# Annex 1: Selection of Reference Plant Configuration

**Option A1.1: Central Receiver with Combined Cycle**

HTF Options: compressed air

Advantages: high efficiency for electricity

can be placed in difficult terrain

Disadvantages: not yet demonstrated

Storage: not yet available but possible (ceramics)

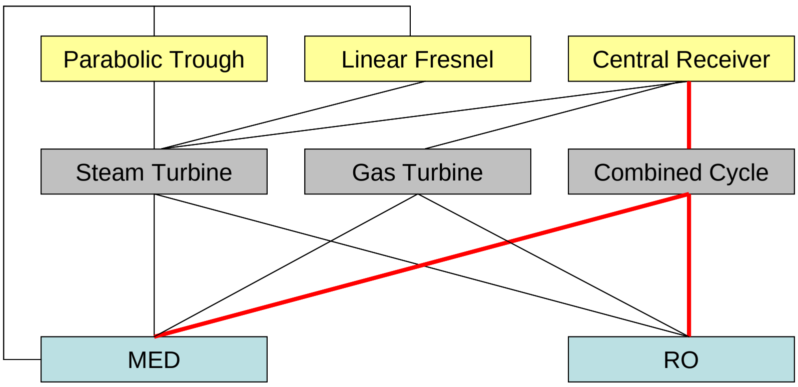


**Figure A1.1: Central Receiver with Combined Cycle**

**Option A1.2: Central Receiver with Gas Turbine**

HTF Options: compressed air

Advantages: can be placed in difficult terrain

no water consumption of power block

low cost power block

Disadvantages: reject heat at very high temperature for MED

low efficiency for electricity

high space requirement

only prototypes available (REFOS, Empoli)

Storage: not yet available but possible (ceramics)

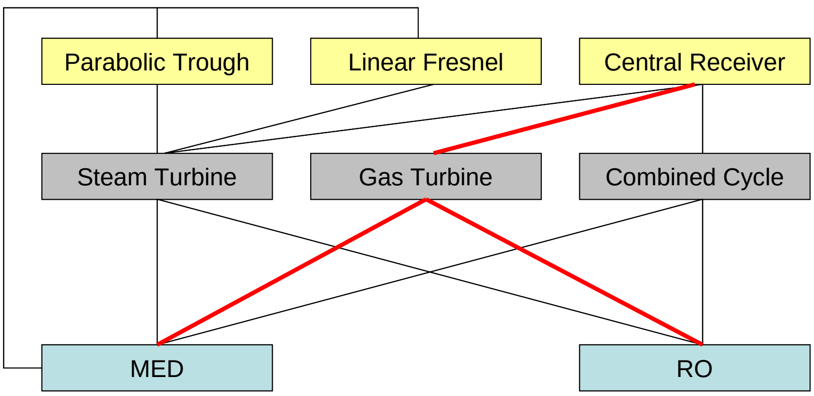


**Figure A1.2: Central Receiver with Gas Turbine**

**Option A 1.3: Central Receiver with Steam Turbine**

HTF Options: molten salt, direct steam, air

Advantages: can be placed in difficult terrain

Disadvantages: steam more expensive than by linear concentrators
high space requirement
only prototypes available (PS10, KAM, Solucar)

Storage: molten salt and ceramics demonstrated

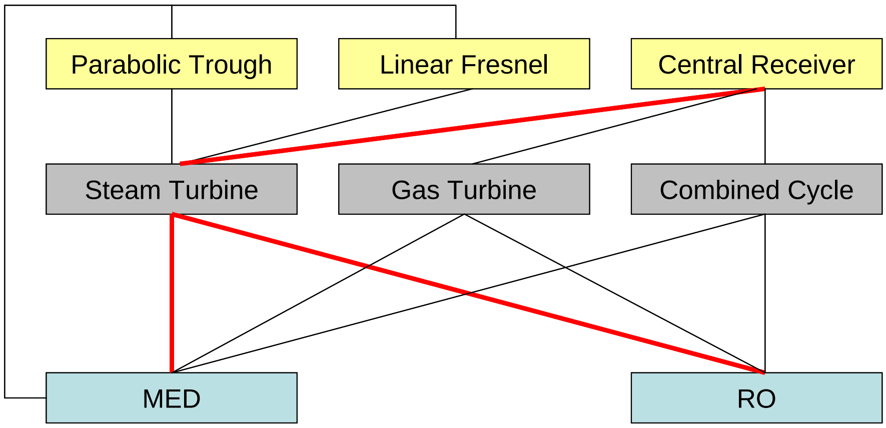


**Figure A1.3: Central Receiver with Steam Turbine**

**Option A 1.4: Linear Fresnel with Steam Turbine**

HTF Options: direct steam (oil or molten salt possible)

Advantages: low cost collector
low space requirement
easy integration (buildings, agriculture)

Disadvantages: only prototypes available (Novatec, MAN/SPG, SHP)

Storage: phase change or molten salt

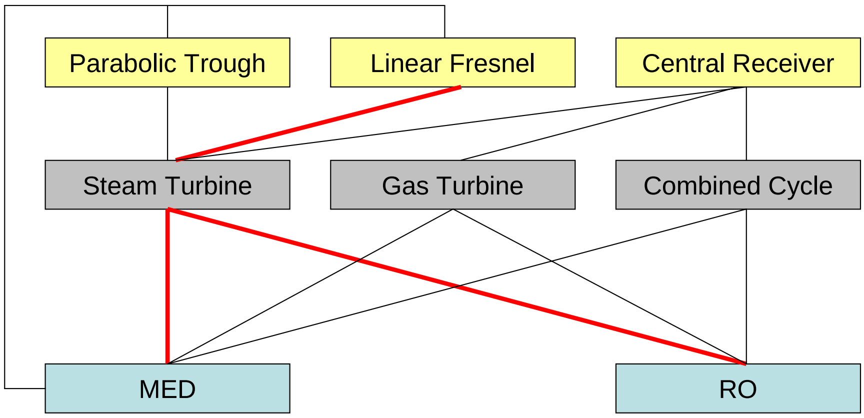


**Figure A1.4: Linear Fresnel with Steam Turbine**

**Option A1.5: Linear Fresnel for Direct Heat**

HTF Options: direct steam

Advantages: low space requirement

easy integration (buildings, agriculture)

Disadvantages: only prototypes available (Novatec, MAN/SPG, SHP)

Storage: very easy (hot water)

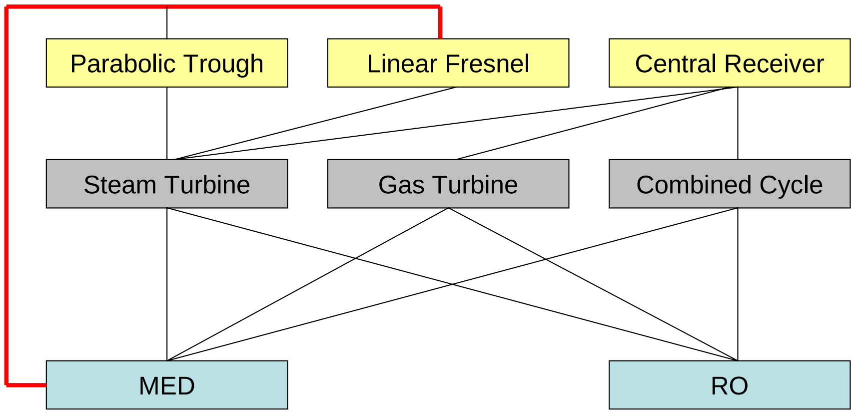


**Figure A1.5: Linear Fresnel for direct heat**

**Option A 1.6: Parabolic Trough with Steam Turbine**

HTF Options: oil, direct steam, molten salt

Advantages: most mature technology (Skal-ET, Schott, Flabeg, SMAG)

large plants build in Spain and USA (Acciona, Cobra)

Disadvantages: high precision required

high cost

high land requirement

no easy integration to buildings or agriculture)

Storage: concrete, phase change or molten salt

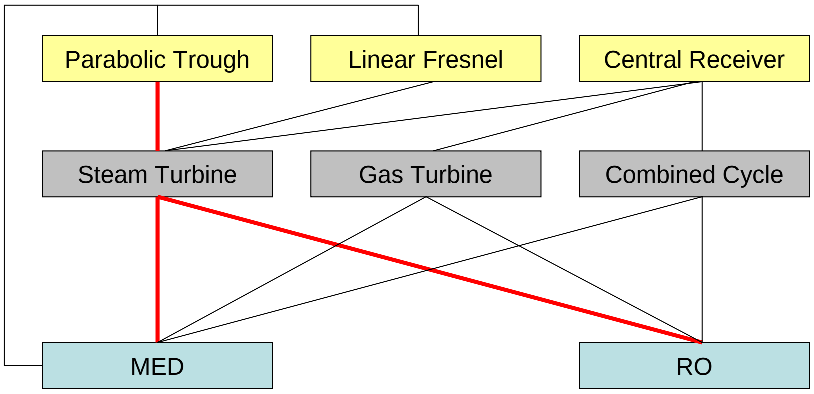


**Figure A1.6: Parabolic Trough with Steam Cycle**

**Parabolic Trough for Direct Heat**

Advantages: direct steam generation

low temperature collector available (Solitem)

Disadvantages: high cost

Storage: very easy (hot water)

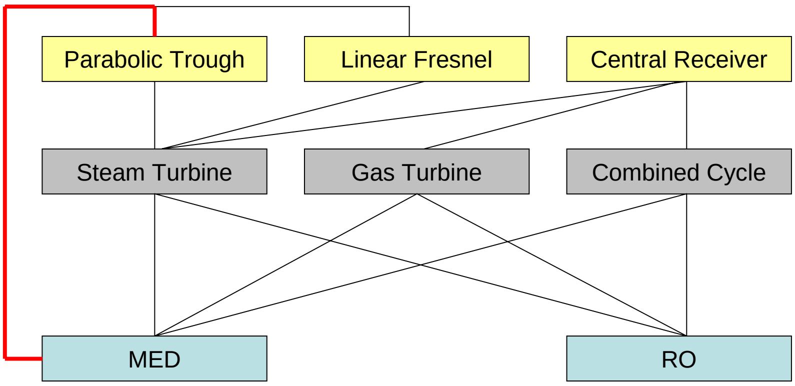


**Figure A1.7: Parabolic Trough for Direct Heat**

## Annex 2: Controversial Publications on CSP/RO and CSP/MED

Several publications have recently appeared stating that a combination of CSP with RO is much more productive and cost-efficient than CSP/MED, creating a rather controversial and unfruitful discussion within the CSP and desalination community. As they contain methodical errors, they are not quoted within our main report, but only within this annex, and errors are explained.

**Reference A 2.1:**

**G. Burgess and K. Lovegrove. Solar thermal powered desalination: membrane versus distillation technologies. Proceedings of the 43rd Conference of the Australia and New Zealand Solar Energy Society, Dunedin, November 2005.**

http://engnet.anu.edu.au/DEresearch/solarthermal/pages/pubs/DesalANZSES05.pdf

The authors state that the specific water output per square meter of collector area of a CSP (Parabolic-Dish-Steam-Cycle) system coupled to RO is much higher than that of a CSP/MED plant. This is in principle correct, as the electricity produced by the CSP plant will be fully used by RO, while MED will only use low-temperature steam extracted from the turbine and about 2 kWh/m³ of electricity for pumping, leaving most of the electricity generated by the CSP plant for other purposes. Therefore, a comparison on the basis of collector area only makes sense taking into account both products of the CSP plant (power and water).

Furthermore, the low values assumed by the authors for RO power consumption of 1.0 – 3.5 kWh/m³ suggest that not all the relevant components of the RO process have been taken into account, and that the delivered water quality is probably not comparable. The effect that MED replaces the cooling system of a CSP plant together with all its parasitic electricity consumption has been neglected. Therefore, the above mentioned conclusion of the authors generalising an advantage of CSP/RO is based on a miss-interpretation of their results and on incomplete input parameters for their comparison.

**Reference A 2.2:**

**O. Goebel. Solar thermal co-generation of power and water – some aspects to be considered. 13th International Symposium on Concentrated Solar Power and Chemical Energy Technologies, SolarPaces, Sevilla, Spain 2006**

This paper compares a CSP/MSF (Multi-Stage-Flash) configuration with CSP/RO and comes to the conclusion that the combination of CSP with RO would lead to a higher electricity output than combined generation when producing the same amount of desalinated water.

This statement is in principle correct, as MSF is a process that requires a lot of energy and operates with high temperature steam, resulting in a painfully reduced electricity output of the connected steam turbine. In fact, for those reasons MSF was discarded from our pre-selection in favour of MED. Unfortunately, the author does not mention that coupling MED instead of MSF to a CSP-plant would lead to a much better performance of solar thermal co-generation due to a lower internal electricity demand and lower operating temperature of the MED process. A CSP/MSF process cannot be considered representative for a modern solar powered co-generation system of this type, as suggested by the author.

**Reference A 2.3:**
**O. Goebel, A. Wiese, SOWELSI – Solar Water and Electricity for Sinai, International Desalination Association BAH03-069**

This paper compares a CSP (Parabolic Trough Steam Cycle with Storage) system with MED and one with RO seawater desalination, and comes to the conclusion that the distillation process clearly leads to higher power and water costs than RO, because RO requires less investment and energy.

The authors compare two CSP steam cycle power plants with identical parabolic trough solar fields, one coupled with RO and the other with MED that produce identical amounts of potable water. In design point, the CSP/MED variant produces 10 MW of extra net power, while the CSP/RO system produces 11 MW of extra power. This small difference of net power output, multiplied with the annual operating hours of the plant, finally leads to a seeming advantage of CSP/RO in terms of internal rate of return.

The comparison is based on the assumption that MED consumes 3 kWh electricity per $m^3$ of water. This is equivalent to 3.5 MW of required capacity which is subtracted from the rated output capacity of the power plant. A generally accepted value of power consumption of a modern MED would however be around 2 $kWh/m^3$ equivalent to less than 2.5 MW capacity.

The fact that a MED plant substitutes the cooling system of the CSP plant and its parasitic power consumption of 1-2 MW was neglected. A more realistic appraisal of input parameters would thus eliminate the seeming advantage of CSP/RO and lead on the contrary to an advantage of CSP/MED yielding at least 12 MW of extra net power compared to CSP/RO with only 11 MW.

The difference between CSP/MED and CSP/RO in terms of technical and economic performance is rather small. Although Goebel and Wiese admit using rough estimates of input parameters for their analysis, they neglect that a small variation (like e.g. power demand of MED and consideration of parasitic losses) would lead to an opposite result of their comparison. A general preference for one or the other technology, and especially for CSP/RO as suggested by the authors of the paper, is therefore not scientifically sound.

## Annex 3: Integrated Solar Combined Cycle System (ISCCS)

A **combined cycle (CC)** power station consists of a gas turbine (Brayton Cycle) and a steam turbine (Rankine Cycle). Fuel is used to provide hot, pressurized gas that directly drives the gas turbine for power generation. The residual gas leaving the gas turbine is still relatively hot and can be used to generate high pressure steam to drive a steam turbine for power generation with approximately half the capacity of the gas turbine. The gas turbine will provide 65-70 %, the steam turbine about 30-35 % of the total capacity of the CC plant. Today, this system has the highest efficiency of power generation from fossil fuel of well over 50 %.

An **integrated solar combined cycle systems (ISCCS)** has a parabolic trough solar field that additionally provides steam for the Rankine cycle of a combined cycle system. The steam turbine must be oversized to about 50 % of total capacity, because during daytime it will have to take both the flue gas from the gas turbine and additional solar heat, while it will be partially idle at night when no solar heat is available. During night time there will be a lower efficiency of power generation, either due to part load of the turbine or because of additional steam generation by fuel.

The solar share in design point operation is limited to the extra capacity of the steam turbine that is 20 % of total. A base load plant with 8000 operating hours per year will operate for about 2000 hours (a quarter of the time) with 20 % solar share and for 6000 hours (three quarters) on 100 % fuel. This translates to an annual solar share of only 5 %. This relatively small solar share will in any case be partially and in the worst case totally compensated by the lower efficiency during night time operation, as explained before.

If the system is build in a remote area because of higher solar irradiance, 95 % of the input energy – fuel – will have to be transported there, and electricity will have to be brought back to the centres of demand, causing additional energy losses. There is a considerable risk that an ISCCS would consume more fuel per net delivered electric kWh than a standard fuel-fired combined cycle on a usual site.

When Gottlieb Daimler invented the automobile, he took a horse wagon and a combustion motor, and put them together. Putting a concentrating solar field, a steam turbine and a desalination plant together would be something like that. If Daimler would have left the horse on the wagon when building his first car, he would have invented something like an ISCCS.

For those reasons, ISCCS has not been taken here into consideration as possible representative combination of CSP with seawater desalination.

# Annex 4: Current Project Proposals for CSP Desalination

In the following we will shortly present some statements on presently ongoing project developments for CSP desalination:

## Libya – MAN / Solar Power Group

The initial Libyan project is a R&D plant to expand and demonstrate the feasibility of solar thermal electricity and desalinated water production for Libya. It is expected that there will be a large demand for water desalination in Libya in the future, and solar powered systems could be a perfect fit for this situation. This is also expressed in the fact that the Libyan government has signed a cooperation agreement with SPG/MAN for 3,000 MW installed capacity of solar thermal power plants to be built within the next decade. The pilot plant will be build at the Center for Solar Energy Studies near Tripoli.

The technology to be applied will be of Fresnel-type solar thermal collectors with direct steam generation. The mirror area will be about 140,000 $m^2$. The rated output of the steam turbine will be about 15 MW while the maximum output of the multiple effect desalination plant is about 700 $m^3/h$ (http://www.solarpowergroup.com).

## Water for Sana'a from Solar Desalination at the Red Sea

The City of Sana'a is the Capital of the Republic of Yemen and it is one of the oldest and World Heritage City (see Fig.1). It is situated in the north west part of the country having an elevation of 2,400 meters above sea level. The population of Sana'a city according to 2004 census was 1.75 million (Total population of Yemen stands at about 20 Million inhabitants) with a population growth rate of 5.5% (2004 national census).

**Fig. 1: Window on UNESCO World Heritage City of Sana'a**

The water supply of the city and its surroundings is mainly extracted from the ground water reserves and from harnessing rain water. The ground water comes from a water basin which has a surface area of 3,250 $km^2$ while the rain water harnessing comes from the average annual rainfall of 200 – 400 mm that falls over the region.

The present water situation of Sana'a shows that the total ground fossil water reserve is at best in the region of 2 - 3 Billion $m^3$. The extraction rate for both domestic and irrigation purposes has been quoted at 260 Million $m^3$ per year (1), while the ground recharge rate has been averaging at about 52 Million m$^3$ per year[(1)]. It is therefore, been estimated that Sana'a Basin will be depleted between the years 2015 and 2020.

## The Water Demand

The water supply for Sana'a is approaching a critical point since about 80% comes from the extracted fossil reserves of its basin. As the basin is estimated to deplete by the year 2020 and the population of the city expected to exceed the 2.5 Million figure, it is imperative that the demand will be to supply enough water for at least 2 Million inhabitants by this time as the rechargeable water will only be enough for about 0.4 Million inhabitants. Therefore, it is proposed strategically that a water supply project targeting a supply of Solar Desalinated Water from the Red Sea in the region of 1.0 Billion m$^3$/year before the year 2020.

## The Sana'a Solar Desalination Water Project Proposal

The proposed Solar Desalination Water for Sana'a from the Red Sea Project is aimed at desalinating water using Concentrating Solar Power (CSP) from the Red Sea close to the coastal city of Hudaidah. The quantity of the desalinated water would then be transported a distance of about 250 km with an elevation of 2,700 m (Fig.2).

Even though Yemen is in the lucky situation of having oil and gas fields, of 3 Billion barrels of oil and of 480 Billion m$^3$ gas according to present estimates, their reach into the future is too limited for a water supply system: with the present production rate the oil reserves will be depleted in about 2022. If gas takes over however most of oil services after 2020, it is unlikely that gas supplies will last much beyond 2040, unless new fields are discovered.

The bottom line on desalination with fossil energy is: the domestic reserves may cease to be available after 2040. This will then lead to a nation-wide collapse of desalination and of power generation with fatal implications for the existence of Sana'a and with dramatic implications for the whole country.

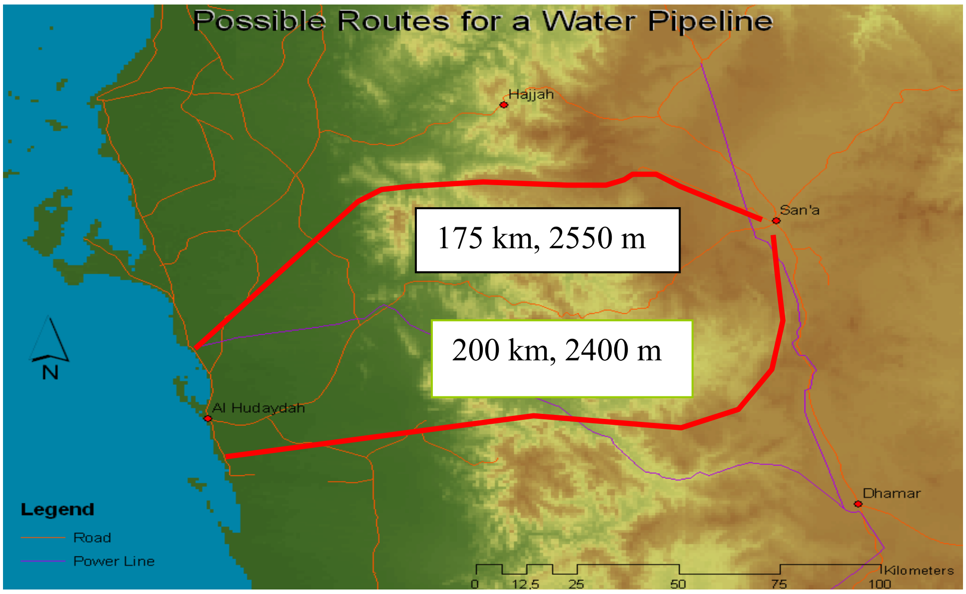


**Fig.2: Sana'a Water Project Pipeline Routes**

For above reasons the option of solar energy as the basis for a water and energy supply system with long-term security was chosen. Table 1, Fig. 3 and Fig. 4 shows that Solar Energy has great potential in Yemen, much larger than would be needed to accommodate the desalination and power generation needs of the country for the foreseeable future. For desalinating and pumping 1 Billion m³/year, a collector area of about 20 km² is needed. Therefore, "Solar Power Generation and Desalination of Seawater" as the preferred strategy for Water and Energy Security for Sana'a and for Yemen, and thus was considered for the "Sana'a Solar Water Project Proposal".

| | |
|---|---|
| Technical Potential | 14,150 TWh/y **(DNI > 1800 kWh/m²/y)** |
| Economic Potential | 10,230 TWh/y **(DNI > 2000 kWh/m²/y)** |
| Power Demand 2000 (Yemen) | 3 TWh/y |
| Power Demand 2050 (Yemen) | 383 TWh/y |
| Tentative CSP 2050 | 300 TWh/y |
| Coastal Potential | 390 TWh/y **(<20m a.s.l.)** |
| Water Demand 2050 | 62 TWh/y (Power for Desalination) |
| Sana'a Solar Water Project | 10 TWh/y (Desalination and Pumping) |

**Table 1: The Solar Thermal Power Potential in Yemen**[(2)]

## The Sana'a Solar Water Project Components

The Sana'a Solar Water Project is composed of three main components and these are the Solar Thermal Power Plant with a 1,250 MW power capacity which will provide enough electrical energy for the Desalination Processes and the Pumping Machinery, the Desalination Plants and the Transportation hardware such as Pipes, Pumps etc.. These components are described below:

| | |
|---|---|
| **Solar Thermal Power Plants** | **1,250 MW** |
| Solar Field Size | 21,120,000 m² (75% solar, 16 h storage) |
| Electricity Production | 10,000 GWh/y |
| Electricity for RO & MED | 2,700 GWh/y |
| Electricity for Pumping | 7,300 GWh/y |
| **Desalination** | |
| Multi-Effect-Desalination | 700 Mill. m³/year |
| Reverse Osmosis | 300 Mill. m³/year |
| **Transport** | |
| Pipeline: | 250 km steel pipeline, dia. 3000 mm |
| Pumping: | 4 pump stations and buffer basins |
| Infrastructure: | roads, power lines, … |

**The Sana'a Solar Water Project Investment Costs**

The Sana'a Solar Water Project investment is estimated to reach near the 11 Billion US$ covering the cost of all the three components of the project. The details of the share of the investment cost of each component are shown below:

| | |
|---|---|
| • Solar Thermal Power Plants | 4.0 Bill. US$ |
| 1,250 MW | |
| • Multi-Effect-Desalination | 1.5 Bill. US$ |
| 300 Mill. m³/year | |
| • Desalination Reverse Osmosis | 2.5 Bill. US$ |
| 700 Mill. m³/year | |
| • Infrastructure | 3.0 Bill. US$ |
| Pipeline/Pumping | |
| **Total Investment** | **11.0 Bill. US$** |

**The Sana'a Solar Water Project Water Costs**

The Sana'a Solar Water Project using CSP as compared to using an alternative energy such as the normal fossil fuels proves its economic viability as illustrated below:-

| **Fuel price in 2015** | **42 $** | **60 $** | **80 $/bbl.** |
|---|---|---|---|
| **CSP / Solar with MED/RO** | **Investment 11.0 Bill. $** | | |
| Water production costs | 0.7 $/m³ | 0.8 $/m³ | 0.8$/m³ |
| Pumping costs | 1.0 | 1.0 | 1.2 |
| Water costs in Sana'a | **1.7** | **1.8** | **2.0** |
| *(after 20 year depreciation)* | *0.7* | *0.8* | *1.0* |
| | | | |
| **Fossil with MED/RO** | **Investment 7.0 Bill. $** | | |
| Water costs in Sana'a | **2.2** | **2.7** | **3,4** |
| | | | |
| **Fossil CC with RO** | **Investment 6.7 Bill. $** | | |
| Water costs in Sana'a | **1.8 $/m³** | **2.3 $/m³** | **2.8 $/m³** |

- (est.: interest 6 % p.a., dept period 20 years, 40 years pipe & plant life)
- Sana'a WSS Corporation Tariff of 2004: about 160 Y.Rial / 0.86 $/m³)

**The Sana'a Solar Water Project Schedule of Phases (as of May 2007)**

- **-now- Kick-off: establish teams and base**
- **2007 Pre-Feasibility (6 months)**
- **2008 Feasibility (12 months)**
- **2009-12 Pilot Projects Yemen Al Hudaidah**
- **2009 EPC of the Pipeline**
- **2012 Operation of the Pipeline**
- **2010-17 Lighthouse 'Sana'a Solar Water'**

Edited by Towfik Sufian, University of Sana'a and Hussein Altowaie, University of Aden, Yemen.

