POTENTIAL OF SOLAR ELECTRICITY COMBINED WITH SEAWATER DESALINATION AROUND THE MEDITERRANEAN

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ABSTRACT

A study commissioned by the German Federal Ministry of Environment and conducted by the German Aerospace Center DLR under participation of several scientists from the Middle East and North Africa investigated the demand on electricity and water for the countries around the Mediterranean till 2050, as well as the available potential of renewable energies.

The sustainable sweet water resources of Northern Africa are today almost used to their limits, and therefore, no considerable increase of their exploitation can be expected for the future. Unsustainable use from fossil desalination and from excessive ground water withdrawal is already taking place to a considerable extent.

The study shows how renewable energies, especially thermal solar power stations may be effectively used to solve two future problems: Electricity demand and water, both at affordable costs.

Key words: Mediterranean, Desalination, Solar Electricity, Renewable Energies

INTRODUCTION

The analysis of renewable energy potentials around the Mediterranean, mainly Middle-East and North-Africa (MENA) showed that the solar energy potential is by far higher than any other renewable energy potential in the region. Beside its higher availability and reliability, it offers the option of hybrid operation and relatively economic thermal storage to bridge the night time and cloudy days.

The MED-CSP study [1] gives data resulting from analysis of the countries around the Mediterranean with respect to their energy and water demands and the possibility to satisfy these demands by solar thermal power plants in the coming decades.
The first part of this paper shows the population growth expectations in the MENA countries and the development of urban and rural population in the single countries and regions.

The second part analyses the available freshwater resources, the future demand and the growing deficits on the basis of two different scenarios for economic growth. One scenario is based on slow economic growth, assuming that the difference of per capita Gross Domestic Product (GDP) income in MENA and Europe will remain constant until 2050. The second scenario assumes that the per capita GDP of the MENA countries will achieve that of Europe by 2050. It is surprising to see that both scenarios lead to comparable water demands by 2050.

A scenario is not a prediction

A scenario is one of many possible ways to reach a certain future situation. It will require a social and political effort to reach that goal, it will not happen spontaneously. A scenario should be free of inconsistencies or it will be disregarded. With a scenario, one can examine if a preset goal is desirable or not, if a consistent way to that goal exists and what kind of measures could or must be taken to reach or to avoid it. One can vary the input parameters of a scenario to see if there are different, maybe better ways to reach the goal. A scenario represents a span of possible futures of which one may become reality if the preconditions are fulfilled.

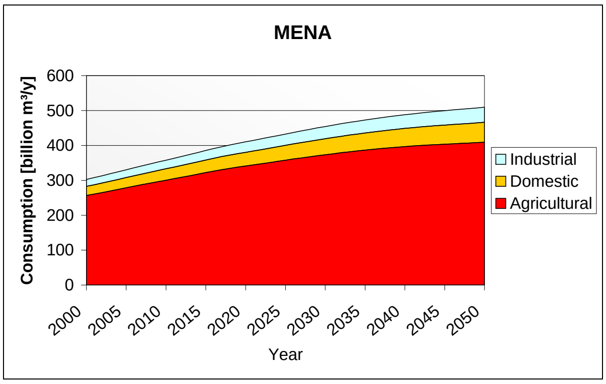

Figure 1: Water demand structure in MENA and its evolution until 2050. Scenario "Following Up"

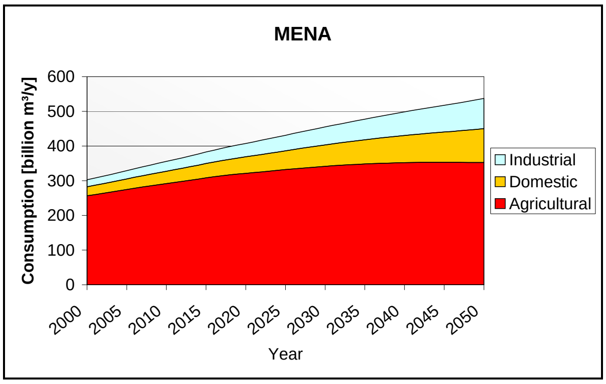

Figure 2 : Water demand structure in MENA and its evolution until 2050. Scenario "Closing the Gap"

The third part shows the potential of solar thermal power plants for sea water desalination. Concentrating Solar Power (CSP) plants can subsequently reduce the non-sustainable freshwater production from excessive groundwater withdrawals and from fossil fired desalination plants, leading to a sustainable water supply system until 2050.

CONCLUSION

Only sustainable desalination – by means of renewable energies - has the potential to cover the increasing demand on water in the Mediterranean region as the available water resources are at their limit already now.

The Arab oil producing countries will probably maintain a rather high share of oil and gas for power generation/desalination, which is unsustainable, and slowly change to solar schemes, while biomass, wind and hydropower are rather limited in this region.

All other MENA countries in North Africa, Western Asia and the Arabian Peninsula will increasingly make use of concentrating solar power as an ideal technology for a transition from an oil/gas fired power generation to a renewable energy driven scheme. The other renewable energy sources will also have a considerable, though smaller share. Geothermal power is very promising in Turkey, Saudi Arabia and Yemen. Wind power potentials are strongest in Morocco, Egypt and Oman.

POPULATION GROWTH IN MENA

According to a country by country analysis of the MENA region, FAO 2004 [2], the population in MENA will steadily grow from today 400 million people to over 700 million people by 2050 (Figure 3).

In most countries and in the region as a whole, the growth of the rural population will come to stagnation and reversal after 2020, while the urban population will steadily expand.

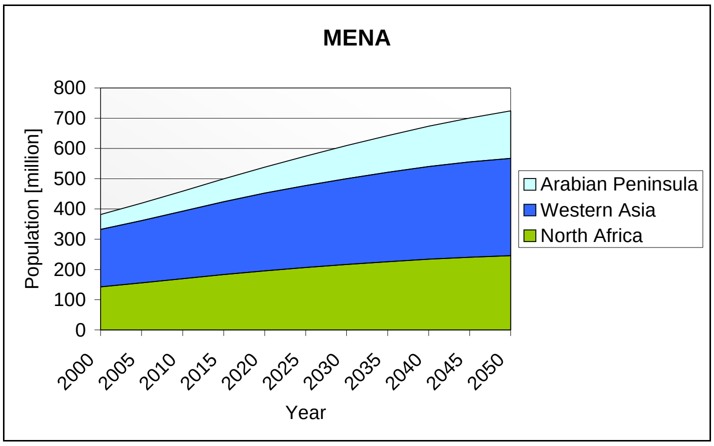

Figure 3: Population growth in MENA until 2050

1- North Africa

The population in North Africa will grow from today 150 million to 250 million in 2050. In terms of population, Egypt is the dominating country, accounting for 50% of the population of the total region.

