AQUA-CSP

Concentrating Solar Power for Seawater Desalination

Executive Summary

by

German Aerospace Center (DLR)
Institute of Technical Thermodynamics
Section Systems Analysis and Technology Assessment

Study commissioned by

Federal Ministry for the Environment,
Nature Conservation and Nuclear Safety
Germany

The Federal Ministry
for the Environment,
Nature Conservation
and Nuclear Safety

DLR

The full **AQUA-CSP Study Report** can be found at the website:
http://www.dlr.de/tt/aqua-csp

Contents:

Project Responsible:

Dr. Franz Trieb
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)
Institute of Technical Thermodynamics
Systems Analysis and Technology Assessment
Pfaffenwaldring 38-40
D-70569 Stuttgart
Germany
Tel.: ++49-711 / 6862-423
Fax: ++49-711 / 6862-783
Email: franz.trieb@dlr.de
http://www.dlr.de/tt/system

Stuttgart, November 2007

AQUA-CSP Team

German Aerospace Center (Germany)
Dr. Franz Trieb, Dipl. Geo. Julia Gehrung, Dr. Peter Viebahn, Dr. Christoph Schillings, Dipl. Phys. Carsten Hoyer

National Energy Research Center (Jordan)
Eng. Malek Kabariti, Waled Shahin, Ammar Al-Taher

University of Aden, (Yemen)
Prof. Dr. Hussein Altowaie

University of Sana'a, (Yemen)
Prof. Dr. Towfik Sufian

University of Bahrain, (Bahrain)
Prof. Dr. Waheeb Alnaser

Prof. Dr. Abdelaziz Bennouna, formerly at CNR (Morocco)

Intern. Forschungszentrum für Erneuerbare Energien e.V. (Germany)
Dr. Nasir El-Bassam

Kernenergien – The Solar Power Company (Germany)
Dipl.-Ing. Jürgen Kern

Nokraschy Engineering GmbH (Germany)
Dr.-Ing. Hani El-Nokraschy

Deutsche Gesellschaft Club of Rome (Germany)
Dr. Gerhard Knies, Dr. Uwe Möller

House of Water and Environment (Palestine)
Dr. Amjad Aliewi, Hafez Shaheen

Center for Solar Energy Studies (Libya)
Dr. Ibrahim Elhasairi

Centre de Developpement des Energies Renouvelables (Morocco)
Madame Amal Haddouche (Director General)

University of Bremen (Germany)
Dr. Heike Glade

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.

Index of the AQUA-CSP Report

Some Remarks about this Study

Thousands of years ago, prosperous conditions in fertile river locations throughout the world motivated nomadic people to form sedentary, agrarian communities. The inhabitants of these areas built cities, learned to fabricate pottery and to use metals, invented writing systems, domesticated animals and created complex social structures. In short, civilization was born when hunters and gatherers became settlers and farmers.

Except for energy: today's civilization is still based on gathering different forms of fossil energy, just like our ancestors, that collected berries and hunted animals until resources were depleted and they had to move elsewhere. Today, fossil energy resources are still sought and gathered until the last drop is spent. It becomes more and more evident that this is not a civilized behaviour, and certainly not a sustainable one, because there is no other planet in view to move to after resources are depleted and the atmosphere is spoiled.

However, our hunting and gathering ancestors found a solution to that dilemma: they became farmers, sowing seeds in springtime and harvesting corn and fruits in autumn, making use of technical know-how and the abundance of solar energy for their survival. That's exactly what is overdue in the energy sector: we must become farmers for energy, sow wind farms, wave- and hydropower stations, biomass- and geothermal co-generation plants, photovoltaic arrays, solar collectors and concentrating solar power plants and harvest energy for our demand.

The same is true for freshwater: if the freely collectable natural resources become too scarce because the number of people becomes too large, we have to sow rainwater-reservoirs, waste-water reuse systems and solar powered desalination plants, and harvest freshwater from them for our daily consumption. Maybe as a side-effect of this more "civilized" form of producing energy and water, we will also – like our ancestors – find another, more developed social structure, maybe a more cooperative and peaceful one.

