The 3rd International Conference on Water Resources and Arid Environments (2008)
and the 1st Arab Water Forum

Concentrating Solar Power for Seawater Desalination – AQUA-CSP

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Abstract

The countries of the Middle East and North Africa (MENA) have an outstanding potential for solar energy. Using concentrating solar thermal power (CSP) plants to power desalination plants either by solar electricity or in combined generation by solar steam to solve the water scarcity problem in MENA is an obvious approach. The AQUA-CSP study sponsored by the German Federal Ministry for the Environment quantifies the potential of this technology in MENA and the socio-economic and environmental impacts implied by a large scale dissemination in order to provide a reliable data base for decision and policy makers in the water sector and to facilitate the inclusion of this approach in national expansion plans. We present a long-term scenario for the demand of freshwater in the MENA region and show how it can be covered by a better use of the existing renewable water sources and by sea water desalination powered with solar energy. The presentation shows how sustainable energy sources for desalination can be assessed by remote sensing and geographic information systems (GIS). Growth of population and economy, increasing urbanization and industrialization, and the rather limited natural resources of potable water in MENA are leading to serious deficits of freshwater in many parts of MENA. Modern infrastructure for water distribution, enhanced efficiency of use and better water management are to be established as soon as possible. However, even the change to best practice efficiencies would leave considerable deficits, which are poorly covered by over-exploiting groundwater resources. Increased use of desalted seawater is therefore unavoidable in order to maintain a reasonable level of water supply. Concentrating solar power offers a sustainable solution for large scale sea-water desalination.

Keywords: Solar Seawater Desalination, Middle East, North Africa

Introduction

"Solar desalination" is commonly perceived as small scale option for decentralised water supply in remote places, an important option for the development of rural areas, but no solution for the increasing water deficits of the quickly growing urban centres of demand. Large scale conventional seawater desalination is on the other hand perceived as expensive, energy consuming and limited to rich countries in view of a quickly escalating cost of oil, natural gas and coal.

Environmental impacts of large scale desalination are increasing with growing capacities, on one side in form of airborne emissions from energy consumption and on the other side from the discharge of brine and chemical additives to the sea. Contemporary strategies for sustainable water consider seawater desalination only as a marginal element of supply. The focus of most recommendations lies on the efficient use of water, better accountability, re-use of waste water, enhanced distribution and advanced irrigation systems. To this adds the recommendation to reduce agriculture and rather import food from places where water is abundant. Sources that do recommend seawater desalination as part of a solution to the water crisis usually propose nuclear fission or fusion as indispensable option.

None of the presently discussed strategies include concentrating solar power (CSP) for seawater desalination within the portfolio of possible alternatives. However, quickly growing population and water demand and quickly depleting groundwater resources in the arid regions of the world require solutions that are affordable, secure and compatible with the environment – in one word: sustainable. Such solutions must be able to cope with the magnitude of the demand and must be based on available or at least demonstrated technology, as strategies bound to uncertain technical breakthroughs – if not achieved in time – would seriously endanger the prosperity of the affected regions.

Among all available energy sources, solar energy is the one that correlates best with the demand for water, because it obviously is the main cause of water scarcity. The resource-potential of concentrating solar power is several hundred times larger than global energy demand. The environmental impact of its use was assessed in the AQUA-CSP study and has been found to be acceptable, as it is based on abundant, recyclable materials like steel, concrete and glass for the concentrating solar thermal collectors. The cost of heat from concentrating solar collector fields at optimal sites is today equivalent to about 50 US$ per barrel of fuel oil (8.8 US$/GJ), and coming down by 10-15 % each time the world wide installed CSP-capacity doubles. In the medium-term by 2020, a cost equivalent to about 20 US$ per barrel (3.5 US$/GJ) can be achieved. In the long-term, it can become one of the cheapest sources of energy, at a level as low as 15 US$ per barrel of oil (2.5 US$/GJ)[1]. Lately, increasing steel prices have slightly slowed down the speed of cost reductions, but trends remain. Due to their thermal energy storage capability CSP plants can deliver solar energy during night-time for the continuous operation of

[1] In constant monetary value 2005, inflation must be considered to obtain nominal values

desalination plants, and are therefore a “natural” resource for seawater desalination.

In the first part of this paper the technical options of combining concentrating solar power stations with seawater desalination and the existing solar energy potentials are described. In the second part the present and future demand for water is analysed for the MENA region and present and future deficits are quantified. Next, a scenario for sustainable supply of freshwater is developed starting in the year 2000 and reaching until 2050. Finally, the socio-economic and environmental impacts of such a scenario and the barriers for its implementation are discussed.

Concentrating Solar Power for Electricity and Desalination

Concentrating solar thermal power (CSP) plants are based on the concept of concentrating solar radiation to provide high-temperature heat for electricity generation within conventional power cycles based on steam turbines, gas turbines or combustion engines (Figure 1). For concentration, those systems use glass mirrors that continuously track the position of the sun. The sunlight is focused on specially designed receivers were it is converted to heat. A fluid flowing through the receivers takes the heat away towards a thermal power cycle, where e.g. high pressure, high temperature steam is generated to drive a turbine. Air, water, oil and molten salt can be used as heat transfer fluids /Müller-Steinhagen and Pitz-Paal 2006/.

Power cycles can be operated with fossil fuel as well as with solar energy. Hybrid operation increases the value of electricity by increasing power availability and by reducing costs, making more effective use of the power block. Solar heat collected during the daytime can be stored in concrete, molten salt, ceramics or phase-change media. At night, it can be extracted from the storage to run the power block. Fossil fuels like oil, gas, coal and renewable fuels like biomass can be used for co-firing the plant, thus providing power capacity whenever required. This is a very important feature for the coupling with desalination processes, as they usually prefer steady-state operation and are not very easily operated with fluctuating energy input.

Three different technical options to combine CSP and desalination are shown in Figure 2: small-scale decentralised thermal desalination plants directly heated by concentrating solar thermal collectors, large scale concentrating solar power stations providing electricity for reverse osmosis membrane desalination (CSP/RO), and combined generation of electricity and heat for thermal multi-effect desalination systems (CSP/MED). Multi-Stage Flash (MSF) desalination, although at present providing the core of desalted water in the MENA region, has not been considered as recommendable future option for solar powered desalination, due to its low energy efficiency. Nevertheless, CSP may be an option for upgrading existing MSF plants in order to enhance their performance.

Future CSP/RO and CSP/MED systems with 24,000 cubic metres per day of desalting capacity and 21 MW net electricity to consumers can achieve base-load operation with less than 5 % of the fuel consumption of conventional plants, at a cost of water that may be well below 0.50 $/m^3$ /AQUA-CSP 2007/. Annual hourly time-step simulation for both plant types was made for seven different sites in the MENA region from the Atlantic Ocean to the Gulf Region showed an acceptable technical and economic performance.

In terms of environmental impact, concentrating solar power can avoid the airborne emissions stemming from energy supply that are considerable for conventional desalination plants. In advanced future RO and MED plants, chemical residues in the effluents could be effectively substituted by seabed- and nano-filtration of the intake water, making obsolete most of biocides, antifouling and anti-corrosion agents added today to the desalination processes. The additional energy required for filtration could be easily provided by the huge solar energy resource available in the Middle East and North African countries.

