3. THE DESERTEC CONCEPT SUSTAINABLE ELECTRICITY AND WATER FOR EUROPE, MIDDLE EAST AND NORTH AFRICA

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Summary

This paper describes the perspective of a sustainable supply of electricity for Europe (EU), the Middle East (ME) and North Africa (NA) up to the year 2050. It shows that a transition to competitive, secure and compatible supply is possible using renewable energy sources and efficiency gains, and fossil fuels as backup for balancing power. A close cooperation between EU and MENA for market introduction of renewable energy and interconnection of electricity grids by high-voltage direct-current transmission are keys for economic and physical survival of the whole region. However, the necessary measures will take at least two decades to become effective. Therefore, adequate policy and economic frameworks for their realization must be introduced immediately. The role of sustainable energy to secure freshwater supplies based on seawater desalination is also addressed.

A Introduction

In order to find a viable transition to an electricity supply that is inexpensive, compatible with the environment and based on secure resources, rigorous criteria must be applied to ensure that the results are compatible with a comprehensive definition of sustainability (Table 1). A central criterion for power generation is its availability at any moment on demand. Today, this is achieved by consuming stored fossil or nuclear energy sources that can provide electricity whenever and wherever required. This is the easiest way to provide power on demand. However, consuming the stored energy reserves of the globe has a high price: they are quickly depleted and their residues contaminate the planet.

With the exception of hydropower, natural flows of energy are not widely used for power generation today, because they are not as easily stored and exploited as fossil or nuclear fuels. Some of them can be stored with a reasonable technical effort for a limited time-span, but others must be taken as provided by nature (Table 1). The challenge of future electricity supply is to find a mix of available technologies and resources that is capable of satisfying not only the criterion of "power on demand", but all the other criteria for sustainability, too.

The paper describes a scenario of electricity demand and supply opportunities by renewable energy in the integrated EUMENA region up to the middle of the century, and confirms the importance of international cooperation to achieve economic and environmental sustainability (MED-CSP 2005, TRANS-CSP 2006).

Criteria for Energy Sustainability	Technology Portfolio	
✓ **Inexpensive** low electricity cost no long term subsidies	✓ **Coal, Lignite** ✓ **Oil, Gas** ✓ **Nuclear Fission, Fusion**	**ideally stored energy**
✓ **Secure** diversified and redundant supply power on demand based on undepletable resources available or at least visible technology	✓ **Concentrating Solar Power (CSP)** ✓ **Geothermal Power (Hot Dry Rock)** ✓ **Biomass** ✓ **Hydropower**	**storable energy**
✓ **Compatible** low pollution climate protection low risks for health and environment fair access	✓ **Wind Power** ✓ **Photovoltaic** ✓ **Wave / Tidal**	**fluctuating energy**

Table 1: Criteria for sustainability and portfolio of technologies and resources for power generation

B Pressure on Electricity and Water is Increasing

As a first step, our analysis quantifies electricity demand in Europe and MENA up to the middle of the century. Growing freshwater deficits in MENA are also part of the energy problem, as there will be an increasing demand for seawater desalination. For simplicity we assume that in the long term, the necessary energy for desalination will also be supplied by electricity.

Population growth is a major driving force for electricity and water consumption. According to the World Population Prospect of the United Nations the population of the European region will stabilize at around 600 million while MENA will grow from 300 million in the year 2000 to a similar 600 million by the middle of the century (UN 2004).

The second driving force is economic growth, which usually has two opposite effects on energy and water demand: on the one hand, the demand increases because new services are requested within a developing economy. On the other hand, efficiency of production, distribution and end-use is enhanced, thus allowing the provision of more services for a given amount of energy. In past decades, all industrial nations observed a typical decoupling of economic growth and energy demand.

In order to be able to afford efficiency measures, a certain economic level beyond sheer subsistence must have been attained, something that is now true of most countries in EUMENA. The demand study is described elsewhere (Trieb, Klann 2006).

Our analysis shows that by 2050 electricity consumption in the Middle East and North Africa is likely to be around 3000 TWh/year (Figure 1), which is comparable with what is consumed in Europe today. Meanwhile, European consumption is likely to increase to and stabilize at a value of about 4000 TWh/year (Figure 2). Due to increased efficiency gains, our model yields lower levels of predicted demand than most other scenarios (IEA 2005, IEA 2006, CEC 2006, Mantzos and Capros 2005). However, there are also scenarios indicating lower demand (Benoit and Comeau 2005, Teske et al., 2007). The reduction of demand in Europe after 2040 (as shown in Figure 2) is however uncertain. Stagnant or slowly growing demand is also a possibility, since efficiency gains may be transformed into new energy services not considered here, such as, for example, electric vehicles or hydrogen for the transport sector.

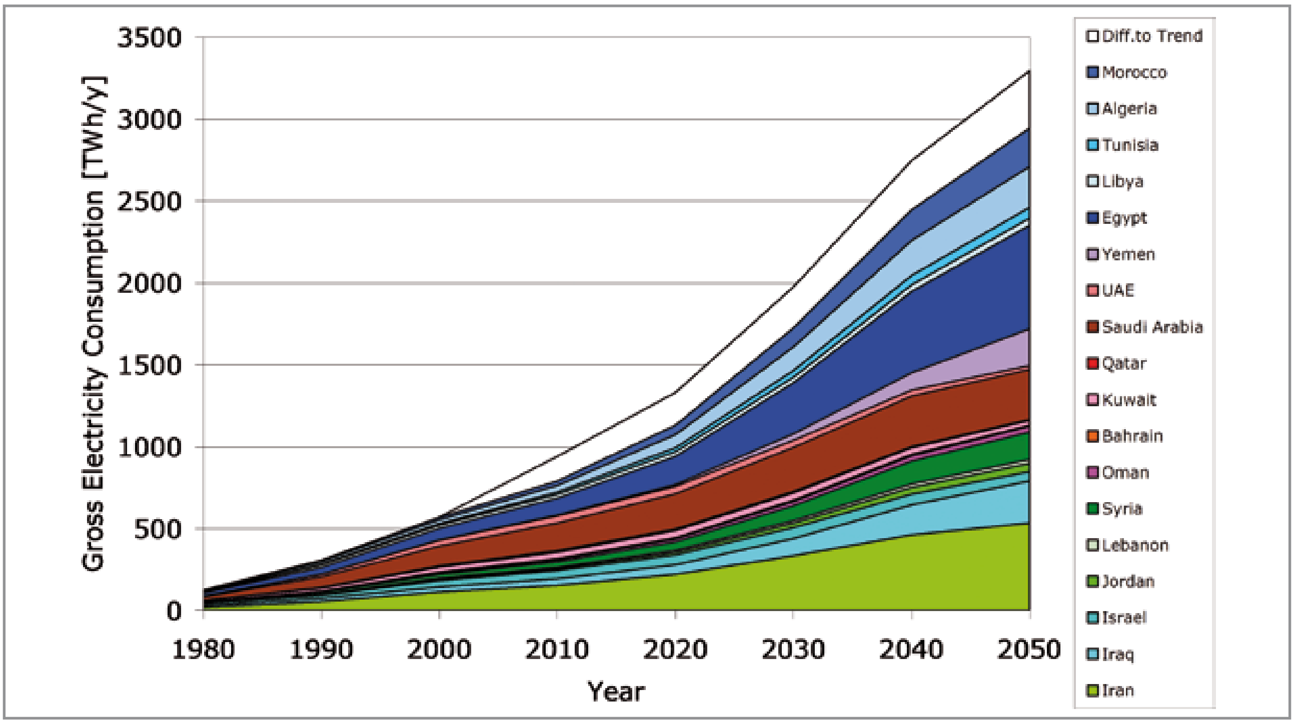

Figure 1: Electricity demand scenario for the MENA countries considered in the study (MED-CSP 2005)

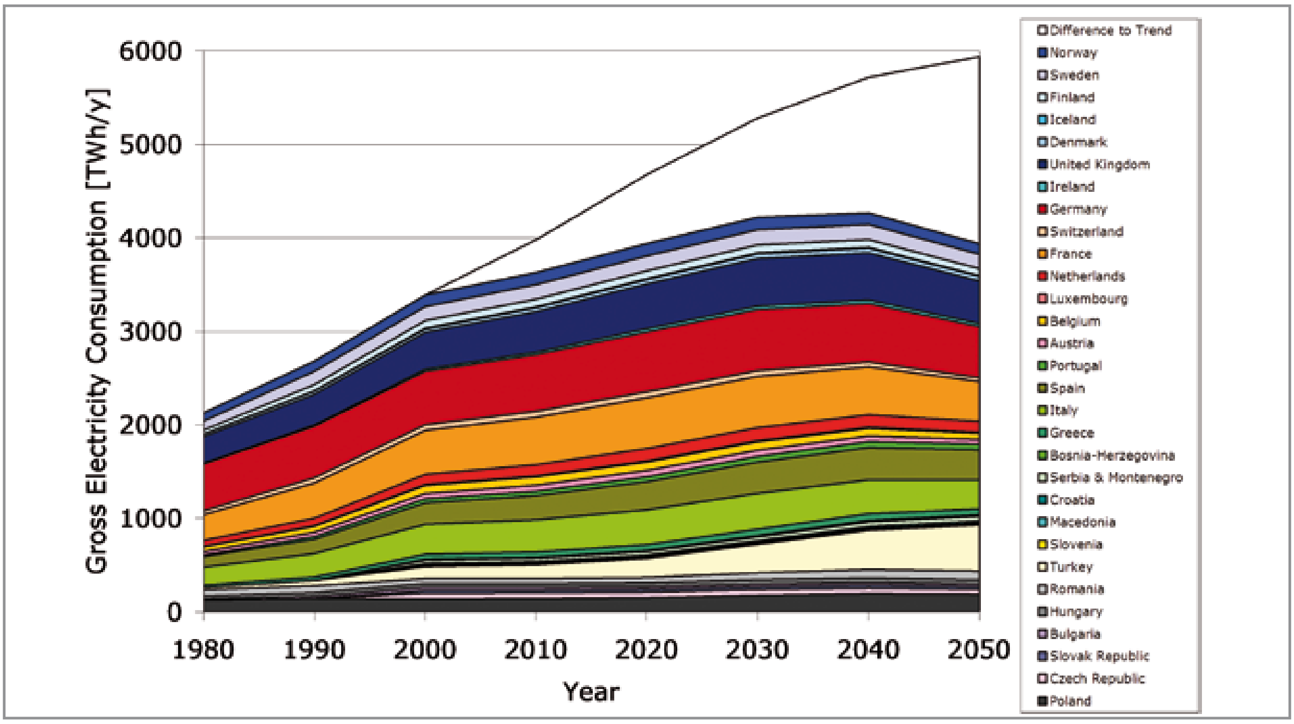

Figure 2: Electricity demand for the European countries considered in the study (TRANS-CSP 2006)