Among the North African countries, Egypt has the largest share of rural population which is well above the MENA average, while Libya and Malta show a very low rural / urban population ratio. The other countries are close to the MENA average.

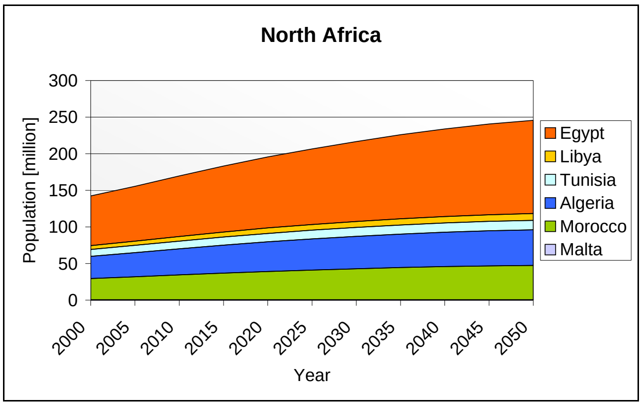

Figure 4: Population growth in North Africa

2- Western Asia

The population in the Western Asian countries will grow from 200 to well over 300 million people by 2050, being Iran and Turkey the dominating countries in this region.

Only Syria displays a rural population share that is well over the MENA average, however the total Western Asian rural population share is clearly below the MENA average. Israel and Lebanon are the countries with less rural population (Figure 5).

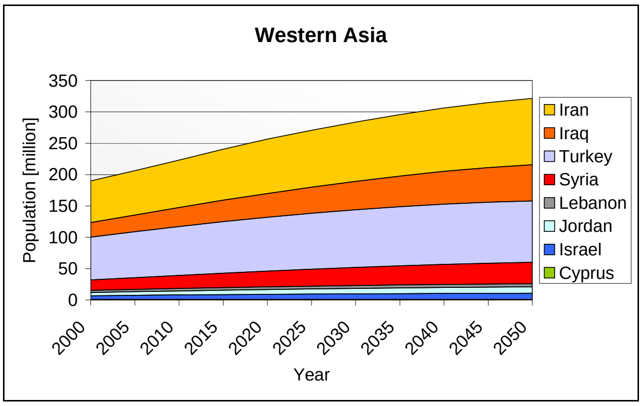

Figure 5: Population growth in the Western Asian countries

3- Arabian Peninsula

The population on the Arabian Peninsula will increase from today 50 million to 160 million people in 2050. The dominating countries are Saudi Arabia and Yemen. While the Saudi Arabian population will be stabilising by the middle of the century, the population in Yemen will still be growing quickly by that time, becoming the most populated country in this region. (see Figure 6)

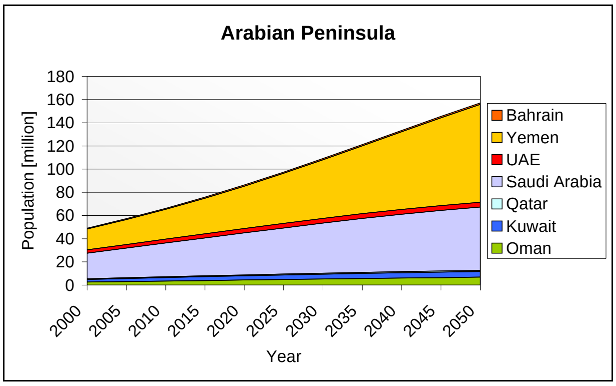

Figure 6: Population growth on the Arabian Peninsula

All countries in the region have a rural population share well below the MENA average, except Yemen, which has an outstanding high rural population share. Due to the strong influence of Yemen, the rural / urban population ratio of the Peninsula will become higher than the MENA average, although it is below its average today.

WATER RESOURCES AND WATER DEMAND IN MENA

The analysis shows scenario predictions for the demand and the resources of sweet water on country level. Inside a country, there might be regions with deficits that cannot be identified on the basis of statistical country wide data. The analysis of Spain or Italy at that level would not yield any deficits, however, we know that in Andalusia and Sicily, there is a severe water shortage, and plans are underway to build desalination plants in order to solve that problem. Excessive withdrawal of groundwater is also a common problem in many regions. The study concentrates on

those cases that can be identified as problematic on the basis of national statistics. Sub-national demand for non-conventional freshwater resources is neglected.
The following definitions have been used for the water balances in this study:

Renewable Water = Renewable Surface Water + Renewable Groundwater - Overlap

Exploitable Water = Renewable Water * Exploitable Share

Sustainable Water = Exploitable Water + Reused Waste Water

Water Demand = Agricultural + Domestic + Industrial Demand

Unsustainable Water	=	Water Demand - Sustainable Water
	=	Fossil Fuelled Desalination + Excessive Groundwater withdrawal
	=	Potential Future Deficit (to be covered by wind and solar powered desalination)

