“FEASIBILITY OF CONCENTRATED SOLAR POWER UNDER EGYPTIAN CONDITIONS”

Thesis
by
Rawya Mostafa ElShazly

Submitted in partial fulfillment of the Renewable Energy & Energy Efficiency for the MENA Region Master Program (M.Sc.)

Awarded by the University of Kassel (Germany) and Cairo University (Egypt)

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Thesis

by

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Declaration for the Master’s Thesis

I hereby affirm that the master thesis at hand is my own written work and that I have used no other sources and aids others than those indicated. Only the sources cited have been used. Those parts which are direct quotes or paraphrases are identified as such.

(Place) Cairo (date) 27.02.2011

(Signature) Rawia Asery
ACKNOWLEDGMENT

I owe my greatest gratitude to my supervisors for their continuous support despite the compressed time frame and long distance. Their guidance, instructions and advice were vital in producing this work. I would like to specifically thank Prof. Dr. Mohamed F. El-Refaie, Dr. Franz Trieb and Prof. Dr. Jürgen Schmid, working with them was educational, inspiring and an honor. Their contribution was of great impact to this thesis.

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This thesis is dedicated to my beloved country Egypt in hopes that it can contribute towards the establishment and development of the local CSP market.
ABSTRACT

Population growth and economic development are leading to a continuous increase in energy demand in Egypt. At the same time conventional energy sources are diminishing amid growing global concern for the environment. These factors underline the importance of increasing the use of Renewable Energy sources. Egypt has enormous potential in Solar energy. There is sufficient proof of Egypt’s potential for extracting energy from Concentrated Solar Power, especially power on demand generation. CSP represents a reliable and sustainable source of energy for Egypt with different outputs that can be used. In order to exploit it, the private sector needs to be involved. This thesis studies the feasibility of CSP in Egypt from regulatory and institutional conditions to technological characteristics and economic competitiveness under Egyptian conditions.
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<tr>
<th>Acronym</th>
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<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>AfDB</td>
<td>African Development Bank</td>
</tr>
<tr>
<td>BOOT</td>
<td>Build-Own-Operate-Transmit</td>
</tr>
<tr>
<td>BP</td>
<td>British Petroleum</td>
</tr>
<tr>
<td>BREPP</td>
<td>Bulk Renewable Energy Electricity Production Program</td>
</tr>
<tr>
<td>CBE</td>
<td>Central Bank of Egypt</td>
</tr>
<tr>
<td>CC</td>
<td>Combined Cycle</td>
</tr>
<tr>
<td>CDM</td>
<td>Clean Development Mechanism</td>
</tr>
<tr>
<td>CER</td>
<td>Certified Emission Reduction</td>
</tr>
<tr>
<td>CoF</td>
<td>Cost of Fuel</td>
</tr>
<tr>
<td>CSP</td>
<td>Concentrated Solar Power</td>
</tr>
<tr>
<td>DLR</td>
<td>German Aerospace Centre</td>
</tr>
<tr>
<td>DNI</td>
<td>Direct Normal Irradiance</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>EEAA</td>
<td>Egyptian Environmental Affairs Agency</td>
</tr>
<tr>
<td>EEHC</td>
<td>Egyptian Electricity Holding Company</td>
</tr>
<tr>
<td>EETC</td>
<td>Egyptian Electricity Transmission Company</td>
</tr>
<tr>
<td>EGP</td>
<td>Egyptian Pounds</td>
</tr>
<tr>
<td>EIB</td>
<td>European Investment Bank</td>
</tr>
<tr>
<td>EPC</td>
<td>Engineering, Procurement, Construction</td>
</tr>
<tr>
<td>ESIA</td>
<td>Environmental and Social Impact Assessment</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EUMENA</td>
<td>Europe, the Middle East and North Africa</td>
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<tr>
<td>EUR / €</td>
<td>Euro</td>
</tr>
<tr>
<td>FCR</td>
<td>Fixed Charge Rate</td>
</tr>
<tr>
<td>FDI</td>
<td>Foreign Direct Investment</td>
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<td>GDP</td>
<td>Gross Domestic Product</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<td>---------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>GEF</td>
<td>Global Environmental Fund</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse Gases</td>
</tr>
<tr>
<td>GT</td>
<td>Gas Turbine</td>
</tr>
<tr>
<td>HDI</td>
<td>Human Development Index</td>
</tr>
<tr>
<td>HTF</td>
<td>Heat Transfer Fluid</td>
</tr>
<tr>
<td>HVDC</td>
<td>High Voltage Direct Current</td>
</tr>
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<td>ICO</td>
<td>Spanish Development Fund</td>
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<tr>
<td>IEA</td>
<td>International Energy Agency</td>
</tr>
<tr>
<td>IPP</td>
<td>Isolated Power Plants</td>
</tr>
<tr>
<td>IRENA</td>
<td>International Renewable Energy Agency</td>
</tr>
<tr>
<td>ISCCS</td>
<td>Integrated Solar Combined Cycle System</td>
</tr>
<tr>
<td>kTOE</td>
<td>Kilo Ton of Oil Equivalent</td>
</tr>
<tr>
<td>LCOE</td>
<td>Levelized Cost of Electricity</td>
</tr>
<tr>
<td>MASEN</td>
<td>Moroccan Agency for Solar Energy</td>
</tr>
<tr>
<td>MED</td>
<td>Multi-Effect Desalination</td>
</tr>
<tr>
<td>MENA</td>
<td>Middle East North Africa nations</td>
</tr>
<tr>
<td>MOEE</td>
<td>Ministry of Electricity and Energy</td>
</tr>
<tr>
<td>MSF</td>
<td>Multi Stage Flash Water Desalination System</td>
</tr>
<tr>
<td>MSP</td>
<td>Mediterranean Solar Plan</td>
</tr>
<tr>
<td>MW</td>
<td>Mega Watt</td>
</tr>
<tr>
<td>NREA</td>
<td>New and Renewable Energy Authority</td>
</tr>
<tr>
<td>OECD</td>
<td>Organization for Economic Cooperation and Development</td>
</tr>
<tr>
<td>OME</td>
<td>Observatoire Mediterranee de L’Energie</td>
</tr>
<tr>
<td>ONE</td>
<td>Office National de l’Electricité (Morocco)</td>
</tr>
<tr>
<td>PPA</td>
<td>Power Purchase Agreement</td>
</tr>
<tr>
<td>PPP</td>
<td>Public-Private Partnerships</td>
</tr>
<tr>
<td>RCREEE</td>
<td>Regional Center for Renewable Energy and Energy Efficiency</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>RE</td>
<td>Renewable Energy</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>RES</td>
<td>Renewable Energy Sources</td>
</tr>
<tr>
<td>RET</td>
<td>Renewable Energy Technology</td>
</tr>
<tr>
<td>RO</td>
<td>Reverse Osmosis</td>
</tr>
<tr>
<td>SCE</td>
<td>Supreme Council for Energy</td>
</tr>
<tr>
<td>ST</td>
<td>Steam Turbine</td>
</tr>
<tr>
<td>SWOT</td>
<td>Strengths, Weaknesses, Opportunities and Threats</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations Development Program</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environmental Program</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
</tr>
<tr>
<td>USD / $</td>
<td>United States Dollar</td>
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CHAPTER ONE
INTRODUCTION
Energy is one of the most basic and crucial elements upon which to base a life and an economy nowadays. Energy is needed for daily tasks in homes, schools, hospitals, industries and countless other places. Egypt is a country with high energy demand growth rate exceeding 6%. [1]

Due to the rapid depletion of conventional energy resources, such as natural gas, and increased energy demand, conventional primary energy resources in Egypt will be unable to satisfy demand by 2020. [2] To avoid this situation, the government should adopt two strategies: reduce demand and increase supply. In this context Renewable Energy and Energy Efficiency is particularly relevant. Renewable Energy addresses the supply of energy and guarantees environmental, economic and social sustainability in the energy sector. There are different types of Renewable Energy, such as solar, wind, biomass, and geothermal. Each type has its applications as well as advantages and disadvantages. A well balanced mix of them can secure the energy supply in the country and even replace conventional energy electricity. This can then be saved for other purposes and for future generations. Moreover, Renewable Energy serves two key objectives: generating energy to meet demand and protecting the environment with emissions-free energy. Energy Efficiency addresses the need for a reduction in the demand for electricity by achieving the maximum utilization of generated energy while reducing waste.

Renewable Energy and Energy Efficiency are considered “the main pillars of environmental compatibility” [3]. It is not efficient to produce green electricity that is unwisely consumed, as it results in opportunity loss, high waste and a burden on the economy. To guarantee real and meaningful progress toward energy security and sustainability, a government should work on both spheres simultaneously. Egypt has great potential for the use of solar power due to long sun duration hours, few cloudy days, low rainfall and high-constant sun radiation. With a potential of 73,000 TWh/year, Egypt is considered one of the countries with the highest potential for solar power not only in the Middle East but worldwide. The potential of Concentrated Solar Power (CSP) is of special importance, as Egypt is one of the sun-belt countries with high Direct Normal Irradiance (DNI). [3] The use of solar power is not new to Egypt. In 1913, the first CSP experience took place in Maadi-Cairo. Frank Shuman designed a system to provide irrigation from the Nile to a surrounding desert area. [4, 5] While this potential was discovered in the last century, it unfortunately was not further utilized. It is noteworthy that with solar power the country could generate enough electricity to satisfy domestic demand as well as that from Europe, the Middle East and North Africa (EUMENA), as well as worldwide.

This concept is the core of the DESERTEC initiative, which contemplates the production of electricity from Renewable Energy sources in the MENA region and the exportation of some of this energy to Europe. Thus the MENA region and Europe would have a secure energy supply to meet growing demand. The establishment of a Renewable Energy industry would bring economic development to the MENA region.
and income from electricity exports to Europe. Furthermore, new European Union (EU) legislation paves the way with regulations that promote and govern this trade in green energy. These rules require that electricity imported from any third country “must be produced by a newly constructed installation that became operational or by the increased capacity of an installation that was refurbished after January 2009.” EU members could also support “schemes and measures of cooperation with third countries.” [6] Moreover, since 2008 the 27 EU member states have been obliged to work toward increasing their share of energy from renewable sources in gross final consumption of energy from today’s 8.5% to an expected 20% in 2020. This underpins the development of CSP projects in MENA countries because it explicitly mentions that green electricity from “third countries” can be used to achieve the member states’ national targets. [6]

An added advantage of solar power for developing countries is the relative availability of the technology needed. Solar Concentrators are used whenever the required collector-output temperature is beyond the reach of the flat plate collector. They are used for intermediate temperatures (100-170°C) and high temperatures (>170°C).

All concentrating collectors follow the same pattern to reach the required concentration. The general concept of the technology is to receive direct solar radiation on a large area (the aperture) and redirect/concentrate it on a smaller area, the absorber/receiver as illustrated in figure 1.

![CSP technology component](image)

Figure 1: CSP technology component [4]

This absorber/receiver transfers the heat to a fluid (Heat Transfer Fluid) or to a material that initiates a traditional Gas or Steam Cycle. [4] There are different CSP technology families that differ mainly in the design, direction of the concentration (line or point focused), the receiver type and the tracking system. Those are summarized in table 1:
Table 1: The four CSP technology families [7]

(*CRS: central receiver system)

The first commercial solar power plant began operations in California between 1984 and 1991. With the decrease of the worldwide fossil fuel price, this CSP plant stopped its operations. In 2006, with the introduction of governmental incentives for CSP in Spain and the United States, new plants were installed. By 2010 the CSP installments worldwide reached almost 1 GW, while more projects are still in development or planning phases in China, India, Morocco, Spain, United States and Egypt. [7] Some barriers still exist that hinder the large deployment of CSP, such as lack of a framework, supportive policies and incentive schemes to promote CSP.

This thesis, titled “Feasibility of CSP under Egyptian Conditions” will attempt to answer two main questions:

- In Egypt there is a need for private investment to promote Renewable Energy especially CSP. How can Egypt attract private investment in the local CSP market in terms of a motivating framework?

- To formulate policy it is always important to contemplate economic factors. In order to help policymakers plan the capacity and the installation of CSP it is important to answer this question: When is it more economical to install CSP instead of conventional energy sources?