Figure 1: Mainstream concentrating solar power solar field technologies for the production of high-temperature solar heat for power generation and seawater desalination via thermodynamic cycles and process steam: parabolic trough concentrating solar thermal collector (top left), heliostat field in front of a solar central receiver tower (upper right), parabolic trough field around a steam cycle plant with night-time energy storage (bottom left), linear Fresnel collector (bottom right). Sources: Schott AG, PSA, ACS Cobra, MAN/SPG

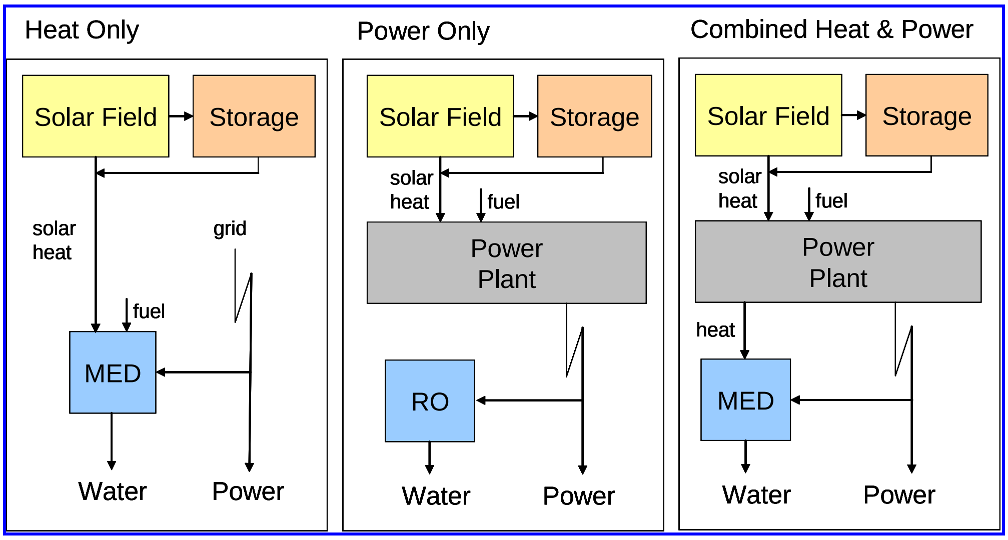

Figure 2: Different configurations for desalination by concentrating solar power. Left: Concentrating solar collector field with thermal energy storage directly producing heat for thermal multi-effect desalination. Center: Power generation for reverse osmosis (CSP/RO). Right: Combined generation of electricity and heat for multi-effect desalination (CSP/MED).

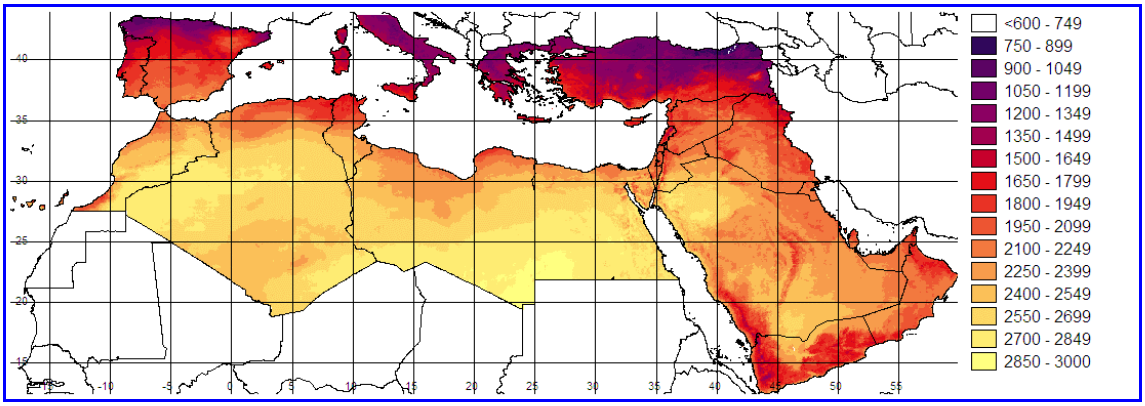

Figure 3: Solar energy atlas for Southern Europe, the Middle East and North Africa, showing the annual sum of direct normal irradiance (DNI) in kWh/m²/y. DNI is defined as the direct solar irradiance perpendicular to a surface that continuously tracks the sun /MED-CSP 2005/.

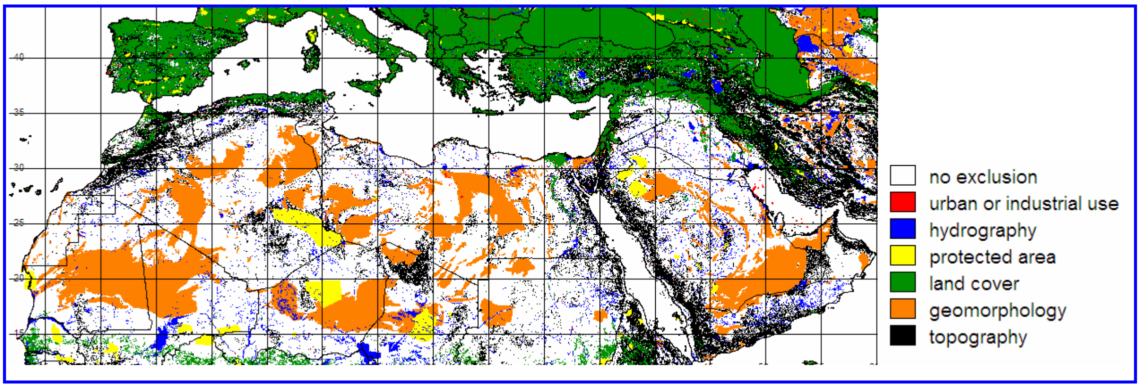

Figure 4: Exclusion of areas that are not suited for the placement of CSP plants by a geographic information system using different land characteristics as exclusion criteria. The remaining CSP electricity potential of each country has been assessed in /MED-CSP 2005/.

While freshwater is rather scarce in the MENA region, the cause of this scarcity – solar energy – is very abundant (Figure 3). From each square kilometre of desert land, about 250 GWh of electricity[1] can be harvested every year using concentrating solar thermal power technology. This is over 200 times more than can be produced per square kilometre by biomass or 5 times more than can be generated by the best available wind and hydropower sites world wide. Each year, each square kilometre of land in MENA receives an amount of solar energy that is equivalent to 1.5 million barrels of crude oil[2]. A concentrating solar thermal power plant of the size of Lake Nasser in Egypt (Aswan) would harvest energy equivalent to the present Middle East oil production[3]. After excluding all areas that are not suited for the placement of CSP plants (Figure 4), the remaining total CSP electricity potential in the MENA region still amounts to 630,000 TWh per year (note: world electricity demand is 18,500 TWh/year). A CSP plant covering one square kilometre of desert land will deliver enough energy to desalinate an average of 165,000 cubic metres of seawater per day over the whole year, which is equivalent to a major contemporary desalination unit[4].

Water Demand and Water Deficits

To date only four MENA countries have renewable freshwater resources that are well above the threshold of 1000 cubic metres per capita and per year that is commonly considered as demarcation line of water poverty /World Bank 2007/. With a population expected to be doubling until 2050, the MENA region will be facing a serious water crisis, if it remains relying only on the available natural renewable freshwater resources.

Internal renewable freshwater resources are generated by endogenous precipitation that feeds surface flow of rivers and recharge of groundwater. External sources from rivers and groundwater from outside a country can also

[1] Solar irradiance 2400 kWh/m^2/y * 11 % Annual Solar-Electric Net Efficiency * 95 % Land Use (Linear Fresnel)

[2] Solar irradiance 2400 kWh/m^2/y x 1 million m^2/km^2 : 1600 kWh/bbl heating value = 1.5 million bbl/km^2/y

[3] Lake Nasser has 6000 km^2 x 1.5 million bbl/km^2/y = 9 billion bbl/y = Middle East oil production

[4] Solar irradiance 2400 kWh/m^2/y x 11 % CSP efficiency * 95 % Land Use : 4.2 kWh/m^3 RO power con sumption : 365 days/y = 0.165 m^3/m^2/day x 1 million m^2/km^2 = 165,000 m^3/km^2/day

have major shares as e.g. the Nile flowing into Egypt. The exploitable share of those water resources may be limited by very difficult access or by environmental constraints that enforce their protection.

Non-renewable sources like the large fossil groundwater reservoirs beneath the Sahara desert can also be partially exploited, if a reasonable time-span to serve several generations (e.g. 500 years) is assured. Additional measures like re-use of waste water, advanced irrigation, better management and accountability, improved distribution systems and new, unconventional sources of water will be imperative to avoid a foreseeable collapse of water supply in the MENA region.

