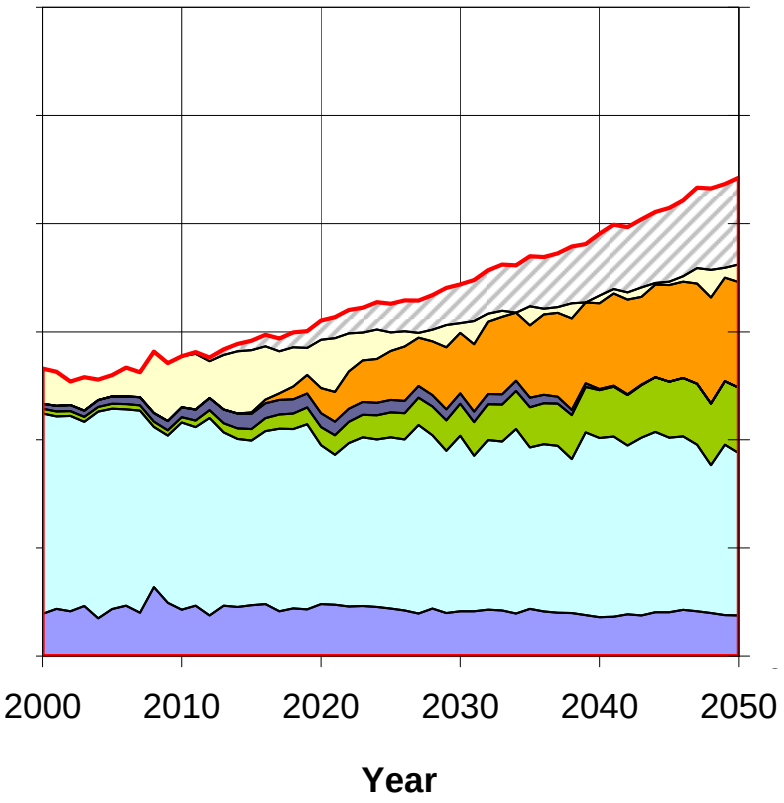
Year	2000	2010	2020	2030	2040	2050
Efficiency Gains	0	0	17,655	35,959	57,108	80,036
Unsustainable Extractions	32,432	47,015	44,636	9,104	7,093	16,589
CSP Desalination	0	0	23,405	55,855	79,461	97,658
Conventional Desalination	4,598	9,210	12,679	9,732	1,054	0
Wastewater Reuse	4,445	4,929	16,965	29,618	44,125	60,357
Surface Water Extractions	185,256	172,975	146,749	162,131	165,735	150,024
Groundwater Extractions	39,136	43,051	48,116	41,491	36,032	37,700
Total Demand BaU	265,868	277,180	310,205	343,891	390,609	442,364