## References

(1) Source: Sana'a Water and Sanitation Local Corporation (SWSLC), Yemen

(2) Source: DLR MED-CSP Study, see: www.TRECers.net

# Annex 5: Individual Country Data

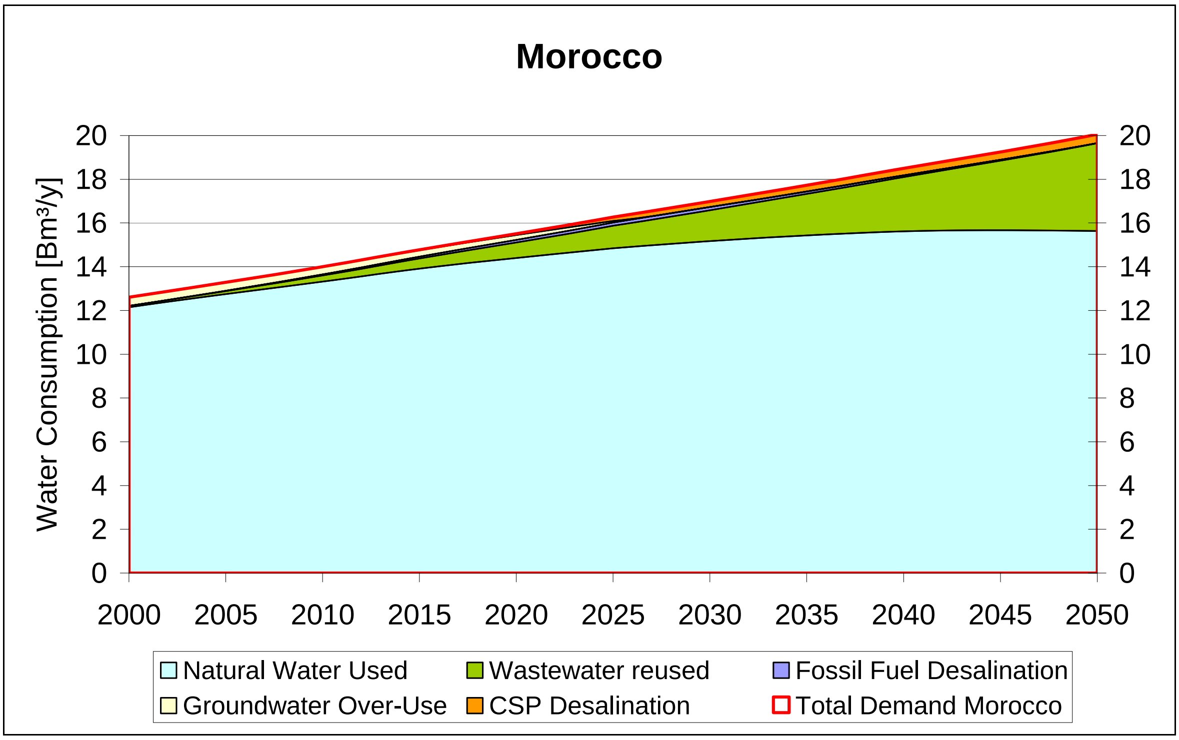


**Figure A- 1: Water supply scenario until 2050 in Morocco**

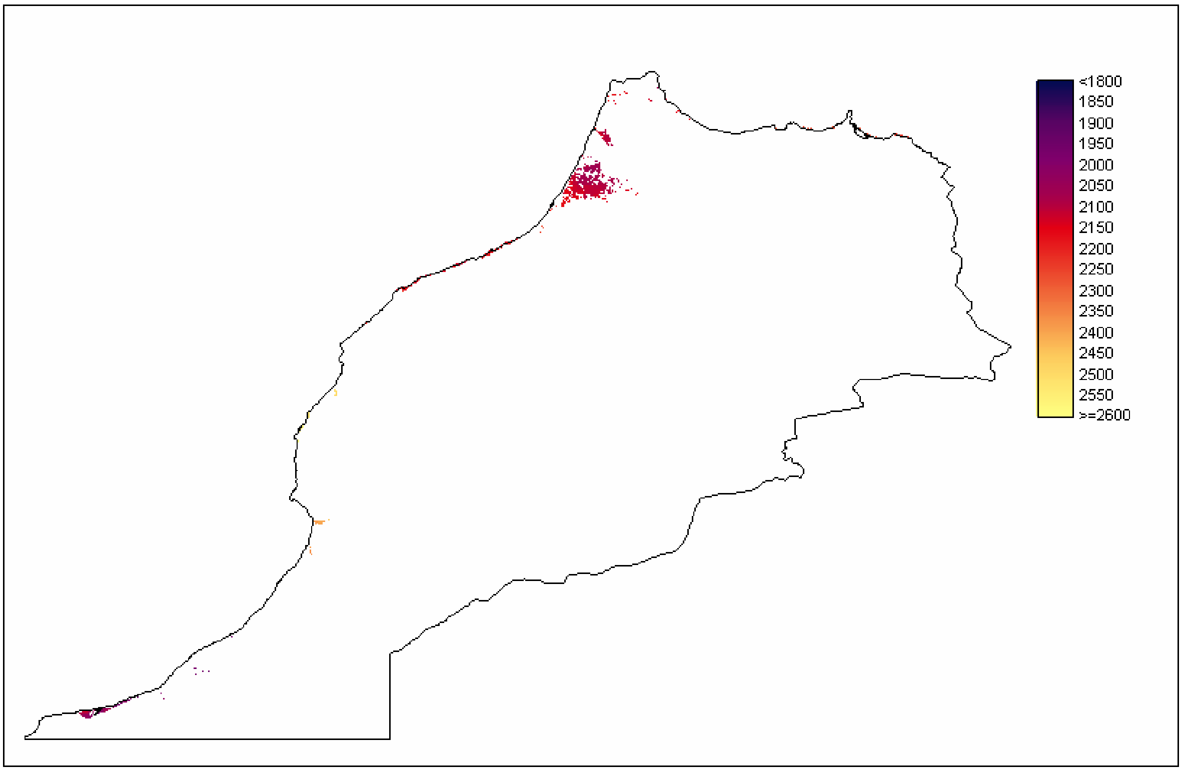


**Figure A- 2: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination plants**

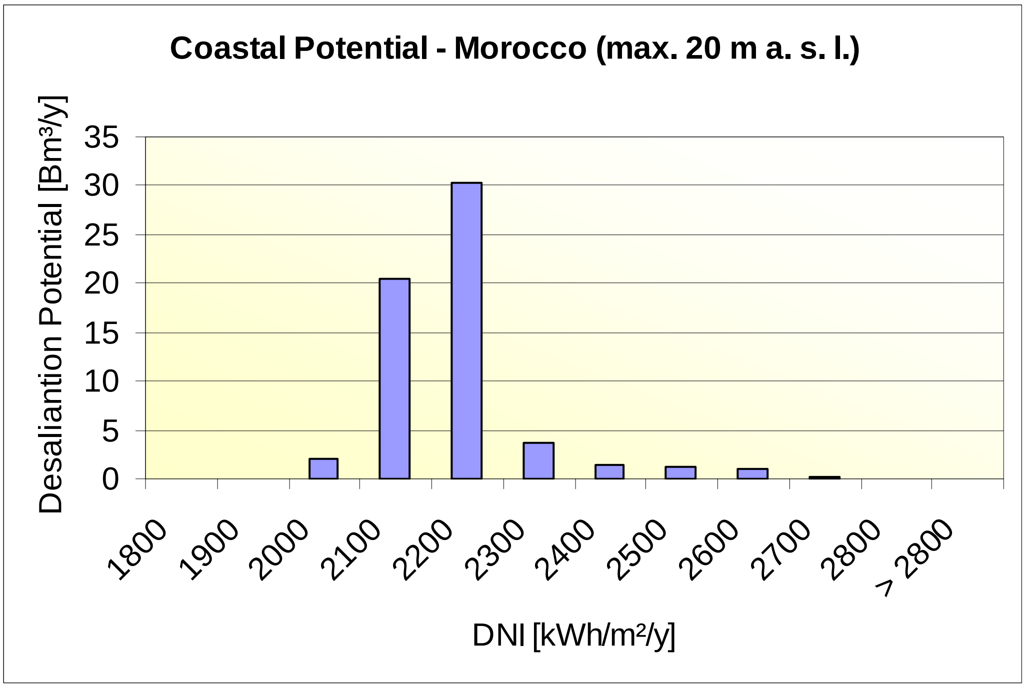


**Figure A- 3: Statistical analysis of the DNI map for CSP-desalination in Morocco**

| **Morocco** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 29.2 | 33.8 | 38.3 | 42.0 | 44.8 | 46.4 |
| Exploitable Water | Bm³/y | 20 | 20 | 20 | 20 | 20 | 20 |
| Sustainable Water | Bm³/y | 12.21 | 13.67 | 15.27 | 16.83 | 18.43 | 20.05 |
| Irrigation Efficiency | % | 0.37 | 0.40 | 0.44 | 0.47 | 0.50 | 0.54 |
| Agricultural Use | Bm³/y | 11.01 | 11.7 | 12.2 | 12.4 | 12.4 | 12.0 |
| Municipal Efficiency | % | 0.66 | 0.69 | 0.71 | 0.74 | 0.76 | 0.79 |
| Municipal Use | Bm³/y | 1.2 | 1.79 | 2.55 | 3.52 | 4.74 | 6.22 |
| Industrial Use | Bm³/y | 0.4 | 0.52 | 0.74 | 1.03 | 1.38 | 1.81 |
| Total Demand Morocco | Bm³/y | 12.6 | 14.0 | 15.5 | 17.0 | 18.5 | 20.1 |
| per capita Consumption | m³/cap/y | 432 | 414 | 405 | 405 | 413 | 432 |
| Wastewater reused | Bm³/y | 0.06 | 0.3 | 0.7 | 1.4 | 2.5 | 4.0 |
| Non-sustainable Water | Bm³/y | 0.4 | 0.4 | 0.3 | 0.1 | 0.1 | 0.0 |
| CSP-Desalination Potential | Bm³/y | 0.00 | 0.00 | 0.06 | 0.26 | 0.32 | 0.40 |
| Fossil Fuel Desalination | Bm³/a | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 |
| Groundwater Over-Use | Bm³/y | 0.4 | 0.3 | 0.2 | 0.0 | 0.0 | 0.0 |

**Table A- 1: Main scenario indicators until 2050 for Morocco**

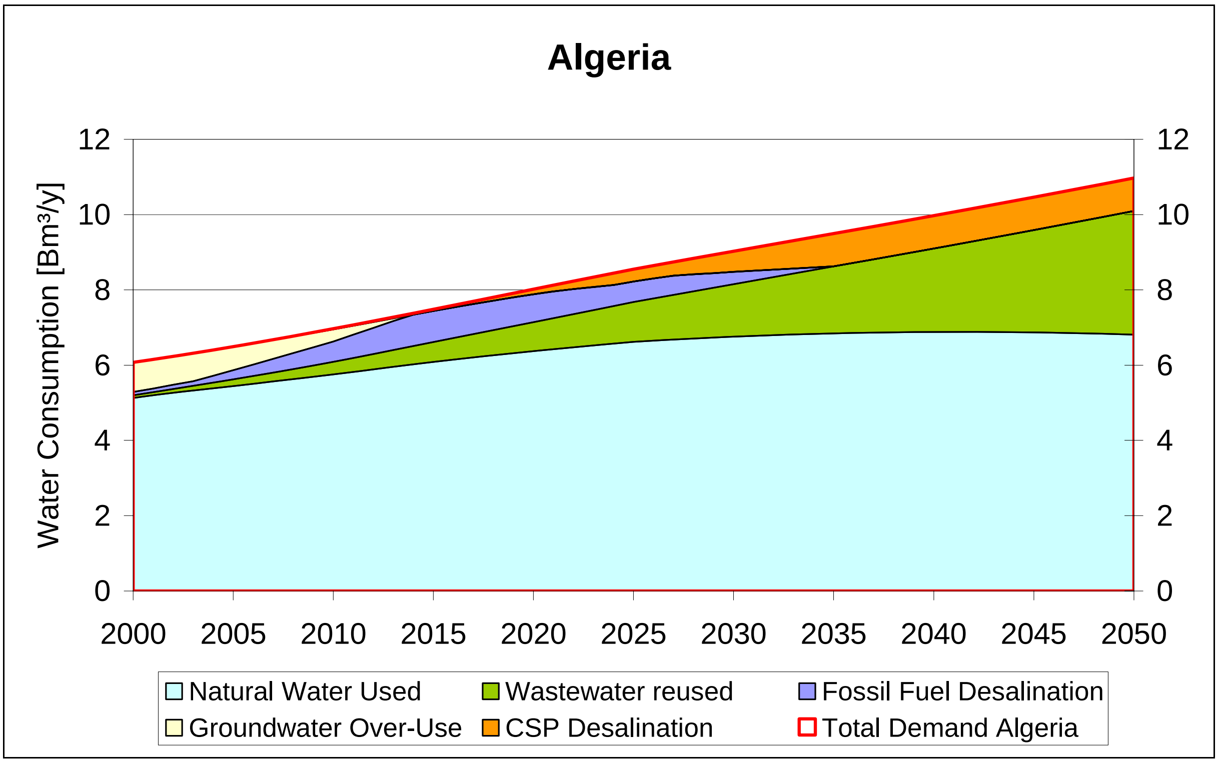


**Figure A- 4: Water supply scenario until 2050 in Algeria**

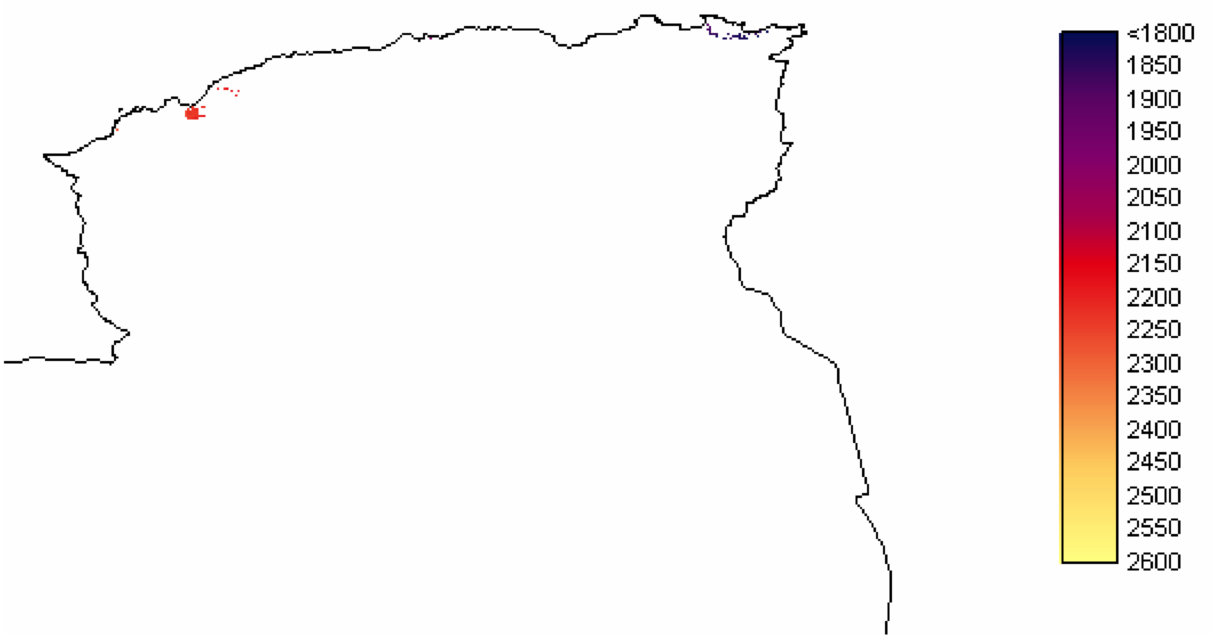


**Figure A- 5: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Algeria**

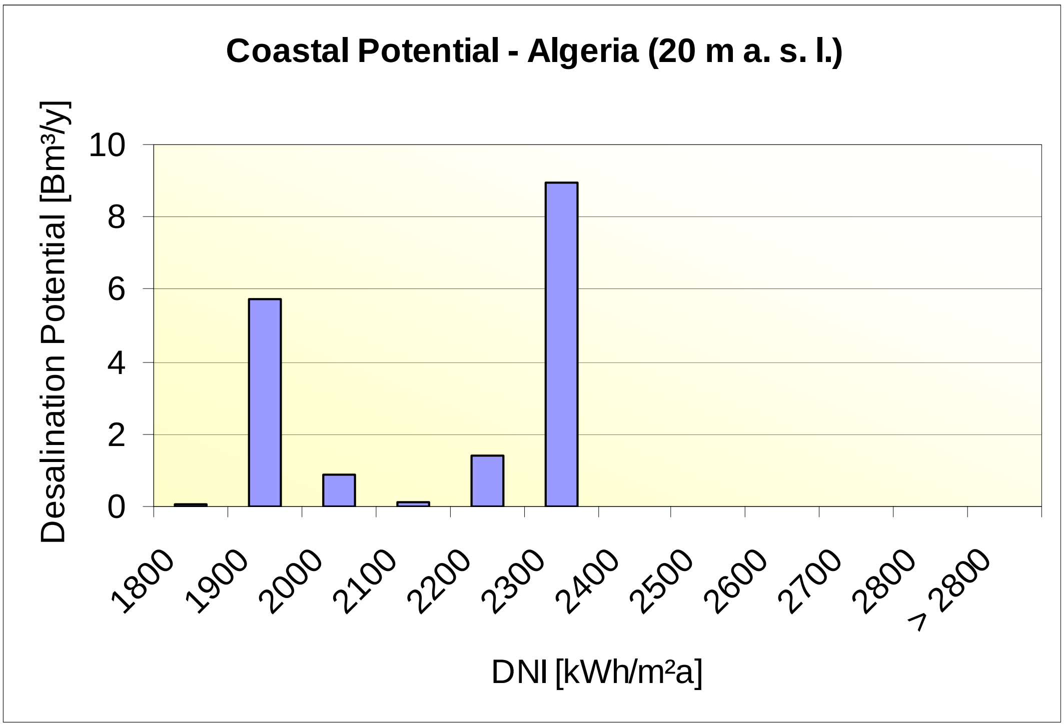


**Figure A- 6: Statistical analysis of the DNI map for CSP-desalination in Algeria**

| **Algeria** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 30.5 | 35.4 | 40.6 | 44.7 | 47.5 | 49.5 |
| Exploitable Water | Bm³/y | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 |
| Sustainable Water | Bm³/y | 5.20 | 6.24 | 7.48 | 8.67 | 9.79 | 10.97 |
| Irrigation Efficiency | % | 0.37 | 0.40 | 0.44 | 0.47 | 0.50 | 0.54 |
| Agricultural Use | Bm³/y | 3.94 | 4.2 | 4.4 | 4.5 | 4.5 | 4.4 |
| Municipal Efficiency | % | 0.49 | 0.54 | 0.59 | 0.63 | 0.68 | 0.73 |
| Municipal Use | Bm³/y | 1.3 | 1.73 | 2.24 | 2.81 | 3.42 | 4.11 |
| Industrial Use | Bm³/y | 0.8 | 1.04 | 1.35 | 1.69 | 2.06 | 2.47 |
| Total Demand Algeria | Bm³/y | 6.1 | 7.0 | 8.0 | 9.0 | 10.0 | 11.0 |
| per capita Consumption | m³/cap/y | 199 | 197 | 198 | 202 | 210 | 222 |
| Wastewater reused | Bm³/y | 0.07 | 0.3 | 0.8 | 1.4 | 2.2 | 3.3 |
| Non-sustainable Water | Bm³/y | 0.9 | 0.9 | 0.7 | 0.3 | 0.0 | 0.0 |
| CSP Desalination | Bm³/y | 0.00 | 0.01 | 0.14 | 0.55 | 0.87 | 0.87 |
| Fossil Fuel Desalination | Bm³/a | 0.1 | 0.5 | 0.7 | 0.3 | 0.0 | 0.0 |
| Groundwater Over-Use | Bm³/y | 0.8 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |

**Table A- 2: Main scenario indicators until 2050 for Algeria**

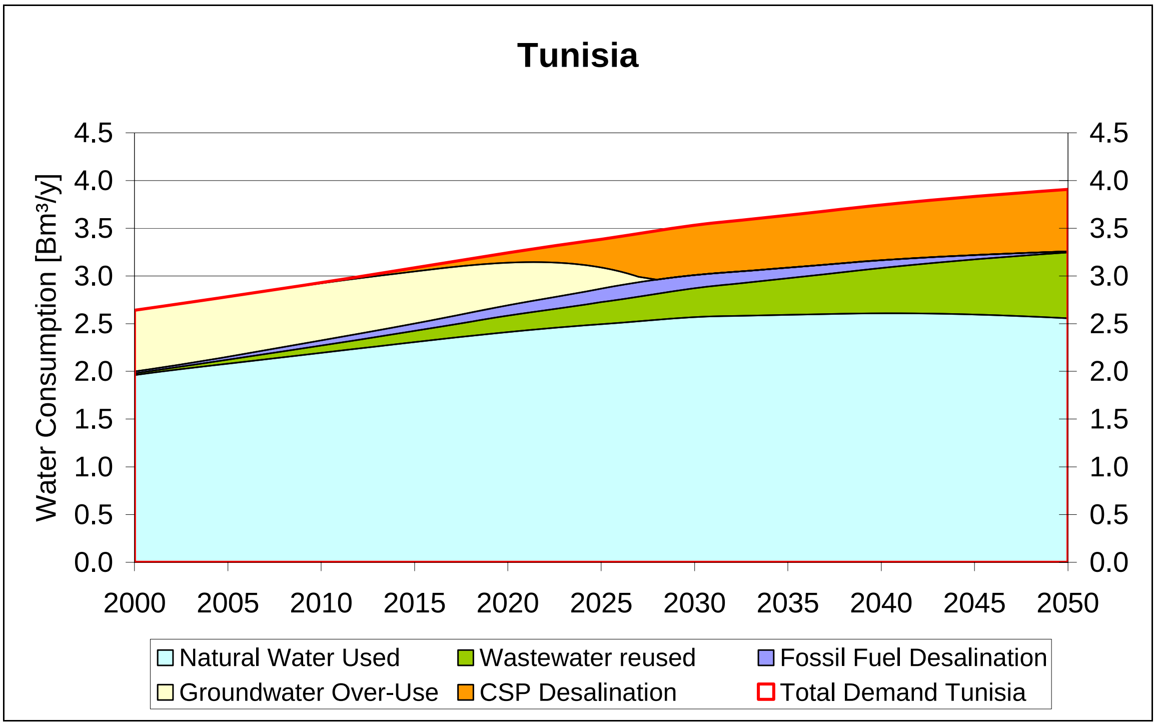


**Figure A- 7: Water supply scenario until 2050 in Tunisia**

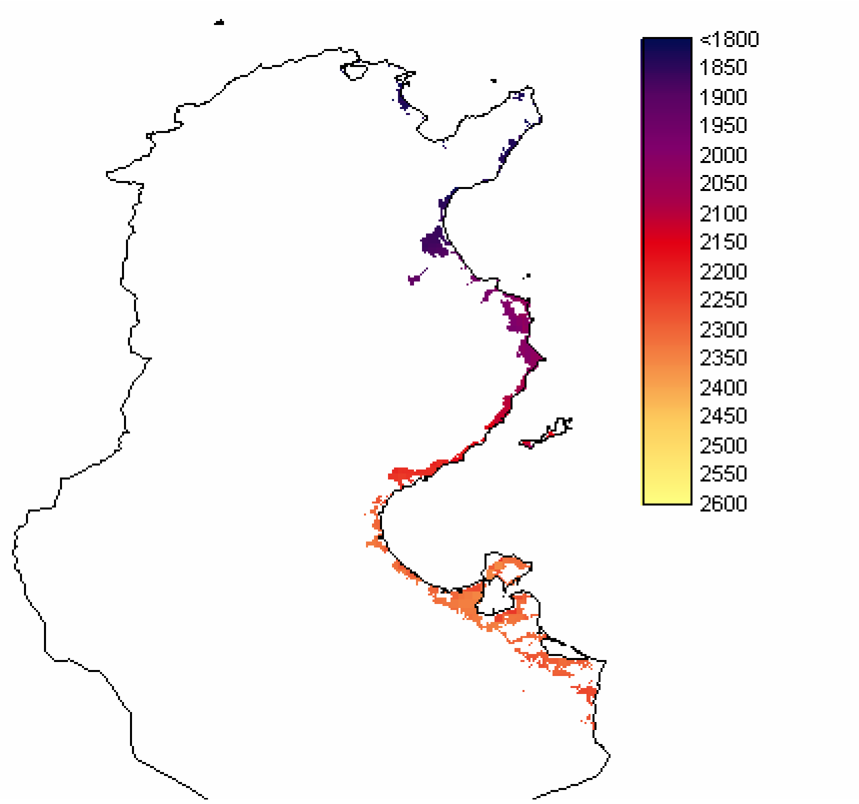


**Figure A- 8: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Tunisia**

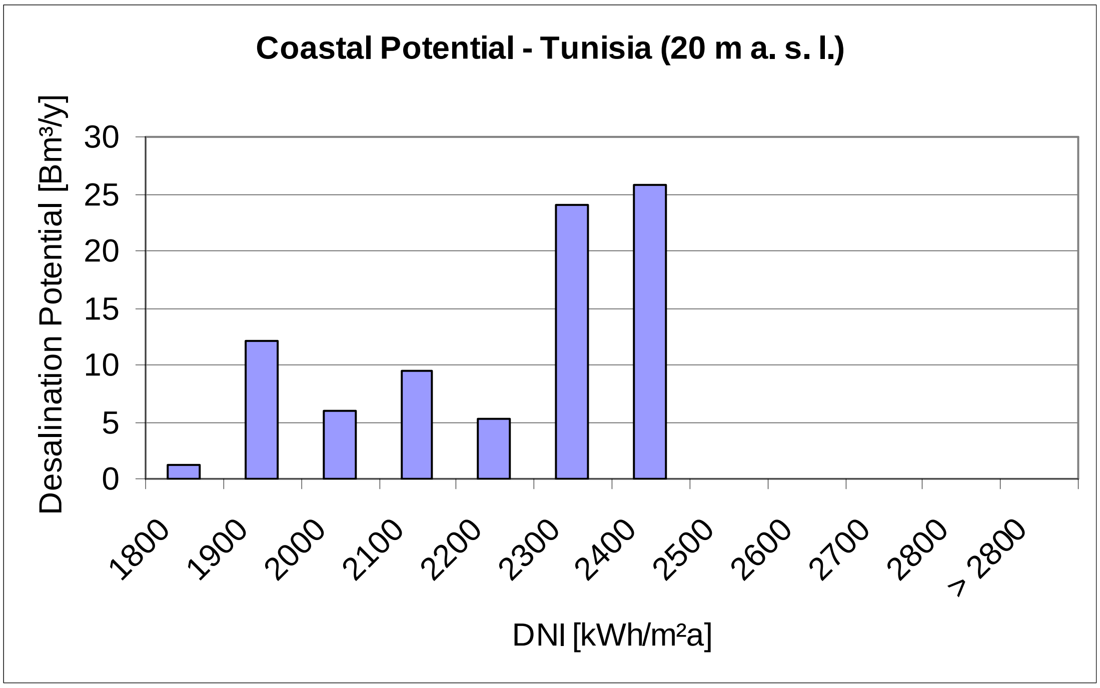


**Figure A- 9: Statistical analysis of the DNI map for CSP-desalination in Tunisia**

| Tunisia | | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 9.6 | 10.6 | 11.6 | 12.4 | 12.8 | 12.9 |
| Exploitable Water | Bm³/y | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| Sustainable Water | Bm³/y | 1.98 | 2.39 | 2.84 | 3.26 | 3.61 | 3.91 |
| Irrigation Efficiency | % | 0.54 | 0.56 | 0.57 | 0.59 | 0.61 | 0.62 |
| Agricultural Use | Bm³/y | 2.2 | 2.3 | 2.5 | 2.6 | 2.6 | 2.5 |
| Municipal Efficiency | % | 0.75 | 0.76 | 0.78 | 0.79 | 0.80 | 0.82 |
| Municipal Use | Bm³/y | 0.4 | 0.47 | 0.60 | 0.74 | 0.90 | 1.06 |
| Industrial Use | Bm³/y | 0.1 | 0.14 | 0.18 | 0.22 | 0.27 | 0.32 |
| Total Demand Tunisia | Bm³/y | 2.6 | 2.9 | 3.2 | 3.5 | 3.7 | 3.9 |
| per capita Consumption | m³/cap/y | 275 | 276 | 280 | 285 | 293 | 303 |
| Wastewater reused | Bm³/y | 0.02 | 0.1 | 0.2 | 0.3 | 0.5 | 0.7 |
| Non-sustainable Water | Bm³/y | 0.7 | 0.7 | 0.6 | 0.1 | 0.1 | 0.0 |
| CSP Desalination | Bm³/y | 0.00 | 0.01 | 0.10 | 0.52 | 0.58 | 0.65 |
| Fossil Fuel Desalination | Bm³/a | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 |
| Groundwater Over-Use | Bm³/y | 0.6 | 0.6 | 0.4 | 0.0 | 0.0 | 0.0 |