The concept described within this report still leaves some open questions. A study like this cannot give all answers. However, much is gained if the right questions are finally asked, and if solutions are sought in the right direction. The AQUA-CSP study, like its predecessors MED-CSP and TRANS-CSP, is a roadmap, but not a wheel-chair: it can show the medium- and long-term goal, it can also show the way to achieve that goal, but it will not carry us there, we'll have to walk by ourselves.

Franz Trieb
Stuttgart, November 12, 2007

It is not essential to predict the future,
but it is essential to be prepared for it.

Perikles (493 – 429 a. C.)

Our world can only be developed by creating lasting values,
but neither by cultivating luxury nor by saving costs.

(Lesson learned during the edition of this report)

Introduction

The general perception of "solar desalination" today comprises only small scale technologies for decentralised water supply in remote places, that may be quite important for the development of rural areas, but that do not address the increasing water deficits of the quickly growing urban centres of demand. Conventional large scale desalination is perceived as expensive, energy consuming and limited to rich countries like those of the Arabian Gulf, especially in view of the quickly escalating cost of fossil fuels like oil, natural gas and coal. The environmental impacts of large scale desalination due to airborne emissions of pollutants from energy consumption and to the discharge of brine and chemical additives to the sea are increasingly considered as critical. For those reasons, most contemporary strategies against a "Global Water Crisis" consider seawater desalination only as a marginal element of supply. The focus of most recommendations lies on more 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 other places. On the other hand, most sources that do recommend seawater desalination as part of a solution to the water crisis usually propose nuclear fission and fusion as indispensable option.

None of the presently discussed strategies include concentrating solar power (CSP) for seawater desalination within their 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 also 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 whole region.

Renewable energy sources have been accepted world wide as sustainable sources of energy, and are introduced to the energy sector with an annual growth rate of over 25 % per year. From all available energy sources, solar energy is the one that correlates best with the demand for water, because it is obviously the main cause of water scarcity. The resource-potential of concentrating solar power dwarfs global energy demand by several hundred times. The environmental impact of its use 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. Its cost is today equivalent to about 50 US$ per barrel of fuel oil (8.8 US$/GJ), and coming down by 10-15 % each time the world wide installed capacity doubles (e.g. present world market price of crude-oil is at 90 US$/barrel). In the medium-term by 2020, a solar energy cost equivalent to about 20 US$ per barrel (3.5 US$/GJ) will be achieved. In the long-term, it will become one of the cheapest sources of energy, at a level as low as 15 US$ per barrel of oil (2.5 US$/GJ). CSP can deliver energy "around the clock" for the continuous operation of desalination plants, and is therefore the "natural" resource for seawater desalination.

Main Results

The AQUA-CSP study analyses 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 that have been identified within the AQUA-CSP study at hand:

- 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,
- 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 will become the least cost option for electricity (below 4 ct/kWh) and desalted water (below 0.4 €/m³),
- 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 50 % of the long-term deficit of the MENA region,
- 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.

Chapter 1 (Technology Review) gives a review of the present state of the art of desalination and of concentrating solar power technologies, and shows the main options for a combination of both technologies for large scale solar powered seawater desalination.

Three different technical mainstreams were addressed (Figure 1): small-scale decentralised desalination plants directly powered by concentrating solar thermal collectors, 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 viable future option for solar powered desalination, due to the high energy consumption of the MSF process.

Reference systems for CSP/RO and for CSP/MED were defined with 24,000 cubic metres per day of desalting capacity and 21 MW net electricity to consumers. An 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 in order to compare their technical and economic performance under different environmental conditions.

Both systems have the medium-term potential to achieve base-load operation with less than 5 % of fuel consumption of conventional plants, at a cost of water well below 0.3 €/m³. Today, such integrated plants have been found to be already competitive in some niche markets, like e.g. on-site generation of power and water for very large consumers like hotel resorts or industry.

