SOLAR ENERGY PERSPECTIVES IN EGYPT

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Egypt belongs to the global sun-belt. The country is in advantageous position with solar energy. In 1991 solar atlas for Egypt was issued indicating that the country enjoys 2900-3200 hours of sunshine annually with annual direct normal energy density 1970-3200 kWh/m^2 and technical solar-thermal electricity generating potential of 73.6 Petawatt hour (PWh). Egypt was among the first countries to utilize solar energy. In 1910, a practical industrial scale solar system engine was built at Maadi south to Cairo using solar thermal parabolic collectors. The engine was used to produce steam which drove a series of large water pumps for irrigation. Nowadays utilization of solar energy includes use of photovoltaic cells, solar water heating and solar thermal power. Use of solar thermal technology may include both electricity generation and water desalination, which is advantageous for Egypt taking in consideration its shortage in water supply. The article discusses perspectives of solar energy in Egypt and developmental trends till 2050.

EGYPT NEEDS FOR ENERGY

Energy is a major drive of modern economic development. With the increase of world population, more energy is required to satisfy rising human needs to maintain welfare. Improving of living standards and prolongation of human life itself depends, in the average, on the energy consumption per person. Moreover global demand for energy grows as more developing counties enter industrial and service stages of their development. In Egypt, as everywhere, energy plays a substantial role in country's economic development contributing to macroeconomic variables as gross domestic product (GDP), commodity exports and investments. On the other hand, Egypt as a developing fast growing country suffers from rapid annual population growth currently at a rate of 1.68%. As of July 2008, the population of Egypt was estimated as 78.9 millions. According to the Cairo Demographic Centre, Egypt's population is expected to reach 110 millions by 2031 and 128 millions by 2051. Such a fast population growth along with other environmental challenges is overstraining the limited energy resources of the country [1,2]. Fig.1 shows Egypt's projected population growth till 2036.

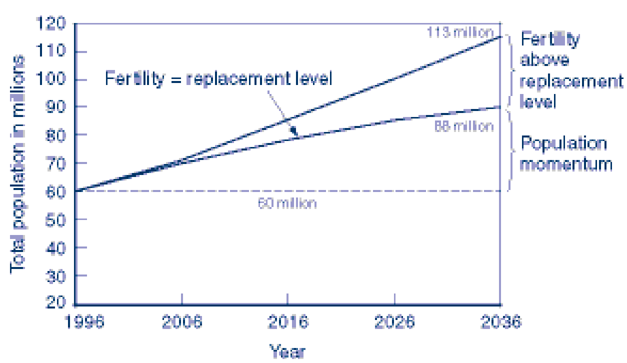

Fig 1. Egypt's projected population growth till 2036

On the other hand improvement of human factor indicators including health care and general welfare necessitates corresponding increase in per capita electric power consumption, as indicated in table 1. A carefully tailored energy policy is to be implemented to attain sustainable development.

Table 1. Egypt's population and electric power indicators (2007-2052)

Year	**2007**	**2012**	**2017**	**2022**	**2027**
Population (million)	78.3	85.2	92.1	98.8	105.1
Per capita installed power (MW/c)	0.28	0.34	0.41	0.48	0.55
Total (GW)	21.9	29.0	37.8	47.1	57.7
Installed power annual growth rate (%)	4.4	5.8	5.4	4.5	4.0
Year	2032	2037	2042	2047	2052
Population (million)	111.1	116.5	121.2	125.3	128.5
Per capita installed power (MW/c)	0.63	0.72	0.82	0.92	1.02
Total (GW)	70.0	84.0	100	115	132
Installed power annual growth rate (%)	4.0	3.7	3.5	2.8	2.7

EGYPT ENERGY PROFILE

Primary sources of energy in Egypt include:

- Crude oil and natural gas
- Hydropower
- New and renewable energy: mostly wind and solar
- Other minor sources in rural areas as agricultural and animal residues
- The state had adopted plans to establish electronuclear stations that produce electricity through nuclear means [3,4].

Status of Egypt's oil and gas balance during the period 1997-2007 is summarized in table 2.

