

2 Renewable Energy Technologies and Applications

The study focuses on concentrating solar thermal power generation because this is by far the greatest renewable energy resource in the EU-MENA region, but other renewable energy sources are represented as well, in order to obtain a well balanced mix of energies that can not only cope with the growing energy demand, but also with the needs of power security and grid stability. The renewable energy technology portfolio that was considered within the study is described in the following. An overview and comparison of all technologies is given in Table 2-3 and in the literature /BMU 2004-2/, /ECOSTAR 2004/, /NREL 2003/.

2.1 Concentrating Solar Thermal Power Technologies

Concentrating solar thermal power technologies (CSP) are based on the concept of concentrating solar radiation to be used for electricity generation within conventional power cycles using steam turbines, gas turbines or Stirling engines. For concentration, most systems use glass mirrors that continuously track the position of the sun. The concentrated sunlight is absorbed on a receiver that is specially designed to reduce heat losses. A fluid flowing through the receiver takes the heat away towards the power cycle, where e.g. high pressure, high temperature steam is generated to drive a turbine. Air, water, oil and molten salt are used as heat transfer fluids.

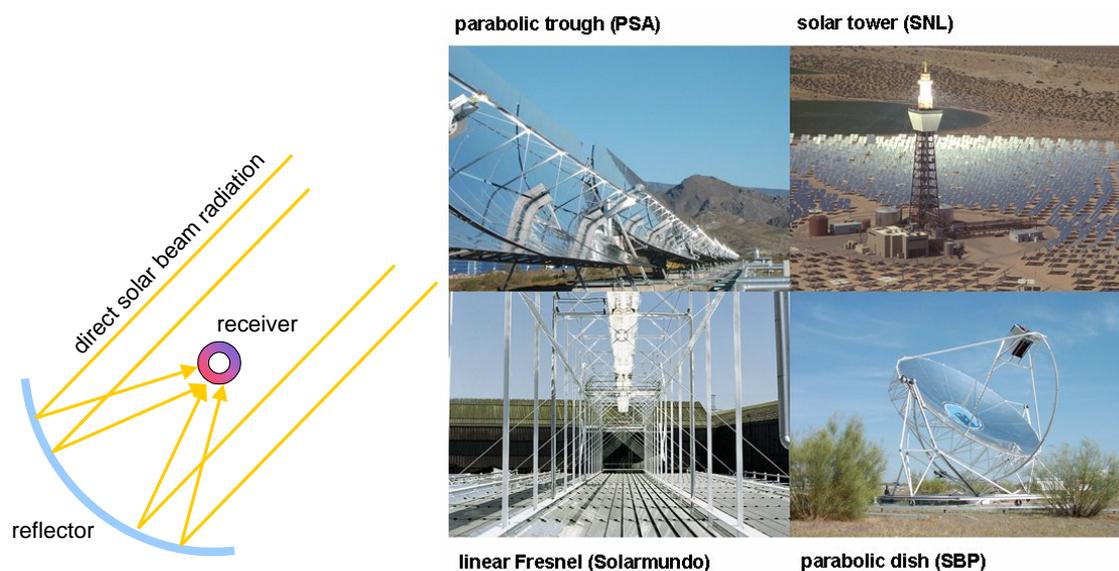


Figure 2-1: Principle of concentrating solar beam radiation and the four CSP collector technology main streams realised up to date (Sources: DLR, SNL, Solarmundo, SBP)

Parabolic troughs, linear Fresnel systems and power towers can be coupled to steam cycles of 5 to 200 MW of electric capacity, with thermal cycle efficiencies of 30 – 40 %. Dish-Stirling engines are used for decentralised generation in the 10 kW range. The values for parabolic troughs have been demonstrated in the field. Today, these systems achieve annual solar-to-electricity-efficiencies of about 10 – 15 %, with the perspective to reach about 18 % in the medium term (Table 2-1). The values for the other systems are based on component and prototype system test data and the assumption of mature development of current technology. The overall solar-electric efficiencies include the conversion of solar energy to heat within the

collector and the conversion of the heat to electricity in the power block. The conversion efficiency of the power block remains basically the same as in fuel fired power plants.

Power towers can achieve very high operating temperatures of over 1000 °C, enabling them to produce hot air for gas turbine operation. Gas turbines can be used in combined cycles, yielding very high conversion efficiencies of the thermal cycle of more than 50 %.

