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FORECASTING TRANSITION ELECTRICITY SOLAR ENERGY FROM MENA TO EUROPE

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ABSTRACT

Over the world, the climate change is a major global concern. CO_2 is the main cause of global warming, and at least 90% of CO_2 emission results from the combustion of fossil fuels (oil, coal, natural gas) for energy generation. Hence, clean energy included renewable sources (solar, wind, hydro, and geothermal) has been the focal point of most regulations of governments to aim at greenhouse gas reduction. The Mediterranean region encompassing Europe, North Africa and Middle East has enormous potential in solar energy. It has abundant solar radiation, cheap land and high electricity demand. So it could make this region the global hub for CSP generation. This paper explores the market potential of Concentrated Solar Power (CSP) in Europe, North Africa, and the Middle East. The paper covers recent CSP trends and discusses in detail the CSP market development, forecasts and outlook of CSP deployment for electricity generation in Europe, North Africa, and the Middle East.

Keyword: electricity, CSP, solar energy, renewable energy, green energy, (MENA).

INTRODUCTION

World energy demand is growing by over 50% up to the year 2030; Figure-1 shows the energy consumption per person to the year 2050. Today, climate change is a major global concern. The main cause of global warming is CO_2, and at least 90% as a result from the combustion of fossil fuels for energy generation, it is the cause of climate change which is the main global concern.

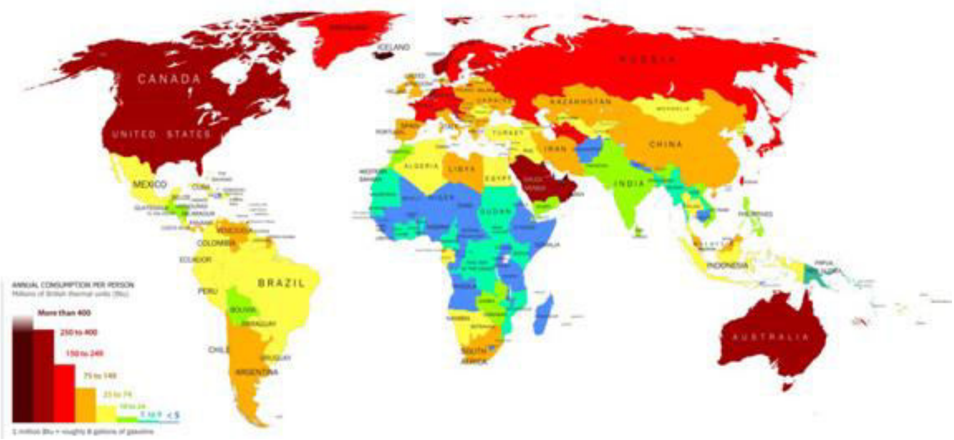

Figure-1. Energy consumption per person [1].

Europe intends to achieve electricity system without carbon in by 2050 so it will require the replacement of much of the existing generating capacity. Figure-2 shows CO_2 emissions from the traditional power energy and solar energy. The price volatility in traditional energy has forced nearly all countries to review their energy policy, this is prompting countries which depend on imported fossil fuels, to explore and evaluate alternative sources of energy to generate electricity.

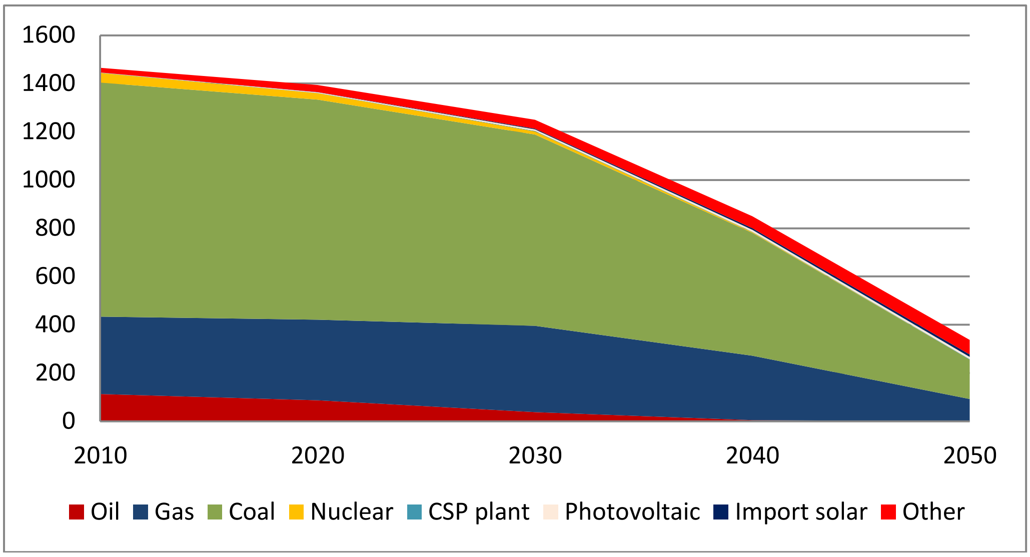

Figure-2. CO_2-emissions (1000 G g/year) from the various sources of energy.

According to the European Commission's Directorate-General for Energy and Transportation, through an interconnected electric grid, MENA could provide the EU with 700 TWh/year of electricity by 2050. Twenty power lines with a capacity of 2.5-5.0 GW could be developed by 2050, providing about 15% of the European electricity demand by solar imports.[2] Figure-3 shows the concentrating solar thermal power plants in the world.