Figure 5 and Figure 6 provide a long-term scenario of freshwater demand for all MENA countries and quantifies the increasing gap opening between natural renewable reserves and water demand. Freshwater demand was calculated as function of a growing population and economy starting in the year 2000 and taking into consideration different driving forces for industrial and municipal demand on one site and for agriculture on the other site, that yield a steadily growing freshwater demand until 2050 in all MENA countries. Individual data for each country can be found in the annex of the AQUA-CSP report at the internet www.dlr.de/tt/aqua-csp.

Today, agriculture is responsible for 85 % of the freshwater consumption in MENA, a number that is expected to change to 65 % by 2050, because the industrial and municipal sectors will gain increasing importance. In our AQUA-CSP reference scenario, the total water consumption of the MENA region will grow from 270 billion cubic metres per year in the year 2000 to about 460 billion cubic metres per year in 2050. Water deficits that are presently covered by over-exploitation of groundwater and – to a lesser extent – by fossil-fuelled desalination, would increase from 50 billion cubic metres per year to 150 billion cubic metres per year, which would equal about twice the physical volume of the Nile River. These numbers are based on a scenario that already considers significant enhancement of efficiency of end-use, management and distribution of water, advanced irrigation systems and re-use of waste-water (Figure 7).

In a business-as-usual-scenario following present policies with less emphasis on efficiency, consumption would grow much further to 570 billion cubic metres per year in 2050. This would result in a deficit of 235 billion cubic metres per year that would put an extraordinary – and unbearable – load on the MENA groundwater resources. On the other hand, a scenario built on extreme advances in efficiency and re-use of water would lead to a demand of 390 billion cubic metres per year, but would still yield a deficit of 100 billion cubic metres per year, which could only be covered by new, unconventional sources. The results of our demand side assessment have been compared to several investigations from literature, that unfortunately did not cover all countries and water supply sectors of the MENA region, and that did not look beyond the year 2030. However, the time span and sectors that could be compared show a fairly good co-incidence with our results /AQUA-CSP 2007/.

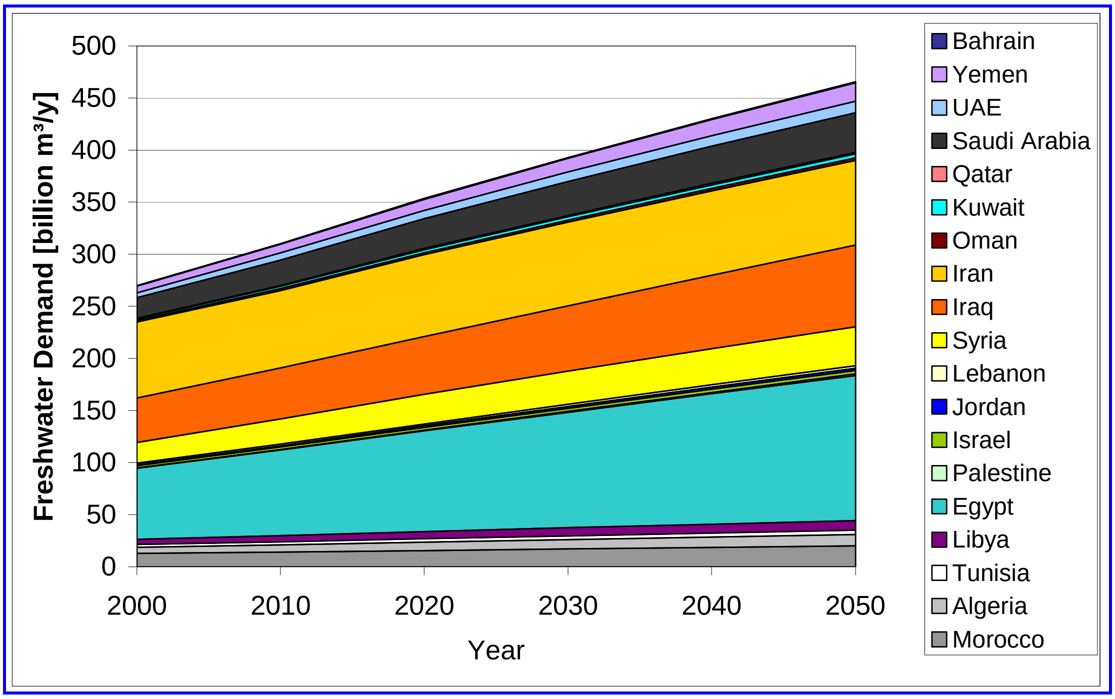

Figure 5: Water demand and deficit: results of the model calculation with minimum (top), reference (centre) and maximum (bottom) measures to increase the efficiency of water use, water distribution and irrigation and the re-use of waste-water for all MENA countries.

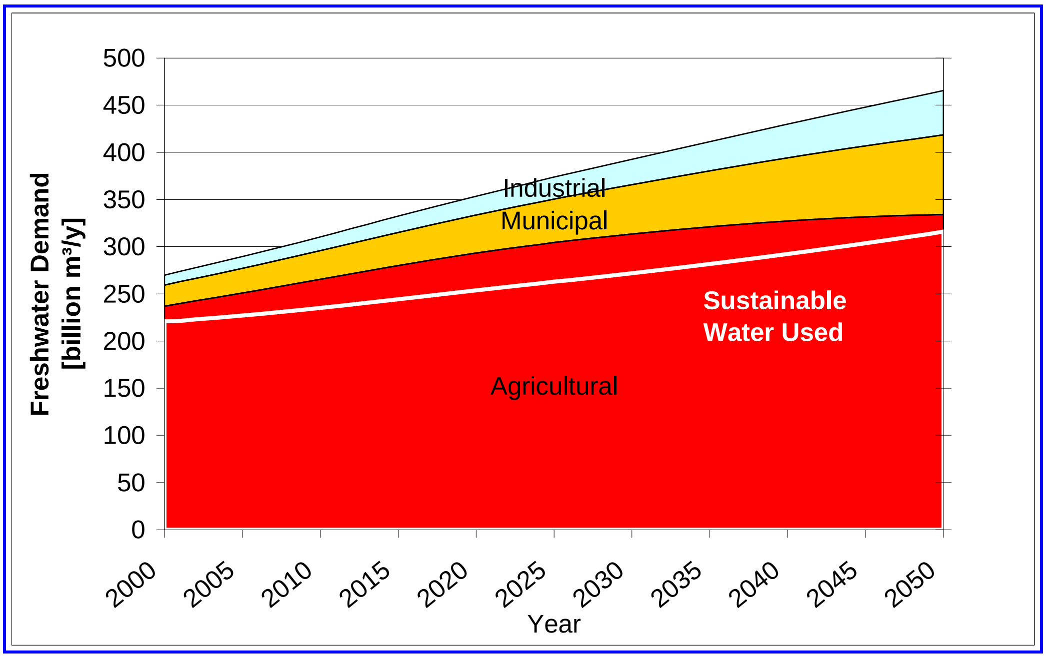

Figure 6: Industrial, municipal and agricultural freshwater demand in MENA in comparison to sustainable used freshwater resources of the region (white line). The increase of de-facto used sustainable water is due to enhanced re-use of wastewater and to resources in some countries remaining untapped until now.