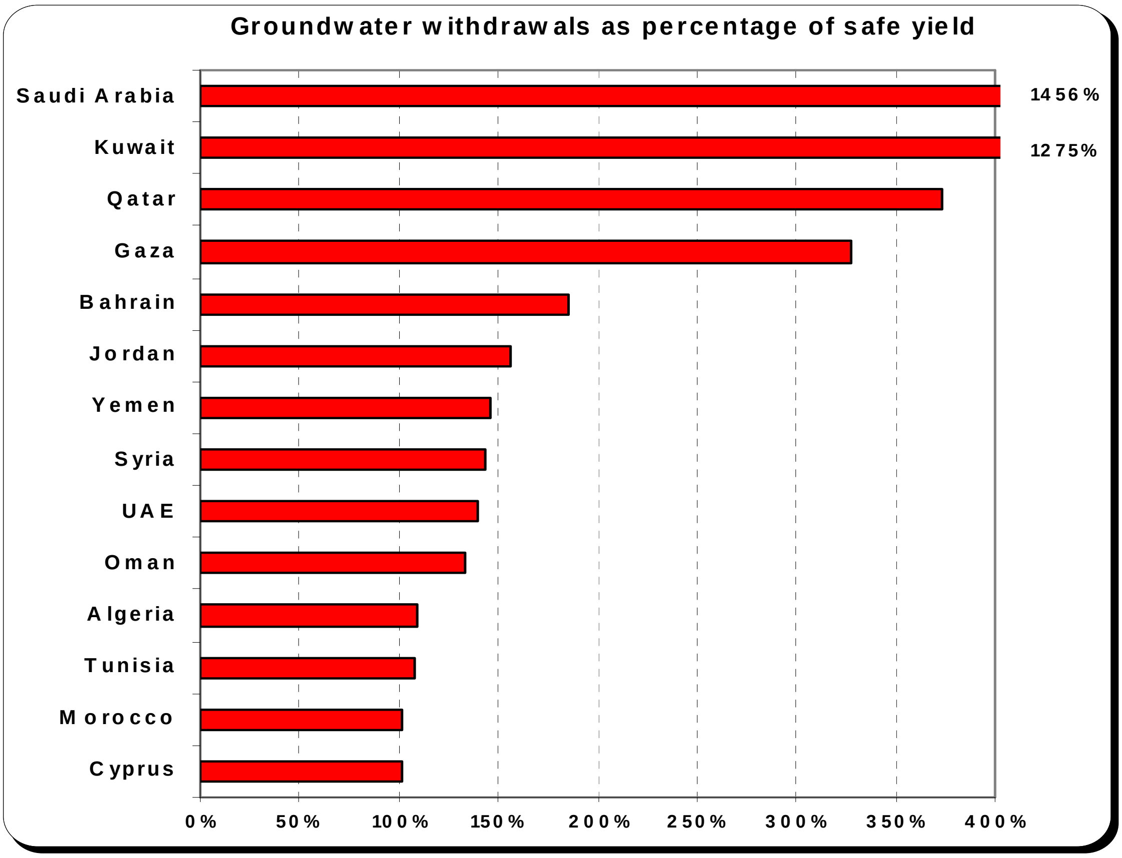

Figure 7: Groundwater withdrawals as percentage of safe yield for selected countries, Saghir 2000 [3]

Most of the actual data on water resources and use has been obtained from the AQUASTAT Database of the Food and Agriculture Organisation of the United

Nations (FAO), AQUASTAT 2004 [4]. Extrapolations to the future have been made on the basis of population and GDP growth rate expectations as described.

The extrapolation of future water demand on country level is based on the assumptions that:

1. Agricultural production and its water demand per capita will be maintained as today. This means that the demand of the agricultural sector will be growing proportionally to population,
2. the demand of the domestic and industrial sector will grow proportionally to the Gross Domestic Product GDP, which is calculated for every country adding the population growth rate to the per capita GDP growth rate,
3. the efficiency of water use in the agricultural and municipal sector will be increased from today's country specific values to a maximum value which depends on the selected scenario, the water demand growth rate thus becoming lower than the population or GDP growth rates. Enhanced technologies will additionally de-couple water demand from economic growth as experienced e.g. in Australia in the past decades, Gleick 1998 [7] and PWT 2004 [6].

Two different economic scenarios have been used as baseline for water demand predictions:

The scenario ***"Following Up"*** assumes an average per capita GDP growth rate of only 1.2% for every country from today until 2050. This implies that the relative distance between the actual GDP/capita (US$-PPP) of the respective country and Europe will remain constant because the GDP of Europe at the same time will also be growing by 1.2%. Efficiencies of the agricultural and the municipal water supply system and the reuse of wastewater increase gradually from the present national performance values to a future better value of an enhanced system. However, the efficiency enhancements are limited by the slow economic development. Population growth and the agricultural sector dominate the water demand growth rates in this case. De-coupling of the water demand from the economic growth by using enhanced water supply technologies is also limited in this scenario, Gleick 1998 [7] and PWT 2004 [6].

The scenario ***"Closing the Gap"*** assumes that the relative distance between the actual GDP/capita (US$-PPP) in Europe and the respective country is reduced to 0% until 2050 while the GDP of Europe at the same time is growing by 1.2%. This scenario assumes that the MENA countries will by 2050 achieve GDP per capita values close to that of the European countries. In this case, the industrial and domestic sectors will dominate the water demand growth. However, efficiencies will also be increased and a significant de-coupling of water demand and economic growth as experienced in Australia in the past decades will take place.

The 50 year average of GDP growth is limited to a maximum of 7% for both scenarios. This limits the per capita GDP growth rate for those countries that have a very high population growth rate, like e.g. Yemen.

The water demand in the MENA region is made up today by 85% agricultural use, 9% domestic use and 6% industrial use. The future demand is calculated individually for every country and aggregated to the regions of North Africa, Western Asia and Arabian Peninsula.

Under the assumptions of the scenario ***"Following Up"***, the share of agricultural water use will fall to about 80%, and the domestic and industrial share will increase to 12% and 8%, respectively. The total water demand will increase from today 300 billion m^3/y to about 510 billion m^3/y in the year 2050 (see Figure 1). The scenario reflects the influence of enhanced water management, policies and efficiencies that are of highest priority for a sustainable water future in MENA, but that are limited by the slow economic growth within this scenario.

Under the assumptions of the scenario ***"Closing the Gap"***, the share of agricultural water use will fall to about 66%, and the domestic and industrial share will increase to 18% and 16% respectively, more and more dominating the water demand. The total water demand will increase from today 300 billion m^3/y to about 540 billion m^3/y in the year 2050 (see Figure 2). The scenario also reflects the pronounced influence of enhanced water management, policies and efficiencies, giving them highest priority for a sustainable water future in MENA, especially in this scenario oriented to a high economic growth.