The research methodology was based on the review of previous papers and studies as well as published reports by local governmental authorities in Egypt such as the New and Renewable Energy Authority (NREA), the Egyptian Electric Holding Company (EEHC), international organizations concerned with Renewable Energy in general and
others specialized in CSP. In order to have a reflection of real life practices, several personal interviews were conducted with key players in the Egyptian solar energy market. A diverse selection of stakeholders was chosen so as to obtain a comprehensive understanding of the issue. Those interviewed included representatives of NREA, international donors, and consultants. To calculate the point at which CSP becomes more economical than conventional energy power plants, a model published in a paper of Trieb et al. was applied to the Egyptian case. The literature review together with interviews provided insight into the CSP situation in Egypt and facilitated an analysis of the situation. This in turn resulted in conclusions, recommendations and ideas to be implemented in Egypt that could promote the CSP deployment in the country.

To date there is no single pure CSP plant in Egypt, as will be explained in the government plan and current projects for CSP. On the other hand, the wind energy market offers many successful examples of how different policies and procedures were applied to encourage this sector. This makes the wind market a good reference for studying how Egyptian Renewable Energy market policies could also be applied to CSP. Therefore while studying CSP policies, regulations and incentives, references to wind energy examples will be drawn upon.

Answers to the study questions and analysis of the thesis topic will be presented in the different chapters as follows:

Chapter one: Introduction

Chapter two: Briefly presents the energy scene in Egypt, beginning with the current energy consumption, a description of Egypt’s great CSP potential and a status update on its strategy. Energy pricing will also be briefly discussed, particularly the existence of a high government subsidy.

Chapter three: Outlines the Egyptian framework for attracting investment with a description of regulatory guidelines and key authorities in the Renewable Energy sector. Also, the most common international market incentives are analyzed to pinpoint the most effective ways to promote CSP investments. Within this overview, a study of the Moroccan Solar Experience is conducted to compare cases and extract lessons that could enhance the design of an Egyptian strategy. These studies provide the foundation for recommendations for the improvement of the Egyptian framework. They also informed a section on the measures Egyptian authorities can adopt to promote CSP in Egypt and attract private investment, be it foreign or local.

Chapter 4: Presents an overview of the existing CSP plants worldwide to know the global installed capacity as well as the planned capacity. CSP is a comprehensive technology that allows different uses and benefits. The different applications of CSP in power generation, heat for industry, water desalination or cooling will be explained. In addition, the potential of the local manufacturing sector will be studied, as this is the key to accelerating the development of the technology and expanding the
economic benefits for the country. In this chapter an overview of the local manufacturing capacity for CSP components is given.

Chapter five: Discusses the feasibility of CSP plants in Egypt in terms of common incentive systems for Renewable Energy in general and CSP, in particular feed-in tariff. Steps to design the feed-in tariff will be described as well as important dimensions/parameters that should be taken into consideration when doing its design. One of the main challenges facing CSP is high investment costs. These costs have great potential to be reduced thanks to the learning opportunities that come with the installation of each megawatt CSP in the world. This cost decrease could be plotted through an experience curve over time according to the expected CSP installments worldwide. On the other hand, fuel cost is increasing, resulting in a continual increase in the cost of producing electricity from conventional sources. At a certain point CSP will be more economical than conventional power plants. These points are determined for Egypt and are followed by sensitivity analysis for some parameters.

Chapter six: Conclusion
CHAPTER TWO

ENERGY SCENE IN EGYPT
In order to analyze the feasibility of CSP in Egypt and propose strategies for its promotion, it is important to take a closer look at the energy situation in Egypt and its potential for solar power. This chapter includes an overview on the current demand and supply of energy in Egypt as well as a forecast of the future. An assessment of solar power potential will be offered, with a demonstration of the role that could be played by CSP, the current status as well as government plans for its use. In the last section, the cost of energy, which plays an important role in CSP promotion, will be briefly discussed.

2.1. Energy Consumption

Egypt relies to a large extent on thermal power generation. Hydro power comes in second place, while the power obtained from Renewable Energy – only wind – is still minimal. Still, an increase of 39.3% in Renewable Energy utilization from 2007/2008 to 2008/2009 was achieved.

The total installed capacity in Egypt currently exceeds the peak load, which means that the country is able to meet the demand for power through its own production, as shown in Table 2 below. However if wind and hydro are considered only partially as firm capacity, there will not be security margin left, which is a critical issue.

<table>
<thead>
<tr>
<th>Description [MW]</th>
<th>2008/09</th>
</tr>
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<tbody>
<tr>
<td>Peak Load</td>
<td>21,330</td>
</tr>
<tr>
<td>Hydro</td>
<td>2,800</td>
</tr>
<tr>
<td>Thermal</td>
<td>18,230</td>
</tr>
<tr>
<td>Wind</td>
<td>425</td>
</tr>
<tr>
<td>Private Sector BOOTs (Thermal)</td>
<td>2,047</td>
</tr>
<tr>
<td><strong>Total Installed Capacity</strong></td>
<td><strong>23,502</strong></td>
</tr>
</tbody>
</table>

Table 2: Installed capacity in Egypt vs. peak load [1]

Energy from conventional sources remains the main source of energy, as demonstrated in Figure 2 below. Oil has been playing a significant role since 1972, while gas has been gaining more importance during the past decade. Hydro power has also made a contribution, but its deployment has almost reached the maximum of its potential, around 2.8 GW.
The power generation figures in Table 3 also prove that hydro power has been deployed, and has even decreased its contribution to national power generation from 2007/2008 to 2008/2009. On the other hand, power purchased from isolated power plants (IPPs) and power from Renewable Energy has increased as these represent also part of the government energy strategy, as will be explained in the coming sections.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>15,510</td>
<td>14,682</td>
<td>(5.3)</td>
</tr>
<tr>
<td><strong>Thermal</strong>¹</td>
<td>95,782</td>
<td>101,898</td>
<td>6.4</td>
</tr>
<tr>
<td>Wind (Zafarana)²</td>
<td>831</td>
<td>931</td>
<td>12</td>
</tr>
<tr>
<td>Energy purchased from IPPs³</td>
<td>14</td>
<td>17</td>
<td>21.4</td>
</tr>
<tr>
<td>Private Sector (BOOTs)</td>
<td>12,642</td>
<td>13,241</td>
<td>4.7</td>
</tr>
<tr>
<td>Isolated Plants</td>
<td>350</td>
<td>271</td>
<td>(22.6)</td>
</tr>
<tr>
<td><strong>Total Power Generated</strong></td>
<td>125,129</td>
<td>131,040</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Table 3: Energy generation in Egypt [1]

(1) Includes commissioning tests
(2) Connected to grid
(3) Power purchased from industrial plants self generation (IPPs) year 2008/2009 as follows: Petrochemical (6.2 GWh), Carbon Black (4.3 GWh), Medallek and Medor (0.1 GWh) and Talkha Fertilizer (6.4 GWh)
(4) There are 257 MW installed Capacity for isolated units, including 5 MW Wind at Hurghada [1]

In order to produce thermal electricity, conventional primary energy is required. In Egypt this is usually natural gas or petroleum. This is not the case when producing electricity from Renewable Energy sources, so the conventional primary energy sources that are saved represent an opportunity gain. Taking this into consideration, the average fuel consumption rate for producing electricity is 216.1 gm of oil equivalent per kWh in 2008/2009. The higher the Renewable Energy share, the lower the rate.

In addition to the consumption of primary energy sources and the associated eventual depletion of conventional energy sources, conventional power production has another
dangerous side effect: it leads to CO2 emissions amounting to 2.55 ton co2/t.o.e. As evident in Table 4 below, Renewable Energy sources have the advantage of protecting the environment, thus earning their categorization as “green energy.”

<table>
<thead>
<tr>
<th>Fuel Consumption (thousand t.o.e.)</th>
<th>Thermal</th>
<th>24,896</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>(3,173)</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>(205)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CO2 Emissions (thousand ton)</th>
<th>Thermal</th>
<th>63,488</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>(8,075)</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>(520)</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Fuel consumption and CO2 emissions [9]

The energy demand in Egypt is expected to increase due to a predicted increase in population -annual population growth 1.8% [10]-, as well as economic growth -GDP growth rate 2009 4.6% [11]. Conventional energy sources are limited and will gradually be depleted, which will create a shortage in supply in the near future (See Figure 3 below). This could be resolved by decreasing demand through energy efficiency. To fill the remaining gap in supply, alternative energy sources shall be found which will most likely be Renewable Energy sources.

Figure 3: Expected future “conservative” energy scenario till 2022 [12]

Taking this forecast into consideration, the MED CSP study has developed a scenario for future energy production during peak load days (See Figure 4). Renewable Energy, especially CSP, will play a significant role in energy production while fuel will play a very small part.
Egypt’s geographical location allows it to be well connected with different countries and continents in a variety of ways. The most important of these are the Arab Electrical Interconnection, connecting Egypt to some Arab countries and then to Europe through two paths. The first path goes from Egypt to Jordan, Syria, Lebanon, Libya, Iraq and Turkey. The second path connects Egypt to Arab Maghreb extending from Libya to Morocco, then to Europe through Spain. In 1998 a connection to Libya (400kV) and Jordan (220 kV) was established, while in 2000, a connection was set up with the Syrian electricity grid (440 kV) which was extended in 2009 to Lebanon. These networks are the result of Egypt’s participation in the Observatoire Mediterranean de l’Energie (OME) [2] and are expected to facilitate the trade of energy and electricity with Europe.

Other interconnections to Saudi Arabia, and African countries are being studied and developed, which shall open another important channels for energy exchange. Other linkages are already operational.
2.2. Potential of Solar Energy in Egypt

Solar Energy is a key energy source but it is distributed unevenly worldwide. Figure 5 shows which areas of the world have highest potential for CSP, and demonstrates why Egypt is considered one of the Sun Belt countries.

Figure 5: Annual heat output per unit collector area [kWh/m²] from solar thermal power plants [8]

A Solar Atlas was created for Egypt in 1991, which revealed that the country is endowed with high intensity direct solar radiation (See Figure 6). This radiation ranged from 1970 – 3200 kWh/m²/year from north to south, with the southern areas of the country demonstrating greater potential than the northern areas. The duration of sunlight ranged from 9 – 11 hours with few cloudy days year long. [9]

Figure 6: Solar atlas for Egypt [9]
Many studies were conducted by the German Aerospace Centre (DLR) to evaluate the potential of Renewable Energy resources, especially CSP, according to technical and economic potential. In these studies, technical potential represents “the potential that can be accessed for power generation by the present state of the art technology” [3]. The “economic potential are those with a sufficiently high performance indicator that will allow new plants in the medium and long term to become competitive with other renewable and conventional power sources, considering their potential technical development and economies of scale.” [3]

The highest economical potential Egypt has from Renewable Energy sources is CSP, amounting to 73,656 TWh/year [3]. This is clearly illustrated in Figure 7. The other Renewable Energy sources barely register due to their low value in comparison to CSP. However some other resources are very important even on the international map such as wind.

![Economic potential of Renewable Energy in Egypt](image)

**Figure 7:** Economic potential of different Renewable Energy sources in Egypt [3]

Compared to other countries interested in utilizing the CSP potential in the MENA region, Egypt is the second richest after Algeria, as demonstrated in Figure 8.
Egypt’s technical potential is also high, as demonstrated by the different DNI levels as demonstrated in Figure 9:

The DLR has produced detailed studies on forecasted electricity consumption for Egypt up until 2050, predicting a significant increase in electricity demand, for the reasons mentioned in the last section. This is due to an expected population increase as well as the expected economic growth, which has a proportional relationship to the electricity demand. As explained earlier, this increase cannot be met by conventional energy sources, so the government will need to rely on Renewable Energy sources. Topping the list of these Renewable Energy sources is CSP, upon which Egypt will largely depend to satisfy the electricity demand, according to the scenario. DLR
predicts a mixture of electricity sources will be used to allow “Egypt [to] make optimal use of its major domestic sources of energy: natural gas as ideally stored energy form, wind power and photovoltaic as fluctuating forms of energy, and concentrating solar thermal power as a technology that combines the characteristics of a renewable and a fossil-fuel-based power system” [14]. Figure 10 draws this expected power output from the different sources, while figure 11 shows the expected installed capacity of the different sources in comparison to the peak load and firm capacity. However, in order for this CSP contribution to be realized, strong supportive policies need to exist. These policy options and methods of implementation will be addressed in the next chapter.