Each of these technologies can be operated with fossil fuel as well as solar energy. This hybrid operation has the potential to increase the value of CSP technology by increasing its power availability and decreasing its cost by making more effective use of the power block. Solar heat collected during the daytime can be stored in concrete, molten salt, ceramics or phase-change media. At night, it can be extracted from the storage to run the power block. Fossil and renewable fuels like oil, gas, coal and biomass can be used for co-firing the plant, thus providing power capacity whenever required (Figure 2-2).

| | Capacity Unit MW | Concentration | Peak Solar Efficiency | Annual Solar Efficiency | Thermal Cycle Efficiency | Capacity Factor (solar) | Land Use m ² /MWh/y |
|----------------------|------------------|---------------|-----------------------|-------------------------|--------------------------|-------------------------|--------------------------------|
| Trough | 10 – 200 | 70 - 80 | 21% (d) | 10 – 15% (d) | 30 – 40 % ST | 24% (d) | 6 - 8 |
| | | | | 17 – 18% (p) | | | |
| Fresnel | 10 - 200 | 25 - 100 | 20% (p) | 9 - 11% (p) | 30 - 40 % ST | 25 - 90% (p) | 4 - 6 |
| Power Tower | 10 – 150 | 300 – 1000 | 20% (d) | 8 – 10 % (d) | 30 – 40 % ST | 25 – 90% (p) | 8 - 12 |
| | | | 35 % (p) | 15 – 25% (p) | | | |
| Dish-Stirling | 0.01 – 0.4 | 1000 – 3000 | 29% (d) | 16 – 18 % (d) | 30 – 40 % Stirl. | 25% (p) | 8 - 12 |
| | | | | 18 – 23% (p) | | | |

Table 2-1: Performance data of various concentrating solar power (CSP) technologies

(d) = demonstrated, (p) = projected, ST steam turbine, GT Gas Turbine, CC Combined Cycle. Solar efficiency = net power generation / incident beam radiation
Capacity factor = solar operating hours per year / 8760 hours per year

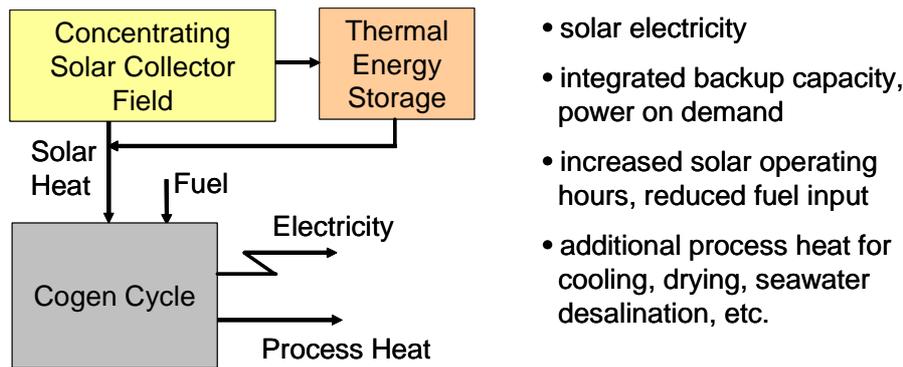
Moreover, solar energy can be used for co-generation of electricity and process heat. In this case, the primary energy input is used with efficiencies of up to 85 %. Possible applications cover the combined production of industrial heat, district cooling and sea water desalination.

All concepts have the perspective to expand their time of solar operation to base load using thermal energy storage and larger collector fields. To generate one Megawatt-hour of solar electricity per year, a land area of only 4 to 12 m² is required. This means, that one km² of arid land can continuously and indefinitely generate as much electricity as any conventional 50 MW coal - or gas fired power station.

Thus, two main characteristics make concentrating solar power a key technology in a future renewable energy supply mix in MENA:

- it can deliver secured power as requested by demand
- its natural resource is very abundant and practically unlimited

Their thermal storage capability and hybrid operation with fuels allows CSP plants to provide power on demand. Their availability and capacity credit is considered to be 90 %. CSP plants can be build from several kW to several 100 MW capacity.



- solar electricity
- integrated backup capacity, power on demand
- increased solar operating hours, reduced fuel input
- additional process heat for cooling, drying, seawater desalination, etc.