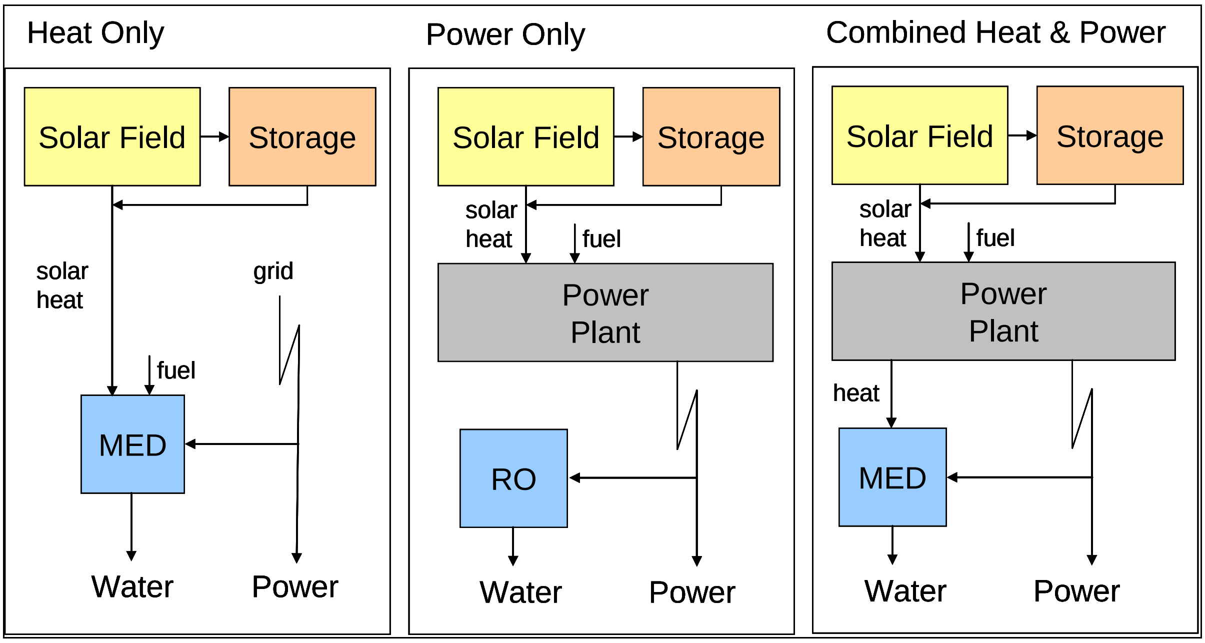

Figure 1: Different configurations for desalination by concentrated solar power. Left: Concentrating solar collector field with thermal energy storage directly producing heat for thermal multi-effect desalination. Center: Power generation for reverse osmosis (CSP/RO). Right: Combined generation of electricity and heat for multi-effect desalination (CSP/MED).

Chapter 2 (Natural Water Resources) quantifies the natural renewable and exploitable resources of freshwater in the twenty analysed countries of the MENA region. To date only four 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 (Figure 2). With a population expected to be doubling until 2050, the MENA region would be facing a serious water crisis, if it would remain 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 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. However, their excessive use has already triggered significant environmental impacts, like the reduction of the groundwater level and several oases falling dry. Additional measures like re-use of waste water, advanced irrigation, better management and accountability, improved distribution systems and new, unconventional sources of water like the desalination of seawater will therefore be imperative to avoid a foreseeable collapse of water supply in the MENA region.