In terms of water demand, both scenarios are rather optimistic compared to other scenarios that predict a doubling of demand already for the year 2025, by extrapolating the water demand growth rates as experienced in the last decades. However, we believe that a reduction of the agricultural sector and the successive de-coupling of economic growth and water demand are more realistic approaches. On a first glance, it is surprising that both scenarios culminate in a rather similar water demand of 510 / 540 billion m^3/y by 2050 which obviously will be achieved with or without economic growth. It reflects the positive impact of economic stability and development on water supply. In the scenario "following up", consumption is limited by availability, while in the scenario "closing the gap", it is rather limited by the enhanced efficiency of the supply system.

As the future deficits and the additional demand for non-conventional resources will not change considerably assuming one scenario or the other, the scenario ***"Closing the Gap"*** **-** which is more desirable from the point of view of the MENA countries - will be used as reference in the further analysis.

Western Asia still has large sustainable water resources that will be increasingly exploited in the future. However, even in this region, non-sustainable use as from fossil fuelled desalination and from unsustainable groundwater withdrawal is already experienced on a local level and shows an increasing trend in the future. Unsustainable water supply from fossil fuelled desalination and from excessive groundwater withdrawal is considered as potential future deficit.

The sustainable sweet water resources of Northern Africa are today almost used to their limits, and therefore, no considerable increase of their exploitation can be expected for the future. Unsustainable use from fossil desalination and from excessive ground water withdrawal is already taking place to a considerable extent, with a dramatic increase of this situation ahead. On the Arabian Peninsula, the relation of sustainable and unsustainable use of water is even more dramatic.

The total annual water deficits in MENA will increase from today 35 billion m^3/y that are at present supplied by excessive groundwater withdrawals and fossil fuelled desalination, to about 155 billion m^3/y by the year 2050. There is no sustainable resource in sight to supply such deficits except renewable energies. The cost of fossil fuels is already today too high for intensive seawater desalination and its volatility and the fact that fossil fuels are limited in time eliminates fossil fuels as a resource for sustainable water security in MENA. Nuclear power is as well a very limited and costly resource, and in addition to that faces unsolved problems like nuclear waste disposal, proliferation and other serious security issues.

The water demand growth rates will decline in all three MENA regions from about 1.5%/y to less than 1%/y. The per capita water demand and its future trend is different in the three regions. The MENA average per capita demand is expected to stay almost constant at about 800 m^3/capita/year. Western Asia will reduce its per capita demand from 1000 to about 900 m^3/cap/y, while the demand in North Africa will grow from 700 to about 800 m^3/cap/y which is due to a relative moderate growth of the population and an increasing importance of the domestic and industrial sector, mainly in Egypt. The specific consumption on the Arabian Peninsula will fall from today 600 to about 400 m^3/capita and year, due to a strong growth of the population and a persisting importance of the agricultural sector, coupled with very limited natural water resources.

North Africa

The scenario assumptions lead to a linear growth of the water demand in North Africa from today 100 billion m^3/y to 200 billion m^3/y in 2050. The reduction in the agricultural sector is compensated by the growth of the domestic and industrial sectors. Sustainable sources in North Africa cannot be exploited to a greater extent than today. All countries will experience growing deficits, with Egypt being by far the dominating case, due a very strong agricultural sector and large population, followed by Libya and the Maghreb countries. The deficit of Egypt expected for 2050 might arise to the present water capacity of the Nile River of about 70 billion m^3/y. An official expectation of a deficit of 32 billion m^3/y until 2025 was recently published, Al-Ahram 21.03.04 [9]

The strong economic growth of the scenario “Closing the Gap” reveals the challenge of this path, as the water demand of the industrial and domestic sector will growth very quickly and overcompensate possible reductions in the agricultural sector.

