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DESERT DEVELOPMENT CORRIDOR ENERGY SYSTEMS INTEGRATION

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ABSTRACT: The systems integration issues involved in utilizing renewable energy sources such as wind, solar, hydroelectric and nuclear power in the contemplated Egypt's Desert Development Corridor proposed by Farouk El Baz, are considered. The conceivable estimate of energy outcome is provided for the currently pursued renewable energy projects. In addition to that the most promising regions based on solar and wind atlases are presented. As a "shovel-ready" project, the proposal of utilizing the natural depression at Qattara in northern Egypt as a combined wind and hydroelectric-solar generation is discussed with pumped storage. Various methods of renewable energy storage systems are briefly considered as remedies to the major problem of intermittency of renewable energy sources. Considering the challenges in the difficulty of provision of water and energy in a desert environment, it is suggested that the northern corridors have a better chance to be implemented as a starting point in the project. The economic, financial, social, and political framework of integration into the Desertec Project with the European Nations providing technology and financing and the Middle Eastern and North African (MENA) nations providing the Manpower, Land Mass and energy sources are discussed.

INTRODUCTION: DESERT DEVELOPMENT CORRIDOR

The Desert Development Corridor is a project proposed by Farouk El Baz about 20 years ago, and is being reconsidered due to the development issues faced by Egypt. The project aims to build a 1,200 km superhighway parallel the Nile River in the Western Desert from west of Alexandria to the southern border of Egypt, with an interconnected railroad, water pipeline and electric power line, as shown in Fig. 1. Additionally, 12 cross-cutting corridors are to link this eight-lane highway to the major cities.

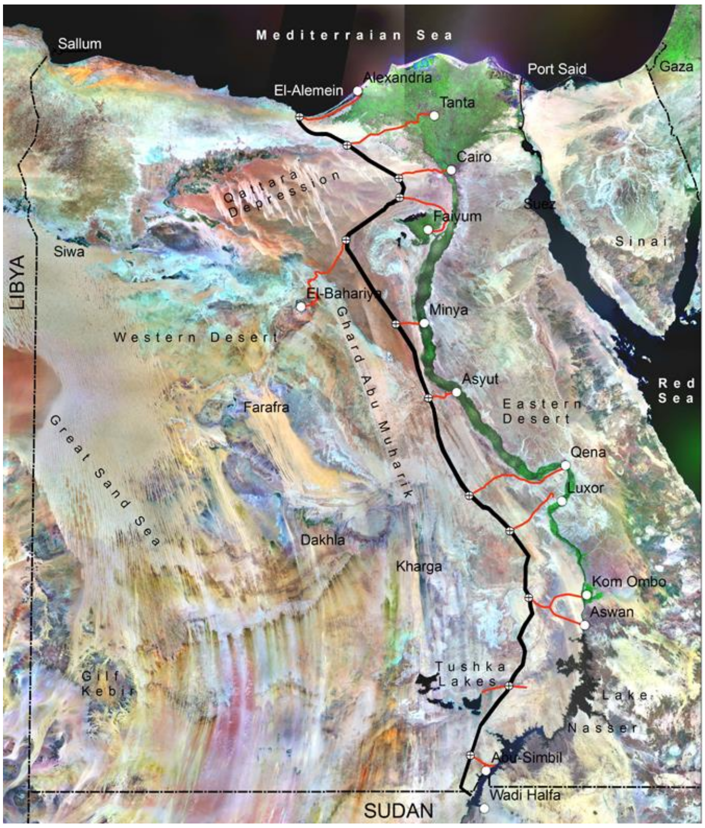

Figure 1. Identified energy development areas within the Desert Development Corridor Project Map. Source: faroukelbaz.com

According to his article entitled: “Desert Development Corridor: Into the Sahara,” that appeared in Al Ahram Weekly May 2006, Farouk El Baz suggests that, in addition to facilitating transport throughout Egypt, the benefits of the project include: suppressing urban encroachment on agricultural land in the Nile Valley, opening new land for desert reclamation and the production of food, establishing new areas for urban and industrial growth near large cities, and creating new jobs opportunities for Egyptian labor.