Figure 10: Electricity scenario by primary energy sources for power generation in Egypt [3]

Figure 11: Installed capacity required for the electricity supply, according to the DLR scenario in Egypt [14]
The Egyptian market is ready-made for CSP utilization, as only some policy and industrial adjustments are needed. The characteristics for solar energy market, especially electricity generation are:

- High intensity of solar irradiation, as explained earlier.
- Large potential for Solar Energy. This has been demonstrated, especially in the southern part of the country. Since most of the land in this area is owned by the government, it is possible to utilize this potential through large CSP plants.
- Uninhabited large flat desert.
- Expanded gas pipeline network.
- Extended national power grid and regional interconnection.
- Cheap labor and intensive skills.
- Local industrial capabilities, however they are not yet developed.
- Potential further cost reduction of all CSP components.
- Experience with ISCCS (Integrated Solar Combined Cycle System) through the plant in Kuraymat with a CSP component.
- Political will to develop a local Renewable Energy market [15]

As a country with big potential and high electricity demand, Egypt is expected to become one of the top nations with CSP installed capacities (figure 12).

Figure 12: Solar thermal electricity generation in the MED CSP scenario [3]
2.3. Status and Vision of CSP

In the early 1980s the government of Egypt first considered a Renewable Energy strategy by studying the applicability of different Renewable Energy technologies in Egypt, as well as sources of financing, and investment opportunities. The Supreme Council of Energy in Egypt announced a strategy for Renewable Energy in 2008 stating: “Contribution of Renewable Energies by 20% of the total electricity generation by the year 2020. The share from the grid-connected wind power should be 12% of the total electricity generation, and that would represent about 7200 MW total capacities. Also, other Renewable Energy applications, led by hydropower and solar energy, will have a significant contribution.” [6, 2, 9] The exact role and mission of NREA will be discussed and evaluated in chapter 3. It is noteworthy that in this strategy a clear input of solar energy was not specified. Although solar energy is considered important, especially with the large DNI available in Egypt, government efforts to promote solar deployment have paled compared to wind power. [2]

In the five-year energy plan for 2012-2017 the Supreme Council for Energy tried to give a more specific target for solar energy by including a strategy for developing 100 MW of CSP and 20 MW of photovoltaic. A pre-feasibility study for 18 different locations was conducted within the scope of the “EM Power” study, in cooperation with KfW (German Development Bank). This study selected the Kom Ombo site for the first CSP plant in Egypt. This site is 60 km from Aswan, at N24.62° and E32.89° at the border of Faris village. An area of approximately 750 hectares of flat land is available for this plant. This location can be easily connected to the grid through a substation that shall be linked to a medium voltage line one kilometer away from the site. The site has an average yearly DNI of 2516 kWh/m² with minor seasonal variations. The location is also quite near to the Nile River, which guarantees the availability of water for cooling purposes. [2]

An initial plan for Kom Ombo is for it to include 100 MW CSP plus storage, equivalent to 150 MW, however a detailed feasibility study is expected to be conducted soon. [16]

There is also a proposal for a CSP project with capacity of 30 MW (with 8 hours thermal storage) in Marsa Alam city, to serve as a model for electricity generation projects by the private sector. [9]

One kind of power generation plant involving a solar component is the Combined Cycle System power plant. NREA initiated a program for large scale electricity generation using ISCCS power plants called the Bulk Renewable Energy Electricity Production Program (BREPP). [17] The first project implemented is the Kuraymat ISCCS power plant, which is one of the first three of its kind in the MENA region.
Kuraymat ISCCS site selection criteria:

- 92 km south of Cairo
- Uninhabited flat desert
- High intensity of solar irradiation (2400 kWh/m²/year)
- Availability of cooling water (Nile River)
- Expanded natural gas pipeline network
- Expanded (500, 220, 66 kV) unified power grid

The project consists of two parts, Solar Island and a typical Combined Cycle Island (figure 13), according to the following specifications:

<table>
<thead>
<tr>
<th>EPC Company</th>
<th>Solar Island</th>
<th>Combined Cycle Island</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPC Contract</td>
<td>66 Mio USD</td>
<td>17,430 Mio JPY</td>
</tr>
<tr>
<td></td>
<td>188 Mio EGP</td>
<td>281 Mio EGP</td>
</tr>
<tr>
<td>Operation &amp; Management</td>
<td>3 Mio USD</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>16 Mio EGP</td>
<td></td>
</tr>
<tr>
<td>Construction Supervisor</td>
<td>Fichtner GmbH</td>
<td>Fichtner GmbH</td>
</tr>
<tr>
<td>Capacity (MWe)</td>
<td>20</td>
<td>Gas Turbine 79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Steam Turbine 76.5</td>
</tr>
<tr>
<td>Electric Output (GWh/y)</td>
<td>33</td>
<td>852</td>
</tr>
<tr>
<td>Fuel saving [toe/y]</td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td>CO2 reductions [t/y]</td>
<td>20,000</td>
<td></td>
</tr>
</tbody>
</table>

**Technical Specifications**

130,800 m² total area
Parallel rows of 1920 Solar Collectors into sets of typical “U shaped” glass mirrors forming parabolic troughs. The trough focuses solar energy on an absorber pipe located along its focal line. The solar collectors are connected in series and parallel. Tracking of the sun follows from east to west while rotating on a north-south axis.
A heat transfer fluid (HTF), (typically synthetic oil) is circulated through the receiver heated to 393 °C at 20 bar.

One Gas Turbine (79 MW) firing Natural Gas as fuel to generate electricity.
One Heat Recovery Steam Generator (HRSG) that uses the exhaust gases from the gas turbine to produce superheated steam.
One steam turbine (63 MW). Cooling system in which the steam turbine exhaust will be condensed in the condenser.

Table 5: Kuraymat ISCCS technical details [9]
Kuraymat ISCCS Financial Scheme:

- Global Environmental Facility (GEF): allocated a grant of 50 million USD to cover the incremental cost
- Japan Bank for International Cooperation (JBIC): allocated a soft loan of about 97 million USD to finance the thermal portion of the plant
- NREA: will cover the local currency portion required for the project [9]

Currently solar thermal energy is used in Egypt for three main applications: electricity generation, solar water heating, and solar industrial process heat.

Egypt is heavily engaged in international and regional Renewable Energy activities, as it is one of the countries with great potential. It participates in many programs and initiatives related to Renewable Energy, especially CSP, which could help lead to rapid CSP promotion and deployment in Egypt. The main initiatives are:

Mediterranean Solar Plan (MSP)
The MSP is implemented in the framework of the Union for the Mediterranean, which includes many Arab and European countries on the Mediterranean Sea. The ‘Plan Solaire’ establishes a scenario to satisfy the base and intermediate load of the EUMENA (Europe and MENA) region with Renewable Energy, especially solar, generated and exchanged within the region through interconnections. This will lead to a 75% savings of emissions resulting from conventional sources of energy in the business-as-usual scenario. [17] This plan will also lead to reduced CSP costs and will stabilize the electricity prices. It will also create other sources of income for the country by exporting the locally-generated green electricity to other countries. The
MSP indirectly promotes Energy Efficiency and strengthens capacity-building and knowledge transfer to Southern Mediterranean countries.

Currently two regional programs are proposed up to 2020:
- Fostering the establishment of a series of solar thermal plants which satisfy local consumption and export the surplus to Europe.
- Promoting the use of solar air conditioning and cooling technologies through a regional program in the south and north Mediterranean. [17]

International Renewable Energy Agency (IRENA)
On the international level, Egypt hosted the second conference of the IRENA, following the founding conference in Bonn where 75 countries signed the IRENA statute. IRENA aims to become the global representative of Renewable Energy and the main driver for the promotion and sustainable use of Renewable Energy worldwide. IRENA’s mandate includes:
- Developing a comprehensive knowledge base.
- Providing comprehensive assistance on selecting and adapting energy sources, technology and system configurations, business models, and organizational and regulatory frameworks.
- Promoting technology transfer and providing advice on financing
- Enhancing capacity building
- Stimulating research
- Networking to cooperate with other organizations, institutions and networks [9]

Regional Activities
On the regional level, Egypt is the host country for RCREEE (Regional Center for Renewable Energy and Energy Efficiency). This is an independent regional think tank dedicated to the promotion of Renewable Energy and Energy Efficiency, the formulation of policies that support the use of green energy and the regional exchange of ideas on technology and policy issues. The group was formed out of the conviction that the promotion of Renewable Energies and Energy Efficiency required a coordinated effort in the region. RCREEE also encourages the participation of the private sector in promoting the growth of a regional Renewable Energy industry. [19]

An Arab Strategy for the use of Renewable Energy is also being prepared under the League of Arab States, which will coordinate and promote Renewable Energy within the Arab countries.

DESERTEC
DESERTEC is a non-profit foundation based in Germany to encourage the development of solar power in desert areas. It follows the holistic concept of “combining energy security and climate protection with fresh water generation, socio-economic development, security policy and international cooperation.” This is achieved with the production of green electricity, mainly from solar and wind power,
in countries with very high potential, allowing them to meet their energy consumption needs and export the excess to Europe. These countries tend to be underdeveloped. The target is to supply 10-15% of Europe's demand from clean electricity from the MENA countries by 2050 [20]. With the help of High Voltage Direct Current (HVDC) transmission lines, this green electricity could be transported for distances exceeding thousands of kilometers to "consumption centers" in other countries. [21] As Eng. Nokrashy noted, “Political will is essential to establish a legal and financial framework to govern actions and activities of such a huge project, whereas it shall be considered that at the start phase strong support from the European countries to the MENA-countries will accelerate this positive development.” [20]

2.4. Energy Pricing

While regional and international organizations encourage the development of Renewable Energy, especially solar power, the chances of their widespread adoption depend on the price consumers must pay for green energy. Egypt is one of the countries that sell energy - especially electricity - at very low prices to consumers. These large energy subsidies represent a burden on the government budget, which affects the general economic performance of the country (table 6).

<table>
<thead>
<tr>
<th>Year</th>
<th>Budgetary transfers for subsidies</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006-2007</td>
<td>51 bn LE</td>
<td>-</td>
</tr>
<tr>
<td>2007-2008</td>
<td>64.5 bn LE</td>
<td>Increase comes from increased energy consumption and increased international energy prices</td>
</tr>
<tr>
<td>2008-2009</td>
<td>40 bn LE</td>
<td>Mainly because of decrease of international energy prices, as well as slight increase of energy pricing in Egypt</td>
</tr>
</tbody>
</table>

Table 6: Energy subsidy in Egypt [12]

The energy subsidy for Egypt was expected to reach 67 million EGP in 2010/2011, representing 16.8% of the government’s budgeted expenditures. The electricity subsidy will be 6 million EGP for the same period representing another 1.6% of the government’s budget. [22]

The electrical energy tariff in Egypt is determined according to two main factors:
- Voltage levels; the lower the voltage the higher the tariff because of extra operation costs
- Purpose of consumption; whether residential, commercial, public, industrial, agricultural, etc. [23]

The government has planned for several years to reduce energy subsidies. This plan was first drawn up in 2004 but was put into force gradually in 2009 for all types of
end users. However this increase had to be frozen after the recent international economic crisis, but shall be resumed again. [12]

Reasons for an increase in energy tariffs:
- High budgetary spending on energy subsidy.
- Strongly subsidized energy pricing’s negative effect on the promotion of Renewable Energy technology, especially CSP. As will be discussed in further chapters, the investment costs for CSP are high, therefore with low domestic energy prices in Egypt, investors are not motivated to invest in CSP, as it does not show a positive business advantage compared to conventional energy. In order to promote the deployment of CSP it is essential to increase domestic energy prices.
- Increase in energy demand which reached an average of 7% during the past five years.
- High increase in costs of the construction of new power plants and associated networks due to the international increase in the equipment cost as a result of the increase of copper, aluminum and cement prices.
- Depreciation of the Egyptian pound vs. the U.S. dollar and the Euro.
- Increase of wages at an average rate of about 12% annually.