**Table A- 3: Main scenario indicators until 2050 for Tunisia**

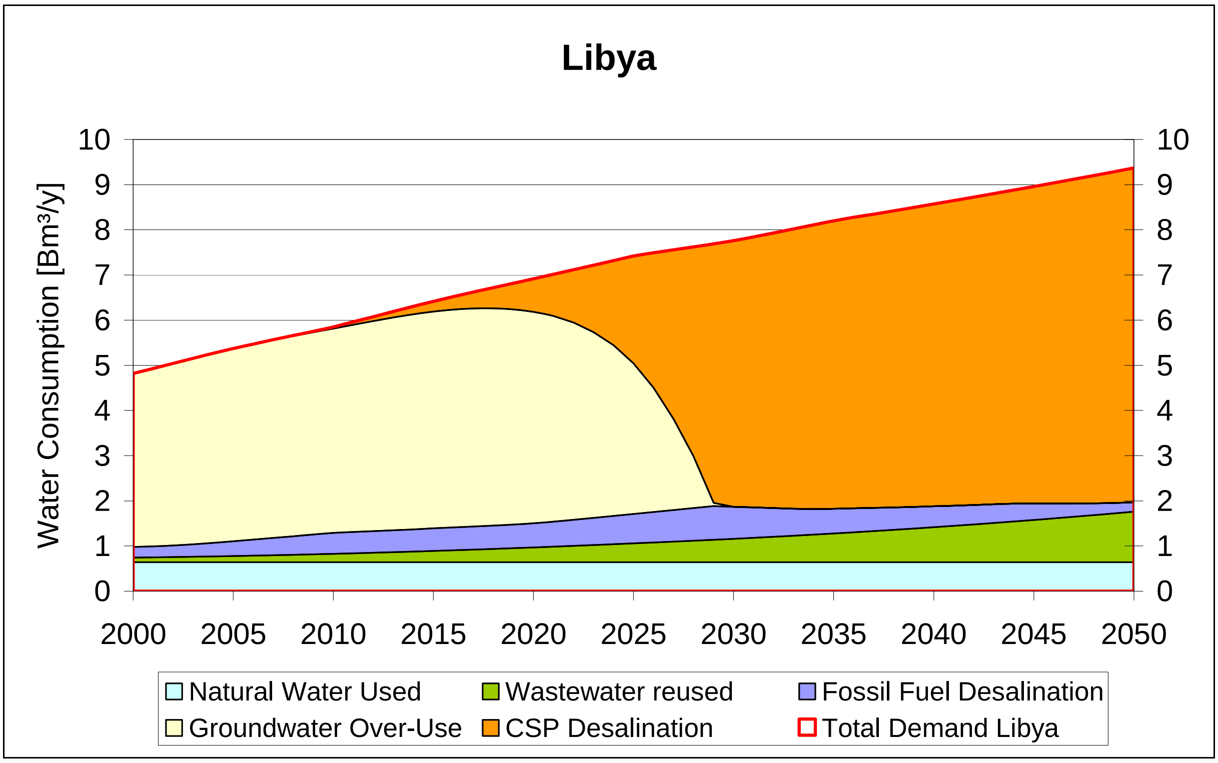


**Figure A- 10: Water supply scenario until 2050 in Libya**

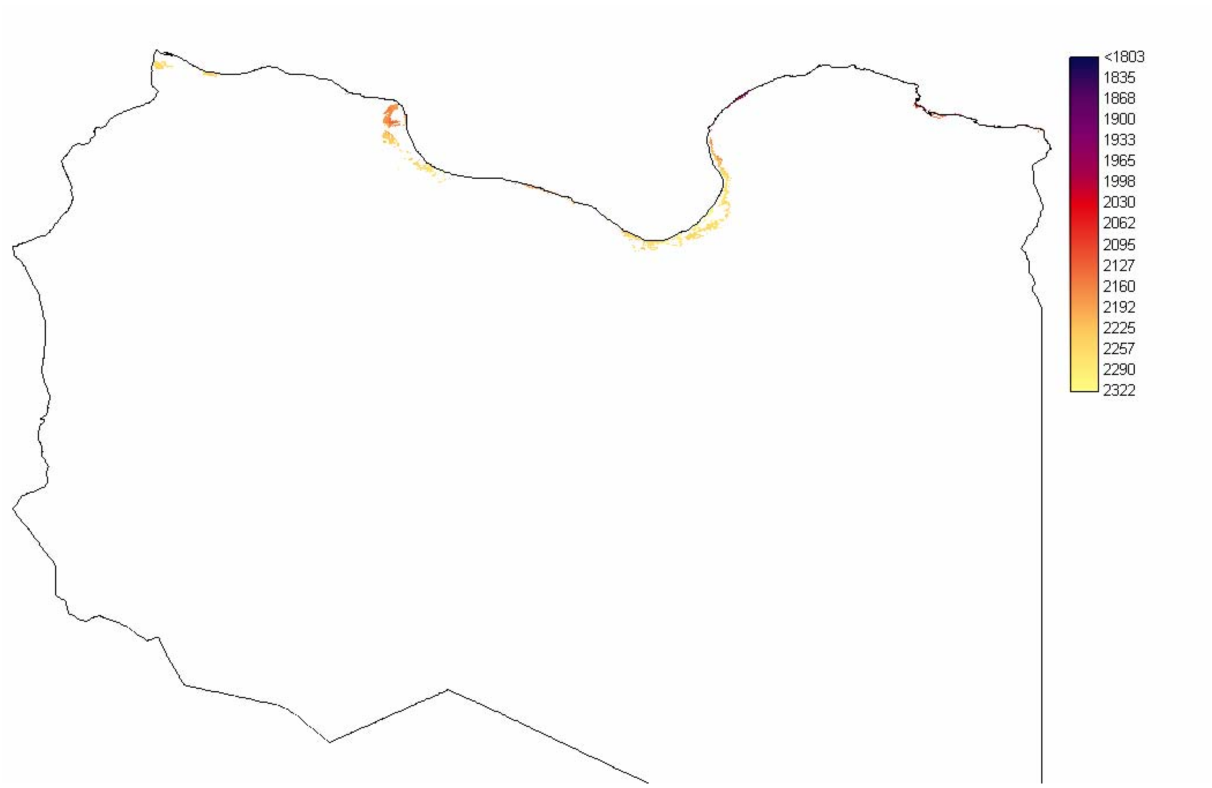


**Figure A- 11: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Libya**

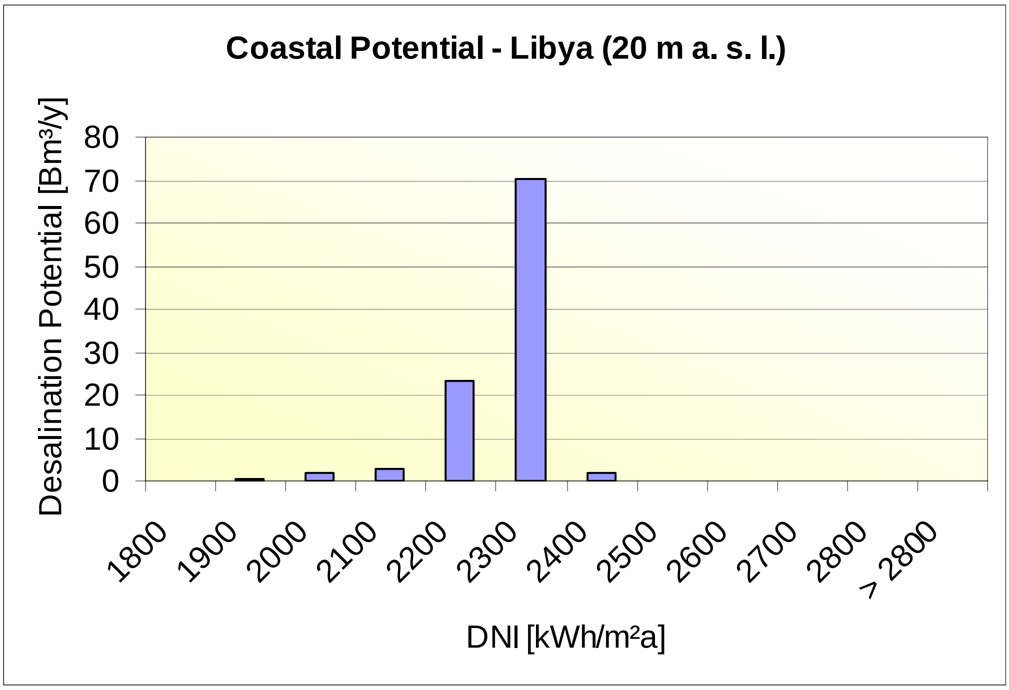


**Figure A- 12: Statistical analysis of the DNI map for CSP-desalination in Libya**

| **Libya** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 5.3 | 6.4 | 7.5 | 8.3 | 9.0 | 9.6 |
| Exploitable Water | Bm³/y | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 |
| Sustainable Water | Bm³/y | 0.74 | 0.83 | 0.97 | 1.16 | 1.41 | 1.76 |
| Irrigation Efficiency | % | 0.60 | 0.61 | 0.62 | 0.63 | 0.64 | 0.65 |
| Agricultural Use | Bm³/y | 4.3 | 5.1 | 5.8 | 6.4 | 6.8 | 7.1 |
| Municipal Efficiency | % | 0.70 | 0.72 | 0.74 | 0.76 | 0.78 | 0.80 |
| Municipal Use | Bm³/y | 0.4 | 0.57 | 0.78 | 1.02 | 1.30 | 1.63 |
| Industrial Use | Bm³/y | 0.2 | 0.21 | 0.29 | 0.38 | 0.49 | 0.61 |
| Total Demand Libya | Bm³/y | 4.8 | 5.8 | 6.9 | 7.8 | 8.6 | 9.4 |
| per capita Consumption | m³/cap/y | 909 | 914 | 922 | 935 | 952 | 976 |
| Wastewater reused | Bm³/y | 0.10 | 0.2 | 0.3 | 0.5 | 0.8 | 1.1 |
| Non-sustainable Water | Bm³/y | 4.1 | 5.0 | 5.2 | 0.7 | 0.5 | 0.2 |
| CSP Desalination | Bm³/y | 0.00 | 0.04 | 0.73 | 5.89 | 6.69 | 7.40 |
| Fossil Fuel Desalination | Bm³/a | 0.2 | 0.5 | 0.5 | 0.7 | 0.5 | 0.2 |
| Groundwater Over-Use | Bm³/y | 3.8 | 4.5 | 4.7 | 0.0 | 0.0 | 0.0 |

**Table A- 4: Main scenario indicators until 2050 for Libya**

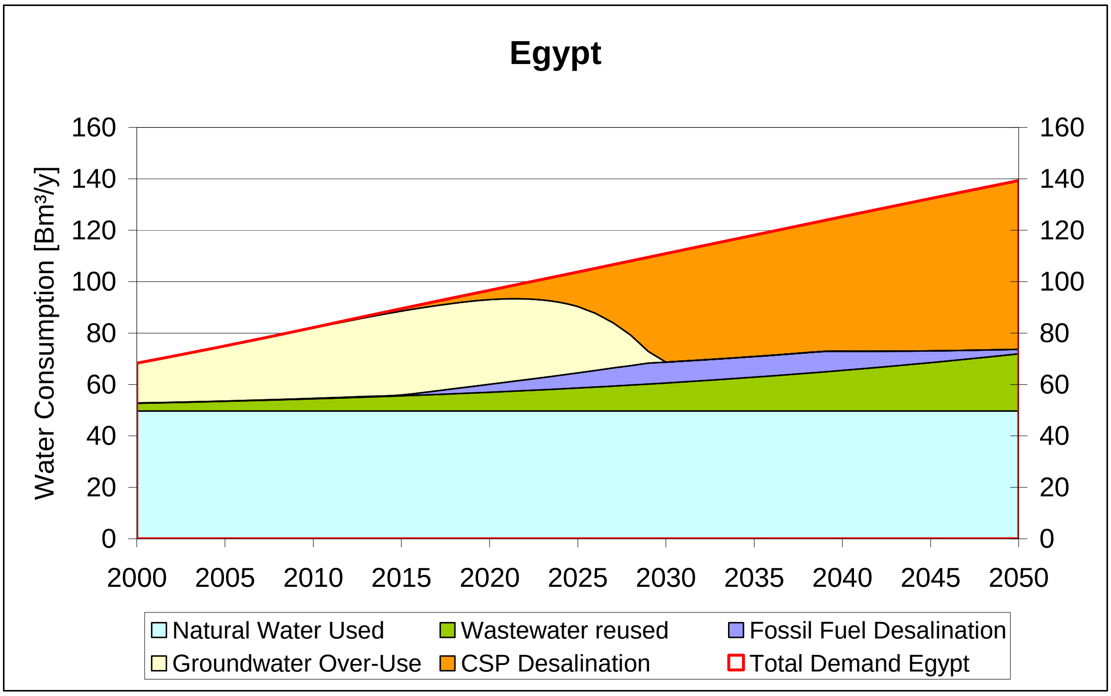


**Figure A- 13: Water supply scenario until 2050 in Egypt**

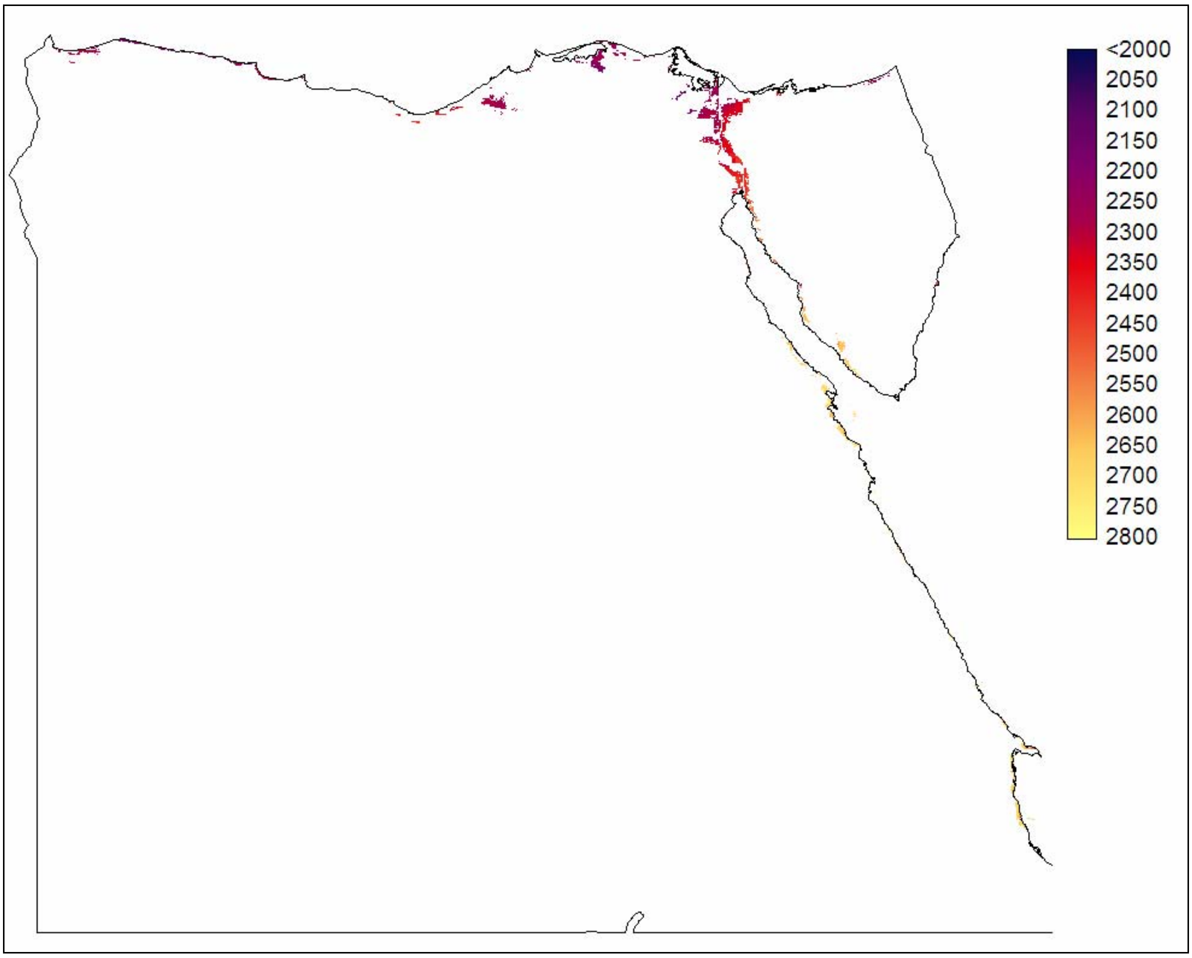


**Figure A- 14: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Egypt**

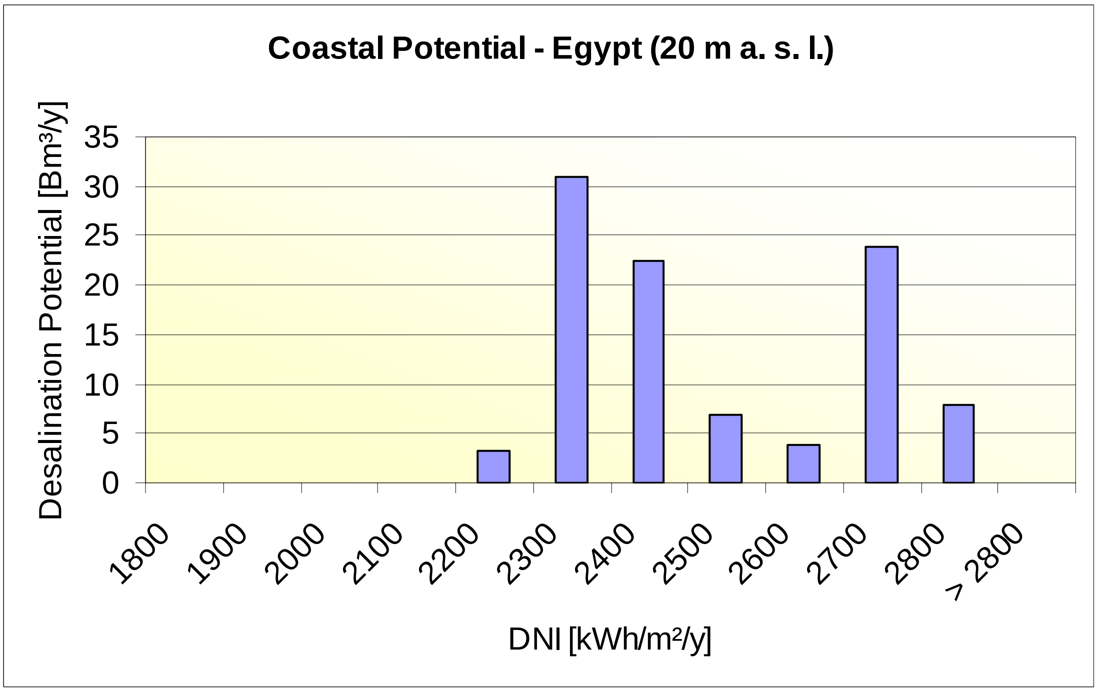


**Figure A- 15: Statistical analysis of the DNI map for CSP-desalination in Egypt**

| Egypt | | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 67.3 | 81.1 | 94.8 | 107.1 | 117.8 | 125.9 |
| Exploitable Water | Bm³/y | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 |
| Sustainable Water | Bm³/y | 52.68 | 54.40 | 56.97 | 60.56 | 65.46 | 71.93 |
| Irrigation Efficiency | % | 0.53 | 0.55 | 0.56 | 0.58 | 0.60 | 0.62 |
| Agricultural Use | Bm³/y | 59.0 | 68.8 | 78.0 | 85.5 | 91.3 | 94.9 |
| Municipal Efficiency | % | 0.50 | 0.55 | 0.59 | 0.64 | 0.69 | 0.73 |
| Municipal Use | Bm³/y | 5.3 | 7.59 | 10.63 | 14.51 | 19.39 | 25.34 |
| Industrial Use | Bm³/y | 4.0 | 5.73 | 8.02 | 10.95 | 14.64 | 19.12 |
| Total Demand Egypt | Bm³/y | 68.3 | 82.2 | 96.7 | 111.0 | 125.3 | 139.3 |
| per capita Consumption | m³/cap/y | 1015 | 1013 | 1020 | 1036 | 1064 | 1107 |
| Wastewater reused | Bm³/y | 3.0 | 4.7 | 7.3 | 10.9 | 15.8 | 22.2 |
| Non-sustainable Water | Bm³/y | 15.6 | 27.6 | 36.0 | 8.1 | 7.4 | 1.8 |
| CSP Desalination | Bm³/y | 0.00 | 0.13 | 3.66 | 42.26 | 52.45 | 65.63 |
| Fossil Fuel Desalination | Bm³/a | 0.1 | 0.2 | 3.1 | 8.1 | 7.4 | 1.8 |
| Groundwater Over-Use | Bm³/y | 15.5 | 27.4 | 32.9 | 0.0 | 0.0 | 0.0 |

**Table A- 5: Main scenario indicators until 2050 for Egypt**

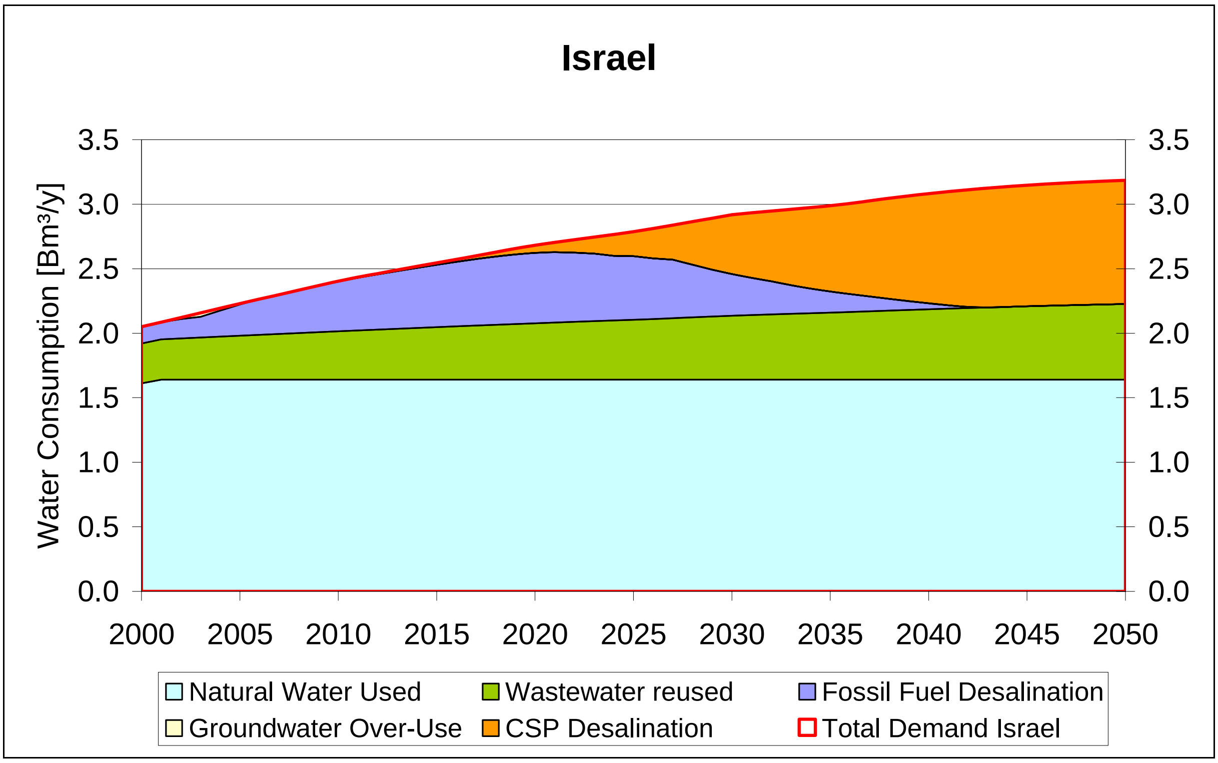


**Figure A- 16: Water supply scenario until 2050 in Israel**

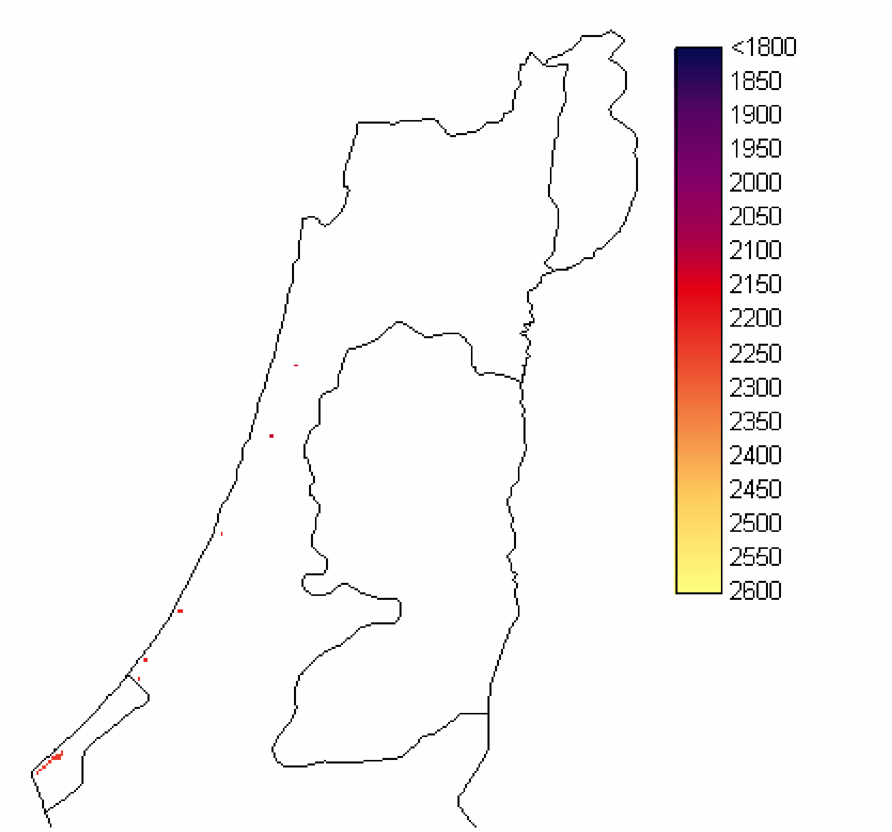


**Figure A- 17: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Israel**

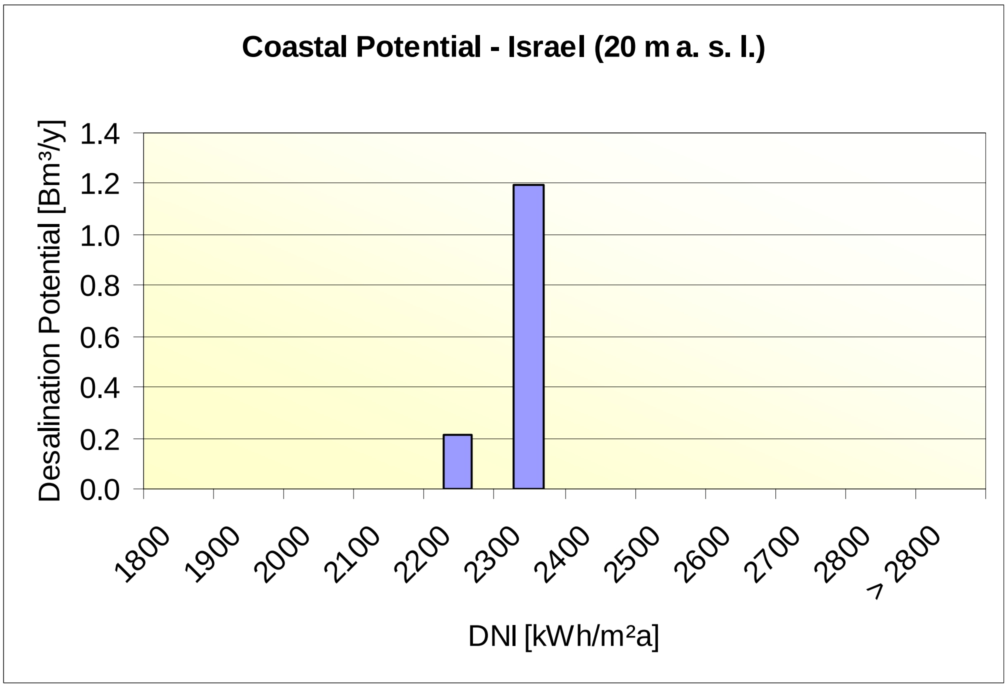


**Figure A- 18: Statistical analysis of the DNI map for CSP-desalination in Israel**

| **Israel** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 6.1 | 7.3 | 8.3 | 9.2 | 9.9 | 10.4 |
| Exploitable Water | Bm³/y | 1.64 | 1.64 | 1.64 | 1.64 | 1.64 | 1.64 |
| Sustainable Water | Bm³/y | 1.92 | 2.02 | 2.08 | 2.14 | 2.19 | 2.23 |
| Irrigation Efficiency | % | 0.60 | 0.61 | 0.62 | 0.63 | 0.64 | 0.65 |
| Agricultural Use | Bm³/y | 1.3 | 1.5 | 1.7 | 1.8 | 1.9 | 2.0 |
| Municipal Efficiency | % | 0.69 | 0.71 | 0.73 | 0.75 | 0.77 | 0.80 |
| Municipal Use | Bm³/y | 0.6 | 0.73 | 0.82 | 0.88 | 0.93 | 0.96 |
| Industrial Use | Bm³/y | 0.1 | 0.16 | 0.18 | 0.20 | 0.21 | 0.21 |
| Total Demand Israel | Bm³/y | 2.1 | 2.4 | 2.7 | 2.9 | 3.1 | 3.2 |
| per capita Consumption | m³/cap/y | 336 | 329 | 323 | 317 | 311 | 306 |
| Wastewater reused | Bm³/y | 0.308 | 0.4 | 0.4 | 0.5 | 0.5 | 0.6 |
| Non-sustainable Water | Bm³/y | 0.13 | 0.4 | 0.5 | 0.3 | 0.0 | 0.0 |
| CSP Desalination | Bm³/y | 0.00 | 0.00 | 0.06 | 0.46 | 0.85 | 0.96 |
| Fossil Fuel Desalination | Bm³/a | 0.1 | 0.4 | 0.5 | 0.3 | 0.0 | 0.0 |
| Groundwater Over-Use | Bm³/y | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**Table A- 6: Main scenario indicators until 2050 for Israel**

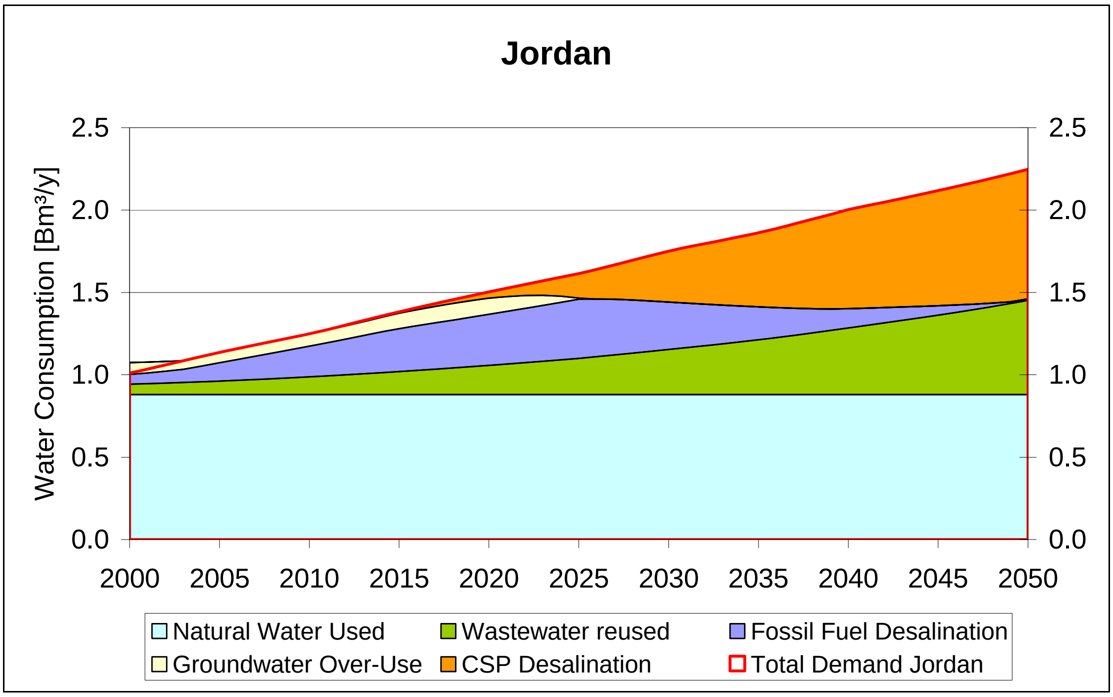


**Figure A- 19: Water supply scenario until 2050 in Jordan**

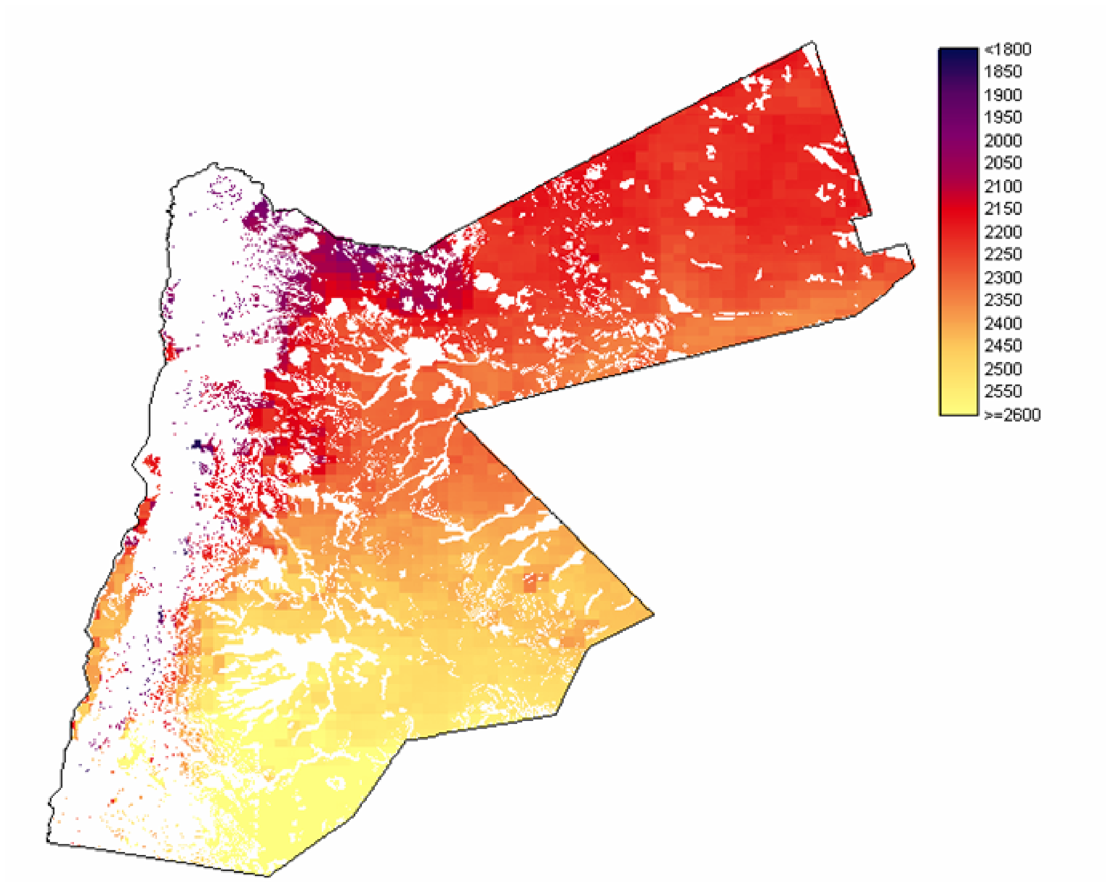


**Figure A- 20: Direct normal irradiance in kWh/m²/y at potential sites for CSP power generation in Jordan. There is almost no coastal potential below 20 m a. s. l. except for the Red Sea Shore near Aqaba.**