Figure 2-2: Principle of solar thermal co-generation of heat and power

Prospects of CSP Research and Development and Projects Ahead

While present parabolic trough plants use synthetic oil as heat transfer fluid within the collectors, and a heat exchanger for steam generation, efforts to achieve direct steam generation within the absorber tubes are underway in the DISS and INDITEP projects sponsored by the European Commission, with the aim to reduce costs and to enhance efficiency by 15-20% (Table 2-2). Direct solar steam generation has recently been demonstrated by CIEMAT and DLR on the Plataforma Solar in Almeria/ Spain, in a 500 m long test loop, providing superheated steam at 400 °C and 100 bar. All those R&D efforts aim at increasing efficiency and reducing costs.

A European industrial consortium has developed the new parabolic trough collector SKAL-ET, which aims to achieve better performance and cost by improving the mechanical structure and the optical and thermal properties of the parabolic troughs. Another European consortium has developed a simplified trough collector prototype with segmented flat mirrors following the principle of Fresnel.

The high temperatures available in solar towers can not only be used to drive steam cycles, but also for gas turbines and combined cycle systems. Such system promises up to 35 % peak and 25 % annual solar-electric efficiency when coupled to a combined cycle power plant. A solar receiver was developed within the European SOLGATE project for heating pressurised air by placing the volumetric absorber into a pressure vessel with a parabolic quartz window for solar radiation incidence. Multi-tower solar arrays may be arranged in the future so that the heliostat reflectors can alternatively point to various tower receivers. Like in other Fresnel systems, the horizontally arranged heliostats almost completely cover the land area and create a bright, semi-shaded space below for agricultural or other purposes.

A review of presently existing or developed CSP projects is given in Annex 9.

Table 2-2: Selected CSP Technology Overview *

| Technology | Experience | Next Step | Current Providers/Developers of the Solar Components |
|---|---|---|---|
| Parabolic trough reflector with oil-cooled vacuum-isolated absorber tube in hybrid steam cycle power plant | SEGS I – IX , 354 MW installed between 1985 and 1991 in California, since then operating, steam generated in oil/steam heat exchangers at 370°C, 100 bar | 50+ MW projects under development in Israel and USA | Solel, Israel (design, absorber), Flagsol (Germany) (reflectors) |
| Re-designed and up-scaled structure of oil-cooled parabolic trough for steam cycle operation | 100 & 150 m units of SKAL-ET (up-scaled EuroTrough) collector integrated to SEGS VI in California since April 2003 | 2 x 50 MW project under development in Southern Spain | EuroTrough Consortium, Solarmillennium AG, Flagsol, Schlaich, Bergemann & Partner, Schott, Germany (reflectors, structure, absorber tube) |
| Direct steam generating parabolic trough | 700 m DISS test-loop in Plataforma Solar de Almeria, Spain, direct steam generation demonstrated at 400 °C, 100 bar | Concept for a 5 MW demo plant under development (INDITEP project) | Iberinco, Initec, Ciemat, (Spain) Flagsol, DLR, ZSW (Germany) |
| Solar tower system with pressurised hot-air central receiver for solar gas turbine and combined cycle operation | 240 kW gas turbine operated first time December 2002 at Plataforma Solar de Almeria, gas turbine operated at 800 °C, 8 bar, (SOLGATE project) | 2 x 80 kW gas turbine co-generation system for electricity and cooling under construction in Italy | DLR (Germany), Esco Solar (Italy) |
| Solar tower system with un-pressurised volumetric hot-air receiver | 3 MW _{thermal} TSA project in 1996-1998, steam generated at 550 °C, 100 bar; new modular ceramic hot-air-receiver presently tested in the European. Solair Project | Receiver endurance test and concept development for a 2 MW prototype plant within the German Cosmosol project | Solucar, Ciemat (Spain), Heliotech (Denmark), DLR, Kraftanlagen München, (Germany) |
| Linear Fresnel collector with secondary concentrator and direct steam generating absorber tube | 100 m prototype tested in Liege, Belgium, direct saturated steam generated at 275 °C Compact Linear Fresnel Reflector 1 MW _{th} prototype installed in a steam cycle plant in Liddell in New South Wales, Australia | 200 m test loop for superheated steam generation at Plataforma Solar, Spain Design and construction of a first 1 MWe pilot plant | FhG-ISE, PSE, DLR (Germany) Solar Heat & Power (Germany) |

* only the existing plants in California and selected European main-stream activities are listed, RD&D of CSP technology is also taking place in other parts of the world, mainly USA and Australia (the famous solar tower test facility Solar 2 has been deactivated in the meantime). There is also parabolic trough development going on in Italy, however, the author had no reliable information on that.

2.2 Renewable Energy Technology Options for Europe and MENA

The market potential of CSP plants must be seen in the context of other renewable energy technologies for power generation. In the following we show those options and how they are modelled within the study (Figure 2-3). A description of each technology can be found in /BMU 2004-3/.