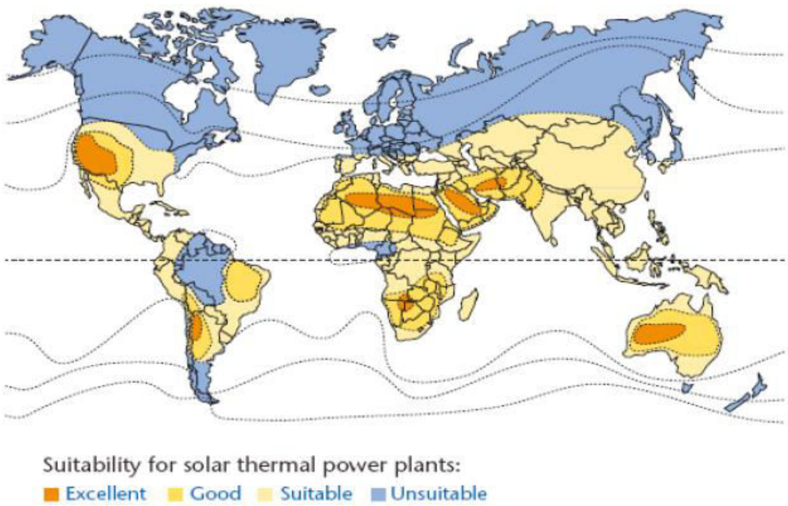

Figure-3. Suitability for solar thermal power plants.

Future energy supply

According to the interconnection different sources of solar power generation in MENA with different centers of demand in Europe, in 2050, about 20 major links could be installed, with a total transfer capacity of 100 GW, equivalent to 7 % of the total installed power capacity in Europe by that time. With an average use of 7000 full load operating hours per year, these lines would transfer 700 TWh/y of solar electricity to Europe, with a value of 35 billion €/y at an average cost of 5 cents/kWh.

In MENA, The cost of solar electricity production by CSP plants is composed of 4 cents/kWh and 1 cent/kWh for the transmission to Europe including electricity losses, capital cost and cost of operation system, and expected a discount rate of 5 %/y as for the other technologies. The total investment of CSP plants and transmission would be 395 billion € between 2020 and 2050, that is an average of 10 - 15 billion € per year over that time span.

Outlook for CSP in Europe and MENA

The amount of electricity produced from CSP plants depends on the level of direct normal irritation (DNI) [3]. Europe has different areas of solar irradiance

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due to seasonal variations unlike the MENA region. Where North African region offers a vast potential for production of electricity from CSP due to higher solar irradiance levels the opportunity for exporting CSP electricity to Europe. This would open up new opportunities for economic and technical co-operation between the two regions and to protect environmental considerations by reducing the CO_2 emissions.

In Europe, The economic potential of CSP is limited to Spain, Portugal, Greece, Turkey and the Mediterranean Islands and amounts to 1580 TWh/y of which 1280 TWh/y are located in southern Spain. Mediterranean Sea is more attractive sites for CSP, An annual direct solar irradiance of up to 2800 kWh/m²/y. Figure-4 Show the irradiance in the world.

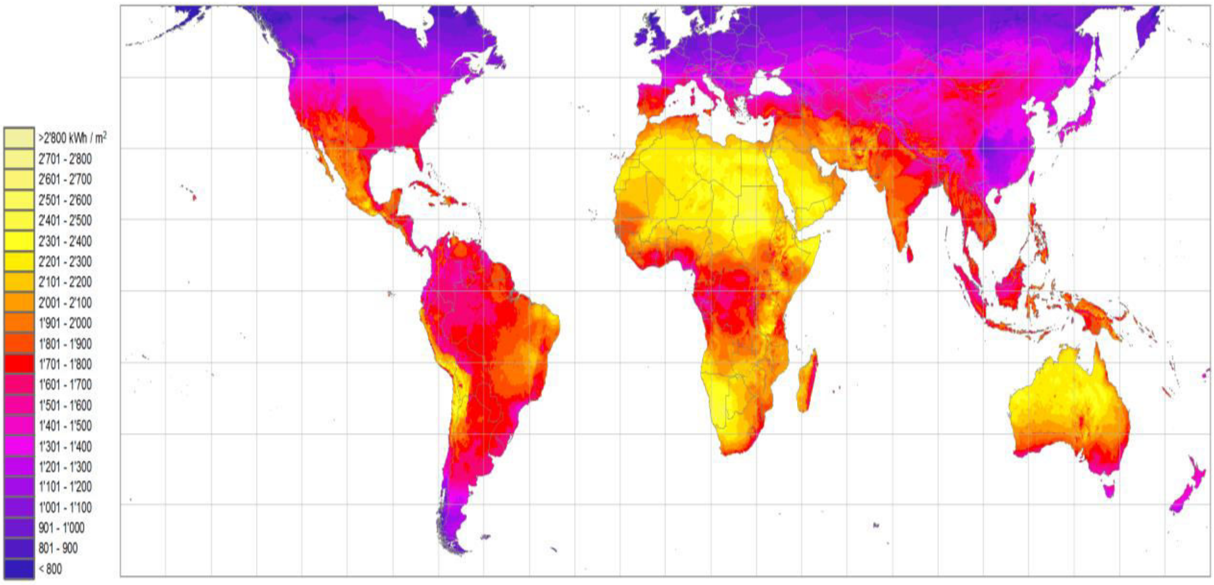

Figure-4. Yearly sum of global irradiation [4].

Electricity from CSP

In Europe, the total electricity demand of the 30 analysed countries starts with roughly 3530TWh/y in the year 2010 and reaches a maximum of 4300 TWh/y in 2040 [5]. Figure-5 represents the expected future electricity demand in Europe to 2050 that available to cover the demand with a surplus of 45%. However, it must be taken into account that about 30 % of the analysed countries show considerable deficits, while on the other hand considerable surpluses are concentrated in only 7 countries as shown in Figure-6. Roughly one quarter of the potential is represented by one single resource in one single country that is concentrating solar power in Spain.