Table 2. Egypt's oil/gas balance

	1997	**1999**	**2001**	**2003**	**2005**	**2007**
Oil						
Production (10^3 barrels/d)	856	852	720	712	658	637
Consumption (10^3 barrels/d)	531	563	544	561	604	680
Proved reserves (Billion barrels)	3.70	3.50	2.95	3.70	3.70	3.70
Natural Gas						
Production (B cubic feet)	477	518	867	1058	1501	7.5/d
Consumption (B cubic feet)	477	518	867	1046	1208	6.1/d
Proved reserves (T cubic feet)	20.36	31.50	35.18	58.5	58.5	66.0

EGYPT ELECTRICITY GENERATION PROFILE

Egypt development plans include projects of land reclamation, food production, industrialization and community development. Demand on electricity as suitable form of transferable energy has dramatically increased during the past decades and required ever increase generation. Total generated electricity in terawatt hour (TWh) increased from 41.4 in 1990 to 125.1 in 2008 at an average annual growth rate 6.34% over the period. Installed power in GW increased from 10.3 in 1990 to 22.6 in 2008 at an average annual rate of 4.61%, while peak load in GW has increased from 7.21 in 1990 to 19.7 in 2008 [5].

Promising renewable energy (RE) resources in Egypt include wind, solar and biomass with interest in applications going back to 1970. In early 1980s, a renewable energy strategy was formulated as an integral part of the national energy planning. The strategy has been revised in view of the projections for possible RE technologies/application options, available financing resources and investment opportunities. In 1986 New and Renewable Energy Authority (NREA) was established to act as the national focal point for expanding efforts to develop and introduce RE technologies to Egypt. In April 2007, the Supreme Council for Energy adopted an ambitious plan which aims at covering 20% of the country's total electricity needs using RE by 2027. The plan opens the door for the private sector to play an active role in developing new and RE resources. The Egyptian electricity sector recently is drafting a new electricity act to encourage renewable energy utilization and private sector involvement in the process. Electricity generation mix (%) in 2008 was 86.07 for gas and oil, 12.58 for hydropower and 1.35 for wind power. The 2009 statistics of the Ministry of Electricity and Energy (MoEE) targets to satisfy 11.26% of the electric energy generation from RE sources (basically wind) by the year 2027 [6].

Table 3. MoEE Generation Plans 2007-2027 (76.660 GWe)

	2007	**2007-12**	**2012-17**	**2017-22**	**2022-27**	**Total**	**Total (%)**
Thermal	18.936	6.550	11.900	10.450	13.000	60.836	79.358
Hydro	2.783	0.064	0.032	-	-	2.879	3.755
Wind	0.225	1.600	2.980	2.500	0.500	7.805	10.181
Solar-thermal	-	0.140	-	-	-	0.140	0.183
Nuclear	-	-	1.000	2.000	2.000	5.000	6.552
Total	21.944	8.354	15.912	14.950	15.500	76.660	100

SOLAR ENERGY

Egypt is in advantageous position with solar energy. It belongs to the global sun-belt, Fig. 2. In 1991 solar atlas for Egypt was issued indicating that the country enjoys 2900-3200 hours of sunshine annually with annual direct normal energy density 1970-3200 kWh/m2 and technical solar-thermal electricity generating potential of 73.6 Petawatt.hour (PWh) [7]. Egypt was among the first countries to utilize solar energy. In 1910, American engineer F. Shuman built a practical industrial scale solar system engine at Maadi south to Cairo using solar thermal parabolic collectors, Fig. 3. The engine was used to produce steam which drove a series of large water pumps for irrigation [8].