A similar analysis has been done for the water sector in MENA. The difference between the available sources of fresh water that are renewable and growing demands for water leads to the water deficit displayed in Figure 3.

There is already a significant deficit today, which is poorly met by sea-water desalination via fossil fuels and mainly by the over-exploitation of groundwater resources, leading in many regions in MENA to falling levels of groundwater, intrusion of salt water into groundwater reservoirs and to a fast expansion of deserts.

According to our projection, this deficit tends to increase from the current 60 billion m³ per year, which is almost the annual flow of the Nile River, to 150 billion m³ in the year 2050. Egypt, Saudi Arabia, Yemen, and Syria are the countries with the largest deficits. Enhancement of efficiency of water distribution, water (re-)use and water management to achieve best-practice standards is already included in the underlying assumptions of this scenario.

It is obvious that the MENA countries will be confronted with a very serious problem in the not too distant future, if those measures and the necessary additional measures are not initiated in good time. Seawater desalination is one of those additional options. Assuming that, on average, 3.5 kWh of electricity is needed to desalinate one cubic meter of seawater, this would mean an additional demand for almost 550 TWh/y by 2050 for desalination. This would be equivalent to the current electricity demand of a country like Germany (MED-CSP 2005).

C Available Resources and Technology Options

In the financial and insurance business there is a clear answer to the question of security and risk management: the diversification of the assets portfolio (Awerbuch and Berger 2003). This simple truth has been completely ignored in the energy sector. Here, investment decisions were based on "least cost and proven technology" and the portfolio was usually limited to fossil fuel, hydropower and nuclear plants.

This short-sighted policy has been harmful both for consumers and for the environment: prices of all kinds of fossil fuels and of uranium have multiplied several times since the year 2000 and the burning of these fuels is seriously contaminating the global atmosphere. Today, consumers and taxpayers have no choice but to pay the higher cost of

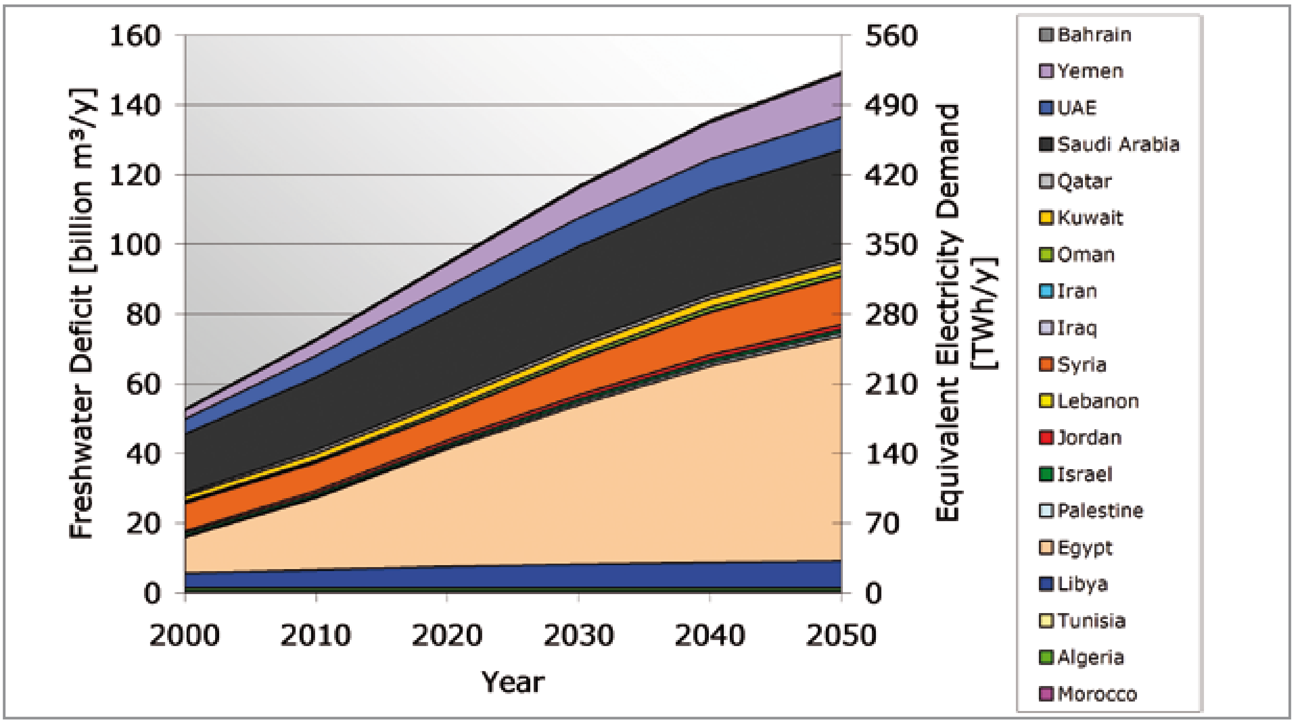

Figure 3: Freshwater deficit defined as the difference between water demand and renewable freshwater resources for each of the MENA countries, and equivalent electricity demand for seawater desalination (Trieb and Müller-Steinhagen 2007)

fossil fuels, as the energy policies of the past failed to build up alternatives in good time and to establish them as part of the energy market. To add insult to injury, fossil and nuclear energy technologies still receive 75 % of current energy subsidies (EEA 2004), a number that increases to over 90 % if the failure to include external costs is also considered.

Nevertheless, an impressive portfolio of renewable energy technologies is available today (Dürrschmidt et al. 2006). Some of these produce fluctuating output, like wind and photovoltaic power (PV), but some of them (such as biomass, hydropower and concentrating solar thermal power (CSP)) can meet both peak- and base-load demands for electricity (Table 2).

The long-term economic potential of renewable energy in EUMENA is much larger than present demand, and the potential of solar energy dwarfs them all. From each km² of desert land, up to 250 GWh of electricity can be harvested each year using the technology of concentrating solar thermal power. This is 250 times more than can be produced per square kilometre by biomass or 5 times more than can be generated by the best available wind and hydropower sites. Each year, each square kilometre of land in MENA receives an amount of solar energy that is equivalent to 1.5 million barrels of crude oil[1]. A concentrating solar collector field with the size of Lake Nasser in Egypt (Aswan) could harvest energy equivalent to the present Middle East oil production[2].

[1] reference solar irradiance 2400 kWh/m²/year, 1600 kWh heating value per barrel

[2] Lake Nasser has a surface of 6000 km², Middle East oil production is currently 9 billion barrels/year

