A SUSTAINABLE SOLUTION TO THE GLOBAL PROBLEM OF WATER SCARCITY IN THE ARAB WORLD

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ABSTRACT

One of the biggest obstacles on the path of development of the southern Mediterranean countries is the limited water resources. The evolution in the last decades shows that the present limitation may strongly increase due to climate change. Considering the demographic development in these countries, leads to the collapse of the natural water supply system in the near future.

To visualise this dramatic situation, the statistics of surface water in Morocco in the last 70 years are analysed. The declination of rain volume and withdrawal of forests result together in a continuous and rapidly increasing silting of the water reservoirs.

As a recently published study performed by the Egyptian „National Water Research Center“ about non-conventional water resources, like seeding rain clouds to induce rain and seawater desalination, showed that seawater desalination is the only possible option to cover the growing water demand in the Arab World. The main disadvantage of this option is its high specific energy requirement, which is covered today mainly by burning fossil fuels.

Considering the enormous potential of available renewable energy resources, especially sun energy in the southern Mediterranean area, it is necessary, for the sake of sustainability, to use renewable energies for seawater and well-water desalination. In this respect, the concept of Combined Heat and Power (CHP) gives high advantages: in addition to producing electricity – which is needed any way – the waste heat of the power plant is used for thermal desalination. Significant cost effectiveness is achieved due to this “Double Product” strategy.

The paper presents a technology which combines these advantages and moreover, is maintenance-friendly and easy-to-install. The costs of the two products: Electricity and desalted water are within the range of competition, because several parts of the solar collector can be manufactured locally, taking advantage of the lower production costs.

Adopting this strategy ensures a real sustainability, because the blessing of strong sun power is available every where in the Arab World; and seawater is inexhaustible. The suggestion boosts economic growth and social development because of its simplicity thus giving the opportunity for local manufacturing of many components.

RAIN AND WATER AVAILABILITY IN MOROCCO:

Due to the geographic situation of Morocco, mountains in the north and desert in the south, the rain fall in a few parts reaches up to 2000mm/a, while in 80% of the states area less than 400mm/a and even in 40% of the area less than 100mm/a are the long term average.

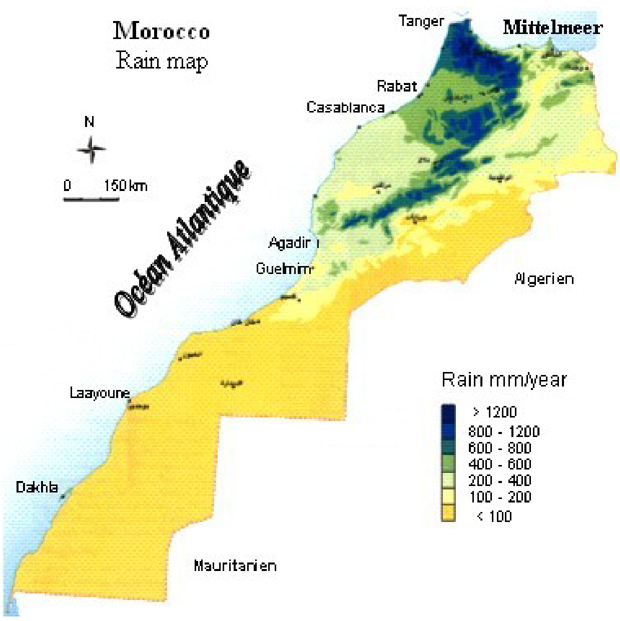

Fig. 1 Rain map of Morocco

The high solar irradiation of 2000kWh/m² yearly average on the total area results in an evapo-transpiration share of 80% of the total rain water volume.

The long term average 1935-1970 shows that 150 Billion m³/a rain falls on Morocco, however, only 30 Bm³/a are available after the evapo-transpiration.

About 10 Bm³/a infiltrate in the ground and fill up the ground water layers. A share of 2.5 Bm³/a emerge to the surface as water sources and add to the usable rain water of 20 Bm³/a giving 22.5 Bm³/a surface water. The remaining 7.5 Bm³/a of the infiltrated rain water add to the regenerative ground water potential. 2.5 Bm³/a of this potential are acting as barrier to prevent seawater intrusion to the costal ground water. A minimal stream from ground to Atlantic Ocean/Mediterranean of this magnitude is required to prevent effectively intrusion of salty water along the Moroccan coasts. Accordingly only 5 Bm³/a may be mobilized by extraction pumping from ground water wells.