[23]

Although an increase in electricity rates paid by consumers is essential, it is important to consider the socio-economic impact and its effect on low-income families and businesses. To this end, the tariff scheme should be set smartly. Currently a tiered electricity scheme is used, with a low tariff for low-consuming residential customers. Almost 98.5% of the total residential consumers (20 million consumers) received a subsidy for their electricity in 2007/2008, totaling 2.9 billion LE. [23, 2] Figure 14 shows the electricity tariff structure for 2008. It is also important to ensure that if energy is subsidized, the subsidy goes to the poor consumer rather than the rich one. A reduction over the long term is recommended in order not to disturb other industries and the economy. Also the Renewable Energy plants will not be installed at once, on the contrary they need time in order to be able to fully depend on them in meeting the total energy demand of the country. A slow energy subsidy reduction promotes Renewable Energies, especially CSP.
**Figure 14:** Electricity tariff structure in Egypt as per Prime Minister Decree no.175 for 2008 [2]
CHAPTER THREE
EGYPTIAN FRAMEWORK FOR PRIVATE INVESTMENTS IN CSP
As noted in the previous chapter, Egypt has great untapped potential for Renewable Energy sources, especially CSP. In order to utilize it, the private sector has to be encouraged to invest in the sector. Therefore this chapter will study the current Egyptian framework as well as policies that can be adopted to promote private investment in Renewable Energy and especially in CSP.

3.1. Regulatory Setting

To understand the regulatory framework for a Renewable Energy plant, it is important to study the organizational structure of electricity and energy institutions in the country. In Egypt, the Ministry of Electricity and Energy (MOEE) is responsible for all matters regarding the generation of electricity and energy. The MOEE supervises different companies and authorities, each managing parts of the electricity and energy sector as shown in figure 15.

![MOEE organizational structure](image_url)

The electricity sector is managed by the Egyptian Electricity Holding Company (EEHC), which is chaired by the minister. The organizational structure of the EEHC is outlined in Figure 16.
The main objective of EEHC is to ensure the availability and stability of the electricity supply for all consumers, be they industrial, commercial, agricultural or residential. This is done by coordinating, supervising, monitoring and following-up on affiliated companies’ activities in the fields of electricity generation (production companies), transmission (transmission companies) and distribution (distribution companies). The EEHC has the additional role of improving and developing the technical, operational and financial performance of companies to achieve the goal of optimizing the use of all resources and maximizing the profit. [23]

Below are the main responsibilities of the EEHC sub-companies:

**Egyptian Electricity Transmission Company (EETC)**

1. Management, operation and maintenance of electric power transmission grids on extra-high and high voltages nationwide, with the optimal economic usage of those grids.
2. Organization of energy transmission on extra-high and high voltage grids nationwide through the National Dispatch Centre and the Regional Control Centres.
3. Purchase of electric power from power plants according to existing needs and the sale of this power to consumers and Electricity Distribution Companies on the extra-high and high voltages.
4. Coordination with production and distribution companies to provide electric energy of various voltages for all uses with high efficiency.
5. Cooperation with the EEHC in preparing technical and economic studies to meet the electricity demand and ensure its stability.
6. Implementation of electric power transmission projects on extra-high and high voltages, as approved by EEHC management and in accordance with time schedules.

7. Implementation of interconnection projects approved by the EEHC Board of Directors, including the exchange of electric power with other power grids interconnected to the Egyptian Grid.

8. Development of demand forecasts for its direct customers as well as financial and economic forecasts for the company.

9. Execution of all other tasks and activities related to meeting the company’s objectives as well as any jobs that may be entrusted to it within the scope of its responsibilities. [23]

Other EEHC sub-companies also perform similar roles in managing Egypt’s low and medium voltage electricity --as well as other activities-- are the Electrical Power Distribution Companies

1. Distribution and sale to customers on medium and low voltage grids; the purchase of medium voltage electric power from the EETC and the Egyptian Electricity Production Companies; and purchase of power from industrial and other Isolated Power Plants (IPPs) -- provided EEHC Board approval is obtained. Management, operation and maintenance of medium and low voltage grids in the company, in compliance with instructions from dispatch centres.

2. Preparation of forecast studies on loads and energy for customers as well as economic and financial forecasts for the company.

3. Development of studies, research, designs, and the implementation of electric projects for different purposes on the medium and low voltages, as well as performing all expected tasks.

4. Management, operation and maintenance of isolated production units.

5. Execution of other tasks and activities related to meeting the company’s objectives, as well as any jobs that may be entrusted to it by the EEHC within the scope of its responsibilities.

6. Performance of other jobs entrusted to the company by other parties, within its scope of work, so as to obtain economic benefits for the company.

[23]

The government of Egypt is fully aware of the scarcity of conventional energy and the negative effects it has on the global climate. Therefore it decided to increase the efficiency of energy utilization and move towards the deployment of Renewable Energy resources. This strategy motivated the government to initiate activities and adopt decisions which promote Energy Efficiency and Renewable Energy. The most important steps taken by the government are:

- Proposing a new electricity law. This draft law addresses energy efficiency and Renewable Energy issues. (It will be further discussed in the next section.)
• Forming the energy committee at the Federation of Egyptian Industries.
• Supporting the Egyptian Energy Saving Council for Industry.
• Establishing the New and Renewable Energy Authority (NREA). (Its role and activities will be discussed forthwith.)
• Establishing an Electric Regulatory Agency.
• Creating a national energy committee.
• Adjusting energy prices (including freezing and unfreezing them).
• Analyzing studies by national and international entities on energy pricing and subsidies.

NREA (New and Renewable Energy Authority)
In order to strengthen the role of Renewable Energy and to encourage its further development and promotion, the Egyptian government decided to form a specialised institution dedicated to this matter. According to law no.102 of 1986, NREA was founded to “prepare initiatives, draft regulations, monitor progress, ensure compliance, administer funds and perform other administrative activities” [12]. This demonstrated the seriousness of the Egyptian government in promoting Renewable Energy, and has contributed to growing commercial interest in investments in the Renewable Energy sector.

NREA is one of the institutions/bodies directly reporting to the MOEE, similar to the EEHC as previously demonstrated in figure 15. It plans its activities in coordination and cooperation with different state entities involved in the field of Renewable Energy.

According to EEHC, the cooperation between EEHC and NREA includes:
• Planning electricity generation to take into account the output of Renewable Energy plants.
• Network planning to ensure the capability of power transfer from the renewable projects.
• Preparing the PPA (Power Purchasing Agreement) to acquire energy output from Renewable Energy plants (till now only from wind farms) [23]

NREA was established with a broad mandate to encourage the establishment and promotion of the Renewable Energy market. The scope of its responsibilities includes:

1. Assessment of Renewable Energy resources.
NREA shall be responsible for the assessment and evaluation of potential Renewable Energy resources and for the elaboration of plans for their development and utilization. It shall also conduct surveys, analyze data and maintain a full Renewable Energy database.
2. **Research, development, demonstration, testing and evaluation of different Renewable Energy technologies focusing on solar, wind and biomass.**

   This includes conduction of technical, economic and environmental studies. These shall facilitate Renewable Energy utilization and encourage investors to support Renewable Energy projects by making all required information available and providing answers to all questions.

3. **Implementation of Renewable Energy projects.**

   NREA is the promoter of Renewable Energy in Egypt and shall implement projects related to green energy. These projects could be owned by NREA or by other parties, wholly or partly. NREA is responsible for administering Renewable Energy funds, whether from the state, donors or the private sector. NREA is expected to play a significant role in meeting the government’s goal of achieving 20% Renewable Energy by 2020, with at least one third of that produced by the NREA itself.

4. **Proposing national standards for Renewable Energy equipment & systems.**

   To develop these specifications NREA must conduct regular tests and evaluations. It must also manage certification programs for equipment performance.

5. **Rendering consultancy services in the field of Renewable Energy.**

   NREA should act as a consultant to all entities seeking to join the Egyptian Renewable Energy market, such as investors, suppliers and manufacturers. It shall provide the technical know-how and expertise for the development of national industries.

6. **Education, training and information dissemination**

   NREA is responsible for organizing trainings for different categories of stakeholders. This entails coordinating with companies, state entities, universities and professional bodies on Renewable Energy issues. NREA is also charged with analyzing and preparing information on different Renewable Energy users and markets and making this information available to interested parties.

7. **Policy advising and programs organizing**

   NREA is a regulator. It establishes rules and follows procedures for the allocation of land for wind farms and CSP plants. It also designs Renewable Energy promotional programs to encourage investment in these fields in the long and short term. This includes monitoring and evaluating the market and analyzing the effect of incentive programs. NREA also acts as liaison within the different state entities to facilitate issues related to Renewable Energy, such as mediating with the taxation office. [12, 9]
Supreme Council for Energy
Another important entity with a dynamic role in the Egyptian energy sector is the SCE. Operating parallel to state institutions that regulate the energy and electricity sector, SCE is a council set up by ministries responsible for the strategic functions of the energy policy. One of the most important roles of this council, given its close contact to all ministries, is handling price reform. If the electricity tariff were to be adjusted, Renewable Energy electricity—especially CSP—could be more competitive. This is because the current electricity tariff with high subsidies makes it difficult to promote Renewable Energy electricity. [12]

Egyptian Electric Utility & Consumer Protection Regulatory Agency (Egypt ERA)
This agency was established in 1997 to regulate, supervise and control all issues related to electric power generation, transmission, distribution, and consumption to guarantee availability of supply. The agency also works to avoid monopolies within the electric utilities and increase competition. [24]

3.2. Legal Basis and Possible Market Incentives
The Egyptian government has proposed a new law to govern the electricity sector. It represents the most recent legal initiative to encourage Renewable Energy use and private electricity generation. This law is expected to be discussed in the new parliament. The new electricity draft law is a simple indicator of the government’s vision of the Renewable Energy market and its expectations for future Renewable Energy development.

New Electricity Law
The first chapter of Part IV of the draft law discusses Renewable Energy regulations. Article 45 describes the following mechanism, according to which power could be generated from Renewable Energy plants:

1. Competitive Bid System:
   a. The Authority [NREA] shall call for tenders to establish Electricity Generation plants from Renewable Energies to operate on their own and sell the generated electric power to the Egyptian Electricity Transmission Company (EETC) at a rate proposed by the Agency [EEHC] and approved by the cabinet.
   b. EETC shall coordinate with the Authority [NREA] to call investors for public tenders to build, own and operate Electricity Generation plants using one of the Renewable Energy resources and to sell the generated electric power to EETC at the price contracted between EETC and the investor.
2. Investors may build, own and operate Electricity Generation plants using one of the Renewable Energy resources and sell the electricity to EETC under a contract at the price approved and announced by the Cabinet. Such contracts shall be effective for 15 years provided the price [indicating the PPA] is not reduced during this period by more than 2% per annum.
EETC shall purchase and pay the value of the available power from the generation plants using Renewable Energies.” [25]

It is noteworthy that the proposed law obliges the Renewable Energy power plant to pay for the expenses of the required expansion of transmission lines. This is will increase the costs and could hold back investments.

In order to buy the electricity generated from Renewable Energy, a special fund is planned called "Fund for Development of Power Generation from Renewable Energies." As noted in draft law, “the Fund shall have a juridical personality whose function is to provide necessary support for EETC to purchase electric power available from the generation plants using Renewable Energy as specified by the executive regulations.” This fund shall obtain its budget from the following sources:

1. Amounts from financial allocations from the State budget.
2. Endowments, donations, grants and other resources acceptable by the Fund's board of directors.
3. Proceeds from Fund investments.” [25, 26]

The proposed electricity law offers an overview of the market incentives the government is planning to adopt in order to promote the Renewable Energy market.

It is now relevant to take a closer look at the most important market incentives applied in other countries that could potentially be applied in Egypt. The following graph gives an analytical overview of some successful market incentives and their applicability. Some market incentives affect the demand side while others target the energy supply. Also some of them are based on capacity output while others on generated electricity. [2]

Figure 17: Classification of Renewable Energy policy mechanism [2]
Bidding system
The current legal procedure in Egypt for private investments in large-scale Renewable Energy is the competitive bidding system on land owned by the state. A fictional example of the process for a CSP plant was described in a report on Egypt by the Regional Centre for Renewable Energy and Energy Efficiency (RCREEE):

- The country -through NREA- will make available a parcel of land meeting the needs of a CSP plant (with no costs for investors).
- The concession will be auctioned in a two-stage procedure (pre-qualification and competitive bidding).
  - Pre-qualification: The admission criteria will be proven experience and financial capacity
  - Competitive bidding: Selection of the most attractive bid
- For the bid-evaluation there will be:
  - Bid acceptance criteria, evaluating the bidder’s qualification
  - Ranking criteria; according to electricity sector policy
- The concession will be further negotiated with the first-ranked bidder on concession contract, tariff (long term PPA contract) and other technical details
- During the project implementation, the Egyptian government will provide oversight with regular monitoring procedures.
- There could be several parallel bidding rounds.