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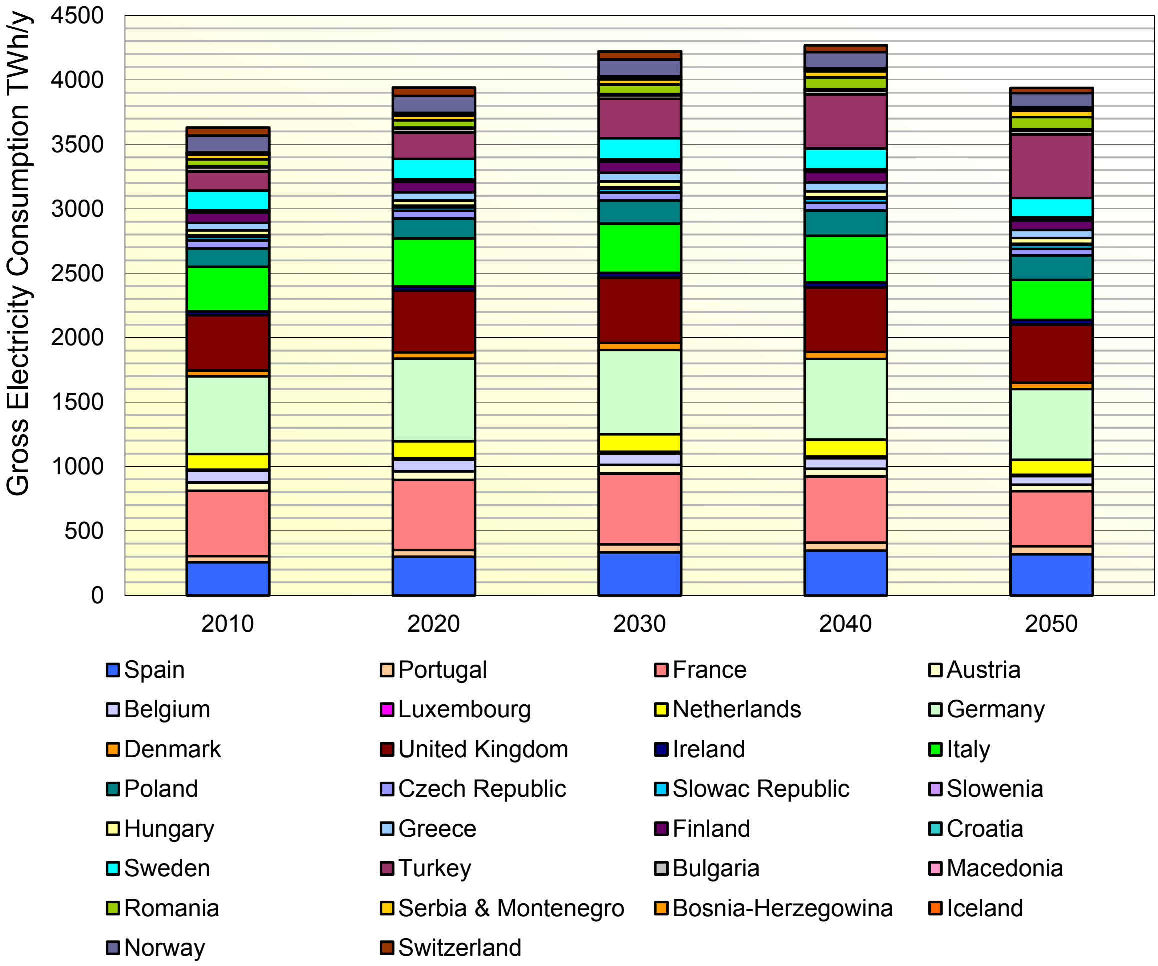

Figure-5. Electricity consumption of the European countries analysed between 2010 and 2050.

The expected electricity mix in Europe in 2050 is 65% European renewable energies, 17% solar electricity imports, and 18% fossil fuelled backup and peak load power plants [6]. CSP would generate about 1.6% and 5.5% of the projected EU gross electricity consumption. This is quite similar to the estimated values for the share of CSP in the electricity mix of 1.5% to 6.5% between 2020 and 2030 [7], as shown in Figure-7.