The particular strip of the Western Desert that runs parallel to the Nile River was specifically chosen for various reasons: proximity to high-density population centers, gentle northward slope from west of Aswan to the coast of the Mediterranean sea, which facilitates pavement, absence of east-west crossing valleys that are prone to flash floods, as in the case of the Eastern Desert, and proximity to fertile soils that are amenable to reclamation using groundwater resources.

Furthermore, the region is endowed with plentiful sunlight and persistent northerly wind. These conditions allow the use of renewable solar and wind energy in generating electricity.[1]

POTENTIAL RENEWABLE ENERGY RESOURCES IN EGYPT

In a world with escalated global concerns for energy supply and efficient energy systems, the emerging field of renewable energy systems continues to grow. Egypt is blessed with plentiful renewable energy resources that can effectively alleviate the concerns for energy supply. To name a few of the potential renewable energy sites in Egypt, the area west of the Gulf of Suez from south off Al Soukhna to Hurghada, especially the Gulf of Al Zait, has an outstanding wind resource regime. The wind speed averages 9.5 m/s for most of the area, as shown in the wind regime map in Fig. 2. Moreover, this region is considered to be one of the uninhabited desert regions that could perhaps host up to 20,000 MW of rated installed wind farm capacity. Other areas, such as Al Owaynat, Sinai and the north coast, present moderate potential with wind speeds in the range of 5–7 m/s.[2,3]

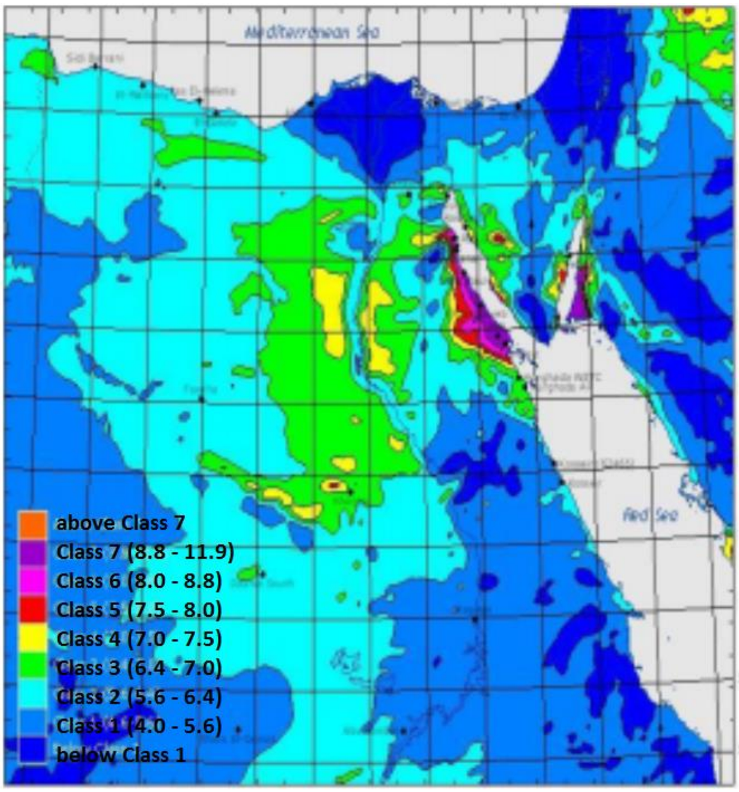

Figure 2. Wind Atlas of Egypt identifies substantial wind resources along the Gulf of Suez and the Gulf of Aqaba.[2]

The solar atlas of Egypt identifies it as one of the sun-belt countries. It is bestowed with high intensity direct solar radiation of 2,000–3,200 kW hr/ (m².year), as shown in Fig. 3. The sunshine daily duration throughout the year ranges from 9 to 11 hours with the exception of few cloudy days. Solar energy presents a promising potential for power generation, which amounts to an economic worth of about 74,000 TW.hr/year.[4,5]