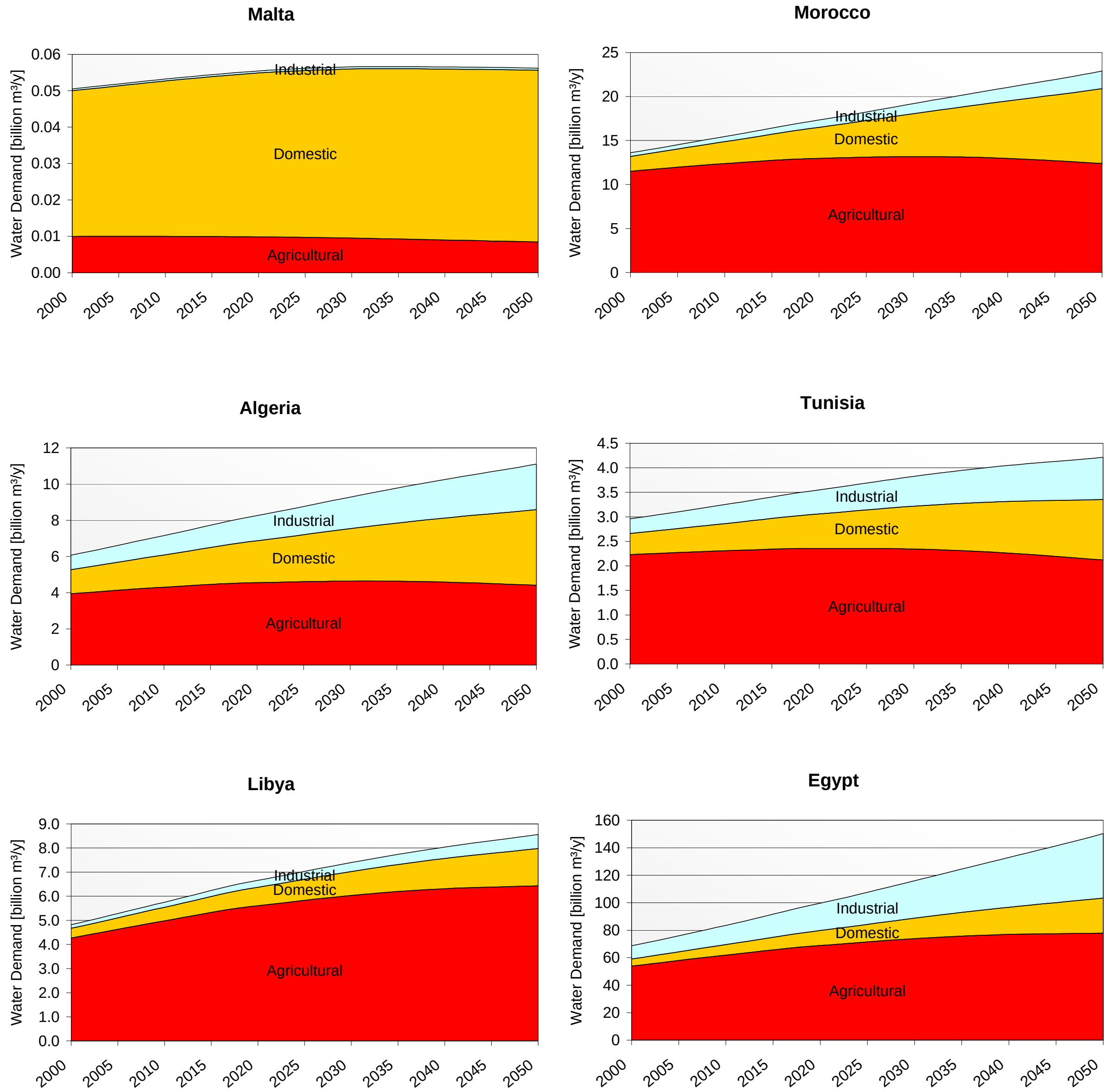

Figure 8: Development of the water demand structure for the North African countries until 2050

Western Asia

The water demand in Western Asia will increase from today 175 billion m^3/y to about 275 billion m^3/y in 2050, showing a slight stabilisation trend by that time.

There are vast sustainable water resources in that region which will be increasingly exploited in the future. However, local deficits will occur in Syria, Jordan, Israel and later also in Iraq.

The demand growth rates are high in Jordan but at a very low level of per capita demand, as can be appreciated from Figure 9. Strong consumers are Iraq, Turkey and Syria, with only Syria facing a short-term deficit. The average per capita demand of the Western Asian region will be slightly reduced from 950 to 850 m^3/cap/y, while in all countries the consumption growth rates will be reduced.

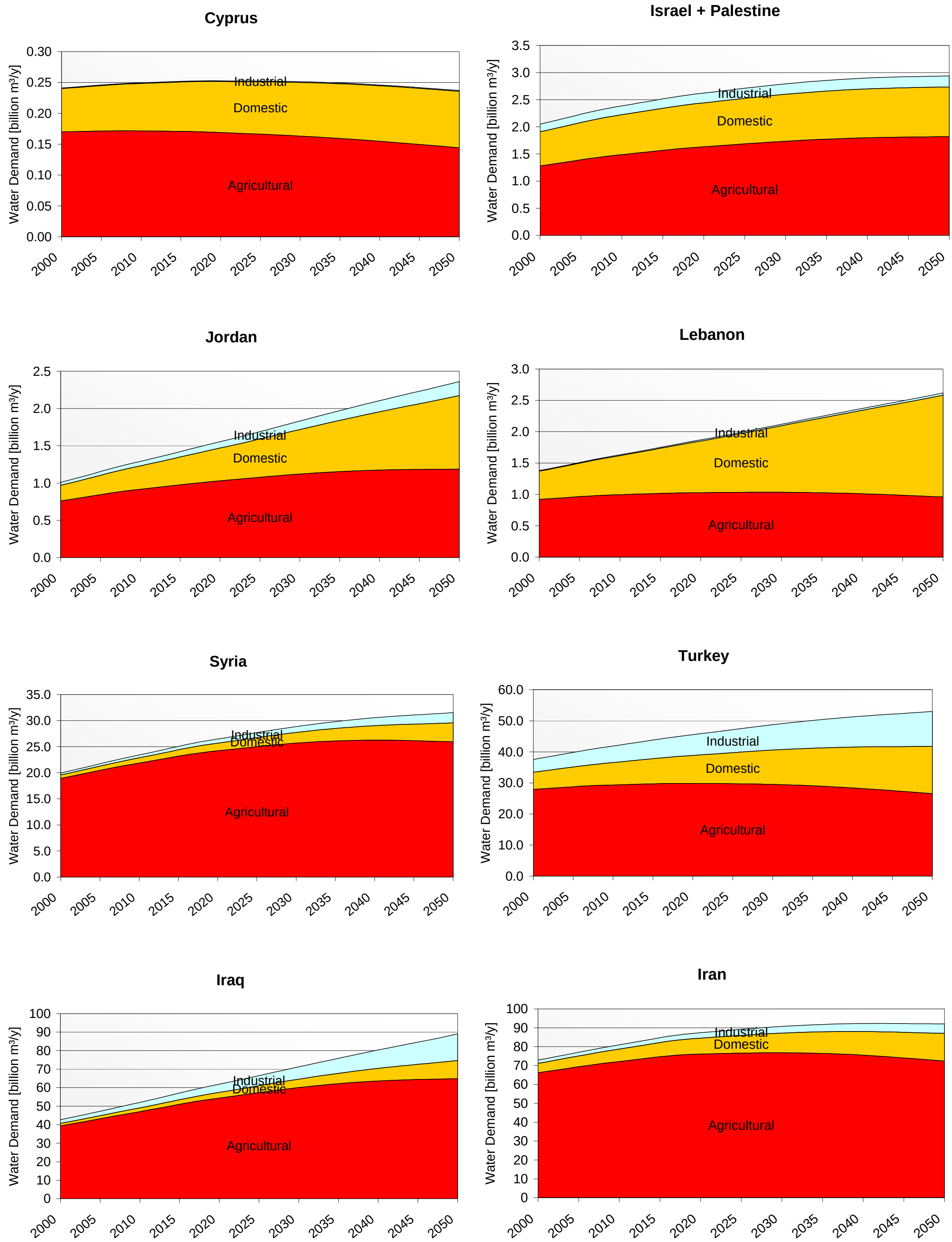

Figure 9: Development of the water demand structure for the Western Asian countries until 2050