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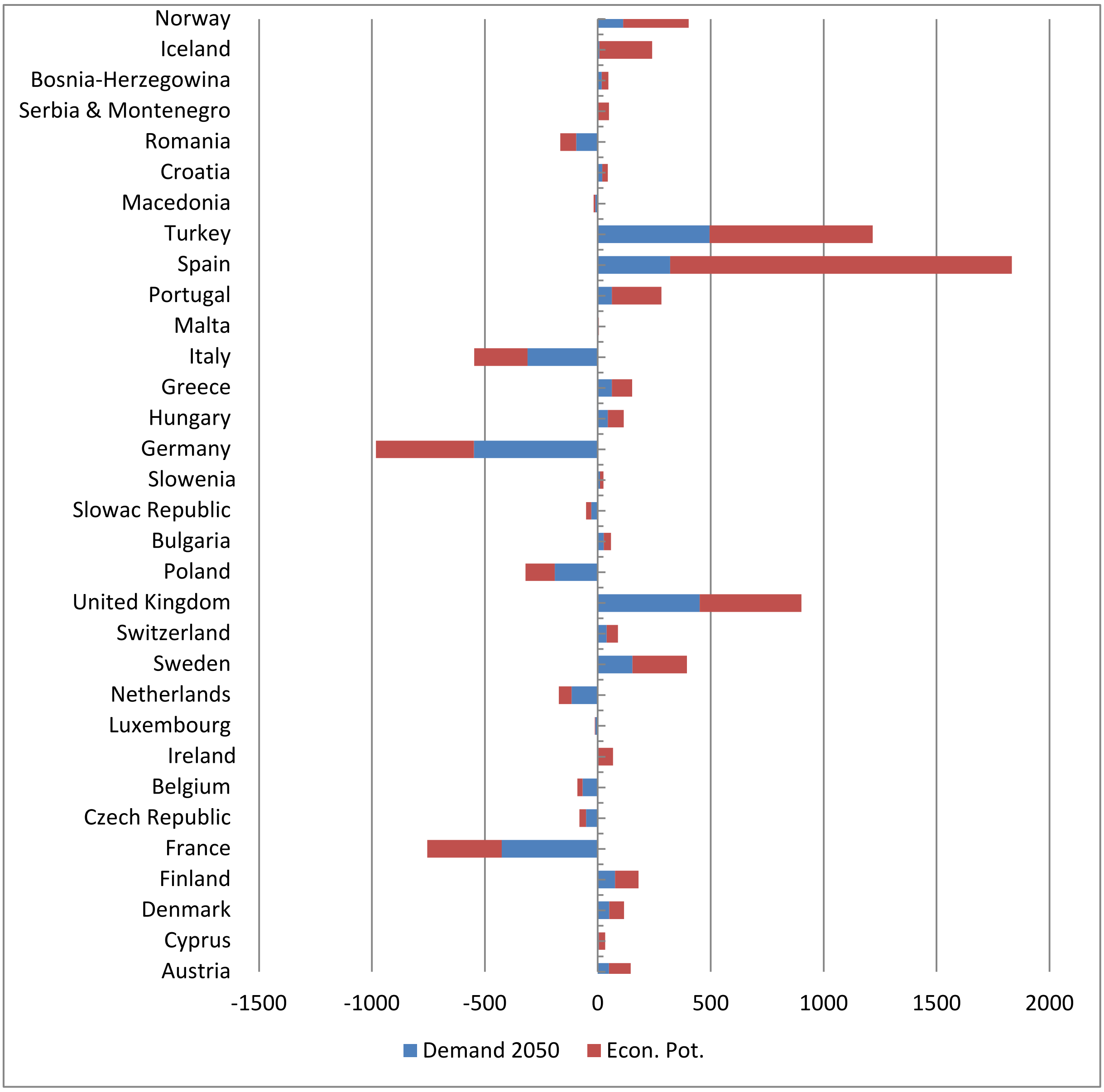

Figure-6. Electricity demand in 2050 compared to the total economic renewable electricity potential of the analyzed countries without solar electricity imports.

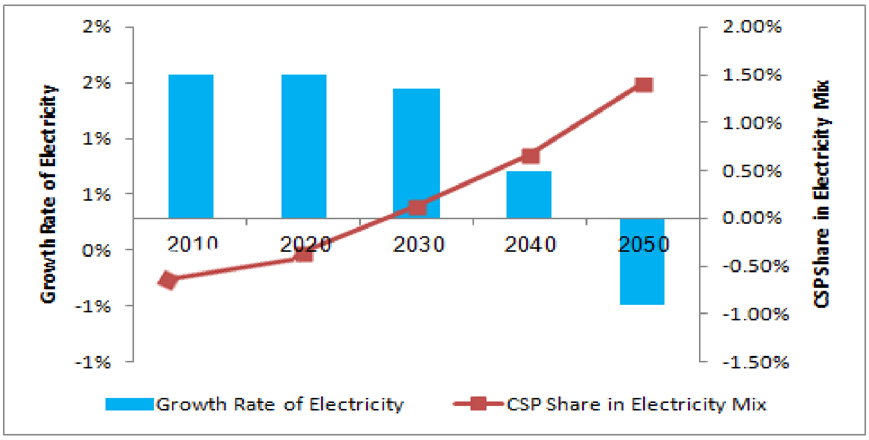

Figure-7. Growth rate of electricity demand and CSP share in Europe [8].

Future energy demand

In North Africa, an increasing Electricity demand and production as a result of increasing the population from 150 million in 2005 to 250 million in 2050. The total electricity consumption is expected to rise at a CAGR of 3.17% along with the rise in population. The total installed generating capacity is also expected to grow at a CAGR of 3.28% to meet the rising electricity demand and bridge the demand-supply gap [9], Figure-8 represents the electricity production by sources from 2000 to 2050.

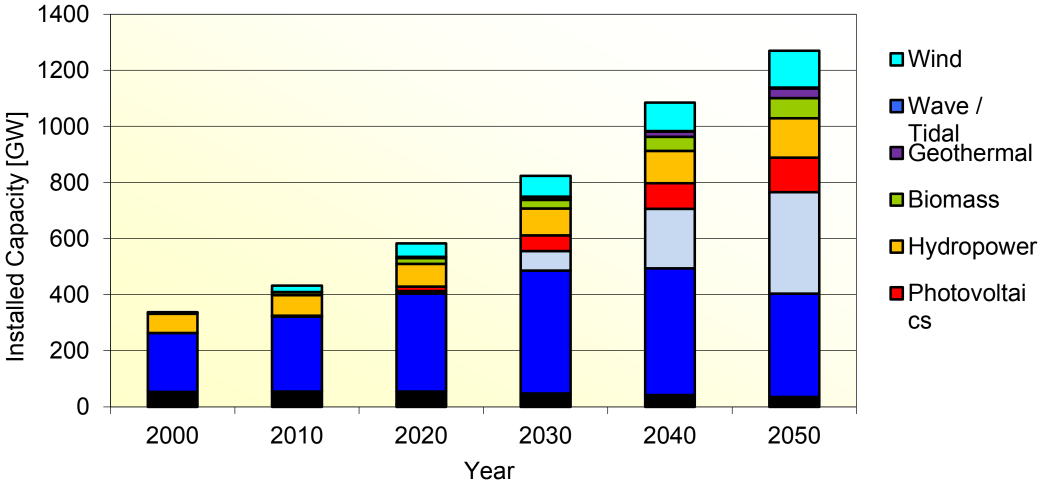

Figure-8. Installed capacity of all MENA countries by sources.