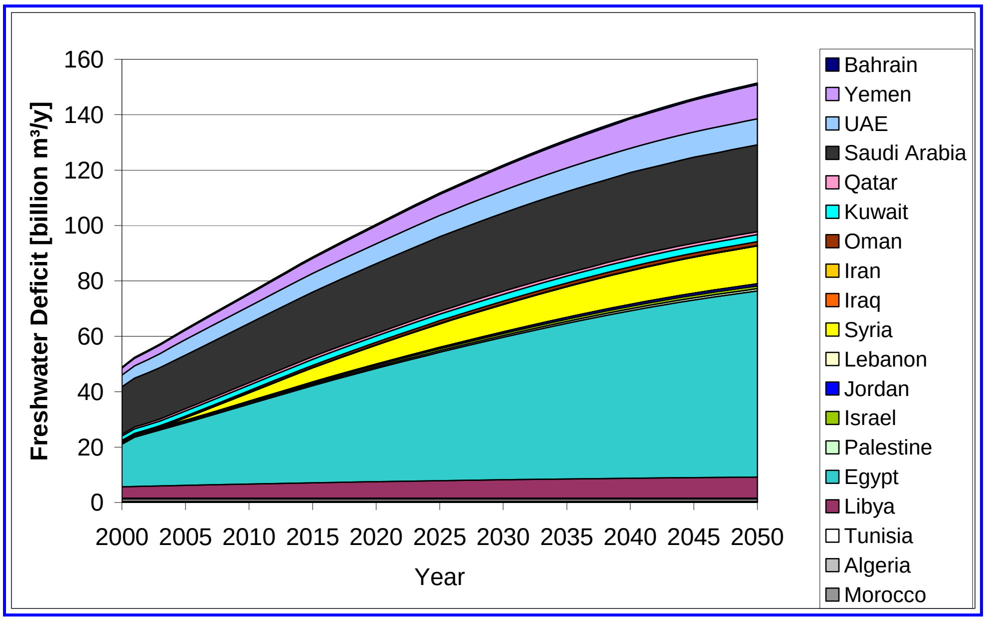

Figure 7: Freshwater deficit defined as the difference between water demand and sustainable freshwater for each of the MENA countries according to the AQUA-CSP scenario. Today, part of the water demand is covered by desalination powered by fossil fuels and by the exploitation of non-renewable groundwater. These are not considered as sustainable sources and thus are included as potential future deficits.

Our analysis shows clearly that measures to increase efficiency of water use and distribution are vital for the region, but insufficient to cover the growing demand in a sustainable way. The situation in MENA after 2020 would become unbearable, if adequate counter measures are not initiated in good time. The use of new, unconventional sources of freshwater will be imperative, and seawater desalination powered by concentrated solar energy is the only option that can seriously cope with the magnitude of that challenge.

A Scenario for Sustainable Water Supply

The AQUA-CSP study describes the market potential of solar powered seawater desalination between the year 2000 and 2050. The CSP-desalination market has been assessed on a year-by-year basis in a scenario that also considers other sources of water, the natural renewable surface- and groundwater resources, fossil groundwater, conventionally desalted water, re-use of waste water and measures to increase the efficiency of water distribution and end-use. The analysis confirms the economic potential of CSP-desalination to be large enough to solve the threatening MENA water crisis. On the other hand, it shows that the process to substitute the presently unsustainable over-use of groundwater by solar powered desalination will take at least until 2025 to become visible (Figure 8 and Table 1), while the total elimination of groundwater over-use will at the best take until 2035 to become accomplished.

Over-use will increase from 44 billion cubic metres per year in 2000 to a maximum of 70 billion cubic metres per year in 2020, before it can be subsequently replaced by large amounts of freshwater from solar powered desalination. There is strong evidence that in some regions the available groundwater resources may collapse under the increasing pressure before sustainability is achieved. In those cases, a strong pressure will also remain on fossil fuelled desalination, which will probably grow to five times the present capacity by 2030.

The industrial capability of expanding the production capacities of concentrating solar power will be the main limiting factor until about 2020, because CSP is today starting as a young, still small industry that will require about 15-20 years of strong growth to become a world market player. MENA governments would therefore be wise to immediately start market introduction of this technology without any delay, as their natural resources may not last long enough until sustainable supply is achieved.

The largest medium-term market volumes for CSP-desalination until 2020 were found in Egypt (3.6 Bm³/y), Saudi Arabia (3.4 Bm³/y), Libya (0.75 Bm³/y), Syria (0.54 Bm³/y), and Yemen (0.53 Bm³/y). All MENA countries together have a total market volume of 10.5 Bm³/y until 2020, and 145 Bm³/y until 2050. They will require a decided policy to introduce the technology to their national supply structure and to achieve the necessary market shares in good time (Figure 9).

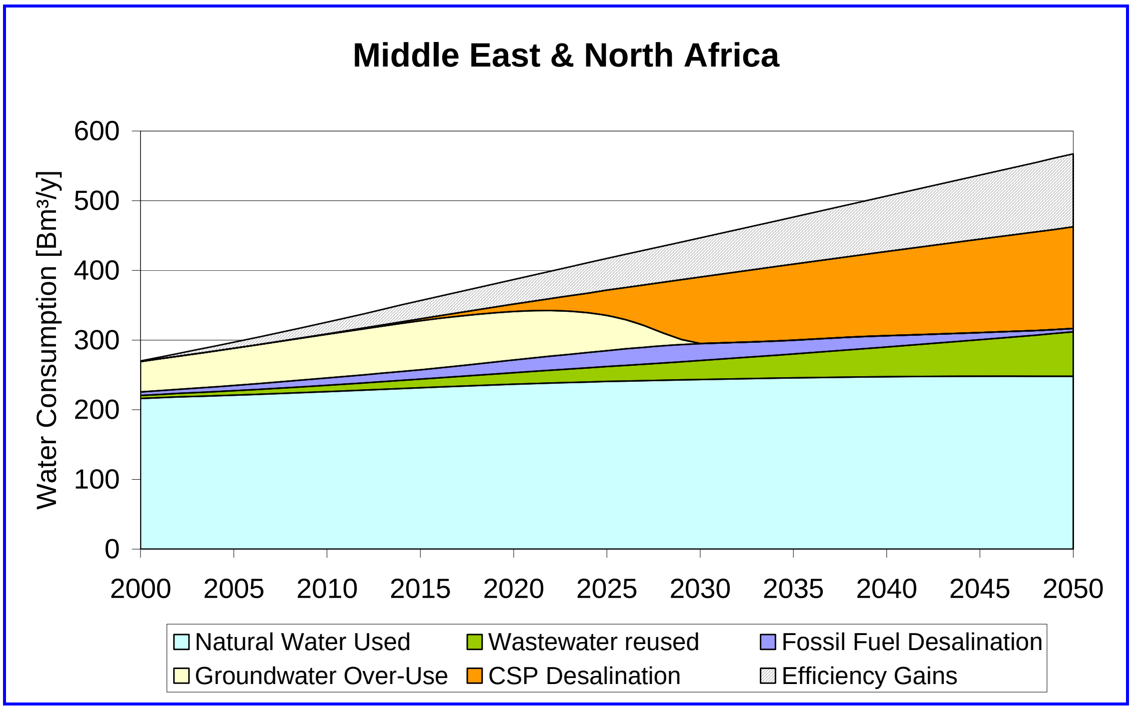

Figure 8: Water supply scenario for MENA until 2050 based on sustainable sources, unsustainable sources and solar desalination. (shaded area: efficiency gains with respect to business as usual).