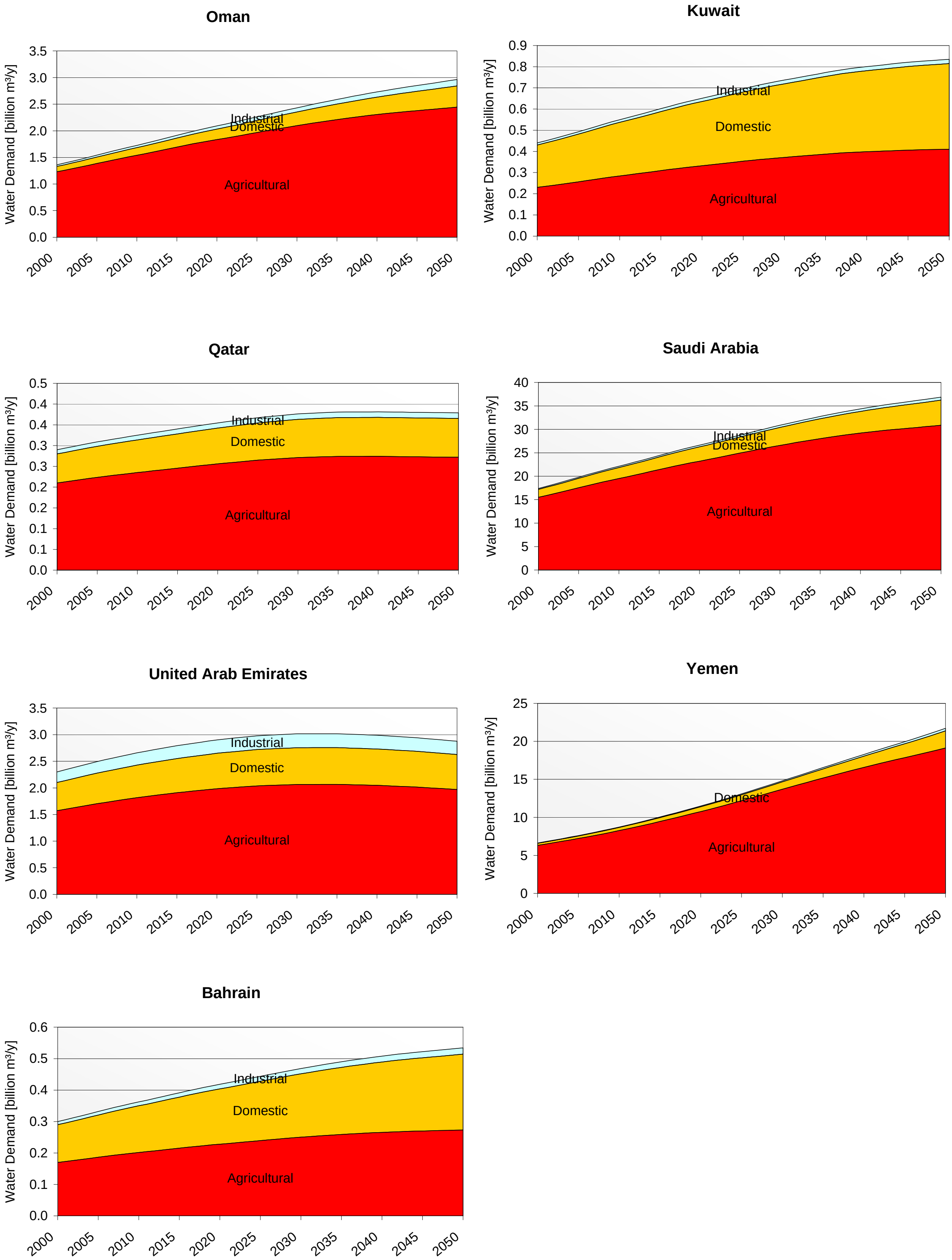

Figure 10: Development of the water demand structure for the countries of the Arabian Peninsula until 2050

Arabian Peninsula

The Arabian Peninsula is characterised by a strongly growing population and a dominating agricultural sector. The demand will increase from 30 to 65 billion m^3/y. The region's water demand is dominated by Saudi Arabia and Yemen, both relying to a great extent on non-sustainable sources, like fossil-fuelled desalination and excessive groundwater withdrawal. Due to the combination of high population and high dependency on agriculture, both countries will be facing considerable deficits, if their water supply would be persistently based on the limited resources of fossil fuels and non-renewable groundwater, as is the case today because the sustainable natural resources of this region are very limited.

The per capita consumption on the Arabian Peninsula will be reduced from 600 to 450 m^3/cap/y. Saudi Arabia and UAE will have the highest consumption per capita of about 800 – 700 m^3/cap/y. The strongest decrease of per capita consumption will be experienced in Yemen.

In terms of population growth and share of the agricultural sector, Yemen is a very specific case among the MENA countries. The per capita consumption will decrease from 400 to 250 m^3/cap/year, but the consumption growth rates will not decrease until after 2030. The scenario "Closing the Gap" would require a continuous GDP growth rate of Yemen of 11% until 2050 (a necessary 7.8% per capita growth rate to close the GDP per capita gap with Europe plus a 3.2% population growth rate), which is unrealistic and therefore was limited in this study to a maximum of 7%.

THE POTENTIAL OF DESALINATION BY CONCENTRATING SOLAR POWER

The previous analysis of water deficits in MENA shows that there is a pressing need for new, non-conventional, sustainable water sources in many countries of this region. The hot spots can be found in North Africa (mainly Egypt and Libya) and the Arabian Peninsula (mainly Yemen and Saudi Arabia), while the situation is by far less critical in the countries of Western Asia. However, Syria, Jordan and Israel also face considerable deficits. Although the demand of the agricultural sector, which in MENA makes up 85% of the total, will not grow as fast as in the past decades, this will be compensated by a quickly growing demand of the urban centres and industry, Al-Zubari 2002 [5].

The use of water is today heavily subsidised in many MENA countries, Saghir 2003 [3]. This reflects the fact that the cost of supplying water is already too high today considering the per capita income level, especially in the agricultural sector. Today, the cost of desalting water using fossil fuels ranges between 0.5 \$/m^3 (reverse osmosis) and 1 \$/m^3 (thermal desalination methods), which would be higher than the prices paid for water in most MENA countries. Economies building their water supply to a great extent on desalination with fossil fuels would suffer from additional subsidy loads, from the volatility of fossil fuel costs and from the gradual depletion and cost escalation of fossil energy resources. A severe stagnation of investments in the water sector is the consequence of this situation, the total water sector becoming more and more dependent on national and international subsidisation.