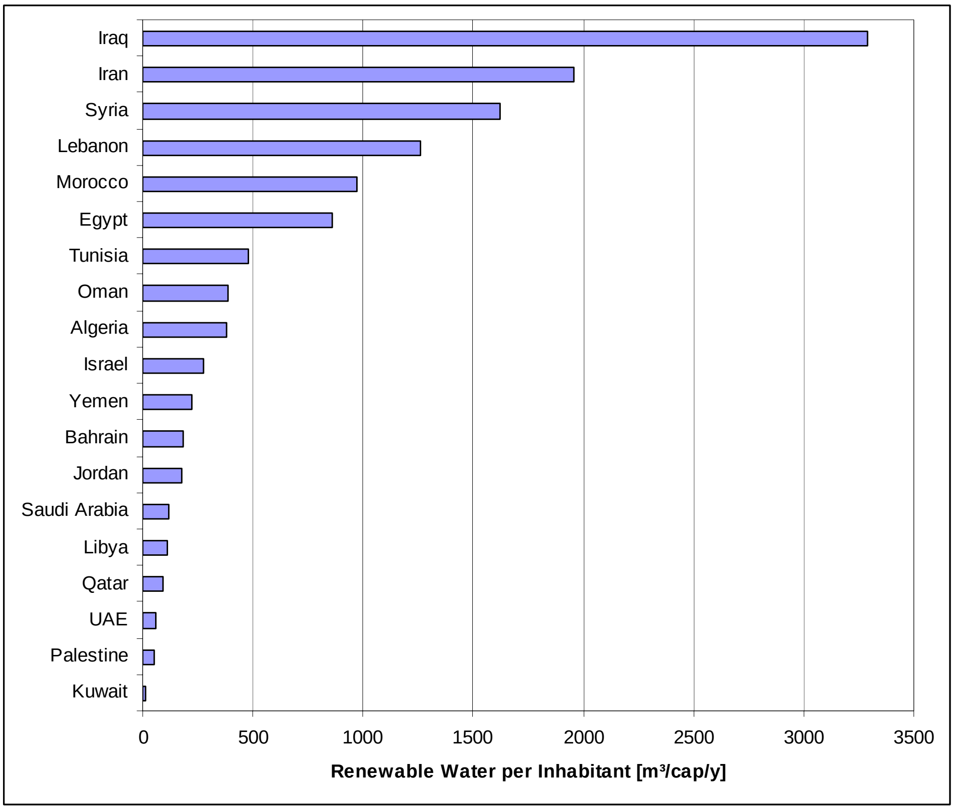

Figure 2: Total available natural renewable freshwater sources available per capita in the MENA region of the year 2000. Only four countries are beyond the water poverty threshold of 1000 m³/cap/y.

Chapter 3 (Water Demand and Deficits) provides a long-term scenario of freshwater demand for all MENA countries and quantifies the increasing gap opening between natural renewable reserves and water demand until 2050. Freshwater demand is 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 in all MENA countries.

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 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 (Figure 3).

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. The AQUA-CSP reference scenario already considers significant enhancement of efficiency of end-use, management and distribution of water, advanced irrigation systems and re-use of waste-water.

In a business-as-usual-scenario following present policies with less emphasis on efficiency consumption would grow much further – theoretically, because this will not be possible in reality – to 570 billion cubic metres per year in 2050, resulting 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 analysis from the literature, that unfortunately do not cover consistently all countries and water supply sectors of the MENA region, and that do not look beyond the year 2030. However, the time span and sectors that could be compared show a fairly good co-incidence of our results with the general state of the art.

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 will 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 already visible option that can seriously cope with the magnitude of that challenge.

