EU-GCC Clean Energy Network Workshop on "RES Integration in the Grid“ Muscat, Oman

Water Desalination using Renewable Energy Sources

EU-GCC Clean Energy Network Conference
"RES Integration in the Grid"
13th - 15th May 2013, Muscat, Oman, Crown Plaza Hotel

Jürgen Kern

Deutsches Zentrum für Luft und Raumfahrt e.V. (DLR)
German Aerospace Center

Knowledge for Tomorrow

enerMENA Towards a Sustainable Implementation of Solar Thermal Power Plants Technology in the MENA

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www.dlr.de
www.dlr.de/enerMENA

Research Areas

- Aeronautics
- Space Research and Technology
- Transport
- Energy
- Space Administration
- Project Management Agency

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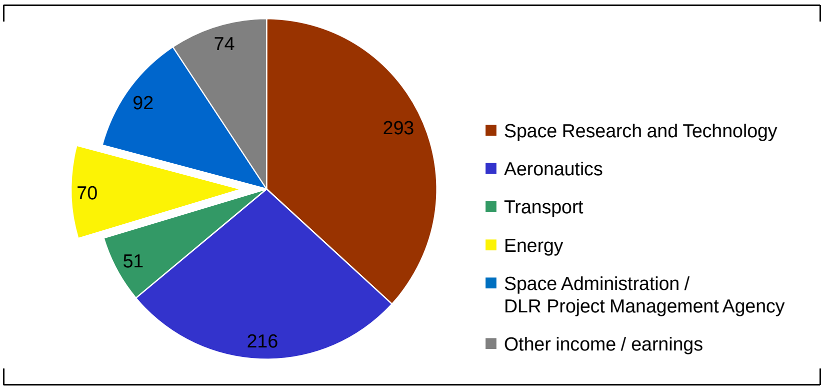
Total income 2011 – Research, operations and management tasks (excluding trustee funding from the Space Administration / DLR Project Management Agency): € 796 Mio.

All values in € million



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Participation in the Helmholtz Association

- Success in obtaining program-oriented funding
- Added value from support of the Helmholtz Association
- Helping to shape the organisational development process

HELMHOLTZ | GEMEINSCHAFT

AWI DESY dkfz. DLR DZNE GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel

GSI GFZ Helmholtz-Zentrum Potsdam HZB Helmholtz Zentrum Berlin HZDR Helmholtz Zentrum Dresden Rossendorf Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung JÜLICH Forschungszentrum

KIT Helmholtz Zentrum für Infektionsforschung HelmholtzZentrum münchen Helmholtz Zentrum für Umweltforschung UFZ MDC IPP

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Energy Program Themes

- Efficient and environmentally compatible fossil-fuel power stations (turbo machines, combustion chambers, heat exchangers)
- Solar thermal power plant technology, solar conversion
- Thermal and chemical energy storage
- High and low temperature fuel cells
- **Systems analysis and technology assessment**

- Plataforma Solar de Almería (PSA)

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Energy, Renewables and Solar Power

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Energy

Shortage of energy ?

- 25 cm crude oil annually on the hole surface of earth
    - 2 millions barrels per square kilometer

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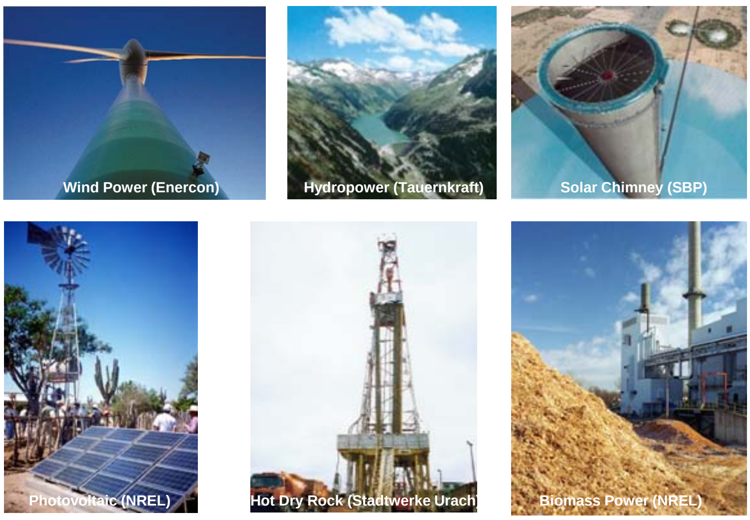
Renewable Energy for Power Generation



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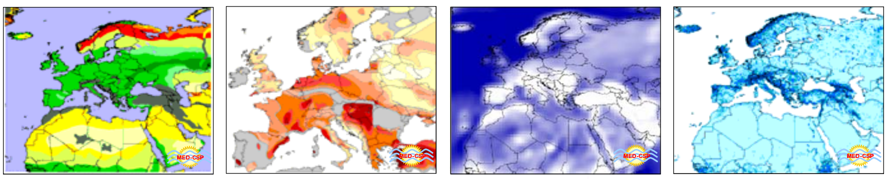
Solar Power Technologies

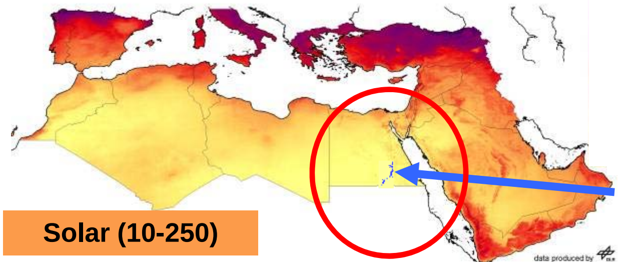
Market available Technology proofed since 1986

Different Technologies for different use

Renewable Electricity Potentials in EUMENA and GCC

Biomass (0-1) | Geothermal (0-1) | Wind (0-50) | Hydro (0-50)





A CSP plant of the size of Lake Nasser equals the total **Middle East oil** production

Solar (10-250)

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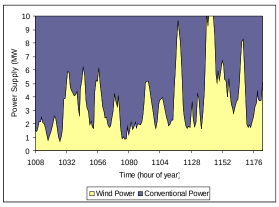
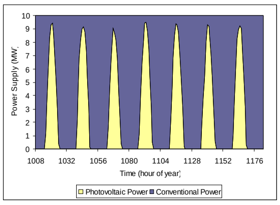
Renewable Power – Continuous Capacity

Wind



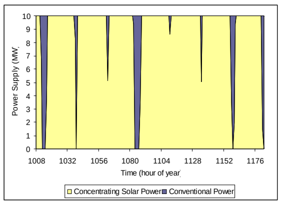
Power supplied by 10 MW wind capacity and conventional backup power from the grid needed to provide constant 10 MW base load supply.

PV



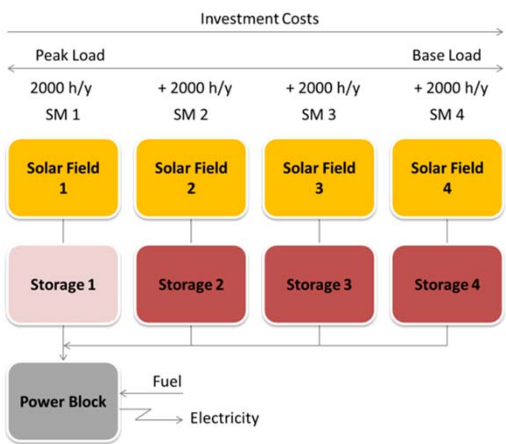
Power supplied by 10 MW PV capacity and conventional backup power from the grid needed to provide constant 10 MW base load supply.

CSP



Solar power provided by a CSP-plant with 16 hour storage and conventional power from fuel from the same plant for constant 10 MW base load supply.

CSP plants can be designed to operate within a certain load segment



Qualities of CSP Plants:

- Operating as peak, medium or base load power plant
- Firm & flexible capacity
- Power on demand
- Spinning reserve
- Combined generation of process heat for industry, cooling, desalination, etc.

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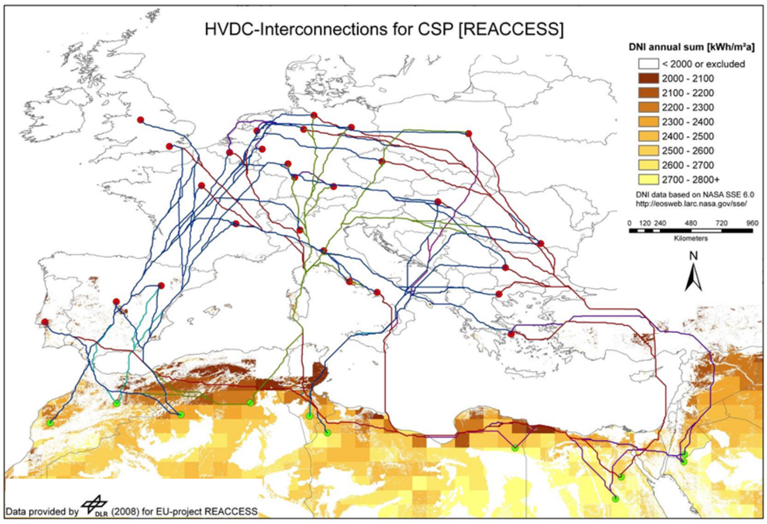
Solar Electricity Corridors – MENA/GCC to Europe