Today, many countries try to avoid an increasing dependency on desalination and fossil fuels by exploiting their groundwater resources. However, in many countries the exploitation rate is much higher than the renewable groundwater resources, making this solution not more sustainable than the dependency on fossil fuels. Therefore, a renewable, sustainable freshwater source with much lower and more stable costs than fossil fuels is required.

In the present study, we have assumed that the unsustainable water supplied by groundwater depletion and fossil fuelled desalination represents a potential future deficit that could be covered by Concentrating Solar Power (CSP) plants in co-generation with Multi-Effect Desalination (MED), and additionally using the remaining electricity for Reverse Osmosis (RO) desalination.

To estimate the minimum CSP capacity potential in the water supply sector, we have assumed that all plants would be coupled to MED desalination plants, while the electricity generated is completely used for RO desalination in order to produce larger amounts of desalted water. In view of the quick increase of future deficits of water in MENA, this could become necessary in order to substitute the un-sustainable water supply more quickly. This approach leads to the minimum installed capacity of CSP that is necessary to cover the future water deficits in MENA.

The capacity potential for CSP would in reality be higher, as part of the plants would be only used for co-generation of city power and MED desalination, but without RO desalination. The installation of such plants would be limited to the sea shore. Another part would only be used for power generation for RO, but without making use of co-generation with MED plants. Those CSP plants could be anywhere on the grid, while only the RO desalination plant must be located at the sea shore.

Today, 35 billion m^3/y of the water consumption in MENA are covered by non-sustainable water sources. According to the reference scenario “Closing the Gap”, this deficit will increase to about 155 billion m^3/y by 2050.

The figures show how these deficits could be subsequently covered by CSP desalination plants, reducing the non-sustainable water supply and providing most of the non-conventional water by the year 2030 and afterwards using solar energy. Deficits will have to be bridged by fossil fuelled desalination and groundwater withdrawals, hoping that those resources will remain available and affordable until then. This may seem optimistic, but there are no sustainable and affordable alternatives. On the other side, it is a reassuring fact that the potential of CSP is nether limited by the solar energy resource nor by its cost, but only by the possible speed of CSP capacity expansion, and that there is a solution for the freshwater deficits in

MENA that can be realised until 2030. However, a lot of time has been unnecessarily lost, leading to a considerable increase of non-sustainable water until 2030. This calls for the intensive additional use of other renewable sources like geothermal and wind power for non-conventional water production, and also calls for an intensive freshwater management in urban and rural applications. Only a decided employment and efficient combination of all possible measures will lead to a satisfactory and sustainable water supply security in MENA.

In MENA, the capacity of CSP plants until 2050 – if installed exclusively for seawater desalination – could amount to a total of 67 GW. North Africa (35 GW) has the largest potential for CSP desalination plants, followed by the Arabian Peninsula (24 GW) and the Western Asian countries (8 GW).

North Africa

The deficit in North Africa will grow from 16 billion m^3/y in 2000 to 84 billion m^3/y in 2050 with a major share of Egypt. The CSP capacity potential for desalination amounts to 32 GW for Egypt and 3 GW for Libya, while the other countries have minor shares. On the basis of country statistics, no potential can be detected for Morocco, Malta and Tunisia, although there may be deficits on the local level.

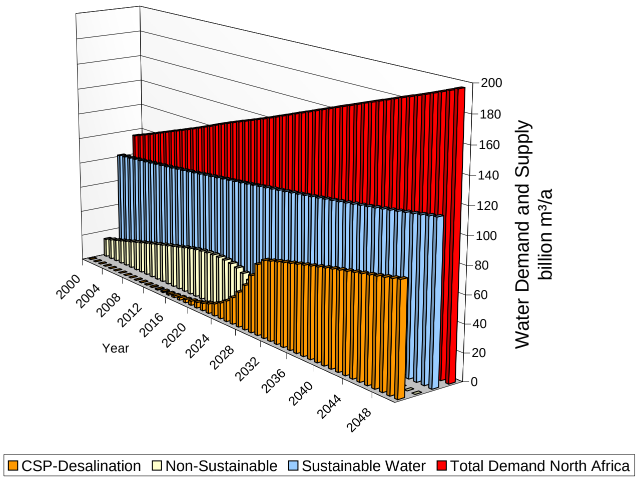

Figure 11: Water demand in North Africa

Western Asia

The deficit in Western Asia will grow from 0.5 billion m^3/y in 2000 to 20 billion m^3/y in 2050 with a major share of Syria, and after 2040, also Iraq. The CSP capacity potential for desalination amounts to 5 GW for Syria and 1 GW for Israel and Jordan, each. The other countries have minor shares. On the basis of country statistics, no potential can be detected for Cyprus, Lebanon, Turkey and Iran, although there may be deficits on the local level.

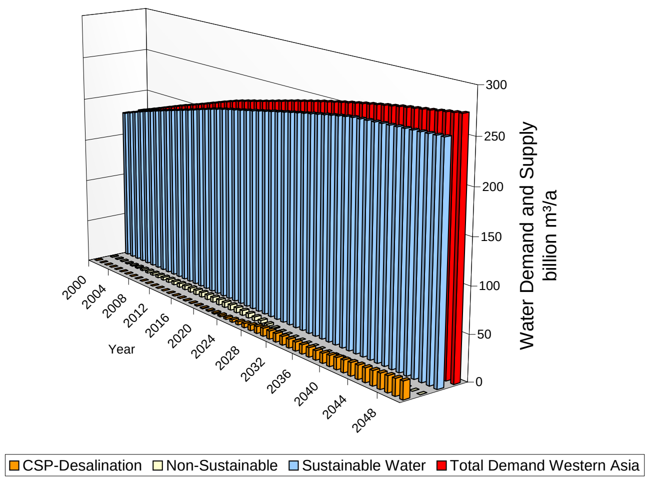

Figure 12: Water demand in Western Asia

Arabian Peninsula

The renewable water resources on the Arabian Peninsula are below 10 billion m^3/y. They may increase with time due to re-use efficiency gains, but will still remain small compared to the growing demand. The deficit on the Arabian Peninsula will therefore increase from 27 billion m^3/y in the year 2000 to 61 billion m^3/y in 2050 with a major deficit in Saudi Arabia and Yemen. The CSP capacity potential for seawater desalination amounts to 14 GW for Saudi Arabia and 8 GW for Yemen, while the other countries have minor shares.