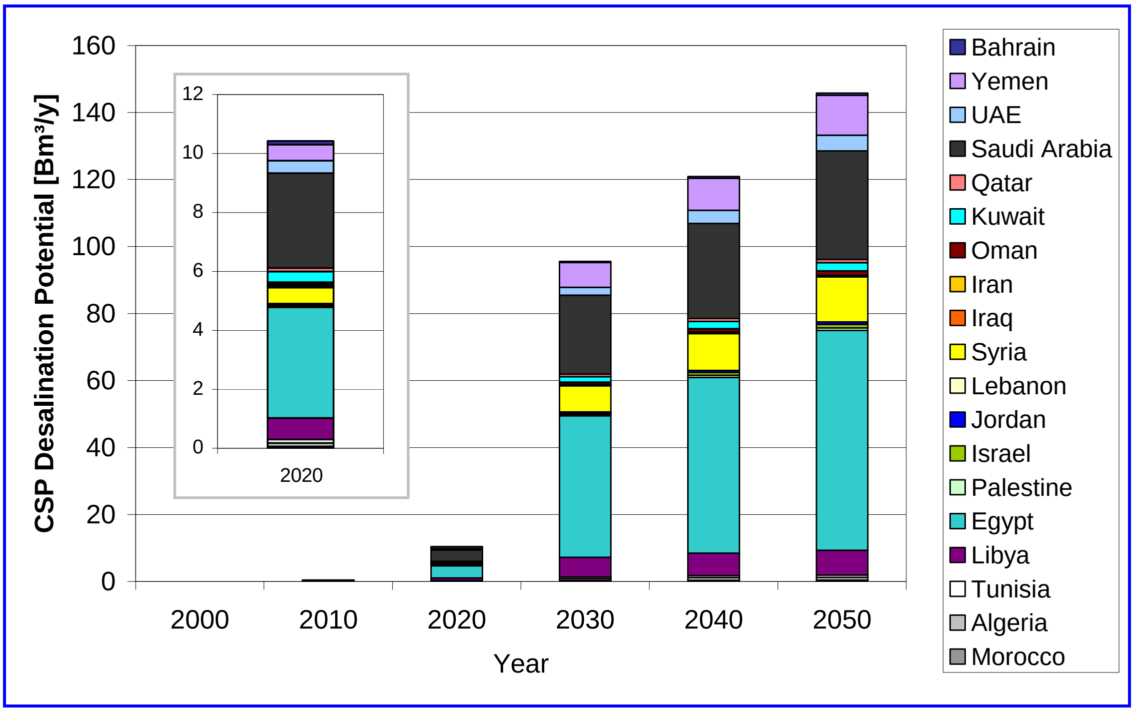

Figure 9: CSP potential for seawater desalination in all MENA countries until 2050.

Table 1: Aggregated data of all MENA countries of the AQUA-CSP scenario until 2050. North Africa: Morocco, Algeria, Tunisia, Libya, Egypt. Western Asia: Iran, Iraq, Syria, Jordan, Lebanon, Israel, Palestine. Arabian Peninsula: Saudi Arabia, Kuwait, Bahrain, Qatar, United Arab Emirates, Oman, Yemen. Source: www.dlr.de/tt/aqua-csp

North Africa		**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Population	Million	141.9	167.3	192.8	214.5	231.9	244.3
Exploitable Water	Bm³/y	81.8	81.8	81.8	81.8	81.8	81.8
Sustainable Water Used	Bm³/y	72.8	77.5	83.5	90.5	98.7	108.6
Agricultural Demand	Bm³/y	80.4	92.1	103.0	111.4	117.6	120.9
Municipal Demand	Bm³/y	8.6	12.1	16.8	22.6	29.7	38.4
Industrial Demand	Bm³/y	5.4	7.6	10.6	14.3	18.8	24.3
Total Demand North Africa	Bm³/y	94.4	111.9	130.3	148.3	166.1	183.6
per capita Consumption	m³/cap/y	666	669	676	691	716	752
Wastewater Re-used	Bm³/y	3.2	5.6	9.2	14.5	21.7	31.3
CSP Desalination	Bm³/y	0.0	0.2	4.7	49.5	60.9	74.9
Minimum CSP Capacity	GW	0.0	0.1	2.0	21.2	26.1	32.1
Desalination by Fossil Fuel	Bm³/a	0.4	1.3	4.6	9.5	8.1	2.0
Groundwater Over-Use	Bm³/y	21.2	33.2	38.3	0.0	0.0	0.0
Natural Water Used	Bm³/y	69.6	71.6	73.5	74.9	75.5	75.3
Western Asia		**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Population MP	Mp	126.0	149.9	177.2	200.6	220.8	236.9
Exploitable Water	Bm³/y	238.3	238.3	238.3	238.3	238.3	238.3
Sustainable Water Used	Bm³/y	139.3	148.8	160.6	170.3	180.0	190.2
Agricultural Demand	Bm³/y	127.7	136.7	147.1	153.1	155.9	155.8
Municipal Demand	Bm³/y	8.5	10.9	14.4	18.6	23.9	30.5
Industrial Demand	Bm³/y	4.2	5.7	7.8	10.7	14.8	20.2
Total Demand Western Asia	Bm³/y	140.4	153.4	169.4	182.4	194.6	206.5
per capita Consumption	m³/cap/y	1114	1023	956	909	881	872
Wastewater Re-Used	Bm³/y	0.9	2.5	5.3	9.5	15.9	25.3
CSP Desalination	Bm³/y	0.0	0.0	0.8	9.4	13.6	16.5
Minimum CSP Capacity	GW	0.0	0.0	0.3	4.0	5.8	7.1
Fossil Fuel Desalination	Bm³/a	0.7	1.8	3.0	3.1	1.4	0.4
Groundwater Over-Use	Bm³/y	0.4	2.8	5.2	0.0	0.0	0.0
Natural Water Used	Bm³/y	138.5	146.3	155.2	160.8	164.1	164.8
Arabian Peninsula		**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Population	Million	48.5	64.8	82.0	99.4	115.8	131.0
Exploitable Water	Bm³/y	7.8	7.8	7.8	7.8	7.8	7.8
Sustainable Water Used	Bm³/y	8.2	8.8	9.8	11.1	12.8	15.0
Agricultural Demand	Bm³/y	29.5	36.7	43.4	49.3	53.9	57.3
Municipal Demand	Bm³/y	4.1	5.7	7.2	8.8	10.5	12.4
Industrial Demand	Bm³/y	0.6	0.9	1.1	1.3	1.6	1.8
Total Demand Arabian Peninsula	Bm³/y	34.3	43.3	51.6	59.4	66.0	71.6
per capita Consumption	m³/cap/y	707	667	630	597	570	547
Wastewater Re-Used	Bm³/y	0.4	1.0	2.0	3.3	5.0	7.1
CSP Desalination	Bm³/y		0.2	5.0	36.6	46.4	54.4
Minimum CSP Capacity	GW	0.0	0.1	2.1	15.7	19.8	23.3
Fossil Fuel Desalination	Bm³/a	4.0	7.7	10.7	11.3	6.8	2.3
Groundwater Over-Use	Bm³/y	22.1	26.5	26.1	0.3	0.0	0.0
Natural Water Used	Bm³/y	7.8	7.8	7.8	7.8	7.8	7.8
Total MENA		**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Population	Million	316.4	382.0	452.0	514.5	568.5	612.2
Exploitable Water	Bm³/y	327.9	327.9	327.9	327.9	327.9	327.9
Sustainable Water Used	Bm³/y	220.2	235.2	253.9	271.9	291.5	313.8
Agricultural Demand	Bm³/y	237.6	265.6	293.5	313.8	327.4	334.1
Municipal Demand	Bm³/y	21.2	28.7	38.4	50.0	64.1	81.2
Industrial Demand	Bm³/y	10.3	14.2	19.5	26.3	35.2	46.4
Total Demand MENA	Bm³/y	269.1	308.5	351.4	390.1	426.7	461.7
per capita Consumption	m³/cap/y	851	808	777	758	751	754
Wastewater Re-Used	Bm³/y	4.4	9.1	16.5	27.3	42.6	63.8
CSP Desalination	Bm³/y	0.0	0.5	10.4	95.5	120.9	145.8
Minimum CSP Capacity	GW	0.0	0.2	4.5	40.9	51.7	62.4
Fossil Fuel Desalination	Bm³/a	5.2	10.8	18.3	23.9	16.3	4.6
Groundwater Over-Use	Bm³/y	43.7	62.5	69.6	0.3	0.0	0.0
Natural Water Used	Bm³/y	215.9	225.7	236.6	243.5	247.4	248.0

Socio-Economic Impacts

Due to technical advancements, economies of scale, mass production and increasing competition there will be a significant cost reduction of CSP-technologies under the condition that market expansion would take place as described before /Neij 2003/, /Pitz-Paal 2005/. The cost of heat from concentrating solar collector fields is at present equivalent to heat from fuel oil at 50-70 US$/barrel, heading for 35-45 US$/barrel around 2010 and 20-30 US$/barrel by 2020. In the long-term a cost of 15-25 US$/barrel may be achieved for solar “fuel” while fossil fuel is not expected to ever return to such low levels of cost. This means that heat from concentrating solar collector fields will become one of the least cost options for energy in MENA, if not the cheapest at all. Please note that all cost values within this report are given in constant monetary value of the year 2005 (real value) and assuming a long-term exchange rate of 1 €/$. Nominal values will develop according to inflation, price escalation and exchange rates. Original numbers were calculated in constant €-2005.