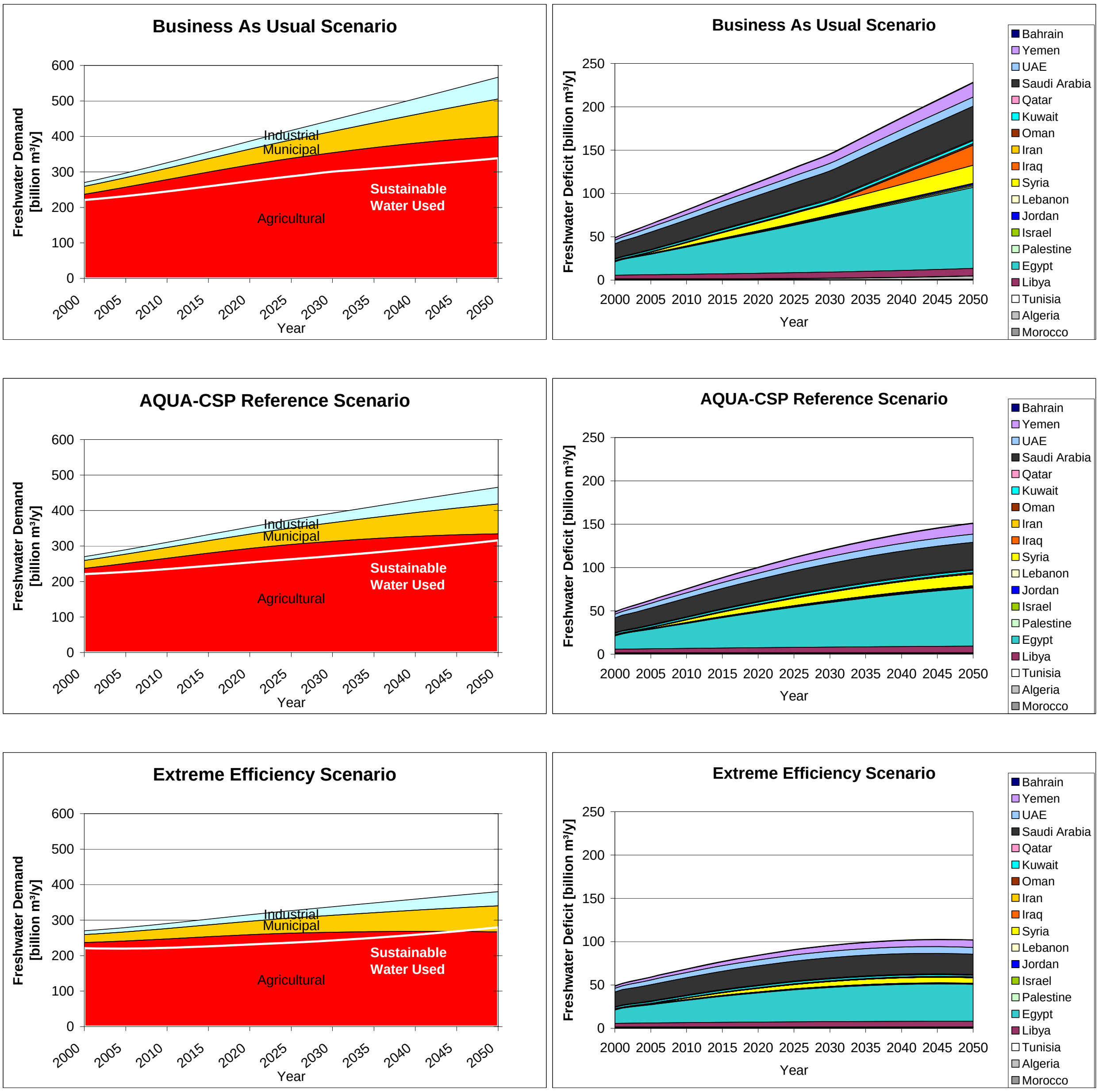

Figure 3: Results of the model calculation with minimum (top), reference (centre) and maximum (bottom) measures to increase the efficiency of water use, water distribution and irrigation and the re-use of waste-water for all MENA countries (data for individual countries is given in the annex of the main report)

Chapter 4 (Seawater Desalination Markets) 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 until 2025 to become visible (Figure 4 and Table 1).