Figure 2-3: Renewable energy technologies considered in the MED-CSP study in addition to concentrating solar thermal power plants

Wind Power

Wind power can be generated in distributed wind power plants of up to 5 MW capacity each, or in large wind parks interconnecting tens or even hundreds of such plants. There are onshore and offshore wind parks, build into the sea where it is not deeper than 40 m. Wind power is typically fluctuating and cannot be delivered on demand. Wind power is stored for some seconds in the rotating mass of the wind turbines or as chemical or mechanical energy in batteries or large pump storage systems. There are also investigations on storing wind power in form of pressurized air. Fluctuations of the wind velocity are only correlated within a few kilometres of distance. Therefore, the fluctuations of a number of wind mills spread over a large area will usually compensate each other to some extent, leading to power supply transients that are quite manageable by the rest of the power park. However, their share on secured power capacity (capacity credit) is only between 0 and maximum 30 % of their installed capacity in very good areas with continuous trade winds /EWEA 2002/.

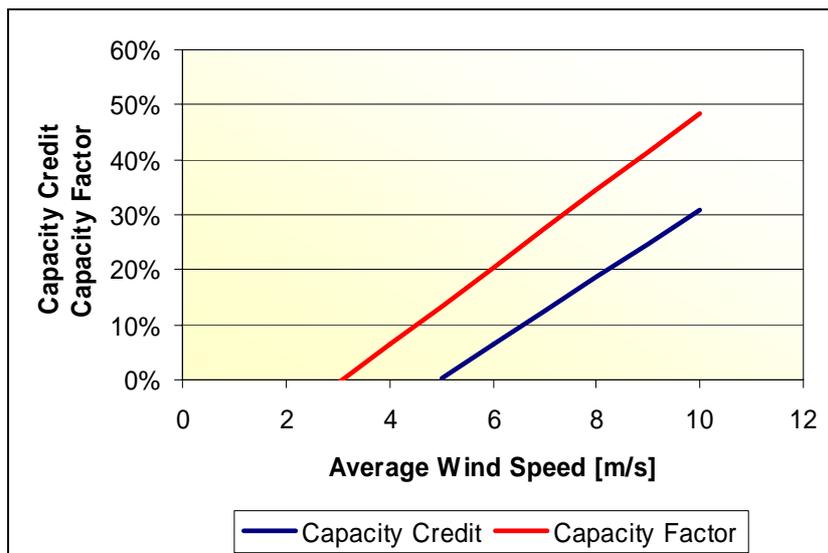


Figure 2-4: Capacity factor and capacity credit of wind power as function of the average wind speed derived from /EWEA 2002/ pp. 47 and from own calculations based on time series analysis

The technical performance of large wind power parks is modelled by the functions shown in Figure 2-4 that define their overall annual full load hours and their annual electricity yield. Even under optimum conditions with an average wind speed of 10 m/s, a large wind park will deliver only 50 % of its capacity over the year, and only 30 % as secured continuous contribution.

The electricity yield E_{wind} from wind power plants is calculated with the following equation, taking into consideration the capacity factor of the wind power park that is approximately a function of the average annual wind speed as shown in Figure 2-4:

$$E_{\text{wind}} = P_{\text{wind}} \cdot CF_{\text{wind}} \cdot 8760 \text{ h/y}$$

E_{wind} Annual electricity yield from wind power [MWh/y]

CF_{wind} Capacity factor as function of the average annual wind speed

P_{wind} Installed wind power capacity [MW]

8760 represents the total hours per year

Photovoltaic Power

PV systems are typically used for distributed or remote power systems with or without connection to the utility grid. Their capacity ranges from a few Watt to several MW. Batteries are usually applied in smaller decentralized supply systems to store the solar energy over the night. There are also scenarios for very large PV systems up to 1.5 GW each to be built in desert areas until 2050 /IEA 2003-1/. Both small and large scale options have been included in the MED-CSP scenario, but only grid connected PV has been quantified in the renewable electricity mix. The electricity yield of PV systems is modelled as function of the global irradiance on a surface tilted at the respective latitude angle. PV cannot offer any secured capacity. Backup capacity must be provided by other technologies within the grid. Energy from

very large PV could be stored in pump storage systems. The annual capacity factor and the annual full load hours are defined by the annual solar irradiance and the relation of the annual mean system efficiency to the layout efficiency (q-factor). The q-factor is today typically 0.67 and expected to become 0.85 in the year 2050. This results in the performance functions shown for different annual irradiances in Figure 2-5.