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Projects and Milesstone

- MED-CSP — www.dlr.de/tt/med-csp — 2005
- TRANS-CSP > DESERTEC — www.dlr.de/tt/trans-csp — 2006
- AQUA-CSP — www.dlr.de/tt/aqua-csp — 2007
- MED-CSD — 2008-2010
- **EU GCC Clean Energy Network** — **2010-**
  - “Water And Power: Challenges And Solutions” — 2012
  - **"RES Integration in the Grid“** — **today**
- CSP Finance — 2011
- World Bank MENA Water Outlook — 2011
- IRENA Solar Atlas — 2010-2013
- BETTER — 2012-
  - **B**ringing **E**urope and **T**hird countries closer **T**ogether trough **R**enewable **E**nergies
- QatDLR — 2012-

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Water Desalination using Renewable Energy Sources

Motivation

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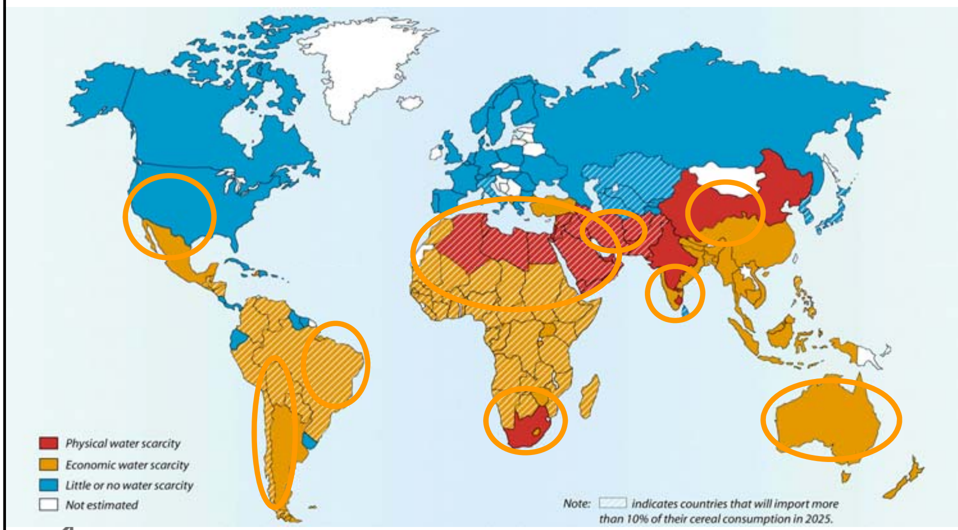
Global Water Scarcity



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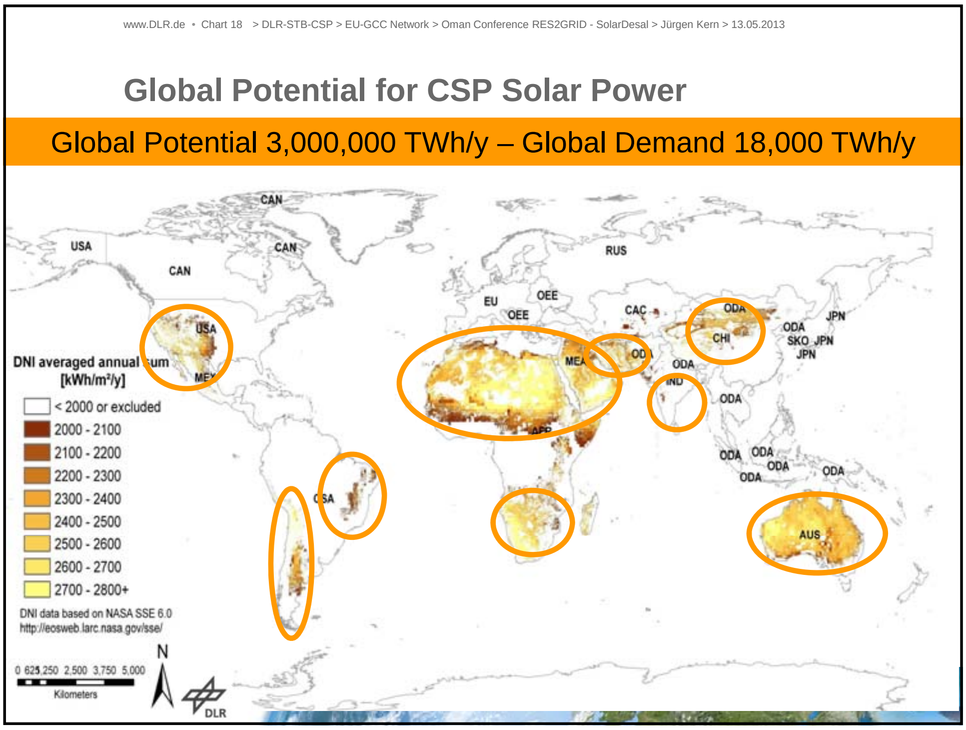

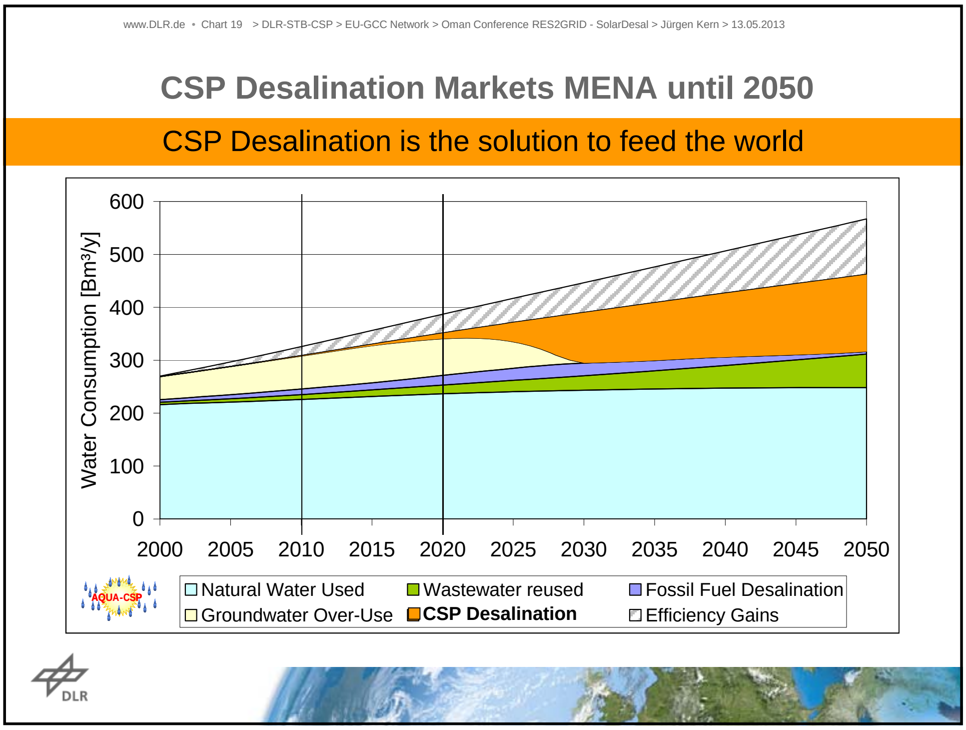

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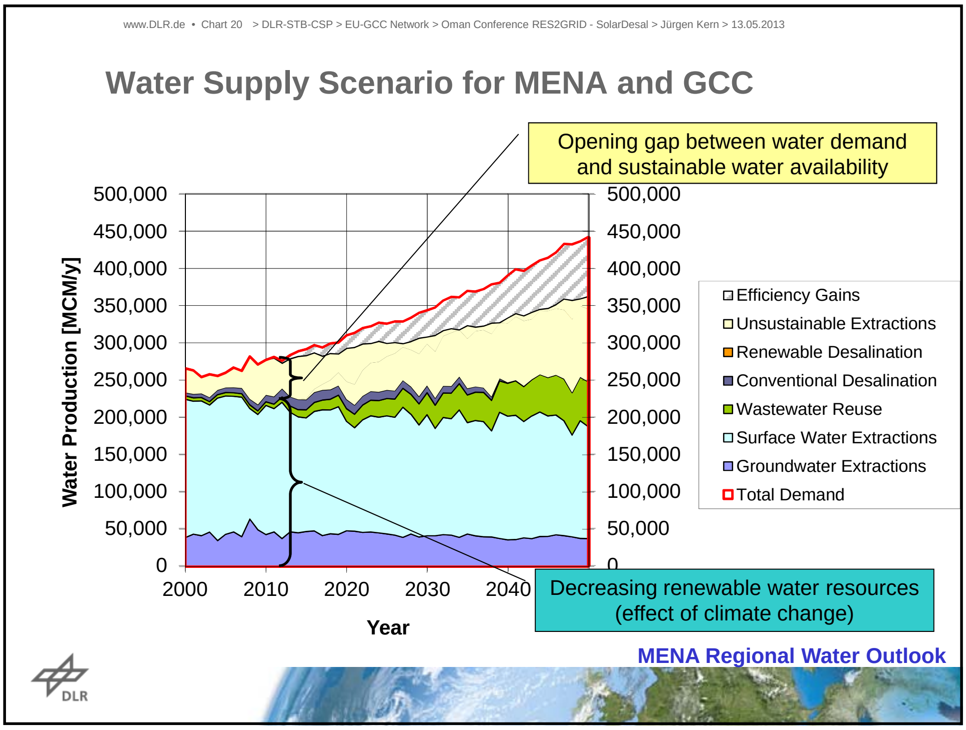

