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Economic Future of Concentrating Solar Power for Electricity Generation

Enas Raafat Maamoun Shouman

Additional information is available at the end of the chapter

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Abstract

Worldwide, the climate change is a major universal concern. CO₂ is the main cause of international warming, and at least 85% emission results of CO₂ came from conventional energy depleted sources (oil, natural gas and coal) for energy generation. Hence, renewable energy has been the focal point of most regulations of governments to aim at greenhouse gas reduced. In Egypt, greenhouse gas emissions from rural activities amount to some 25% of national greenhouse gas emissions, amounting to approximately 27 million t CO₂ equivalent annually. Moreover, these emissions are supposed to increase rapidly in the coming decades, more than doubling in the next 15 years, as rural populations grow and activities become increasingly energy intensive. The Mediterranean region embraces Europe, North Africa and Middle East and has enormous potential in solar energy. It has abundant solar radiation, cheap land and high electricity demand, which could make this region the universal hub for concentrating solar power (CSP) generation. This chapter discusses the Egypt market potential of CSP. The chapter covers recent CSP trends and discusses in detail the CSP market development. The chapter aims to obtain the data sources to compare the CSP and levelized electricity cost. Enas Shouman presents a strategy for CSP plant market entrance in Egypt and a comparison between the electricity cost for Egypt model case and the cost evolution of CSP plants on the basis of expectations for the expansion as an international level. This chapter proposes a concept strategy for management CSP in Egypt. The chapter included two applied parts. The first part is to calculate the generating electricity cost from conventional power sources and its expansion in the future. Then, the second part will be followed by identifying the CSP cost and its growth in the future.

Keywords: solar energy, CSP, renewable energy, economics, levelized cost, electricity

1. Introduction

1.1. Outlook for CSP in Europe and MENA

The solar direct normal irradiation (DNI) plays a great role for the of electricity generation amount from CSP plants. Europe has vast variations in solar radiation unlike the Middle East and North Africa. It has enormous potential for generating electricity from solar energy, with great average solar energy irradiance (**Figure 1**). This allows the Middle East and North Africa to export energy to Europe [1, 2].

This would open up new opportunities for economic and technical cooperation between the two regions and protect environmental considerations by reducing the CO₂ emissions in Europe. World energy demand is growing by over 50% up to the year 2030; **Figure 2** shows the energy consumption per capita up to the year 2050 [3, 4].

The CSP economic potential is limited to Spain, Portugal, Greece, Turkey and the Mediterranean Islands and amounts to 1570 TWh/y of which 1280 TWh/y are located in Southern Spain. Mediterranean Sea is a more attractive site for CSP, with direct solar irradiance of about 2800 kWh/m²/y.

1.2. Universal cumulative installed CSP capacity

- Spain and the USA have 69 and 29% of installed capacity, respectively, and they have dominated the market; United States used to be a leader actor in solar power generation until 2007 when Spain design its first plant (PS10).
- Spain developed 1.9 GW of CSP, and it dominates the market with 69% of the universal installed capacity.

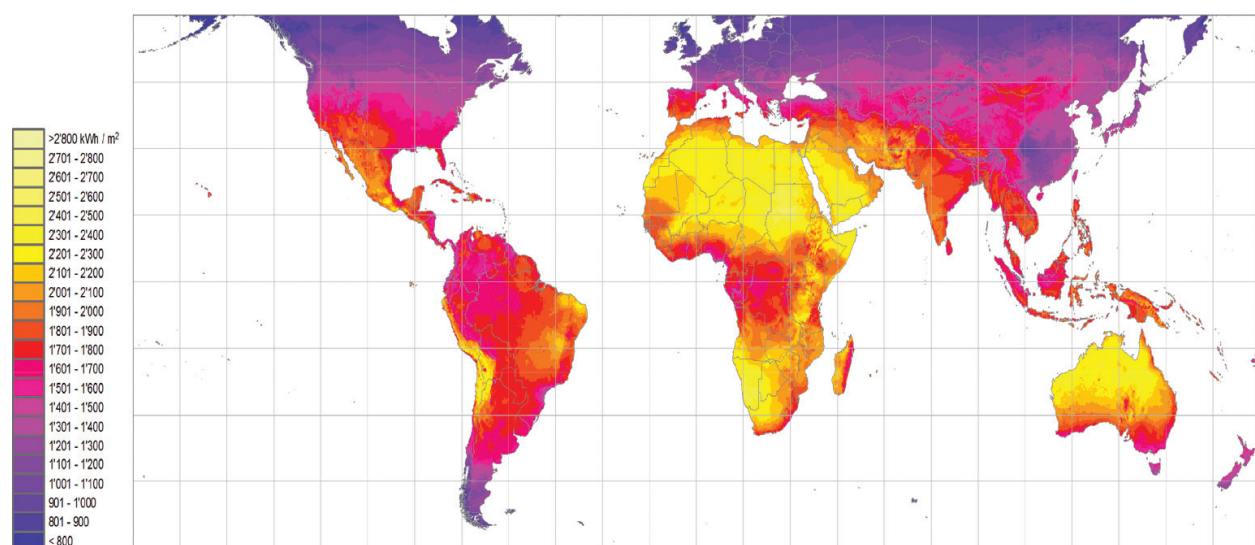


Figure 1. Sum of universal irradiation annually [1, 2].

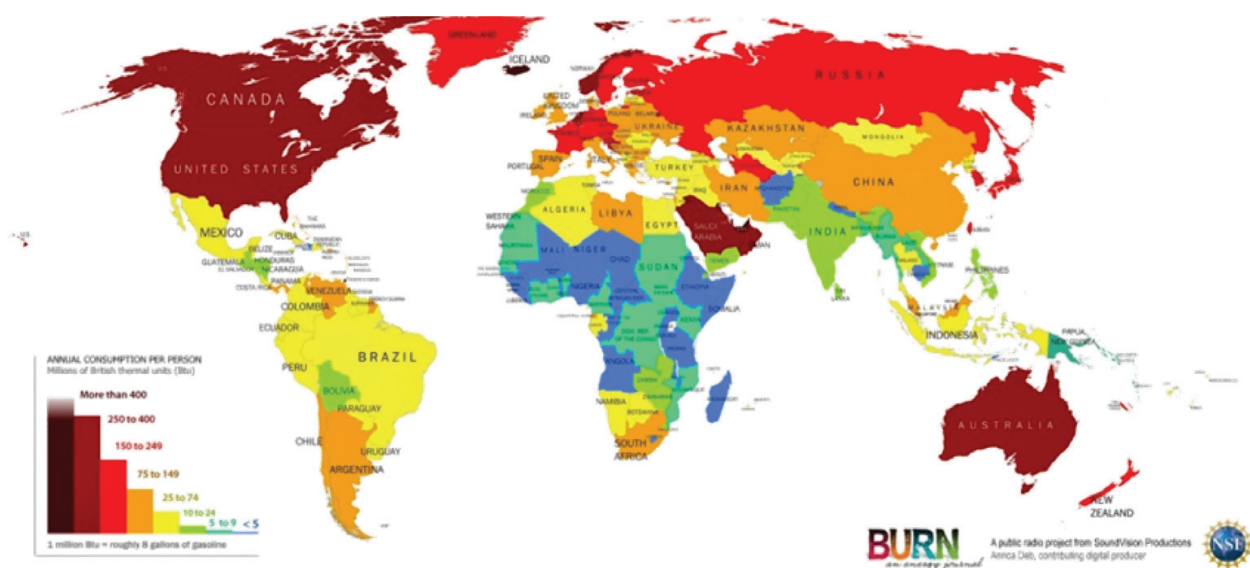


Figure 2. Energy consumption per capita [3, 4].