Figure 10 and Figure 11 show that CSP plants providing power and desalted water can be operated economically with attractive interest rates if reasonable, unsubsidised prices are paid either for electricity or water. This must be seen in the context of present power and water utilities in MENA, that often show a zero or negative rate of return of investment, thus highly subsidising power and water.

While it is clear that the threatening MENA water crisis cannot be solved by conventional desalination, it can indeed be solved by solar powered desalination combined with efficient use of water reserves and re-use of wastewater. Building water supply on limited, fossil energy resources with unknown cost perspectives would be very risky, while building a good portion of water supply on renewable resources that will become cheaper with time would be rather reasonable. CSP-desalination can also help to reduce the subsidiary load of most MENA governments from the power and water sectors and thus liberate public funds that are badly needed for innovation and development.

The concept of sustainable supply of water for the MENA region found within the AQUA-CSP study that is based on efficiency and renewable energy is not only secure and compatible with society and the environment, but also affordable, while a business-as-usual approach would finally end in a devastating situation for the whole region.

Sound investments and favourable economic frame conditions are now required to start market introduction and massive expansion of CSP technology for power and desalination in the MENA region. A population doubling until 2050 will not only require more energy and water, but also more space for living. CSP opens the long-term option to gain arable land from the MENA deserts for rural and urban development for the generations to come. Instead of increasingly fighting for limited resources, MENA has now the opportunity to change to a cooperative exploitation of renewable ones.

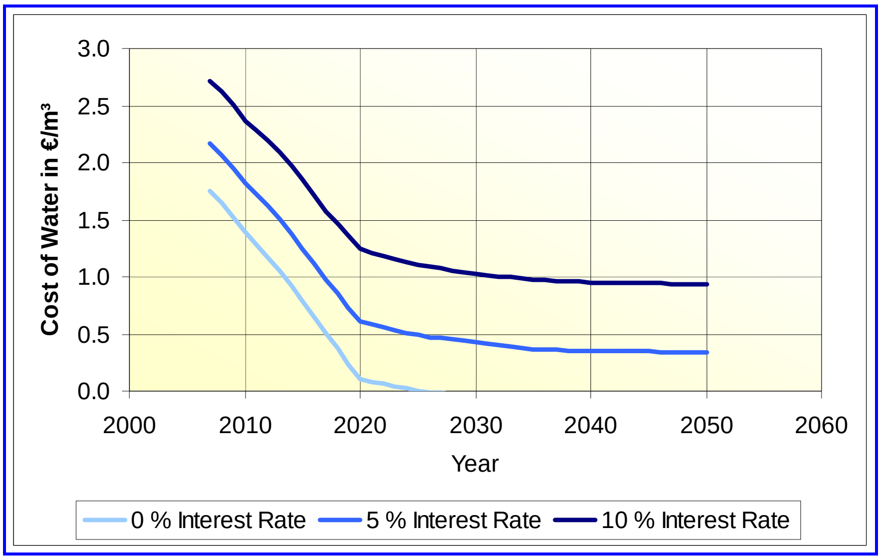

Figure 10: Cost of water from CSP/MED plants for different interest rates assuming that electricity produced by the plants will achieve a fixed revenue of 0.05 €/kWh. In the long-term, a cost of water of 0.34 €/m³ and 0.05 €/kWh for electricity can be achieved in the AQUA-CSP reference case with 5 % interest rate (annual real project rate of return). Increasing electricity price will reduce the cost of water and vice versa. Assumed long-term exchange rate US$/€ = 1. All values in constant monetary value of the year 2005.

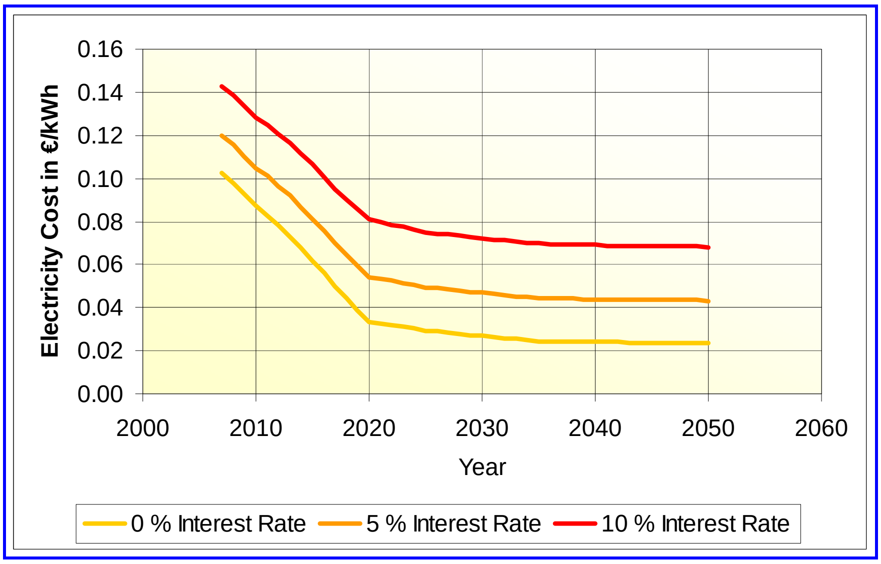

Figure 11: Cost of electricity from CSP/MED plants for different interest rates assuming that water produced by the plants will achieve a fixed revenue of 0.5 €/m³. In the long-term, a cost of electricity of 0.04 €/kWh and 0.5 €/m³ of water can be achieved in the AQUA-CSP reference case with 5 % interest rate (annual real project rate of return). Increasing electricity price will reduce the cost of water and vice versa. Assumed long-term exchange rate US$/€ = 1.

Environmental Impacts

The main environmental impacts caused by conventional seawater desalination are the following /Lattemann, Hoepner 2003/, /Lattemann, Höpner 2007/:

- Seawater intake for desalination and for the cooling system may cause impingement and entrainment of organisms,
- airborne emissions of pollutants and carbon dioxide are caused by the generation of electricity and heat required to power the desalination plants,
- chemical additives and biocides used to avoid fouling, foaming, corrosion and scaling of the desalination plants may finally appear in the brine,
- discharge of hot brine with high salt concentration to the sea may affect local species.

The airborne emissions of CSP/RO and CSP/MED reference plants have been assessed on a life-cycle basis, including the construction, operation and de-commissioning, and their environmental impacts have been compared to conventional desalination schemes (Figure 12, Figure 13). The analysis shows that impacts from operation of conventional desalination plants can be reduced by almost 99 % using solar energy, as they are primarily caused by fuel consumption (Figure 14, Table 2)

Due to the direct impacts of desalination plants to their coastal environment a thorough impact analysis must be performed in every case prior to the erection of large scale desalination plants, as sensitive species may be heavily affected. Only sites should be chosen that allow for an effective and quick dilution of brine in order to avoid local overheating and high concentration of salt. Horizontal drain tubes beneath the seabed were recently proposed for intake and discharge, allowing on one hand for a pre-filtering of feed-water and on the other hand for an effective pre-cooling and distribution of the brine /Peters et al. 2007/. Pre-filtering can be enhanced further by applying nano-filtration, which will require more (solar) energy but will avoid chemical additives like anti-fouling, anti-foaming and anti-scaling agents as well as biocides /Bartels et al. 2008/. Substituting chemicals by solar energy can thus mitigate both chemical additives and emissions from energy supply.

Advanced future CSP/RO and CSP/MED desalination plants have the potential to operate with extremely low environmental impacts compared to today’s conventional desalination systems, at an about 20 % higher investment cost, but using solar energy that will be considerably less expensive than today’s fossil fuel sources. Considering the large amounts of water to be desalted in MENA according to our scenario, very clean desalination processes will be necessary in order to remain compatible with the environment. The environmental impacts from conventional desalination will increase considerably until 2025, as advanced solar powered systems will still be a minority until then. After 2025 the share of advanced solar powered desalination will quickly increase, and overall emissions can then be brought back to a compatible level.