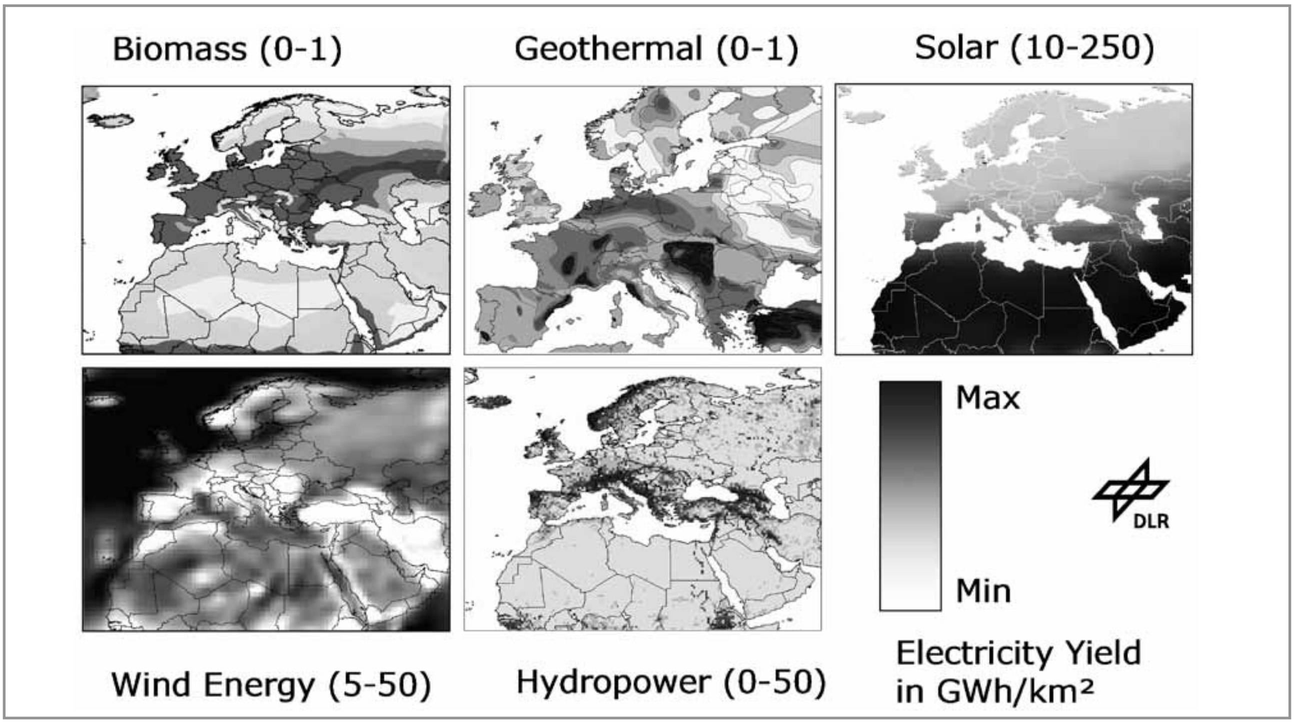

Figure 4: Renewable energy resource maps for EUMENA, showing the minimum and maximum annual electricity yield (as specified in brackets) that can be harvested by each technology from 1 km² of land area. Solar includes both photovoltaic and concentrating solar thermal power technologies. The overall potential and the different characteristics of each resource are given in Table 2 (MED-CSP 2005)

In addition, there are other large sources of renewable energy in EUMENA: there is potential of almost 2000 TWh of wind power and 4000 TWh/y of power from geothermal, hydro and biomass sources including agricultural and municipal waste. Also PV, wave and tidal power have considerable potentials in the region. By contrast with fossil and nuclear fuels, renewable energy sources in the region are over-abundant.

However, each renewable energy resource has a specific geographic distribution (Figure 4). Each country will therefore have its specific mix of resources, with hydropower, biomass and wind energy being the preferred sources in the North, and solar and wind energy being the most powerful sources in the South of EUMENA.

	Unit Capacity	Capacity Credit*	Capacity Factor**	Potential*** (TWh/y)	Type of Resource	Applications	Comment
Wind Power	1 kW -5 MW	0 - 30%	15 - 50%	1950	kinetic energy of the wind	electricity	fluctuating, supply defined by resource
Photovoltaic	1W -5 MW	0%	5 - 25%	325	direct and diffuse irradiance on a surface tilted with latitude	electricity	fluctuating, supply defined by resource
Biomass	1 kW -25 MW	50 - 90%	40 - 90%	1350	municipal and agricultural organic waste and wood	electricity and heat	seasonal fluctuations but good storability, power on demand
Geothermal (Hot Dry Rock)	25 MW -50 MW	90%	40 - 90%	1100	heat from hot dry rocks of several 1000 meters depth	electricity and heat	no fluctuations, power on demand
Hydropower	1 kW -1000 MW	50 - 90%	10 - 90%	1350	kinetic and potential energy from water flows	electricity	seasonal fluctuations, good storability in dams, also used as pump storage for other sources
Solar Updraft Tower	100 MW -200 MW	10 - 70% depending on storage	20 - 70%	part of CSP potential	direct and diffuse irradiance on a horizontal surface	electricity	seasonal fluctuations, good storability, base-load power
Concentrating Solar Thermal Power (CSP)	10 kW -200 MW	0 - 90% depending on storage and hybridisation	20 - 90%	630,000	direct irradiance on a surface tracking the sun	electricity and heat	fluctuations are compensated by thermal storage and (bio)fuel, power on demand
Gas Turbine	0.5 MW -100 MW	90%	10 - 90%	n.a.	natural gas, fuel oil	electricity and heat	power on demand
Steam Cycle	5 MW -500 MW	90%	40 - 90%	n.a.	coal, lignite, fuel oil, natural gas	electricity and heat	power on demand
Nuclear	>500 MW	90%	90%	n.a.	uranium	electricity and heat	base-load power

Table 2: Some characteristics of contemporary power technologies. * Contribution to firm power and reserve capacity. ** Average annual utilisation. *** Technical electricity potential in EUMENA that can be exploited in the long-term at competitive cost considering each technology's learning curve. In the case of PV only the demand-side potential used until 2050 was assessed; the technical potential is comparable to that of CSP

Fossil energy sources like coal, oil and gas can be a useful complement to the renewable energy mix, being stored forms of energy that can easily be used for balancing power and for grid stabilization. If their consumption is reduced to the point where they are used exclusively for this purpose, their cost escalation will be reduced and cause only a minor burden to economic development and their environmental impact will be minimized. Moreover, their availability will be extended for decades or even centuries.

By contrast, nuclear fission plants are not easily combined with renewables because their output cannot, economically, be varied to meet fluctuating demands. Moreover, decommissioning costs of nuclear plants exceed their initial investment (NDA 2002) and, half a century after market introduction, there are still unsolved problems like plutonium proliferation and nuclear waste disposal. The other nuclear option, fusion, is not expected to be commercially available before 2050 and is therefore not relevant for our proposals (HGF 2001).

Several renewable power technologies can also provide base-load and balancing power. These include: geothermal (hot dry rock) systems that are today in a phase of research and development; hydropower plants with large storage dams in Norway, Iceland and the Alps; most biomass plants; and concentrating solar thermal power plants (CSP) in MENA. CSP plants use the high annual solar irradiance of that region, the possibility of solar thermal energy storage for overnight operation and the option of backup firing with fossil fuels or biomass. CSP in Europe is subject to significant seasonal fluctuations. Constant output for base-load power can only be provided with a considerable fossil fuel share. Due to the higher solar irradiance in MENA, the cost of concentrating solar power there is usually lower and its availability is better than in Europe. Therefore, there will be a significant market for solar electricity imports to complement the European sources and provide firm renewable power capacity at competitive cost.

D Concentrating Solar Power as Key Element of the Energy Mix

Steam turbines and gas turbines powered by coal, uranium, oil and natural gas are today's guarantors of electrical grid stability, providing both base-load and balancing power. However, turbines can also be powered by high temperature heat from concentrating solar collector fields (Figure 5). Power plants of this type with 30 - 80 MW unit capacity are operating successfully in California since 20 years, and new plants are currently erected in the U.S. and Spain. The concentrating solar collectors are efficient fuel savers, today producing heat at a cost equivalent to 50 $/barrel of fuel oil, with the perspective to achieve a level below 25 $/barrel within a decade (MED-CSP 2005, Pitz-Paal et al. 2005).

Just like conventional power stations, concentrating solar power plants can deliver base-load or balancing power, directly using sunshine during the day, making use of thermal energy storage facilities during the night and in case there is a longer period without sunshine, using fossil or biomass fuel as backup heat source. Just like fossil fuel fired conventional power stations, CSP plants have an availability that is close to 100 %, but with significantly lower fuel consumption. A CSP plant with a thermal energy storage facility for additional 8 hours of full load operation is currently build in the Spanish Sierra Nevada near Guadix, allowing solar electricity generation also during night-time. This plant with a capacity of 50 MW will have a minimum annual solar share of 85 %.

Another feature that distinguishes CSP is the possibility of combined generation of electricity and heat to achieve the highest possible efficiencies for energy conversion. In addition to electricity, such plants can provide steam for absorption chillers, industrial process heat or thermal seawater desalination. A design study for such a plant was finished late 2006, the plant is scheduled to be commissioned for early 2009 (Figure 5, left). It will provide 10 MW of power, 40 MW of district cooling and 10,000 cubic metres per day of desalted water for a large hotel resort in Aqaba, Jordan (Trieb et al. 2007).

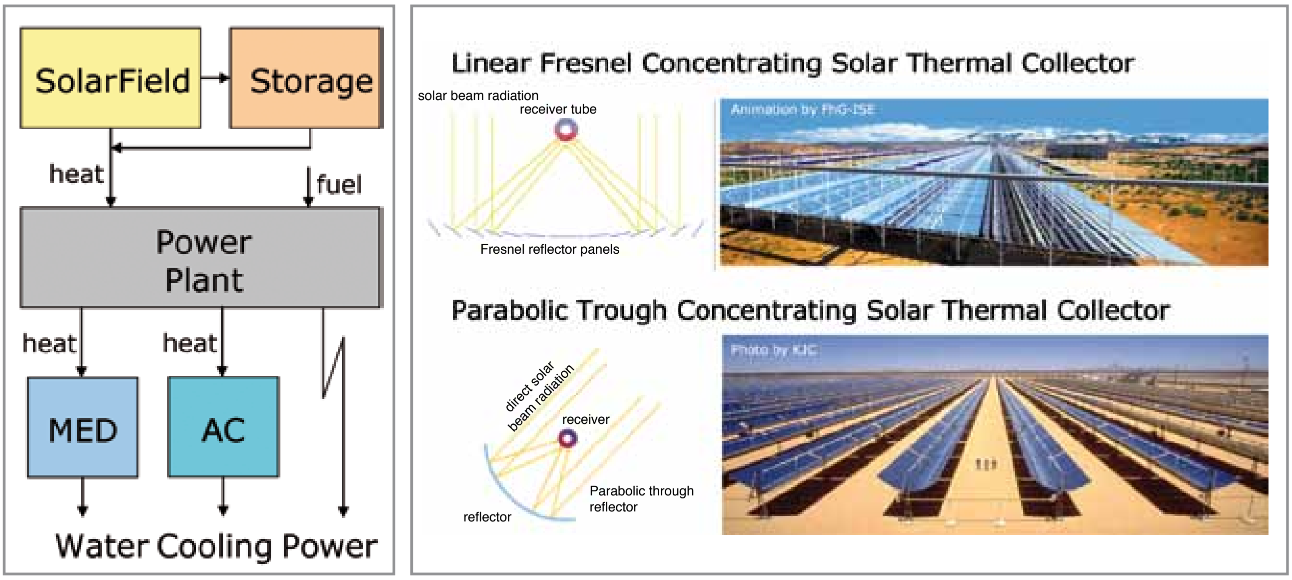

Figure 5: Left: Configuration of a concentrating solar power station for combined generation of electricity and heat for absorption cooling (AC) and multi-effect seawater desalination (MED). Right: Line-concentrating solar thermal collector technologies.