Advantages of bidding system for the government
- Low bid preparation effort. In order to call for a tender, the government only needs to allocate a parcel of land and have an assessment of the Renewable Energy potential in the area; DNI for solar plants or wind measurements for wind farms.
- Site development. The government does not assume any burden or risks for the development of the site or for project implementation. These are assumed by the investor with the government performing only a monitoring role.
- Fast Market feedback. Through this process, quick feedback from interested investors is received by the government, which allows them a better assessment of the market.
- Market regulation and policy making. This bidding system will allow better analysis of the market and of the investors’ requested margin, so as to study the feed-in tariff system and value. [12]

Disadvantage of the bidding system
Opportunity loss. The frequency of the available bids might not be as high as the market potential.

Based on the above analysis, the tendering system appears to have more advantages than disadvantages when applied to the field of Renewable Energy. Denmark recently
decided to use tendering for the development of off-shore wind projects. [27] Within Egypt, tendering will be used by a new wind farm project called “Gabal El Zeit”.

In the case of the wind farm, the advantages of the bidding system for the investor include:

- Land in return for a symbolic fee to compensate the cost of allocating the land and clearing mines. This fee could be paid in installments after operation.
- Ready prepared Environmental and Social Impact Assessment (ESIA).
- PPA for 25 years.
- Guarantee of PPA payment from the government and the Central Bank of Egypt (CBE).
- Elimination of custom duties.
- Reduced taxation.
- The project company is granted a license for power generation from the Egyptian Electricity Regulatory Agency. [16,12]

**Feed-in tariff**

The feed-in tariff is one of the price-based market instruments to promote Renewable Energy and reward investors in this field. It has been successfully applied in countries such as Spain and Germany with positive impact on the development of Renewable Energy markets. There have been requests from investors to apply this incentive in Egypt, but it is still in the negotiation phase. However, such a tariff is contemplated in the draft new electricity law for Egypt.

The feed-in tariff is a long-term power purchase agreement that a government determines for the different Renewable Energy resources. This means that every Renewable Energy resource (CSP, wind onshore, wind off-shore, photovoltaic, etc) has its own feed-in tariff. This is because each technology has its own cost curve, maturity, investment cost, and risks. Possible characteristics of the feed-in tariff will be discussed further in chapter 5.

**Types of feed-in tariffs**

- *Fixed Tariff*: paid as a price per unit of electricity (e.g EGP/kWh), constant over a specified time (sometimes only corrected to inflation)
- *Premium/Bonus*: Is an amount added to the market price of electricity. [28]

**Advantages of feed-in tariff:**

- *Low transaction costs and easier programme administration*. When the general conditions of the programme are well-designed and clearly set, it will be easy to administer and transaction costs will be minimized.
- *Transparency and healthy investment environment*. The guidelines for investment procedures (legal and contractual frameworks) and tariffs would be
known to all investors, who could therefore have a clear picture when making decisions and planning investments.

- Participation of national investors. Feed-in tariffs encourage national investors such as big factories and producers of residential compounds to enter the field. For example a cement factory could produce its electricity with Renewable Energy technology and sell the excess production to the national grid in return for a feed-in tariff.

- Performance based. Represent a cost to the government/financer only if the project is actually operating and there is output.

- Innovation promotion. Annual reduction of tariffs for new installations drives technological efficiency

- Drives economies of scale. Investment and demand are rising, and manufacturing expansion is taking place globally in response, thus lowering costs further over time.

- Stability promotion. Change of government does not affect the system, as it does not cost taxpayers anything through taxes, and so cannot be cut from the national budget

- Creates fair market participation conditions for every energy provider.

[28]

Disadvantages of feed-in tariffs:

- Requires long-term government commitment and up-front administrative costs. This is in order to pay the cost regularly.

- If not designed effectively it could represent a burden on the financer (government’s budget). If the feed-in tariff is set too high, the financer (government’s budget) will have to finance high costs for a long period.

- Feed-in tariff does not push price competition between developers. This is because the tariff is constant for all the investors. However the lower the investment cost on the investor, the higher his profit margin. It also leads to competition between manufacturers, since the ones that offer lowest cost will gain the larger market share. This should take into account the quality of a product, because if a poor quality products were installed, the output will be lower, which will result in decreased profits.

[12, 27, 26, 29]

A good feed-in law can overcome many barriers to market entry for Renewable Energy producers. For example, the German Renewable Energy Sources Act:

- Gives Renewable Energy priority access to the grid

- Obliges grid operators to purchase electricity from renewable sources at feed-in tariff

- Allows grid operators to incorporate the cost of the feed-in tariff into their overall electricity sales prices, forcing consumers to invest in Renewable Energy

- Sets the price for Renewable Energy electricity for long, fixed periods
Sets no limit to the amount of Renewable Energy feeding into the grid [28], although this could lead to problems in balancing the electricity grid. It needs to be controlled.

Spain is an example of a country that successfully designed a feed-in tariff to promote and develop the Renewable Energy market. Spain is highly dependent on imported energy. Having good solar radiation and high solar thermal power potential, the Spanish government decided to increase its annual electricity production from solar-thermal power plants (CSP) to about 4000 GWh. To do so, it designed a well-structured feed-in tariff for the CSP market, making it one of the most attractive markets for CSP investors. [30]

The feed-in tariff for CSP is defined for plants with a maximum capacity of 50 MW per power plant. The operator is allowed to choose between two options. The first is the fixed feed-in tariff where the operator gets a fixed amount in return for every kWh produced. This came to 0.27839 EUR/kWh in 2008. The second option is a premium the operator receives on top of the daily market price of electricity, on condition that the sum of the market price and the premium are within predefined prices. In 2008 those price limits were 0.262548- 0.355499 EUR/kWh. This price scheme is guaranteed for 25 years, adjusted yearly to inflation (figure 18). [30]

![Diagram of Feed-in tariff systems and values in Spain](image-url)

Figure 18: Feed-in tariff systems and values in Spain [30]
A study for RCREEE made a detailed comparison between the competitive bidding process and feed-in tariff incentives, as shown in table 7.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Competitive Bidding</th>
<th>Feed-in tariff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal development of the resource</td>
<td>Promotes large scale development of Renewable Energy plants.</td>
<td>Uncoordinated development of sites could limit production from the combined area. Promotes small and medium sized plants as well. Therefore detailed monitoring by regulator is needed, but at considerable effort.</td>
</tr>
<tr>
<td>Minimal administrative costs</td>
<td>High, e.g. preparing tender documents and evaluating bids. Yet these could be considered small in the case of large projects.</td>
<td>Considerable effort is needed to design the tariff and provide the legislation and regulations for policy implementation. Afterwards the costs will be very low as this will be a standard procedure.</td>
</tr>
<tr>
<td>Surprise-free procedures</td>
<td>Surprises may arise if the preferred bidder withdraws at a late stage of negotiations. Therefore speed in negotiations, transparency and clarity in objectives and conditions is critical.</td>
<td>Surprises could appear at the beginning in the market response to feed-in tariff schemes.</td>
</tr>
<tr>
<td>Strong competitive pressures for cost reduction on manufacturers</td>
<td>Depends on the government plan and the number and size of projects it decides to announce for tenders. Therefore not strongly promoting price reduction.</td>
<td>Encourages producers to lower the product price, so that the investment costs are lower on the developers. With a fixed feed-in tariff, their profit will increase. This will then encourage more Renewable Energy (CSP) deployment.</td>
</tr>
<tr>
<td>Power purchasing price</td>
<td>Tendering process should ensure the lowest price for electricity with consideration to the technical required specifications.</td>
<td>Determining the feed-in tariff is very critical. Offering low feed-in tariff will lead to very few projects being realized, while high feed-in tariff will result in too many projects exceeding the target.</td>
</tr>
</tbody>
</table>

Table 7: Comparison between competitive bidding and feed-in tariff [12]

**Direct Subsidy**
Another financial incentive is the direct subsidy, which is giving the operators of CSP plants a lump sum for the installation of the plant -for instance 10,000 EGP per MW installed. This mechanism is appealing because it decreases investment costs, but it does not motivate them to maximize the utilization of the power plant to produce the maximum output of electricity. This is because the incentive they are getting is for the capacity of the plant, not its output. This mechanism has proven a success in Tunisia with the Prosol Programme for the installation of domestic solar water heaters.
Governments should be very cautious with this mechanism because it could represent a serious burden on their budget. Egypt, for example, cannot afford more government budget deductions. [31]
Certificates
One of the indirect ways to offer a subsidy is by creating a new product with value only for electricity generated from Renewable Energy sources. This product could be in the form of certificates issued per unit of electricity from Renewable Energy sources. Other suppliers of electricity from conventional sources would be obliged to buy those certificates. If there are different suppliers of conventional electricity in the market, the government could obligate each to buy a minimal quantity of the certificates. This would create a market for those certificates with a price, which the operators of Renewable Energy plants could use as additional income.

In Egypt the only supplier of energy from conventional sources is the EEHC. Therefore competition and a real market would not be created. In this case the government would have to set a price for those certificates which would be bought by the EETC (the government) from the operators of Renewable Energy plants. So this would have the same effect as the feed-in premium previously explained.

Another application for certificates is for them to be traded on the international market. This is the concept behind Clean Development Mechanism (CDM), under the United Nations Framework Convention on Climate Change (UNFCCC) framework. “The CDM allows emission-reduction projects in developing countries to earn Certified Emission Reduction (CER) credits, each equivalent to one tonne of CO₂. These CERs can be traded and sold, and used by industrialized countries to meet a part of their emission reduction targets under the Kyoto Protocol.” [32]. Projects of Renewable Energy or Energy Efficiency are allowed to choose between two time frames for the CDM, either 10 years non-renewable or 7 years renewable twice. [2] Egypt signed the Kyoto Protocol on 15 March 1999, and a special unit, “The Climate Change Unit,” serves as the national focal point for climate policy issues. It is also the Designated National Authority (DNA) for CDM in Egypt. Egypt has an emissions factor of 0.525 tCO₂/MWh. [2]

CSP projects -and Renewable Energy projects in general- could be registered for CDM to benefit from the price of the CERs.
NREA is qualifying the following wind farm projects as CDM projects:
- Zaafarana 120 MW wind power plant project in cooperation with Japan.
- Zaafarana 120MW wind power plant project in cooperation with Denmark.
- Zaafarana 80MW wind power plant project in cooperation with Germany.
- Zaafarana 85 MW wind power plant project in cooperation with Spain.
- Gulf of El-Zayt 220 MW wind power plant project in cooperation with Japan.
- Gulf of El-Zayt 200 MW wind power plant project in cooperation with Germany, European Comission (EC) and European Investment Bank (EIB).

Three wind farms are already registered. [12]

Sometimes the developers/operators of Renewable Energy plants are awarded the purchasing price as a combination of the PPA and CER. If the developer receives a CER, then the PPA will be lower. For large scale projects, the developer could better
market the CERs. For small scale projects, however, it would be better for the state to consolidate the CERs and manage them together.

Quota Obligation
The quota obligation is a quantity-based market instrument, where the government sets a specific target of Renewable Energy electricity for producers, suppliers and consumers. This quota is usually facilitated by tradable certificates (same as the Certificate mechanism explained earlier). If the producer/consumer is unable to meet his quota from Renewable Energy production/consumption, he is obliged to buy certificates for the value of the remaining amount or be subjected to a penalty. In Germany this system is applied to producers of electricity. The certificates are tradable on the market, where their price is determined.
This mechanism is not technology specific, so it may not be appropriate if the government wants to promote a specific technology such as CSP, unless separate quotas are determined for each technology. One important drawback of the quota mechanism is high transaction costs.

Fiscal incentives
In contrast to financial incentives, fiscal incentives are indirect subsidies because they are not directly funded. In fact they represent an opportunity loss for the government, as they appear in form of tax- or customs exemptions for those who meet predefined criteria. For example, producers of green electricity shall be exempted from taxes for 10 years. The effectiveness of this tax exemption depends on the original tax types and rates. In some Organization for Economic Cooperation and Development (OECD) countries, which apply high energy taxes, these tax exemptions can be enough to stimulate the use of renewable electricity. In countries with lower energy tax rates, they need to be accompanied by other measures. [27]
Egypt relies to a large extent on fiscal incentives from the suppliers’ side to promote Renewable Energy. The Egyptian investment law, for instance, grants private energy generators privileges such as “tax exemption (for the first five years), currency conversion, full repatriation of profits as well as protection against nationalization and expropriation” (Law No. 8/1997, Article 16; Law No 162/2000, Article 1). [33]
Moreover the terms and conditions in a decree from the Ministry of Finance, reduce taxes for equipment and components for new and Renewable Energy. “Wind energy/solar energy and its spare parts shall be subject to 2% of the value or the import tax imposed whichever is lower.” [2]

State operated plants by NREA (PPA)
In Egypt all existing wind projects were financed with grants and low cost loans. In all developed wind farms, the state, through NREA, was the project owner and developer. A PPA was signed between NREA and EETC to buy all output of the wind farm for a value of 0.14 EGP/kWh in 2010 (0.12 EGP the purchasing price from the EETC and 0.02 EGP from the Ministry of Petroleum) with a yearly increase [16].
This purchasing price is low compared to investment costs and international feed-in tariffs, however both NREA and EETC are governmental bodies, both under the
EEHC, and therefore in the end have the same budget. This number and model will need to be revised when dealing with private investors.