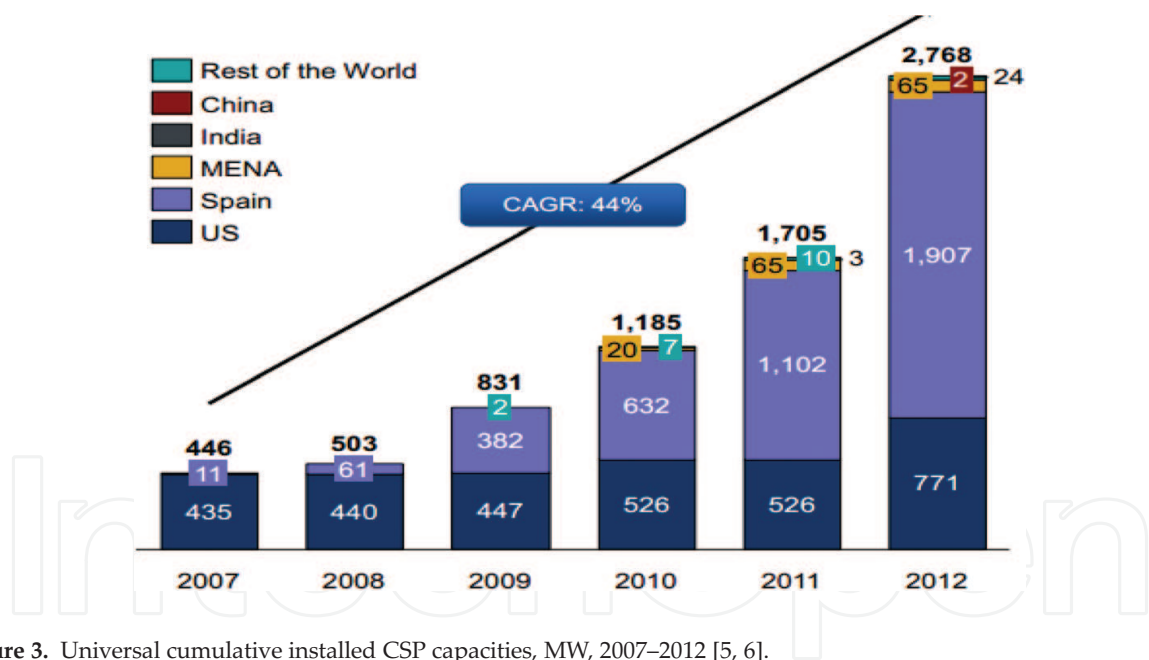


Figure 3. Universal cumulative installed CSP capacities, MW, 2007–2012 [5, 6].

- Between 2010 and 2011, Middle Eastern and African countries (Algeria, Morocco and Egypt) have generated 65 MW. The UAE has a 100 MW plant (Shams 1) which is established in 2013.
- China and India have started to generate CSP since 2010, and at the end of 2012, their installed capacity was about 1.5 and 2.5 MW, respectively (Figure 3).
- Australia, France, Thailand, Germany and Italy have developed CSP plants with nominal capacities of 1–9 MW.

1.3. CSP deployment beyond 2030

By 2040, the universal installed CSP capacity will be about 715 GW, with an average capacity factor of 45% (3900 h/year), thereby providing 2790 TWh yearly. The solar share of 85%, or 2370 TWh, represents 8.3% of universal electricity generation [7, 8]. By 2050, the universal installed capacity will reach 1089 GW, with an average capacity factor of 50% (4380 h/y). In the year 2010, the total electricity demand for 30 countries in Europe was 3530 TWh/y, which is projected to reach a maximum of 4310 TWh/y in 2040 [9, 10].

Figure 4 represents the future electricity demand expected in Europe in 2050, which would cover the demand with a surplus of 45%. However, it must be considered that about 30% of the countries which have been analyzed show considerable deficits, while on the other side considerable surpluses are concentrated in seven countries as shown in **Figure 4**.

Figure 5 shows where CSP electricity will be produced and consumed by 2050. North America would be the leader in producing solar energy, followed by Africa, India and the Middle East. Africa would be the largest exporter and Europe the largest importer. Indeed, the Middle East and North Africa are the largest reproducers when all solar products are considered [11].