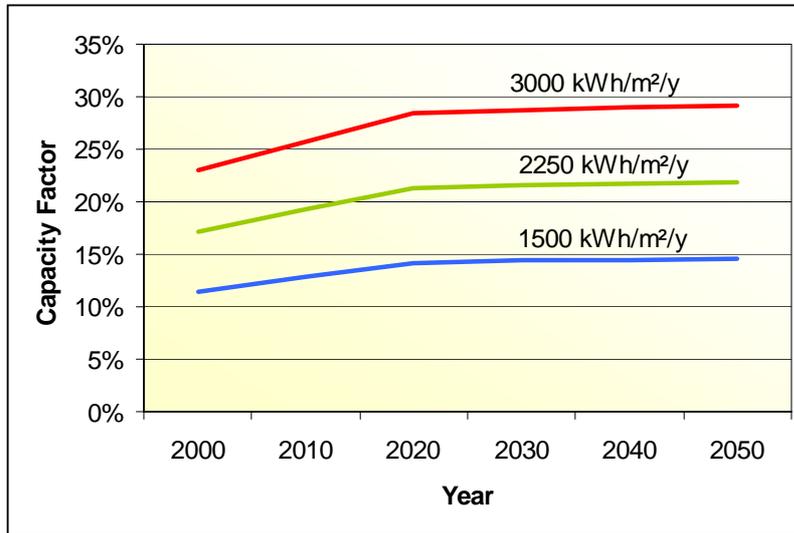


Figure 2-5: Capacity factor of grid-connected PV systems as function of global irradiance on a surface tilted at latitude angle and year of commissioning. There is no capacity credit for PV-power.

The electricity yield E_{PV} from photovoltaic systems is calculated with the following equation, taking into consideration the capacity factor of the PV power plants that is a function of the average annual irradiance on a tilted surface as shown in Figure 2-5:

$$E_{PV} = P_{PV} \cdot CF_{PV} \cdot 8760 \text{ h/y}$$

$$CF_{PV} = q_{PV} \cdot GTI \cdot \eta_{PV} \cdot A_{PV} / 8760 \text{ h/y}$$

- E_{PV} Annual electricity yield from photovoltaics [kWh/y]
- CF_{PV} Capacity factor as function of the annual global irradiance
- P_{PV} Installed photovoltaic power capacity [kW]
- q_{PV} annual system efficiency / standard design efficiency
- GTI Global irradiance on a tilted surface [kWh/m²/y]
- η_{PV} Annual PV system efficiency in first year (assumed as $\eta_{PV} = 0.1$)
- A_{PV} Design collector area for standard efficiency [m²/kW] ($A_{PV} = 10 \text{ m}^2/\text{kW}$)
- 8760 represents the total hours per year

Geothermal Power (Hot Dry Rocks)

Geothermal heat of over 200 °C can be delivered from up to 5000 m deep holes to operate organic Rankine cycles or Kalina cycle power machines. Unit sizes are about 1 MW today and limited to about 100 MW maximum in the future. Geothermal energy is often used for the co-generation of heat and power. Geothermal power plants are used all over the world where surface near geothermal hot water or steam sources are available, like in USA, Italy and the

Philippines. In the MED-CSP study region those conventional geothermal potentials are significant in Island, Italy, Turkey, Yemen and Iran. Those potentials are small in comparison to the HDR potentials and are not quantified separately in the study. The Hot Dry Rock technology aims to make geothermal potentials available everywhere, drilling deep holes into the ground to inject cold water and receive hot water from cooling down the hot rocks in the depth /IGA 2004/. However, this is a very new though promising approach and technical feasibility must still be proven. Geothermal power plants provide power on demand using the ideal storage of the earth's hot interior as reservoir. They can provide peak load, intermediate load or base load electricity. Therefore, the capacity factor of geothermal plants is defined by the load and their operation mode. Assuming a plant availability of 90 %, their capacity credit would have that same value.