The situation in the rural coastal areas e.g. between “Kenitra” and “Aljadida”, in which salty water intrusion already occurred showed that ground water extraction – especially during the dry years – exceeded its allowable limit thus reducing the minimal required stream of ground water in direction to the ocean. The inertia of this effect seems to be high, because following several good rainy years did not show a significant reduction of salt concentration in the wells affected.

Also the available surface water cannot be used in total. As seen from the rain map (Fig. 1) the largest rain volume is in the western part of the Rif Mountains. Two big dams “Alwahda” with a storing capacity of 3.73 Bm³ and “Oued-Elmakhazin” with 0.77 Bm³ storing capacity beside several other small dams were built on the south-western side of the mountains. The north-eastern side of the mountains having equally high rain volumes are characterised by a steep slope to the Mediterranean, thus limiting the technical and economic possibilities for erecting dams with water reservoirs.

Due to the mentioned above, the lost quantity of ground water and surface water is estimated to be 9 Bm³/a, that is about one third of the usable rain water.

EVOLUTION OF MOROCCAN WATER POTENTIAL:

The long term average values (1935-1970) of water availability are still used in many publications, even official ones. However, the yearly rain yield since 1970 shows, relative to the long term average of 150 Bm³/a, a trend to lower values (see Fig. 2). Also the extreme values, higher as well as lower in the last years coincide with the expectations of the climatologists in respect to the effects of green house gases in this region, namely reduction of the average rain volume and higher peak values of weather phenomena.

Run-off surface water is affected in analogy (see Fig. 3), then less rain does not only result in a higher share of evaporated water, but also may result in absolutely higher evaporation values. Years with lower rain yield are generally less cloudy, thus resulting in higher sun irradiance that accelerates evaporation. Accordingly the negative deviations in Fig. 3 are higher in Magnitude than corresponding ones in Fig. 2. While the negative deviation in Fig. 2 does not exceed -50% it is in the same year as high as 80% in Fig. 3

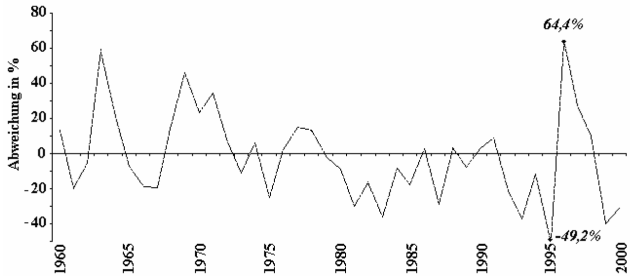

Fig. 2: Deviation of yearly rain yield from average 1935-1965

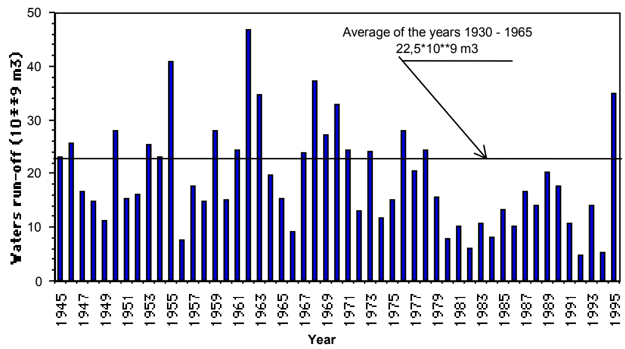

Fig. 3: Moroccan run-off surface water 1945-1995

Limiting the average to a 30 year period, shows a significant trend that may be described as dangerous (Fig 4). The run-off water 30-year-average yields a clear reduction in the second half of the twentieth century. Average of 1969-1998 is only 72% of the average 1950-1979.

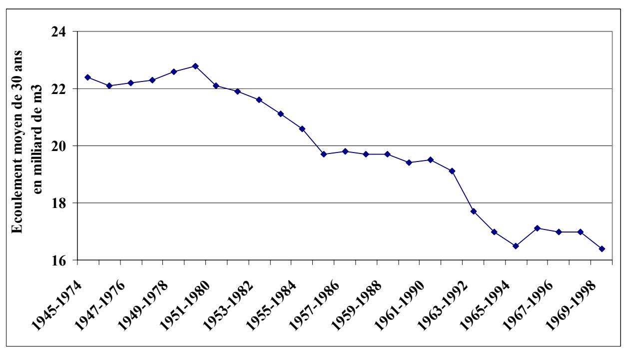

Fig. 4: 30-year average of run-off water

In some parts of the country this effect is still stronger. Fig. 5 and 6 originating from the neighbourhood of the “Alwahda” dam, show that the last 30-year average is nearly 40% less than that of the first 30-year average. (shows also the Moroccan average).