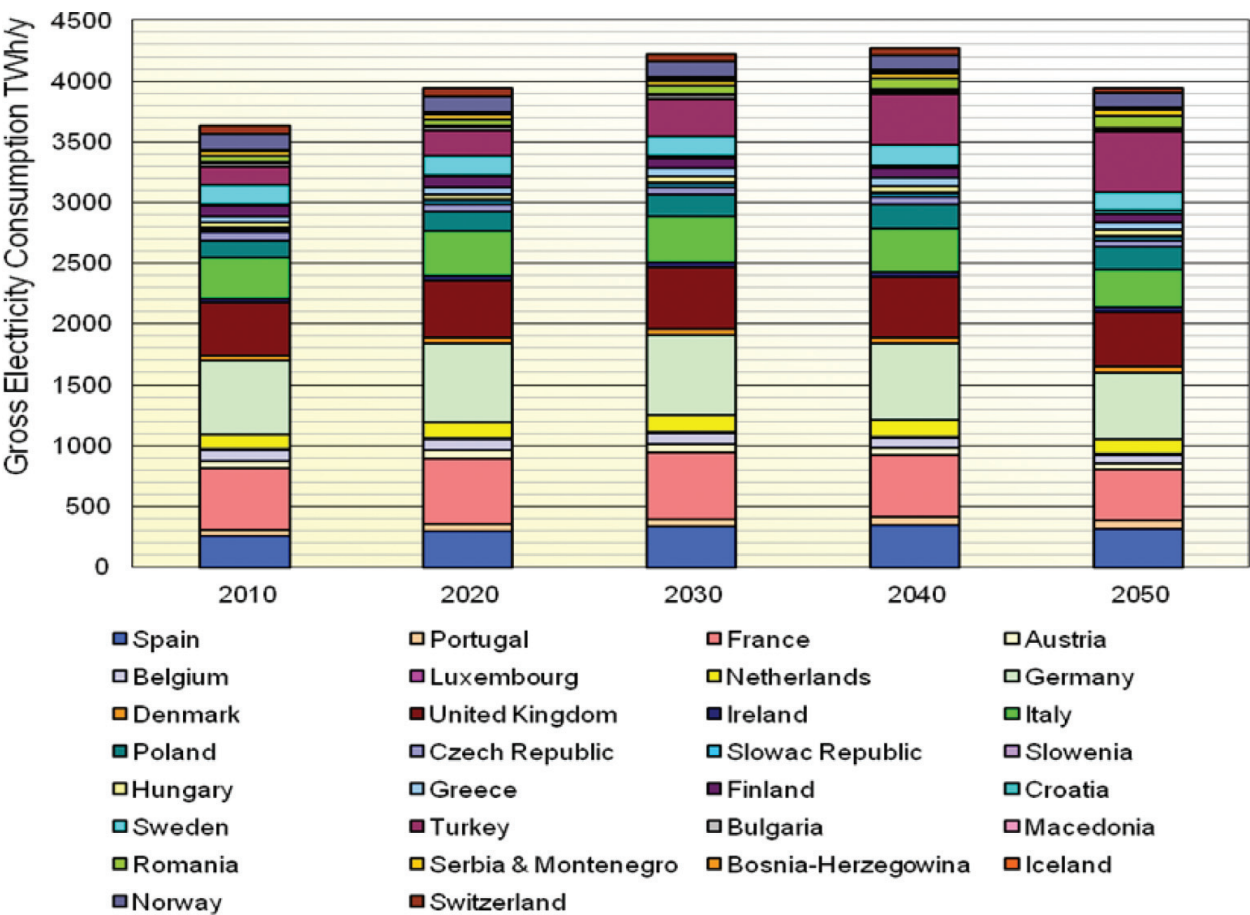


Figure 4. Electricity consumption of European countries between 2010 and 2050.

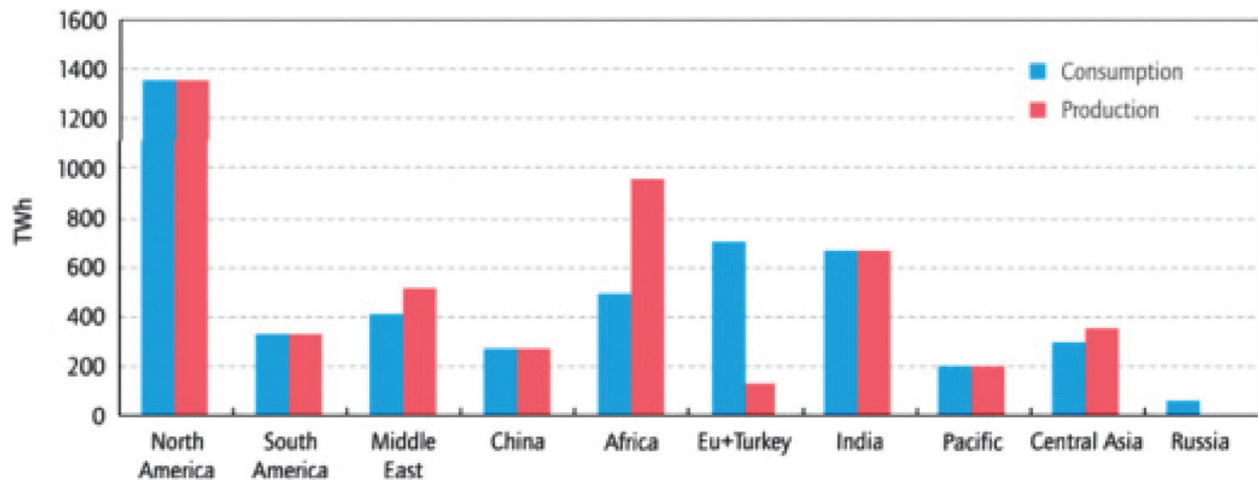


Figure 5. Production and consumption of CSP electricity by 2050 (in TWh) [12, 13].

2. Future energy demand

2.1. World electricity consumption

In North Africa, as a result of increasing population from 150 million in 2005 to a projected 250 million in 2050, an increasing electricity demand and production is expected.

Total electricity consumption is prospective to increase at a compound yearly growth rate of 3.17% with a rise in population. Total installed generating capacity is also expected to rise at a compound annual growth rate of 3.28% to meet the growing demand of electricity and to fill the shortfall of supply and demand. **Figure 6** represents electricity production by different sources from 2000 to 2050.

Total electricity generation from CSP has been supposed to increase to contribute by more than 40% of the total electricity produced in North Africa by 2030 through efficiencies

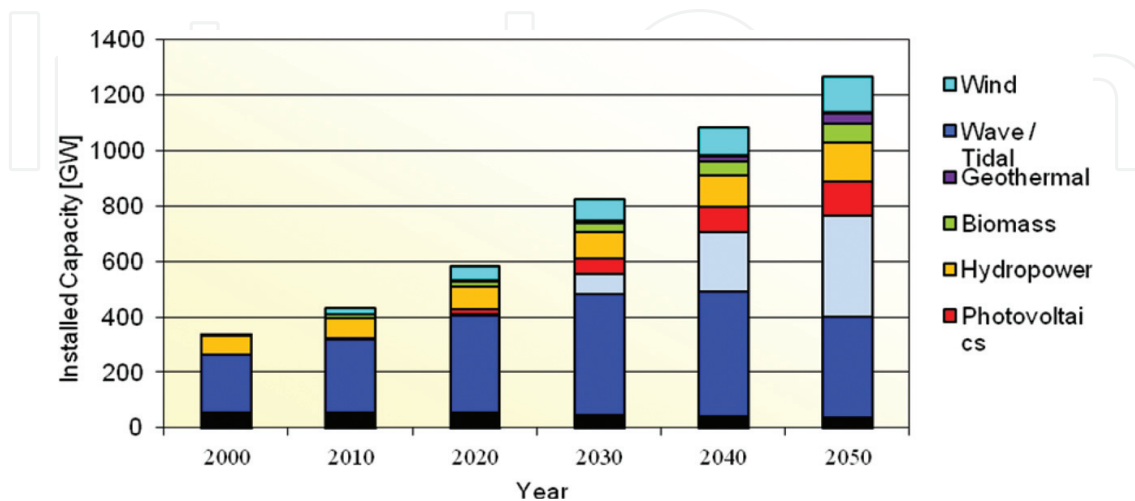


Figure 6. MENA region installed capacity by sources.

achieved on account of advancements in CSP technology [14]. **Figure 7** shows MENA region renewable energy resources.

Figure 8 shows the comparison between El-Kharga in Egypt and different areas in Europe and North Africa. **Figure 8** represents the monthly electricity yield of a best-case CSP plant with 24-h storage capacity throughout the year.