E Sustainable Energy and Water for EUMENA

Following the criteria for sustainability in Table 1 and additional technical, social and economic frame conditions described in other reports (MED-CSP 2005, TRANS-CSP 2006), we have developed a scenario for electricity generation for 50 countries in EUMENA up to the year 2050. Except for wind power that is already booming today, and hydropower that has been established since decades, renewable energy will hardly become visible in the electricity mix before 2020 (Figure 6 and Figure 7). At the same time, phasing out of nuclear power in many European countries and the stagnating use of coal and lignite due to climate protection will generate increasing pressure on natural gas resources, increasing their consumption as well as their installed capacity for power generation. Until 2020, renewables like wind and PV power will mainly have the effect of reducing fuel consumption, but will do little to replace existing capacities of balancing power. Owing to growing demands and the replacement of nuclear power, consumption of fossil fuels cannot be reduced before 2020.

Fuel oil for electricity will largely disappear by 2030 and nuclear power will follow after 2040. The consumption of gas and coal will increase until 2030 and thereafter be reduced to a compatible and affordable level by 2050. In the long term, new services such as electric vehicles may increase the electricity demand further and thus require a higher exploitation of renewables.

The electricity mix in the year 2000 depends mainly on five resources, most of them exhaustable, while the mix in 2050 will be based on ten energy sources, most of them inexhaustable. Thus, our scenario responds positively to the European Strategy for Sustainable, Competitive and Secure Energy declared by the European Commission in the corresponding Green Paper and Background Document, aiming at higher diversification and security of the European energy supply (Commission of the European Communities 2006).

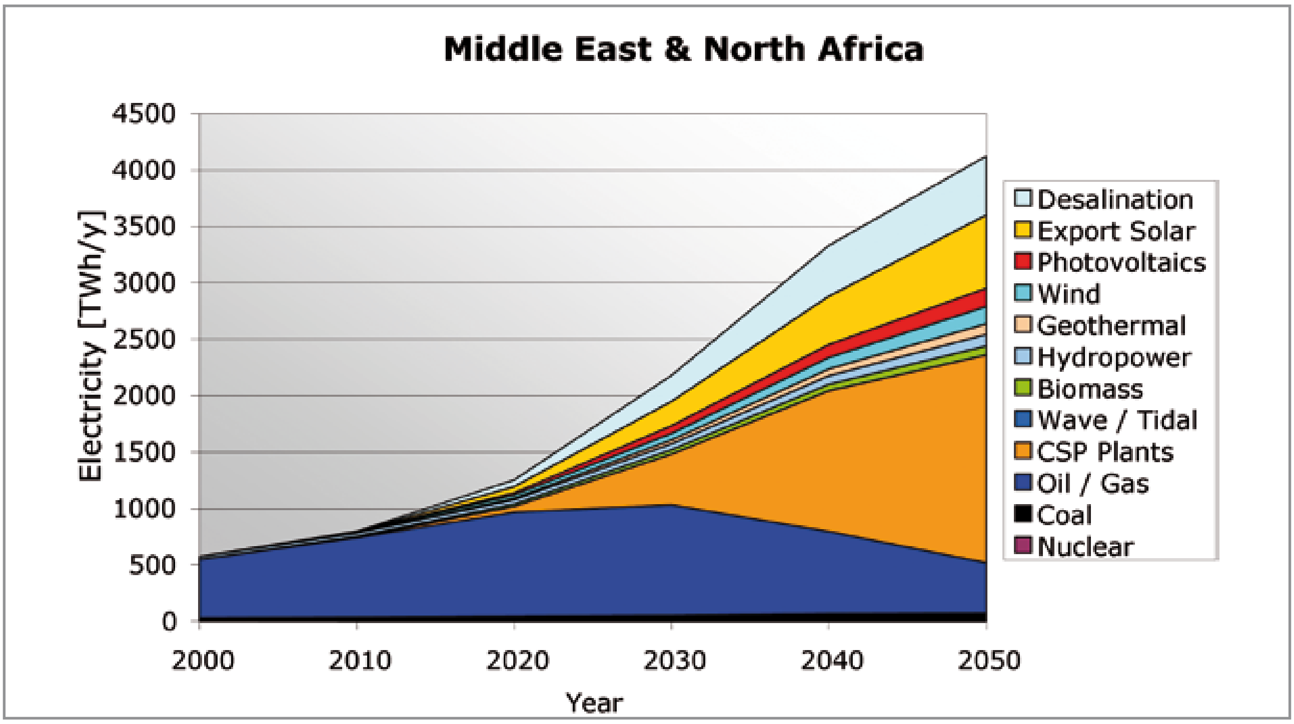

Figure 6: Electricity generated for regional demand according to Figure 1 and in addition for seawater desalination and for export to Europe using the different forms of primary energy available in MENA

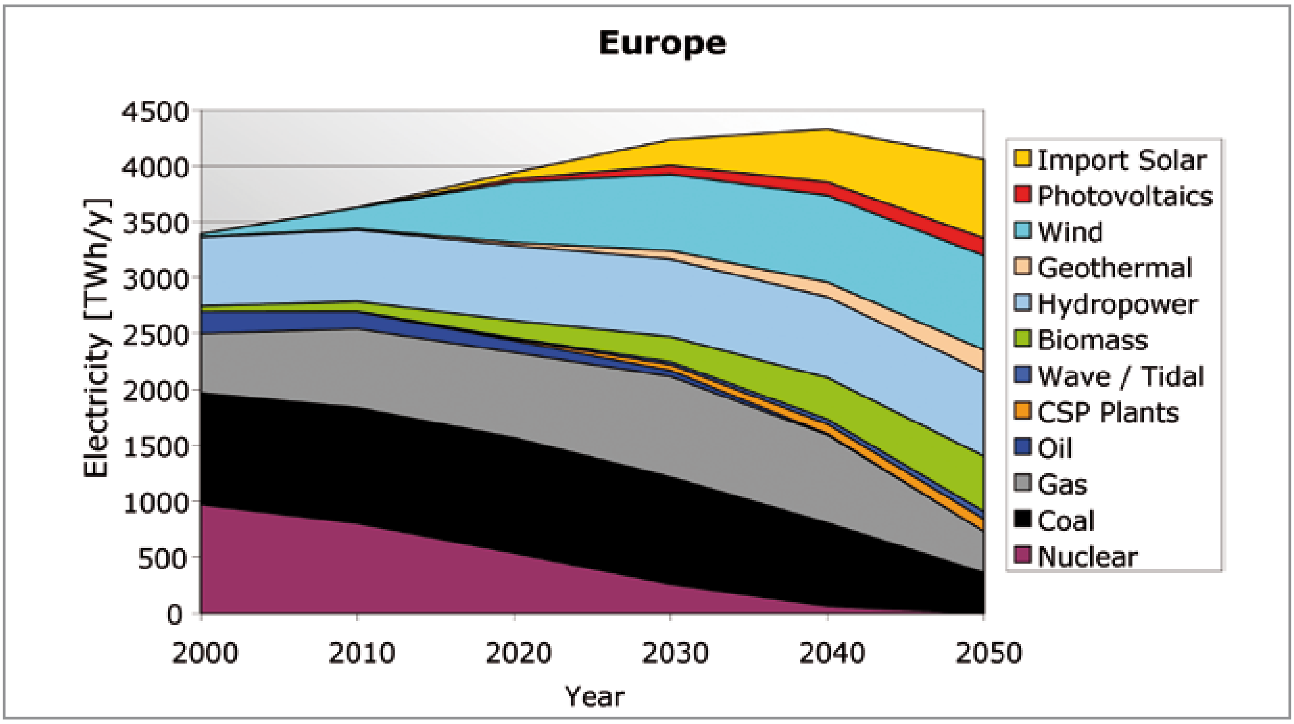

Figure 7: Electricity generated from the different forms of primary energy in Europe including the import of solar electricity from MENA

A prerequisite of the electricity mix is to provide firm capacity with a reserve of about 25 % in addition to the expected peaking load (Figure 8). Before significant CSP transmission starts in the year 2020, this can only be provided by extending the capacity and fuel consumption of gas fired peaking plants based on natural gas and later eventually on coal gasification. In Europe, the consumption of natural gas doubles with respect to the starting year 2000; but it is then brought back to the initial level, after the introduction in 2020 of increasing shares of CSP transmission from MENA as well as geothermal and hydropower from Scandinavia, via High-Voltage Direct-Current (HVDC) interconnections. European renewable energy sources that could provide firm capacity are rather limited from the point of view of their potential. Therefore, CSP transmission from MENA to Europe will be essential to reduce both the installed capacity and the fuel consumption of gas fired peaking plants and to provide firm renewable power capacity.