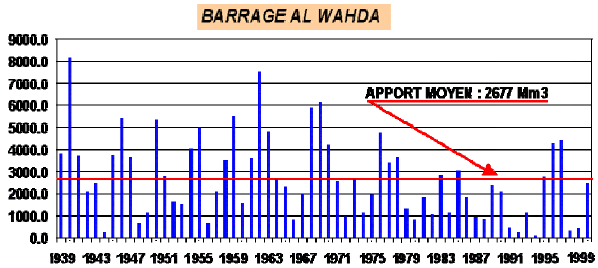

Fig. 5: Yearly average water run-off at “Alwahda” dam

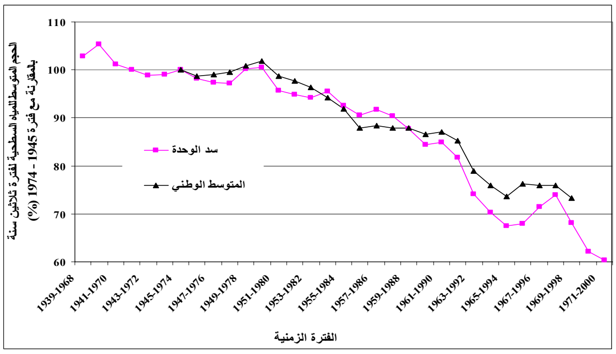

Fig. 6: 30-year average water run-off at “Alwahda” dam

Regarding ground water availability, the situation is still more dramatic. The reason thereof is the accumulating and partly strengthening effects of some parameters:

- Reduction of rain volume. As Fig. 2 shows, the years with reduced rain volume (relative to the 1935-1965 average) are more frequent in the last decades.
- Reduction of forest area. The usage of wood for heating in most regions of the country is larger than its production. This results in a yearly reduction of forest area of 30 000 to 50 000 hectares. This results again in less water infiltration and stronger erosion which in turn, not only means loss of fertile earth, but also a further reduction of water infiltration and silting of the storage basins of dams.
- Due to the increase of population, ground water withdrawal in most parts of the country exceeded the natural feeding by the ground water layers. In some regions land cultivation had to be reduced and, in extreme cases even abandoned by the farmers. In many villages the remaining ground water feed does not satisfy the drinking water demand for humans and domestic animals.

Fig. 7 shows the evolution of ground water level since 1980 in the rural region of the Moroccan cultural capital “Fes”. The high rain volume of 1996 caused a slight improvement of water level in the next three years, which was eliminated within the next 18 months as the water level sank for further 20 meters. Improvement of the water level in the year 1996 was reinforced by reduced water withdrawal for irrigation because of richly available rain water.

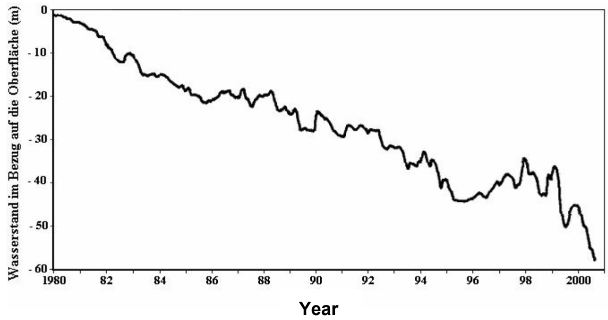

Fig.7: Ground water level in the region „Fes-Saïs“

The observed changes in the region of “Fes” were found – with different intensities – nearly every where in the country. In “Elhaouz”, a region westwards of the city of “Marrakech” extending to the Atlantic coast, results of measurements in a calibration well showed less dramatic results, Fig. 8.