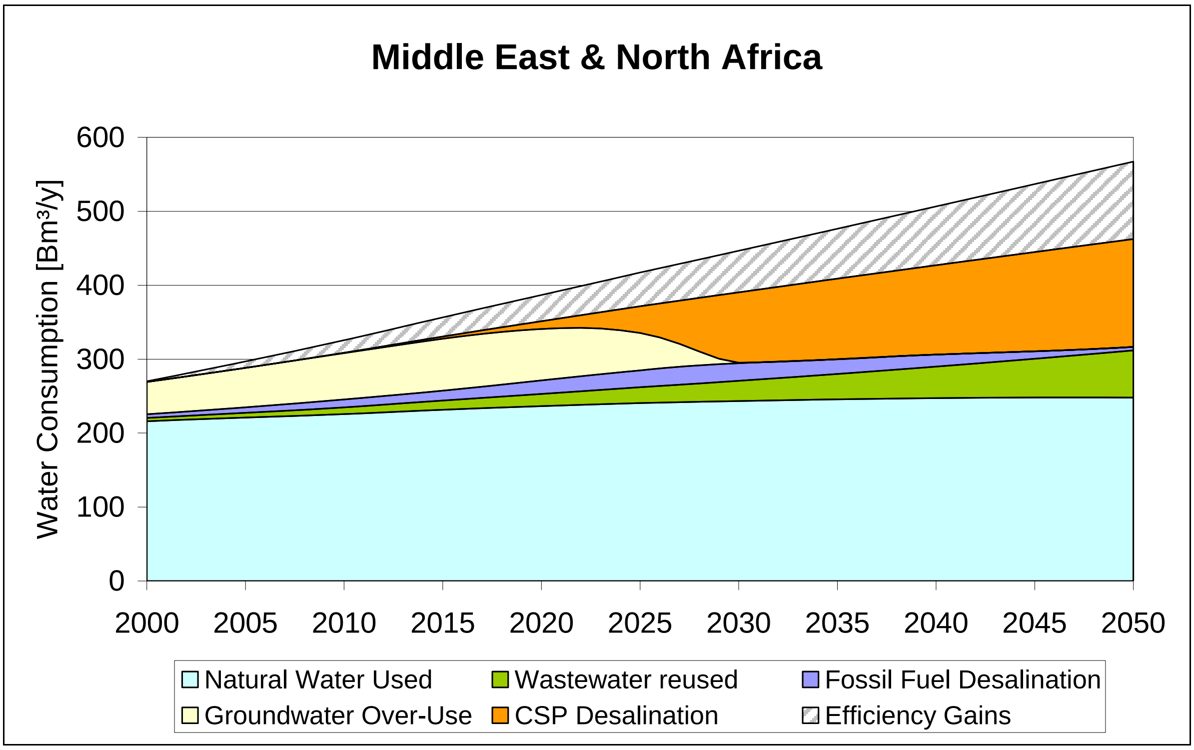

Figure 4: Water demand scenario for MENA until 2050 and coverage of demand by sustainable sources, by unsustainable sources and by solar desalination. (shaded: efficiency gains with respect to business as usual)

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 a sustainable supply is achieved.

The largest medium-term market volumes for CSP-desalination until 2020 were found in Egypt (3.6 Bm^3/y), Saudi Arabia (3.4 Bm^3/y), Libya (0.75 Bm^3/y), Syria (0.54 Bm^3/y), and Yemen (0.53 Bm^3/y). All MENA countries together have a total market volume of 10.5 Bm^3/y until 2020, and 145 Bm^3/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.

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

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.

Chapter 5 (Socio-Economic Impacts) assesses the perspectives of cost reduction of CSP-desalination under the condition that market expansion would take place as described before. The cost of heat from concentrating solar collector fields is at present equivalent to heat from fuel oil at 50 US$/barrel, heading for 35 US$/barrel around 2010 and 20 US$/barrel by 2020. In the long-term a cost of 15 US$/barrel will be achievable for solar "fuel" while fossil fuel is not expected to ever return to such low levels equivalent to those in the mid 1990ies. 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.

Figure 5 and Figure 6 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 reasonable share of water supply on renewable resources that 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.

After comparing the expected cost of solar powered seawater desalination, the cost of measures to increase the efficiency of water use and economic losses induced by the over-use of groundwater, we found that the unsustainable use of groundwater is not only a threat to the environment, but also to the national economies that suffer under such schemes, with losses of national income by a reduced gross domestic product amounting to billions every year.

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 more secure and more compatible with society and the environment, but in the medium-term also cheaper than a business-as-usual approach, that 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 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 the opportunity to change to a cooperative exploitation of renewable ones.