In MENA, concentrating solar power is the only source that can really cope with rapidly growing electricity consumption, providing both base-load- and balancing power. By 2050, fossil energy sources will be used solely for backup purposes. This will reduce their consumption to a sustainable level and bring down the otherwise rapidly escalating cost of power generation. Fossil fuels will be used to guarantee firm balancing power capacity, while renewables will serve to reduce their consumption for everyday use and base-load supply.

An efficient backup infrastructure will be necessary to complement the renewable electricity mix: on one hand to provide firm capacity on demand by quickly-reacting, natural-gas-fired peaking plants, and on the other hand as an efficient grid infrastructure that allows the transmission of renewable electricity from the best centres of production to the main centres of demand. The best solution is a combination of High-Voltage Direct-Current (HVDC) transmission lines and the conventional Alternating Current (AC) grid.

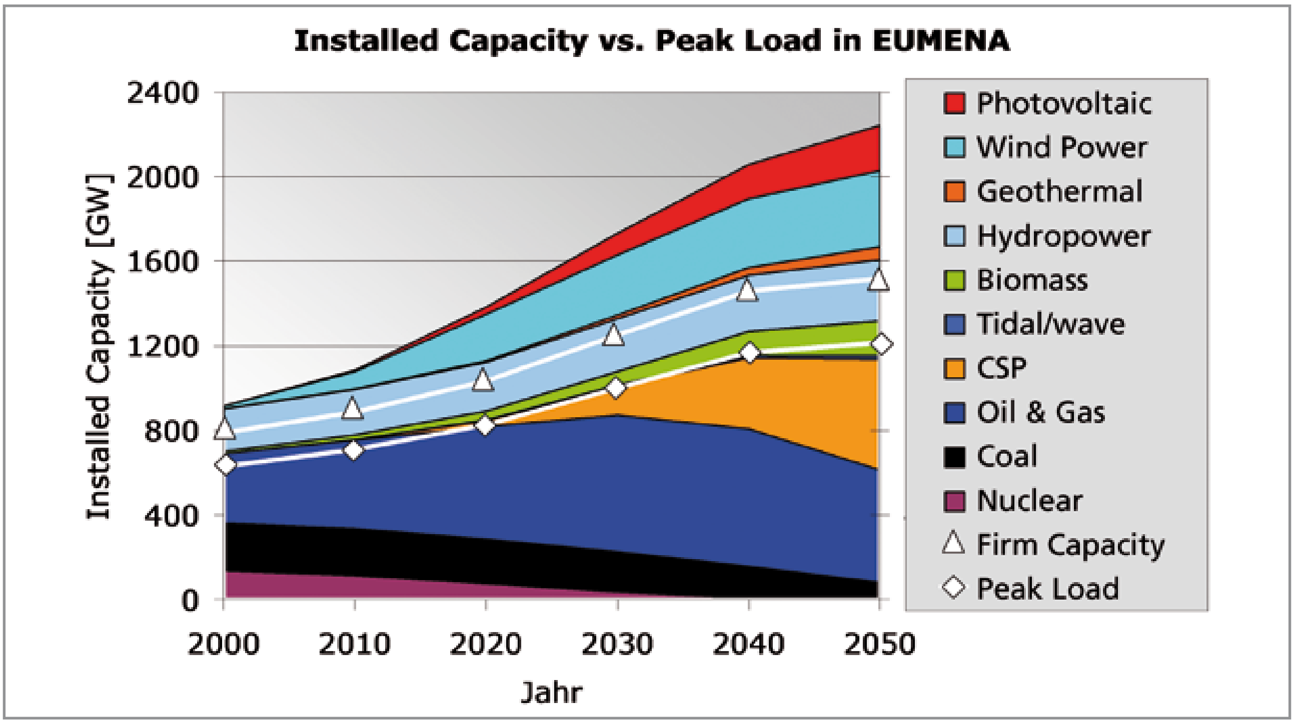

Figure 8: Scenario of the installed power capacity in comparison to the cumulated peak load of all countries in the EUMENA region. Firm power capacity is calculated on the basis of capacity credits for each technology according to Table 2. By the year 2050, 68 % of the installed CSP capacity is used for local supplies, 19 % for long-distance transmission and 13 % for desalination.

At lower voltage levels, decentralised structures will also gain importance, combining, for example, PV, wind and micro-turbines operating together just like a single virtual power plant. Such a grid infrastructure will not be motivated by the use of renewables alone. In fact, its construction will probably take place anyway, in order to stabilize the growing European grid, to provide greater security of supply, and to foster competition (Asplund 2004, Eurelectric 2003). By 2050, transmission lines with a capacity of 2.5-5.0 GW each will transport about 700 TWh/y of solar electricity from 20-40 different locations in the Middle East and North Africa to the main centres of demand in Europe (Figure 9 and Table 3).

HVDC technology has been a mature technology for several decades and is becoming increasingly important for the stabilisation of large-scale electricity grids, especially if more fluctuating resources are incorporated. HVDC transmission over long distances contributes considerably to increase the compensational effects between distant and local energy sources, and it allows failures of large power stations to be accommodated via distant backup capacity. It can be expected that a HVDC backbone will be established in the long term to support the conventional electricity grid and to increase the stability of the future power-supply system.

Figure 9: Concept of a “EUMENA Supergrid” based on HVDC power transmission as “Electricity Highways” to complement the conventional AC electricity grid, as developed by TREC in 2003. The symbols for power sources and lines are only sketching typical locations.

As a spin-off effect of this development, solar electricity from MENA will become an attractive means of diversifying the European power-generation portfolio. Due to the abundance and seasonal uniformity of solar energy from deserts it will be cheaper and better available than solar electricity generated in Europe. In a coming renewable energy alliance of Europe and MENA solar and wind energy, hydropower, geothermal power and biomass will be generated in places where they work best and where they are most abundant. This power will be distributed all over Europe and MENA through a highly efficient HVDC grid at high-voltage levels, and delivered to consumers by the conventional interconnected AC grid at low-voltage levels. By analogy with the network of interstate highways, a future HVDC grid will have a low number of inlets to and outlets from the conventional AC system because its primary purpose will be to serve long-distance power transmission, while the AC grid will function in a manner that is analogous to the operation of country roads and city streets. In our calculations we assume that about 10 % of the generated solar electricity will be lost by HVDC transmission from MENA to Europe over 3000 km distance.

In 2050, twenty to forty power lines with 2500 - 5000 MW capacity each could provide about 15 % of the European electricity as clean power from deserts, motivated by a low production cost of around 5 €-cent/kWh (not accounting for further cost reduction via carbon credits) and their high flexibility for base-, intermediate- and peak-load operation. In future transmission losses may be lowered to 5 % per 3,000 km by new developments in HVDC technology (Asplund 2007).

There is a wide-spread belief that for every wind farm or PV plant a fossil fuel fired backup power plant must be installed. However, hourly time series modelling of the power supply system of selected countries according to our scenario showed that even without additional storage capacities for electricity, the existing balancing capacity is sufficient for the purpose of covering fluctuations in demand. No extra backup or storage capacity is needed as long as the fluctuating renewable energy share is smaller than the existing peaking plant capacity, which is the case in our scenario.

Year		2020	2030	2040	2050
Transfer Capacity GW		2 x 5	8 x 5	14 x 5	20 x 5
Electricity Transfer TWh/y		60	230	470	700
Capacity Factor		0.60	0.67	0.75	0.80
Turnover Billion €/y		3.8	12.5	24	35
Land Area km x km	CSP HVDC	15 x 15 3100 x 0.1	30 x 30 3600 x 0.4	40 x 40 3600 x 0.7	50 x 50 3600 x 1.0
Investment Bilion €	CSP HVDC	42 5	143 20	245 31	350 45
Elec. Cost €/kWh	CSP HVDC	0.050 0.014	0.045 0.010	0.040 0.010	0.040 0.010

Concentrating Solar Thermal Power (CSP) plants use mirrors to concentrate sunlight for steam and power generation. Solar heat can be stored in tanks of molten salt and used for nighttime operation of the turbines, which can also be powered by oil, natural gas or biomass fuels.

High Voltage Direct Current (HVDC) transmission lines are used in some 100 projects world wide transmitting today about 80 GW of electricity from remote, mostly renewable sources like large hydropower dams and geothermal plants to large centres of demand.

Table 3: Main indicators of a EUMENA High Voltage Direct Current (HVDC) interconnection for Concentrating Solar Thermal Power (CSP) from 2020 – 2050 according to the TRANS-CSP scenario (data 2006). In 2050, lines with a capacity of 5 GW each will transmit about 700 TWh/y of electricity from 20-40 different locations in the Middle East and North Africa to the main centres of demand in Europe.

In fact, as a consequence of the increasing share of renewable electricity generation, the need for conventional base load plants with constant output will step by step disappear (Figure 10). Base load will be covered by plants for combined generation of heat and power (CHP) using fossil and biomass fuels, river run-off hydropower, wind power and photovoltaics. Intermediate power capacity will be provided by better storable sources like hydropower from dams, biomass and geothermal power. This combination of power sources will not totally cover, but fairly approximate the daily load curve. The remaining balancing capacity will be supplied by pump storage, hydropower dams, concentrating solar power and fossil fuel fired peaking plants. In addition to that, enhanced demand side management will increasingly be used to minimise the need of pump storage capacity and fossil fuel consumption for peaking power, which both will remain in the same order of magnitude as today (Brischke 2005).