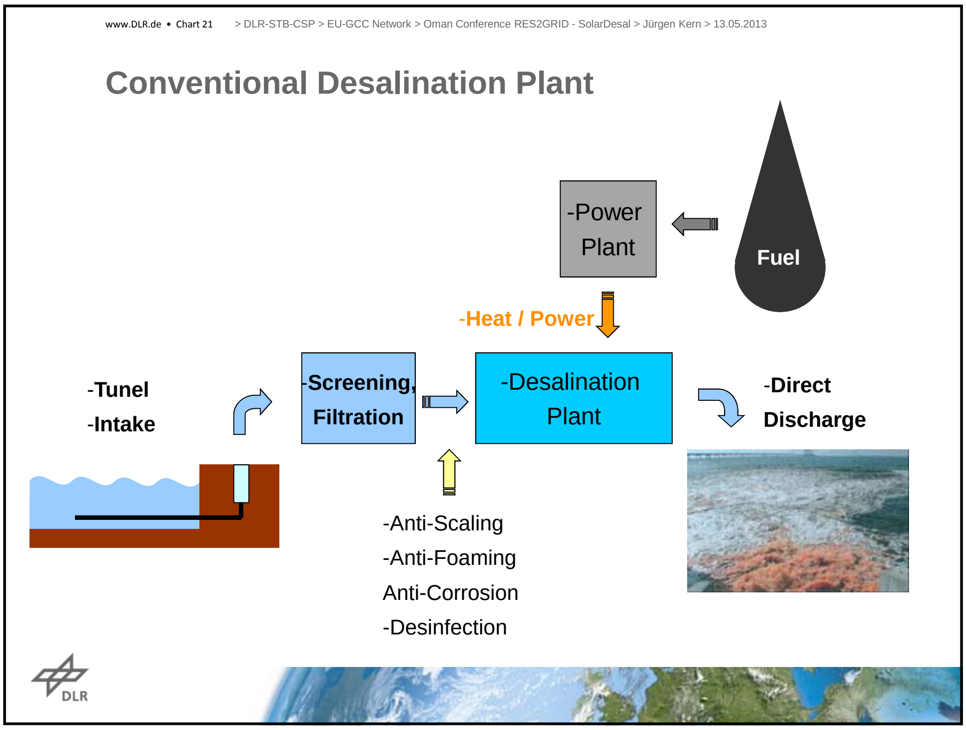

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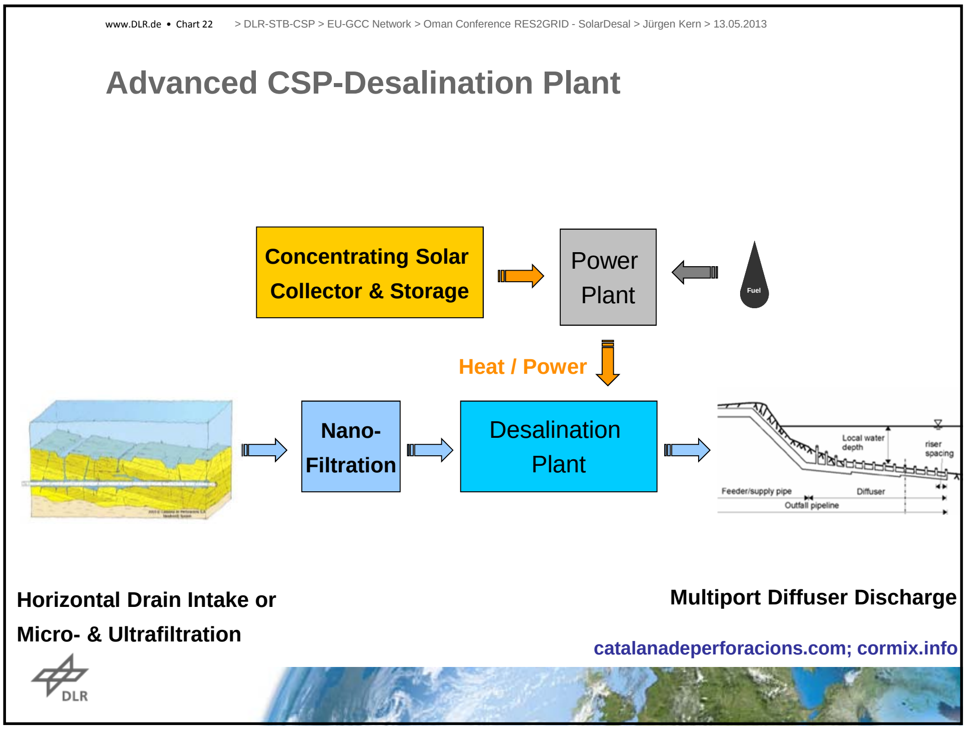

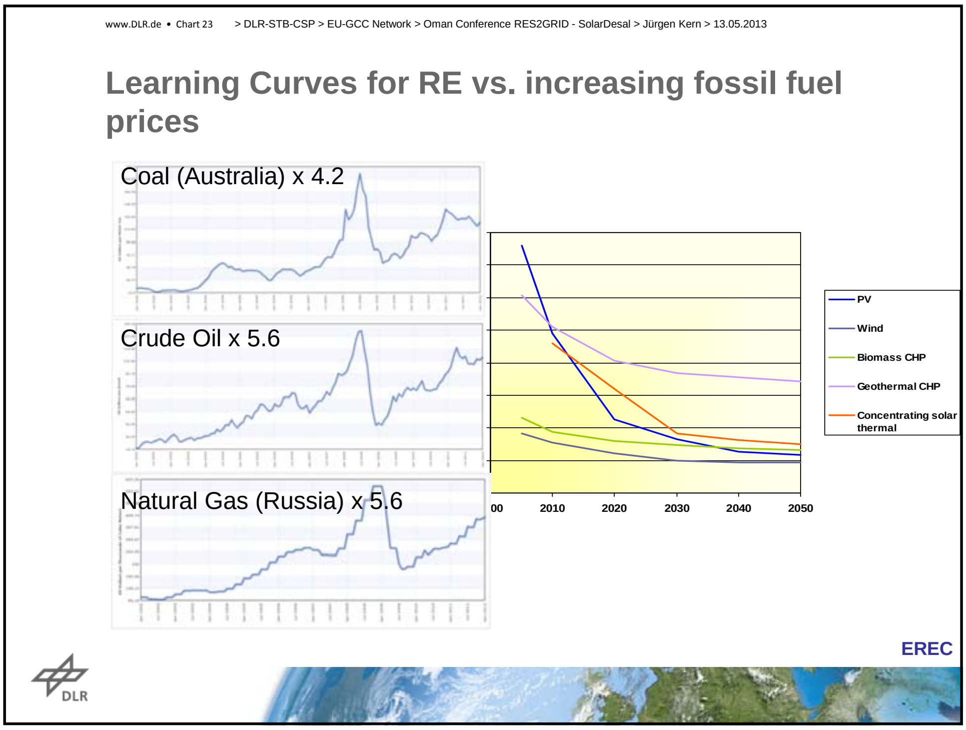

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The MENA Water Outlook Project

- Project supported by the World Bank
- In collaboration with Governments in the MENA Countries
- Objectives:
  - review of desalination potential in combination with CSP
  - development of a water supply scenario for MENA

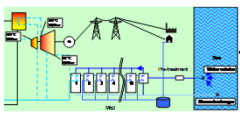
THE WORLD BANK FICHTNER FutureWater DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.

Worldbank MENA Water Outlook - Project structure

Water Demand Model

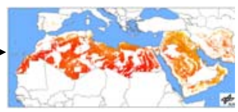
- Climate change models
- Monthly approach for water scarcity calculation
- Result: water deficit per country/ sector in the period 2000 - 2050

Configuration of typical CSP+DES plants



- Different configurations considered
- Result: typical land use

CSP Potential in MENA/GCC



- GIS analysis
- Exclusion map overlay
- Result: Area of suitable areas for CSP+DES plants

Water Supply Scenario for MENA/GCC

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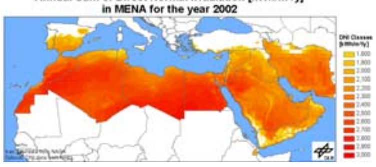
CSP Potential in MENA and GCC

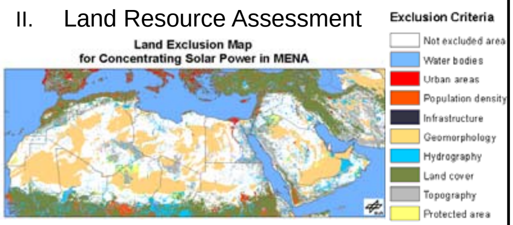
I. Solar Resource Assessment

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



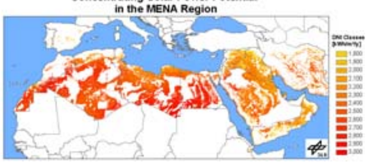
II. Land Resource Assessment

Land Exclusion Map for Concentrating Solar Power in MENA



III. CSP Potential

Concentrating Solar Power Potential in the MENA Region



Conclusions of WorldBank MENA Water Outlook

- **High uncertainty on future water availability!** Unmet water demand of MENA and GCC in 2050 between 85 km³ and 283 km³ (average scenario 199 km³)
- Yearly adaptation cost US$ 103 Billion $€_{2010}$.
- Yemen (11.8%), Iraq (7.5%), Morocco (4.7%), Jordan (4.0%) and Egypt (2.4%) will face the highest cost in relation to the GDP.
- **Almost all countries have enough potential** to develop CSP also on coastal areas
- Start to act now in order to build-up the required industrial capacities. **Political support is required!**

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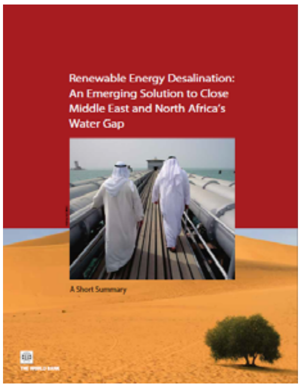
Publications