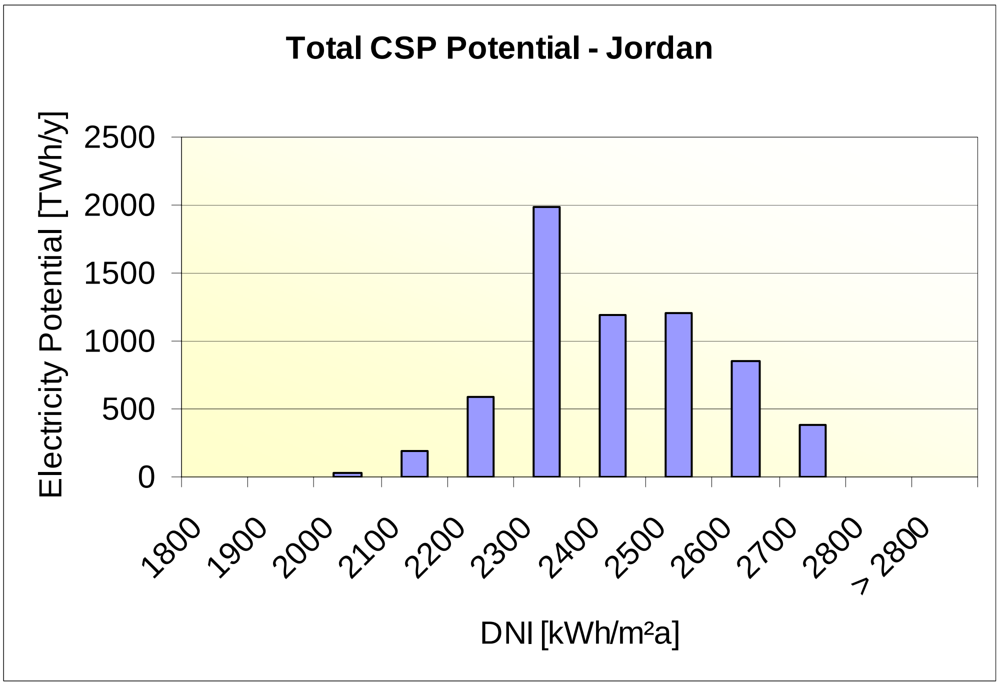


**Figure A- 21: Statistical analysis of the DNI map for CSP-power generation in Jordan. There is almost no coastal potential available in Jordan except for the Red Sea coast at Aqaba. To cover the demand for CSP desalination 4 TWh/y of electricity will be required from CSP.**

| Jordan | | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 5.00 | 6.30 | 7.60 | 8.70 | 9.60 | 10.20 |
| Exploitable Water | Bm³/y | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 |
| Sustainable Water | Bm³/y | 0.88 | 0.99 | 1.06 | 1.15 | 1.28 | 1.45 |
| Irrigation Efficiency | % | 0.39 | 0.42 | 0.45 | 0.48 | 0.52 | 0.55 |
| Agricultural Use | Bm³/y | 0.8 | 0.9 | 1.0 | 1.1 | 1.1 | 1.1 |
| Municipal Efficiency | % | 0.48 | 0.53 | 0.58 | 0.63 | 0.68 | 0.73 |
| Municipal Use | Bm³/y | 0.2 | 0.30 | 0.43 | 0.58 | 0.76 | 0.96 |
| Industrial Use | Bm³/y | 0.0 | 0.06 | 0.08 | 0.11 | 0.14 | 0.18 |
| Total Demand Jordan | Bm³/y | 1.0 | 1.2 | 1.5 | 1.8 | 2.0 | 2.2 |
| per capita Consumption | m³/cap/y | 202 | 198 | 198 | 201 | 209 | 220 |
| Wastewater reused | Bm³/y | 0.063 | 0.1 | 0.2 | 0.3 | 0.4 | 0.6 |
| Non-sustainable Water | Bm³/y | 0.13 | 0.3 | 0.4 | 0.3 | 0.1 | 0.0 |
| CSP Desalination | Bm³/y | 0.00 | 0.00 | 0.04 | 0.31 | 0.60 | 0.79 |
| Fossil Fuel Desalination | Bm³/a | 0.1 | 0.2 | 0.3 | 0.3 | 0.1 | 0.0 |
| Groundwater Over-Use | Bm³/y | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |

**Table A- 7: Main scenario indicators until 2050 for Jordan. Most of the desalination potential will have to be powered by electricity from CSP plants inside the country.**

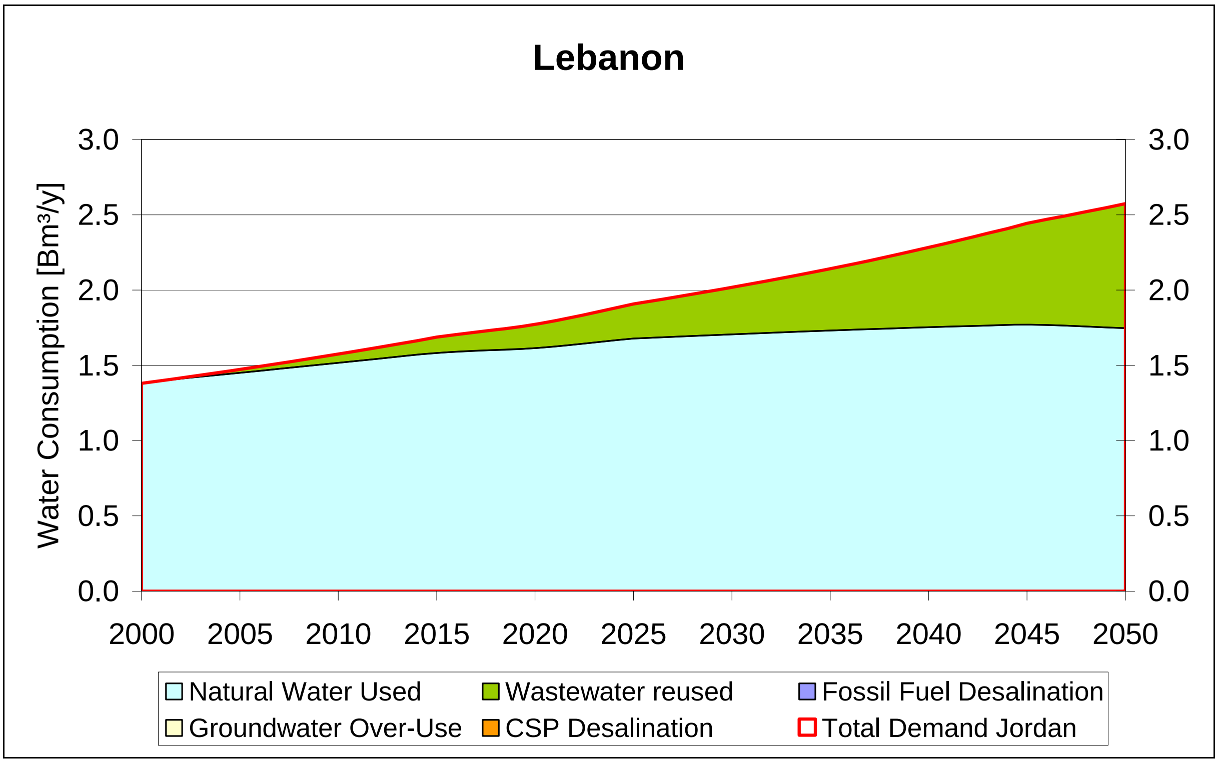


**Figure A- 22: Water supply scenario until 2050 in Lebanon. No obvious demand for desalination if the potentials for wastewater re-use and the remaining natural resources are efficiently exploited.**

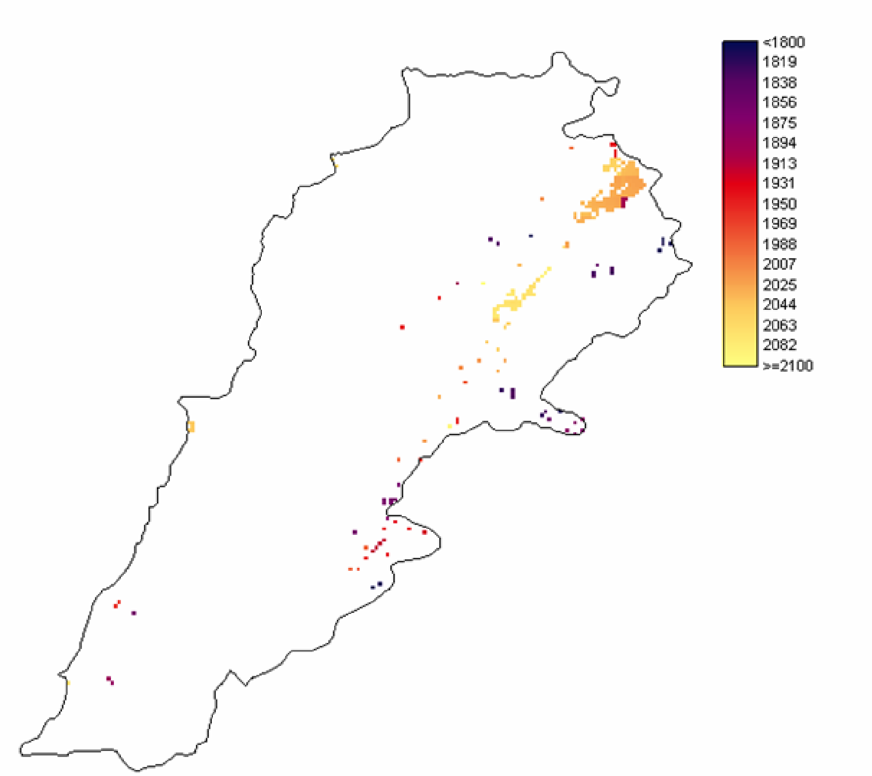


**Figure A- 23: Direct normal irradiance in kWh/m²/y at potential sites for CSP power generation in Lebanon. Due to agriculture and topography there is almost no coastal potential below 20 m a.s.l.**

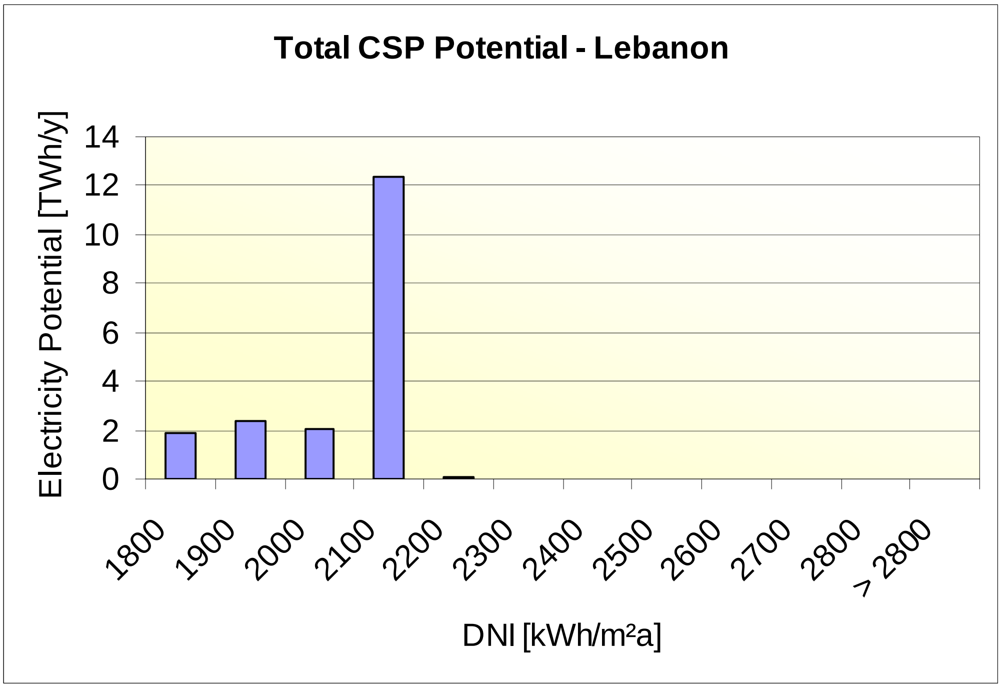


**Figure A- 24: Statistical analysis of the DNI map for CSP-desalination in Lebanon**

| **Lebanon** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 3.4 | 3.8 | 4.1 | 4.4 | 4.6 | 4.7 |
| Exploitable Water | Bm³/y | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 |
| Sustainable Water | Bm³/y | 1.38 | 1.57 | 1.77 | 2.02 | 2.28 | 2.57 |
| Irrigation Efficiency | % | 0.40 | 0.43 | 0.46 | 0.49 | 0.52 | 0.55 |
| Agricultural Use | Bm³/y | 0.9 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 |
| Municipal Efficiency | % | 0.65 | 0.68 | 0.70 | 0.73 | 0.76 | 0.78 |
| Municipal Use | Bm³/y | 0.5 | 0.61 | 0.79 | 1.03 | 1.30 | 1.62 |
| Industrial Use | Bm³/y | 0.0 | 0.01 | 0.02 | 0.02 | 0.03 | 0.04 |
| Total Demand Lebanon | Bm³/y | 1.4 | 1.6 | 1.8 | 2.0 | 2.3 | 2.6 |
| per capita Consumption | m³/cap/y | 406 | 414 | 432 | 459 | 496 | 548 |
| Wastewater reused | Bm³/y | 0.001 | 0.1 | 0.2 | 0.3 | 0.5 | 0.8 |
| Non-sustainable Water | Bm³/y | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| CSP Desalination | Bm³/y | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Fossil Fuel Desalination | Bm³/a | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Groundwater Over-Use | Bm³/y | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**Table A- 8: Main scenario indicators until 2050 for Lebanon**

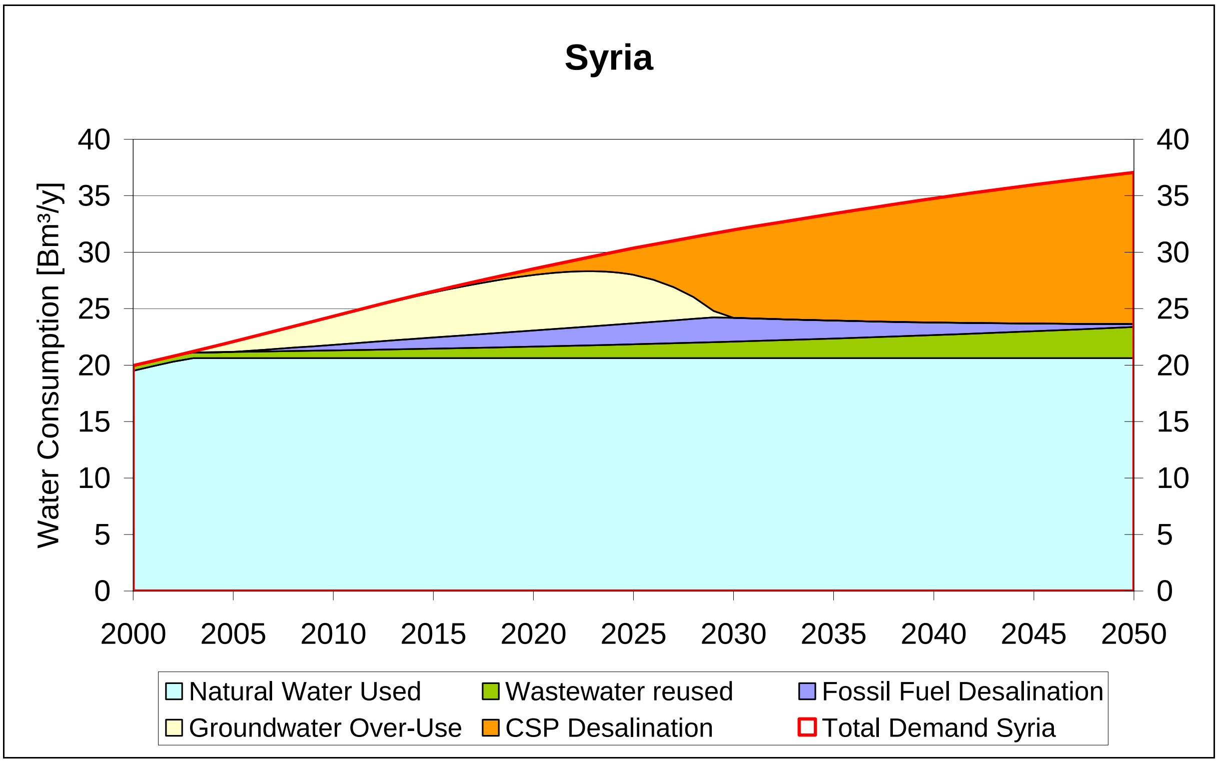


**Figure A- 25: Water supply scenario until 2050 in Syria**

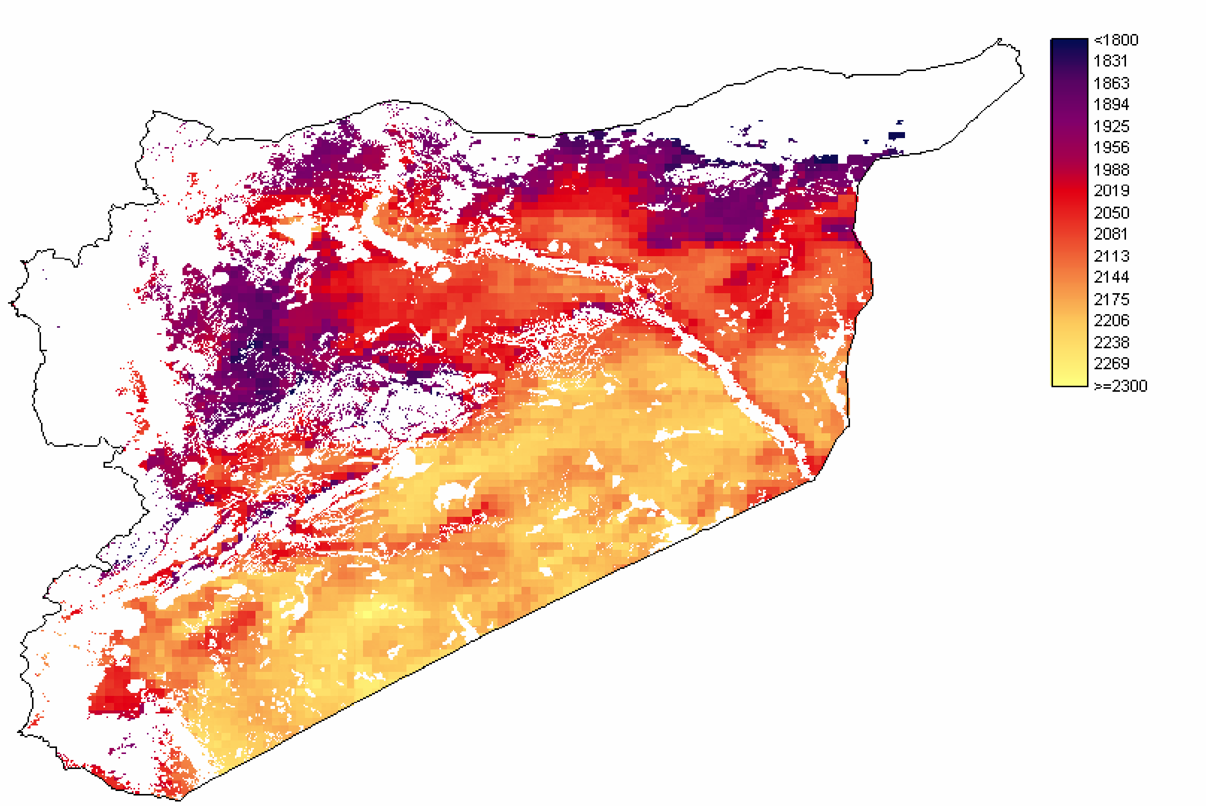


**Figure A- 26: Direct normal irradiance in kWh/m²/y at potential sites for CSP power generation in Syria. Due to agriculture and topography there is almost no coastal potential below 20 m a.s.l.**

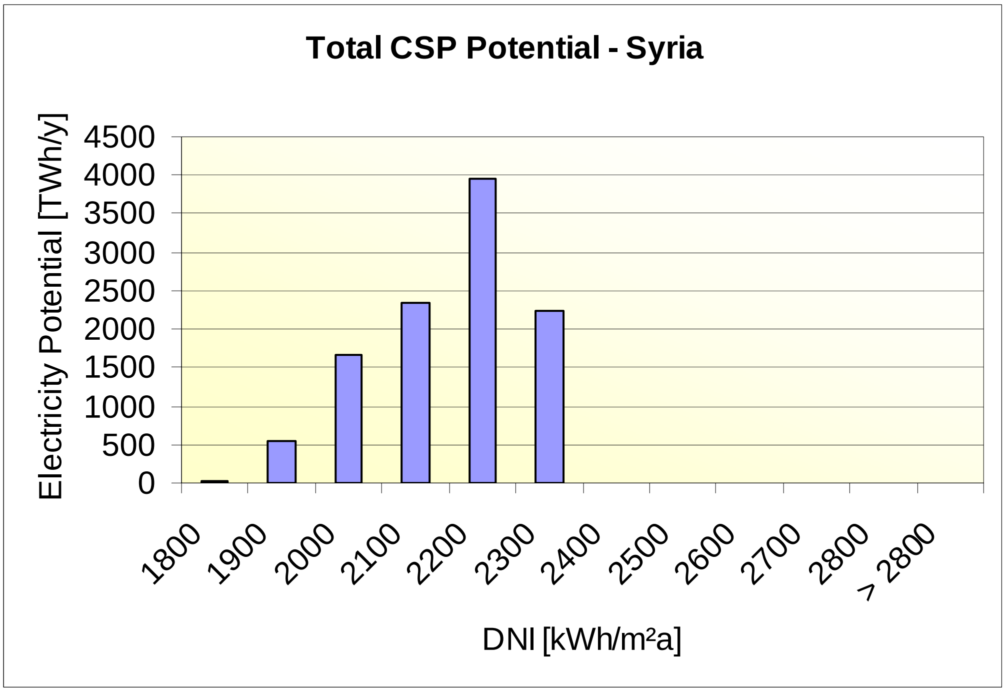


**Figure A- 27: Statistical analysis of the DNI map for CSP-desalination in Syria**

| **Syria** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 16.8 | 21.4 | 26.0 | 30.0 | 33.3 | 35.9 |
| Exploitable Water | Bm³/y | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 |
| Sustainable Water | Bm³/y | 19.95 | 21.30 | 21.64 | 22.08 | 22.65 | 23.38 |
| Irrigation Efficiency | % | 0.45 | 0.48 | 0.50 | 0.53 | 0.55 | 0.58 |
| Agricultural Use | Bm³/y | 18.9 | 22.8 | 26.3 | 28.9 | 30.6 | 31.5 |
| Municipal Efficiency | % | 0.48 | 0.53 | 0.58 | 0.63 | 0.68 | 0.73 |
| Municipal Use | Bm³/y | 0.7 | 0.98 | 1.43 | 2.00 | 2.71 | 3.59 |
| Industrial Use | Bm³/y | 0.4 | 0.54 | 0.78 | 1.09 | 1.48 | 1.96 |
| Total Demand Syria | Bm³/y | 20.0 | 24.3 | 28.5 | 32.0 | 34.8 | 37.1 |
| per capita Consumption | m³/cap/y | 1188 | 1137 | 1097 | 1066 | 1044 | 1033 |
| Wastewater reused | Bm³/y | 0.459 | 0.7 | 1.0 | 1.5 | 2.1 | 2.8 |
| Non-sustainable Water | Bm³/y | 0.0 | 3.0 | 6.3 | 2.1 | 1.1 | 0.3 |
| CSP Desalination | Bm³/y | 0.00 | 0.01 | 0.54 | 7.80 | 11.01 | 13.44 |
| Fossil Fuel Desalination | Bm³/a | 0.0 | 0.5 | 1.4 | 2.1 | 1.1 | 0.3 |
| Groundwater Over-Use | Bm³/y | 0.0 | 2.5 | 4.9 | 0.0 | 0.0 | 0.0 |

**Table A- 9: Main scenario indicators until 2050 for Syria. Most of the desalination potential will have to be powered by electricity from CSP plants inside the country or some of the coastal agricultural areas will have to be used for this purpose.**

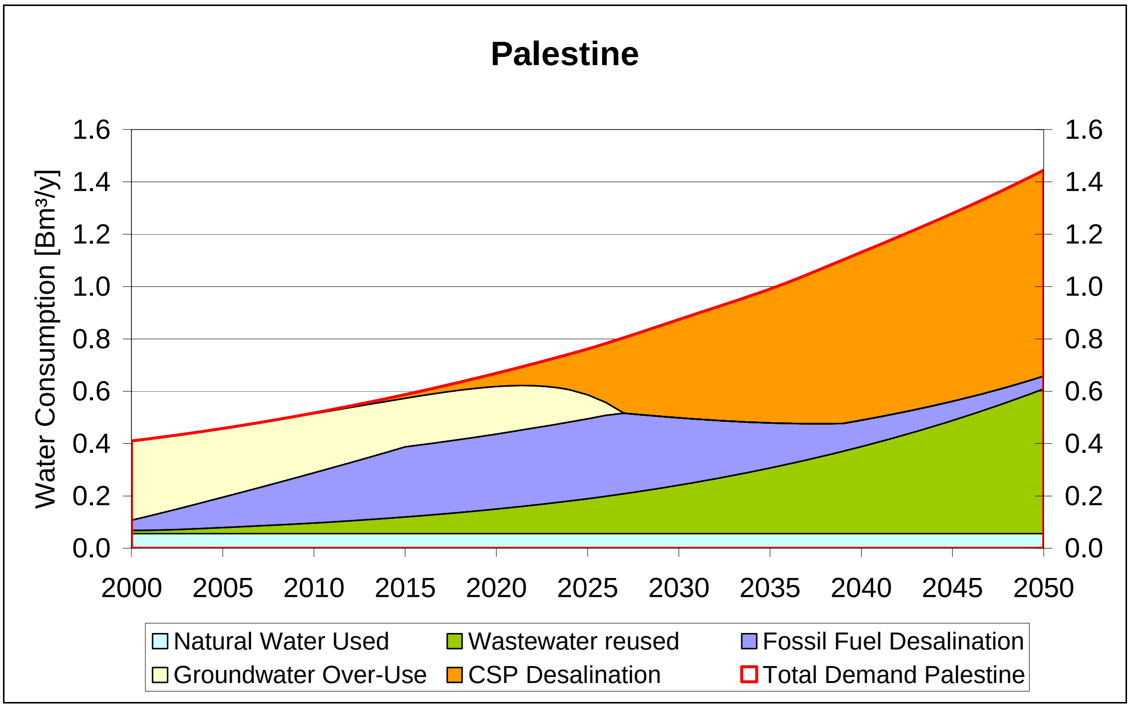


**Figure A- 28: Water supply scenario until 2050 in Palestine.**

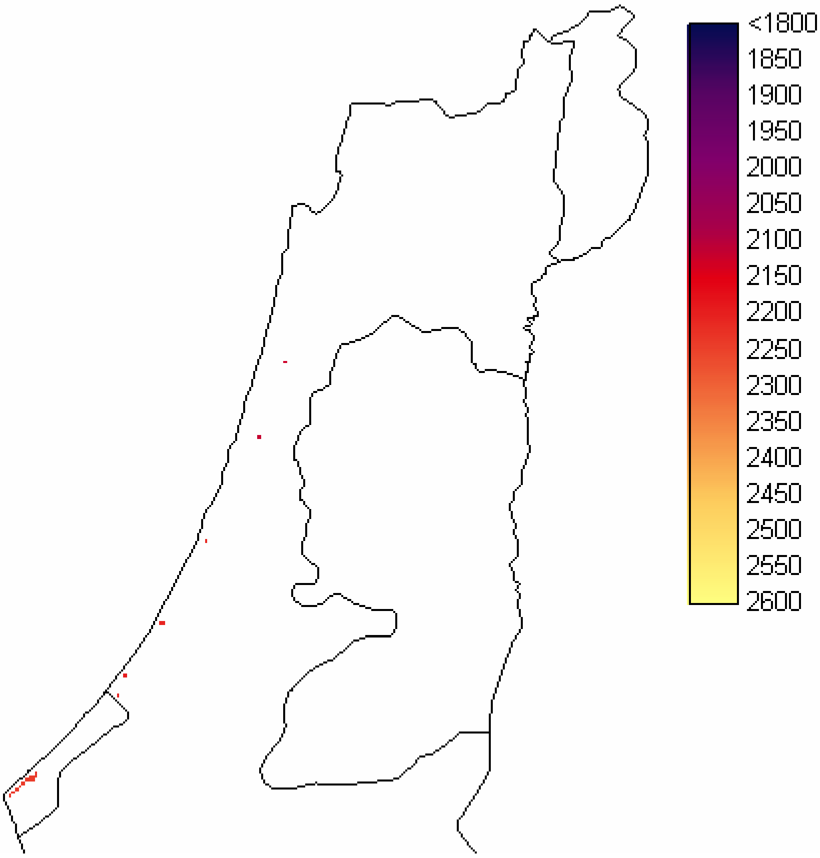


**Figure A- 29: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Palestine. There are only very limited potentials in Gaza.**