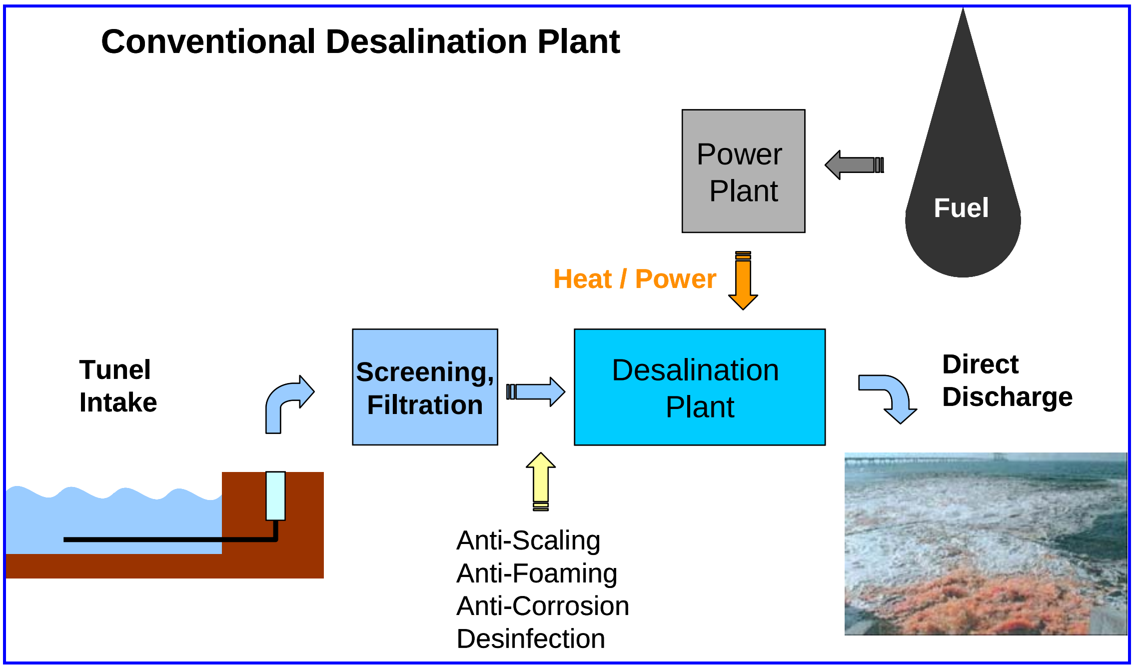

Figure 12: Sketch of a conventional seawater desalination plant configuration

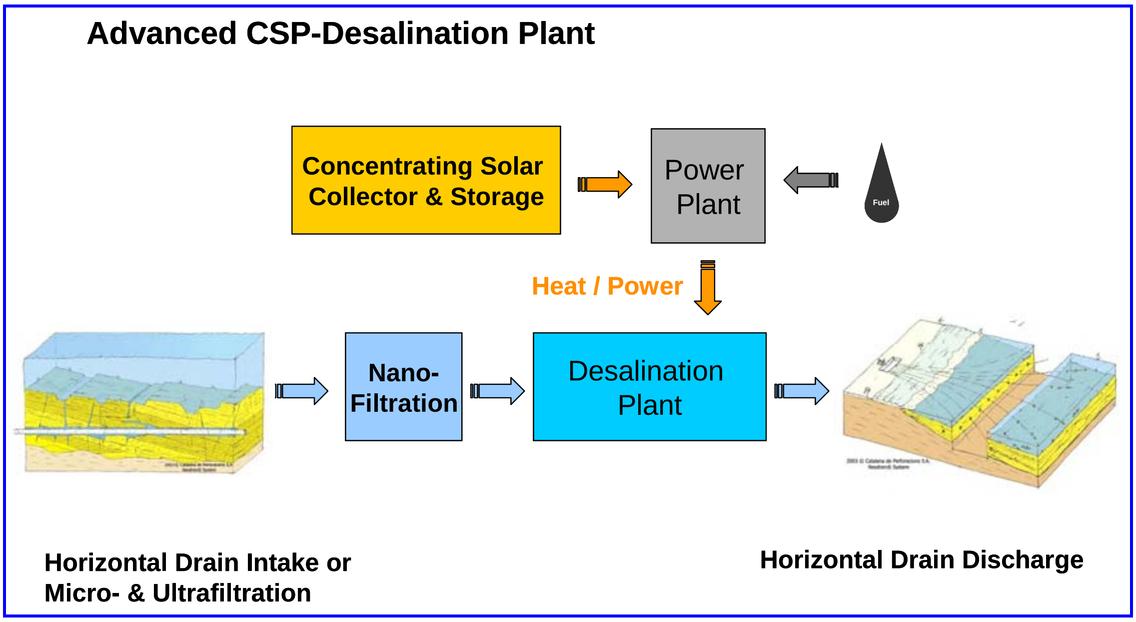

Figure 13: Sketch of an enhanced solar powered seawater desalination plant configuration: fossil fuels and chemicals are as far as possible substituted by solar energy input from concentrating solar power.

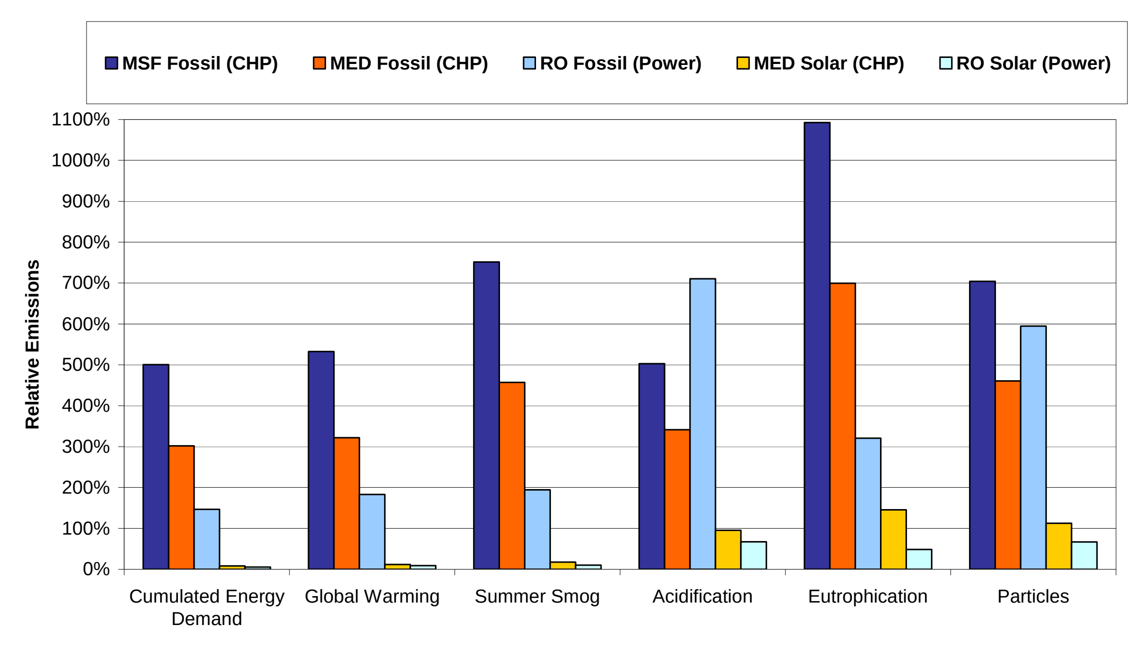

Figure 14: Life-cycle emissions of seawater desalination technologies in the MENA region based on fossil fuel and concentrating solar power compared to the best possible conventional solution based on a gas-fired combined cycle power plant providing electricity for reverse osmosis (100%). MSF Multi-Stage Flash, CHP Combined Heat & Power, MED Multi-Effect Desalination, RO Reverse Osmosis, "Solar" stands for concentrating solar power (CSP).