3.3. **Benefiting from the Moroccan Solar Experience**

The Moroccan government decided to focus on extracting the country’s potential on Renewable Energy sources for three main reasons: i) to reduce its dependence on imported fossil fuels, ii) to protect the environment, and iii) to contribute to sustainable development. To this end, in 2009 the Moroccan Council of Government announced the Renewable Energy law. The new law set the legislative framework for promoting the deployment of Renewable Energy and encouraging investments in this sector. [6]

The first Moroccan pilot Integrated Solar Combined Cycle System (ISCCS) power plant is “Ain Beni Mathar.” This project has many similarities to the “Kuraymat ISCCS” plant in Egypt. Ain Beni Matha ISCCS is 86 km south of Qujda, eastern Morrocco. It has an installed capacity of 472 MW of which 20 MW are generated by the solar component. The total estimated cost is 400 million EUR, with different sources of funding from the African Development Bank (AfDB), Global Environmental Fund (GEF), Spanish Development Agency (ICO) and National Electricity Office of Morocco (ONE). [34]

Morocco had the foresight to play a leading role in the European plan of drawing solar power from the southern Mediterranean countries. This vision prompted it to ensure the harmonization of laws and energy regulations. The Kingdom of Morocco has a very optimistic Renewable Energy plan to achieve 42% of the installed capacity from Renewable Energy sources, of which 14% are to come from solar.(Figure 19) [35, 36, 37, 38, 39]

![Figure 19: Morocco Renewable Energy plan/strategy for installed capacity](image-url)
The Moroccan Solar Plan involves five stations over an area of 10,000 hectares which will represent 14% of the installed power by 2020, with an estimated budget of 9 billion USD (figure 20).

This project will allow annual savings of around one million tons of oil equivalent which is around 3.7 million tones of CO₂ emissions. [35, 36, 37, 38, 39] The first project of the plan is Quarzazatte Power Plant with 500 MW planned capacity, with the 125 MW in the first phase [35]. This site has an average DNI of 2,635 kWh/m²/year. An area of 2,500 hectares has been allocated to this project and an estimated electricity output of 1,150 GWh is expected annually. [40, 39]

![Solar map of Morocco with the locations of the 5 planned projects](image)

Figure 20: Solar map of Morocco with the locations of the 5 planned projects [36]

To ensure the achievement of this important project, an agency dedicated to solar power was created in 2010, called the Moroccan Agency for Solar Energy (MASEN). It is responsible for steering and guiding initiatives to develop solar electricity projects. Its tasks include site qualification, design, education, selection of operators, and monitoring project implementation as well as supervising, facilitating and coordinating all project activities. The budget of the Agency comes from three sources: the state budget, the Hassan II Fund for Social and Economic Development, Energy Investment Corporation and ONE. [36, 38, 39]

MASEN’s mission includes:

- Design of integrated solar development projects, the "solar projects", for tracts of land suitable for domestic electricity generation from solar energy.
- Contribution to research, and mobilization of needed financing for the implementation and operation of solar projects.
- Development of a proposal for submission to the government on the industrial integration of each solar project.
• The role of prime contractor for the implementation of solar projects.
• Construction of infrastructure to link solar stations to the power grid for transmission of electricity and ensuring access to a reliable water supply.
• The promotion of the solar energy program to national and foreign investors.

Within the framework of the above responsibilities, there are six tasks that are priorities for MASEN:
• The location of production sites
• The supervision of technical details, planning and safe construction, and operation and maintenance of solar plants
• The development of mechanisms to ensure the economic and financial balance of solar projects
• The negotiation of terms and conditions of export
• The clarification of conditions and modalities for technical control facilities of solar projects
• The elaboration of terms and conditions for return to the state, or any other public sites and installations, of solar projects at the end of validity of the agreement

[37]

According to the new law, competitive bidding will be applied as a legal framework for the farms, and the PPA will be financed by ONE and MASEN. Any gaps in this financing will be covered by the kingdom’s budget and international donors [35].

Although Morocco is the poorest of the European Union's southern neighbors, it is very close to Europe and already has an established transmission line with Spain. Morocco has a history of political stability and reforms to improve the business climate have steadily increased the flow of foreign investment in the past decade. Morocco is open to all forms of partnerships with companies and donors. It is looking for public-private-partnerships (PPP) as well as national-and-foreign partnerships, according to Moroccan Energy Minister Eng. Amina Benkhadra. [38]

Regarding the Clean Development Mechanism (CDM), Morocco has been one of the most successful MENA countries in registering projects for it. The United Nations Development Program (UNDP) and the United Nations Environmental Program (UNEP) helped Morocco design a strategy in 2003-2005 to develop the institutional procedures required for the CDM. At the beginning there were some difficulties and overlapping of activities between the Ministry of Environment and Ministry of Energy. To avoid conflicts, these ministries were merged. Currently 5 projects out of a portfolio of 61 projects have been registered in Morocco, including some Renewable Energy projects. [26]
3.4 How to Attract Private Investment to Egypt for CSP?

In order to develop the Renewable Energy market in general and the CSP market in particular, the private sector must play an active role in their development. Since Egypt has great DNI potential and perfect locations for CSP plants, only a few promotional measures are needed from the government to guarantee the private sector’s involvement in CSP investments. In this section the conditions that may discourage investment are described as well as the conditions needed to attract private investment.

Most challenging CSP market distortions in the energy sector:

- Distorted energy prices because of the high subsidies which drive down the price of electricity in Egypt.
- The lack of a clear and ambitious government strategy for CSP, resulting in an unpredictable market size which cannot be guaranteed.
- Reluctance in the local financial market to lend funds for Renewable Energy investments, making it difficult to obtain new financing.
- Poor fiscal, institutional and legislative framework for Renewable Energy (CSP) development.
- Insufficient trained workforce on installation, operation and maintenance of CSP plants. A shortage of trained workers capable of the installation, operation and maintenance of CSP plants.
- Undeveloped local manufacturing capacity for CSP components.
- Lack of information and awareness of the opportunities in the CSP sectors.
- High risks, be they in investments due to lengthy bureaucratic procedures, or political risks due to the uncertain post 2011 revolution future.

In order to attract private investment, especially foreign direct investment (FDI), the previous market distortions need to be overcome. Measures must also be introduced to offer some guarantees to the market. For investments to be attracted to a country, a market has to exist first. Therefore a target has to be defined and some demonstration projects developed. A profit also has to be guaranteed, such as the high feed-in premium used in Spain. Investors also require a long-term stable environment (25 years), be it political stability or output purchasing by the government. The legal framework should be improved to better protect private investments and FDI in the Renewable Energy field. [31] The following measures are therefore recommended to improve the CSP situation and market in Egypt:

**Targets**
In order to better define the market for investors, the government needs to set clear and specific targets for CSP. There should also be targets for longer time frames. The definition of this target would prove the government’s will to increase CSP projects.
The current Egyptian target of 100 MW till 2017 is too low in comparison to the country’s potential. This target represents only one project until 2017. Also CSP is not mentioned in the government plan of 20% energy generation from Renewable Energy sources till 2020. If we compare this target to Morocco’s, they have developed a Moroccan Solar Plan with 5 projects and target of 2000 MW till 2020. Moreover, it is important to find a mechanism to enforce the electricity plan and policy. One mechanism could be assigning targets to certain actors. NREA was assigned to attain one third of the Renewable Energy target for 2020 (7200 MW Wind) with the rest to be developed by private investors.

Another way the government can increase the development of CSP power is by promoting “Auto-Producing,” which is encouraging large factories, residential compounds or touristic resorts to produce their own electricity from CSP with the national grid as an auxiliary system. [31] This policy will encourage stand-alone electricity generation from CSP for low budgets. It will also lighten the burden on governmental electricity production companies in generating the required electricity for those consumers.

**Regulatory and legal improvements**

In order to better promote Renewable Energy in Egypt, an appropriate legal framework with low administrative costs and regulatory barriers is required. Therefore the new proposed electricity law should be approved by Egypt’s new parliament and announced effective as soon as possible.

Some critics have concerns about the new proposed law, as it specifies the PPA for electricity from Renewable Energy for only 15 years, which is insufficient to eliminate the investment risk. Accordingly, the electricity purchasing price should be set high to compensate this risk and guarantee a positive rate of return for investors. This is of special importance for newer technologies in Egypt such as CSP in contrast to wind power, which has longer experience in Egypt.

Another criticism is that the power purchasing price could be changed within the contract period. Although this change in price has a ceiling of 2%, it is still a threat to investors. The power purchasing price should be kept constant at least till the loan is paid back. Therefore, this needs to be changed in the law or compensated by even a higher purchasing price.

The proposed law stipulates that the cost of expanding the transmission line to Renewable Energy power plants should be paid by the investors, which increases the investment costs and discourages investments. The infrastructure should be considered part of “public works” and financed by the government (EETC).

Political concerns may arise regarding the issue of plant ownership. This was previously addressed when announcing IPP’s. At the time it was said the contracts should be based on the BOOT concept -- Build-Own-Operate-Transmit. It is
important to remember a Renewable Energy power plant has an estimated lifetime of 25-40 years, after which it will have to be decommissioned or refurbished. In both cases a new contract with a new PPA/ feed-in tariff will need to be applied.

One way to encourage investment in CSP is to identify the actors in the market and clearly distinguish their roles. The roles of the NREA, Energy Council at the Cabinet of Ministries, Egyptian Environmental Affairs Agency (EEAA) and MOEE should be clearly described, with a separation of responsibilities and activities of each. It is important to be able to guarantee cooperation and collaboration between the actors without a contradiction in roles, objectives and activities. NREA could be responsible for identifying the Renewable Energy potential in the country and providing technical support to potential investors. The Energy Council could focus more on defining the share of Renewable Energy in national energy production, as well as adjusting the legal conditions to promote the Renewable Energy market, such as energy production regulations, energy law and energy pricing. Moreover, it is necessary that working staff be assigned to the institutions in proper numbers and with proper qualifications and that these entities receive adequate financing. [39]

**Recommendations for NREA**

Although NREA has a significant impact on the promotion and development of Egyptian Renewable Energy, there is still room for improvement.

NREA began as a regulatory authority to develop the Renewable Energy market, but today it also functions as the biggest developer of Renewable Energy plants in Egypt - a clear conflict of interest. In other words, the authority that is responsible for advising investors and proposing new rules and regulations to develop the market, also owns almost all of the Renewable Energy projects. The role of NREA should be restudied and its authority restructured. One possible solution would be to divide NREA into different and separate arms with different responsibilities, management and budgets. One solution contemplates splitting the agency into three branches as follows:

- One arm as the regulatory body charged with all the Renewable Energy regulatory objectives and roles. This arm should be state-owned and affiliated to MOEE.
- A second arm would be also responsible for research and promotion of Renewable Energy in Egypt. They would work closely with the regulatory branch and could be state-owned or privatized.
- The third arm would be the Renewable Energy Commercial Developer; building, owning and operating Renewable Energy plants in Egypt. This branch would have different departments for the different Renewable Energy sources, such as wind energy, CSP, photovoltaic and biomass. The budget for this arm would be separate from the other arms to avoid conflicts of interest; moreover it could be either state-owned or privatized.
Given the problems in entities such as the NREA, the best way to promote CSP as the technology with the highest potential in Egypt is through a separate agency. This agency could focus solely on CSP promotional programs and activities, much as Morocco did with MASEN. There are different measures that this authority could undertake to facilitate CSP investments for the private sector, such as:

- Select and indentify sites suitable for CSP plants.
- Acquire and allocate land for CSP projects, which would speed the procedures for investors.
- Conduct DNI measurement campaigns at different locations over longer time frames. As known, DNI is the most critical measure for CSP. Therefore, in order to reduce the project risk, DNI measurements on the site for at least one year are vital. [2] These could be complemented with satellite analysis over the long term (15-20 years).
- Prepare a pipeline project based on findings from the previous activities. This would reduce market entry barriers and make it easier for private investors to start their projects, as well allow the pre-defined target to be achieved. This pipeline would also encourage local banks to issue credit lines for CSP projects, because they will have gained trust in the market, thus reducing project risks.
- Identify strong business partners in Egypt that can work jointly with international investors.
- Provide technical support to investors, developers, operators and manufacturers.
- Make data and information available and easily accessible to facilitate feasibility studies.
- Support and encourage the local manufacturing of CSP components. This could be done through workshops and trainings as well as by offering credit lines and fiscal incentives such as customs and tax reductions.
- Develop brochures with all the steps, documents and procedures needed for a CSP investment. This is important, because in practice there are too many procedures that need to be followed, and not all of them are known to the investors. Bureaucratic surprises could delay the launch of investments and result in opportunity losses. A clear set of steps for investors to follow could speed up the investment process and prevent problems caused by unclear procedures. NREA should therefore coordinate with all governmental entities to consolidate all their requirements. This would include governorates, the EETC, the Ministry of Social Affairs, Workers office, different chambers of industry and commerce and others involved in the Renewable Energy industry.