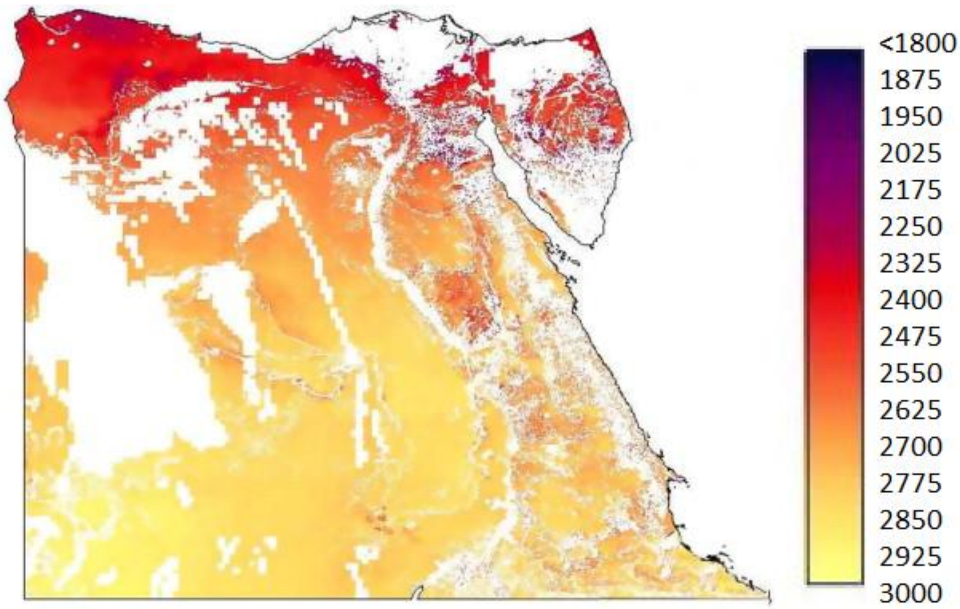

Figure 3. Solar Radiation Intensity Map of Egypt.[2]

Hydroelectric power is another renewable energy source that can hold a major contribution to generating electricity. In this paper, the idea of utilizing the natural depression at Qattara in northern Egypt in generating electric power is discussed. This idea aims to transfer water from the Mediterranean Sea in an open channel, piping or a tunnel, make use of the natural head, and allow for the continuous transfer of water by the high evaporation rate from the surface of the salt lake that would be formed within the depression.[6]

SOLAR ENERGY RESOURCES IN THE WESTERN DESERT

Egypt was one of the pioneers in utilizing solar energy. As far back as 1910, American solar pioneer Frank Shuman built a solar system engine at Al Meadi south of Cairo, using solar thermal parabolic collectors. The solar engine was used to produce steam to drive large water pumps for irrigation.[4] Currently, various methods of utilizing solar energy have emerged. These include the use of Photo Voltaic (PV) panels, solar thermal power, and solar water heating. In Egypt, according to the New and Renewable Energy Authority (NREA), there is a wide variety of applications for PV technologies, such as lighting, commercial advertisements, wireless communications and cell phone networks, and in water pumping for irrigation. The estimated capacity of PV systems installed in Egypt is close to 5 MW peak.[7]

Solar Water Heating (SWH) is currently used increasingly in residential and commercial buildings. Although the current installed capacity for solar water heating is around 300 MW, the potential capacity could easily surpass 1 GW. Solar thermal technology can be used in both electricity generation and water desalination. As an estimate of the solar power parameters for Egypt, one square kilometer of desert equipped with modern trough or Fresnel flat mirror technology can produce about 300 GW.hr per year of solar electricity and 13 million cubic meters of fresh water per year, which could contribute substantially to solving the problems of dependence on the Nile river and existing shortage of water supplies.[10]