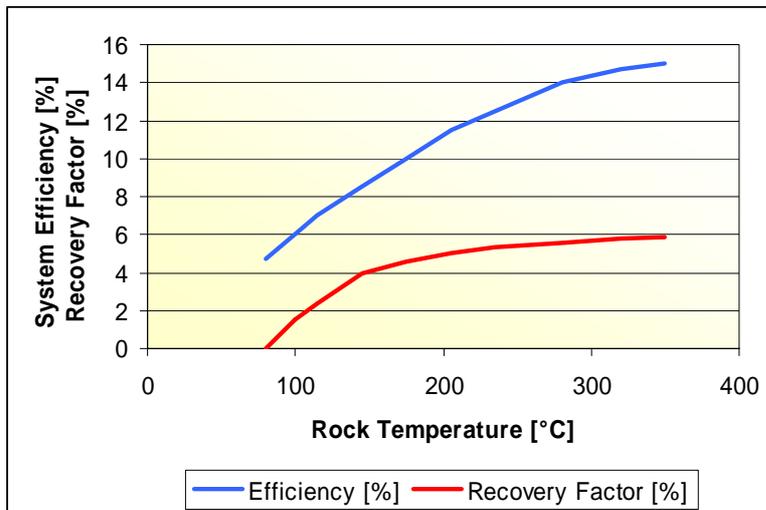


Figure 2-6: Efficiency (η) and recovery factor (R) of geothermal power schemes as function of temperature adapted from /TAB 2003/.

The available heat in place E_{th} is calculated as a function of the volume of rocks that will be affected by the cooling process /TAB 2003/. From that, the extracted geothermal electricity per year E_{geo} can be calculated as a function of the power cycle efficiency, the recovery factor and the total time of extraction. The recovery factor takes into account that only a small part of the affected rock volume is cooled down, and that the lower cycle temperature is higher than the surface temperature.

$$E_{th} = c_G \cdot \rho_G \cdot V \cdot (T_{5000} - T_{surface})$$

$$E_{geo} = E_{th} \cdot R \cdot \eta / t_{extract}$$

E_{th} Heat in place [J]

E_{el} Extracted geothermal electricity [J/y]

c_G Specific heat of the rocks [J/kg K]

ρ_G Density of the rocks [kg/m³]

V Volume of rock affected [m³]

T_{5000} Temperature of the rocks at 5000 m depth [°C]

| | |
|----------------------|--------------------------|
| T_{surface} | Surface Temperature [°C] |
| R | Recovery Factor |
| η | System Efficiency |
| t_{extract} | Extraction time [y] |

For the study we have made the following assumptions:

$$c_G = 840 \text{ [J/kg}\cdot\text{K]}, \rho_G = 2600 \text{ kg/m}^3, T_S = 10^\circ\text{C}, V = 1 \text{ km}^3, t_{\text{extract}} = 1000 \text{ years}$$

Biomass Power (Waste and Wood)

There are a number of potential sources to generate energy from biomass: biogas can be produced by the decomposition of organic materials like municipal liquid waste, manure or agricultural residues. Biogas reactors usually require large quantities of water. The calorific value of biogas is about 6 kWh/m³. Biogas can be used in combustion engines or turbines for electricity generation and for co-generation of heat and power. Landfill gas can be used in a similar way.

Solid biomass from agricultural or municipal residues like straw or bagasse and from wood can be used to generate heat and power. From every ton of solid biomass about 1.5 MWh of heat or 0.5 MWh of electricity can be generated in steam cycle power plants.

There is also the possibility to raise energy crops. However, this option has been neglected in the MENA region due to their competition with food crops and the severe water supply situation.

The size of biomass plants ranges from some kW (combustion engines) to about 25 MW. Biomass can be stored and consumed on demand for power generation. However, there are often seasonal restrictions to the availability of biomass. Typical plants have capacity factors between 0.4 and 0.6 that are equivalent to 3500 – 5500 full load hours per year. They are usually operated to provide intermediate or peaking power but seldom for base load. The availability of biomass plants is high at 90 % and so is their capacity credit. This credit can be lower if the plants are used for co-generation of heat and power and if heat is the primary product. Electricity generation from biomass is calculated with the following equations:

$$E_{\text{bio}} = E_{\text{mun}} + E_{\text{agr}} + E_{\text{wood}}$$

$$E_{\text{mun}} = N \cdot w_{\text{mun}} \cdot e_{\text{bio}}$$

$$E_{\text{agr}} = w_{\text{agr}} \cdot e_{\text{bio}}$$

$$E_{\text{wood}} = p_{\text{wood}} \cdot A_{\text{forest}} \cdot e_{\text{bio}}$$

E_{bio} Electricity from biomass [MWh/y]

E_{mun} Electricity from municipal waste [MWh/y]

E_{agr} Electricity from agricultural residues [MWh/y]

E_{wood} Electricity from wood [MWh/y]

e_{bio} Specific electricity yield from biomass [MWh/ton]

| | |
|---------------------|---|
| w_{mun} | Specific municipal waste production per capita [tons/capita/year] |
| w_{agr} | Agricultural waste production [tons/year] |
| p_{wood} | Biomass productivity [tons/ha/year] |
| A_{forest} | Forest area of a country [ha] |
| N | Urban population [persons] |

For the study we have made the following assumptions: $e_{\text{bio}} = 0.5$ MWh/ton, $w_{\text{mun}} = 0.35$ ton/capita/year.