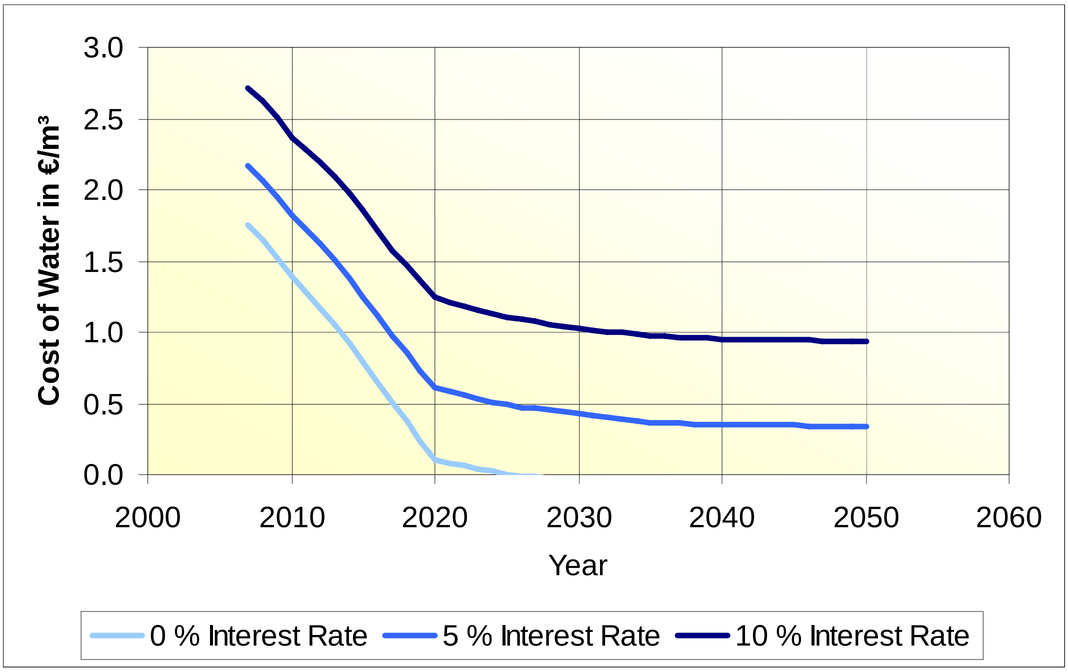

Figure 5: Cost of water from CSP/MED plants for different interest rates assuming that electricity produced by the plants will achieve a fixed revenue of 0.05 €/kWh. In the long-term, a cost of water of 0.34 €/m³ and 0.05 €/kWh for electricity can be achieved in the AQUA-CSP reference case with 5 % interest 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.