The electricity produced from CSP is expected to contribute more than 35% of the total electricity produced in North Africa by 2030. This rise would be primarily after 2020 as the total electricity generation from CSP would increase through efficiencies achieved on account of advancements in CSP technology and higher investments attracted due to its economic potential.[10], Figure-9 shows the resources Renewable energy in MENA region. Figure-10 shows at different locations in Europe and North Africa. The site El-Kharga in Egypt represents the best case of the monthly electricity yield of a solar thermal power plant with 24 hour storage capacity throughout the whole year.

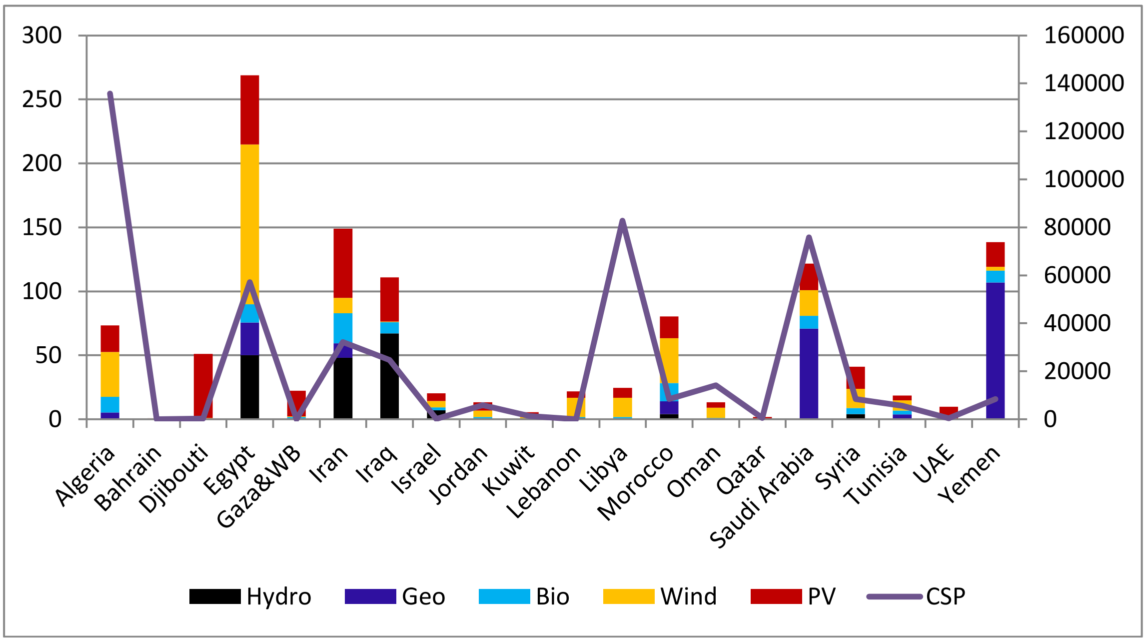

Figure-9. Renewable power generation potential by sources in TWh/y [11].

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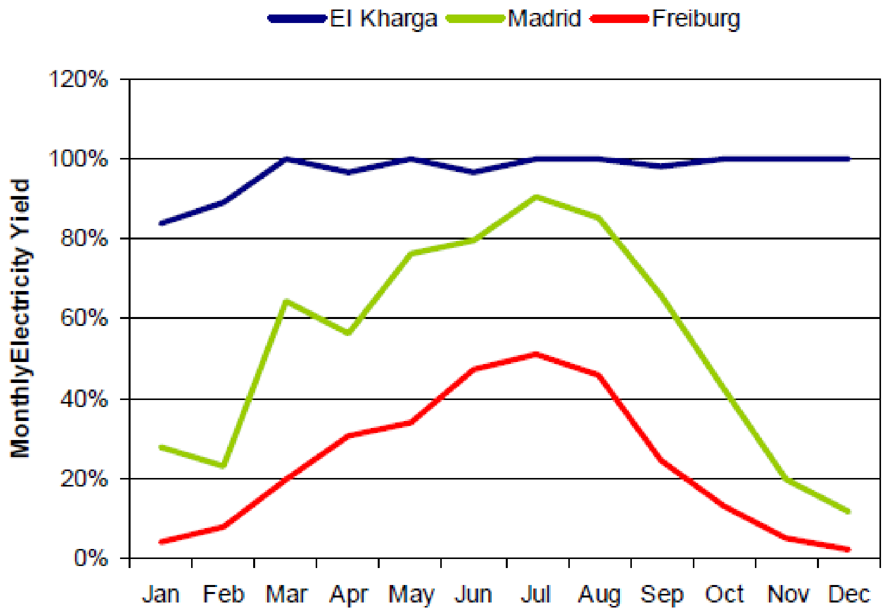

Figure-10. Simulation of the relative monthly electricity yield of CSP plant with 24 hour storage at different sites with different DNI equivalent annual full load hours: Freiburg (Germany) 2260 h/y, Madrid (Spain) 5150 h/y, El Kharga (Egypt) 8500 h/y /May 2005/.