Almost all the solar thermal electricity, and about half of the world’s total solar electricity is provided by Concentrating Solar Thermal (CST) Technologies nowadays. This promising technology uses mirrors to concentrate sunlight to produce steam and generate electricity. The idea is that additional collectors can be used to store a fraction of heat in tanks of molten salt, which then can be used to power the steam turbines during the night, or when there is a peak in demand. In order to overcome the intermittency problem during overcast periods or bad weather, the turbines can be supplemented by natural gas or biomass fuels. Another major advantage of utilizing this technology is that the waste heat from the power-generation process can be used in seawater desalination and to generate thermal cooling.[8,9]

INTEGRATED SOLAR COMBINED CYCLE (ISCC) TECHNOLOGY

The Kuraymat plant is a pioneering integrated solar combined cycle system (ISCC) in Egypt, located roughly 100 kilometers south of Cairo. This type of hybrid power plants uses both natural gas and solar energy in generating electricity with a rated capacity of 140 MW, from which 20 MW are of solar origin.[18]

The solar field for Egypt's first modern solar thermal large-scale facility, which consists of parabolic trough collectors with an overall surface area of 130,000 square meters,[18] was completed in December 2010. All 2,000 collectors in the solar field are automatically oriented towards the position of the sun. The Kuraymat site is endowed with more than 2,400 kW.hr/(m^2.year) of solar irradiation, which is channeled to parabolic-shaped mirrors, and then reflected onto an absorber pipe in the focal line of the collector. The absorber pipes contain a circulating heat transfer fluid, which is heated to 300-400 degrees Celsius as a result of the concentrated sunlight. The heat transfer fluid is then pumped into the central power block and the thermal energy coming from the solar field is converted into electrical energy.[10]

QATTARA DEPRESSION HYBRID WIND/SOLAR HYDROELECTRIC GENERATION SITE

The Qattara Depression, which is located in Northwest Egypt in the Libyan Desert, has a length of about 300 kms at sea level, a maximum width of 145 kms and a surface area of 19,500 km². The lowest point is found at a level of about 134 m below sea level.

The idea of utilizing the depression as a hydroelectric site would be accomplished by transferring water from the Mediterranean Sea, making use of the natural head, and allowing for the continuous transfer of water by the high evaporation rate from the surface of the salt lake that would be formed within the depression.[6]

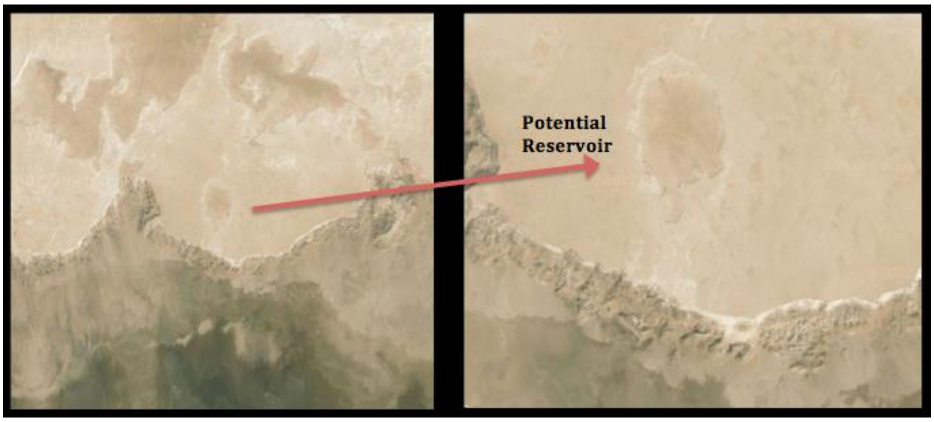

Figure 4. A potential pumped energy storage reservoir north of the Qattara Depression. Source: Google Earth