Hydropower

Hydropower is already used in many MENA countries. Plants range from large multi-Megawatt dams like Aswan to micro-hydropower schemes of several kW capacity. Hydropower is often submitted to seasonal fluctuations and especially in MENA, dry years often lead to hydropower shortages. There are run-of-river plants that provide power according to the available water flow. Dam storage power plants can provide power on demand and can be used to compensate the fluctuations of other renewable energies. In MENA hydropower is used mainly for peaking and intermediate load with 1000 to 4000 full load hours per year. Capacity factors are defined by the individual regional power demand and water resources. The Nile river is the most plentiful hydropower resource of the region. However, there are some indications that the hydropower potentials in the Southern Mediterranean region may be submitted to a reduction of up to 25 % in the course of this century due to climate change /Lehner et al. 2005/. Capacity credit and availability of hydropower plants are considered to be 90 %. Electricity generation from hydropower is well documented and thus taken from literature /WEC 2004/, /Horlacher 2003/.

$$E_{\text{hydro}} = P_{\text{hydro}} \cdot CF_{\text{hydro}} \cdot 8760 \text{ h/y}$$

| | |
|---------------------|--|
| E_{hydro} | Annual electricity yield from hydropower plants [MWh/y] |
| CF_{hydro} | Capacity factor (from existing hydropower plants of a country) |
| P_{hydro} | Installed hydropower capacity [MW] |
| 8760 | represents the total hours per year |

Concentrating Solar Thermal Power and Solar Chimneys

Concentrating solar thermal power plants with thermal energy storage and fuel co-firing can provide power on demand, with a capacity credit and availability of 90 % like conventional power plants. Electricity generation is a function of their capacity factor which is defined by the demand. The plants are operated in accordance with the rest of the renewable energy mix in order to minimize the gap between the load and the renewable electricity supply.

The electricity yield E_{CSP} from solar thermal power plants is calculated with the following equation, taking into consideration the capacity factor that is defined by the load. The solar

share is steadily increased and the fossil share reduced, by increasing the solar collector field and storage capacities.

$$E_{\text{CSP}} = P_{\text{CSP}} \cdot \text{CF}_{\text{CSP}} \cdot 8760 = E_{\text{solar}} + E_{\text{fossil}}$$

| | |
|--------------------------|---|
| E_{CSP} | Annual electricity yield [MWh/y] |
| E_{solar} | Annual solar electricity yield [MWh/y] |
| E_{fossil} | Annual fossil electricity yield [MWh/y] |
| CF_{CSP} | Capacity factor as function of load |
| P_{CSP} | Installed capacity [MW] |
| 8760 | represents the total hours per year |

Solar chimneys are also considered as solar thermal power plants, though not concentrating. They consist of a very large glass or plastic roof with a chimney in its centre. The air underneath the glass roof is heated and by its lower weight forced into the chimney, where it activates a wind turbine for power generation. They can be built in the range of 100 - 200 MW capacity. Heat can be stored in the soil and in water storage below the collector for night-time operation. They cannot be used for co-generation of electricity and heat. Hybrid operation with fuels is not possible. Their availability and capacity credit is considered 90 %. They are suited for base load and intermediate power. Solar chimney potentials are considered part of the solar thermal power potential and are not quantified separately.

Conventional Power

The MED-CSP study also looks at conventional power technologies as possible alternative or complement to a sustainable energy supply. The availability and capacity credit of all conventional systems is assumed to be 90 %. They provide power on demand with different capacity factors. All thermal plants can be used for co-generation of electricity and heat.

➤ Oil and Gas fired Power Plants

Oil and gas can be used in steam cycle, gas turbine or combined cycle power plants. They are built in all capacity classes from several kW to several 100 MW. They can provide peak, intermediate and base load.

➤ Coal Steam Plants

Only a few countries in MENA use coal fired steam cycles. Coal must be imported. Capacities range from some 10 to several 100 MW. Due to the long start-up time and the relatively high investment cost, they are only applied in the intermediate and base load segment.