Market potential for solar import electricity

Solar import electricity is one of the least cost options for electricity in Europe. Capital investment for solar-only reference systems of 50 MW are currently of the order of 3 300 to 4 500 €/kW. The upper limit accounts for systems with thermal storage to achieve capacity factor of between 5000 to 6000h, as shown in Figures (11, 12).

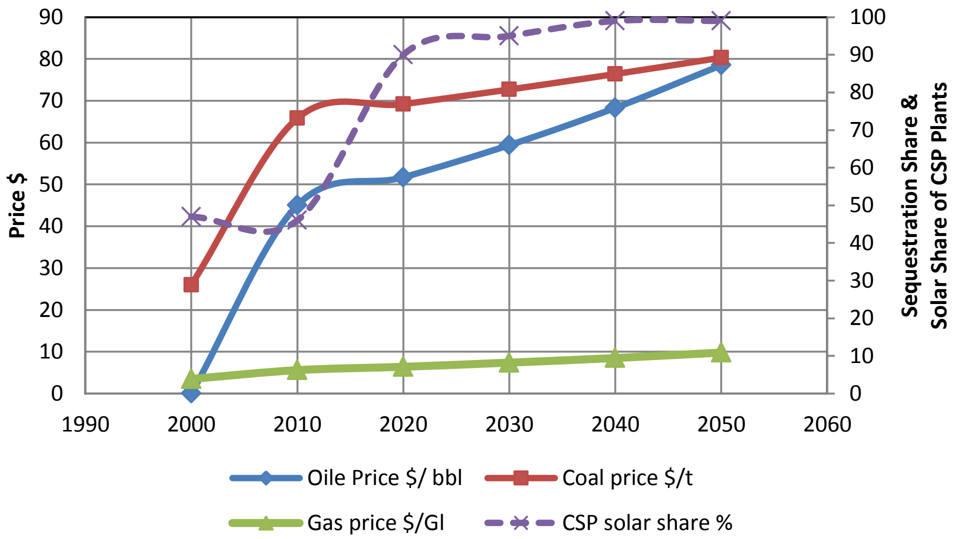

Figure-11. Energy price trends (2000-2050).

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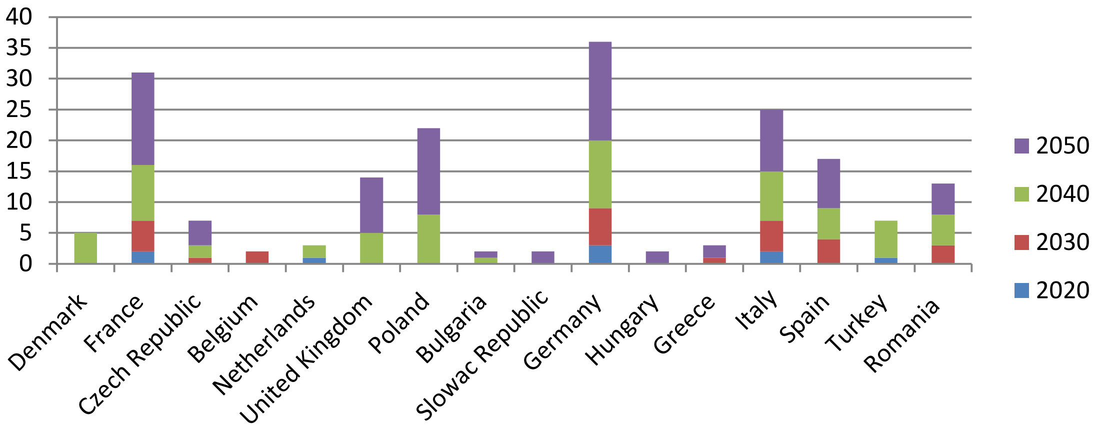

Figure-12. Total HVDC solar import capacity in GW.

Case Study: Exporting potential for electricity generated from CSP

The possibility of producing renewable energy in the Middle East and North Africa region (MENA) and exporting it to the European Union (EU) countries has become one of the most interested subjects among the scientists all over the world. This is due to the high renewable energy resources availability in MENA region as shown in Figure -13. In addition, for MENA countries, exporting green electricity could materialize into various benefits such as energy security, technology transfer, development of private sector, and job creation.

A satellite image from NASA (Figure-13) shows the light emissions as an indicator for the electricity demands. In addition, the figure demonstrates the potential of generating green electricity all over the world. It is shown that the European countries have high demands, and the MENA region has high potential for generating green electricity from CSP plants by 2050. Also, it is expected that the European countries are likely to import up to 20% of its electricity needs from MENA region at a significantly lower cost than if clean electricity would be provided in Europe.