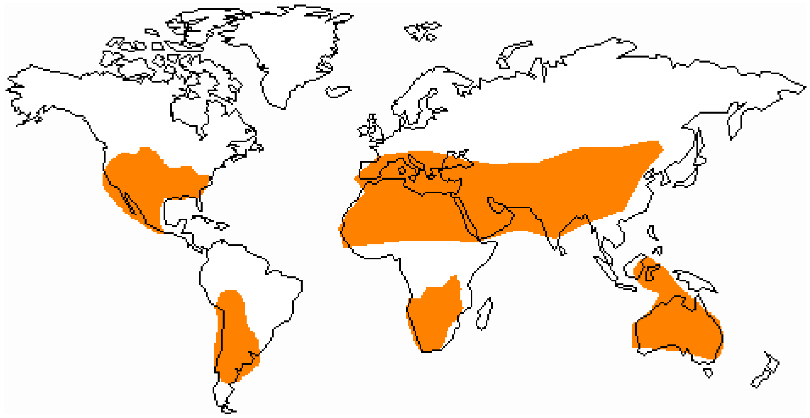

Fig. 2. Egypt as part of the solar belt.

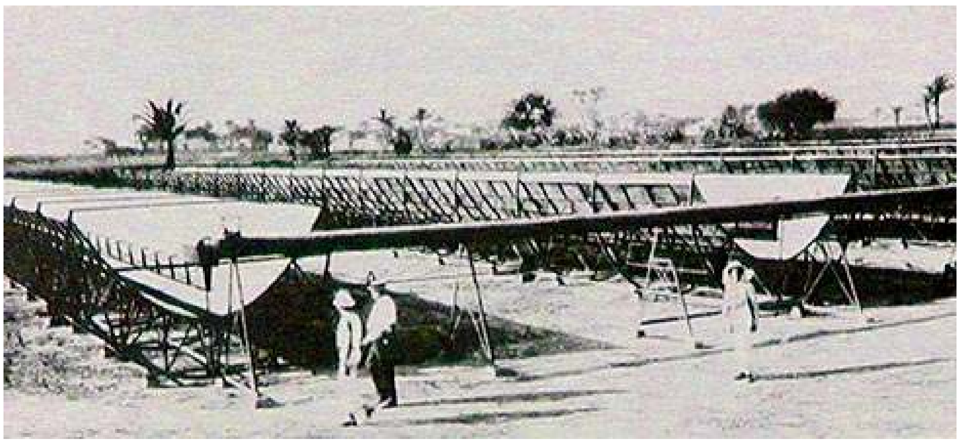

Fig. 3 Frank Shuman parabolic solar collectors, Maadi 1912.

Distribution of solar direct normal irradiance over Egypt is shown in Fig. 4. As is clear from Fig. 5 preferable locations for solar energy farms are along the North Coast, while those for wind energy farms are along the Red Sea Coast and in the West of Oweinat area.

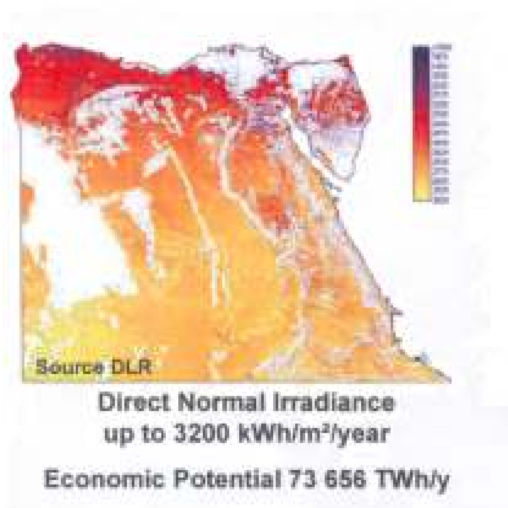

Fig. 4. Distribution of solar direct normal irradiance over Egypt

Fig. 5. Preferred locations for renewable energy components over Egypt

Solar Energy Utilization

Nowadays utilization of solar energy includes use of photovoltaic cells, solar water heating and solar thermal power. In Egypt PV systems are considered one of the most appropriate applications for remote areas away from national grid. According to NREA photovoltaic technologies are in use for lighting, commercial advertisements, wireless communications and cell phone networks, in water pumping for irrigation in newly reclaimed lands, in rural electrification, refrigeration, etc. It is estimated that present Egypt's PV systems installed capacity is close to 5 MW peak, the distribution by sector of which is shown in Fig. 6.