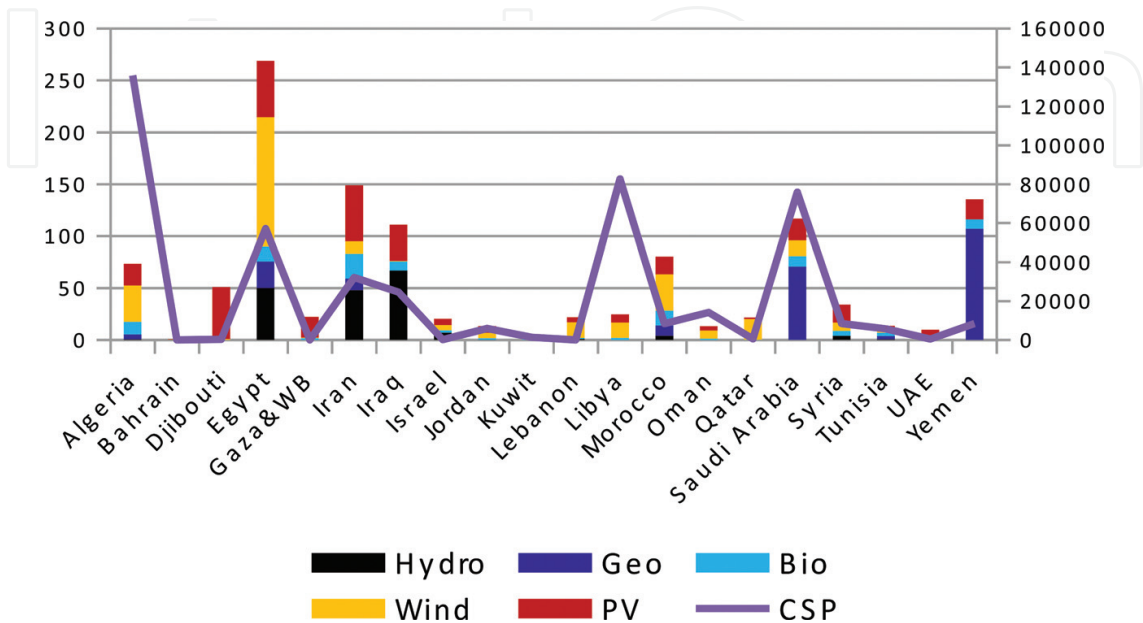


Figure 7. Renewable power generation potential by sources in TWh/y [15].

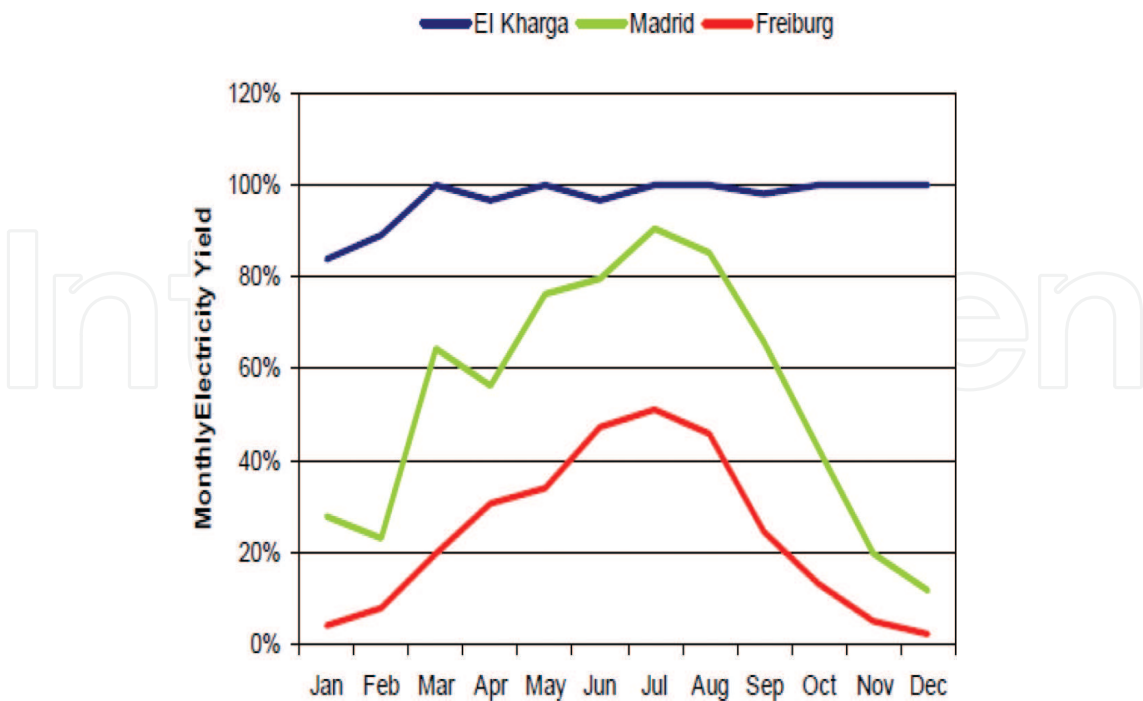


Figure 8. Proportional monthly electricity generation simulation of CSP plant with 24-h storage for equivalent annual full load hours in different sites with different DNI, Freiburg in Germany 2260 h/y, Madrid in Spain 5150 h/y, El Kharga in Egypt 8500 h/y/May 2005/.

2.2. Egypt electricity consumption

The German Aerospace Center has produced statistic studies on forecasted electricity consumption for Egypt up until 2050. Egypt will largely depend on CSP to satisfy the electricity demand due to the unpredictable population increase as well as the prospective economic growth (Figures 9 and 10). In 2020, in Egypt, electricity generated from CSP will likely contribute more than 30% and will reach 55% in 2050 [16, 17].

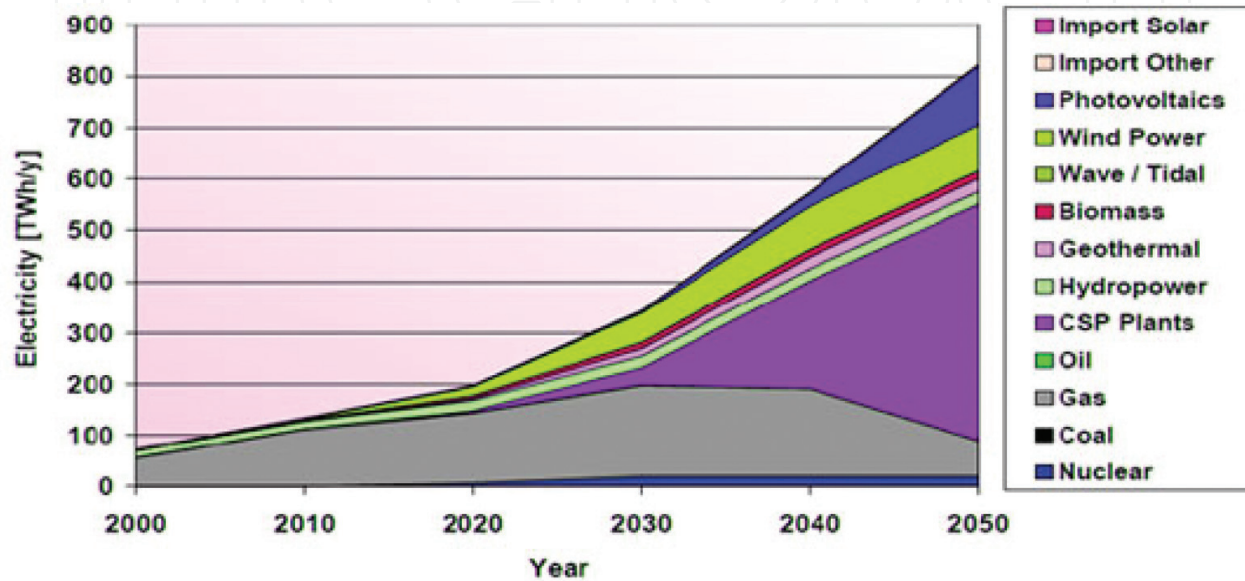


Figure 9. Electricity scenarios by primary energy sources for power generation in Egypt [16, 17].