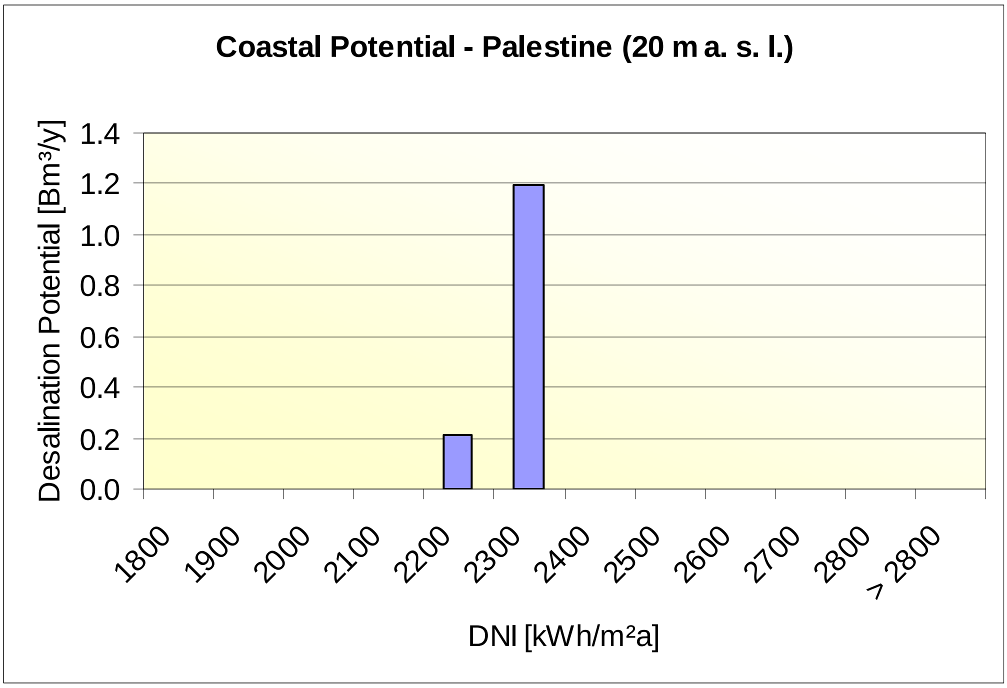


**Figure A- 30: Statistical analysis of the DNI map for CSP-desalination in Palestine**

| **Palestine** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 3.2 | 4.3 | 5.7 | 7.2 | 8.7 | 10.1 |
| Exploitable Water | Bm³/y | 0.056 | 0.056 | 0.056 | 0.056 | 0.056 | 0.056 |
| Sustainable Water | Bm³/y | 0.07 | 0.10 | 0.15 | 0.24 | 0.39 | 0.61 |
| Irrigation Efficiency | % | 0.30 | 0.34 | 0.38 | 0.42 | 0.46 | 0.50 |
| Agricultural Use | Bm³/y | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 |
| Municipal Efficiency | % | 0.30 | 0.37 | 0.45 | 0.52 | 0.59 | 0.66 |
| Municipal Use | Bm³/y | 0.2 | 0.26 | 0.36 | 0.51 | 0.71 | 0.96 |
| Industrial Use | Bm³/y | 0.0 | 0.04 | 0.05 | 0.08 | 0.11 | 0.14 |
| Total Demand Palestine | Bm³/y | 0.410 | 0.516 | 0.668 | 0.874 | 1.132 | 1.445 |
| per capita Consumption | m³/cap/y | 128 | 120 | 117 | 121 | 130 | 143 |
| Wastewater reused | Bm³/y | 0.012 | 0.040 | 0.093 | 0.186 | 0.333 | 0.553 |
| Non-sustainable Water | Bm³/y | 0.3 | 0.4 | 0.5 | 0.3 | 0.1 | 0.0 |
| CSP Desalination | Bm³/y | 0.00 | 0.00 | 0.05 | 0.38 | 0.64 | 0.79 |
| Fossil Fuel Desalination | Bm³/a | 0.0 | 0.2 | 0.3 | 0.3 | 0.1 | 0.0 |
| Groundwater Over-Use | Bm³/y | 0.3 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 |

**Table A- 10: Main scenario indicators until 2050 for Palestine. A potential cooperation of Israel, Palestine and Egypt has been assessed by TREC ([www.trec-eumena.net](www.trec-eumena.net))**

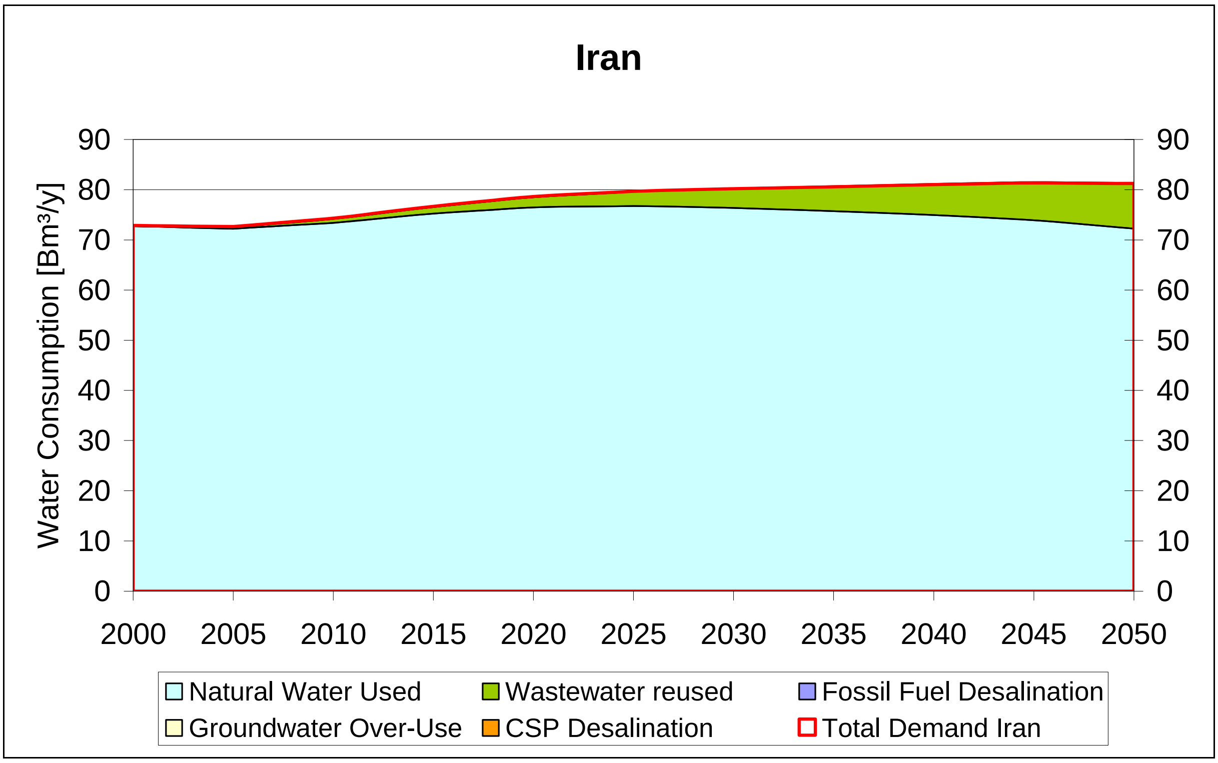


**Figure A- 31: Water supply scenario until 2050 in Iran. No obvious demand for desalination if the potentials for wastewater re-use and the remaining natural resources are efficiently exploited.**

| **Iran** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 66.40 | 74.30 | 85.00 | 92.30 | 98.00 | 101.90 |
| Exploitable Water | Bm³/y | 137.5 | 137.5 | 137.5 | 137.5 | 137.5 | 137.5 |
| Sustainable Water | Bm³/y | 72.72 | 74.16 | 78.56 | 80.15 | 81.00 | 81.21 |
| Irrigation Efficiency | % | 0.32 | 0.36 | 0.40 | 0.44 | 0.48 | 0.51 |
| Agricultural Use | Bm³/y | 66.2 | 66.1 | 68.2 | 67.5 | 65.8 | 63.3 |
| Municipal Efficiency | % | 0.50 | 0.55 | 0.59 | 0.64 | 0.69 | 0.73 |
| Municipal Use | Bm³/y | 5.0 | 6.11 | 7.77 | 9.47 | 11.33 | 13.36 |
| Industrial Use | Bm³/y | 1.7 | 2.08 | 2.65 | 3.23 | 3.86 | 4.55 |
| Total Demand Iran | Bm³/y | 72.9 | 74.3 | 78.7 | 80.2 | 81.0 | 81.2 |
| per capita Consumption | m³/cap/y | 1098 | 1000 | 925 | 869 | 827 | 797 |
| Wastewater reused | Bm³/y | 0.007 | 0.8 | 2.0 | 3.8 | 6.0 | 9.0 |
| Non-sustainable Water | Bm³/y | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 |
| CSP Desalination | Bm³/y | 0.00 | 0.00 | 0.03 | 0.10 | 0.15 | 0.16 |
| Fossil Fuel Desalination | Bm³/a | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 |
| Groundwater Over-Use | Bm³/y | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**Table A- 11: Main scenario indicators until 2050 for Iran**

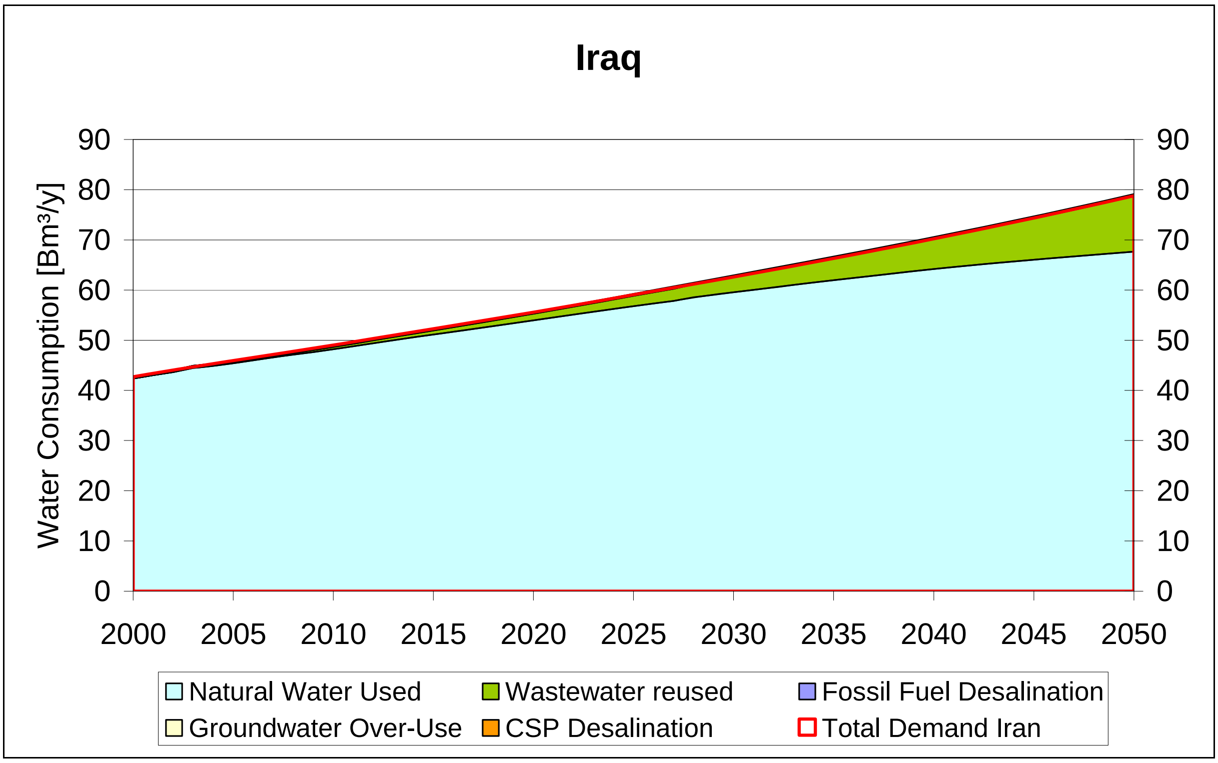


**Figure A- 32: Water supply scenario until 2050 in Iraq. Only small demand for desalination if potentials for wastewater re-use and remaining natural resources are efficiently exploited.**

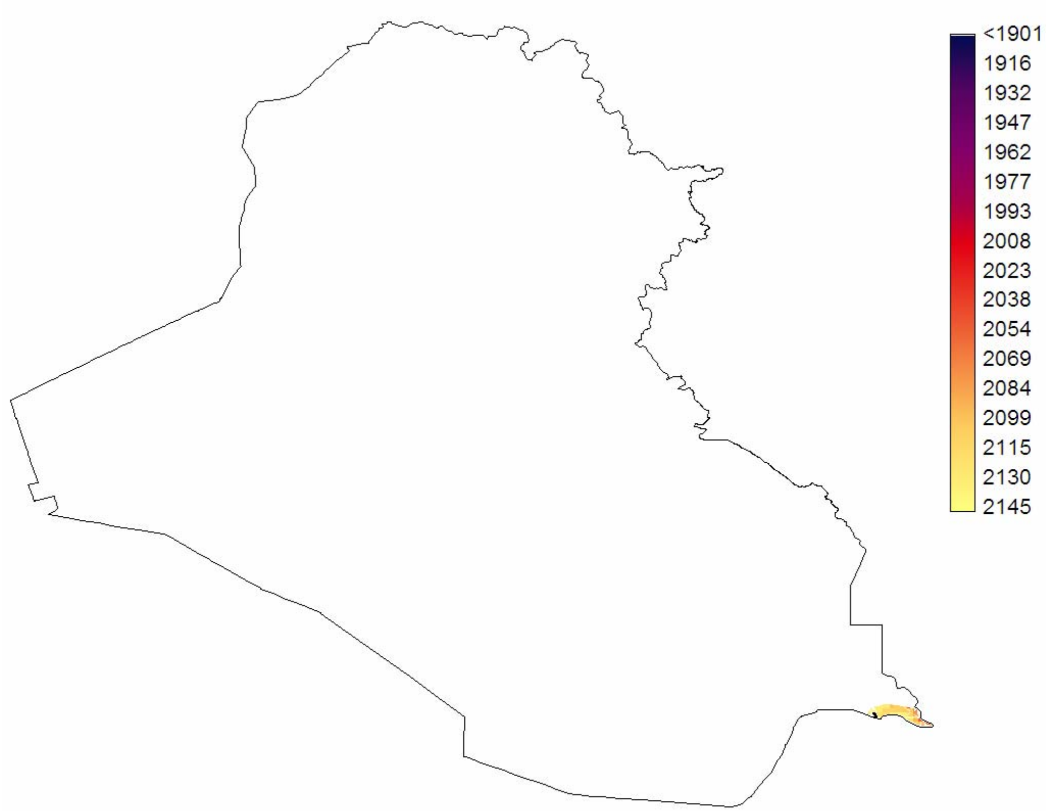


**Figure A- 33: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Iraq**

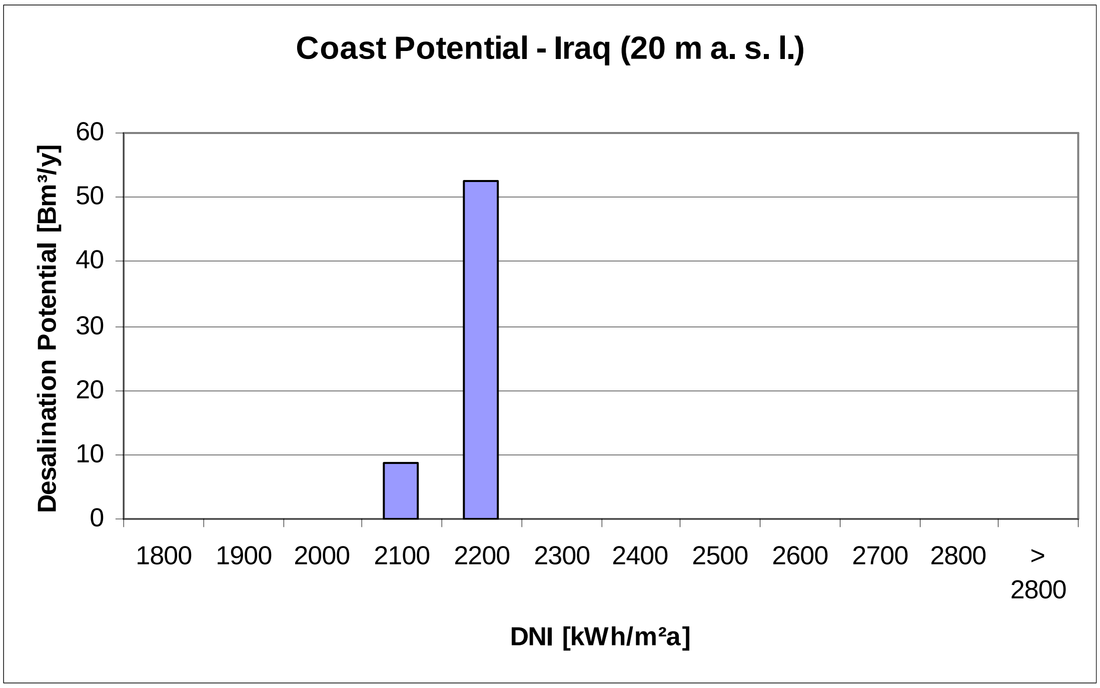


**Figure A- 34: Statistical analysis of the DNI map for CSP-desalination in Iraq**

| **Iraq** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 25.10 | 32.50 | 40.50 | 48.80 | 56.70 | 63.70 |
| Exploitable Water | Bm³/y | 75.4 | 75.4 | 75.4 | 75.4 | 75.4 | 75.4 |
| Sustainable Water | Bm³/y | 42.36 | 48.69 | 55.34 | 62.47 | 70.19 | 78.78 |
| Irrigation Efficiency | % | 0.28 | 0.32 | 0.37 | 0.41 | 0.45 | 0.49 |
| Agricultural Use | Bm³/y | 39.4 | 44.2 | 48.7 | 52.5 | 55.2 | 56.6 |
| Municipal Efficiency | % | 0.40 | 0.46 | 0.52 | 0.58 | 0.64 | 0.70 |
| Municipal Use | Bm³/y | 1.4 | 1.93 | 2.80 | 4.12 | 6.12 | 9.00 |
| Industrial Use | Bm³/y | 2.0 | 2.81 | 4.08 | 6.01 | 8.93 | 13.14 |
| Total Demand Iraq | Bm³/y | 42.7 | 49.0 | 55.6 | 62.6 | 70.3 | 78.8 |
| per capita Consumption | m³/cap/y | 1702 | 1507 | 1372 | 1283 | 1239 | 1237 |
| Wastewater reused | Bm³/y | 0.003 | 0.4 | 1.3 | 3.0 | 6.0 | 11.1 |
| Non-sustainable Water | Bm³/y | 0.4 | 0.4 | 0.3 | 0.0 | 0.0 | 0.0 |
| CSP Desalination | Bm³/y | 0.00 | 0.00 | 0.06 | 0.36 | 0.36 | 0.36 |
| Fossil Fuel Desalination | Bm³/a | 0.4 | 0.4 | 0.3 | 0.1 | 0.1 | 0.1 |
| Groundwater Over-Use | Bm³/y | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**Table A- 12: Main scenario indicators until 2050 for Iraq**

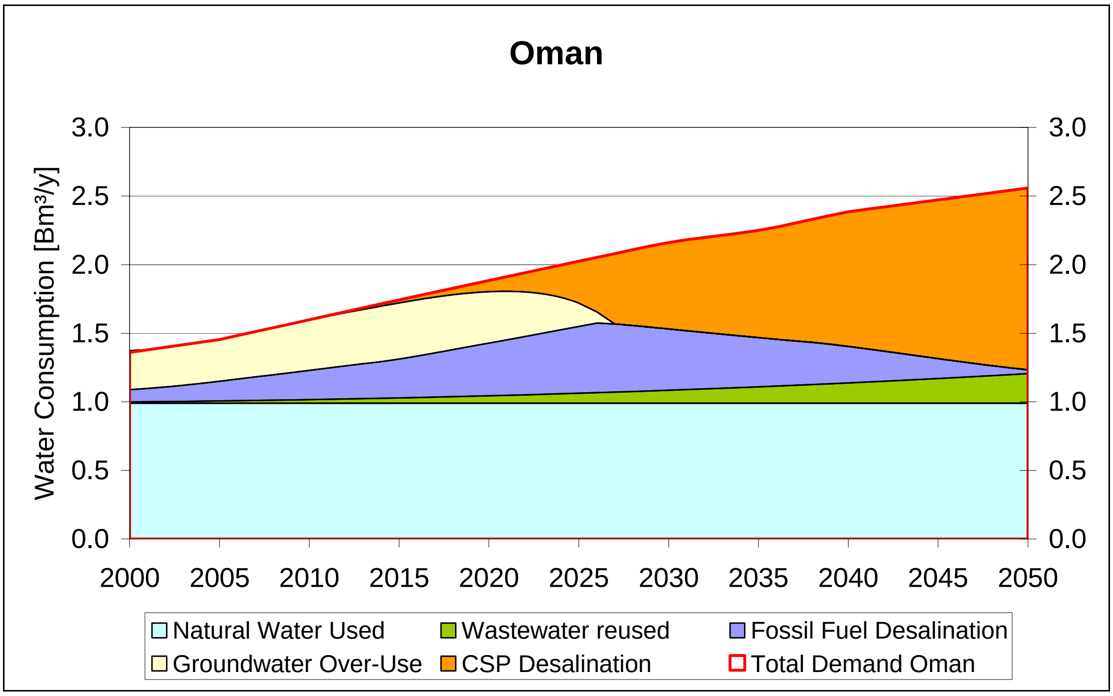


**Figure A- 35: Water supply scenario until 2050 in Oman**

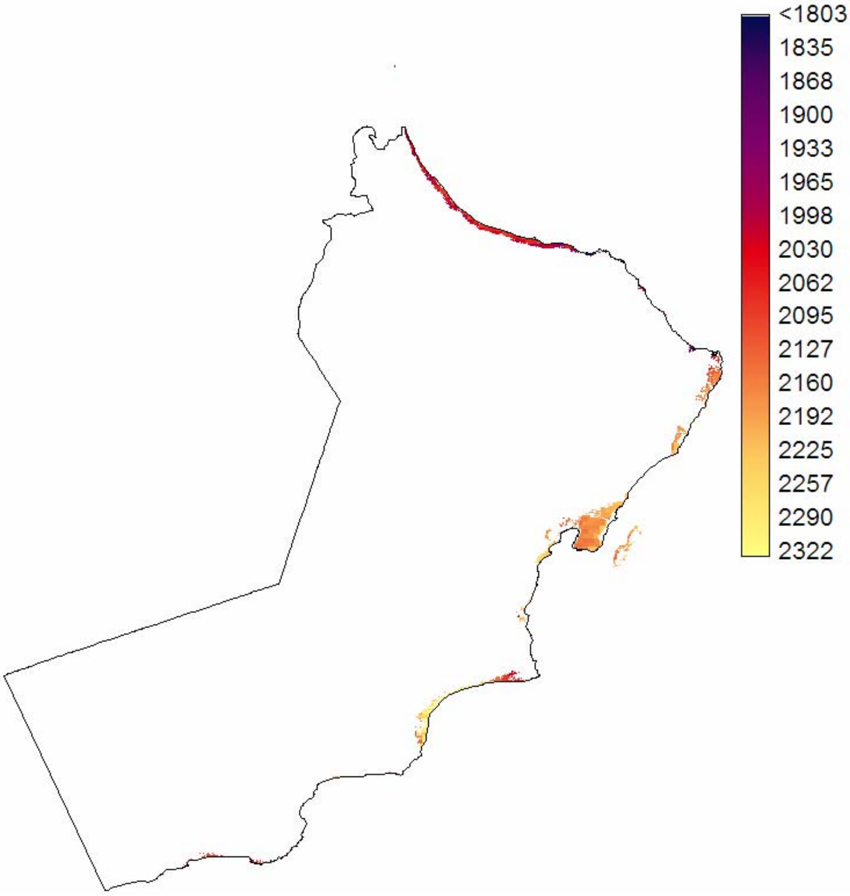


**Figure A- 36: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Oman**

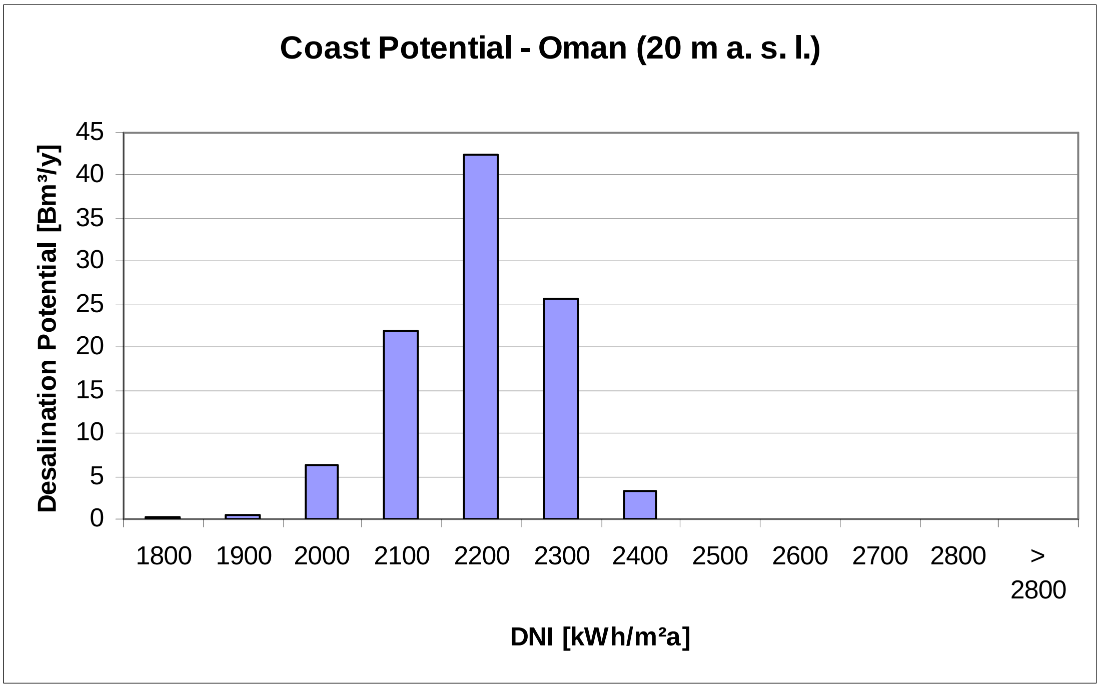


**Figure A- 37: Statistical analysis of the DNI map for CSP-desalination in Oman**

| **Oman** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 2.4 | 2.9 | 3.5 | 4.1 | 4.6 | 5.0 |
| Exploitable Water | Bm³/y | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 |
| Sustainable Water | Bm³/y | 0.99 | 1.02 | 1.04 | 1.08 | 1.14 | 1.21 |
| Irrigation Efficiency | % | 0.50 | 0.52 | 0.54 | 0.56 | 0.58 | 0.60 |
| Agricultural Use | Bm³/y | 1.2 | 1.4 | 1.7 | 1.9 | 2.0 | 2.1 |
| Municipal Efficiency | % | 0.65 | 0.68 | 0.70 | 0.73 | 0.76 | 0.78 |
| Municipal Use | Bm³/y | 0.1 | 0.13 | 0.17 | 0.22 | 0.28 | 0.33 |
| Industrial Use | Bm³/y | 0.0 | 0.04 | 0.05 | 0.07 | 0.08 | 0.10 |
| Total Demand Oman | Bm³/y | 1.4 | 1.6 | 1.9 | 2.2 | 2.4 | 2.6 |
| per capita Consumption | m³/cap/y | 567 | 551 | 538 | 527 | 519 | 512 |
| Wastewater reused | Bm³/y | 0.009 | 0.0 | 0.1 | 0.1 | 0.1 | 0.2 |
| Non-sustainable Water | Bm³/y | 0.4 | 0.6 | 0.8 | 0.4 | 0.3 | 0.0 |
| CSP Desalination | Bm³/y | 0.00 | 0.00 | 0.08 | 0.63 | 0.98 | 1.32 |
| Fossil Fuel Desalination | Bm³/a | 0.1 | 0.2 | 0.4 | 0.4 | 0.3 | 0.0 |
| Groundwater Over-Use | Bm³/y | 0.3 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 |