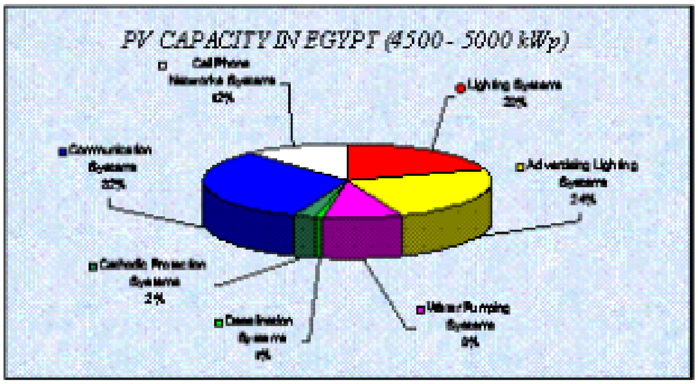

Fig. 6. PV installed capacity, Egypt

Solar water heating is currently used in residential commercial and tourist hotel buildings, especially those located in touristy resorts in Sinai, along the Red Sea coast and Egypt's North Coast (South Mediterranean coast). Estimates on the current installed capacity for solar water heating is around 300 MW, while the potential capacity could easily exceed 1 GW. Use of solar thermal technology includes both electricity generation and water desalination. As an estimate with solar power parameters for Egypt, a 1 km^2 of desert equipped with modern trough or Fresnel flat mirror technology can produce 300 GWh/year of solar electricity and 13 million m^3 of purified water. Water desalination is especially important taking in consideration Egypt's dependence on River Nile and existing shortage of water supplies [9].

Concentrating Solar Technologies (CST) provide all solar thermal electricity today, and about half of the world's total solar electricity. They hold the greatest promises for the future, for producing electricity as well as hydrogen or other fuels. CST use mirrors to concentrate sunlight to raise steam and generate electricity. Excess heat from additional collectors can be stored in tanks of molten salt and then be used to power the steam turbines during the night, or when there is a peak in demand. In order to ensure uninterrupted service during overcast periods or bad weather, the turbines can also be powered by oil, natural gas or biomass fuels. An interesting by-product that can be a great benefit to the local population is that waste heat from the power-generation process can be used to desalinate seawater and to generate thermal cooling [10-12]. Table 3 summarizes status of Concentrated Solar Power (CSP) projects as of June 2004. The technology –although simple and viable- is not in wide use, severely limiting its economic competitiveness. However, it is believed that technology improvement will reduce cost to an acceptable level, as will be outlined later and is evident from Fig. 11 and table 5.

Table 4. Status of CSP projects worldwide, June 2004

Country	Location/Name	Type	Total Plant Power, MWe	Solar Part, MWe
Algeria		Hybrid	150	43
Egypt	Kuraymat	Hybrid	127	31
India	Rajastan	Hybrid	140	35
Iran	Desert of Yazd	Hybrid	398	67
Mexico		Hybrid	312	40
Morocco		Hybrid	228	30 (est.)
Australia		Solar	200	200
Israel		Solar	100	100
South Africa		Solar	100	100
Spain	Seville/PS10 Andalosia/ Solar TRES Andalosia/Andasol EuroSEGS	Solar Solar Solar Solar	10 13 2x50 10	10 13 2x50 10
USA	California/Kramer Junction	Solar	354	354
USA	Nevada	Solar	50	50

Egypt's MoEE has adopted an ambitious program for electricity generation using high temperature solar thermal technology particularly using parabolic trough concentrating collectors. In this respect, an Integrated Solar Combined Cycle (ISCC) power plant is in the stage of final tests at Kuraymat, about 95 km south of Cairo, on the eastern side of the river Nile. The main innovation of an ISCC plant is the integration of steam generated by solar energy into a combined cycle power plant, which will require a larger steam turbine to generate electrical energy from the additional solar-generated steam [13,14].