The World Bank



www.dlr.de/tt/menawater

MENA Regional Water Outlook

Part II
Desalination Using Renewable Energy

FINAL REPORT

Task 1 - Desalination Potential
Task 2 - Energy Requirement
Task 3 - Concentrate Management

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Desalination Technologies

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Reverse Osmosis (RO) Membrane Desalination

membrane stacks and high pressure pumps

Source: Mertes, DME

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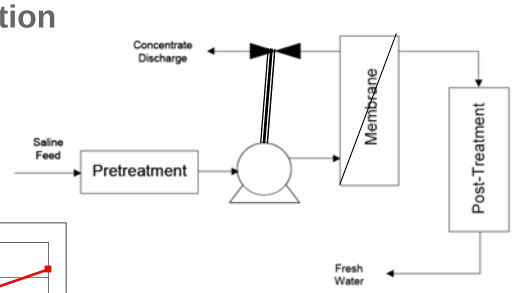
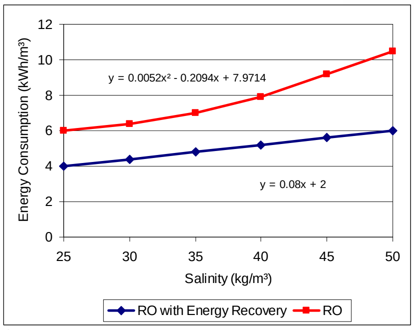
Reverse Osmosis (RO) Membrane Desalination





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SWRO: Key Design Considerations (I)

Operational features

- Large membrane area and narrow flow cross section cause susceptibility to bio-fouling
- Pre-treatment process to be adapted to the seawater conditions
- Seawater salinity and temperature affect the power demand
- No perfect salt rejection – usually a second pass required

Energy

- Electrical energy demand (order of magnitude: 4 kWh/m³)
- Absence of heat demand allows for stand alone configuration
- Method of energy recovery (Pelton turbine, turbocharger or isobaric system)

SWRO: Key Design Considerations (II)

Capacity and plant design

- Plant capacity (current maximum: 500,000 m³/d)
- Modularity allows a high number of process configurations (e.g. train or centre design)

Durability

- Plant availability and service time
- Material selection (e.g. super duplex for high pressure section)

Supplier market

- Major Suppliers: Befesa, Cobra/Tedagua, Degremont (Suez), GE, Hyflux, IDE, OTV (Veolia)

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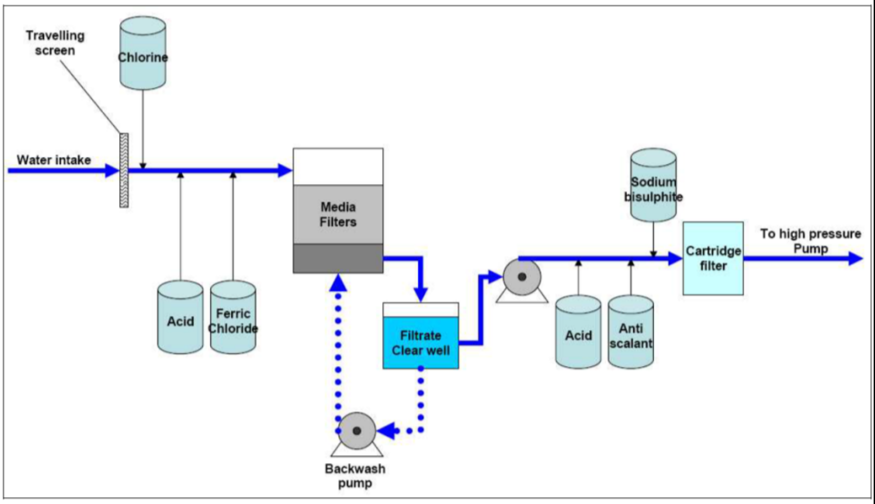
SWRO: Feedwater Treatment



Wilf 200

Multi Stage Flash Desalination (MSF)

Umm Al Nar – Saudi Arabia

87, 000 m³/day

Al Khobar, Saudi Arabia

267,000 m³/day

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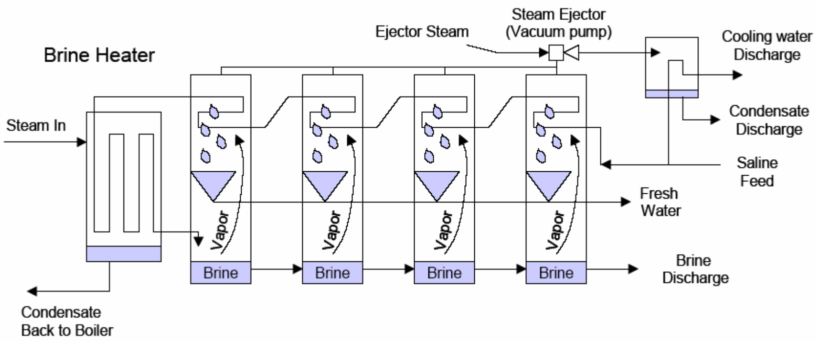
Multi Stage Flash Desalination (MSF)



Stages	20 - 40
Heat	70 - 125 kWh/m³
Power	3 - 5 kWh/m³

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Multi Effect Desalination (MED)

Aquasol - Spain	Abutaraba – Libya	Fujairah II IWPP - UAE

Solar Desalination 1988	VEOLIA / SIDEM 2003	Sidem JV 2009
High Efficiency 14 stages	3 units of 13,333 m³/d	12 units of 38,640 m³/d
Plataforma Solar Almeria	GECOL, Libya	ADWEA , Abu Dhabi

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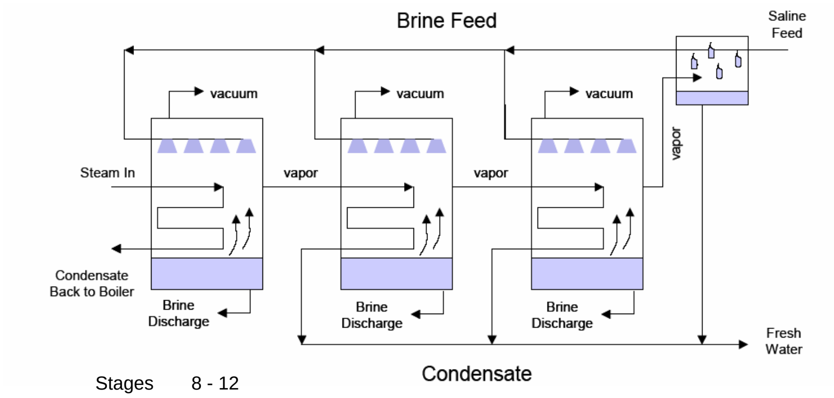
Multi-Effect Distillation (MED)



Stages	8 - 12
Heat	70 - 125 kWh/m³
Power	1 - 2 kWh/m³

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MED: Key Design Considerations (I)

Capacity
- Unit production capacity (current maxium: 38,000 m³/d)
- Number of duty / standby units

Energy demand
- Electrical energy demand (1.5 to 2.5 kWh/m³)
- Heat demand (order of magnitude: 70 kWh/m³)
- Steam demand calls for cogeneration of water and power

Temperature profile
- Temperature of heating steam (upper process temperature)
- Seawater temperature (lower process temperature)
- Number of effects (performance ratio)

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MED: Key Design Considerations (II)

Durability

- Plant availability and service time
- Material selection (e.g. Titanium tubes in top rows and alu brass tubes in below rows)

Operational features

- Robust in regard to seawater salinity and bio-fouling potential
- High distillate quality

Supplier market

- Major MED Suppliers: SIDEM (Veolia); others are following

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Comparison of Desalination Technologies

Technology	Spec. el. Consumption	Steam pressure	Thermal energy	Equivalent power loss	Total energy requirements
	kWh_{el}/m^3	bar	kWh_{th}/m^3	kWh_{el}/m^3	kWh_{el}/m^3
SWRO (Med. Sea)	3.5	-	0	0	3.5
SWRO (Gulf)	4.5	-	0	0	4.5
MSF	4 -5	2.2 – 2.5	80	10 - 20	14 – 25
MED-TVC	1 – 1.5	2.2 – 2.5	80	10 - 20	11 – 21.5
MED	1 – 1.5	0.35 – 0.5	70	3	4 – 4.5

Technology	Advantages	Disadvantages
RO	• For BW or SW applications • Relatively low total energy cons. • Lower CAPEX than MED / MSF • Lower feed water cons. than MED / MSF	• Dependency from pre-treatment effectiveness • More complex operation than MED • Lower product water quality (ca. 200 – 300 ppm for single pass units)
MED	• Also for high saline / bad quality water • High product water quality (< 20 ppm) • Reliability / long operation periods without cleaning • Smaller heat transfer area / better thermal efficiency than MSF • Low spec. electrical consumption	• High investment cost (dependency on steel price fluctuations) • Higher feed water consumption than RO
MSF	• Also for high saline / bad quality water • High product water quality (< 20 ppm) • Reliability / simplicity of operation • Long operation experience • Large units (up to 90,000 m^3/day)	• High investment cost (dependency on steel price fluctuations) • Elevate feed water consumption • High energy consumption