**Table A- 13: Main scenario indicators until 2050 for Oman**

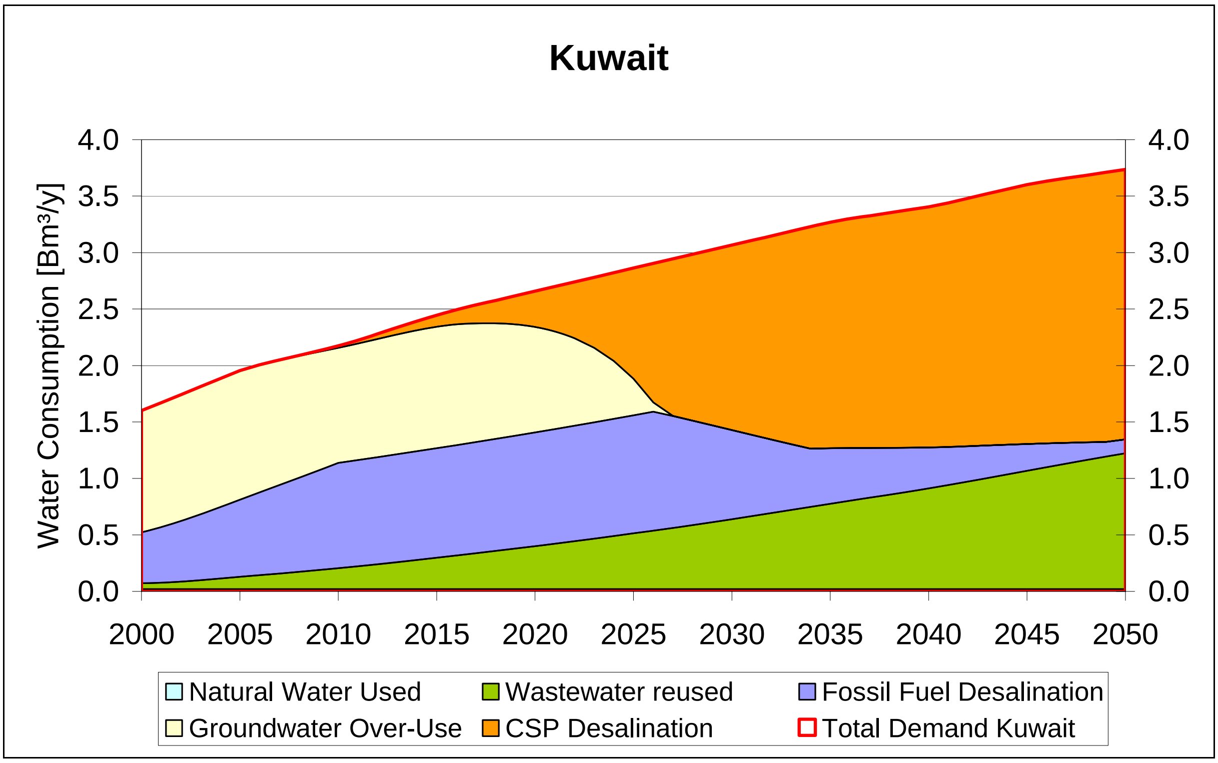


**Figure A- 38: Water supply scenario until 2050 in Kuwait**

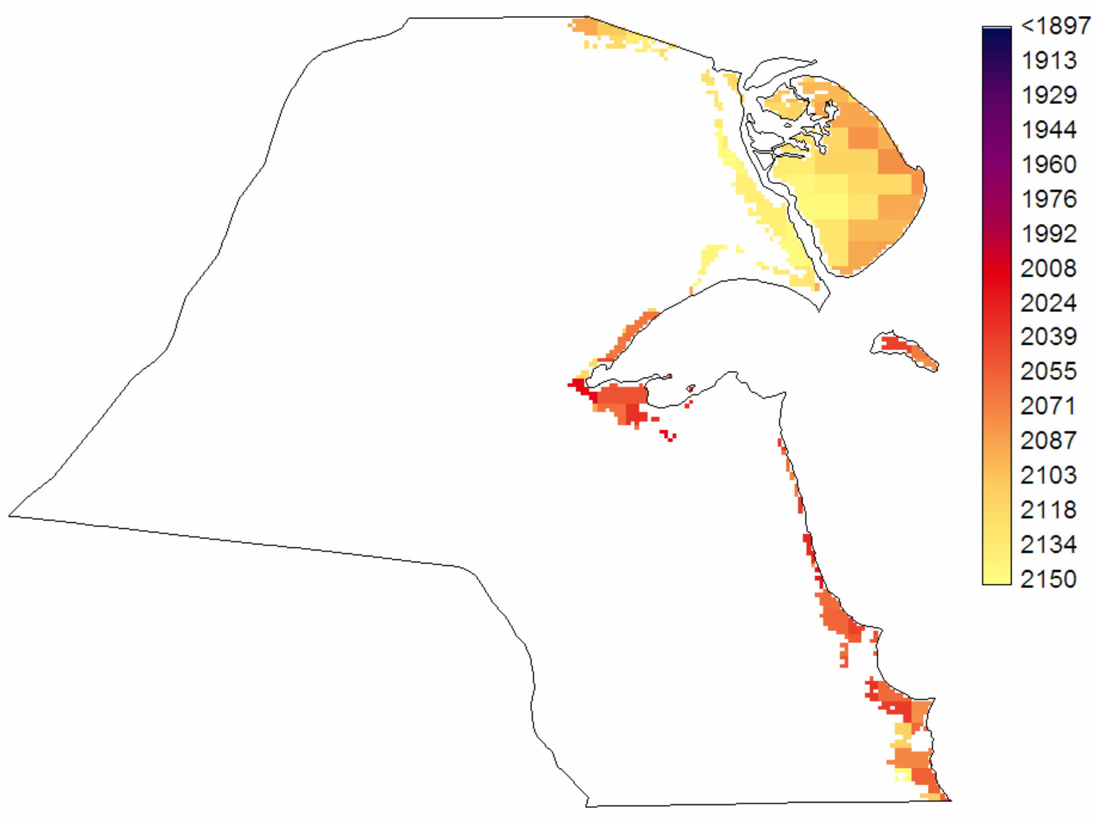


**Figure A- 39: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Kuwait**

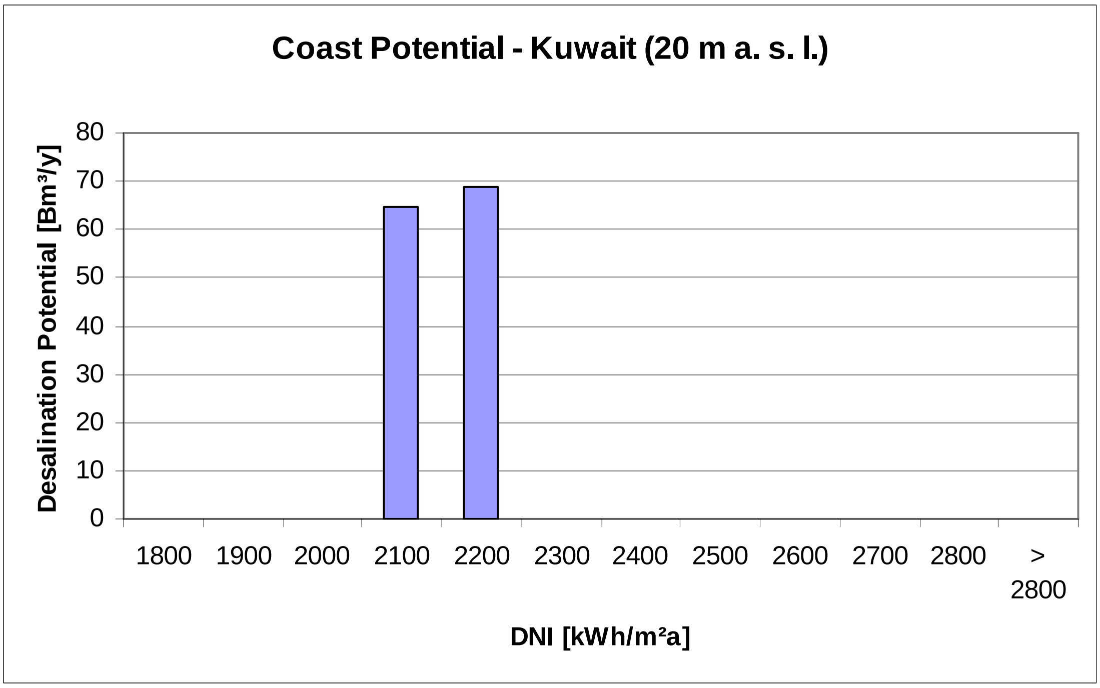


**Figure A- 40: Statistical analysis of the DNI map for CSP-desalination in Kuwait**

| **Kuwait** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 2.2 | 3 | 3.7 | 4.3 | 4.8 | 5.3 |
| Exploitable Water | Bm³/y | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Sustainable Water | Bm³/y | 0.07 | 0.20 | 0.40 | 0.64 | 0.91 | 1.22 |
| Irrigation Efficiency | % | 0.60 | 0.61 | 0.62 | 0.63 | 0.64 | 0.65 |
| Agricultural Use | Bm³/y | 0.60 | 0.8 | 1.0 | 1.1 | 1.2 | 1.3 |
| Municipal Efficiency | % | 0.70 | 0.72 | 0.74 | 0.76 | 0.78 | 0.80 |
| Municipal Use | Bm³/y | 0.90 | 1.23 | 1.51 | 1.76 | 1.96 | 2.16 |
| Industrial Use | Bm³/y | 0.10 | 0.14 | 0.17 | 0.20 | 0.22 | 0.24 |
| Total Demand Kuwait | Bm³/y | 1.60 | 2.2 | 2.7 | 3.1 | 3.4 | 3.7 |
| per capita Consumption | m³/cap/y | 727 | 724 | 718 | 713 | 709 | 705 |
| Wastewater reused | Bm³/y | 0.052 | 0.2 | 0.4 | 0.6 | 0.9 | 1.2 |
| Non-sustainable Water | Bm³/y | 1.5 | 2.0 | 1.9 | 0.8 | 0.4 | 0.1 |
| CSP Desalination | Bm³/y | 0.00 | 0.02 | 0.32 | 1.64 | 2.13 | 2.39 |
| Fossil Fuel Desalination | Bm³/a | 0.5 | 0.9 | 1.0 | 0.8 | 0.4 | 0.1 |
| Groundwater Over-Use | Bm³/y | 1.1 | 1.0 | 0.9 | 0.0 | 0.0 | 0.0 |

**Table A- 14: Main scenario indicators until 2050 for Kuwait**

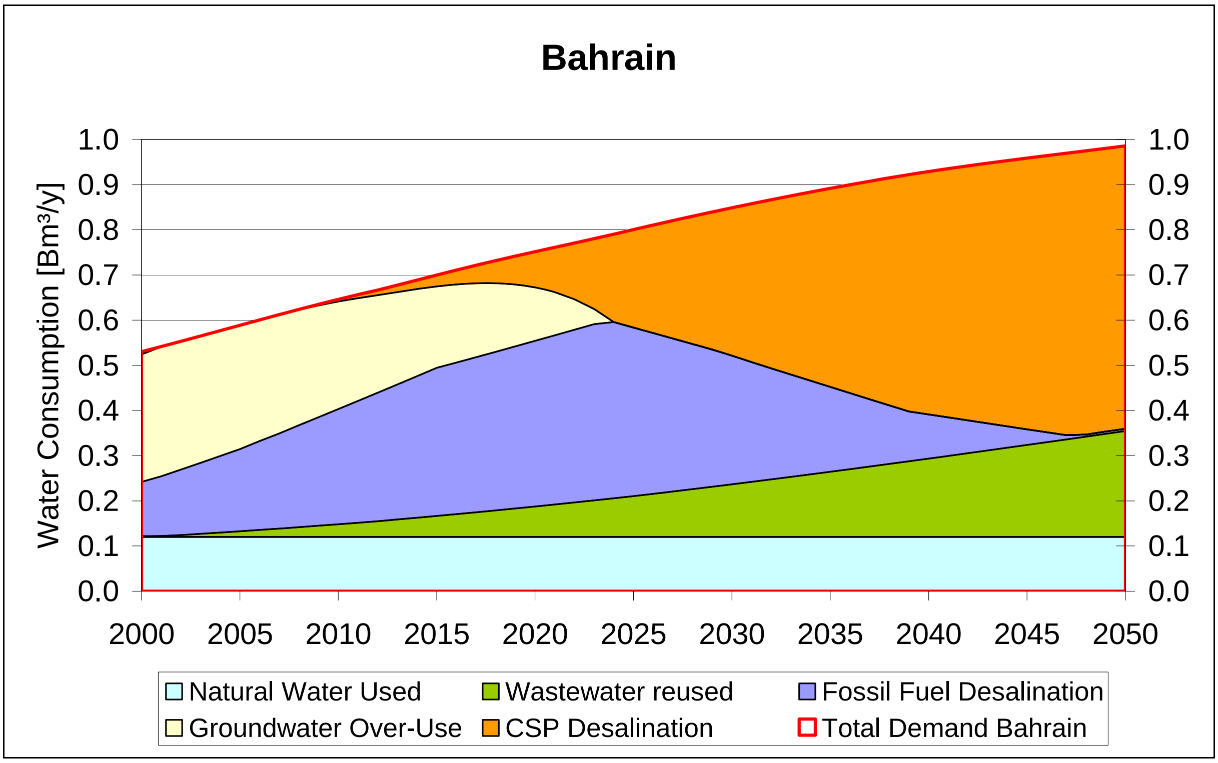


**Figure A- 41: Water supply scenario until 2050 in Bahrain**

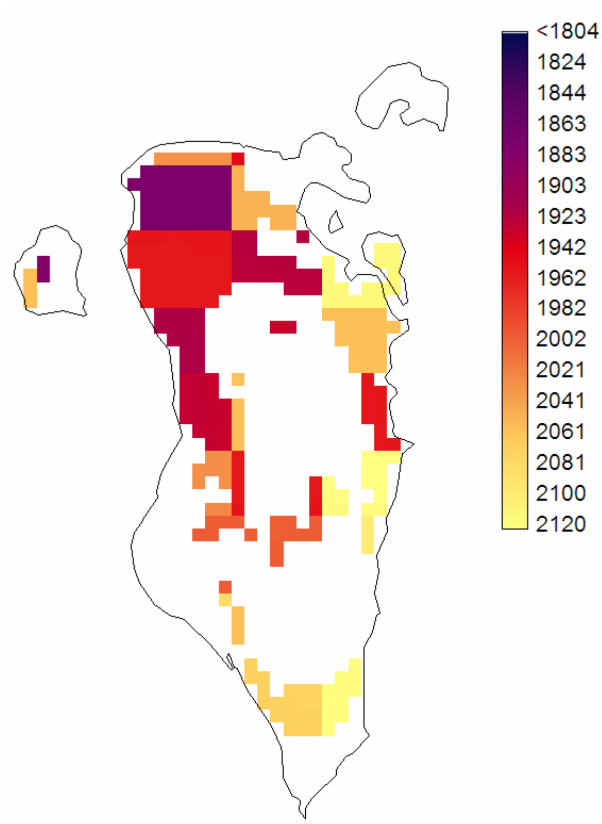


**Figure A- 42: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Bahrain**

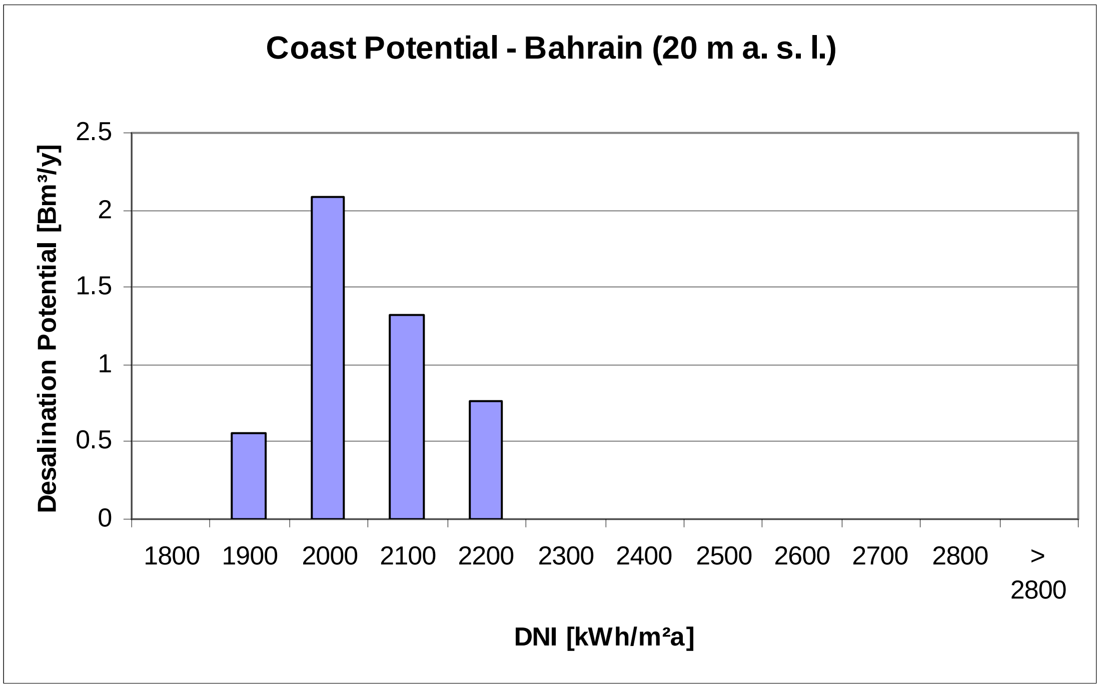


**Figure A- 43: Statistical analysis of the DNI map for CSP-desalination in Bahrain**

| **Bahrain** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 0.7 | 0.8 | 1.0 | 1.1 | 1.2 | 1.3 |
| Exploitable Water | Bm³/y | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 |
| Sustainable Water | Bm³/y | 0.13 | 0.15 | 0.19 | 0.24 | 0.29 | 0.35 |
| Irrigation Efficiency | % | 0.60 | 0.61 | 0.62 | 0.63 | 0.64 | 0.65 |
| Agricultural Use | Bm³/y | 0.3 | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 |
| Municipal Efficiency | % | 0.70 | 0.72 | 0.74 | 0.76 | 0.78 | 0.80 |
| Municipal Use | Bm³/y | 0.2 | 0.25 | 0.29 | 0.34 | 0.38 | 0.41 |
| Industrial Use | Bm³/y | 0.0 | 0.04 | 0.04 | 0.05 | 0.06 | 0.06 |
| Total Demand Bahrain | Bm³/y | 0.5 | 0.6 | 0.8 | 0.8 | 0.9 | 1.0 |
| per capita Consumption | m³/cap/y | 783 | 781 | 780 | 779 | 779 | 780 |
| Wastewater reused | Bm³/y | 0.002 | 0.0 | 0.1 | 0.1 | 0.2 | 0.2 |
| Non-sustainable Water | Bm³/y | 0.4 | 0.5 | 0.5 | 0.3 | 0.1 | 0.0 |
| CSP Desalination | Bm³/y | 0.00 | 0.00 | 0.08 | 0.33 | 0.54 | 0.63 |
| Fossil Fuel Desalination | Bm³/a | 0.1 | 0.3 | 0.4 | 0.3 | 0.1 | 0.0 |
| Groundwater Over-Use | Bm³/y | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 |

**Table A- 15: Main scenario indicators until 2050 for Bahrain**

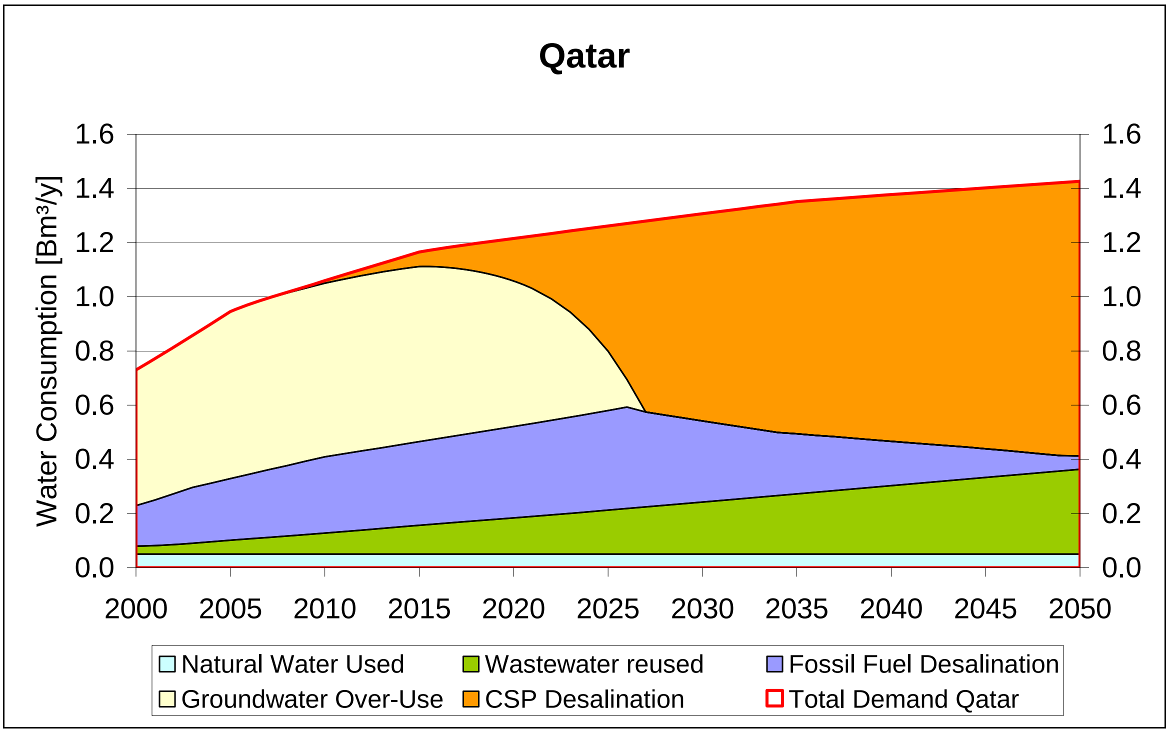


**Figure A- 44: Water supply scenario until 2050 in Qatar**

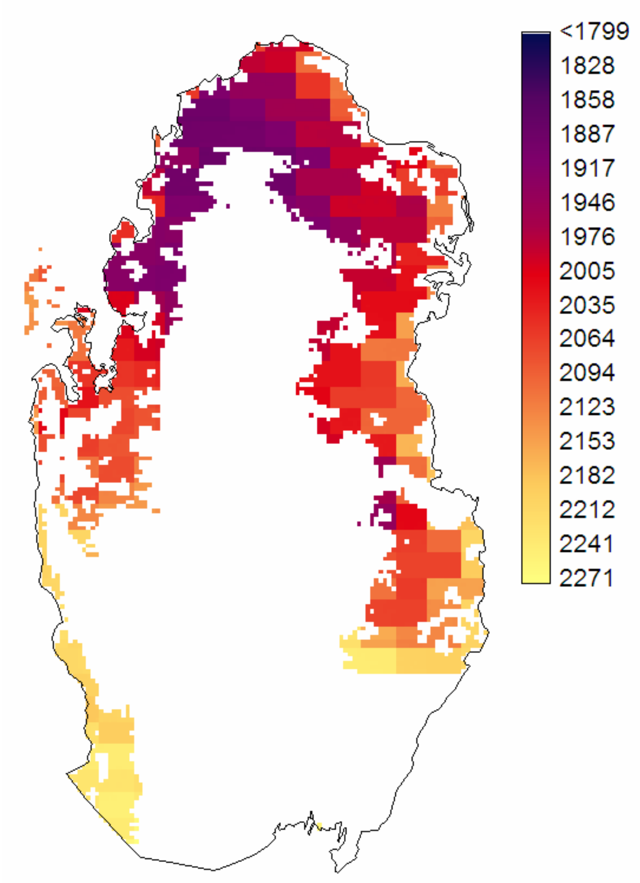


**Figure A- 45: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Qatar**

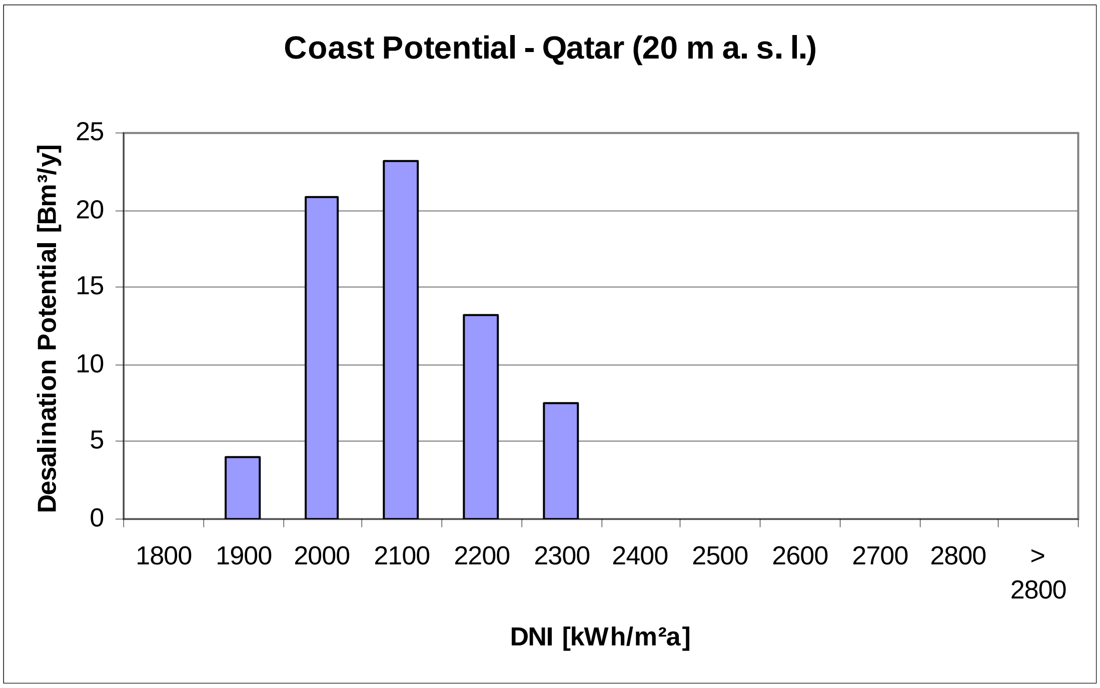


**Figure A- 46: Statistical analysis of the DNI map for CSP-desalination in Qatar**

| Qatar | | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 0.6 | 0.9 | 1.1 | 1.2 | 1.2 | 1.3 |
| Exploitable Water | Bm³/y | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Sustainable Water | Bm³/y | 0.08 | 0.13 | 0.18 | 0.24 | 0.30 | 0.36 |
| Irrigation Efficiency | % | 0.60 | 0.61 | 0.62 | 0.63 | 0.64 | 0.65 |
| Agricultural Use | Bm³/y | 0.4 | 0.6 | 0.7 | 0.7 | 0.8 | 0.8 |
| Municipal Efficiency | % | 0.70 | 0.72 | 0.74 | 0.76 | 0.78 | 0.80 |
| Municipal Use | Bm³/y | 0.3 | 0.43 | 0.49 | 0.52 | 0.55 | 0.57 |
| Industrial Use | Bm³/y | 0.0 | 0.04 | 0.05 | 0.05 | 0.06 | 0.06 |
| Total Demand Qatar | Bm³/y | 0.7 | 1.1 | 1.2 | 1.3 | 1.4 | 1.4 |
| per capita Consumption | m³/cap/y | 1217 | 1177 | 1157 | 1136 | 1116 | 1097 |
| Wastewater reused | Bm³/y | 0.030 | 0.1 | 0.1 | 0.2 | 0.3 | 0.3 |
| Non-sustainable Water | Bm³/y | 0.7 | 0.9 | 0.9 | 0.3 | 0.2 | 0.0 |
| CSP Desalination | Bm³/y | 0.00 | 0.01 | 0.16 | 0.76 | 0.91 | 1.01 |
| Fossil Fuel Desalination | Bm³/a | 0.2 | 0.3 | 0.3 | 0.3 | 0.2 | 0.0 |
| Groundwater Over-Use | Bm³/y | 0.5 | 0.6 | 0.5 | 0.0 | 0.0 | 0.0 |