**Energy Price Reform**

Energy demand is price sensitive, therefore as long as the energy prices are subsidized consumers will not be motivated to invest in Energy Efficiency or green electricity. The need for the elimination of the subsidy is urgent, so electricity from Renewable Energy can be more competitive. The subsidy could be reduced in phases depending
on consumption, location and so forth. For example energy prices could be increased in touristic resorts and residential compounds [31]. However decreasing the subsidy is a very sensitive issue, since this will have other economical and social impacts, especially on the poor people. Therefore this subsidy decreased should be designed very carefully, to eliminate it first from the richer society than from the poorer one as well to design it on a longer time frame.

Putting in mind the current political situation -2011 Egyptian Revolution-, it could be expected that any tariff raise will be freezed for the next period (short term), as no cost increases will be accepted by the Egyptian citizens now.

**Incentives**

Incentives are important to make CSP projects attractive to the private sector. In order to develop the specific framework for the promotion of CSP, the following measures and actions could be taken:

- Increase tax benefits for CSP operators and CSP component manufacturers, such as tax exemptions for the first 5 years.
- Accelerate and facilitate CDM procedures, so developers can benefit quickly from CER income.
- Design an effective feed-in tariff to guarantee investment stability. This would offer long-term security for planning and financing. (This will be discussed further in chapter 5.)
- Create favorable conditions for grid access.

It is important to note that these incentives are only transitional measures that will decrease with time. They are designed to foster and monitor technological innovation and drive technologies such as CSP to reach market competitiveness quickly. [27]

**Financing**

The Renewable Energy fund contemplated in the proposed law is essential in order to fund the PPA and feed-in tariff for plant operators. There is a huge gap between the production cost of CSP (0.25 EUR/kWh [16]) and the purchasing price of EETC (0.14 EGP/kWh [16]). This gap could be only filled by the proposed fund. Furthermore, the PPA or feed-in tariff should include, on top of the cost, a profit margin in order to be appealing to investors.

Development banks and international donors need to support CSP investments with subsidized loans and grants, until the cost curve is pushed downwards and investment costs are reduced. Only then can private investors realize a profit. Moreover, after a couple of successful projects and positive examples, local banks will gain trust in the market and will be more open to offering loans for investors in these fields. [31]

The Egyptian government would do well to consider exporting CSP electricity since international energy prices are much higher than those within the country. This would represent significant income which could cover both the investment cost and a margin of profit for investors. The DESERTEC mechanism could be applied in this case.
In conclusion, it is important to take serious actions in order to have an effective impact on the CSP market. A strong start is recommended, but the approach could always be improved and developed over time. To this end, there should be a continuous monitoring process to check if the applied policies are helping achieve targets or not. Tariff values should also be monitored and adjusted to control massive market expansions. [28]
CHAPTER FOUR
CSP APPLICABILITY IN EGYPT
4.1. Survey of Important CSP Projects Worldwide

CSP is considered the technology of the future. Its use is not yet widespread as a commercial industry, but there are many CSP projects operating around the world and others under construction.

Taking into account the global DNI distribution, figure 21 identifies existing and planned projects in different countries:

![Global DNI distribution with indication to worldwide capacities (existing, under construction and announced) [41]](image)

Below is a list of some of these CSP plants installed (table 8) and planned (table 9), revealing the interest demonstrated by many countries in implementing CSP projects. This will help the spread of this technology and its commercialization:

<table>
<thead>
<tr>
<th>Capacity (MW)</th>
<th>Name</th>
<th>Country</th>
<th>Location</th>
<th>Technology type</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>Solnova</td>
<td>Spain</td>
<td>Seville</td>
<td>Parabolic trough</td>
<td>Completed between May and August 2010</td>
</tr>
<tr>
<td>100</td>
<td>Andasol</td>
<td>Spain</td>
<td>Granada</td>
<td>Parabolic trough</td>
<td>Details will be presented later in text</td>
</tr>
<tr>
<td>64</td>
<td>Nevada Solar One</td>
<td>USA</td>
<td>Boulder City, Nevada</td>
<td>Parabolic trough</td>
<td>--</td>
</tr>
</tbody>
</table>

Legend: existing capacities, capacities under construction; announced capacities; xx: capacity in MW, +: indicates large storage capacities (the capacity of the power plant is larger than the electrical capacity indicated); xx/yy: for Integrated Solar Combined Cycle or fuel saver systems, xx indicates the solar capacity, yy indicates the overall capacity.
<table>
<thead>
<tr>
<th>Capacity</th>
<th>Project Name</th>
<th>Country</th>
<th>Location</th>
<th>Technology</th>
<th>Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>Ibersol Ciudad Real</td>
<td>Spain</td>
<td>Puertollano, Ciudad Real</td>
<td>Parabolic trough</td>
<td>Completed May 2009</td>
</tr>
<tr>
<td>50</td>
<td>Alvarado I</td>
<td>Spain</td>
<td>Badajoz</td>
<td>Parabolic trough</td>
<td>Completed July 2009</td>
</tr>
<tr>
<td>50</td>
<td>Extresol 1</td>
<td>Spain</td>
<td>Torre de Miguel Sesmero (Badajoz)</td>
<td>Parabolic trough</td>
<td>Completed February 2010</td>
</tr>
<tr>
<td>50</td>
<td>La Florida</td>
<td>Spain</td>
<td>Alvarado (Badajoz)</td>
<td>Parabolic trough</td>
<td>Completed July 2010</td>
</tr>
<tr>
<td>20</td>
<td>PS20 solar power tower</td>
<td>Spain</td>
<td>Seville</td>
<td>Solar power tower</td>
<td>Completed April 2009</td>
</tr>
<tr>
<td>17</td>
<td>Yazd ISCCS</td>
<td>Iran</td>
<td>Yazd</td>
<td>Parabolic trough</td>
<td>World's first solar combined cycle power plant</td>
</tr>
<tr>
<td>11</td>
<td>PS10 solar power tower</td>
<td>Spain</td>
<td>Seville</td>
<td>Solar power tower</td>
<td>World's first commercial solar tower</td>
</tr>
<tr>
<td>5</td>
<td>Kimberlina Solar Thermal Energy Plant</td>
<td>USA</td>
<td>Bakersfield, California</td>
<td>Fresnel reflector</td>
<td>AREVA Solar, formerly Ausra demonstration plant</td>
</tr>
<tr>
<td>5</td>
<td>Sierra SunTower</td>
<td>USA</td>
<td>Lancaster, California</td>
<td>Solar power tower</td>
<td>Solar commercial power plant, North America’s only operating solar tower, completed August 2009</td>
</tr>
<tr>
<td>5</td>
<td>Archimede solar power plant</td>
<td>Italy</td>
<td>near Siracusa, Sicily</td>
<td>Parabolic trough</td>
<td>ISCC with heat storage Completed July 2010</td>
</tr>
<tr>
<td>2</td>
<td>Liddell Power Station Solar Steam Generator</td>
<td>Australia</td>
<td>New South Wales</td>
<td>Fresnel reflector</td>
<td>Electrical equivalent steam boost for coal station</td>
</tr>
<tr>
<td>1.5</td>
<td>Maricopa Solar</td>
<td>USA</td>
<td>Peoria, Arizona</td>
<td>Dish stirling</td>
<td>Stirling Energy Systems / Tessera Solar's first commercial-scale Dish Stirling power plant. Completed January 2010</td>
</tr>
<tr>
<td>1.5</td>
<td>Jülich Solar Tower</td>
<td>Germany</td>
<td>Jülich</td>
<td>solar power tower</td>
<td>Completed December 2008</td>
</tr>
<tr>
<td>1.4</td>
<td>Puerto Errado 1</td>
<td>Spain</td>
<td>Murcia</td>
<td>Fresnel reflector</td>
<td>Completed April 2009</td>
</tr>
<tr>
<td>1</td>
<td>Saguaro Solar Power Station</td>
<td>USA</td>
<td>Red Rock Arizona</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Keahole Solar Power</td>
<td>USA</td>
<td>Hawaii</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>Shiraz solar power plant</td>
<td>Iran</td>
<td>Shiraz</td>
<td>CSP</td>
<td>Iran's first solar power plant</td>
</tr>
</tbody>
</table>

Table 8: Most popular operational solar thermal power stations worldwide [11, 42]
# Solar Thermal Power Stations under construction

<table>
<thead>
<tr>
<th>Capacity (MW)</th>
<th>Name</th>
<th>Country</th>
<th>Location</th>
<th>Technology</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>370</td>
<td>Ivanpah Solar Power Facility</td>
<td>USA</td>
<td>San Bernardino County, California</td>
<td>Solar tower</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>Extresol 2-3</td>
<td>Spain</td>
<td>Torre de Miguel Sesmero (Badajoz)</td>
<td>Parabolic trough</td>
<td>With 7.5h heat storage</td>
</tr>
<tr>
<td>100</td>
<td>Andasol 3–4</td>
<td>Spain</td>
<td>Granada</td>
<td>Parabolic trough</td>
<td>With 7.5h heat storage</td>
</tr>
<tr>
<td>100</td>
<td>Palma del Rio 1, 2</td>
<td>Spain</td>
<td>Cordoba</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>Helioenergy 1, 2</td>
<td>Spain</td>
<td>Ecija</td>
<td>Parabolic trough</td>
<td>With heat storage</td>
</tr>
<tr>
<td>100</td>
<td>Solaben 1, 2</td>
<td>Spain</td>
<td>Logrosan</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>Valle Solar Power Station</td>
<td>Spain</td>
<td>Cadiz</td>
<td>Parabolic trough</td>
<td>With 7.5h heat storage</td>
</tr>
<tr>
<td>100</td>
<td>Termosol 1+2</td>
<td>Spain</td>
<td>Navalvillar de Pela (Badajoz)</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>Helios 1+2</td>
<td>Spain</td>
<td>Ciudad Real</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>Martin Next Generation Solar Energy Center</td>
<td>USA</td>
<td>Florida</td>
<td>ISCC</td>
<td>Steam input into a combined cycle</td>
</tr>
<tr>
<td>50</td>
<td>Majadas de Tiétar</td>
<td>Spain</td>
<td>Caceres</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Lebrija-1</td>
<td>Spain</td>
<td>Lebrija</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Manchasol-1</td>
<td>Spain</td>
<td>Ciudad Real</td>
<td>Parabolic trough</td>
<td>With heat storage</td>
</tr>
<tr>
<td>50</td>
<td>La Dehesa</td>
<td>Spain</td>
<td>La Garrovilla (Badajoz)</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Axtesol 2</td>
<td>Spain</td>
<td>Badajoz</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Arenales PS</td>
<td>Spain</td>
<td>Moron de la Frontera (Seville)</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Serrezuela Solar 2</td>
<td>Spain</td>
<td>Talarrubias (Badajoz)</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>El Reboso 2</td>
<td>Spain</td>
<td>El Puebla del Rio (Seville)</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Moron</td>
<td>Spain</td>
<td>Moron de la Frontera (Sevilla)</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Olivenza 1</td>
<td>Spain</td>
<td>Olivenza (Badajoz)</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Medellin</td>
<td>Spain</td>
<td>Medellin (Badajoz)</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Valdetorres</td>
<td>Spain</td>
<td>Valdetorres (Badajoz)</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Badajoz 2</td>
<td>Spain</td>
<td>Talavera la Real (Badajoz)</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Santa Amalia</td>
<td>Spain</td>
<td>Santa Amalia (Badajoz)</td>
<td>Parabolic trough</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Torrefresneda</td>
<td>Spain</td>
<td>Torrefresneda</td>
<td>Parabolic trough</td>
<td></td>
</tr>
</tbody>
</table>
**Andasol (Spain)**