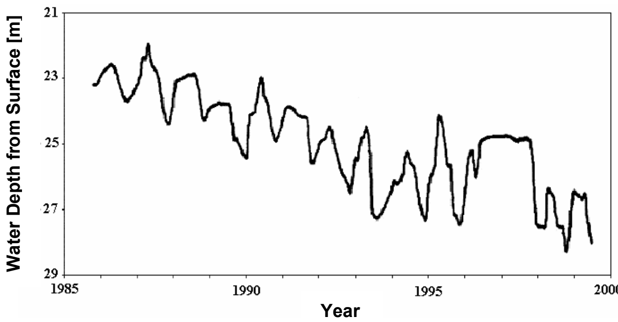

Fig.7: Ground water level in the region „Elhaouz“

In the basin of the river “Oued Sousse” between the two mountains “High Atlas” in the north and “Small Atlas” in the south, eastwards of “Agadir” till “Taroudant” and “Oulad Teima” most of the water bringing layers are to a depth of 270 meters totally or nearly dried. In this region enough water could be pumped from a depth of 30 to 40 meters in the past.

In the coastal region from “Rabat” southwards sank the ground water level in some areas – which are always getting larger – to an extent that seawater intrusion happened and well water became salty so that it cannot be used for drinking and not even for irrigation.

SILTING OF WATER RESERVOIRS:

Depending on ground structure and type of plants and their concentration, wind and water flow cause a natural erosion of the ground surface. As already mentioned, damage of forests increases the erosion. Also ploughing; this is usually done in direction of the natural ground slope, increases the erosion effect of rain water. And this results in silting of the water reservoirs (Table 1). The yearly loss of water storage capacity at the end of the last century was 60 Million m³. This corresponds to a loss of about 0.40% of the available storage capacity per year. The storage basins are burdened by silting in different grades, some small dam basins are so far silted that they are not mentioned in the table of dams.

Table 1: Loss of storage capacity of some selected dams

Dam	Storage Capacity $10^6 m^3$		Loss of Volume	
	1987	1999	$10^6 m^3$	%
Mohamed Elkhamis	725.7	410.9	314.8	43.4
Bin Elouidane	1484	1300	184	12.4
Mansour Eddahbi	566.9	528.9	38	6.7
Machraa Hammadi	42	6.6	35.4	84.3
Idriss Premier	1217	1185	32	2.6
Hassan Eddakhil	369.3	346.8	22.5	6.1

The silting speed cannot be easily reduced, it is even expected that it will increase because no significant activities were realised recently in the fields of ground protection or foresting. Also acceleration of forest damage due to climate change is expected to continue in the near future.

EVOLUTION OF WATER POTENTIAL PER CAPITA:

To demonstrate the urgency of the water topic, another aspect beside the mentioned negative effects that increases the problematic will be addressed now, it is the demographic evolution (Table 2) that is manifested in the water potential per capita.

Table 3 shows the dramatic reduction of water potential per capita from 1956 to 2004. In this period the population increased from 10.5 Millions to 30 Millions.

The development of the last years suggests that the mobilized regenerative water resources per capita will continue to decline. This has two main reasons:

1. The progress of silting cannot be slowed down. It is even expected that the process speeds up because no progress was achieved in ground protection projects and foresting. On the contrary, forest area decrease is continuing with increasing speed due to climate change.

Table 2: Evolution of the population in Morocco

Year	Population (Thausend)	Rate of increase Period	(%)
1900	5000		
1912	5400	1900-1912	0,6
1936	7040	1912-1936	1,1
1952	8953	1936-1952	1,5
1960	11626	1952-1960	3,3
1971	15379	1960-1971	2,6
1982	20419	1971-1982	2,6
1994	26019	1982-1994	2,06
2004	29892	1994-2004	1,4

2. The demographic development cannot be rapidly influenced. To satisfy the water demand of the actual increase of about 460 000 inhabitants per year, the mobilized water capacity has to be increased by about 250 Million m³ per year.

Both parameters together make it necessary to increase the mobilized water capacity by more than 300 Million m³ per year. Such an increase in mobilizing natural water resources is practically impossible. Mobilizing regenerative water resources reached its maximum in 1997 as the largest dam in Morocco, "Alwahda" (3.73 Bm³ storage capacity), was set in operation. Since then the water share per capita is declining.

Table 3: Mobilized Water per Capita

Year	Mobilized water per Capita m³
1956	1960
1966	1530
1976	1190
1986	930
1996	760
2004	690

Without additional water sources, the water deficit will keep growing, even if more dams are built in the future, since they alone will not mobilise more water per capita. Morocco must extend its efforts to find a new formula of water supply for the future.