**Table A- 16: Main scenario indicators until 2050 for Qatar**

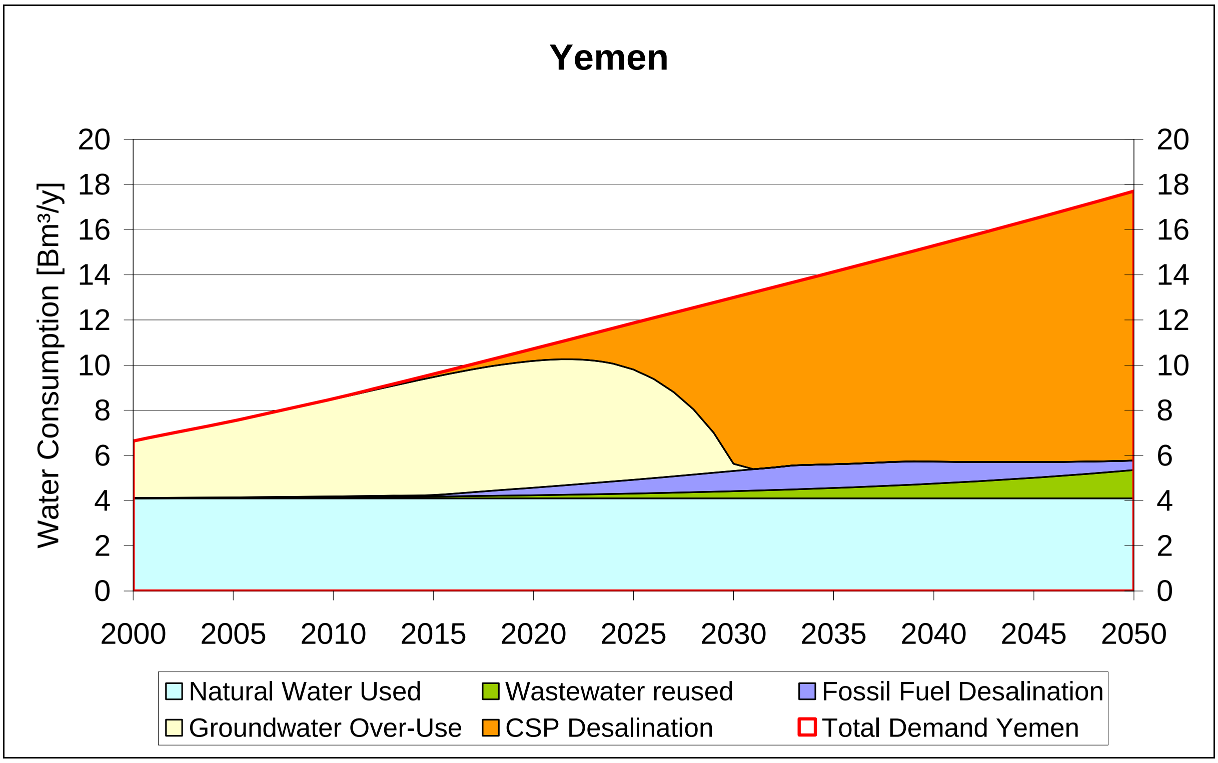


**Figure A- 47: Water supply scenario until 2050 in Yemen**

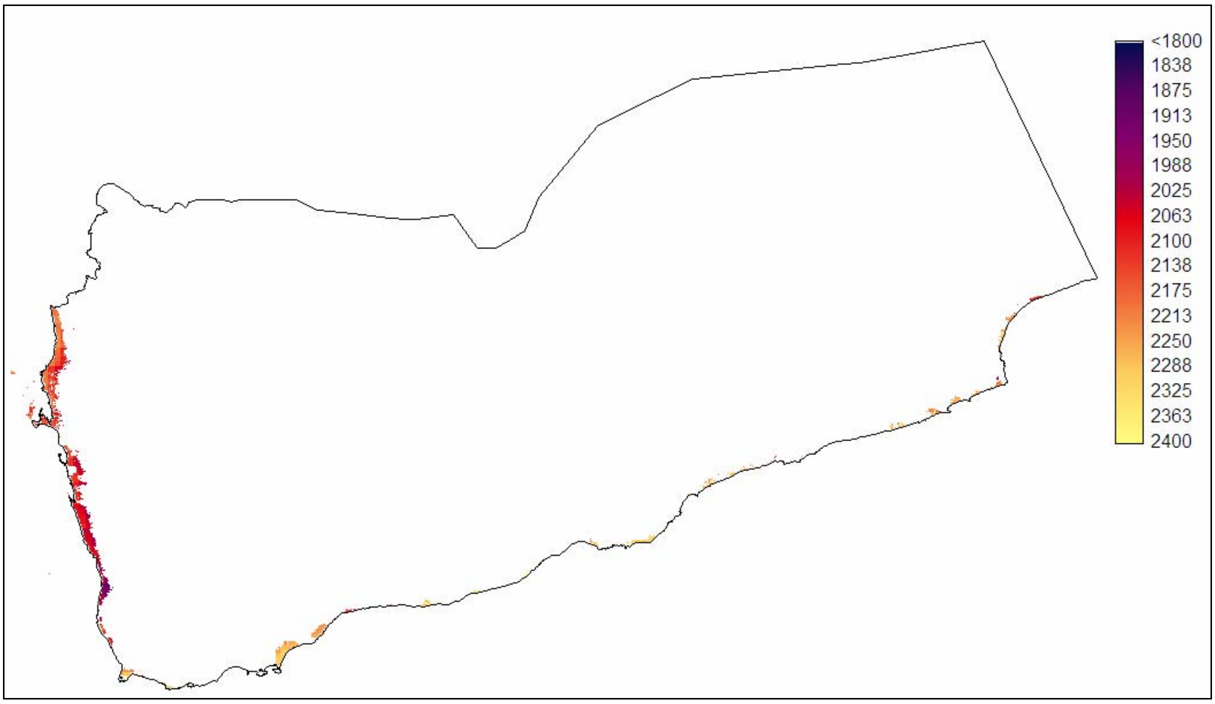


**Figure A- 48: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Yemen**

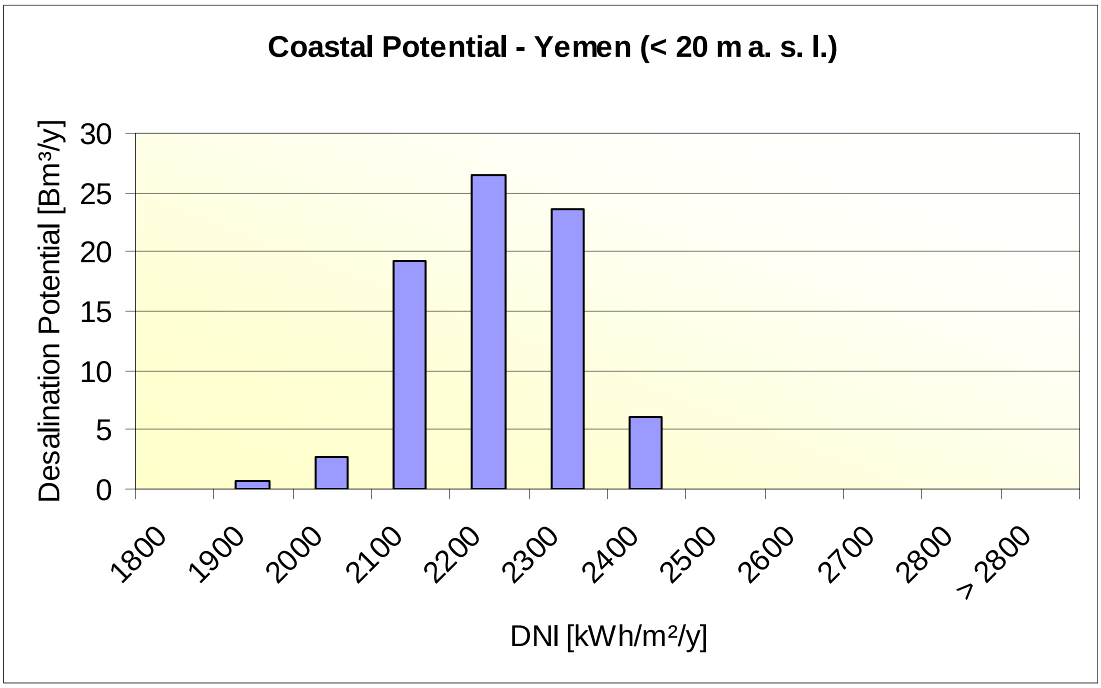


**Figure A- 49: Statistical analysis of the DNI map for CSP-desalination in Yemen**

| Yemen | | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 17.9 | 24.5 | 32.7 | 41.5 | 50.5 | 59.5 |
| Exploitable Water | Bm³/y | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 |
| Sustainable Water | Bm³/y | 4.10 | 4.14 | 4.24 | 4.42 | 4.75 | 5.36 |
| Irrigation Efficiency | % | 0.40 | 0.43 | 0.46 | 0.49 | 0.52 | 0.55 |
| Agricultural Use | Bm³/y | 6.3 | 8.0 | 10.0 | 11.9 | 13.7 | 15.2 |
| Municipal Efficiency | % | 0.50 | 0.55 | 0.59 | 0.64 | 0.69 | 0.73 |
| Municipal Use | Bm³/y | 0.3 | 0.41 | 0.61 | 0.93 | 1.43 | 2.19 |
| Industrial Use | Bm³/y | 0.0 | 0.06 | 0.09 | 0.14 | 0.21 | 0.32 |
| Total Demand Yemen | Bm³/y | 6.6 | 8.5 | 10.7 | 13.0 | 15.3 | 17.7 |
| per capita Consumption | m³/cap/y | 370 | 347 | 328 | 313 | 303 | 298 |
| Wastewater reused | Bm³/y | 0.000 | 0.0 | 0.1 | 0.3 | 0.7 | 1.3 |
| Non-sustainable Water | Bm³/y | 2.5 | 4.3 | 5.9 | 1.2 | 1.0 | 0.4 |
| CSP Desalination | Bm³/y | 0.00 | 0.02 | 0.53 | 7.36 | 9.56 | 11.94 |
| Fossil Fuel Desalination | Bm³/a | 0.0 | 0.0 | 0.3 | 0.9 | 1.0 | 0.4 |
| Groundwater Over-Use | Bm³/y | 2.5 | 4.3 | 5.6 | 0.3 | 0.0 | 0.0 |

**Table A- 17: Main scenario indicators until 2050 for Yemen**

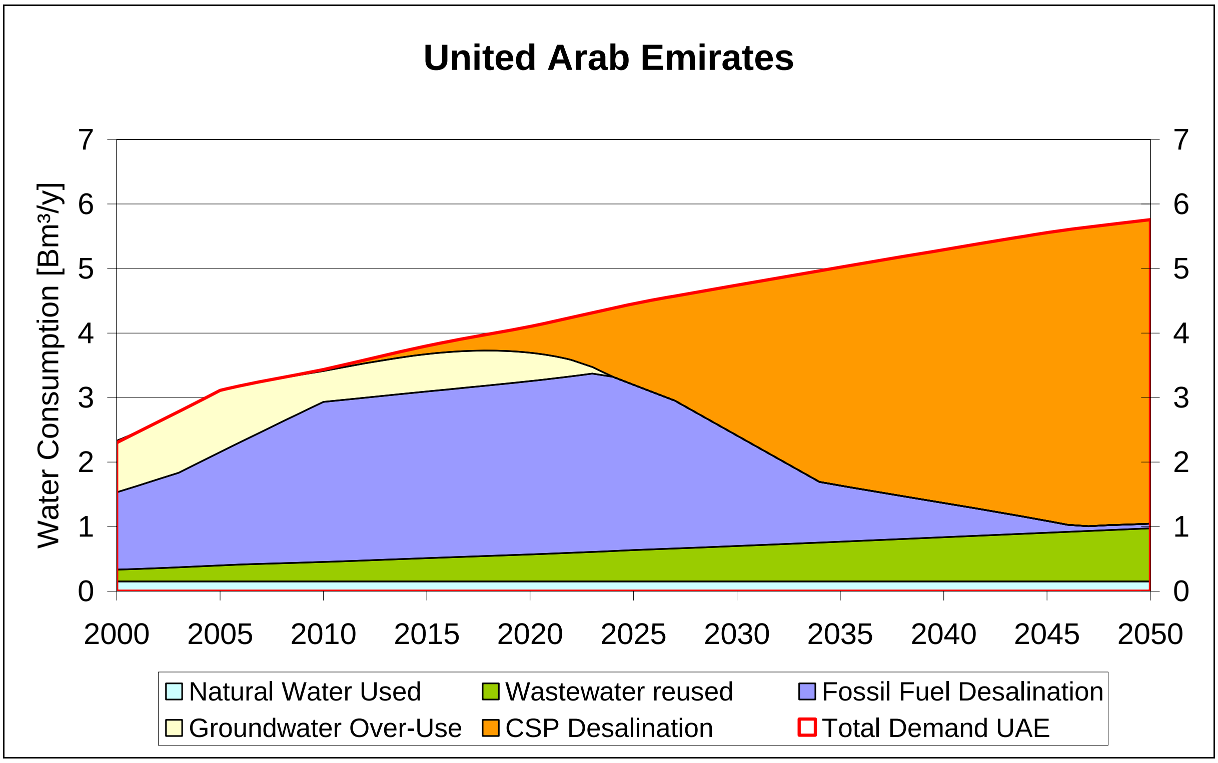


**Figure A- 50: Water supply scenario until 2050 in UAE**

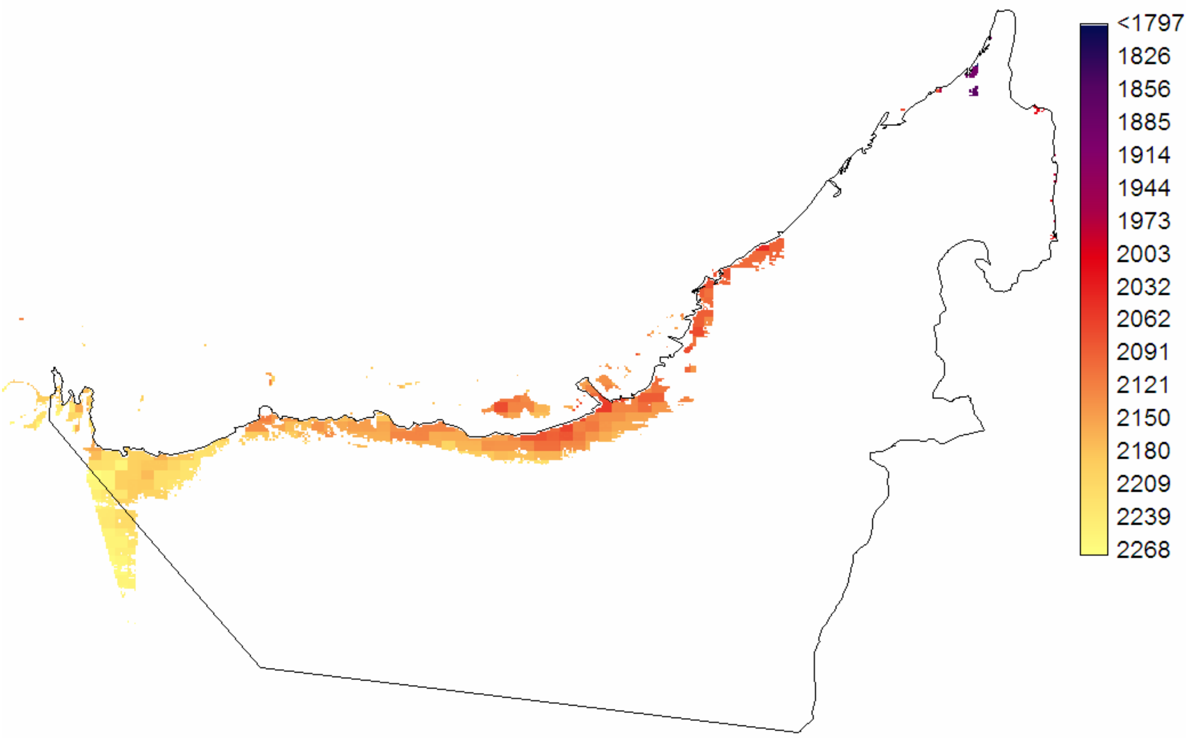


**Figure A- 51: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in UAE**

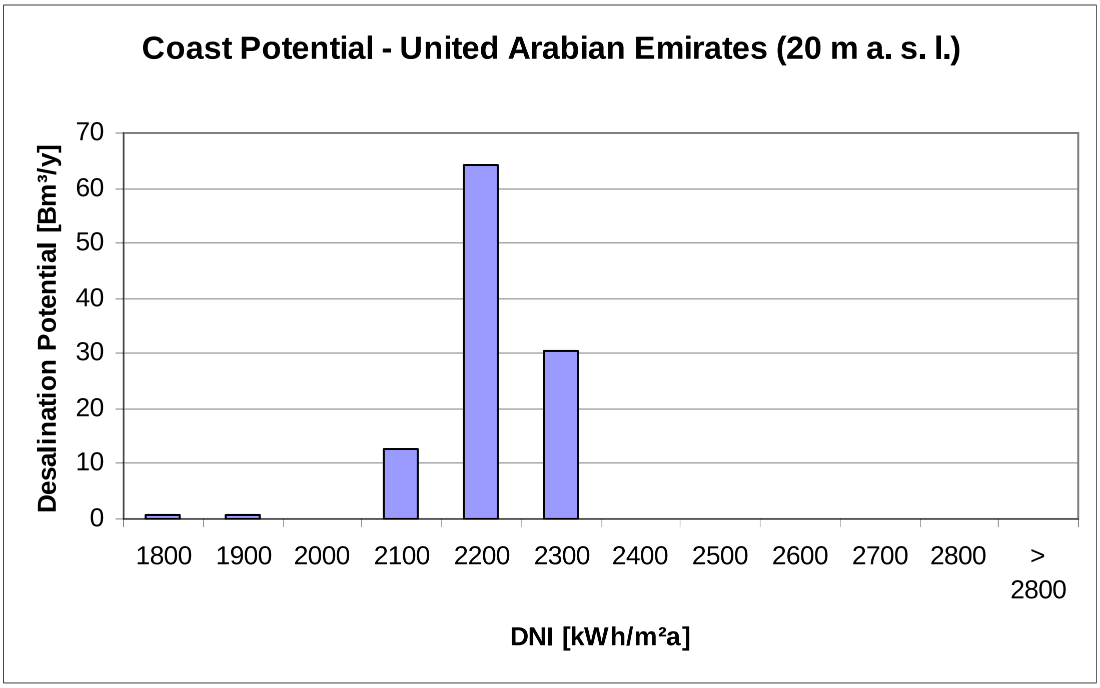


**Figure A- 52: Statistical analysis of the DNI map for CSP-desalination in UAE**

| UAE | | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 3.2 | 5.0 | 6.1 | 7.2 | 8.2 | 9.1 |
| Exploitable Water | Bm³/y | 0.150 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| Sustainable Water | Bm³/y | 0.30 | 0.45 | 0.57 | 0.70 | 0.83 | 0.97 |
| Irrigation Efficiency | % | 0.60 | 0.61 | 0.62 | 0.63 | 0.64 | 0.65 |
| Agricultural Use | Bm³/y | 1.6 | 2.4 | 2.9 | 3.4 | 3.8 | 4.1 |
| Municipal Efficiency | % | 0.70 | 0.72 | 0.74 | 0.76 | 0.78 | 0.80 |
| Municipal Use | Bm³/y | 0.5 | 0.74 | 0.88 | 1.00 | 1.11 | 1.19 |
| Industrial Use | Bm³/y | 0.2 | 0.28 | 0.33 | 0.38 | 0.42 | 0.45 |
| Total Demand UAE | Bm³/y | 2.3 | 3.4 | 4.1 | 4.7 | 5.3 | 5.8 |
| per capita Consumption | m³/cap/y | 719 | 687 | 672 | 659 | 645 | 633 |
| Wastewater reused | Bm³/y | 0.183 | 0.3 | 0.4 | 0.5 | 0.7 | 0.8 |
| Non-sustainable Water | Bm³/y | 2.0 | 3.0 | 3.1 | 1.7 | 0.5 | 0.1 |
| CSP Desalination | Bm³/y | 0.00 | 0.02 | 0.41 | 2.33 | 3.93 | 4.71 |
| Fossil Fuel Desalination | Bm³/a | 1.2 | 2.5 | 2.7 | 1.7 | 0.5 | 0.1 |
| Groundwater Over-Use | Bm³/y | 0.8 | 0.5 | 0.4 | 0.0 | 0.0 | 0.0 |

**Table A- 18: Main scenario indicators until 2050 for UAE**

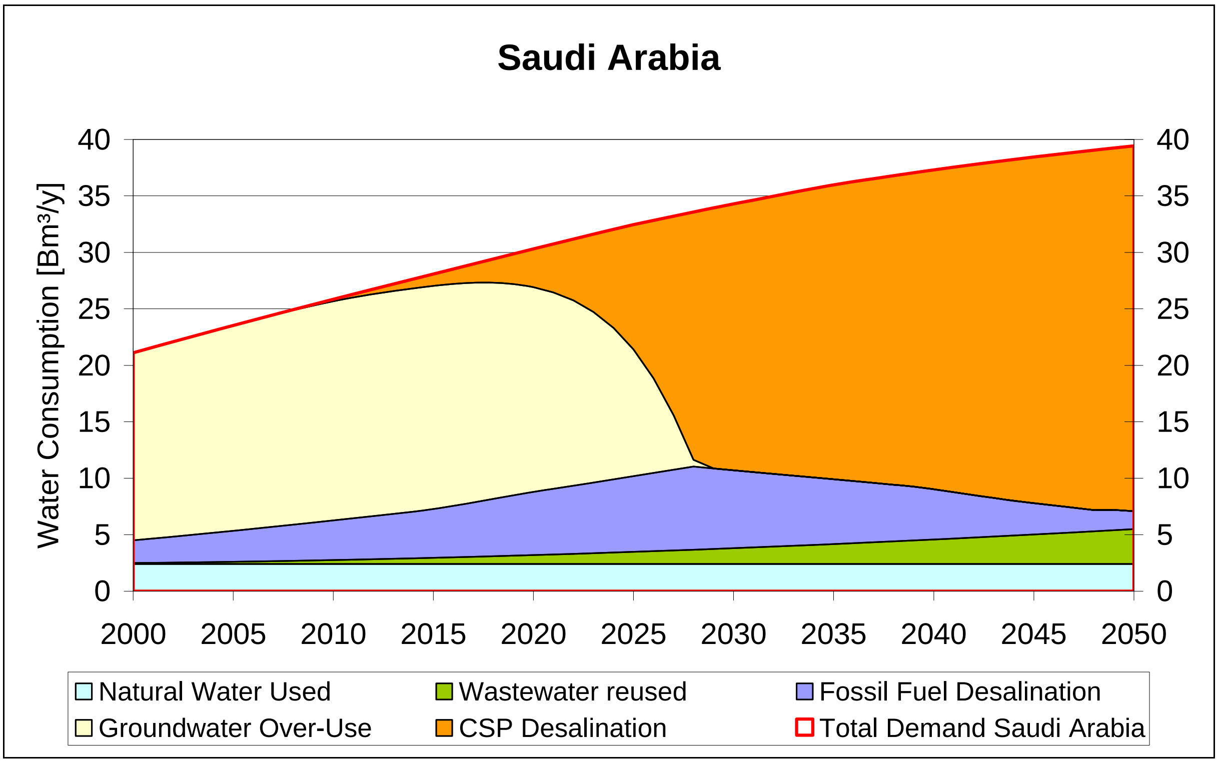


**Figure A- 53: Water supply scenario until 2050 in Saudi Arabia**


**Figure A- 54: Direct normal irradiance in kWh/m²/y at potential coastal sites for CSP desalination in Saudi Arabia**

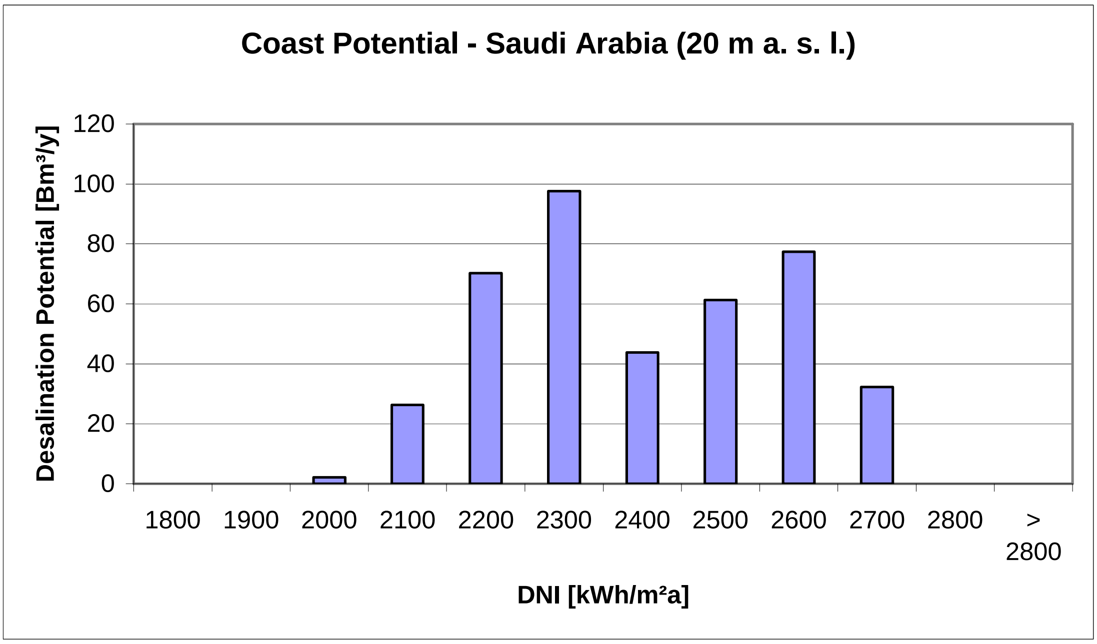


**Figure A- 55: Statistical analysis of the DNI map for CSP-desalination in Saudi Arabia**

| **Saudi Arabia** | | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|
| Population MP | Mp | 21.5 | 27.7 | 34.0 | 40.1 | 45.3 | 49.5 |
| Exploitable Water | Bm³/y | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| Sustainable Water | Bm³/y | 2.49 | 2.75 | 3.19 | 3.80 | 4.57 | 5.49 |
| Irrigation Efficiency | % | 0.43 | 0.46 | 0.49 | 0.51 | 0.54 | 0.57 |
| Agricultural Use | Bm³/y | 19.1 | 23.1 | 26.7 | 29.8 | 32.0 | 33.3 |
| Municipal Efficiency | % | 0.70 | 0.72 | 0.74 | 0.76 | 0.78 | 0.80 |
| Municipal Use | Bm³/y | 1.8 | 2.49 | 3.22 | 4.02 | 4.81 | 5.57 |
| Industrial Use | Bm³/y | 0.2 | 0.27 | 0.35 | 0.44 | 0.53 | 0.61 |
| Total Demand Saudi Arabia | Bm³/y | 21.1 | 25.9 | 30.3 | 34.3 | 37.3 | 39.4 |
| per capita Consumption | m³/cap/y | 982 | 933 | 891 | 855 | 824 | 797 |
| Wastewater reused | Bm³/y | 0.091 | 0.4 | 0.8 | 1.4 | 2.2 | 3.1 |
| Non-sustainable Water | Bm³/y | 18.6 | 22.9 | 23.7 | 6.9 | 4.4 | 1.6 |
| CSP Desalination | Bm³/y | 0.00 | 0.18 | 3.39 | 23.60 | 28.31 | 32.36 |
| Fossil Fuel Desalination | Bm³/a | 2.0 | 3.5 | 5.6 | 6.9 | 4.4 | 1.6 |
| Groundwater Over-Use | Bm³/y | 16.6 | 19.4 | 18.1 | 0.0 | 0.0 | 0.0 |

**Table A- 19: Main scenario indicators until 2050 for Saudi Arabia**

## Annex 6: Concept of Multi-Purpose Plants for Agriculture

International Research Centre for Renewable Energy (IFEED)
Director: Prof. Dr. N. El Bassam
Kirchweg 4A
D-31275 Lehrte-Sievershausen
Germany
Tel.: +49-5302-1303
Fax.: +49-5302-1303
Moblile phone: +49-170-3254301
E-mail: info@ifeed.org
www.ifeed.org

AQUA-CSP-Project 2006, DLR
Project partner No. 7, IFEED (August 2007)

### 1. Introduction

Various human societies have also been established in deserts throughout history. And today deserts are important part of the world's natural and cultural heritage. Among the greatest contribution of desert cultures to the world are the three "religions of the Book": Judaism, Christianity and Islam which have had tremendous impact far beyond their areas of origin.
Deserts represent unique ecosystems which support significant plant and animal biodiversity, particularly with respect to adaptation for survival in arid conditions. With summer ground temperatures, near 80°C, and only very ephemeral pulses of rain, species in deserts have evolved remarkable adaptations to severe conditions, ranging from plant adapted to the fast use ephemerally abundant water or extraordinarily efficient use of scarce water, to behavioral, anatomical and physiological adaptations in animals. Due to their warm climate, deserts also export agricultural products, produced under irrigation to non-desert areas. Agriculture and horticulture are already profitable in many deserts and have great further potential. A new non-conventional desert export is derived from aquaculture , which is paradoxically, can be more efficient in water use than desert plants, and can take advantage of deserts´ mild winter temperatures and low cost of land.
Biologically-derived valuable chemicals, produced by micro-algae as well as medicinal plants, are also manufactured in deserts, capitalizing on their high year-round solar radiation, and exported to global market. Besides the ongoing export of wild plant products from deserts to non-deserts, there is pharmaceutical potential in desert plants which is yet to be exploited.
Within the agriculture sector, one possibility to improve water efficiency is to restrict irrigation to high-value crops (i.e. dates), intensive greenhouse farming or aquaculture.
Groundwater often extracted in excess of meager recharge, rates currently provide 60-100 percent of fresh water needs in most deserts lacking of a large river. The water in rivers that cross deserts is already thoroughly stabilized, if not over used. Useful technologies that can play an important role in future water supply include: drip irrigation and micro-sprinklers; desalination of brackish and saline water; fog harvesting in coastal deserts; and small sediments-holding dams and terraces.
Although deserts do not have much water, they do have other valuable natural resources that benefit people, such as biological and cultural diversity, oil, gas and other minerals. 40-60 % of minerals and fossil energy used globally is extracted from deserts (Oil and gas Belt).
Deserts in general have the highest levels of solar input in terrestrial world. They also have cheap, plentiful space and the potential to generate solar power for electricity, heat and water desalination. Continuously high solar radiation makes deserts ideal locations for solar installations, the potential reach of which is limited to deserts. Renewables might supply one-third to one-half of global energy by 2050 (Shell International 2001). The sun is supplying

deserts (solar belt) with energy equivalent to 250 liters of oil per square meter every year (2500 l oe/1oo m2). In less than 6 hours, deserts receive more energy than humankind uses in a whole year.
The scientific knowledge and engineering skills needed to generate sustainable incomes from desert resources (solar radiation) already exist; appropriate actions and equitable sharing of the proceeds need to be determined. Resource use and management in deserts for their developments focuses and depends heavily on water and energy, tow key resources. Desert development is going to be large determined by largely our common visions and collective actions taken to fulfill them. The challenge remains to harness not only local, but also global policy mechanisms and market incentives to develop future for deserts, where viable future environmental conservation and economic development are achieved.

Apart from technological feasibility, the adoption of solar energy as alternative to fissile fuels depends on global as well as national policy environments and concrete implementation strategies. The AQUA-CSP Project could be considered as a milestone towards achieving the goals of sustainability regionally and globally.

## 1. Objectives of the Subtask

The main objective of the subtask is to integrate agriculture in the system in order to protect the CSP installations, to improve the living and working conditions, stabilize the soils under and around collectors, creation a favorable micro-climate, combat desertification and to produce food, fiber and firewood.
Integration the AQUA-CSP system with agriculture needs the verification and analysis of the following essential determinants:

- Determination of the physiological constrains of water use efficiencies, drought and salt tolerance.
- Identification of desert adapted plant species (crops, flowers, horticulture and forest trees and shrubs).
- Verification of adequate cultivation systems adapted to desert environments (land preparation, sawing, harvesting, and weed and pest control).
- Identification efficient irrigation technologies and schemes for improving the water use efficiency (more crops for drops).
- Greenhouse technologies and facilities.
- Implementation procedures

The results the study of this task will have positive impacts on:

- Protection of the CSP Installations from sand and dust
- Contribution towards combating desertification
- Improving the soil fertility and soil conservation of the site
- Creating of a favorable micro climate for man and equipments
- Implementation of food processing and conservation as well as marketing pathways
- Reducing rural depopulation through job creation for some of the desert population and technicians of different disciplines and offering the possibility for the young people to be trained and improving their skills.
- Availability of vegetables, fruits, meat, fibers, flowers etc.

