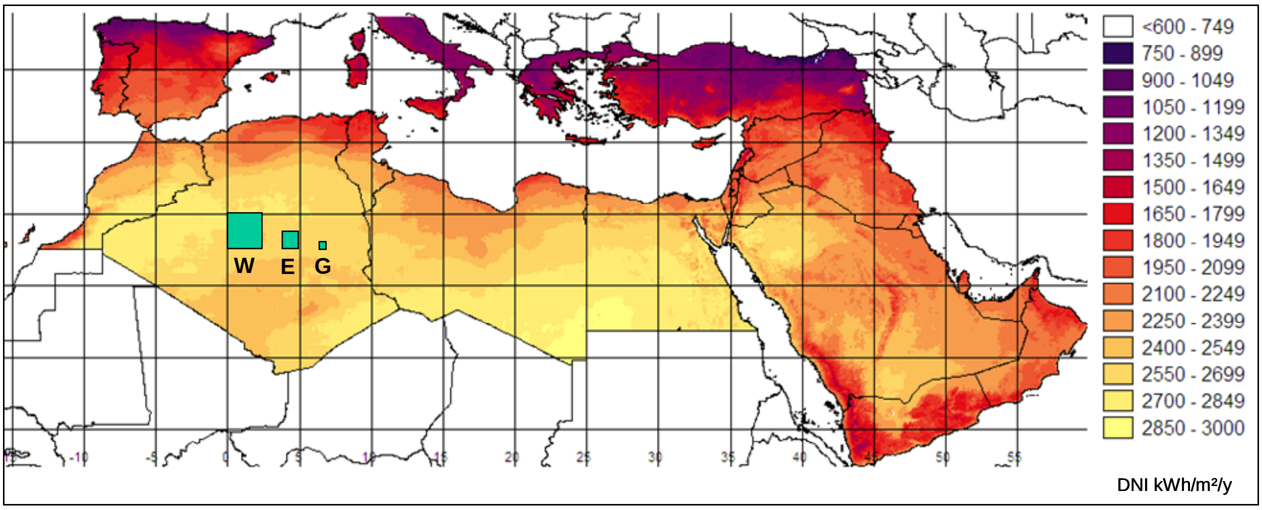
1. How much desert area is theoretically needed to supply the World, European or German electricity demand by Concentrating Solar Power (CSP) stations?

(W) World Power Demand 18,000 TWh/y (Terawatt-Hours per Year = Billion kWh/y)

(E) Europe 4000 TWh/y

(G) Germany 600 TWh/y



Atlas of Annual Direct Normal Solar Irradiance in kWh/m²/y (MED-CSP Study, www.dlr.de/tt/med-csp) and areas required to cover present World (W), European (E) or German (G) electricity demand.

The solar irradiance atlas of the Middle East and North Africa (MENA) shows that the annual direct normal solar irradiance (DNI) ranges between 2000 and 2800 kilowatt-hours per square metre (kWh/m²/y). A typical average site would receive 2400 kWh/m²/y.

With respect to the irradiance of the aperture area of the collectors, concentrating solar power stations have the annual conversion efficiencies for converting direct solar irradiance into electricity shown in the following table.

Over the year about 16% of the direct solar irradiance on the aperture area (that is the cross section surface of the reflectors) of a parabolic trough collector can be converted into electricity. Due to the structure of the parabolic troughs that have a lot of space in between the mirror rows, only 30% of the sunshine on the total land area is reflected and concentrated (land use factor), that means that only 16% times 30% = 4.8% of the total solar irradiance on the land surface is converted into electricity.

Collector & Power Technology	***Solar-Electric Aperture Related Efficiency***	***Land Use Factor***	***Land Use Efficiency***
Parabolic Trough Steam Cycle	13 - 16%	25 - 35%	3.5 - 5.6%
Central Receiver Steam Cycle	12 - 16%	20 – 25%	2.5 – 4.0%
Linear Fresnel Steam Cycle	8 - 12%	60 - 80%	4.8 - 9.6%
Central Receiver Combined Cycle*	20 - 25%	20 - 25%	4.0 – 6.3%
Multi-Tower Solar Array*	15 - 25%	60 - 80%	9.0 – 20.0%

*** future concepts**

$$\text{Solar-Electric Efficiency} = \frac{\text{Annual Power Generation}}{\text{Annual Direct Irradiance on Aperture}}$$

$$\text{Land Use Factor} = \frac{\text{Aperture Area of Reflectors}}{\text{Total Land Area Required}}$$

Land Use Efficiency = Solar-Electric Efficiency x Land Use Factor

Linear Fresnel collectors have lower aperture efficiency than troughs but a better land use factor while central receivers may have better aperture efficiency but lower land use factors than troughs. Taking into consideration potential future efficiency enhancements and technology developments like e.g. central receiver combined cycles or multi-tower solar arrays (MTSA), even better land use efficiencies may be achieved in the long-term. A conservative guess would be that about 10% of the annual solar irradiance on one square metre of land can be converted into electricity.

Multiplying this 10% with the annual solar irradiance, each square metre of land in MENA could supply between 200 and 280 kilowatt-hours of electricity per year, at a typical average site this would be 240 kWh/m²/y. One square kilometre has one million square metres and could thus supply 240 million kWh/km²/y or 240 GWh/km²/y.