SEAWATER DESALINATION IN MOROCCO:

Since Morocco has access to seawater along a coastline of more than 3,500 km, it is obvious that one of the options to get more water is desalination.

The National Office for Potable Water (ONEP) started its desalination experience in 1975 in the city of "Tarfaya" through the setting up of an Electro dialyse (ED) plant for brackish water. In 1977 a Mechanical Vapour Compression (MVC) plant for seawater desalination was set up in the city of "Boujdour".

After the first Reverse Osmosis (RO) seawater desalination plant was installed in 1983 in "Tarfaya" as substitution of the Electro dialyse one, the tendency to build new Reverse Osmosis plants continued as it is shown in Tables 4 giving also the Moroccan planning in the desalination field.

Table 4: Moroccan realizations in desalination field

City	Process	Feed Water	Capacity m^3/year	Set in Operation
Tarfaya	ED	Brackish	75	1976*
Boujdour	MVC	Seawater	250	1977*
Tarfaya	RO	Brackish	120	1983*
Smara	RO	Brackish	330	1986*
Boujdour	RO	Seawater	800	1995
Laâyoune	RO	Seawater	7 000	1995
Tarfaya	RO	Brackish	800	2001
Tan-Tan	RO	Brackish	1728	2002
Laâyoune	RO	Seawater	6 500	2006**
Boujdour	RO	Seawater	2 400	2006**
Tan-Tan	RO	Seawater	11 300	2007**
Agadir	RO	Seawater	43 200	2008**

*in cessation **in construction

(Source: The National Office for Potable Water ONEP)

A clear trend to larger desalination plants is obvious.

WATER SITUATION IN THE ARAB WORLD:

The water situation in Morocco is typical for the all Arab countries. Statistics show a serious deficit of water that already started in most countries and is getting more dramatic in the near future with different extents. Considering this dangerous trend, unconventional resources must be exploited.

As a recent study, performed by the Egyptian National Water Research Institute [1] and published at the 10th International Water Technology Conference (IWTC 10) in Alexandria, March 2006, in which different unconventional methods to produce water; like seeding clouds to induce rain and seawater desalination were investigated. The result was - especially considering Egypt but also valid for all other Arab countries – that seawater desalination is the only feasible method to cover the huge demand of water expected in the future. The apparent disadvantage is the need of energy to drive the desalination process.

A further study [2] presented to the same conference came to the same result (desalination is the only economically feasible solution). The study gave figures for the expected water deficit till 2050 and the required energy for desalination (Table 5).

Table 5: Water demand and energy for desalination in 2050

Country (Alphabetic)	Desalination Mm^3/year	Energy for Desal. TWh/year
Algeria	975	3.43
Bahrain	488	1.67
Egypt	75 000	256.80
Iraq	3 840	13.15
Jordan	1 030	3.53
Kuwait	1 691	5.97
Lebanon	9	0.03
Libya	7 330	25.10
Morocco	340	1.16
Oman	1 820	6.23
Qatar	783	2.68
Saudi Arabia	29 722	101.77
Syria	12 170	41.67
Tunisia	294	1.01
UAE	4 550	15.58
Yemen	18 040	61.77

These figures are calculated taking into consideration the increase in population and under the assumption that the peoples of these countries look forward to achieve the same standard of living – expressed in GDP (Gross Domestic Product) – of Europe in 2050.

Accordingly the energy (needed for development) and water (needed for living) considering all possible energy efficiency improvement possibilities and water saving techniques like reuse and drip irrigation, were calculated to meet these requirements.

It is worth to be mentioned that the study also showed that if these countries do not catch up with Europe till 2050, then the water and energy demands will not be significantly less than that calculated.

A look at table 5 shows that using fossil fuel to provide the necessary energy will not yield a sustainable solution that can be used for generations without drawbacks. Therefore the study came to the result that desalination processes must be mainly driven by a regenerative energy like wind power or concentrating solar power.