The fossil fuel fired power capacities remaining in 2050 will exclusively serve balancing duties and combined generation of heat and power. This is in line with the strategy of using those valuable, perfectly stored energy sources exclusively for what they are best suited for and not wasting them for quotidian use. Base load plants with constant output fuelled by nuclear fission, fusion or lignite will not fit well into such a system, as they are not capable of providing quickly changing output to fill the gap between the partially fluctuating supply from cogeneration and renewables and the otherwise fluctuating demand. In fact, gas driven plants will be the preferred choice for this purpose. In the very long-term after 2050, renewable sources supported by advanced storage and load management in close coordination with other energy sectors like heating and cooling as well as transport and mobility will finally also take over the remaining demand for balancing power and combined generation.

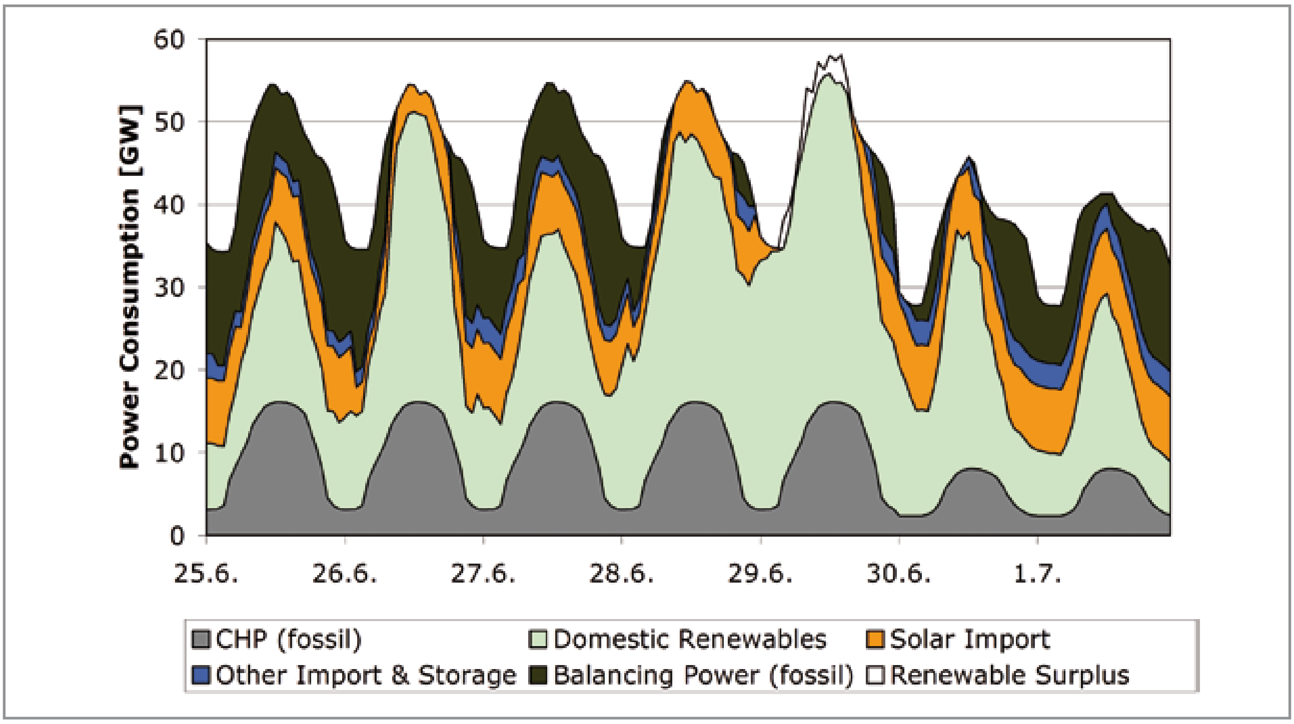

Figure 10: Model of the hourly electricity balance of Germany in 2050 (Brischke 2005)

F Least Cost Electricity from Renewable Sources

Installing CSP plants world wide, a reduction of the solar electricity cost due to economies of scale can be achieved with a progress ratio of about 85-90 %[4] (Pitz-Paal et al. 2005). As an example, a CSP-plant today can produce electricity at about 0.14-0.18 €/kWh depending on solar irradiance (Figure 11). With 5000 MW installed world-wide the cost would drop to about 0.08-0.12 €/kWh, and to 0.04-0.06 €/kWh once a capacity of 100 GW would be installed[5]. A prerequisite for this cost reduction is a global CSP expansion from 415 MW today to about 28 GW by 2020 and roughly 140 GW by 2030 including capacities for seawater desalination (MED-CSP 2005), (TRANS-CSP 2006), (AQUA-CSP 2007). In the long-term, a total of 500 GW could be installed by 2050. For the calculation of this learning curve we have assumed solar only operation, an economic lifetime of 25 years and a real project rate of return of 6.5 %/y.

All renewable energy sources show similar learning curves, becoming cheaper the more they are exploited. While most renewable sources show capacity limits of exploitation, the solar energy resource in MENA is about hundred times larger than demand will ever be. Further, due to better solar radiation costs of clean power from deserts including transmission will be lower than for solar power produced by the same type of power plants located in Europe, as shown for Spain in Figure 12. If we take as example the Spanish electricity mix as described in (TRANS-CSP 2006) a scenario based on a mix of domestic renewable energies, solar electricity from North Africa and fossil fuels for balancing power has the medium-term perspective of stable and even slightly reduced electricity costs (red curves in Fig. 12), while a business-as-usual scenario would lead to steadily escalating costs of energy (black curves) as has happened since the year 2000. In the TRANS-CSP scenario, the expansion of renewable energy will take place in niche markets like the Spanish Renewable Energy Act until about 2020, temporarily leading to slightly higher electricity costs than for a business-as-usual mix. During that time, the share of renewable energy will increase while the cost of renewable energy will decrease. Latest from 2030 onwards solar energy imported to more Northern countries like Germany, will also be clearly cheaper than local production from a fossil-nuclear mix (black curve Germany), and also from fossil sources alone (green curve Germany) as in case of phasing out nuclear as scheduled.

CSP electricity cost is given in constant Euro of the starting point of our scenario in the beginning of the year 2000 (real values). This is to avoid speculations on future inflation rates. To calculate the nominal value in a subsequent year one must consider inflation since the starting year 2000. E.g. the 7.7 c/kWh for CSP in Spain in 2020 given in Fig. 12 would equal 7.7 c/kWh (real value 2000) x 1.03 (assuming 3% Inflation Rate) exp. 21 (Years) = 14.3 c/kWh nominal cost in currency value of 2020. In that case our assumed real interest rate of 5% would change to a nominal 8%. This has to be considered in the interpretation of our results. General inflation as well as technology specific escalation rates (e.g. steel) will have an influence on the nominal values in the future and had an influence in the past since the year 2000.

Our model gives a reasonable estimate of CSP cost development for a broad spectrum of technologies and providers, but may differ from the development of specific technical solutions. Our scenario is not a general prediction of the future, but a consistant model of the future assuming a defined set of frame parametres and their future development.

[4] A progress ratio of 90 % means that the specific investment is reduced by 10 % every time the total installed capacity of the solar collectors is doubled (Neij et al. 2003, Pitz-Paal et al. 2005)

[5] This cost is calculated for solar only operation and would be lower in hybrid mode, as there would be a better amortisation of the power block investment.

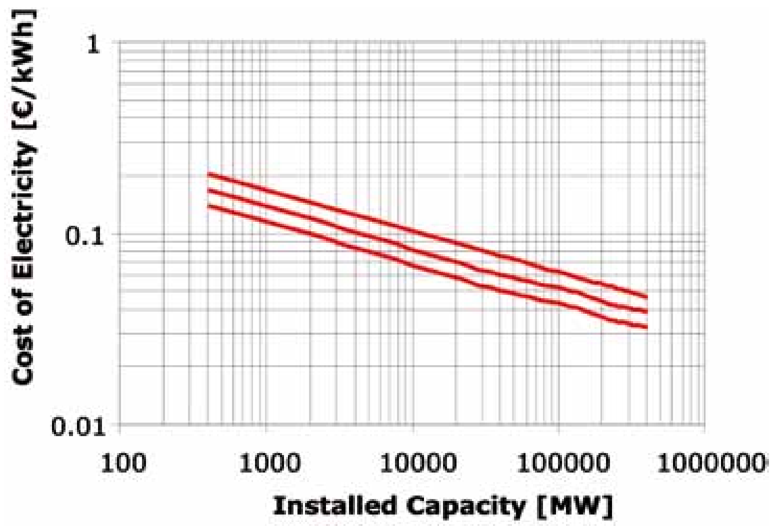

Figure 11: Expected cost of electricity from CSP in solar-only operation as function of installed capacity according to (NEEDS 2007) for an annual irradiance (from top to bottom) of 2000, 2400 and 2800 kWh/m²/y.