Sommariva 2010

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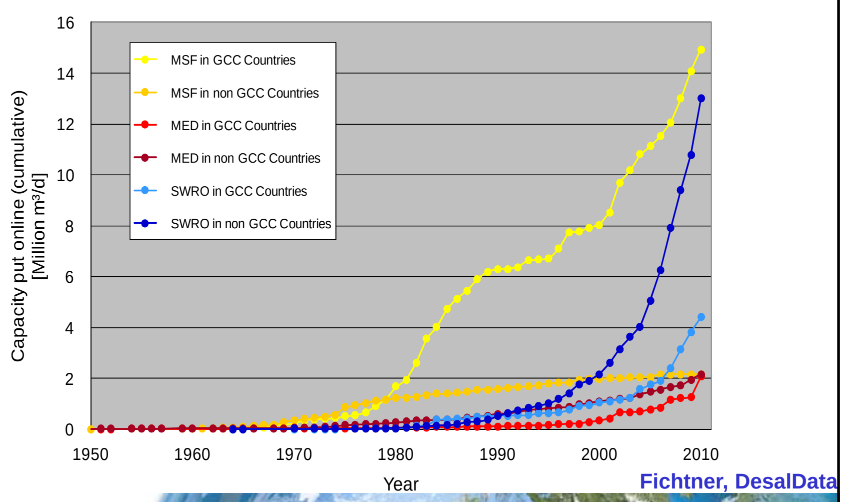
Desalination Markets

Cumulative capacity put online in and outside the GCC countries



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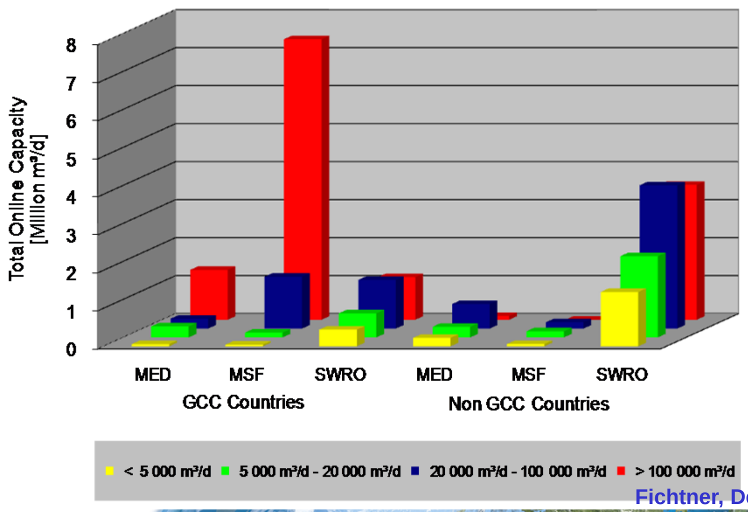
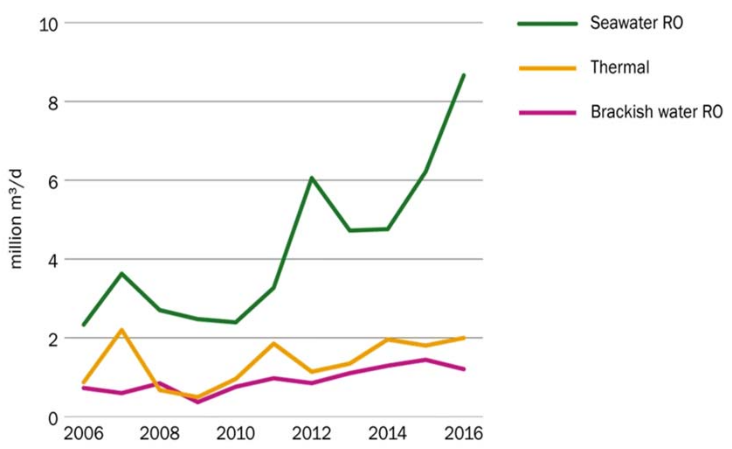
Online Desalination Capacity sorted by technology *and capacity*



Fichtner, DesalData

Forecast Contracted Capacity by Technology (2006-2016)



Fichtner, DesalData

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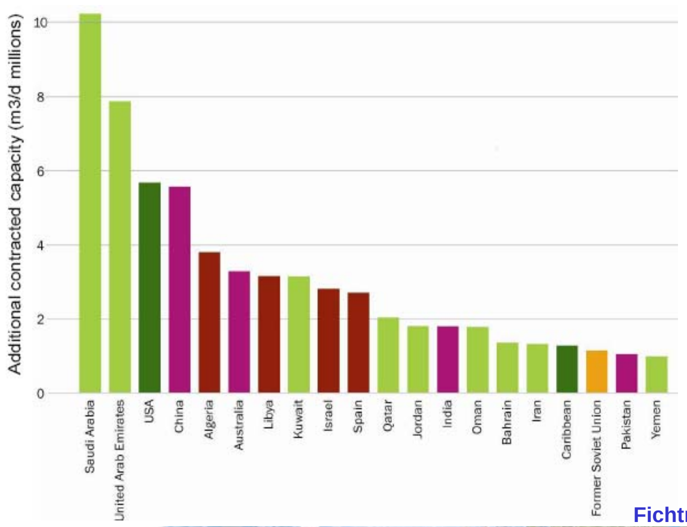
Additional Desalination Capacity (2008-2016)
12 MENA and GCC countries in TOP 20 !



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CSP+D Plants

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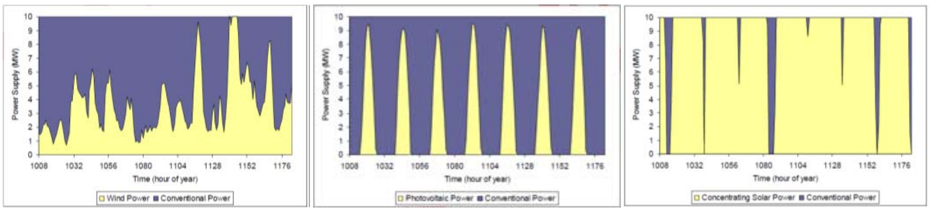
Renewable energies for desalination: why CSP?

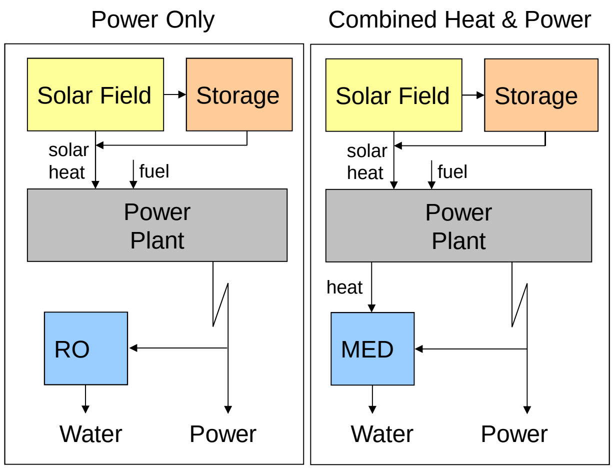


Wind **PV** **CSP**

Desalination plants require continuous operation

- Conflict with the intermittent nature of renewable energies
- CSP offers the option of thermal energy storage
- Hybrid operation is possible in the same power block (no “shadow power plant” required)

CSP-Desalination Plants



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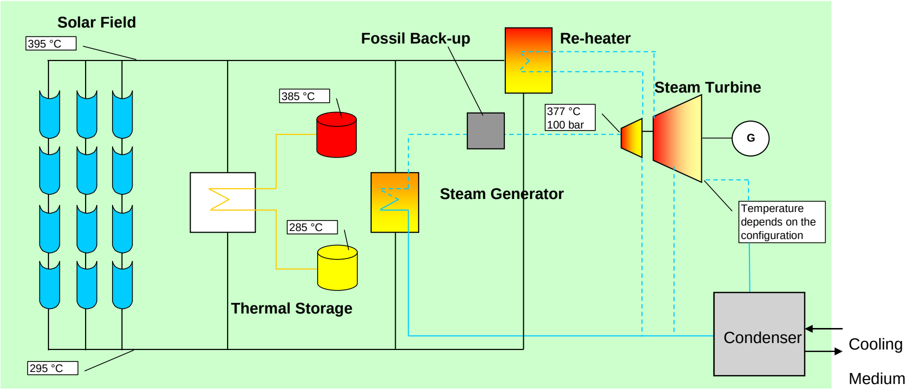
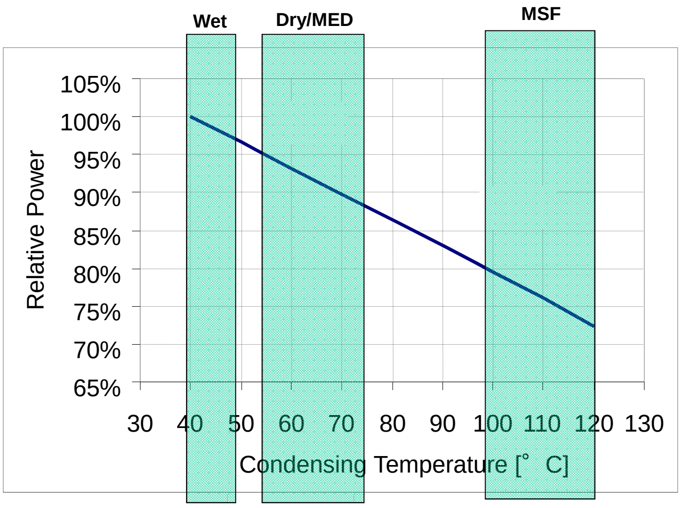
CSP Scheme



www.med-csd-ec.eu

Cooling Systems (Impact on Efficiency)



www.dlr.de/tt/aqua-csp

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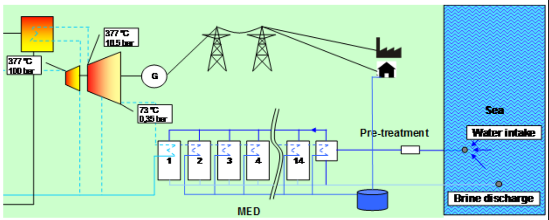
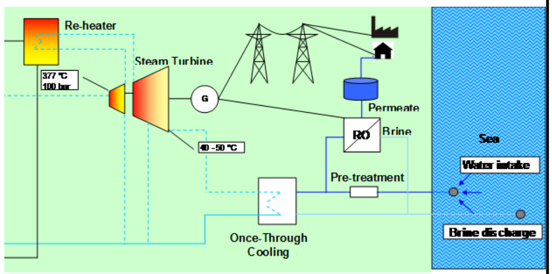
Possible CSP+D Configurations