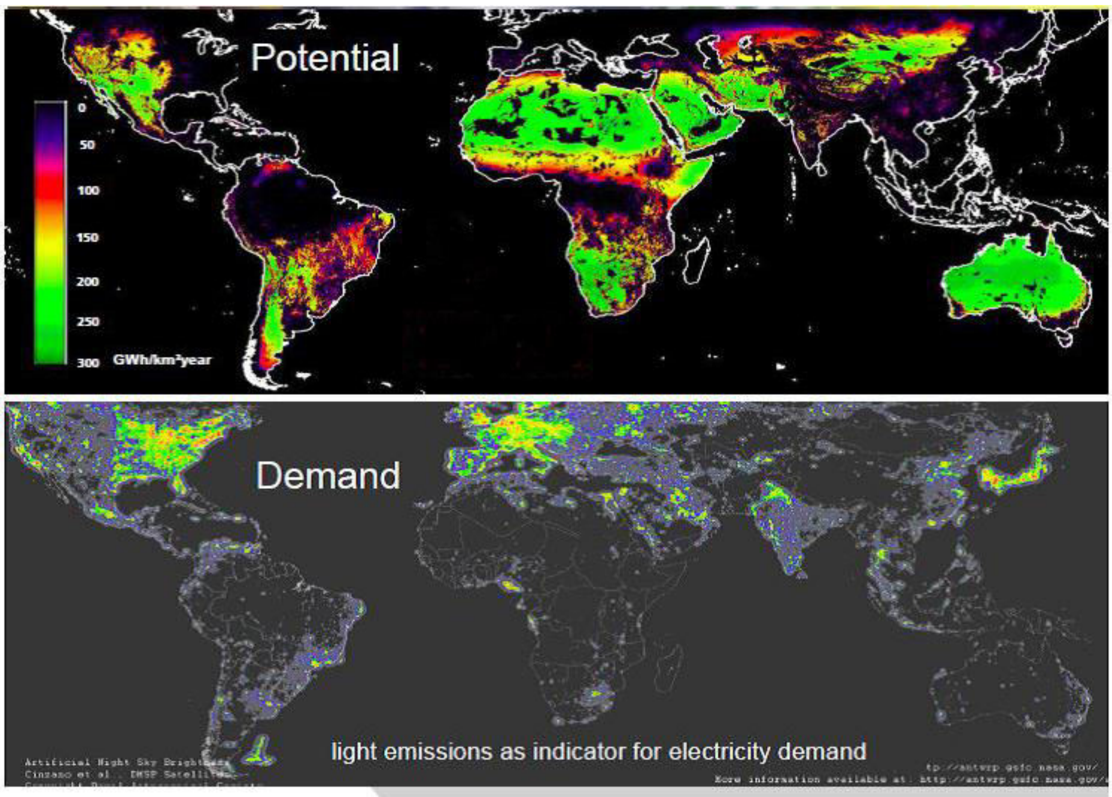

Figure-13. The electricity demands and electricity generation potential all over the world.

Using a geographic information system (GIS), a hypothetical case study of exporting electricity by 2050 from MENA region to Europe and Turkey based on the high potential CSP resources stated in MED-CSP study [12], and the required electricity needed to be imported from European countries stated in Trans_CSP study [13]. The application of such a huge infrastructure including CSP plants and transporting cables could begin in 2020 and would take about 30 years for its finalization.

In this case study, three countries are chosen from MENA region to represent the green electricity exporting points. These countries are Saudi Arabia, Egypt, and Algeria. They are chosen based on their high potentials in generating green electricity from CSP plants. On the other hand, nine countries are chosen to represent the destination nodes. The importing countries are selected based on their distance from the exporting countries. In addition, they are selected according to their expected green electricity importing quantities by 2050, [14], as shown in Figure-14.

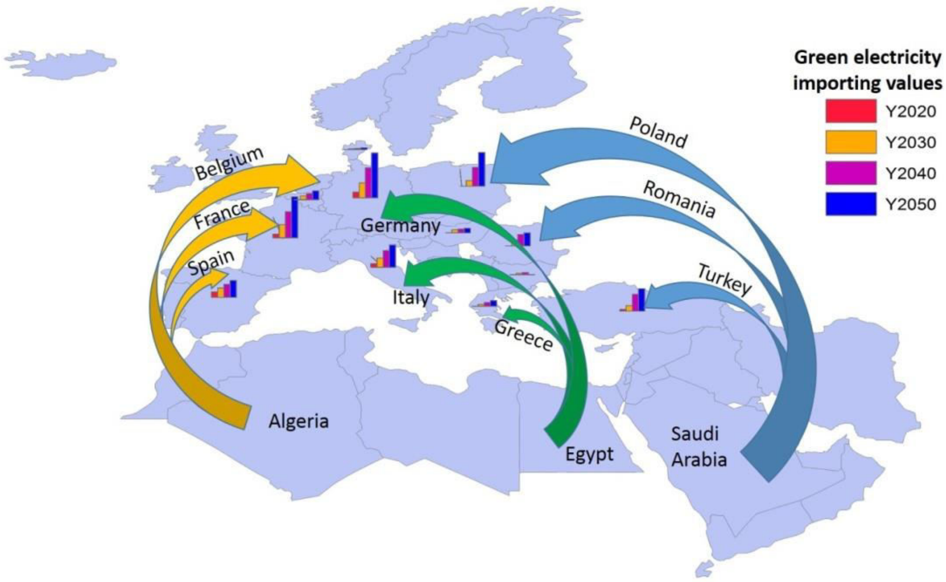

Figure-14. The expected electricity transition from MENA to European.

Each exporting country will export green electricity, generated from CSP plants, to three European countries as demonstrated in Figure-14 and Table-1. Table-1 shows the suggested quantities of exported green electricity in TWh/yr, and the corresponding area required building the CSP plants in each country by 2050. The area required for solar electricity plants were calculated from the reference DNI with a conversion factor of 0.045, which takes into consideration an average annual efficiency of 1.5% and a land use factor of 3.0% for CSP technology, [14], as shown in equation (1). This is state of the art for parabolic troughs and thus a very conservative assumption.

Table-1. Green electricity exporting and importing countries.