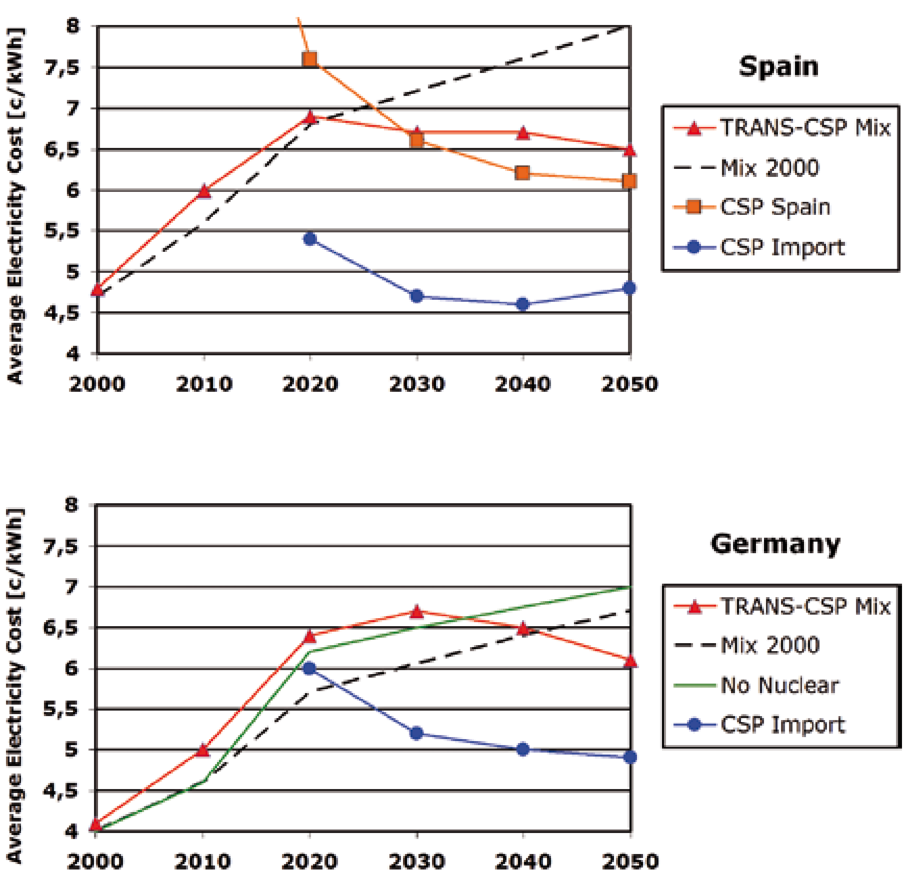

Figure 12: Cost of electricity in Spain and in Germany (TRANS-CSP 2006); red: TRANS-CSP mix with increasing share of renewable sources, black: continuing the mix of the year 2000 with fuel cost escalation, blue: CSP import from Africa, orange: local CSP production in Spain, green: mix 2000 but phasing out nuclear as scheduled in Germany.

Once cost break-even with conventional power is achieved, renewable capacities will be extended faster, avoiding further increases in the nationwide cost of electricity. Thus, the cost of the electricity mix can be maintained constant or in some cases even be brought back to lower levels, by subsequently increasing the share of renewable energy sources. This concept can be realized in all EUMENA countries.

The ongoing electricity cost escalation shows clearly that introducing CSP and other renewable energy sources on a large scale is the only viable solution for avoiding further long-term cost elevation in the power sector and to return to a relatively low cost level for electricity in the medium-term future. This is in line with the utilities' commitment to deliver least cost electricity to their clients. CSP from deserts is a key element of such a strategy.

An affordable and sustainable source of energy is also required for an even more vital commodity: freshwater from seawater desalination. CSP and other renewables can be the solution for this, too (Bennouna and Nokraschy 2006). The AQUA-CSP study shows the potential of CSP for seawater desalination in the MENA region and describes the technical options available, ranging from solar-powered membrane desalination to the combined generation of solar electricity and heat for thermal multi-effect desalination (AQUA-CSP 2007).

In fact, there is no other way to avoid a serious water crisis in the MENA region, than to activate all options for better water management, higher efficiency of water distribution and end-use, re-use of waste-water and seawater desalination based on renewable energy sources (Figure 13).

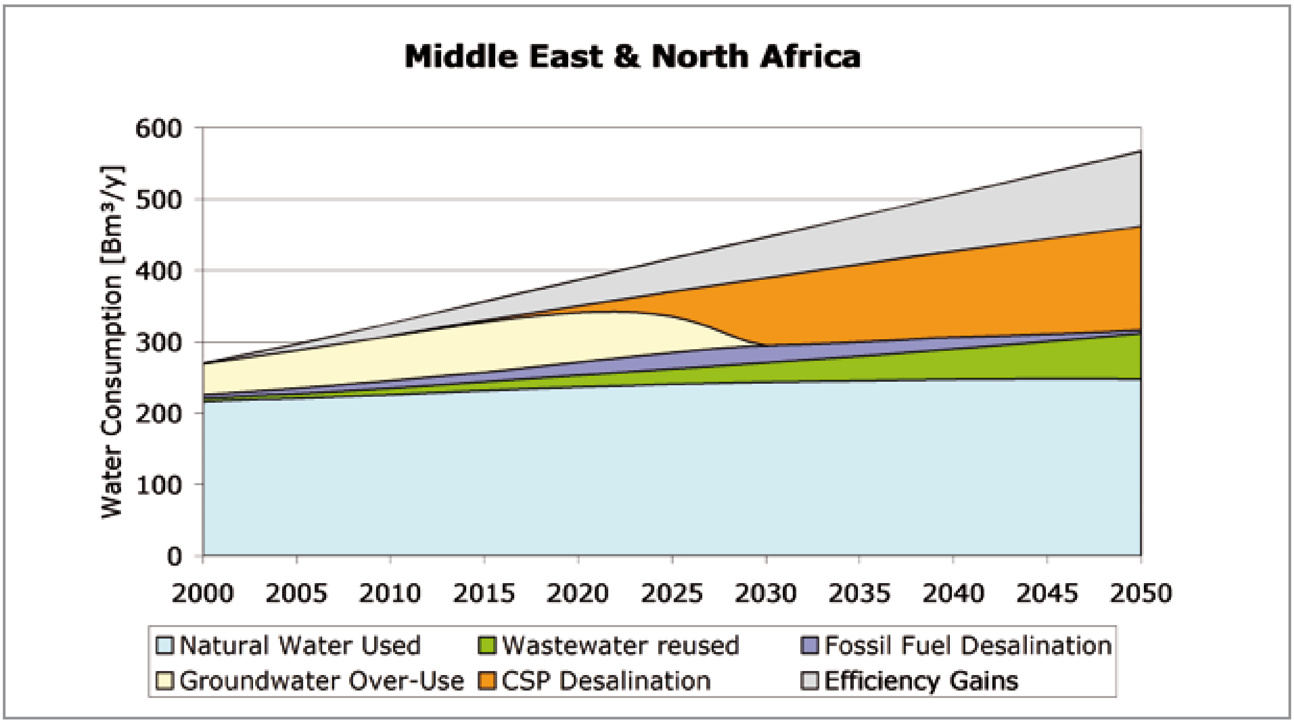

Figure 13: Water demand scenario for MENA until 2050 and coverage of demand by sustainable sources, by unsustainable sources and by solar desalination. (shaded: efficiency gains with respect to business as usual). Source: (AQUA-CSP 2007)

G There is an Alternative to Climate Change and Nuclear Proliferation

By implementing our scenario, carbon emissions can be reduced to values that are compatible with the goal of stabilising the CO_2 content of the atmosphere at 450 parts per million that is considered necessary by the Intergovernmental Panel on Climate Change in order to keep global warming in a range of 1.5 to 3.9 °C (IPCC 2001). Starting with 1790 million tons of carbon dioxide per year in the year 2000, emissions can be reduced to 690 Mt/y in 2050, instead of growing to 3700 Mt/y in a business as usual case (Figure 14). The final per capita emission of 0.58 tons/cap/y in the electricity sector is acceptable in terms of a maximum total emission of 1-1.5 tons/cap/y that has been recommended by the German Scientific Council on Global Environmental Change (Graßl 2003). Further reductions can be achieved after 2050.

Other pollutants are reduced in a similar way, without any need to expand the use of nuclear energy and its associated risks. Carbon capture and sequestration (CCS) has been considered in our study as a complement, but not as an alternative to renewable energy, as it will reduce power plant efficiency and thus accelerate the consumption of fossil fuels. The fact that the cost of carbon capturing always adds to the cost of fossil fuels will accelerate cost break-even with renewables and increase the speed of their market introduction.