Average Climate Change

AQUA-CSP Scenario vs. MENA Water Outlook

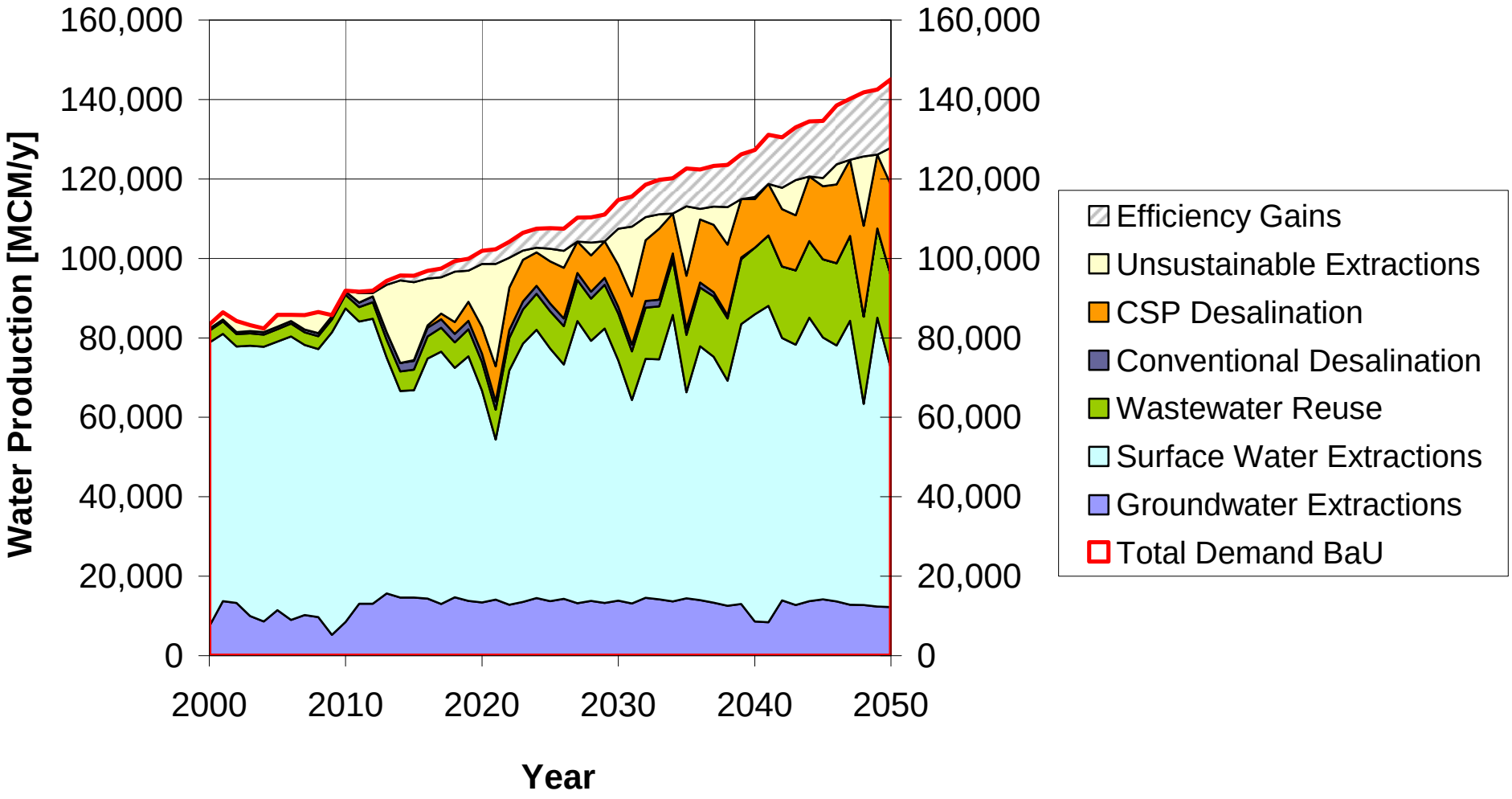




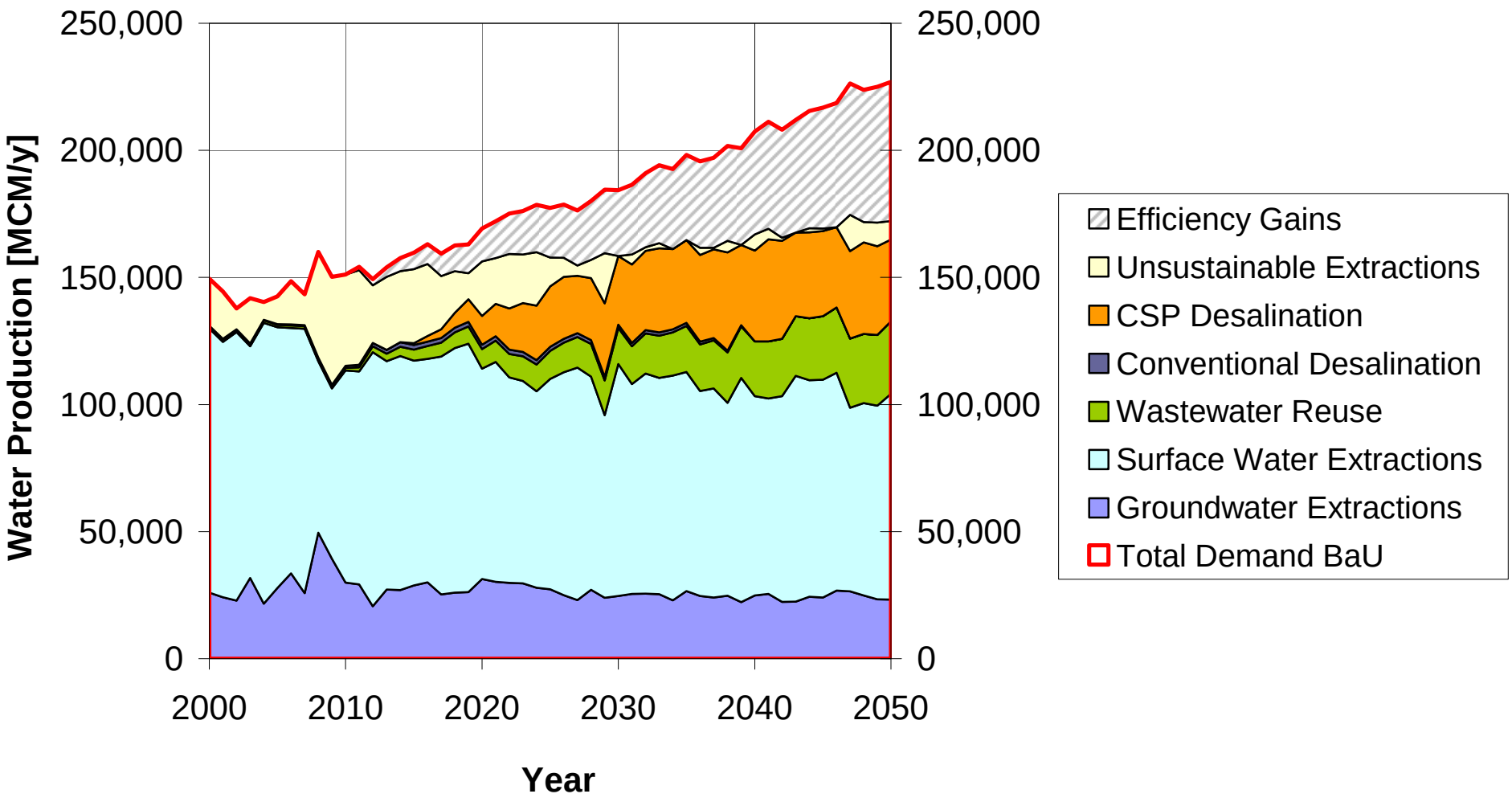
constant reduced

per capita water for irrigation

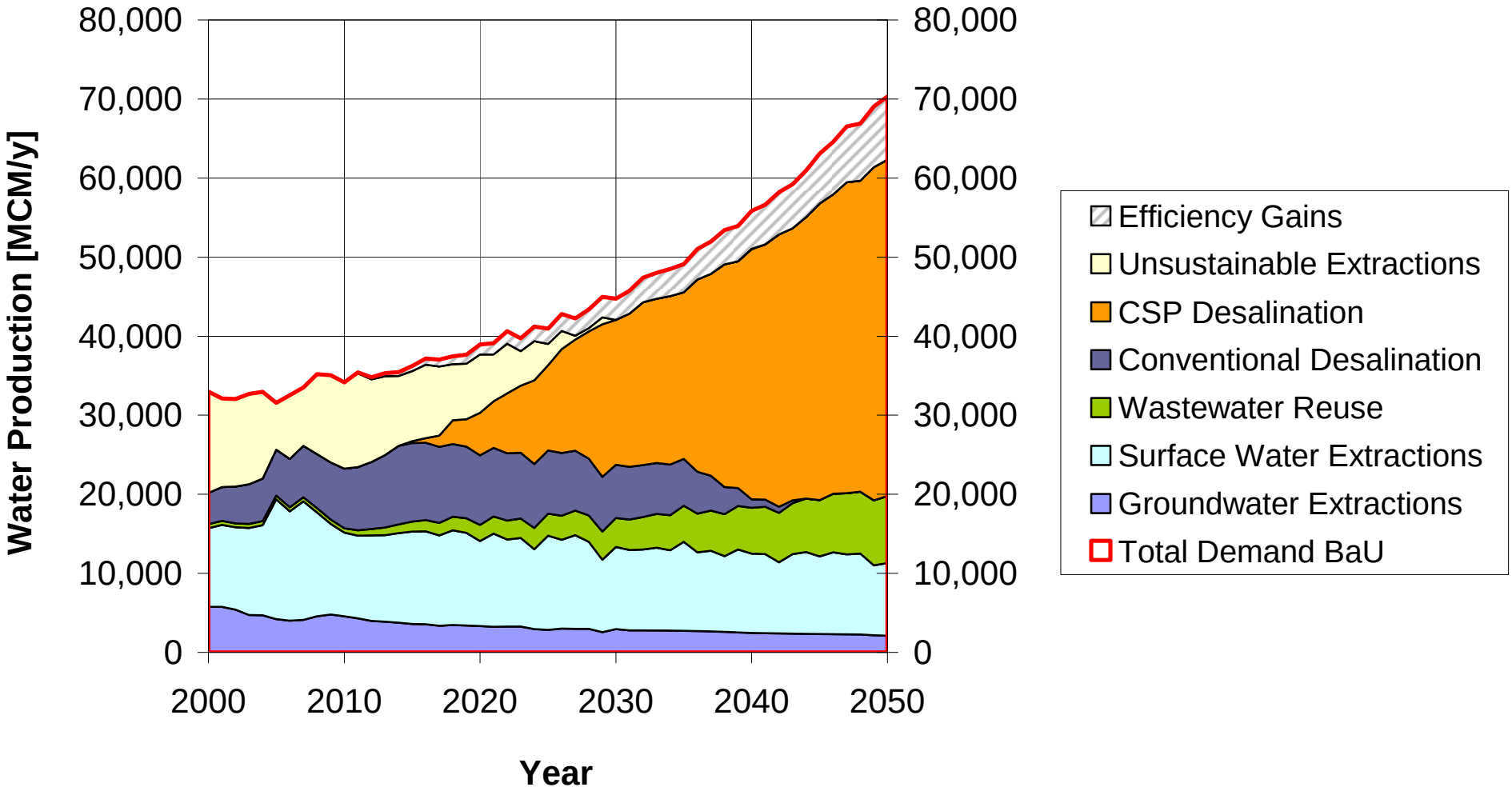
North Africa



Western Asia



Arabian Peninsula



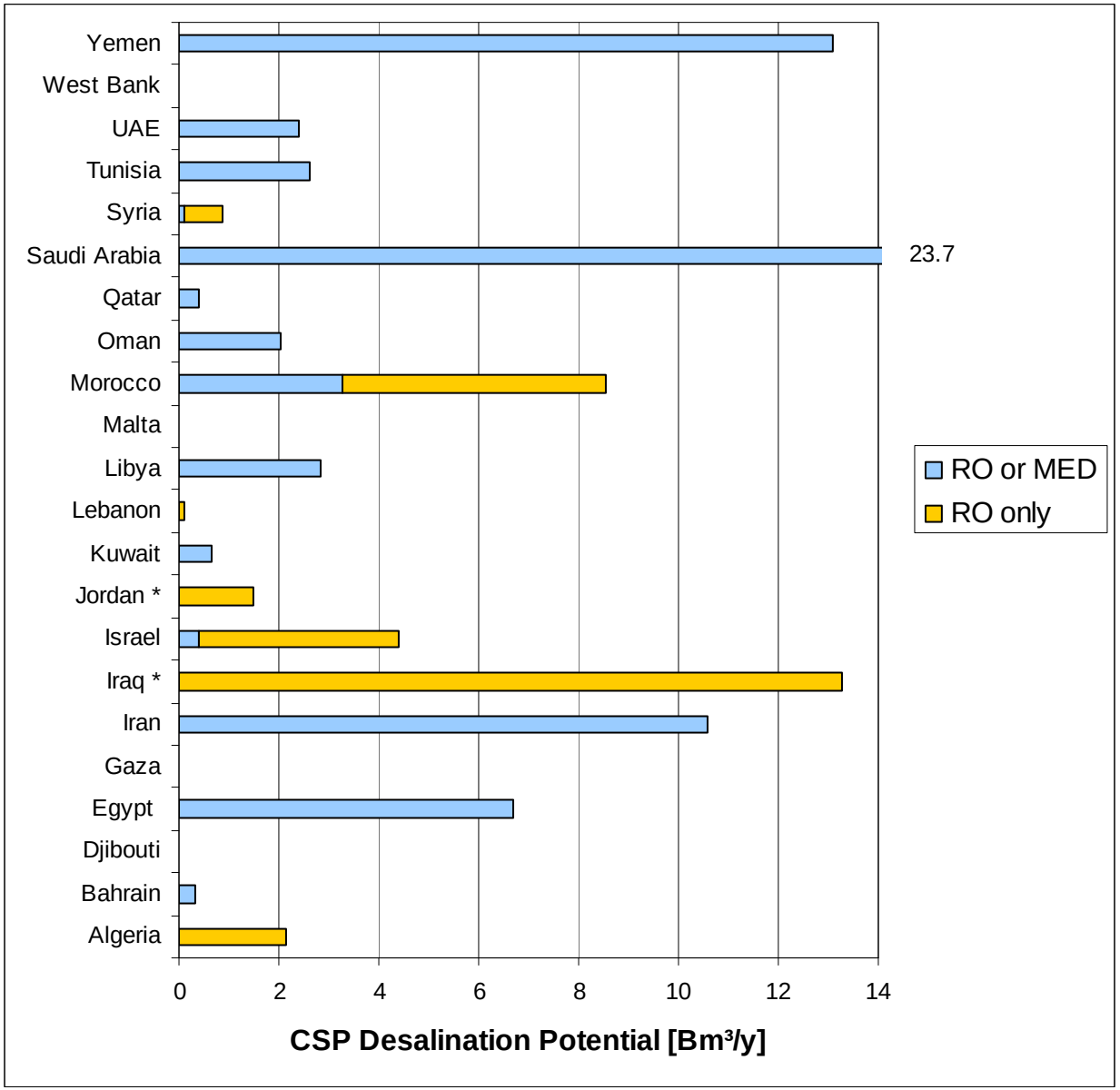
Results of Water Scenarios