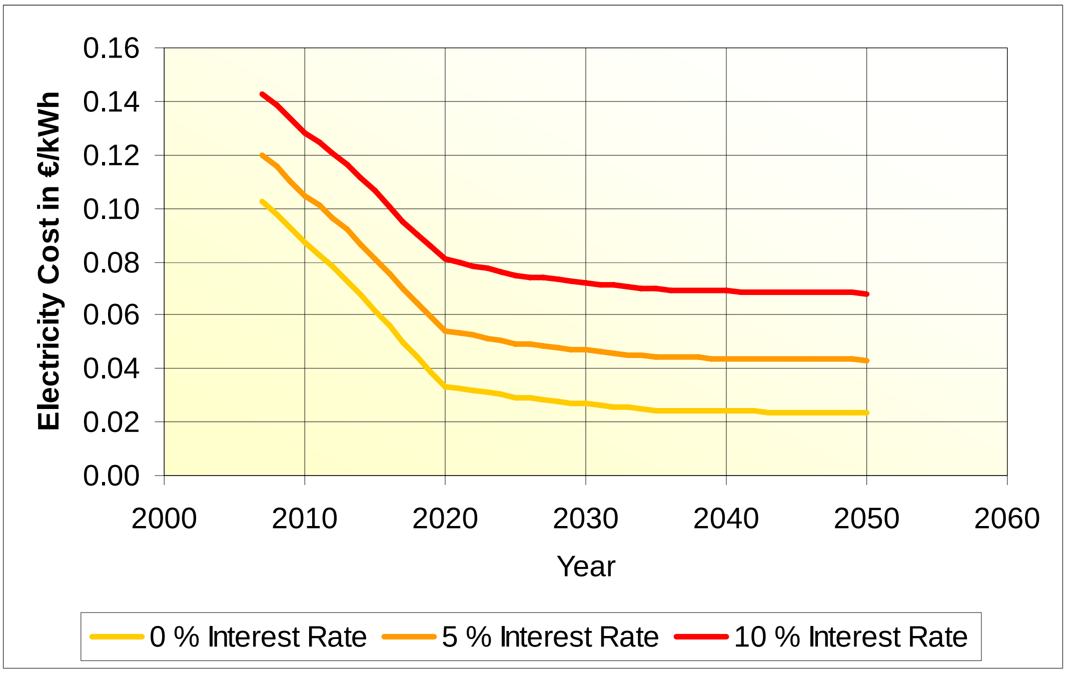

Figure 6: Cost of electricity from CSP/MED plants for different interest rates assuming that water produced by the plants will achieve a fixed revenue of 0.5 €/m³. In the long-term, a cost of electricity of 0.04 €/kWh and 0.5 €/m³ of water can be achieved in the AQUA-CSP reference case with 5 % interest 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.

Chapter 6 (Environmental Impacts) analyses the environmental impacts caused by solar powered seawater desalination. The main impacts from seawater desalination are the following:

- 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 emissions from power generation have been assessed on a life-cycle basis, including the construction, operation and de-commissioning of the reference CSP/RO and CSP/MED plants, and their impacts have been compared to conventional desalination schemes. 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. The remaining impacts caused by the construction of plants that are dominating in the case of solar desalination are reduced effectively in the course of time due to the long-term change of the MENA electricity mix to a higher share of renewable energy, as shown in the MED-CSP study.

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. 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. 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 a fuel that will be considerably less expensive than today’s fossil fuel sources. Clean desalination is possible, but considering the large amounts of water to be desalted in MENA according to our scenario, clean desalination is also absolutely necessary in order to remain compatible with the environment. The environmental impacts from conventional desalination will increase considerably until 2025, as advanced 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 7).

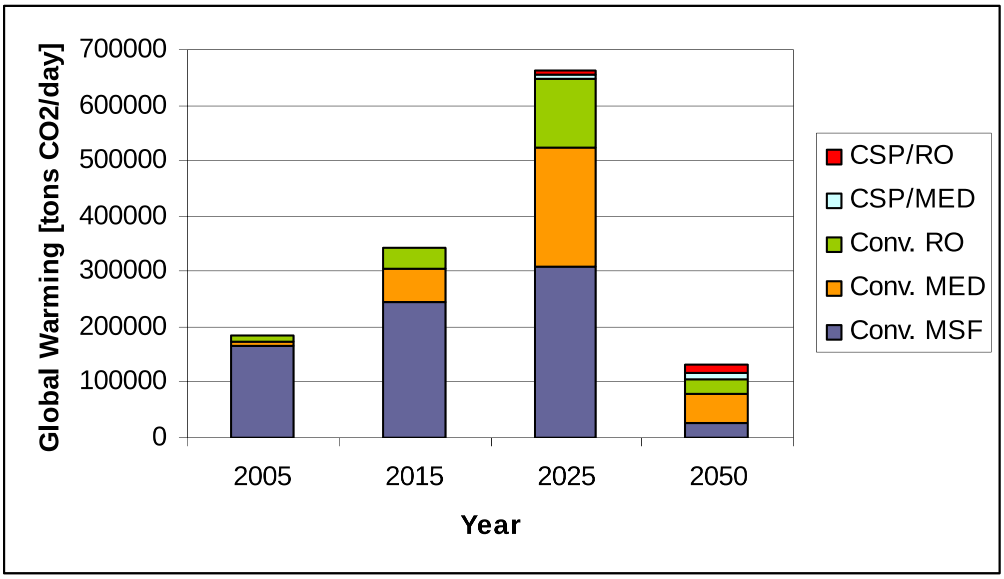

Figure 7: Greenhouse gas emissions from desalination in the AQUA-CSP scenario taking as basis for life-cycle assessment the electricity mix of the MENA countries with increasing renewable shares according to the MED-CSP study. A similar pattern results for all pollutants, showing that the introduction and large scale implementation of advanced CSP/MED and CSP/RO plants is imperative for sustainable supply.

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 a domestic energy source 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 pilot 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.