- 2 desalination technologies:
  - **MED: Multiple-Effect-Distillation**
  - **RO: Reverse Osmosis**
- Desalination: 100,000 m^3/d
- Power: 100 MW_{el}
- Storage: 7.5 h (design)
- Plant operation: base load (8,000 h/y) with fossil fuel back-up
- **Levelized electricity cost: 20 – 24 US$cent/kWh**
- **Levelized water cost: 1.5 – 1.9 US$/$m^3$**





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Comparison of Configurations

System	CSP/MED	CSP/RO
Site Selection	limited to coast	CSP may be anywhere, RO must be at the coast, while the public grid can be used for interconnection
Flexibility	interdependent operation	independent operation possible if plants interconnected through the public grid
Optimal Irradiance	defined by coastal site	CSP can be placed at site with higher irradiance, but certain amount of power is then lost by transmission to RO plant, and dry cooling leads to lower efficiency
Storage Options	molten salt, concrete, low temperature hot water storage possible	molten salt, concrete, phase change materials
Water Quality	independent of raw water quality, very high quality of product water	may be favourable for brackish raw water and if low product water quality is allowed
Other Uses	industrial co-generation of process heat, district cooling, integrated systems for power, cooling, desalination for tourism and rural development	power only

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Water Supply Scenarios

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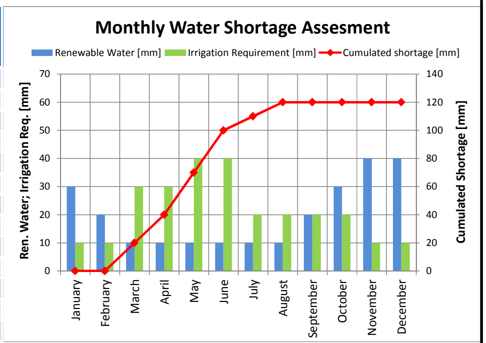
Time-Scale Effect on Water Shortage Calculation

Month	Renewable Water [mm]	Irrigation Requirement [mm]	Cumulated shortage [mm]
January	30	10	0
February	20	10	0
March	10	30	20
April	10	30	40
May	10	40	70
June	10	40	100
July	10	20	110
August	10	20	120
September	20	20	120
October	30	20	120
November	40	10	120
December	40	10	120
TOTAL	**240**	**260**	**120**



FutureWater

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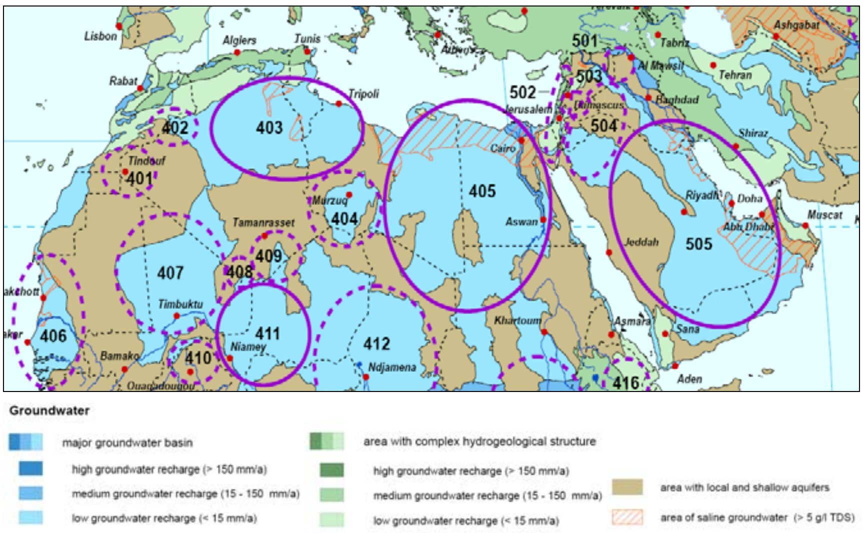
Water Availability

Groundwater in MENA and GCC



BGR 2006

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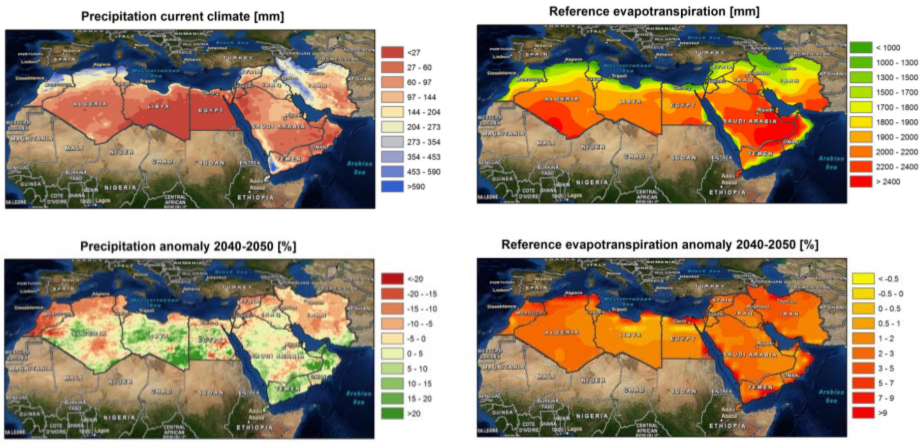
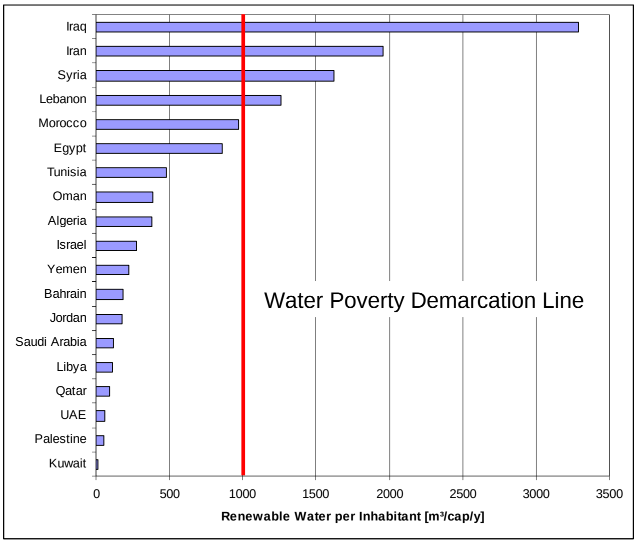
Climate Change in the MENA and GCC Region



FutureWater

Water Availability in MENA and GCC



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Exploitable Renewable Water in MENA and GCC

Renewable and Exploitable Water in MENA	Internal Renewable Groundwater (km³/y)	Internal Renewable Surface Water (km³/y)	Overlap: Surface and Groundwater (km³/y)	Total Renewable Water (actual) (km³/y)	Total Population in 2000 (million)	Total Renewable Water (actual) (m³/cap/y)	Dependency Ratio (%)	Exploitable Water (km³/y)
Morocco	10.0	22.0	3.0	29.0	29.2	993	0	20.0
Algeria	1.4	9.8	0.0	11.6	30.5	380	3	7.9
Tunisia	1.5	3.1	0.4	4.6	9.6	475	9	3.6
Libyan Arab Jamahirija	0.5	0.2	0.1	0.6	5.3	113	0	0.6
Egypt	1.3	0.5	0.0	58.3	67.3	866	97	49.7
North Africa	**14.7**	**35.6**	**3.5**	**104.1**	**141.9**	**733**	**--**	**81.8**
Israel	0.5	0.3	0.0	1.7	6.1	274	55	1.64
Palestine	0.1	0.0	0.0	0.1	3.2	19	18	0.06
Jordan	0.5	0.4	0.2	0.9	5.0	176	23	0.88
Lebanon	3.2	4.1	2.5	4.4	3.4	1297	1	2.19
Syrian Arab Republic	4.2	4.8	2.0	26.3	16.8	1563	80	20.6
Iran, Islamic Rep. of	49.3	97.3	18.1	137.5	66.4	2071	7	137.51
Iraq	1.2	34.0	0.0	75.4	25.1	3005	53	75.42
Western Asia	**59.0**	**140.9**	**22.8**	**246.2**	**126.0**	**1954**	**--**	**238.3**
Oman	1.0	0.9	0.9	1.0	2.4	413	0	0.99
Kuwait	0.0	0.0	0.0	0.0	2.2	9	100	0.02
Qatar	0.1	0.0	0.0	0.1	0.6	83	4	0.05
Saudi Arabia	2.2	2.2	2.0	2.4	21.5	112	0	2.4
United Arab Emirates	0.1	0.2	0.1	0.2	3.2	47	0	0.15
Yemen	1.5	4.0	1.4	4.1	17.9	229	0	4.1
Bahrain	0.0	0.0	0.0	0.1	0.7	171	97	0.12
Arabian Peninsula	**4.8**	**7.3**	**4.4**	**7.8**	**48.5**	**161**	**--**	**7.83**
Total MENA	**78.4**	**183.7**	**30.7**	**358.1**	**316.4**	**1132**	**--**	**328.0**