This study may contribute in formulating the anticipated project proposal "AGRO-CSP"

## 3. Background and Procedure

The FAO of the United Nations in support of the Sustainable Rural Environment and Energy Network (SREN) has authorized IFEED 2002 to develop the concept of the "Integrated Energy Farms, IEF". The IEF concept includes a decentralized living area from which the daily necessities, economic and social activities can be produced and practiced directly on-site. The IEF based on

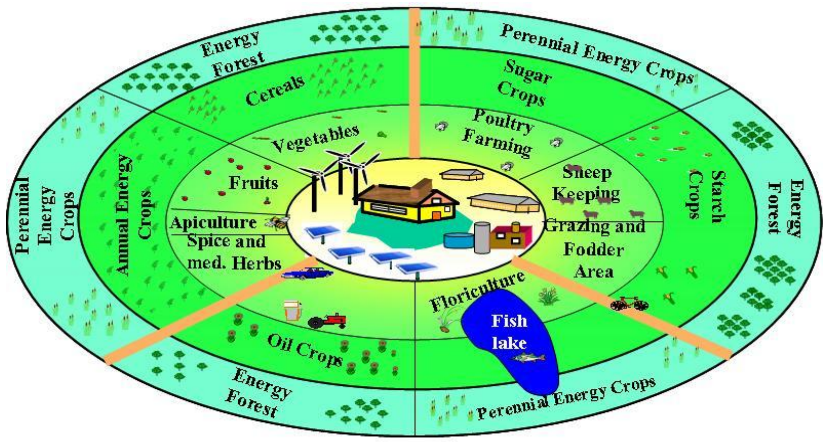


Fig. 1 Layout of the Integrated Energy Farms (IEF)

renewable energy sources would seek to optimize energetic autonomy and ecologically semi-closed system while also providing socio-economic viability (food, water, waste management and employment) and it should consider aspects of landscape and bio-diversity management. Ideally, it has to promote the integration of different renewable energies; contribute to sustainable rural development and to the reduction of greenhouse gas emission as well as improving the environment.

This concept aims at planning, optimizing, designing and building a first plant for solar electricity generation and seawater desalination based on concentrating solar thermal power (CSP) technology in a MENA coastal area with arid or semi-arid climate, and to prepare for the replication of this concept in the MENA region and world wide.

The overall task of IFEED in this project is the adaptation of the FAO concept of Integrated Energy Farming in AQUA- MED-CSP project for rural and agriculture development in Mediterranean desert regions as well as the identification of revenues and demand structures in agriculture and in desert regions.

## 4. Water availability, utilization and Water use efficiency (WUE)

Only 3% of the world water resources are freshwater, with 2, 31 being fixed in glacier sand permafrost in the poles and not available for consumption and about 0, 69% available in rivers, lakes, soil, swamps, groundwater and vegetation. Globally about 70% of water is being used in agriculture. Inefficiency in water use worldwide is huge. Losses in conventional irrigation systems are about 50 – 90%. Only 10-50% of irrigation water reaches the crops. The rest evaporates or seeps away.

Water use efficiency (WUE) is an important indicator for water demand of the crops to produce food. It also is used for meat productivity of various animals (beef, sheep meat and eggs). Productive WUE considers only the actual amount of water need in connection with the photosynthesis or transpiration rate which depends on the air temperature and humidity. Considerable water losses are resulted from surface evaporation, percolation and surface flows (1, 2, 8, and 10).

Huge differences exist in water requirements for different food production chains.
Fig.3 gives information on water consumption in different plant and animal production cycles and the amounts of water in liters required for producing one kilogram (kg) of food as dry matter. It shows clearly that lowest water demand is needed by vegetable crops. Meat production, especially of beef consumes the highest water rate.

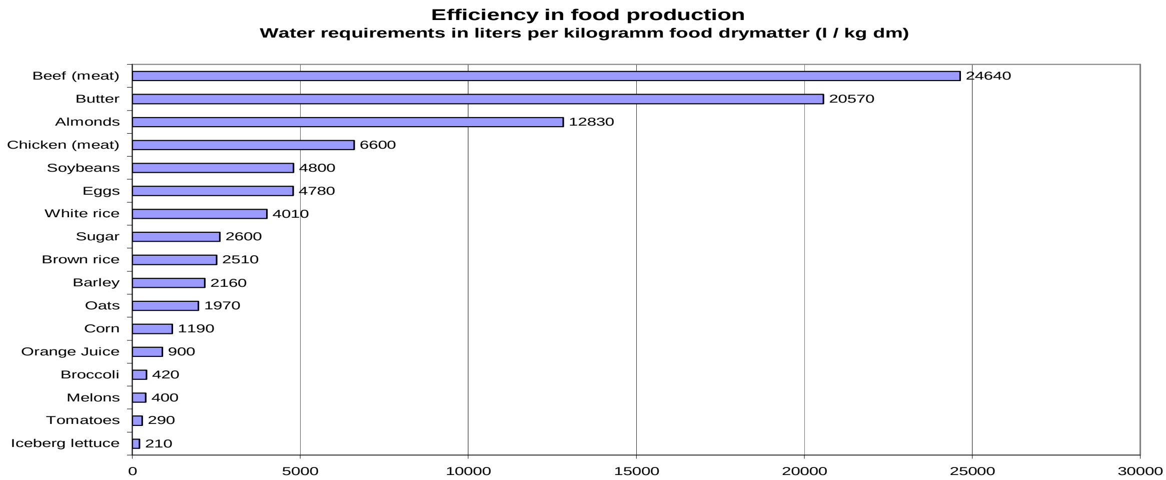


Fig. 2 Water requirements in food production

This project offers the possibility and chance to identify the most effective plant species in water use efficiency, the most effective irrigation system and suitable farming systems for CSP to reduce water demand, to combat desertification and ensure sustainable rural development.

## 5. Physiological background and the potential of plant productivity biomass

The potential growth of plant materials is the results of the interactions between the genotype (genetically fixed potential), environmental constrains (temperature, solar radiation, air humidity, wind velocity and precipitation) and the external inputs (fertilizers, water, chemicals, seeds etc.).

5.1 Environment and plant productivity

The tables 1-4 are essential for the interaction effects of genotypes, light, water and temperatures of the site on yield determination (6, 7).

Table 1: Photosynthesis (mg CO2 / s dw x h) of soil moistures and relative humidity

| Field capacity | Relative humidity | |
|---|---|---|
| | 70% | 30% |
| 30% | 16,5 | 14,3 |
| 70% | 8,8 | 6,6 |

Table 2: Light intensity under natural conditions

| Quants / m² x s | |
|---|---|
| Day light, clear | 800.000 |
| Day light, cloudy | 130.000 |
| Day light under plant shade | 17.000 |
| Twilight | 600 |
| Moon light | 0,2100 |
| Star light | 0,0009 |
| Night sky, cloudy | 0,0001 |

Table 3: Theoretical upper limit of crop production at 40° Latitude

| | | |
|---|---|---|
| Total energy radiation (TER) | 1,47 x $10^{10}$ | kcal/ha |
| Upper limit of efficiency for TER | 6,8 | % |
| Average calorific value of biomass | 4,00 x 10 | kcal/ha |
| Maximum crop productivity | 250 | tons |

Table 4: Photosynthetic efficiency of a standard crop

| | |
|---|---|
| Total energy radiation (TER) | 4,00 x $10^{10}$ |
| Photosynthetically active radiation (PAR)) | 1,47 x $10^{13}$ |
| Caloric value (4.000 cal / g) | 6,32 x $10^{12}$ |

The results of these interactions have been used to classify the major important plant species in 5 main groups I-V (table 6) according to their photosynthetic pathways

Table 5: Physiological characteristics and requirements of different plant species

| Characteristics | Unit | Crop group | | | | |
|---|---|---|---|---|---|---|
| Photosynthetic pathways | | I | II | III | IV | V |
| Radiation intensity at max. photosynth. | cal / cm² x min | 0,2 - 0,6 | 0,3 - 0,8 | 1,0 - 1,4 | 1,0 - 1,4 | 0,6 - 1,4 |
| | | | | | | |
| Operative temperature | °C | 5 -30 | 10 - 35 | 15 - 45 | 10 - 35 | 10 - 45 |
| | | | | | | |
| Max. crop growth rate | g / m² x day | 20 - 30 | 30 - 40 | 30 - 60 | 40 - 60 | 20 - 30 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Water use efficiency | g / g | 400-800 | 300-700 | 150-300 | 150-350 | 50-200 |

Representative Crops

- Group I C 3 pathway: Field mustard, potato, oat, tomato, rye, grape, rape, pyrethrum, sugar beet, bread wheat, chickpea, French bean, Arabic coffee, sunflower, olive, barley. Cabbage, lentil, linseed;

- Group II C 3 pathway: Groundnut, French bean, rice, fig, soybean, cowpea, sesame, tomato, hyacinth bean, roselle, tobacco, sunflower, grape, safflower, kenaf, castor bean, sweet potato, sweet orange, bananas, lemon, avocado pear, coconut, cotton, cassava, mango, Robusta coffee, white yam, olive, greater yam, Para rubber, oil palm, cocoa;

- Group III C 4 pathway: Japanese barnyard millet, foxtail millet, finger millet, common millet, pearl millet, hungry rice, sorghum, maize, sugarcane;

- Group IV C 4 pathway: Japanese barnyard millet, foxtail millet, common millet, sorghum, and maize;
- Group V CAM pathway: Sisal, pineapple

## 6. Identification and evaluation of plant species which meets the requirements of arid and semi-arid regions for food and biomass, under and around the STPD units

More than 450.000 plant species exist worldwide. Only small portion of it is being used at present. For this project, several plant species Tables 6-8 have been selected to meet the requirements of the anticipated sites (4).

The selection of proper plant species is essential to meet the requirements of the project. The main features of these crops should be:

- Drought and heat resistant
- Shadow tolerable
- Salt resistant
- Low input (Fertilizers, Chemicals and Water)
- High productivity

The plant breeding has achieved a great success in the last years in breeding of high yielding varieties and reduction of the inputs. Adapted varieties for different climatic regions produced and are also available. This is the reason why we are producing more food with less area, especially in OECD countries. The selection of the right seeds, beside water availability, is the key element for a successful farming system.
Priority should be given to introduce food and fodder crops and soil conservation. The people working in around the project sites needed to be supplied with vegetables, fruits, meat and other food to be produced locally.

The IEF can also provide an excess of energy resources in solid, liquid and gaseous states. Biomass such as wood and straw can directly used as solid energy for combustion for heat and power generation or for cooking. Oil and ethanol plants can be also cultivated for substitution for liquid fossil fuels. Wastes and other organic residues represent a suitable source to produce high quality organic fertilizers which are essential for soil improvement substitution of chemical fertilizers under and around the solar collectors.

More than 450.000 plant species exist worldwide. Only small portion of it is being used at present. For this project, several plant species Tables 6-8 have been selected to meet the requirements of the anticipated sites (4). Other wild desert plant species should be taken also in consideration.

**Table 6: Food crops suitable for cultivation under the CSP installations**

- Aubergine (*Solanum melongena L.*)
- Beans ( *Vicia faba L.)*
- Chicory (*Cichorium itybus L.*)
- Cress (*Leoidium sativium L.*)
- Cucumber (*Cucmis sativus L.*)
- Herbs and spice plants
- Lady's finger (*Hibiscus esculentus L.*)
- Melons (*Cucumis melo L.*)
- Tomato (*Lycopericon lycopersicum L.*)
- Potato (*Solanum tuberosum L.*)
- Salad (Lactuca sativa L.)
- Peppers (*Capsicum annuum L.*)
- Spinach (*Spinacia oleracea L.*)

**Table 7: Crops suitable for cultivation around CSP**

- Alfalfa (*Medicago sativa L.*)
- Amaranth (*Amaranthus ssp.*)
- Annual ryegrass (L*olium multiflorum Lam.*)
- Barley (*Hordeum vulgare L.*)
- Buckwheat (*Fagopyrum esculentum Moench*)
- Groundnut (*Arachis hypopgea*)
- Hemp (*Cannabis sativa L.*)
- Kenaf (Hibiscus cannabinus L.)
- Rape (*Brassica rapsus L.*)
- Lupines (*Lupinus ssp.*)
- Maize (*Zea mays L. ssp. Mays*)
- Meadow foxtail (*Alopecurus pratensis L.*)
- Quinoa (*Chenopodium quinoa Willd*).
- Reed canary grass (*Phalaris arundinaceae*)
- Rosin weed (*Silphium perfolatium L*)
- Safflower (*Carthamus tinctorius L.*)
- Salicornia (*Salicornia bigelovvi Torr.*)
- Sesame (*Sesamum indicum L*)
- Soybean (*Glycine max (L.) Merr.*)
- Sugar cane (*Saccharum officinarum L.*) *
- Sunflower (*Helianthus annus L.*)
- Sweet sorghum (*Sorghum bicolor L. Moench*)

- Switch grass (*Panicum virgatum L.*)
- Tall fescue (*Festuca arundinaceae Schreb.*)
- Timothy (*Phleum pratense L.*)
- Topinambur (*Helianthus tuberosus L.*) *
- Triticale (*Triticosecal*e)
- Oats (*Avena sativa L.*)
- Rye (*Secale cereale L.*)
- Wheat (*Triticum aestivum L.*)

* = perennial crops (all others are annual)

**Table 8: Trees and tall grasses for cultivation around CSP collectors fields**

- Argan tree (*Argania spinosa*)*
- Bamboo (*Bambusoideae*) *
- Black locust (*Robinia pseudoacacia L*)*
- Broom (Ginestra) (*Spartium junceum*)*
- Cardoon (*Cynara cardunculus L.*)*
- Gigant knotwees (*Polygunum sachalinensis F. Schmidt*)*
- Common reed (*Phragmites communis Trin.*)*
- Cordgrass (*Spartina ssp.*)*
- Date palm (*Phoenix dactylifera*)*
- Eucalyptus (*Eucalyptus spp.*)*
- Fig-tree (*Ficus caraca L.*)
- Giant reed (*Arundo donax*)*
- Jojoba (*Simmondsia chinensis*)*
- Miscanthus (*Miscanthus ssp.*) *
- Olive (*Olea europaea.*)*
- Pomegrante (*Punica granatum L.*)
- Perennial ryegrass (*Lolium perenne L.*) *
- Poplar (*Populus spp.*)*
- Sesbania (*Sesbania spp.*)*

## 6. Cultivation procedures

Special attention should be paid for the crop management which has to allow an efficient of the water. The combination of several measures is essential for water and soil conservation and optimum plant growth:

- Soil preparation
- Water supply
- Plant protection
- Crop management and crop rotation
- Harvesting, storage and conservation
- Ecological farming
- Desert cultivation system

## 7. Identification of water efficient irrigation systems

The identification and application of water saving irrigation technologies is one of the most effective measures to reduce the water required water rates for a proper plant growth. The technologies of irrigation are in the process of continues improvement and the water supply could be considerably reduced. Following advanced systems have to be considered in the project:

- Drip irrigation
- Micro sprinklers
- Advanced spray irrigation technologies (Centre Pivots)

Careful selection of the right systems for various applications; under the solar collectors, around the solar collectors and in the greenhouses has to considered.

## 8. Waste water management

Human activities within of the project produce and also animal husbandry produce considerable amounts of waste water which should be treated and recycled. The reuse of waste waters needs adequate treatment before its re-injection in the irrigation system.

- Micro filter systems for solid separation
- Solid densification > low volume and transportation
- Field irrigation of fluid residues (organic fertilizer)

## 9. Road map

Basic data of the specific sites of the implementation of CSP installations in desert regions are essential for the verification of the integration of agriculture in the whole system. These information are needed for a proper projection

Following specifications of the site are required:

- Climate data
- Soil and ground water characteristics
- Amount of water which could be used
- Market requirement for Food
- Type of CSP to be installed
- Infrastructure

These data should be collected from the site

## 10. Case Study: AQUA-CSP Project

In this study, the FRESNEL-CSP-System has been considered as an example for the verification the necessary input to achieve the integration of agriculture. We recommend creating greenhouse under the FRESNEL installation in order to optimize the crop production, mainly food and cash crops i.e. vegetables and flowers. Calculations and measurements have to be done in order to determine and to create the necessary and adequate production conditions.

## 10.1 Primary growth requirements for crops under CSP collectors

- Light: Light conditions under the collectors are inhomogeneous and of low intensities

Additional artificial light sources is necessary

- Temperatures

Temperatures under the collectors are too high for plant growth. Possible solutions are:
Solution:

- Aeration
- Cooling
- Plantations around the collectors

- Water Supply
    - Efficient irrigation systems i.e. drip, micro sprinkler etc
    - Enhancing the air humidity
    - Reducing the evapo-transpiration
    - Creation of closed system: Greenhouse

- Farming Mechanization

    - Adapted machinery for under and outside the collectors for plowing, weed control and harvesting is necessary

- Weed and Pest Control
    - Mechanical weed control
    - Biological herbicides, insecticides and pesticides

- Farming Systems
    - Organic farming offers the opportunity for healthy food of high economic value and better environmental protection

- Residues Treatment
    - Composting and recycling
    - Production of biofuels i.e. pellets and briquettes for cooking purposes

- Processing and Storage
    - Creating adequate short and midterm storage capacities i.e. cooling, drying etc
    - Introduction of special processing, packaging and preservation technologies

- Marketing Strategies
    - Verifying suitable marketing options
    - Implementation of adequate logistic systems for transport and distribution of the products

- Training of Technicians
    - Selection of technicians for the various activities
    - Training and education facilities

The integration and adaptation of the concept of Integrated Energy Farming in AQUA- MED-CSP project. The integration of agriculture around the CSP needs to combine advanced water supply devices such as drip irrigation and the selection of desert resistant plant species: date palms and olive trees as well as some shrubs using the three levels system:
Level 1: Date palm trees and olive trees
Level tow: citrus and fig trees
Level three: grasses and vegetable plants

Fig. 3 Projected layout of cultivation procedure (greenhouse system) under CSP insulations

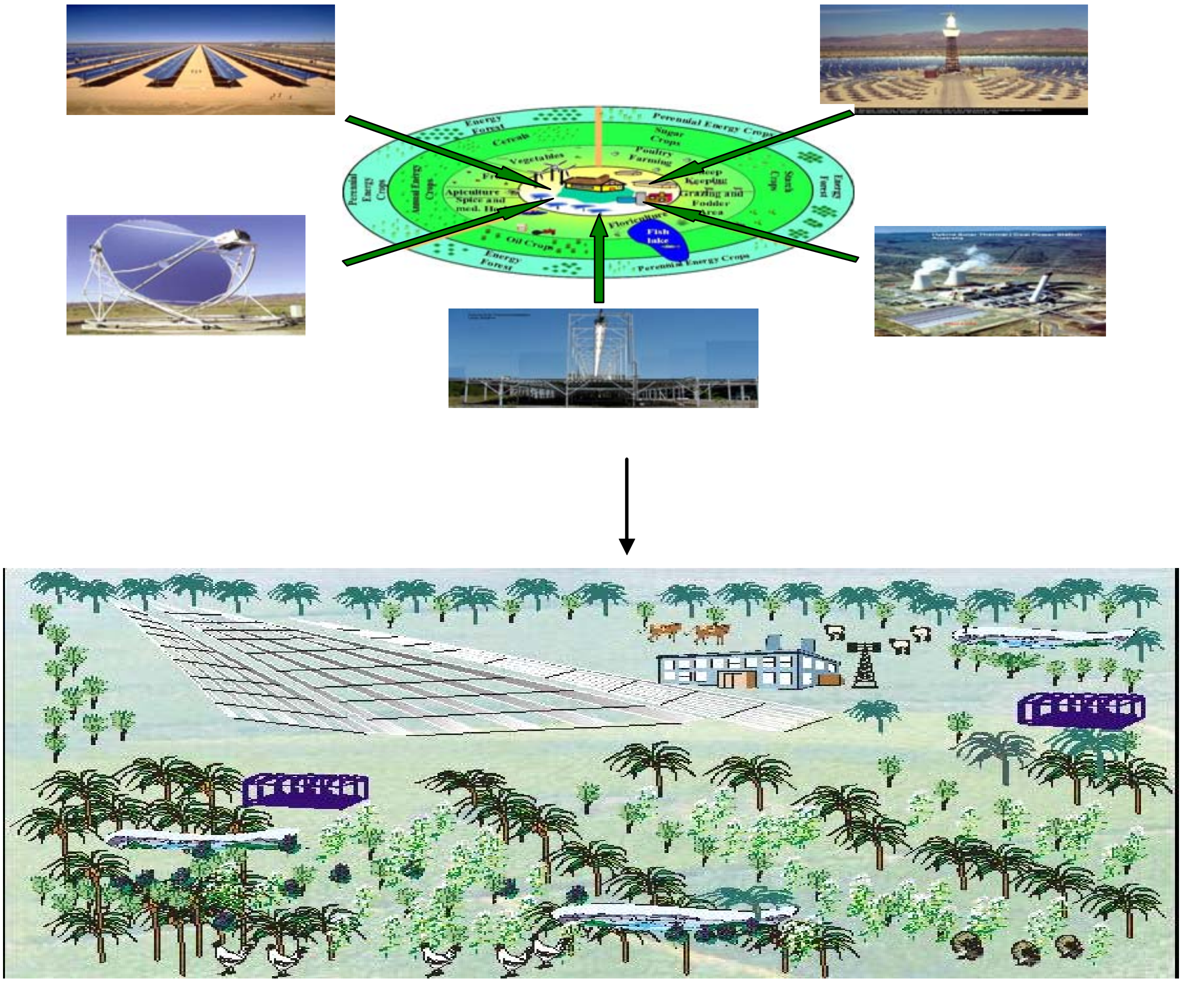

Fig. 4 Projected integration of agriculture around the CSP devices

## 11. Impact on climate, environment and desertification

The implementation of the IEF in the CSP project has several positives effects on the soils, climate and the environment:

- improving soil conservation
- increasing soil fertility
- water conservation
- creating of a favourable micro climate
- protection of the STPD Installations from sand and dust
- combating desertification

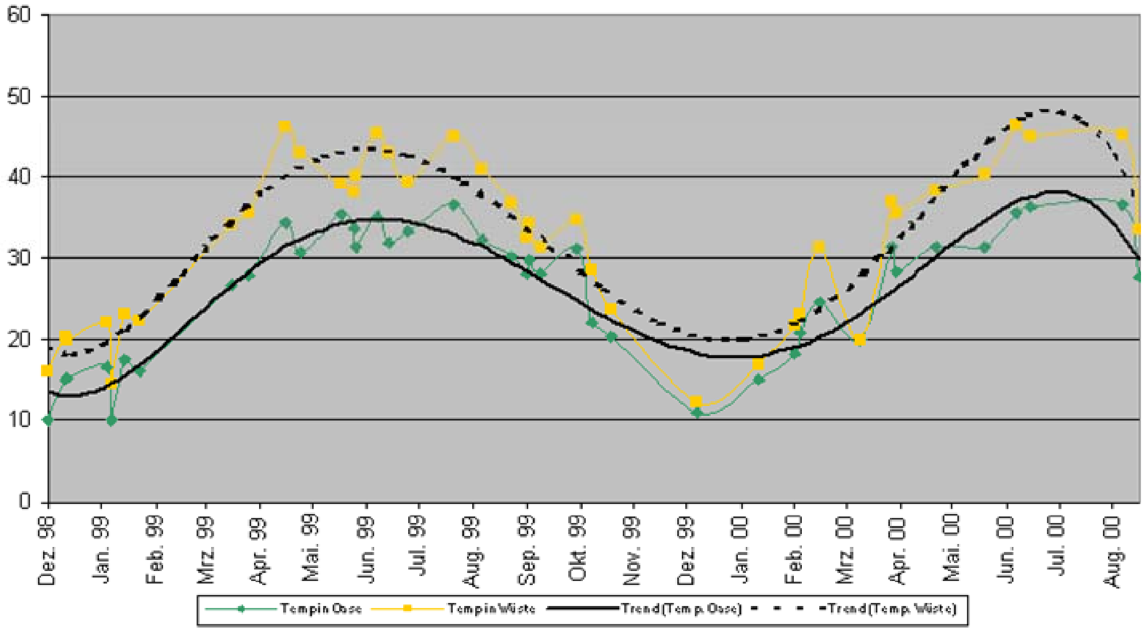


Fig. 6 Temperatures inside (green curve) and outside (yellow curve) and trends in a desert oasis

## 12. Social and economic impact

The concept includes social and economic elements which are of a great importance for the population in remote and areas:

- Job creation for farmers and technicians of different disciplines in farming, irrigation, landscape, animal husbandry, food conservation etc.
- The project opens chances for the young people to be trained and improving their skills.
- It will attract different groups from various disciplines and tourists.
- The processing and conservation of food could have positive economic effects.
- The production of solid fuels from biomass represents additional economic revenue.

## 13. Conclusions

Throughout history water has confronted humanity with some of its greatest challenges. Water is a source of life and a natural resource that sustains our environments and supports livelihoods – but it is also a source of risk and vulnerability. In the early 21st Century, prospects for human development are threatened by a deepening global water crisis. Water demand in Mediterranean countries has doubled in the second half of the last century and has now reached about 290 billion m³ per year. Water scarcity needs to be on the top of the priorities in bi- and multilateral relations among Mediterranean countries, as river basins often cross borders (12, 13 and 14). Efforts towards water savings and increased efficiency alone are essential but will not solve water scarcity problems in the Mediterranean. There is an urgent need to implement intelligent strategies an technologies to producing more water for ever growing demand. The AQUA- CSP project offers an unique opportunity to meet these challenges (8 and 9).

It can be concluded that the adaptation of the FAO Concept “Integrated Energy Farm” (IEF) could offer the possibilities to reduce the water requirements for irrigation through selection of draught and heat resistant adapted crops, using water saving irrigation technologies and introduction of combination between desert cultivation approaches, greenhouse facilities and ecological farming systems.

The planning of the IEF consists of 4 pathways: Food, energy, environmental and social-economic pathways. The outputs are, beside the power, heat and water, food, fodder, education, training and employment. Soil conservation, microclimate improvement are further positive effects on sustainable development of the site.

Several plant species have been identified to be cultivated under and around CSP installations. They include herbal crops, vegetables, grasses, grains, pulses, shrubs and trees. Emphasis will be put on drought tolerant, salt resistant and high productive genotypes with a harvest index (HI) higher than 50%.

The area which can be cultivated with the desalinated water ranges between 17 and 50 ha annually, depending on HI.

Agricultural activities are almost subsidised (OCED countries 1 billion dollars every day). Considering the global market, it could be estimated that the prices of the agricultural products produced under and around CSP stations could range between 0.12 and 1.20 Dollars per kilogram of food.

Greenhouse technologies offer the best possibilities for producing food and cash crops. They are very efficient in water use and water saving and could work all around the year.

The integration of agriculture around the CSP needs to combine advanced water supply devices such as drip irrigation and the selection of desert resistant plant species: date palms and olive trees as well as some shrubs using the three levels system:

Level 1: Date palm trees and olive trees

Level tow: citrus and fig trees

Level three: grasses and vegetable plants

The integration of agriculture in this chain does not represent only an additional services but it is an essential part for sustainable water desalination and power generation in desert regions, protection of the installations and combating further desertification.

All these assumption has to be verified in a demonstration project.

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# Annex 7: List of Abbreviations

| | |
|---|---|
| α | progress factor |
| AC | Alternating Current |
| β | best practice efficiency |
| bar | unit of pressure |
| bbl | barrel of crude oil |
| BGR | Bundesanstalt für Geowissenschaften und Rohstoffe |
| BMU | German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety |
| $Bm^3/y$ | one billion cubic metre per year = 1 $km^3/y$ (one cubic kilometre per year) |
| c | cost variable |
| cap | per capita |
| CC | combined cycle (gas and steam turbine) power plant |
| CED | Cumulated Energy Demand |
| CSP | Concentrating Solar Thermal Power Stations |
| CSP/RO | advanced solar powered reverse osmosis |
| CSP/MED | advanced solar powered multi-effect desalination |
| CHP | Combined Heat and Power |
| CoE | Cost of Electricity |
| Conv. | Conventional |
| $CO_2$ | Carbon Dioxide (greenhouse gas) |
| ct | Euro-cent |
| D | destillate |
| DC | Direct Current |
| DME | Deutsche Meerwasserentsalzung e.V. |
| DNI | Direct Normal Irradiance (solar beam radiation on ideal sun-tracking collectors) |
| € | Euro |
| η | efficiency |
| ED | Electrodialysis |
| EU | Europe |
| EUMENA | Europe, Middle East, North Africa |
| Flh/y | full load hours per year |
| Fresnel | Inventor of a facetted concentrating mirror assembly |
| γ | driving force variable |
| GCC | Gulf Cooperation Council |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gases (emissions responsible for climate change) |
| GIS | Geographic Information System (electronic geographic data base) |
| GJ | giga-Joule (million kilo-Joule, thermal energy unit) |
| GT | gas turbine |
| GW | Giga-watt, one million kilowatt (capacity unit) |
| GWh | 1 million kWh (energy unit) |
| Hybrid | Mixture of solar and fossil primary energy in a concentrating solar power plant |
| IE | Ion Exchange |
| irr | irrigation |
| kg | kilogram |
| kJ | kilo-Joule (thermal energy unit) |
| kV | kilovolt = 1000 Volt (unit of tension) |

| | |
|---|---|
| kW | kilowatt (unit of power) |
| kWh | kilowatt-hour (unit of energy) |
| LC | lethal concentration |
| LCA | Life Cycle Assessment of Emissions, Materials and Energy Consumption (Eco-Balance) |
| LEC | Levelised Electricity Cost |
| MAN/SPG | MAN Ferrostahl Solar Power Group, Essen |
| ME | Middle East |
| Med | Mediterranean Region |
| MED | Multi-Effect-Desalination |
| MED-CSP | Study that can be found at www.dlr.de/tt/med-csp |
| MENA | Middle East & North Africa |
| $Mm^3$ | million cubic metres |
| MVC | Mechanical Vapour Compression |
| m | meter |
| $m^2$ | square metre |
| $m^3$ | cubic metre |
| mm | millimetre |
| MSF | Multi-Stage-Flash Desalination |
| MW | million Watt |
| MWh | 1000 kWh |
| NA | North Africa |
| O&M | Operation and Maintenance |
| RE | Renewable Energy |
| PPA | Power Purchase Agreement |
| ppm | part per million (concentration unit) |
| PPP | purchasing power parity |
| PSA | Test Centre Plataforma Solar de Almeria, Southern Spain |
| PV | photovoltaic |
| R&D | Research and Development |
| RD&D | Research, Development and Demonstration |
| REA | Renewable Energy Act |
| RES | Renewable Energy System |
| RO | Reverse Osmosis Membrane Desalination |
| S | Seawater |
| SD | Solar Distillation (usually small scale) |
| SEGS | Solar Electricity Generating System |
| ST | steam turbine |
| Stirling | Inventor of an external combustion piston engine |
| t | time variable |
| T | temperature |
| TREC | Trans-Mediterranean Renewable Energy Cooperation |
| TRANS-CSP | Study that can be found at www.dlr.de/tt/trans-csp |
| TVC | Thermal Vapour Compression |
| TWh | 1 billion kWh |
| UAE | United Arab Emirates |
| $ | US Dollar = USD |
| $\omega$ | water consumption |
| x | variable describing the abscissa |
| y | year, variable describing the ordinate |