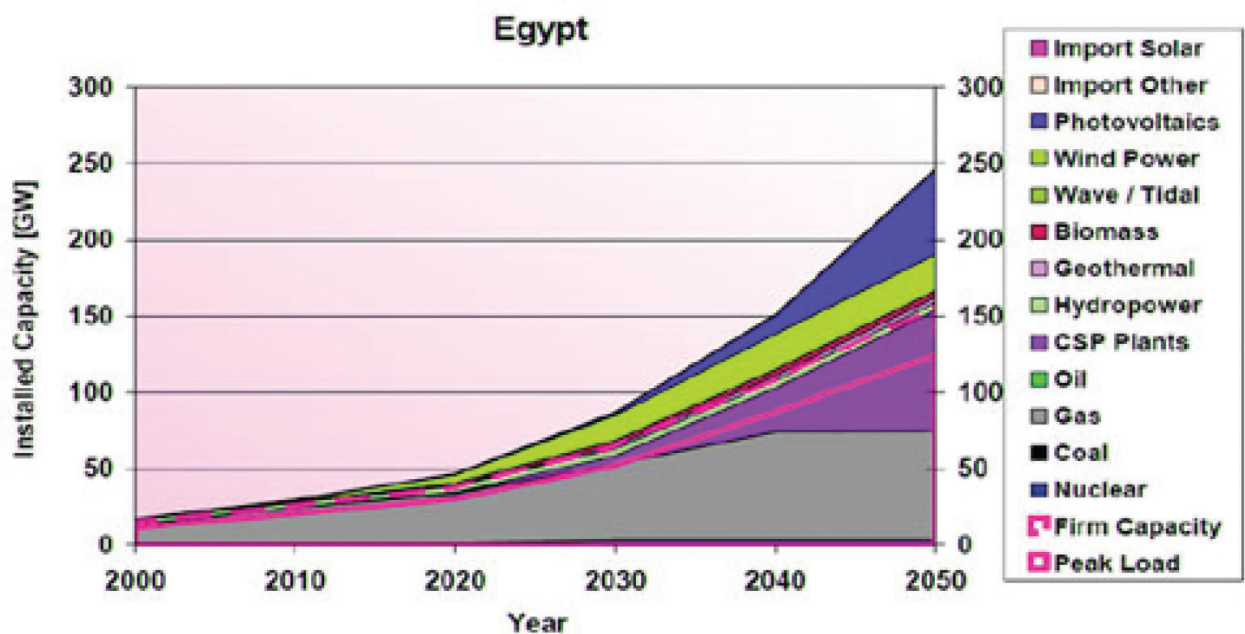


Figure 10. Installed capacities required for the electricity supply in Egypt [16, 17].

3. Economic methods for solar energy financial analyses

There are five economic methods of financial analysis for making investment decisions. Enas R. Shouman et al. have mentioned different methods including payback analysis (Annex 1), saving-to-investment ratio (SIR) (Annex 2), life-cycle cost (LCC) (Annex 3) and an adjusted internal rate of return (AIRR) (Annex 4). These studies evaluated the economics of PV applications by using these financial methods [18].

3.1. Levelized cost of electricity generation

The most significant parameters that determine at 2011 the levelized cost of electricity (LCOE) of CSP plants are as follows:

- Cost of initial investment, including location design for plants, with component costs, structure, grid connection and capitalized costs;
- CSP power plant capacity and efficiency factor.
- Level of DNI at the project location;
- Operation and maintenance (O&M) (\$/y) costs (including insurance) costs; and.
- The capital cost, economic lifecycle, etc.

The economics of CSP technologies are substantially different from that of fossil fuel power technologies. Solar energy has high investment costs, modest operation and maintenance costs and very low or no fuel costs when compared to conventional fossil fuel power which is only very sensitive to the price volatility of the fossil fuel international markets. On the other hand, solar energy technologies are more sensitive to change in the capital and financing condition costs. The levelized cost of electricity of CSP plants is strongly correlated with DNI. Supposing a base of 2100 kWh/m²/year (a typical value for Spain), the estimated LCOE of a CSP plant is declined by 4.5% for every 100 kWh/m²/year that the DNI exceeds 2100 (**Figure 11**). In Egypt, the estimated average value of the DNI is around 2500.

Egypt is in an advantageous position for generating solar energy. It enjoys 2900–3200 h of sunshine annually with annual direct normal energy density 1980–3200 kWh/m² and technical solar-thermal electricity generating potential of 73.6 PWh, so the CSP is a promising technology in Egypt.

CSP capacity growth and cost learning curves from different project locations were taken as a basis for the modeling of the levelized CSP for generating the cost of electricity plants. The chapter uses Spain as a reference value for the successful market in 2010–2011 which its electricity tariff is around 27 €/kWh and define an equivalent value for MENA region in US(\$) currency. Supposing an exchange rate of 1.19 \$/€ and Egypt DNI reference of about 2500 kWh/m²/a compared to Southern Spain DNI of about 2900 kWh/m²/a, our equivalent demand tariff for CSP in the model case reached to 28 UScent/kWh in 2010 [19, 20] (**Figure 12**).