Fig. 7. Kuraymat Solar-thermal plant 30 MW solar + 120 MW thermal

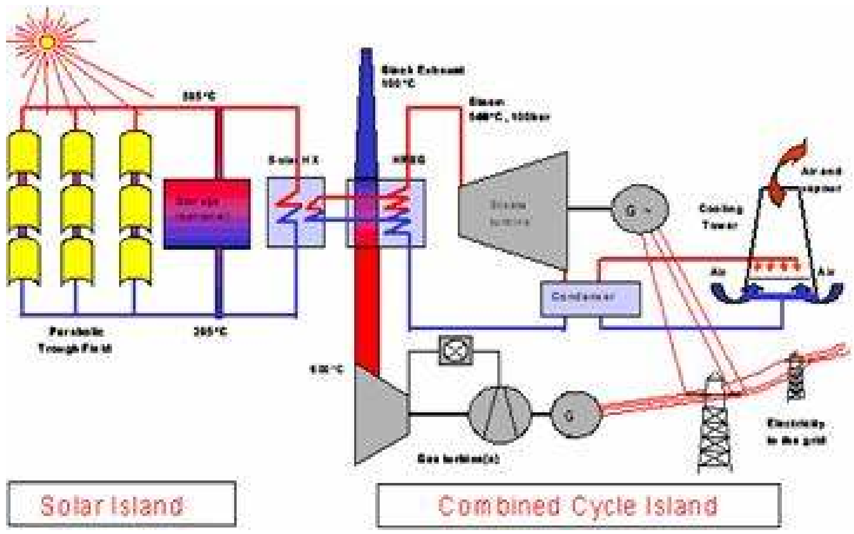

Fig. 8. Kuraymat Solar-thermal plant, schematic

The plant will have a capacity of about 150 MW, combining a conventional fossil fuel portion of about 120 MW and an input from solar sources of about 30 MW. When own consumption of 5.3 MW is deducted, the net overall plant capacity becomes 145.7 MW. The total net energy produced by the plant is expected to be 984 GWh per year, which includes the solar contribution of 64.5 GWh per year. This corresponds to a solar share of 6.6% percent of the total annual energy produced by the plant operating at a full load. The primary fuel for the conventional fossil fuel portion will be natural gas supplied at the site. The integration of solar and thermal fields ensures that the hybrid will provide the required electricity contribution to the system regardless of solar radiation conditions. For these reasons, the hybrid power plant is expected to operate sustainably as an integral part of the Egyptian electric power system [15].

REGIONAL INTEGRATION PLANS

Euro-MENA Plans

Solar Thermal Power Plants such as, for example Parabolic Trough Power Plants, have been in use commercially at Kramer Junction in California since 1985. Further solar power plants are actually planned or in construction e.g. in Nevada and Spain, with German, Spanish and US companies playing a major role. Solar Thermal Power Plants can generate electricity in the deserts of MENA (Middle East and North Africa) at all times of the day and night, throughout the year. In a study commissioned by the Federal Ministry of Environment, Nature Conservation and Nuclear Safety (Germany) and conducted by the German Aerospace Center (DLR), it was calculated that, if Solar Thermal Power Plants were to be constructed in large numbers in the coming years, the estimated cost (including transmission cost) will come down to about 5 EuroCent/kWh [16].

Power transmission over large distances is better achieved using the technology of High-Voltage Direct Current (HVDC). Using this technology, power, transmission losses can be limited to only about 3% per 1000 km. The better solar radiation in North Africa outweighs by far the transmission losses across the Mediterranean of 10-15% to

Europe. Although hydrogen has in the past been proposed as an energy vector, this form of transmission is very much less efficient than HVDC transmission lines [17].