Several methods of transferring water have been discussed, included Nuclear Civil Engineering excavation. Nonetheless, the one that is believed to be the most desirable and economically viable is to integrate a wind and solar hydroelectric project. The idea is to use pipes to transfer water from the Mediterranean Sea to one of the potential upper reservoirs, then down to the depression. Integrating the wind farms plays an important role in pumping water into the reservoir. Based on the reservoirs elevation, energy would be stored in the form of potential energy and allowed to go down the depression to generate electricity on demand. This way, the wind intermittency issue would no longer be a problem, and electricity would be produced at a constant rate that corresponds to the elevation difference as illustrated in Fig. 5.[11]

In order to keep the constant head needed for power gain, the lake filling height should be maintained at 60 m below sea level, for which the evaporation rate is 19 km^3 per year. The replenishment flow rate would thus be:

$$19\frac{km^3}{year}\times 1,000^3\frac{m^3}{km^3}\times\frac{1}{365\times 24\times 60\times 60}\frac{year}{\sec}=602\frac{m^3}{\sec}\quad 600\frac{m^3}{\sec}$$

This entails that pipes have to be designed in a way that guarantees an equilibrium state between the solar evaporation of the formed lake and flow rate at the specified filling level.[11]

The power output of the hydroelectric plant can be estimated as:[11]

$$\begin{aligned} P_e &= \eta\rho\dot{v}gh \\ &= \eta\dot{m}gh \end{aligned} \tag{1}$$

where P_e is the power output in We, $\dot{v}$ is the volumetric flow rate of the water in m^3/s, $\dot{m}$ is the flow rate in kg/s, ρ is the density of salt water in kg/m^3 (1,030 kg/m^3), h is the hydraulic head in m, g is the gravity acceleration constant (9.81 m/s^2), and η is the overall conversion efficiency.

Pumped Storage Hydroelectricity (PSH) is recognized as an efficient energy storage alternative. The efficiency of the turbine is around 90 percent, and the turnaround value of the efficiency is between 70 and 80 percent. The main losses are due to frictional drag and turbulence. A turbine and a generator convert the kinetic energy of the water directly into electricity. Typical power outputs range from a few MWs to hundreds of MWs per turbine. Using Eq. 1 with the values corresponding to a volumetric flow rate of 600 cubic meters per second, a pumping height of 215m and a filling depth of 60m resulting in a hydrostatic head of 215+60= 275m, and an intermediate value of the overall efficiency of 75%, the output power would be:

$$\begin{aligned} P_e &= 0.75\times 600\frac{m^3}{\sec}\times 1,030\frac{kg}{m^3}\times 9.81\frac{m}{\sec^2}\times 275m \\ &= 1.25\times 10^9\,We \\ &\simeq 1,250\,MWe \end{aligned}$$

The Qattara Depression project with its potential hydroelectric energy output could add to the base-load requirements of an electricity-supply system that would be aimed mostly at the northern region of Egypt. Jointly with other Egyptian hydroelectric and thermal plants, such energy production could partly provide 1,250 MWe which amounts to 1250/4000=0.31, or about one third of the country’s electrical demand of about 4,000 MWe of installed capacity.[6]

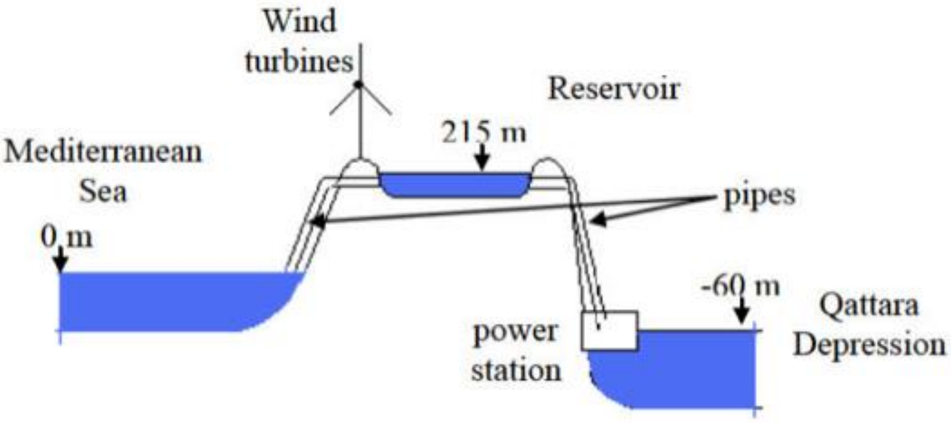

Figure 5. Proposed approach of using wind turbines and pipes at Qattara Depression.[11]