WATER DESALINATION TECHNIQUES:

A brief explanation of the major techniques used for desalination is given here to show the technical possibilities and limitations of application. All desalination processes discussed within this paper are fed with salty water, brackish (low salinity) or seawater (high salinity). It is important to consider the salinity of the feed water when comparing the processes as this is a decisive factor for energy requirement (other less important factors are not considered here). All processes are fed with a stream of salty water and produce two streams, one is potable water and the other is a brine of higher salinity than the feed water, which is usually discarded in the sea. The ratio of the steams depends on the process and the feed water salinity:

- Reverse Osmosis (RO): is pushing the water under a pressure depending on the salinity (up to 20 bar for brackish water and 100-120 bar for seawater) through a special membrane that prevents salt molecules from passing.

  The energy (delivered only by electricity to drive the high pressure pump) required for seawater desalination is much higher than that required for brackish water. Another important factor for calculating the running costs is the life cycle of the membrane.

  Running RO to desalt well water far away from the sea shore means that the brine has to be discarded somewhere. This is not always easy in the desert as the brine (usually big percentage) will infiltrate to the well and render it unusable in a few months.

  The potable water produced by the RO process has very little salinity; it is usable directly for drinking and irrigation.

- Thermal desalination processes: These depend on evaporating the salty water and re-condensing it, thus obtaining water of rain water quality that is usually not tasty for humans, so some salts have to be added. The energy requirement is independent from salinity of the feed water.

  Running costs are mainly the thermal energy used for evaporation, where most processes like MED (Multi Effect Desalination) capture and reuse the heat to minimize energy requirement. Main advantage of this concept is that it is independent from critical parts like membrane, thus delivery problems are avoided.

  Some thermal processes are able to concentrate the brine nearly to the degree of salt saturation, thus producing a much smaller stream of brine that can be stored in a basin in the desert and left for natural evaporation and salt production.

Both concepts are present on the market. RO is mainly used for small and medium sizes with a trend to large units especially with brackish water (less energy required), while the thermal concept is used mainly for medium and large sizes. In both cases energy produced from fossil fuel is the main source for driving the process.

Since most electricity production processes produce waste heat that is blasted in the air (diesel motor) or discarded to a river or the sea (condenser of steam turbine cycle) this waste heat can be used as main driver for the thermal desalination process. Investigations showed that a steam cycle process producing electricity may produce desalted water from its waste heat when designed for it. The heat energy discarded from a steam cycle is more than the electrical energy produced by it.

The cycle is then transformed to a CHP (Combined Heat and Power cycle) with a total cycle efficiency of up to 80% compared to pure electricity production which is in the best case about 40% for steam turbines and 50% for combined cycle electricity generation.

Summarizing the last two sections:

- All Arab countries have a serious water problem.
- Desalination is the only option to solve the problem.
- Energy for desalination must be produced from a renewable source.
- Small desalination units may be wind-power driven RO as they need only electricity.
- Large desalination plants must be driven by waste heat from a steam turbine electricity producing facility, on condition that the steam is produced by concentrating solar power.

The next section will show how CSP (Concentrating Solar Power) may give still more advantages in terms of economy.

POWER OF THE SUN:

The sunniest region on earth is the Sunbelt (Fig. 8)