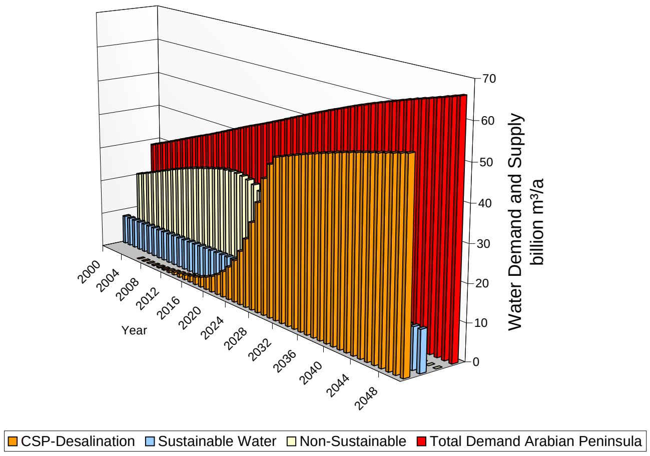

Figure 13: Water demand in the Arabian Peninsula

As a country example, the water demand scenario for Egypt is shown in Figure 14. The actual and predicted desalination capacities are shown in Table 1.

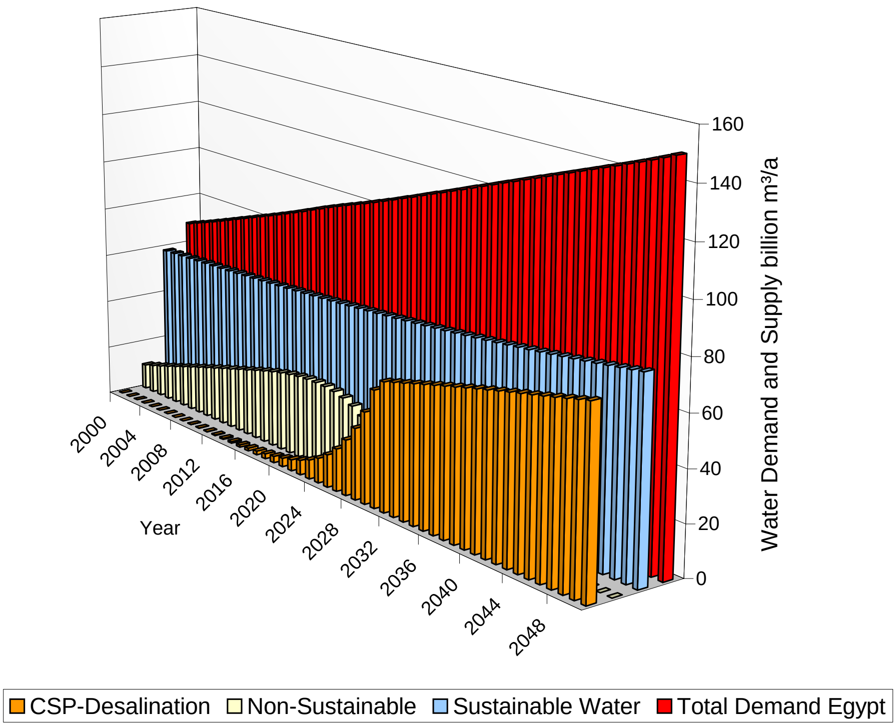

Figure 14: Water demand scenario for Egypt [1]

Table 1: Present seawater desalination capacities and non-sustainable use of water in 2004 and in 2050 as well as energy equivalent required for desalination in the MENA region, Wangnick 2004 [8]

	Multi-Stage-Flash 2004	MED+VC 2004	Reverse Osmosis 2004	Total Desalination 2004	Non-Sust. Water 2004	Desalination Scenario 2050	Energy for Desalination 2050
	Mm³/y	Mm³/y	Mm³/y	Mm³/y	Mm³/y	Mm³/y	TWh/y
Cyprus	2.8	0.9	49.2	52.8	5	90	0.31
Greece	2.5	5.0	7.6	15.1		24	0.08
Italy	93.4	43.3	58.2	194.9		305	1.04
Malta	8.6	1.5	41.2	51.3		80	0.28
Portugal	0.0	0.2	1.0	1.2		2	0.01
Spain	32.5	33.7	563.5	629.7		985	3.37
Turkey	0.0	3.2	0.3	3.5		6	0.02
Iran	116.7	39.8	4.5	161.1		252	0.86
Iraq	0.0	0.2	0.5	0.7		3840	13.15
Israel	2.6	11.0	419.6	433.2	340	1018	3.49
Jordan	0.0	0.4	1.6	2.0	560	1030	3.53
Lebanon	0.2	5.4	0.1	5.6		9	0.03
Syria	0.0	0.0	2.2	2.2	8000	12170	41.67
Bahrain	207.8	18.1	28.2	254.2	170	488	1.67
Kuwait	908.8	3.9	142.6	1055.2	370	1691	5.79
Oman	103.9	25.3	21.0	150.2	340	1820	6.23
Qatar	363.4	92.4	2.4	458.2	210	783	2.68
Saudi Arabia	1765.3	1119.1	288.9	3173.3	14800	29722	101.77
UAE	2122.0	835.4	237.5	3195.0	2000	4550	15.58
Yemen	0.9	22.5	0.3	23.8	2500	18040	61.77
Algeria	92.0	13.3	168.8	274.1	600	975	3.34
Egypt	53.8	7.0	53.0	113.8	10200	75000	256.80
Libya	320.6	156.5	24.7	501.8	4100	7330	25.10
Morocco	2.6	25.0	11.2	38.7	270	340	1.16
Tunisia	0.1	2.0	0.7	2.8	290	294	1.01
Total	**6201**	**2465**	**2129**	**10794**	**44755**	**160844**	**551**

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