Now, dividing the World, European and German electricity demand by the potential supply per square kilometre, we get the desert area needed to theoretically satisfy that demand, e.g. :

World Electricity Demand:

18,000 x 10^9 kWh/y : 240 x 10^6 kWh/km²/y = 75,000 km² = 274 km x 274 km

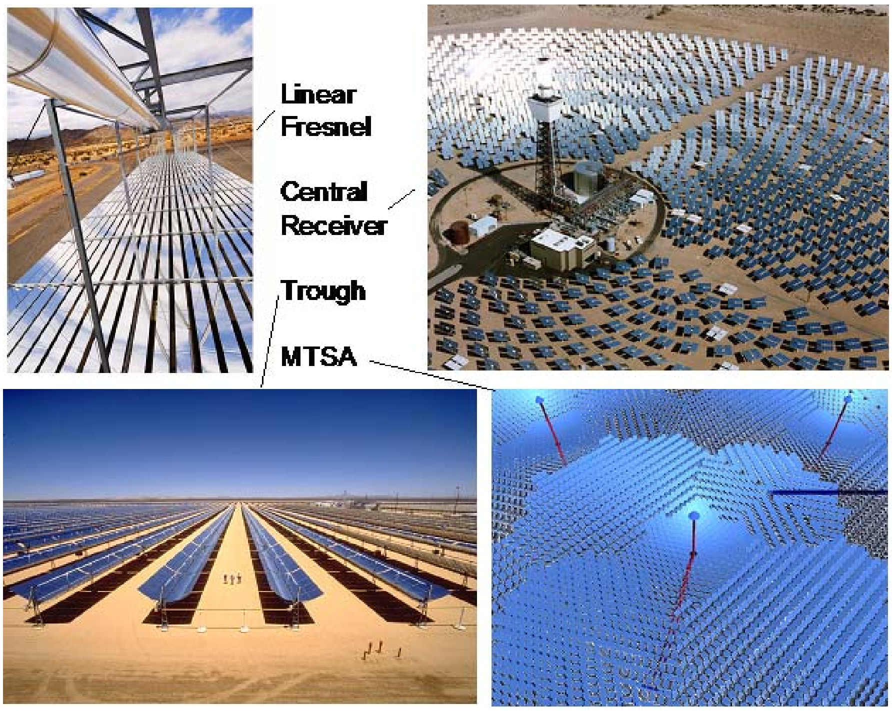
European Electricity Demand:

4,000 x 10^9 kWh/y : 240 x 10^6 kWh/km^2/y = 16,667 km^2 = 129 km x 129 km

German Electricity Demand:

600 x 10^9 kWh/y : 240 x 10^6 kWh/km^2/y = 2,500 km^2 = 50 km x 50 km

If all those power stations would be put at one site within the desert they would make up a square of 274 km times 274 km for the world power demand, 129 km times 129 km for Europe and 50 times 50 kilometres for Germany. For different technologies, differently sized squares would result. Of course all this is theoretical as nobody wants to cover the total power demand by one single technology. However it shows that there is a considerable potential of CSP available. In our scenarios (see web-links below) we consider the generation of 2900 TWh/y by the year 2050 for local power and seawater desalination in MENA and for power export to Europe. This would require a total area of 12,000 km^2 which makes up for 0.12 % of the area of the Sahara desert which is about 10,000,000 km^2.



Land Use of different concentrating solar collector concepts (MTSA shows an artist view)

Renewable Energy Scenarios including CSP can be found at:

www.dlr.de/tt/med-csp
www.dlr.de/tt/trans-csp
www.dlr.de/tt/aqua-csp

2. Will there be a negative impact on the local or global climate by installing large CSP plants in the deserts?

The albedo of desert sand is typically 30-40%. This is the portion of sunlight reflected back to the sky, while the rest (60-70%) is absorbed and converted into heat. The sand gets hot during the day and cools down during the night. Some of the heat is reflected back to space, some is absorbed by the atmosphere and returned to space later.

A concentrating solar power station in the desert will absorb the sunlight. The question is to what extent it will alter the local and global heat balance.

A CSP plant may look darker or brighter than the surroundings depending from where you look at it.

A CSP plant looks much darker than the surrounding as it absorbs sunlight. However, if one looks from the other side, a CSP plant looks brighter than sand, as some of the sunshine is reflected. The difference to sand is that the reflected sunlight has a preferred direction. A CSP collector absorbs about 60-70% of the solar radiation and converts it to useful heat. This is its typical collector efficiency. That means the rest (30-40%) is rejected. In fact it has practically the same albedo as desert sand, but a preferred direction of reflectance.

Over the year, about 5-10% of the solar energy irradiated on the land surface covered by a CSP plant is converted into electricity. After use, this electricity is also converted into heat and rejected to the ambient. The difference to desert sand is that the heat absorbed during daytime is not completely rejected locally. A maximum part of 10% is rejected at other sites where the generated electricity is consumed. In fact this cannot change the global climate, but could have an effect on the local heat balance, if those sites are far away. Our scenarios show that about 700 TWh/y of solar electricity from CSP could be exported to Europe by 2050, from all countries in the Middle East and North Africa. This would require a total area of 2500 km^2 distributed over an area of 12,500,000 km^2. This makes up for one part of 5000 of the solar heat on the total region of which a maximum of 10% could be exported to Europe via solar electricity, cooling down the desert by one part of fifty thousand.