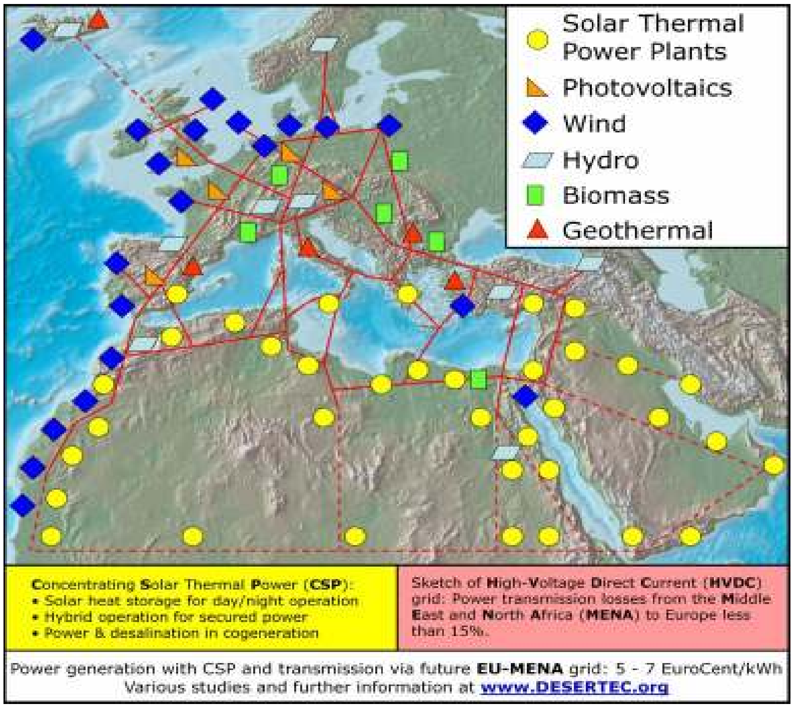

Fig. 9 Euro-MENA integration projects

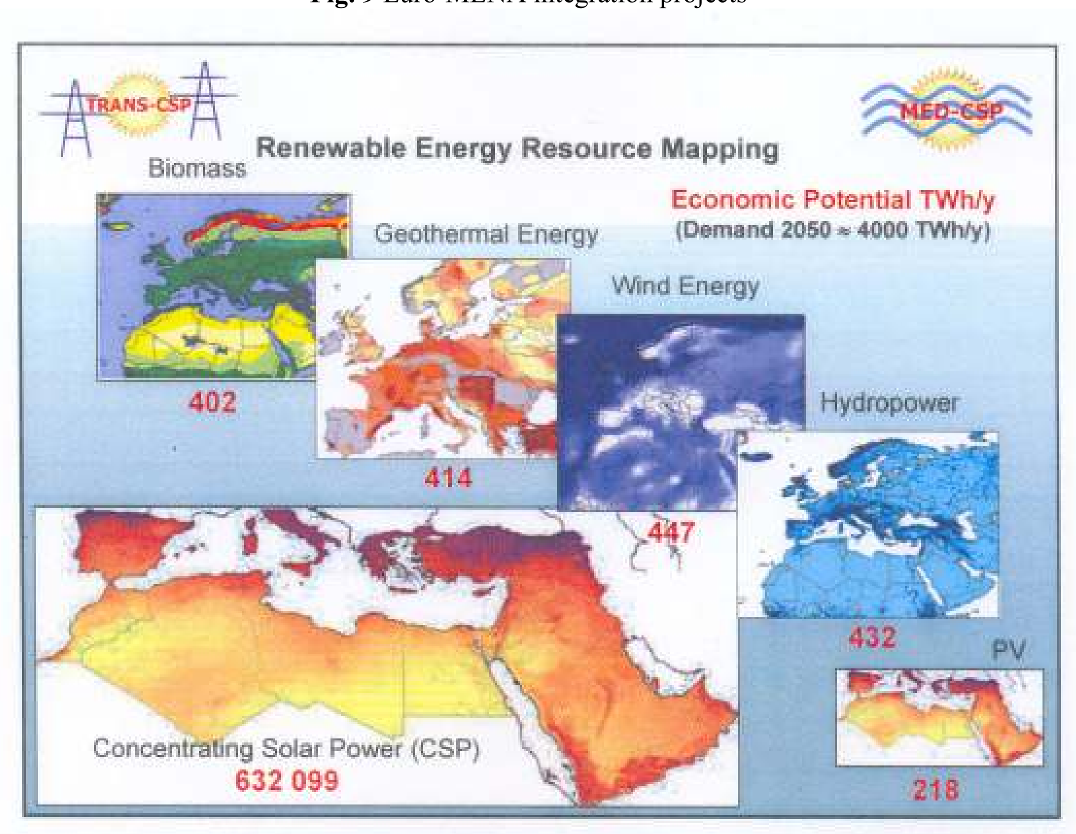

Fig. 10 Euro-MENA renewable energy resource mapping

In order to establish, by 2050, a transmission grid and a capacity of 100 GW of exportable solar power, over and above the domestic needs of Sunbelt countries, the required governmental financial support would be less than 10 billion Euros. Given that level of support for feed-in regulations, the construction of the solar power plants and the necessary transmission grid would very soon be attractive to investors, both private and public. The total investment that would be needed would be about 