Table 1. Economic comparison between the use of pipes and a pumped wind power energy storage system against the use of tunneling alone approaches for the Qattara Depression project[11]

	Tunneling Approach	*Proposed Pipes + Wind Farms*
Capital cost (excluding power block and pipes between reservoir and depression)	$1.98 billion	$5.52 billion
Average power output	338 MWe	1,250 MWe
Capital cost per installed kWe of capacity	5,860 $/kWe	4,416 $/kWe

WIND POWER POTENTIAL IN EGYPT

In spite of the fact that wind energy is economical, has high potential with zero emissions, and needs no fuel, it is still not utilized on a wide scale. The main reason for this is the intermittency issue. Wind has an intermittency factor of only 20 to 30 percent at onshore locations and 40 percent offshore, which is about one-third to one half that of fossil fuels and nuclear power plants. Consequently, without suitable energy storage solutions, wind energy would not be able to serve as a base-load energy provider. Nonetheless, there are regions around the world where the wind is blowing with significantly high velocities at fairly constant rates.

According to the Wind Atlas for Egypt shown in Fig. 2, in the regions of Gulf of Suez and Ras Al Zaafarana the winds blow almost at a constant rate with considerably high speed around 9.5 m/s, with an intermittency factor around 70 percent. An area of 180 kms in length and 50 kms in width from the Gulf of El Zait to Ras Al Zaafarana can be exploited. It currently has an initial installed capacity of 305 MW of rated power. However, due to the intermittency problem, relying solely on wind energy to generate electricity is impractical. Hybrid systems integrating wind energy with other fuels such as natural gas can serve as temporary bridge to the eventual development of cost-effective energy storage systems.[12]

ENERGY STORAGE SYSTEMS AS A SOLUTION TO THE WIND AND SOLAR INTERMITTENCY PROBLEM

The main issue with the sustainable renewable energy technologies is intermittency. This problem arises from the fact that the sun does not shine all the time and the wind does not blow all the time, which results in a non-steady energy output. In order to surmount the intermittency of renewables, various methods of energy storage systems have been developed. These approaches include, but are not limited to, chemical, mechanical, and thermal storage systems.

An example of chemical energy storage systems is the use of hydrogen as a storage medium or energy carrier. Through the process of water electrolysis that uses electricity produced from both renewable and conventional sources, hydrogen can be produced and liquefied cryogenically. Upon energy demand, the combustion of hydrogen can produce emissions-free electricity and heat, or it can be converted into electricity using fuel cells to operate a future visionary transport infrastructure.[14]

Mechanical energy storage systems are also a practical solution to intermittency. For instance, Compressed Air Energy Storage (CAES), is considered as a hybrid storage/power production technique. Excess energy is used in powering a motor that runs compressors forcing air into underground reservoirs such as a rock cavern. In case of high-energy demand, the previous process is reversed. The compressed air is sent back to the surface, heated by fuel such as natural gas, and then taken through the turbines to power the generator producing electricity.

Another form of energy storage systems is the thermal storage method. This approach is particularly suitable for solar energy applications. Basically, water heating, or a substance with low melting point such as a molten salt is utilized, as the substance would give back its latent heat as it goes back to its initial state. This is a convenient application for space heating due to the low-grade heat used.[16]

CONCLUSIONS

Farouk El-Baz suggested that the entire Western Desert strip allocated for the longitudinal corridor is primarily flat and is outlined by a gentle slope from the west of Aswan downwards to Mersa Matrouh. Land reclamation and agriculture activities are viable options for two outlined corridors. The first corridor connects northern Cairo to the Fayoum Oasis. It has a surface area of 60 km^2 of desert that could be developed. The second region is the desert area of 40 km^2 between Fayoum and Beni Soueif, which should also be reclaimed as water could be extracted from the