	Total CSP Potential	CSP Demand 2050	Coastal CSP Potential	CSP-SWD Demand 2050	Power Demand	RO only Supply 2050	RO or MED Supply 2050	CSP-SWD Demand 2050	Total Water Demand 2050
	TWh/y	TWh/y	TWh/y	TWh/y	kWh/m³	BCM/y	BCM/y	BCM/y	BCM/y
Algeria	135771	120	0.0	7.5	3.5	2.1	0.0	2.1	13.6
Bahrain	16	4	8.6	1.3	4.3	0.0	0.3	0.3	0.4
Djibouti	300	1	0.0	0.0	4.3	0.0	0.0	0.0	0.1
Egypt	57140	395	73.9	25.5	3.8	0.0	6.7	6.7	92.6
Gaza	0	0	0.0	1.5	3.5	0.0	0.0	0.4	0.6
Iran	32134	290	267.4	37.0	3.5	0.0	10.6	10.6	114.9
Iraq *	24657	180	0.0	57.1	4.3	13.3	0.0	13.3	74.2
Israel	151	29	1.7	15.4	3.5	4.0	0.4	4.4	6.4
Jordan *	5884	38	0.0	5.7	3.8	1.5	0.0	1.5	2.5
Kuwait	1372	13	17.6	2.9	4.3	0.0	0.7	0.7	1.3
Lebanon	5	5	0.0	1.2	3.5	0.1	0.0	0.3	1.9
Libya	82714	25	132.3	9.9	3.5	0.0	2.8	2.8	6.2
Malta	0	0	0.0	0.3	3.5	0.0	0.0	0.1	0.2
Morocco	8428	110	14.8	29.9	3.5	5.3	3.3	8.5	26.1
Oman	14174	14	83.5	7.1	3.5	0.0	2.0	2.0	3.1
Qatar	555	8	43.2	1.8	4.3	0.0	0.4	0.4	0.6
Saudi Arabia	75832	135	152.4	101.7	4.3	0.0	23.7	23.7	37.2
Syria	8449	117	0.5	3.1	3.5	0.8	0.1	0.9	25.3
Tunisia	5673	34	48.7	9.2	3.5	0.0	2.6	2.6	6.5
UAE	447	40	14.9	10.3	4.3	0.0	2.4	2.4	3.3
West Bank	8	8	0.0	2.3	3.0	0.0	0.0	0.8	1.2
Yemen	8486	65	104.0	49.7	3.8	0.0	13.1	13.1	24.2
Total	**462196**	**1630**	**964**	**380**	**3.9**	**27**	**69**	**98**	**442**