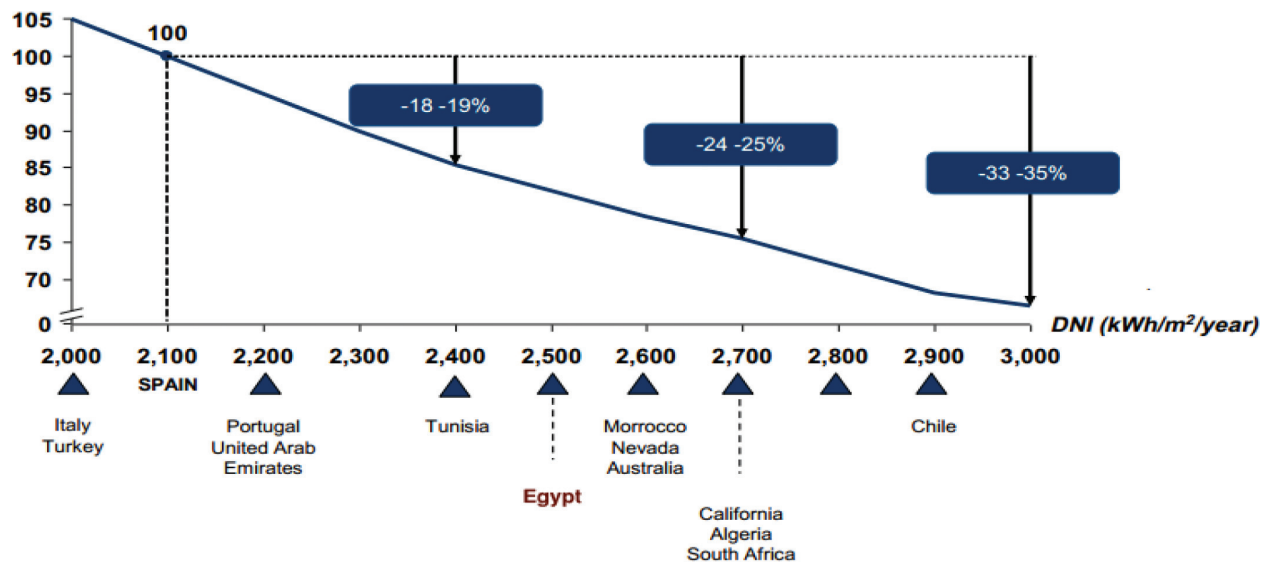


Figure 11. LCOE of CSP plants as a function of DNI [19].

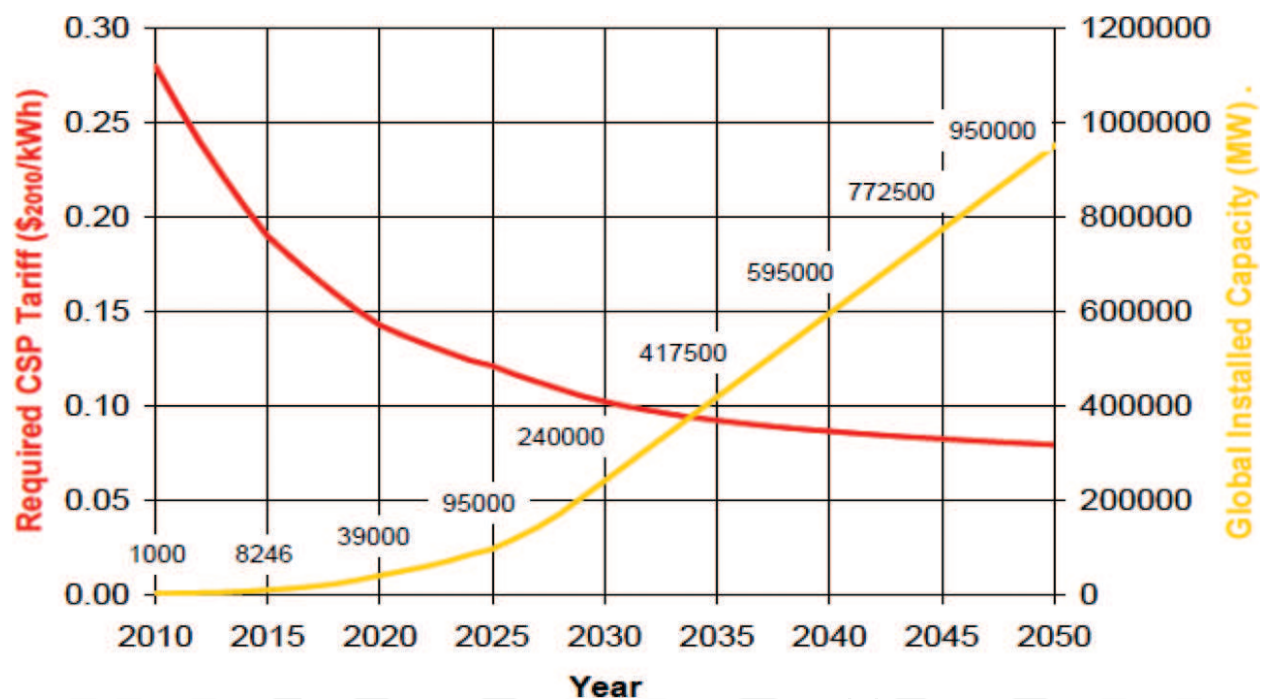


Figure 12. Expansion of universally installed CSP capacity and resulting reduction of demand tariff for the model parameters shown in Table 1.

CSP capacity is expected to increase from 20,000 MW to 150,000 MW by 2020 and about 230,000–340,000 MW by 2030. In 2050, expectation range for installed CSP capacity will be from 850,000 MW to 1,500,000 MW worldwide. In order to calculate the cost of decreased effects for the model reference case, we have selected a moderate universal expansion scenario, reaching about 39,000–240,000 MW in 2020–2030. This assumption will be the basis for the cost model scenario. In 2050, about 950,000 MW is supposed to be installed. The

Preference LCOE of CSP in 2010	\$/kWh	0.280
Preference DNI	kWh/M2/a	2400
CSP progress ratio	%	88.0%

Table 1. Installing CSP model parameters for capacity.

demand tariff for CSP is decreased according to the universal installed capacity, with a progress ratio of about 0.88 according to a model by Neij, that the cost is cut the price by 12% every time worldwide installed capacity doubles [21]. In 2020, with these conditions the required CSP tariff will cut the price to 14 and 10 cent/kWh by 2030. In the long term, a cost below 8 cent/kWh is achieved.

3.2. A strategy for CSP finance in Egypt

3.2.1. Calculating levelized cost parameter of electricity (LCOE)

3.2.1.1. Assuming the electricity output per capita

For this model, the electricity output per capita is needed, while only the total electricity output value is known, which is 101,898 GWh/a [1, 2]. From the reference model for MENA region, the share of each capita could be calculated and supposed to be the same distribution in Egypt. Multiplying this share by the total annual electricity output will give us the electricity output per capita as shown in **Table 2** [22].

3.2.2. Cost of fuel (CoF)

The objective of the coming calculations is to determine the Cost of fuel for the different segments (peak-, medium, and base load). In the annual report of the EEHC a case was given that showed savings of 581 million EGP, when 3195 k toe were saved in the year 2008–2009, fuel cost [EGP/toe] was 181.84 according to the following equation [22].

$$\text{Specific fuel cost [EGP/Toe]} = (\text{fuelcost[EGP]})/\text{fuel[ktoe]} \quad (1)$$

The fuel cost could be about 7.19 \$/MWh according to the following equation, taking into consideration the value proposition in Eq. (1), as well as knowing the total fuel consumed in

Study [23]	Egypt			
	Installed capacity (MW)	Electricity (GWh/a)	Share of electricity (%)	Electricity (GWh/a)
Peak load	1000	2000	5	4852
Medium load	2500	10,000	24	24,261
Base load	4000	30,000	71	72,784
Total	7500	42,000	100	101898

Table 2. Electricity output/capita in Egypt.

electricity generation of about 22,179 ktoe and total electricity generation of about 101,898 GWh/a [22].

$$\text{Specific fuel cost [USD/MWh]} = \frac{\text{fuelconsumption[toe]} * \text{fuelcost}^{\frac{[\text{EGP}]}{[\text{toe}]} * \text{USD}}}{\text{Electricityoutput[MWh]}} \quad (2)$$

Eq. (3) will be followed to measure efficiency which plays a significant role in consumption and fuel cost. The equation would calculate the fuel cost estimated for the medium load and peak load with the fuel efficiency of 35 and 30%, respectively.

$$\text{COF}_{\text{medium/peak}} = \text{COF}_{\text{base}} * \frac{\eta_{\text{base}}}{\eta_{\text{medium/peak}}} \quad (3)$$

where η is the efficiency (%). This will result in a cost of fuel (CoF) medium load of 8.2 USD/MWh and cost of fuel peak load of 9.6 USD/MWh.