Exporting country	**Importing country**	**CSP Exported** (TWh/yr)	**Total CSP** (TWh/yr)	**DNI Ref** (KWh/m^2/yr)	**Area Req.** (Km^2)
ALGERIA	SPAIN	45	179	2700	1473
	FRANCE	110			
	BELGIUM	24			
EGYPT	GREECE	15	195	2800	1548
	ITALY	60			
	GERMANY	120			
SAUDI ARABIA	TURKEY	60	185	2500	1644
	ROMANIA	35			
	POLAND	90			

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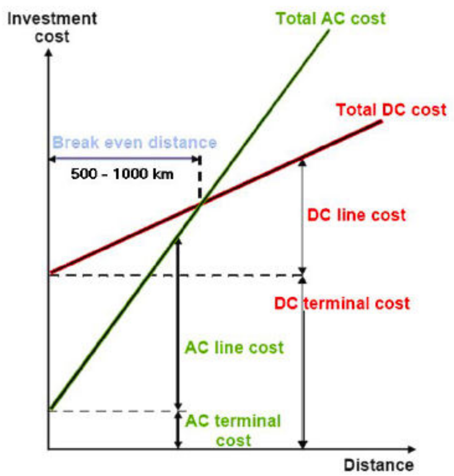
$$Area\ Req.(km^2) = \frac{\text{Total CSP}\left(\frac{\text{TWh}}{\text{yr}}\right)\times 1000}{\text{DNI Ref}\left(\frac{\text{KWh}}{\text{m}^2}/\text{yr}\right)\times 0.045} \quad (1)$$

To export these predicted quantities of green electricity from MENA region to Europe, it is required to build a grid of HVDC cables to connect between the countries. The HVDC cables are more preferable than the HVAC cables due to many reasons. In the next context, some of the advantages of using HVDC grid in transporting green electricity will be listed.

- HVDC technology is widely used for the stabilization of large electricity grids, especially if more and more fluctuating resources are incorporated, [13].
- Only 10 % of the generated electricity will be lost by HVDC transmission from MENA region to Europe over 3000 km distance.
- Losses in HVDC sea cables are in the same range as overhead; while a 750 kV HVAC sea cable does have losses of about 60% per 100 km.
- The HVDC are preferred over HVAC due to the possibility to connect asynchronous interconnections.
- Compared to AC, the DC terminal cost is higher as shown in Figure (15). While by distance, the investment cost of HVDC is lower than HVAC. In the right panel of the figure, it is shown that the breakeven point is at about 830 Km for 5 GW interconnection with overhead line, [15].



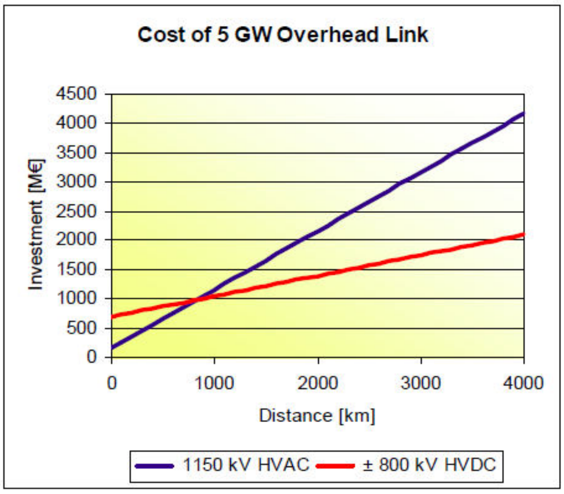


Figure-15. HVAC and HVDC investment costs (left), Cost model used for 5 GW interconnection with overhead line (right).

CONCLUSIONS

As a conclusion, the HVDC technology is the best choice for long distance green electricity transfer from MENA region to Europe, crossing several thousand kilometers with low electricity losses and providing stable, high capacity transfer at reasonable cost and with low environmental impact.

The cost of connecting the MENA region with Europe countries using an electricity grid depends on the distance on the infrastructure suggested to be constructed. The infrastructure system includes the electricity cables and the roads. The infrastructure costs depend on the location in first place, and on the size of the power plant in second order. Therefore, distances and infrastructure costs are very critical for small plants, and less critical for very large plants. Infrastructure costs were calculated with 110,000 $/km for roads and 100,000 $/km for high voltage interconnections, [12].

For very large renewable power export schemes, remote areas with very DNI will subsequently become economically attractive. Therefore, economic potentials are considered to be only limited by the renewable energy performance indicators and not by infrastructure costs. The infrastructure cost of interconnecting a power plant to the Europe countries is shown in Figure-16.

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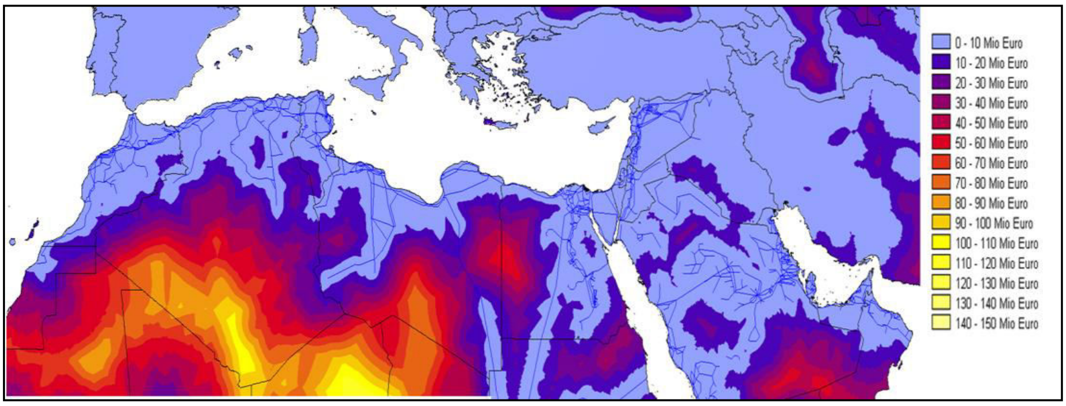

Figure-16. The infrastructure cost of the electricity grid and roads.

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