Nile using pumps, or brought to the area through irrigation canals. In addition, the corridor going from Kom Ombo westwards possesses perfect soil where 30 km^2 could be easily cultivated.[12]

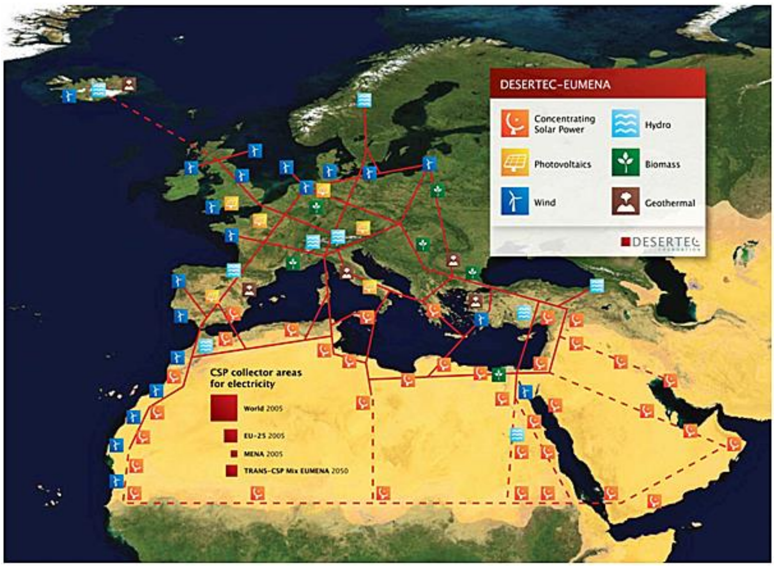

Figure 6. Desertec project as a potential area of energy production collaboration between the European Union and the MENA states. Source: desertec.org.

Egypt is endowed with an ample supply of solar, wind, and hydroelectric power that could help it in overcoming the problem of an ever-increasing energy consumption. The corridors of the northern part of Egypt, such as the one connecting Cairo to the Fayoum Oasis, are the most promising ones for earlier development.

The Qattara Depression project can supply about 1,250 MWe of hydroelectric power to the Egyptian electric grid. Integrated Solar Combined Cycle systems, and wind parks in the area west of the Gulf of Suez from south of Al Soukhna to Hurghada, especially the Gulf of Al Zait, could host up to 20,000 MW of installed wind farm capacity. These systems could start as hybrid systems along with natural gas to produce a steady power output until the energy storage systems reach the final applicable, and at the same time economically feasible state. Energy storage becomes necessary after 30 percent penetration of wind power into the grid supply system and at 6 percent of solar energy penetration.

Considering the electrical grid systems transmission lines, High-Voltage Direct Current (HVDC) power transmission must be considered as it offers various advantages over High Voltage Alternating Current (HVAC) transmission. Over long distances beyond about 200 kms, HVDC transmission entails lower capital costs and transfers power with less ohmic heating and corona discharge losses than an equivalent AC transmission line.

The integration of renewable energy technologies coupled with an efficient use of energy storage systems in the Desert Development Corridor project would be a sustainable approach to powering the project. These technologies can be initiated by existing local engineering and construction expertise. Renewable sources are labor intensive approaches to energy production, contributing to job creation, higher employment and the encouragement of local industries. It is worth noting that solar water heaters activities alone stimulated the inception of nine new manufacturing companies that are almost fully handled by Egyptian staff.[17] The predicted amount of stable energy output could not only enable Egypt to satisfy its own energy consumption needs, but also to export renewable energy electricity to Europe through grid networks interconnections with HVDC cables crossing the Mediterranean Sea. Financing can be sought through joint projects through the Desertec Project vision (Fig. 6) furthering economic collaboration between the European Union (EU) and the Middle East and North Africa (MENA) states.

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