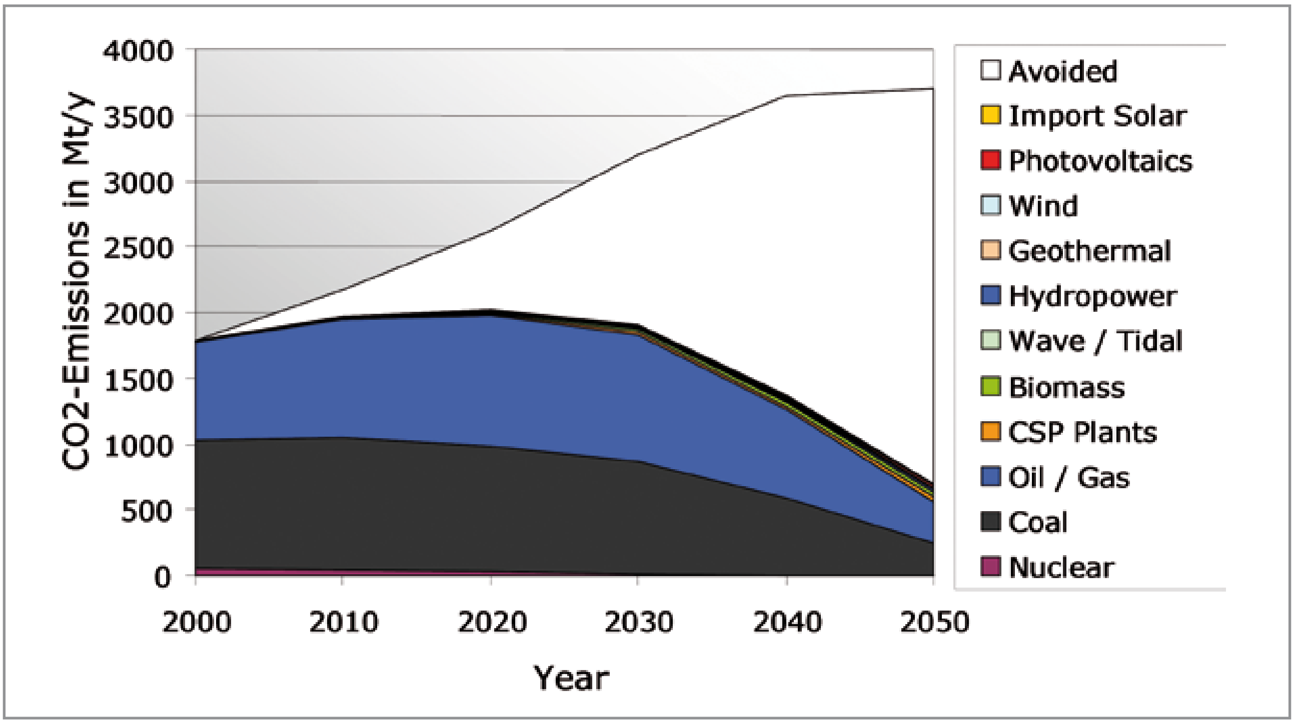

Figure 14: CO_2-emissions from electricity generation in million tons per year for all EUMENA countries and emissions avoided by implementing the proposed scenario with respect to an electricity mix equivalent to that of the year 2000.

The area required for the total renewable energy infrastructure including the proposed HVDC transmission lines for the period up to 2050 amounts to roughly 1 % of the total land area of EUMENA. This is comparable to the land required at present for the transport and mobility infrastructure in Europe. Using a geographic information system (GIS) three examples of HVDC lines connecting very good sites for CSP generation in MENA with three major European centres of demand were analyzed on the basis of a life cycle eco-balance (May 2005). The GIS was programmed to minimize cost, environmental impacts and visibility of the power lines, and we found that the resulting impacts are in an acceptable range. In general, the environmental impacts of HVDC lines are much lower than those of comparable AC overhead lines using conventional technology. Altogether, our scenario shows a way to reduce significantly the negative environmental impacts of power generation, and could also serve as a model for global application. This has been recognized by a study of the U.S. Department of Energy analysing the feasibility of this concept for the U.S. (Price 2007).

If desalination of sea water is powered by solar energy instead by fossil fuels, its environmental impacts are significantly reduced. However, seawater desalination itself is always a considerable burden to the environment, due to the resulting salty brine and the necessary chemical water treatment. Nano-filtration of intake water can mitigate those impacts, but more energy is required in that case. Therefore, activating the existing potential for enhanced efficiency of water use, water management and infrastructure is also a very high priority, in order to minimize the need for desalination. The AQUA-CSP study analyses the environmental impact of a broad application of solar-powered seawater desalination to cover the expected freshwater deficits in MENA (AQUA-CSP 2007). The results will be published by the end of 2007.

Five Focal Points for Sustainable Energy Policy

The timely realization of a scenario that meets all criteria of sustainability will require determined political support and action. Five focal points for national and international policy for all countries in Europe, the Middle East and North Africa (EUMENA) result from our studies:

1. **Increase support for research, for development and for the market introduction of measures for efficient supply, distribution and use of energy (<u>efficiency focus</u>).**

2. **Provide a reliable framework for the market introduction of existing renewable energy technologies, based on best practice experience and increase support for research and development for promising enhancements (<u>renewable energy focus</u>).**

3. **Initiate a EUMENA-wide partnership for sustainable energy. Provide European support to accelerate renewable energy use in MENA (<u>interregional cooperation focus</u>).**

4. **Initiate planning and evaluation of a EUMENA High Voltage Direct Current super-grid to combine the best renewable energy sources in this region and to increase diversity and redundancy of supply (<u>interconnection focus</u>).**

5. **Support research and development for shifting the use of fossil fuels from bulk electricity to balancing power production (<u>balancing power focus</u>)**

H Electricity in other Energy Sectors

A sustainable solution must also be found for the heating, cooling and transport sectors. Energy efficiency and increasing renewable shares are useful guidelines for these sectors. In the long term, there is the option of a partial shift from traditional heat and fuel to electricity. Examples for such a possible shift are electric heat pumps or direct electricity for space and water heating and electric or hybrid vehicles. In terms of sustainability, the higher demand for electricity arising from that shift will not constitute a problem if electricity is mainly produced by renewable energy as assumed in our scenario. In the power sector, each kWh of electricity produced by solar and wind energy will substitute approximately three kWh of primary energy from coal, oil, gas or uranium[6]. This relation depends on the actual efficiency of conventional primary-energy conversion, which ranges from about 20 % in the transport sector to about 80 % in space heating.

Thus, the use of renewable electricity will add to the efficiency gains of primary energy in all energy sectors. A partial long-term shift of other sectors to (clean) electricity is possible, as the renewable electricity potential in EUMENA is large enough to cope with that additional demand. In addition to electricity, direct renewable solutions also exist for those sectors, such as the use of bio-fuels for transport and heating, energy-efficient buildings, absorption cooling and solar water heaters, to give only a few examples (Dürrschmidt et al. 2006).

Combined heat and power is an important measure for increasing the energy efficiency of fossil fuels. Some renewable technologies, such as biomass, geothermal and concentrating solar thermal power plants, can also use this option for the combined generation of electricity and heat – usually via steam – for industrial processes, cooling and desalination, and will gain an increasing share in a future energy supply system.

[6] assuming a typical conventional power plant efficiency of 33%

Conclusions

The report quantifies the renewable electricity potentials in Europe and MENA and confirms their ability to provide firm power capacity on demand. Of great advantage for a fast transition to clean and secure power is an interconnection between the electricity grids of Europe, the Middle East and North Africa (EUMENA). Our study evaluates the potential and benefits of solar power from deserts. The conventional electricity grid is not capable of transferring large amounts of electricity over long distances. Therefore, a combination of the conventional Alternating Current (AC) grid for local distribution and High-Voltage Direct-Current (HVDC) transmission technology for long-distance transfer will be used in a Trans-Mediterranean electricity scheme based mainly on renewable energy sources with some fossil fuel backup. Sustainable energy will also be vital for sustainable freshwater supply by desalination. The results can be summarized in the following statements:

1. A mix of various renewable energy sources backed by fossil fuels can provide sustainable, competitive and secure electricity. Our scenario for EUMENA starts with the 16% share of renewable electricity that existed in the year 2000 and reaches 80 % in 2050. An efficient backup infrastructure will be necessary to complement the renewable electricity mix, providing firm capacity on demand by quickly-reacting gas-fired peaking plants, and by an efficient grid infrastructure to distribute renewable electricity from the best centres of production to the main centres of demand.

2. Market introduction of renewable electricity requires initial support in the form of long term power purchase agreements that cover the costs of operation together with a reasonable return on investment. This will mean only a small increase in national electricity prices, but will avoid their long-term escalation thanks to an increasing proportion of relatively inexpensive renewables and corresponding reductions in cost.

3. If initiated now, the change to a sustainable energy mix will, within a time-span of about 15 years, lead to power generation that is less expensive than it would be in a business-as-usual strategy. Fossil fuels with steadily rising costs will be replaced progressively by renewable forms of energy, most of which will be home-grown. The negative socio-economic impacts of increases in fossil-fuel prices can be reversed by 2020 if an adequate political and legal framework for the introduction of renewables into the market is established in time. Long-term power-purchase agreements like those provided by the German or Spanish Renewable Energy Acts are very effective instruments for the market introduction of renewables. If initial tariff additions are subsequently reduced to zero, they can be considered as a very efficient public investment into affordable and secure power generation rather than as subsidy.

4. Solar electricity generated by concentrating solar thermal power plants in MENA and transferred to Europe via high-voltage direct-current transmission can provide firm capacity for base-load and peaking power, effectively complementing European electricity sources. Starting between 2020 and 2025 with a transfer of 60 TWh/y, solar electricity imports could subsequently be extended to 700 TWh/y by 2050. High solar irradiance in MENA and low transmission losses of around 10 % will yield a competitive price of about 0.05 €/kWh in Europe for import of solar electricity.

5. Instead of a doubling of carbon dioxide emissions in the period up to 2050, which is likely to happen in a business-as-usual scenario, the CO_2 emissions from power generation in EUMENA can be reduced to 38 % of emissions of the year 2000. Only 1 % of the land area will be required for this renewable electricity scheme, which is equivalent to the land used at present for transport and mobility in Europe.

6. Growing freshwater deficits in MENA will increasingly require seawater desalination, but this must be done using sustainable sources of energy. Solar electricity for membrane desalination and combined solar heat and power for thermal seawater desalination are major candidates for such a sustainable solution.

7. European support for MENA for the introduction of renewables into the market can relieve the increasing pressure on fossil fuel resources that would otherwise result from the economic growth of this region, thus helping indirectly to secure fossil fuel supply also in Europe. The necessary political process could be initiated by a renewable energy partnership and a common free trade area for renewable forms of energy in EUMENA and culminate in a Community for Energy, Water and Climate Security.

In order to achieve those benefits, governments in EUMENA must now take the initiative and establish an adequate legal and financial framework for new investment into this least-cost option for clean and sustainable energy. As energy is also a prerequisite for a sustainable supply of water, a timely decision by EUMENA governments to initiate that path is of vital importance for the total region.

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