400 billion Euros over 30 years. An exact investment forecast for the TRANS-CSP scenario has been researched by the DLR [16,17].

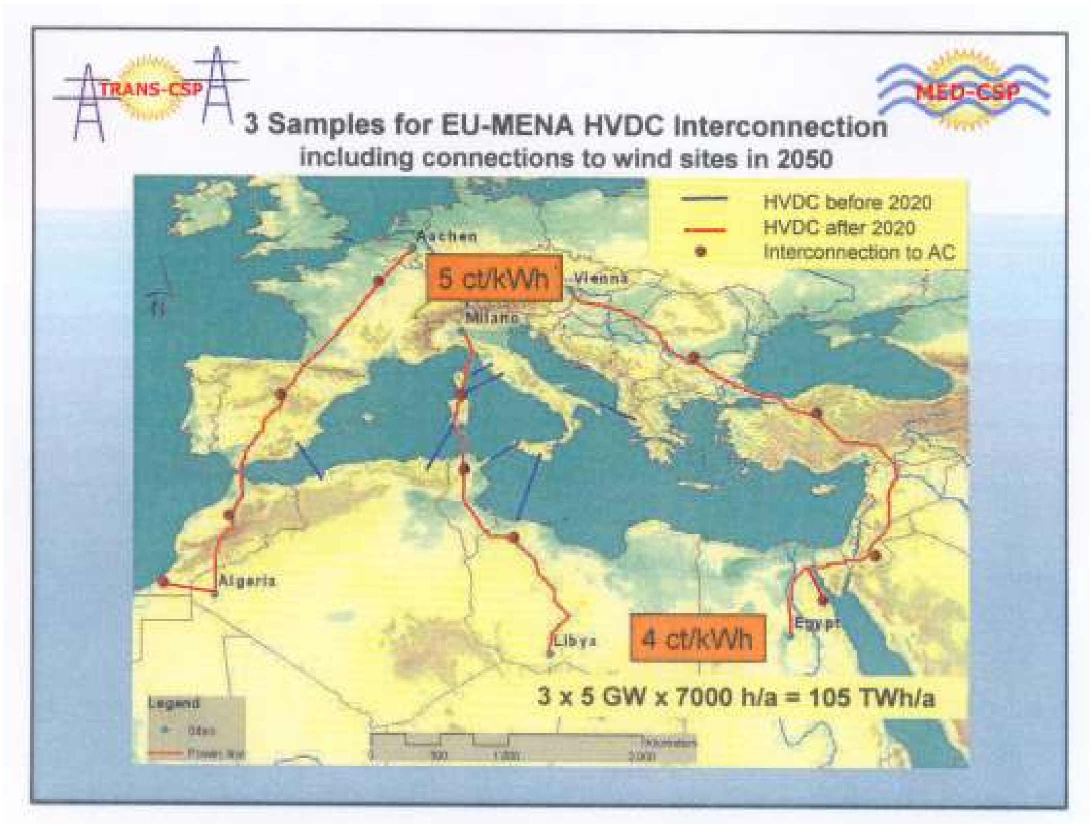

Fig. 11 Euro-MENA HVDC vs. AC interconnection schemes

Table 5. DESERTTEC full cost estimation

Year	2020	2030	2040	2050
Transfer Capacity, GW	2x5	8x5	14x5	20x5
Electricity Transfer, TWh/y	60	230	470	700
Capacity Factor	0.60	0.67	0.75	0.80
Turnover, Billion euro/y	3.8	12.5	24	35
Land Area CSP	15x15	30x30	40x40	50x50
km x km HVDC	3100x0.1	3600x0.4	3600x0.7	3600x1.0
Investment CSP	42	143	245	350
Billion euro HVDC	5	20	31	45
Elec. Cost CSP	0.050	0.045	0.040	0.040
Euro/kWh HVDC	0.014	0.010	0.010	0.010