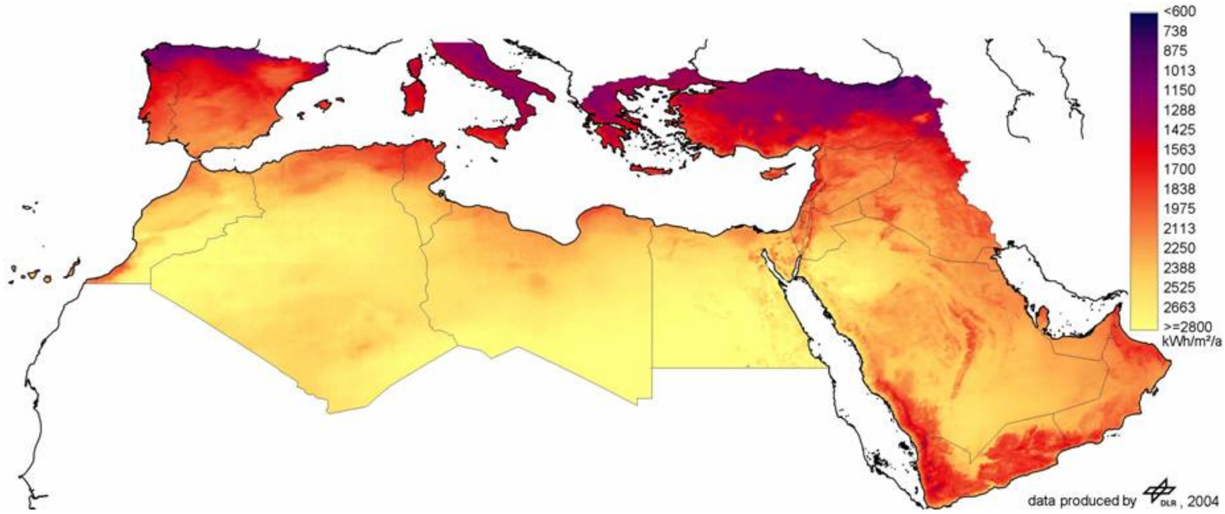

Fig. 8: DNI (Direct Normal Irradiation) with intensities up to 3000 kWh/m²/a (Source DLR)

The intensity of the sun radiation falling on one square kilometre within a year is equivalent to the energy produced by burning one Million Barrels of oil.

Several technologies utilize this intensive radiation. They are called Concentrating Solar Power. In this paper the flat mirror “Fresnel” technology will be describe.

Fig 9: Suggested decentralised power generation for a farm in southern Egypt. 80 000 m² reflector area to produce electricity, desalted water and cooling supported by shadow for farm inhabitants, animals and food processing industry (Source of graph: FHG-ISE)

CONCENTRATING SOLAR POWER TECHNOLOGY

A new approach to concentrating solar power by flat mirrors was proposed for the general development of a farm in southern Egypt (Fig. 9). Because of the multiple synergies that are present in the flat collector approach it is ideally suited for agricultural, industrial and social development in sunny desert regions.

- The simple construction allows its erection without strong foundations, with about half the costs of other solar collectors and to a very large extent with the help of local man power. Moreover, about 50-60% of the material is available in developing countries.
- Maintenance of the collector does not require highly qualified personnel; for this aspect the periodic cleaning of the mirrors is automated.
- The Sun radiation is used for Power Generation: A solar collector of about 80 000 m² allows for high grade steam generation delivering up to 45 MW thermal peak power (Fig. 10). That thermal power can be used for multiple purposes:
    - To drive a small steam turbine generating electric power (about 7 MW). This power could be used by the local farming industry for irrigation pumps and food processing.

- To drive an absorber cooling machine. The cooling power could be used for refrigerators - needed for vegetable storage -, freezing part of the farm production for shipping, or for centralised air conditioning systems.
- To drive multi effect (evaporative) water desalination units for the treatment of salty and brackish water found in the local underground or from the sea in case of coastal areas. The potable water produced – needed for humans, animals and food industry - can run up to 800 000 m³/year. The potable water exceeding the needs of the farm may be sold to neighbouring villages, thus increasing the farm's income.
- To charge a thermal heat storage unit to enable night operation of the turbine and desalination.

Fig. 10: Flat mirrors concentrate sunrays on receiver tube

- The area under the collector (flat mirror roof located between 3 and 5 meter above the ground) can be used for multiple purposes (Fig. 11):
  - Agriculture. In the shade the plants will need less water for irrigation (lower evaporation) but get sufficient indirect light to ensure growth. The water used to wash the mirrors will also be used by the plants.
  - Living and working area: Housing and/or manufacturing areas can also be developed under the mirror roof. They will need much less air conditioning as they are protected from direct sun radiation. For the same reason, stables or chicken farms could also be developed under the mirror roof.

Fig. 11: Available area with shadow under the collector

The high availability of extraordinary sun radiation in the Arab World and the high degree of collecting the sunrays by the flat mirror technology allows a significant fuel saving of about 7000 t/year. Moreover, processing food on site by the generated electricity and clean water gives the possibility to cultivate more valuable crops like vegetables.

The economic and social development of the population in this region will be strongly promoted due to the technology transfer and workmanship needed for erection of the solar field and - once that the plant is running - due to the better living and income conditions offered by the mixed agricultural and industrial structure.

CONCLUSION:

The appropriate solution to solve the problem of water scarcity is seawater desalination; however, this must be performed by renewable energy sources.

Wind power is suitable for driving RO units especially for small applications. Large scale desalination plants shall be driven by the waste heat of steam cycle power stations getting their heat for steam generation from CSP.

LITERATURE:

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