3.2.3. Investment cost of the conventional power plants

The investment cost of the conventional energy plants has three main types of energy generation: combined cycle plants, gas turbine plants and steam turbine energy plants. By multiplying the installed capacity and the share of the production of each type and then these costs with the share of the installed capacity as shown in **Table 3**, we calculate the weighted average for the CSP plant investment cost of 1114.77 USD/kW [23] which is very significant to determine the LCOE.

3.2.4. Cost of operation and maintenance

The fixed O&M costs vary between the different types of generation, as Combined Cycle Charge around 2 US/kW, Gas about 13 USD/kW while the most expensive ones are the Steam energy plants with 28 USD/kW. Using the weighted average according to the, respectively, installed capacity about 7178, 1641 and 11,458 MW, the average fixed operation and maintenance cost could be calculated as 17.58 USD/kW/year [23].

3.3. LCOE for conventional power in Egypt

Figure 13 shows the levelized cost of electricity (LCOE) calculated as in Annex 5 for the peak load, medium load and base load segments as well as for the resulting weighted average cost of electricity.

Type of energy generation	Combine cycle	Gas turbines	Steam turbine energy plants
Investment cost (USD/kW)	800	500	1400
Share of the installed capacity	35%	8%	57%

Table 3. Weighted average for the CSP plant investment cost.

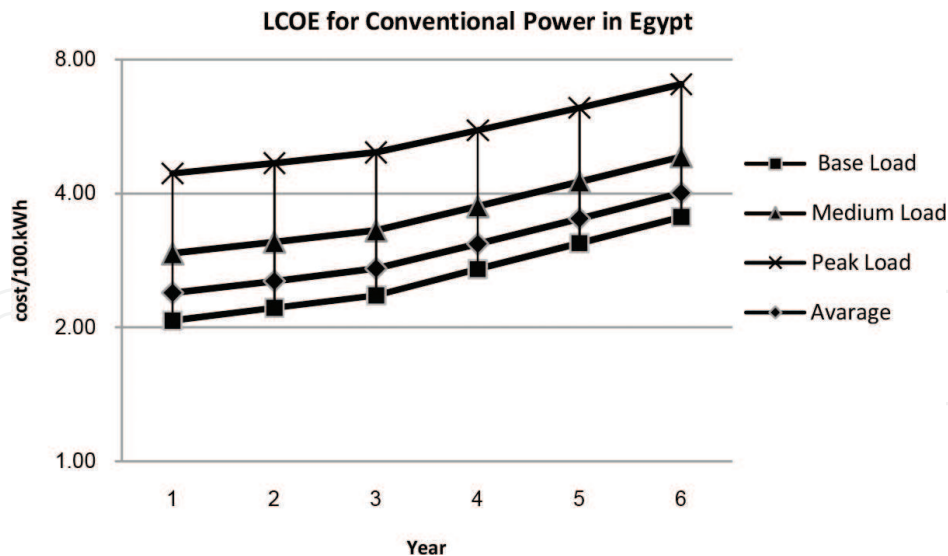


Figure 13. LCOE for conventional power in Egypt.

For rising economies with high demand rise rates, the fuel cost escalation and fuel consumption of installed power capacity are greatly relevant, as it will directly affect economic development negatively. For the Egypt model case, we have assumed a rather moderate 3.6% growth of electricity demand, while growth rates of over 7% yearly.

Egypt has a technical potential exceeding 2800 kWh/m²/y, while the newly identified project location of Kom Ombo in Egypt has DNI average of about 2500 kWh/m²/y [24]. Therefore, this DNI value could be used as an indicator for DNI in Egypt in this model and this indicator compared with Spain with only a DNI level of 2090 kWh/m²/y [7, 8, 11]. These data could be used for calculating C₀ [11].

$$C_{0 \text{ Egypt}} = (CSP)_{\text{ain}} \cdot \frac{DNI_{\text{Spain}}}{DNI_{\text{Egypt}}} * \$/\text{€} \quad (4)$$

Assuming a USD–EUR exchange rate of 1.19, C₀ Egypt is equal to 26.86 ct\$/kWh (Annex 6) (C₀Egypt = 26.86 ct\$/kWh), which is in the lower half of estimated CSP costs worldwide by the IEA of (20–30) ct\$/kWh in 2010 [8]. The cost which is shown in **Figure 14** depends on the yearly solar radiation, and Egypt has high direct normal irradiance. Applying equation to the following data (**Table 4**), **Figure 14** shows the results for Egypt CSP cost curve, which decreases from 26.88 to 7.56 ct\$/kWh from 2010 to 2050, respectively.

In Egypt, CSP potential is about 73,000 TWh/year. Egypt is the highest one in the region. Other promising characteristics are a high DNI which is around 19,870–3200 kWh/m²/year, few cloudy days, high sun duration hours (9–11 h), huge expanses of vacant desert land, and an outstretch national electric grid. All of these elements make Egypt a perfect location for CSP projects.

The chapter aims to obtain a range of data for economic CSP energy. The chapter explains international CSP economic methods with financial analyses on the basis of expectations for the increase of solar energy in Egypt.

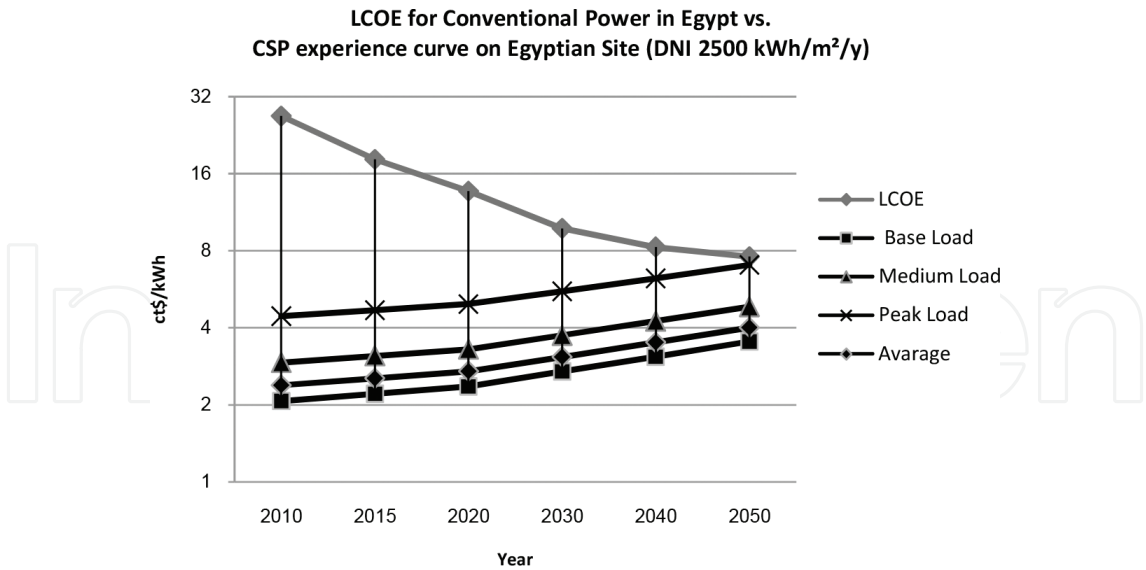


Figure 14. EgyptLCOE (CSP) vs. conventional power.