The Mediterranean Ring Project

The goal of the ongoing Mediterranean Ring project is to provide inter-connection of electric power transmission grids among the countries and regions that encircle the Mediterranean Sea. This, in turn, will increase energy security in the entire region, and enable more efficient power flows at lower costs and with a need for fewer power plants to meet rapidly increasing demand for electricity in the southern and eastern Mediterranean regions. The concept involves linking electric power grids from Spain to Morocco through the remaining Maghreb (North African and Western Arab) countries, on to Egypt and the Mashreq, (Eastern Arab) countries, and from there up to Turkey. From Turkey the Ring would then link back into the European grid via Greece or through the newly interconnected Eastern European country grids [18,19].

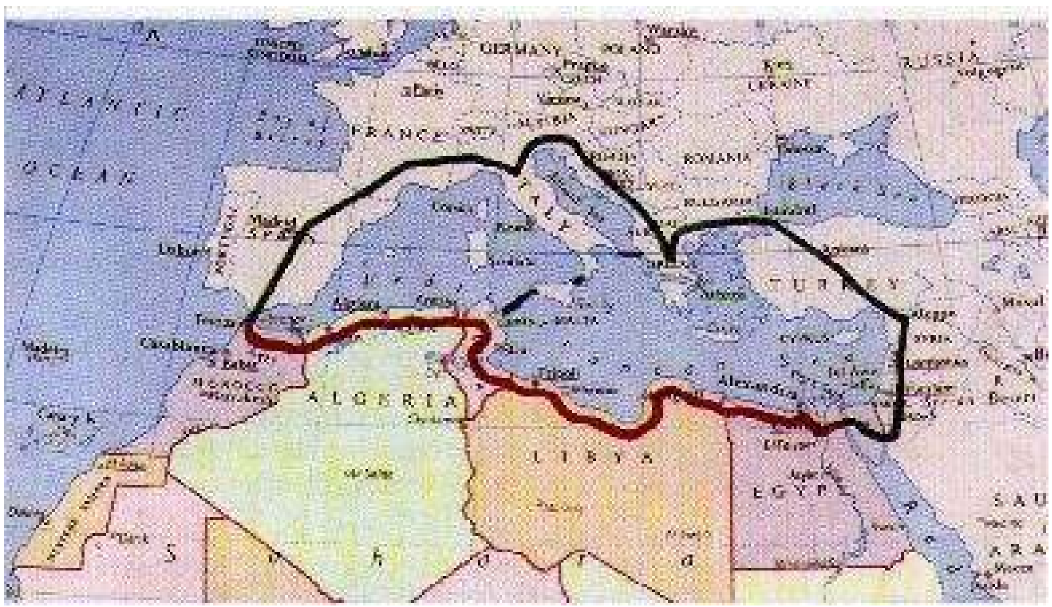

Fig. 12 The Mediterranean Ring Project

CONCLUSION

Analysis and forecast of Egypt's energy resources and needs till 2050 shows the inability to depend on national oil and gas reserves for electricity generation that meets estimated targets at that time. Efficient utilization of energy resources regarding consumption, production and exports/imports requires a major policy shift towards the use of non-fossil techniques for electricity generation. Resources of hydropower are expected to be utilized completely by 2022. According to the national strategy wind and solar power are to be used to cover ~20% of installed power by 2027. Hence a carefully balanced mix is to be adopted taking in consideration regional integration with more reliance on the introduction of concentrated solar technologies. Moreover, gradual introduction of nuclear power starting from 2018 and of coal fired plants from 2032 may be acceptable substitute of the depleting oil and gas resources. A renewable energy share of ~26% and a nuclear share of ~13% of installed power are targeted by 2052. This would reduce the fossil fuel component to 58% as compared to the current value of 86%. Such a mix is believed to be most appropriate to meet Egypt's energy demand till 2052.

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