FAO 2007

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Demand Side Assessment

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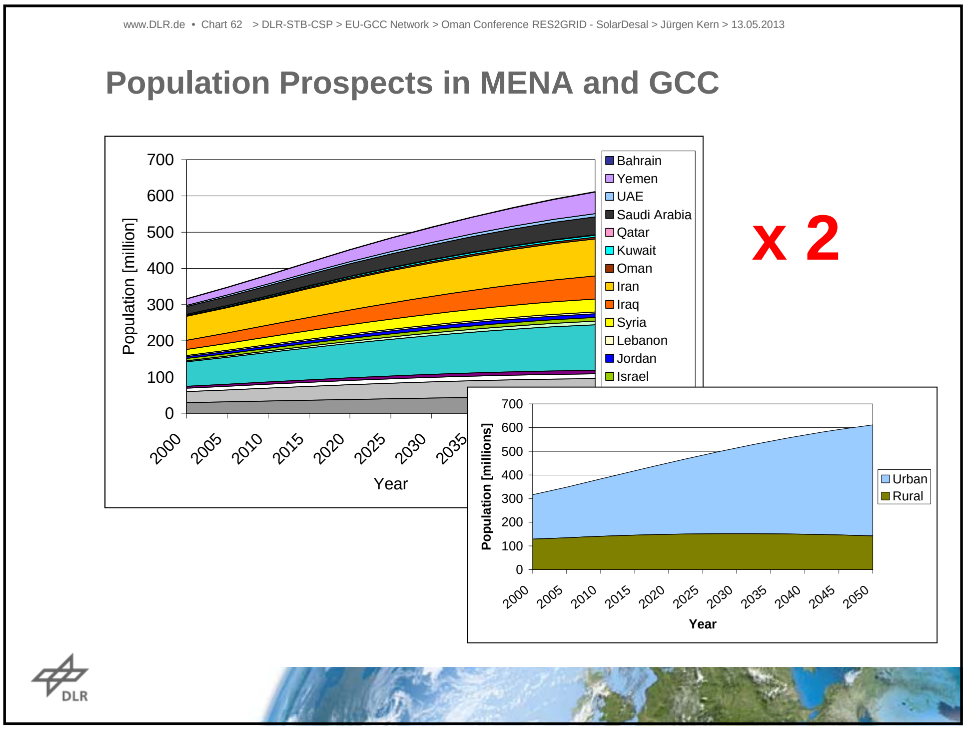

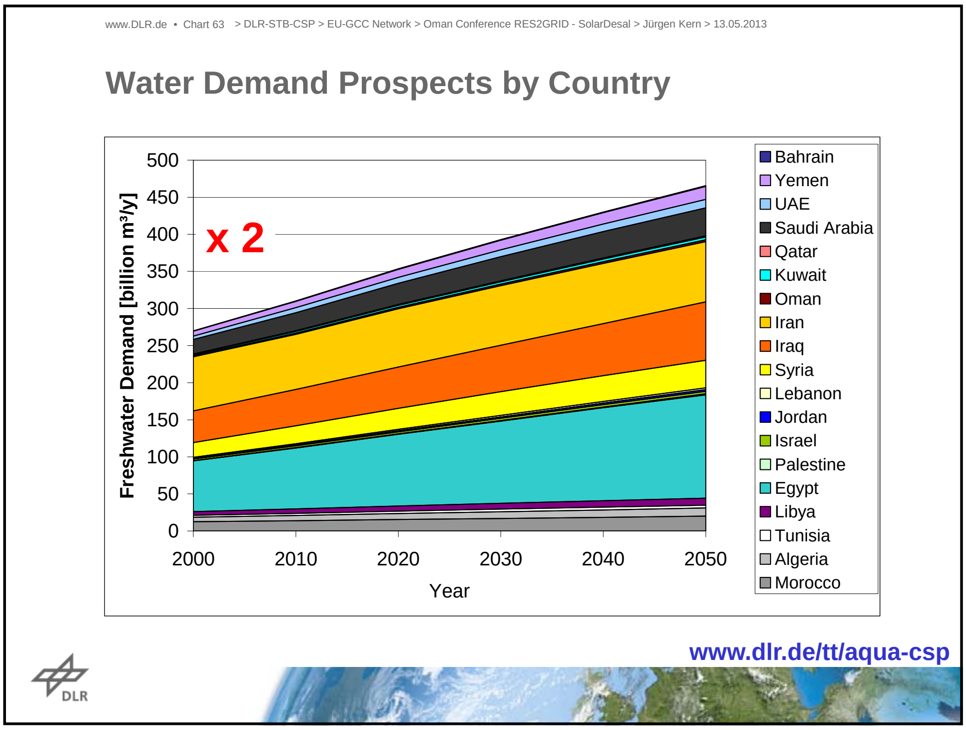

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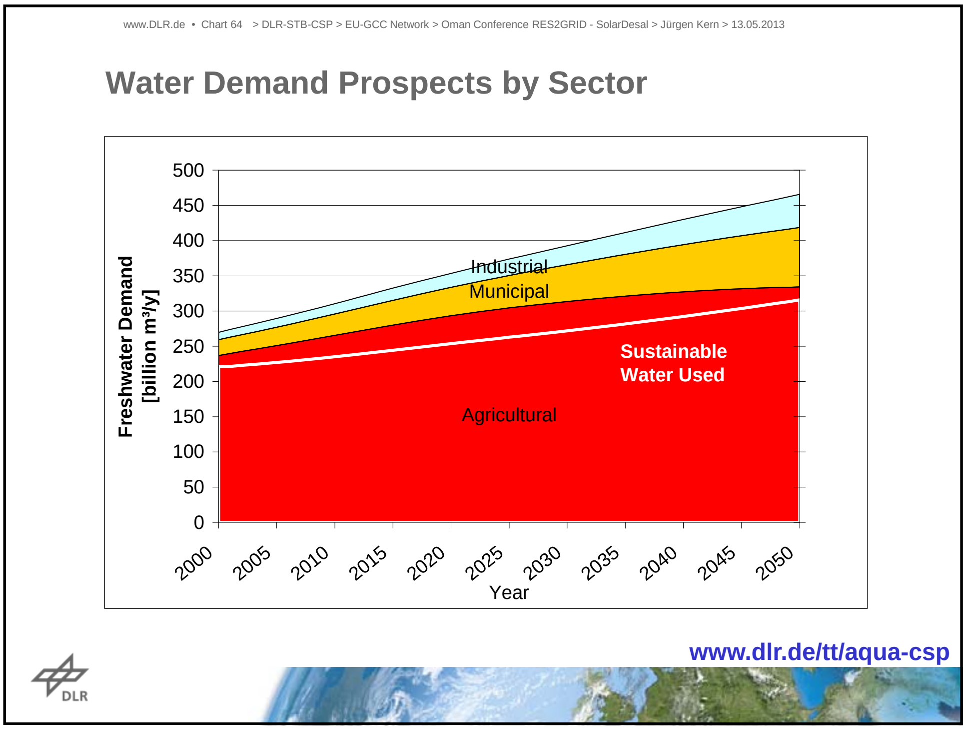

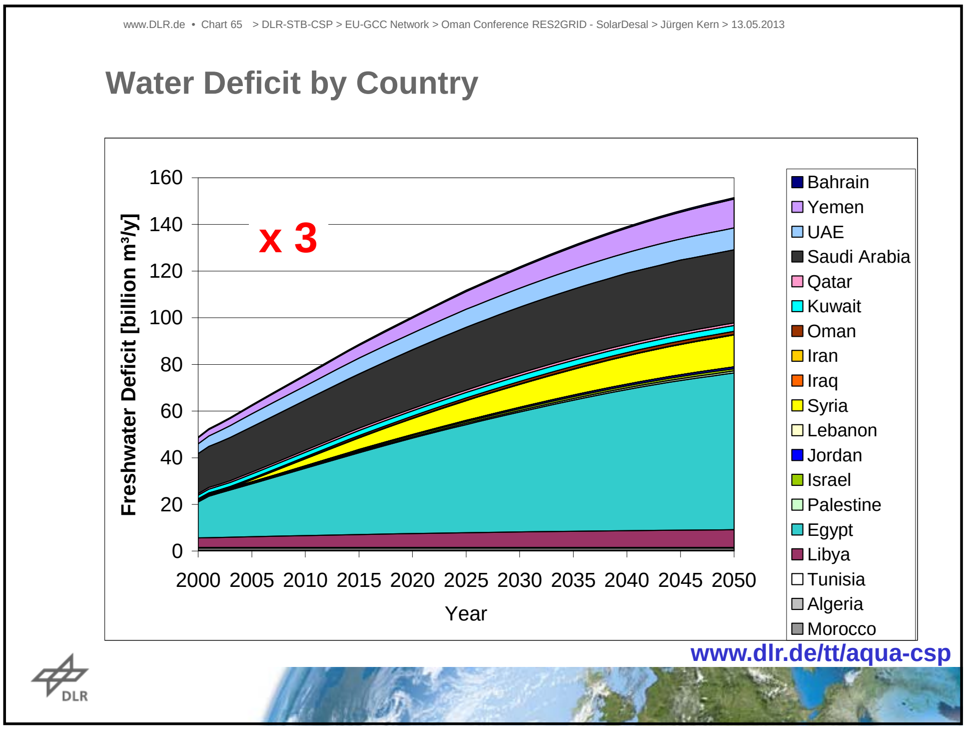

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Conclusions of Water Demand Assessment in MENA