Table 2: Life-cycle emissions of seawater desalination plants in the MENA region based on fossil fuel vs. plants based on concentrating solar power. MSF Multi-Stage Flash, CHP Combined Heat & Power, MED Multi-Effect Desalination, RO Reverse Osmosis, "Solar" stands for concentrating solar power (CSP).

Impact Category	**Unit**	**MED Solar (CHP)**	**RO Solar (Power)**	**RO Fossil (Power)**	**MED Fossil (CHP)**	**MSF Fossil (CHP)**
Cumulated Energy Demand	kJ/m³	3,579	2,298	63,790	131,767	218,417
Global Warming	kg CO2/m³	0.27	0.21	4.41	7.75	12.83
Summer Smog	kg Ethen / m³	5.89E-05	3.30E-05	6.53E-04	1.54E-03	2.53E-03
Acidification	kg SO2 /m³	4.48E-03	3.16E-03	3.35E-02	1.61E-02	2.37E-02
Eutrophication	kg PO4 / m³	4.50E-04	1.49E-04	9.90E-04	2.16E-03	3.38E-03
Particles	kg PM10/ m³	1.01E-03	5.97E-04	5.33E-03	4.13E-03	6.31E-03

Barriers

In the MENA countries, there is no significant renewable energy capacity installed so far. The past decades have been characterised by low fossil fuel prices, while the cost of electricity from renewable sources was still high. This was the major barrier to installing renewable power technology world wide and also in MENA. However, this paradigm has changed.

Prices for renewable energy are coming down significantly. Germany launched its renewable feed-in tariff system in the year 2000 and since then has seen a major growth of renewable energy shares in the power sector at decreasing electricity costs /BMU 2007/. Spain has introduced a similar tariff system with equivalent positive results.

It has been recognized that feed-in tariffs do not represent a subsidy. A feed-in tariff is the price per unit of electricity that a utility has to pay for renewable electricity from private suppliers. The government regulates the tariff rate, which in the past was higher than the tariff paid for conventionally produced electricity. Feed-in tariff systems are guaranteed long-term power purchase contracts of renewable electricity suppliers with local utilities. A major effect of this regulation is that the risk of selling or not selling electricity at a certain tariff is taken away from the investor, thus allowing him to invest with low-risk surcharges. This is reflected by low acceptable rates of return which, for example, range between 6-8 percent for typical investments within the German feed-in tariff system. Investors exposed to that risk would require at least a 10-15 percent rate of return to be able to invest in the same technology without a feed-in regulation. That is why feed-in tariff systems are not only the most effective way to introduce new energy sources to the market, but also the most economical. Once plants are installed, tariffs are maintained constant for 20 years, while for new projects, the tariffs are usually reduced every year, thus forcing industry to subsequently reduce the cost of the new energy technologies by learning, mass production and economies of scale until reaching competitive levels.

A major barrier to the introduction of renewable energies remaining in the MENA is the non-existence of feed-in tariff systems or equivalent measures. On the contrary, the introduction of renewable sources is impeded by competing fossil-fuel powered production that is often heavily subsidized and not related to world market prices. Heat from CSP would already today be significantly less expensive than the same amount of heat produced by fuel oil at world market price, but no MENA country has a tariff system recognizing this fact.

Electricity and water tariffs are often either subsidised or related to subsidised fuel input. There are only flat rate tariffs available covering – in the best case – the average cost of power generation, but not distinguishing between peak load and base load power delivered to the utilities. A major concern of MENA utilities is the overwhelming growth of peak load caused by air conditioning systems. Covering the peak load by fuel-fired power stations operating only for the peaking time is very expensive, but no specific electricity supply tariff is available for producers for peaking. Concentrating solar power stations could cover those electricity demand peaks at a lower cost than fuel-fired plants, but would only receive a flat rate tariff that would not cover their real cost (neither would it cover the cost of equivalent fuel-fired peaking plants, which are usually cross-subsidised by fuel-fired base load power stations).

Concentrating solar power for electricity and water in the MENA would not really require subsidies, but only fair long-term power and water purchase agreements guaranteed by government or international funding organisations and covering the real cost of water and peaking electricity. The design of such a framework for CSP and of equivalent measures for other renewable energy sources will be the challenge for the MENA in the coming years in order to achieve a sustainable supply system as described within this paper.

Conclusions

Contrary to the conclusions of most contemporary strategic analysis of the MENA water sector, seawater desalination can in fact have a major share on freshwater supply that will be affordable for all countries, will be based on domestic solar energy and will not cause major environmental impacts, if concentrating solar power (CSP) is used for energy supply.

Absolutely clean desalination plants will be imperative for a massive implementation to solve the MENA water crisis. This can only be achieved if chemical additives can be substituted by enhanced intake and filtering of seawater that will require more energy than usual. Concentrating solar power is the key to this solution, as it is the only source that is at the same time emission-free, domestic to the MENA region, large enough to cope with the huge demand, based on available technology and expandable to the necessary large volumes within a time-frame of only 15 to 25 years.

Together with appropriate measures to increase the efficiency of water distribution and end-use, market introduction of CSP for power and seawater desalination must start immediately, and adequate political and economic frameworks must be established in the MENA countries to foster implementation of first plants and to assure a quick expansion of this technology in the whole region. Any delay will increase the danger of a catastrophic depletion of groundwater resources that would have major detrimental effects on economic development and social peace.

The AQUA-CSP study has analysed the potential of concentrating solar thermal power technology for large scale seawater desalination for the urban centres in the Middle East and North Africa (MENA). It provides a comprehensive data base on technology options, water demand, reserves and deficits and derives the short-, medium- and long-term markets for solar powered desalination of twenty countries in the region. The study gives a first information base for a political framework that is required for the initiation and realisation of such a scheme. It quantifies the available solar energy resources and the expected cost of solar energy and desalted water, a long-term scenario of integration into the water sector, and quantifies the environmental and socio-economic impacts of a broad dissemination of this concept.

There are several good reasons for the implementation of large-scale concentrating solar powered desalination systems:

- Due to energy storage and hybrid operation with (bio)fuel, concentrating solar power plants can provide around-the-clock firm capacity that is suitable for large scale desalination either by thermal or membrane processes,
- CSP desalination plants can be realised in very large units up to several 100,000 m³/day,
- the huge solar energy potentials of MENA can easily produce the energy necessary to avoid the threatening freshwater deficit that would otherwise grow from today 50 billion cubic metres per year to about 150 billion cubic metres per year by 2050.

- within two decades, energy from solar thermal power plants may become the least cost option for electricity (below 0.05 $/kWh) and desalted water (below 0.5 $/m³), if market introduction is initiated without any delay,
- management and efficient use of water, enhanced distribution and irrigation systems, re-use of wastewater and better accountability are important measures for sustainability, but will only be able to avoid about one third of the threatening long-term deficit of the MENA region in a business as usual case,
- combining efficient use of water and large-scale solar desalination, over-exploitation of groundwater in the MENA region can – and must – be ended around 2030,
- advanced solar powered desalination with horizontal drain seabed-intake and nano-filtration will avoid most environmental impacts from desalination occurring today,
- with support from Europe the MENA countries should immediately start to establish favourable political and legal frame conditions for the market introduction of concentrating solar power technology for electricity and seawater desalination.

The AQUA-CSP study shows a sustainable solution to the threatening water crisis in the MENA region, and describes a way to achieve a balanced, affordable and secure water supply structure for the next generation, which has been overlooked by most contemporary strategic analysis. The full report including individual country data is available at: www.dlr.de/tt/aqua-csp.

Acknowledgements

The AQUA-CSP team thanks the German Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) for sponsoring this project, Ralf Christmann from BMU, Nadine May and Ludger Lorych from VDI/VDE/IT for their efficient project management, Dr. Jürgen Scharfe from entropie, Munich for kindly reviewing part of the report, Sabine Lattemann from Oldenburg University for providing the latest know-how on environmental impacts of desalination, the Trans-Mediterranean Renewable Energy Cooperation (TREC) for providing a very useful discussion forum, our colleagues at DLR, and to everybody else who helped in making this project a success.

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