➤ Nuclear Fission and Fusion

Nuclear plants use nuclear fission processes to generate steam for steam turbines. There is intensive research on nuclear fusion aiming at providing first results in terms of a first

power plant in the year 2050 or beyond. Projected units sizes are in the GW capacity range. Due to their high investment cost, they are only applied in the base load segment.

2.3 Renewable Energy Applications

Electricity Generation

All the technologies investigated within this study can be used for electricity generation. Only biomass, hydropower, geothermal power, solar thermal and conventional power plants can deliver electricity on demand. Photovoltaic systems, micro-hydropower, wind power, biogas motor generators and dish-Stirling engines are specially suited for decentralized and remote electricity generation. In the quantification of market potentials in our scenario we do not distinguish between centralised, grid-connected power and remote systems. Both centralized and decentralized systems have considerable market potentials and will complement each other rather than compete.

Combined Generation of Electricity and Heat

All thermo-electric systems like biomass, geothermal, solar thermal and conventional plants can be used for co-generation of electricity and heat (see Annex 10 for examples).

➤ Seawater Desalination

Electricity can be used for seawater desalination by reverse osmosis, while co-generated heat can be applied to multi-effect, vapour compression and multi-stage flash thermal desalination plants. Also combinations are possible. Thermal seawater desalination uses input steam with a temperature range between 70 – 110 °C.

➤ Cooling

Electricity can be used directly in conventional mechanical compression chillers for air conditioning, cooling and refrigeration. Co-generated heat can be applied to drive vapour absorption chillers. Vapour absorption chillers use input steam with a temperature between 120 – 180 °C. Concentrating solar power has also been directly applied to provide cooling and air conditioning for a Hotel in Turkey.

➤ Industrial Process Heat

Industrial process heat in form of steam or hot air in the temperature range of 50 - 300 °C can be delivered by all thermal systems that are capable of co-generation. It is particularly efficient to cascade the use of heat at different temperature levels.

➤ Integrated Systems and Multipurpose Plants

The collectors of some CSP systems provide shaded areas that could be used for purposes like greenhouse, chicken farm, parking etc. Integrated systems that use power, desalted water and shade for generating a new environment for farming in desert regions could become feasible in the future as countermeasure to desertification and loss of arable land. This requires more investigation on the possibilities and restrictions of such systems (Annex 10).

| | Unit Capacity | Capacity Credit | Capacity Factor | Resource | Applications | Comment |
|--|----------------------|--|------------------------|---|----------------------|---|
| Wind Power | 1 kW – 5 MW | 0 – 30 % | 15 – 50 % | kinetic energy of the wind | electricity | fluctuating, supply defined by resource |
| Photovoltaic | 1 W – 5 MW | 0 % | 15 – 25 % | direct and diffuse irradiance on a fixed surface tilted with latitude angle | electricity | fluctuating, supply defined by resource |
| Biomass | 1 kW – 25 MW | 50 - 90 % | 40 – 60 % | biogas from the decomposition of organic residues, solid residues and wood | electricity and heat | seasonal fluctuations but good storability, power on demand |
| Geothermal (Hot Dry Rock) | 25 – 50 MW | 90 % | 40 – 90 % | heat of hot dry rocks in several 1000 meters depth | electricity and heat | no fluctuations, power on demand |
| Hydropower | 1 kW – 1000 MW | 50 - 90 % | 10 – 90 % | kinetic energy and pressure of water streams | electricity | seasonal fluctuation, good storability in dams, used also as pump storage for other sources |
| Solar Chimney | 100 – 200 MW | 10 to 70 % depending on storage | 20 to 70 % | Direct and diffuse irradiance on a horizontal plane | electricity | seasonal fluctuations, good storability, base load power |
| Concentrating Solar Thermal Power | 10 kW – 200 MW | 0 to 90 % depending on storage and hybridisation | 20 to 90 % | Direct irradiance on a surface tracking the sun | electricity and heat | fluctuations are compensated by thermal storage and fuel, power on demand |
| Gas Turbine | 0.5 – 100 MW | 90 % | 10 – 90 % | natural gas, fuel oil | electricity and heat | power on demand |
| Steam Cycle | 5 – 500 MW | 90 % | 40 – 90 % | coal, lignite, fuel oil, natural gas | electricity and heat | power on demand |
| Nuclear | 1000 MW | 90 % | 90 % | uranium | electricity and heat | base load power |

Table 2-3: Some characteristics of contemporary power technologies