- MENA population will double by 2050
- MENA economies will approximate European level by 2050
- Water demand would grow from 270 Bm³/y in 2000 to 460 Bm³/y in 2050
- Water deficit would increase from 50 Bm³/y in 2000 to 150 Bm³/y in 2050
- Over-use of groundwater is already above 45 Bm³/y
- Extreme efficiency could limit deficit to 100 Bm³/y

➔ Efficiency and new sources will be required to cover water deficits

www.dlr.de/tt/aqua-csp

Options to overcome water shortage

To overcome current and future water shortage countries have a range of options at their disposal

- Increasing the productivity:
  - Improved agricultural practice (including crop varieties)
  - Increased reuse of water from domestic and industry
  - Increased reuse of irrigated agriculture
- Expanding supply:
  - Expanding reservoir capacity (small scale)
  - Expanding reservoir capacity (large scale)
  - Desalination by means of using solar energy
  - Desalination by means of fossil fuel
- Reducing demand:
  - Reduce irrigated areas
  - Reduce domestic and industrial demand

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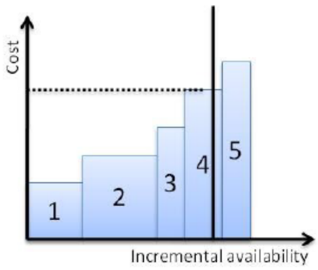
Water Scenario Methodology

- water demand from 2000 to 2050
- total and coastal CSP potential for desalination
- life cycle of old desalination plants opens opportunity for replacement
- top priority for efficiency gains
- second priority for reuse of waste water
- third priority for sustainable surface and ground water extractions
- fourth priority for existing and planned conventional desalination plants
- last priority for CSP desalination after 2015
- no priority for unsustainable water extractions



AQUA-CSP 2007
Regional MENA Water Outlook

Scenario - Results

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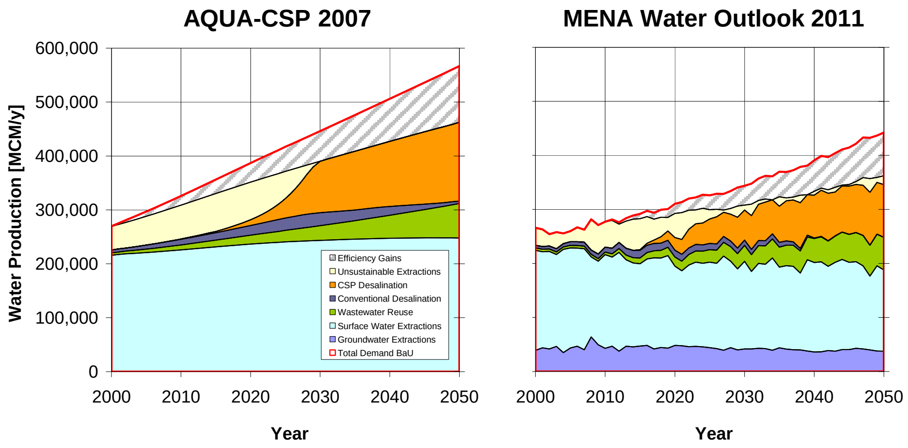
Comparion of Studies 2007-2011



constant per capita water for irrigation reduced

www.dlr.de/tt/menawater

Conclusions of Scenario Analysis

- Sustainable supply must be initiated immediately to avoid groundwater collapse
- Increase efficiency of water production, distribution, end-use and management
- Increase re-use of waste water
- Start introduction and dissemination of CSP-desalination plants
- Over-use of groundwater will still increase from 45 Bm³/y to 70 Bm³/y in 2020
- Conventional desalination will grow by a factor of 5

➔ All measures should be taken to avoid groundwater collapse

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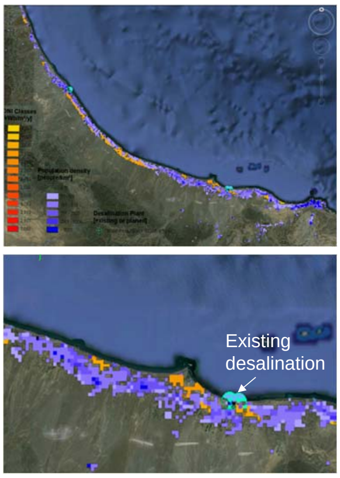
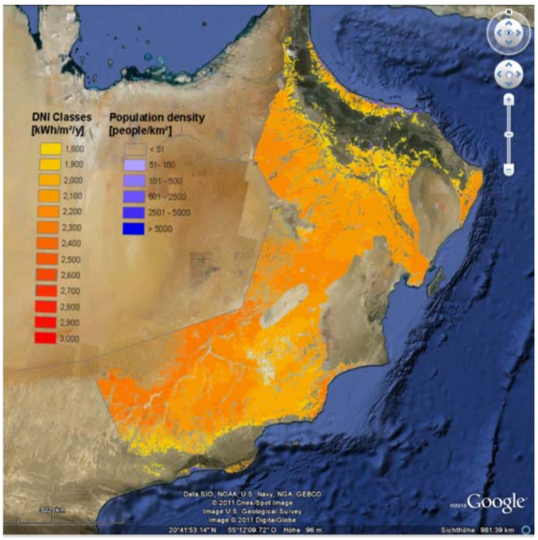
RO or MED Desalination? Assessing Coastal Potentials





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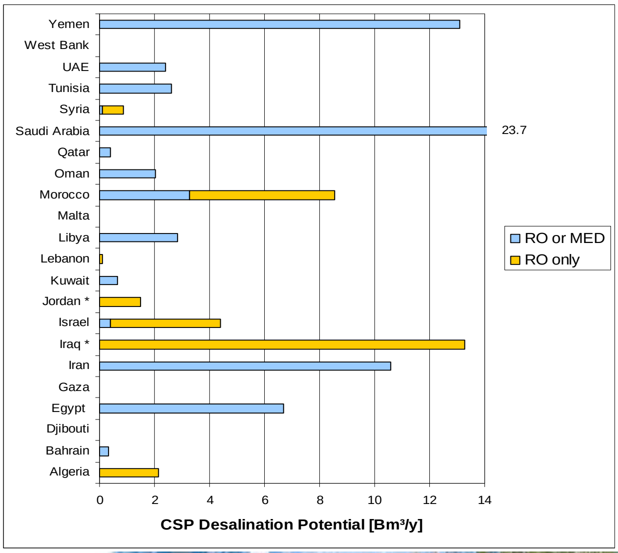
CSP Desalination Potential – RO or/and MED ?



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Results of Water Scenarios: RO or MED?

	Total CSP Potential TWh/y	CSP Demand 2050 TWh/y	Coastal CSP Potential TWh/y	CSP-SWD Demand 2050 TWh/y	Power Demand kWh/m³	RO only Supply 2050 BCM/y	RO or MED Supply 2050 BCM/y	CSP-SWD Demand 2050 BCM/y	Total Water Demand 2050 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

Conclusions

- Large scale conventional seawater desalination would create significant environmental impacts
- CSP can reduce energy related emissions to few percent
- Beachwell or horizontal drain intake and nano-filtration can reduce additives
- Horizontal drain intake can reduce impingement and entrainment and horizontal drain discharge can avoid concentration of heat and salt

➔ Advanced CSP seawater desalination can be compatible with the environment

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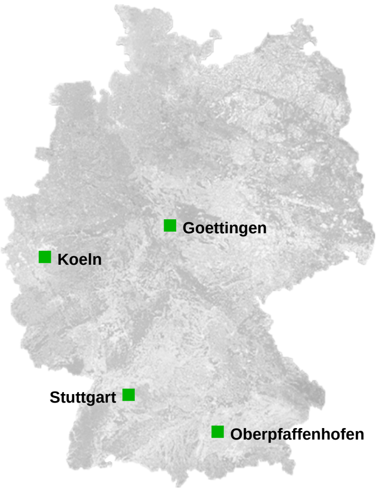
Institutes and Facilities Involved in Energy

- Goettingen
  Institute of Aerodynamics and Flow Technology
- Cologne
  Institutes of Propulsion Technology, **Solar Research** and Materials Research
- Stuttgart
  Institutes of Technical Thermodynamics and Combustion Technology
- Oberpfaffenhofen
  Institute of Communications and Navigation
- Almería (Spain)
  Permanent team from the Institute of Solar Research at the Plataforma Solar de Almería (PSA)



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Size of site: 25,860 m²
Research institutes:

- Institute of Structures and Design
- Institute of Vehicle Concepts
- Institute of Technical Physics
- **Institute of Technical Thermodynamics** www.dlr.de/tt
- Institute of Combustion Technology

"EU-GCC Clean Energy Network Conference "RES Integration in the grid" 15th-16th May, Muscat, Oman, Crown Plaza Hotel

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Selected publications

- MED-CSP www.dlr.de/tt/med-csp
- TRANS-CSP www.dlr.de/tt/trans-csp
- AQUA-CSP www.dlr.de/tt/aqua-csp
- MED-CSD www.med-csd-ec.eu/eng/
- MENA Regional Water Outlook www.dlr.de/tt/menawater
- Financing concentrating solar power in the Middle East and North Africa – Subsidy or investments? Energy Policy 39 (2011) 307-317 http://dx.doi.org/10.1016/j.enpol.2010.09.045
- Solar electricity imports from Middle East and North Africa to Europe Energy Policy 42 (2012) 341-353 http://dx.doi.org/10.1016/j.enpol.2011.11.091

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