CSP Potential < SWD Demand 2050

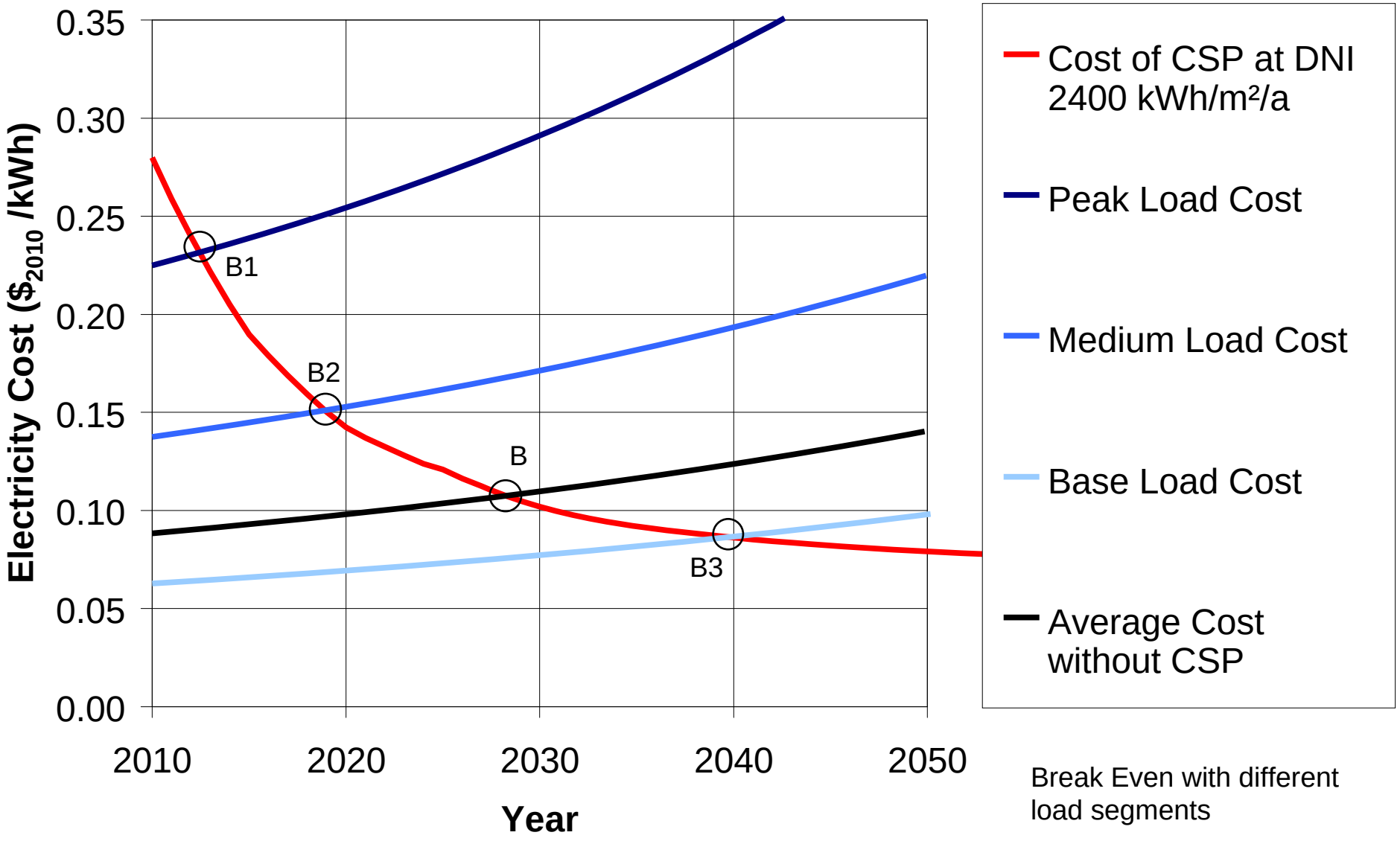
Coastal CSP Potential < SWD Demand 2050

Coastal CSP Potential > SWD Demand 2050

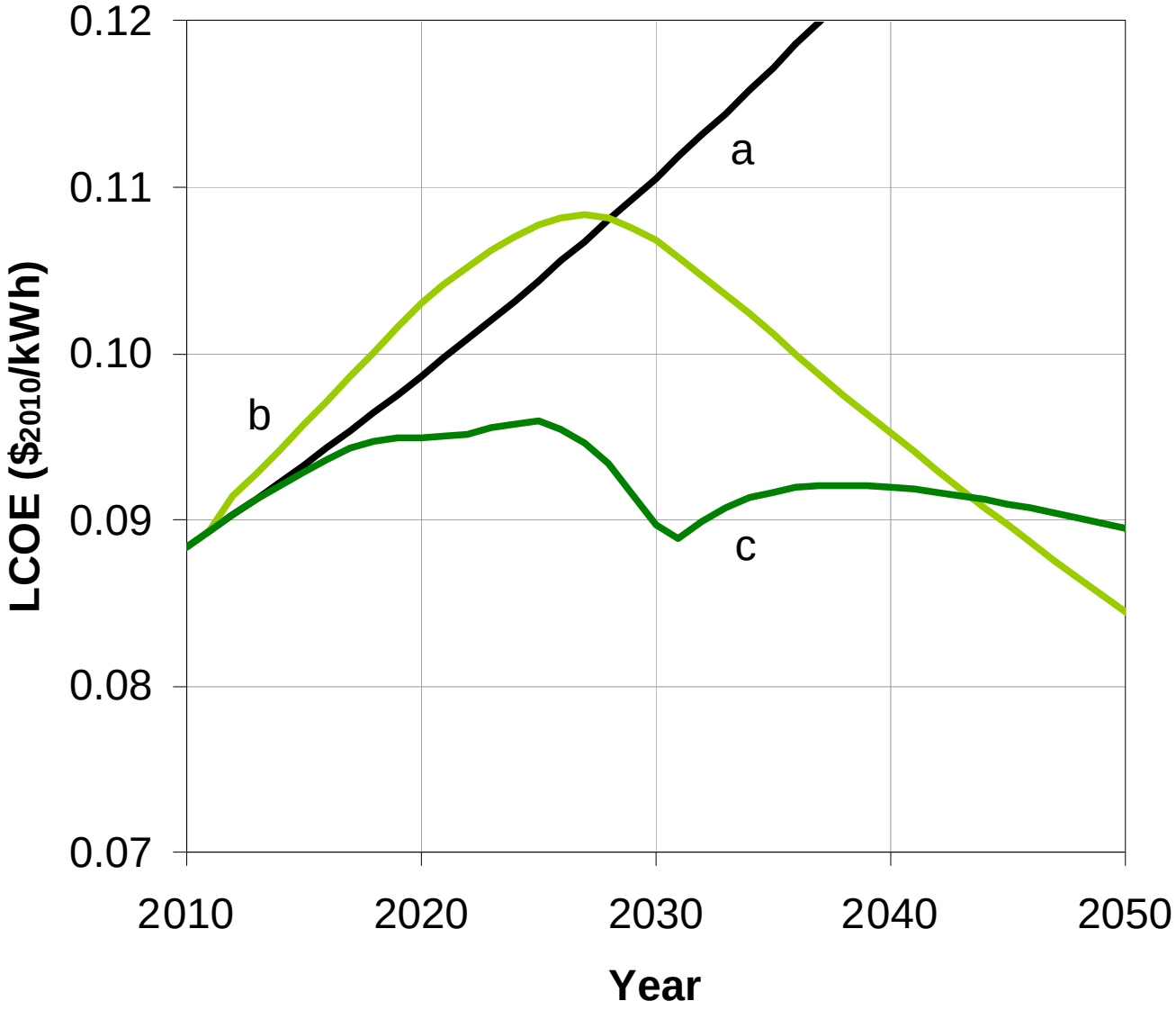

Yemen
West Bank
UAE
Tunisia
Syria
Saudi Arabia
Qatar
Oman
Morocco
Malta
Libya
Lebanon
Kuwait
Jordan *
Israel
Iraq *
Iran
Gaza
Egypt
Djibouti
Bahrain
Algeria
23.7
0
2
4
6
8
10
12
14
RO or MED
RO only
CSP Desalination Potential [Bm³/y]

Why CSP for Water in MENA?

1. CSP potential is very large even at coastal sites
2. good seasonal correlation of availability and demand
3. most abundant in regions with highest water scarcity
4. base load for uninterrupted operation of desalination plants
5. solar powered pre-treatment replaces chemicals



Break Even with different load segments



Case 1: 100% Substitution in peak and medium load segment by CSP

- Average LCOE without CSP
- Average LCOE with CSP
- Average LCOE with Peak CSP

How to finance CSP

1. identify real structure of national power generation cost
2. calculate CSP cost and learning curve under local conditions
3. compare and identify evtl. break even points
4. offer PPA (and WPA) as required
5. call for offers on best quality and longevity for the capacity needed
6. provide national and international guarantee on PPA
7. connect PPA to loan period
8. transparent scheme, quick procedures

Thank You!