CSP progress ratio [22]	0.88
Egypt DNI [kWh/m ² /y]	2500
LCOE for CSP in Egypt in 2010 [ct\$/kWh]	26.86

Table 4. Levelized cost of electricity (LCOE) for CSP in Egypt parameters.

More concern should be devoted to solar energy, especially CSP, by establishing a special sub-authority to support solar energy field. The responsibility of this entity is to measure DNI and also to identify a specific location for solar energy plant project and stand by feasibility studies. They would also assign and acquire land for solar energy plant projects, provide technical support and set a part business partners.

The major objective of this chapter is to create a continuous flow of the required data to be used as a base for taking decisions and to provide sufficient information about project needs. Project specifications, the other similar project in a different site, accurate information market and cost changes help the decision maker to determine and achieve the right target with minimum cost.

The aim is to facilitate the creation in the highest level of decision makers' community to serve the scientific project and to maximize scientific findings and overcome existing barriers of perspective, culture, geography and time. There is a need for scientists, as individuals or as groups, to develop a diversity of data analysis strategies, to clearly identify key target audiences, and to learn how to execute an effective project.

Annex

Annex 1

Payback period is the minimum time it takes to recover investment costs. The payback method is often used as a rough evidence to cost performance. The payback period for the

solar energy project is calculated as the total cost of investment divided by the income of the first year from the energy produced. If the payback period analysis is less than the expected power system life, the projects of the power system are potential to be cost-effective evidence. Projects of power system with short payback periods are considered to have lower risks. **Table 5** shows the equation for payback calculation indicated by Enas R. Shouman et al. [1, 18].

where Y = summation from years 1 to Y; E = reduction in electricity costs in year j;
M = differential maintenance and repair costs in year j; S = differential salvage value in year j;
R = differential replacement costs; and P = differential purchase and installation costs.

Annex 2

Savings-to-investment ratio (SIR) can be used to compare savings to costs of one energy system relative to an alternative power system. For a good result for net savings, the saving-to-investment ratio (SIR) should be greater than one. The higher the ratio, the greater the savings realized relative to the investment. **Table 6** represents the SIR methods in financial analysis by Enas R. Shouman et al. [1, 18].

Annex 3

Life-cycle cost analysis (LCC) shows a summation of all relevant present and future costs to build the system for CSP energy system. These costs include energy, installation, acquisition, operations and maintenance, repair, inflation, replacement (less salvage value) and the discount rate for the life of the investment.

Financial analysis	General formulas: All costs expressed as present value	Evaluation criteria
Discounted payback period (DPB) Minimum time it takes to recover an investment	$DPB = \text{Find } Y, \text{ such that } Y \sum_{j=1} (Ej - MJ - RJ + SJ) = P$ $Payback \text{ Period} = \frac{\text{Overall cost of the power system}}{\text{Total cost of the fuel generator at first year}}$	Payback period is less than the power system project life time

Table 5. Payback period general formulas.

Financial analysis	General formulas: Costs of present value	Criteria evaluation
Savings-to-investment ratio (SIR) The ratio represents how many times savings exceed costs and recompensing for the time value of money.	$SIR = \frac{E - M}{P - S + R}$	$SIR > 1$

Table 6. Savings-to-investment ratio general formulas and evaluation criteria.

If the life cycle cost analysis is lower than that for the base case and in other aspects is equal, then the life cycle cost meets the objectives of investor and budget constraints. It is considered as cost-effective and the preferred investment. **Table 7** shows the equation to calculate LCC [18].

LCC general formulas present value sum of costs and benefits of power system over lifetime which is ($LCC = P1 - S1 + M1 + R1 + E1$) for evaluation criteria to compare LCC among exclusive alternatives. Minimum LCC and $LCC1 < LCC2$.

where P1 is the purchase and installation cost; S1 the salvage value; M1 the maintenance and repair costs;

R1 the replacement costs; and E1 the electricity costs.

Annex 4

Adjusted internal rate of return (AIRR) is a discounted cash flow technique that measures the yearly yield from a solar energy project, taking into account the reinvestment of tentative receipts at a specified rate. The cost-effectiveness of power project estimating adjusted internal rate of return (AIRR) includes comparisons between the projects calculated AIRR and the investor's minimum acceptable rate of return (MARR). **Table 8** represents the cost-effectiveness if the AIRR is greater than the MARR.

where TV is terminal value of all cash flows except investment costs,

PVI the present value of investment, c the costs, and $1/n$ the n th root of the ratio of TV/PVI.

Method financial analysis	General formulas: All costs expressed as present value	Evaluation criteria
Life cycle cost (LCC) Present value sum of costs and benefits over life of a system	$LCC = P1 - S1 + M1 + R1 + E1$ P1, S1, M1, R1, E1	Compare LCC among mutually exclusive Alternatives. Minimum LCC $LCC1 < LCC2$

Table 7. Life Cycle Cost guidelines are to define cost-effectiveness.

Method of financial analysis	General formulas: All costs expressed as present value	Evaluation criteria
Adjusted internal rate of return (AIRR) measures annual yield from a project assuming reinvestment of interim proceeds at the MARR	AIRR = Find the n th root of the ratio of the terminal value of all cash flows (except investment costs) to the present value of investment costs and subtract 1 $AIRR = (TV/PVI)^{1/n} - 1$	AIRR must be equal to or greater than the investor's minimum rate of return

Table 8. General formulas and evaluation criteria for adjusted internal rate of return.

Annex 5

Levelized cost of electricity (LCOE) estimation follows the following calculations.

$$\text{LCOE} = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

where LCOE is the average lifetime levelized cost of electricity.

generation; I_t the investment expenditures in the year t ; M_t the operation and maintenance expenditures in the year t ; F_t the fuel expenditures in the year t ; E_t the electricity generation in the year t ; r the discount rate; and n the life of the system.

Annex 6

The cost experience curve function is

$$c_x = c_0 \left(\frac{P_x}{P_0} \right)^{\frac{\log PR}{\log 2}}$$

where PR is the progress ratio, C_x is the specific investment at point x , C_0 is the specific investment at reference point 0, P_x is the cumulated capacity at point x , and P_0 is the cumulated capacity at reference point 0 [11, 16, 17].

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