It is important to study the Andasol CSP plant in detail, as it was the first CSP plant in Europe, and serves as a good example for the Egyptian case. Andasol was developed by Solar Millennium, which is also the developer of the first ISCCS plant in Kuraymat, Egypt. Andasol has an annual average Direct Normal Radiation (DNI) of about 2136 kWh/m²/year. The distribution of this sunlight over the years is detailed in the graph below:

---

Table 9: Most popular solar thermal power stations under construction worldwide [11, 42]

<table>
<thead>
<tr>
<th>Rank</th>
<th>Station</th>
<th>Country</th>
<th>Location</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>La Puebla 2</td>
<td>Spain</td>
<td>La Puebla del Río (Sevilla)</td>
<td>Parabolic trough</td>
</tr>
<tr>
<td>25</td>
<td>Termosolar Borges</td>
<td>Spain</td>
<td>Borges Blanques (Lerida)</td>
<td>Parabolic trough</td>
</tr>
<tr>
<td>17</td>
<td>Termosolar Borges</td>
<td>Spain</td>
<td>Fuentes de Andalucia (Seville)</td>
<td>Solar tower</td>
</tr>
<tr>
<td>20</td>
<td>Kuraymat Plant</td>
<td>Egypt</td>
<td>Kuraymat</td>
<td>ISCC</td>
</tr>
<tr>
<td>25</td>
<td>Hassi R'mel integrated solar combined cycle power station</td>
<td>Algeria</td>
<td>Hassi R'mel</td>
<td>ISCC</td>
</tr>
<tr>
<td>20</td>
<td>Beni Mathar Plant</td>
<td>Morocco</td>
<td>Ain Bni Mathar</td>
<td>ISCC</td>
</tr>
<tr>
<td>1.4</td>
<td>THEMIS Solar Power Tower</td>
<td>France</td>
<td>Pyrénées-Orientales</td>
<td>solar power tower</td>
</tr>
<tr>
<td>1</td>
<td>Renovalia</td>
<td>Spain</td>
<td>Albacete</td>
<td>dish</td>
</tr>
</tbody>
</table>
Andasol is constructed with parabolic trough technology driving a Rankine Cycle. Located in southern Spain, the plant is being built in three phases. While Andasol 1 is already in operation, Andasol 2 has started the commissioning phase and Andasol 3 is still under construction. The three phases together represent the largest solar power plant in the world in terms of collector area, totaling an impressive 15 million square meters.

An Andasol power plant requires 7,488 collectors divided into 312 collector rows which are connected by pipes. The rows are set up on a north-south axis and follow the course of the sun from east to west. One row is made up of two collector units. Each collector unit comprises 12 collectors. (Figure 24)

The Andasol plants are expected to generate a net electricity output of 150 GWh per year. Each of the three plants has a capacity of 50 MW and thermal storage covering 7.5 hours at full-load. The heat reservoirs are each comprised of two tanks measuring 14 m in height and 36 m in diameter and containing liquid salt. Each provides 28,500 tons of storage medium (mixture of potassium and sodium, and nitrate salts). Figure 23 shows a schematic view of the plant.
This plant was planned so as to support Spain's peak power demand during summer months. It was designed to produce enough green electricity to meet the needs of 600,000 people while reducing carbon dioxide emissions by 450,000 tons a year [30, 43].

As for water requirements, the plant needs about 870,000 m² of water per year, mostly to replenish the condenser-cooling circuit, i.e. to make up for evaporation of water in the cooling towers. Water needs are met primarily with ground water extracted from wells on the site. [30]

The total cost of the Andasol 1 power station is estimated at 300 million EUR, which is approximately 6000 EUR/kW. [44]

Table 10 shows some figures detailing plant efficiency:

<table>
<thead>
<tr>
<th>Andasol CSP plant</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar field</td>
<td></td>
</tr>
<tr>
<td>Peak Efficiency</td>
<td>70%</td>
</tr>
<tr>
<td>Annual Average</td>
<td>50%</td>
</tr>
<tr>
<td>Turbine circuit</td>
<td></td>
</tr>
<tr>
<td>Peak Efficiency</td>
<td>40%</td>
</tr>
<tr>
<td>Annual Average</td>
<td>30%</td>
</tr>
<tr>
<td>Entire Plant</td>
<td></td>
</tr>
<tr>
<td>Peak Efficiency</td>
<td>28%</td>
</tr>
<tr>
<td>Annual Average</td>
<td>15%</td>
</tr>
</tbody>
</table>

Table 10: Overview over Andasol CSP plant efficiencies [30]
4.2. CSP in Egypt SWOT Analysis (strengths, weaknesses, opportunities and threats)

**Strengths**
- Egypt has high solar radiation ranging between 1970 – 2800 kwh/m²/year from North to South. This is a very high DNI and allows high efficiency and output for CSP plants. [9]
- Egypt possesses a land area around one million square kilometers, with a broad desert area interrupted by the Nile Valley and Delta. This makes land availability for CSP deployment very high. In addition, CSP plants require little specific surface area in terms of the amount of energy produced per square meter. [30]
- CSP is a green technology and produces energy with minimized carbon. Lifecycle CO₂ emissions of solar-only CSP plants are assessed at 17 g/kWh against, e.g., 776 g/kWh for coal plants and 396 g/kWh for natural gas combined cycle plants.
- There are various possible outputs from the CSP technology: power, heat, water desalination, and cooling. This will be further discussed in the next section.
- CSP can be used to cover the normal energy load, as the energy it produces can be fed into the grid and distributed to the consumers.
- CSP has an important competitive advantage over other Renewable Energy sources, such as photovoltaic and wind, which is storage capacity. Energy can be stored with higher efficiency and more cost effectiveness than electricity. Various storage technologies exist in the form of heat (Molten Salt, Phase Change Material, and so on). This storage capacity allows production of...
electricity on demand to satisfy the peak and medium loads of a country. Therefore CSP is more appropriate for peak load satisfaction when compared to other Renewable Energy technologies. (Figure 25)

![Figure 25: Estimate of 24-hour CSP energy production with storage and backup [45 cited in 41]](image)

According to the daily load curves of Egypt, a storage size of 6 hours is the minimum needed to cover the early evening hours. Sixteen hours of storage would result in approximately continuous ~24 hour operation. [2] Figures 26 and 27 show a daily load curve in Egypt during a summer day and a winter day respectively.

![Figure 26: Egypt load curve during a summer weekday [2]](image)
CSP operates only with direct solar radiation, therefore the clear Egyptian atmosphere combined with lengthy periods of daily sunshine (9-11 hrs) and few cloudy days, makes it a more attractive area for CSP deployment.

The energy amortization period is used to measure the time a power plant needs to produce the energy required to build the power plant itself. CSP plants have a relatively short amortization period of about five months, which is low when compared to other forms of Renewable Energy. The amortization period for wind farms is 4 to 7 months and for photovoltaic power plants, 2 to 5 years. [30]

The heating capacity of CSP gives it an advantage over flat plate collectors. With CSP you can reach temperatures of 400°C, while with flat plates only up to 90°C. This is very important for some heat transfer fluids such as ammonia, and industrial processes that require heat at high temperatures.

CSP usually requires water for the condensation process, so it is preferable for CSP plants to be located next to water resources. Not only does the Nile River cross Egypt but the nation boasts lengthy coastlines along both the Mediterranean and Red Seas. This increases the availability of locations with high solar radiation and access to water for CSP projects.

**Weaknesses**

- CSP has high investment costs ranging from 4.2-8.4 USD per watt, depending on the solar resource and storage size. [41] In Egypt, the CSP is estimated to cost 0.25 EUR/kWh [16]. However, we are still at the beginning of the learning curve and at the peak of the cost curve. It requires further CSP installations to decrease the investment cost.
In Egypt CSP is still a relatively new technology, since only one Combined Cycle Power Plant has been installed with only 20 MW solar share. Another 100 MW plant is planned.

Up until now, parabolic trough technology has been the only large-scale solar power plant technology with proven reliability over a long period of time.

Long and complex construction. The purchase of components for CSP plants can sometimes take up to two years. [46]

Technical staff is needed on a CSP plant for operation and maintenance, in contrast to photovoltaic, where no personnel are needed on site.

Opportunities

- CSP will help to secure the energy supply for Egypt, a vital task in light of the electricity cut offs experienced in summer 2010.
- From each square kilometre of desert land, about 250 GWh of electricity can be harvested each year using concentrated solar thermal power technology. This is over 200 times more than what can be produced per square kilometre by biomass, and 5 times more than what can be generated by the best available wind and hydropower sites. (Assume: Solar irradiance 2400 kWh/m²/y * 11 % Annual Solar-Electric Net Efficiency * 95 % Land Use (Linear Fresnel) ) [47]
- CSP offers job opportunities, thus helps decrease the unemployment rate in Egypt.
- Other related industries will start to grow as they supply needed CSP equipment, which in turn will improve the Egyptian economy.
- CSP can have a positive impact on the country's economic performance as it begins to export electricity to Europe and elsewhere.
- The Egyptian government has been keen to promote Renewable Energies including CSP, and will facilitate the needed processes for interested investors.
- CSP has a very high potential for cost reduction, with the increased installation of CSP projects worldwide. (more details in chapter 5)
- CSP has a Capacity Credit of almost 90%, which is the contribution to firm capacity and balancing power. This proves that CSP has a potential full contribution to firm capacity. [48]
- Capacity Factor (average annual utilization of the system) of CSP can reach up to 90% depending on the storage capacity and annual radiation. [48]

Threats

- Subsidized energy costs in Egypt combined with low purchasing prices for electricity make it difficult to present a positive business case.
- No feed-in tariff or fixed PPA system in Egypt for Renewable Energies.
- In a CSP plant driving a steam cycle, the mechanism goes as follows. The heat-transport fluid (e.g. oil) is heated in the tube of the solar collector, and pumped into centrally located power block, where it flows through a heat exchanger. The remainder of the process is similar to the steam cycle used in
conventional power plants. The steam produced by the heat exchanger is used to drive a turbine connected to a generator. The steam in the turbine condenses back into water and the water is then re-circulated. For this condenser water is required (ca. 5 liter per kWh) [46]. This could represent a threat, putting in mind the scarcity of water resources in the future. A solution could be the dry cooling. However the cooler represents an extra investment cost to the plant. Moreover it has higher operating costs, since the fans in the dry cooler consume electricity, which also decreases the efficiency of the plant. [6, 30]

- Heat transfer fluid (HTF) as it is hazardous material, if spilled could lead to pollution in soil or water. It has also an unpleasant smell.

### 4.3. Possible Fields of Application of CSP

#### 4.3.1. Power Generation

CSP involves the conversion of solar radiation to thermal energy, which is then used to run a power plant. Solar thermal power generation can integrate well with conventional power options and is attractive to utility markets because it allows the option of adjusting capacity to match national generation needs. This is made possible through the CSPs storage potential, as noted in the previous section.

CSP generation is starting to be cost effective for large-scale (~ MW) power generation systems used mostly to fulfill grid peak power needs, as will be discussed further in the next chapter. In these systems, parabolic troughs are used to focus the solar radiation onto collector tubes, thus heating the working fluid as it moves to a central plant.

For smaller scale power generation (1 ~ 20 kW), a parabolic dish can be used to focus the solar radiation to a point. A collection device or a heat engine, such as a Stirling engine, can then be placed at this focal point. Although a number of dish/Stirling engine CSP systems have been developed over the past few decades only a few have shown promise for implementation. This is due to the fact that, while based on a conceptually simple thermodynamic cycle, a reliable long-lasting Stirling engine requires effort and cost to design, build and maintain, as experience has demonstrated. [49]

Parabolic troughs, linear Fresnel systems and solar towers can be coupled to steam cycles of 5 to over 200 MW of electric capacity, with thermal cycle efficiencies of 30-40%. The values for parabolic troughs have been demonstrated in the field. [47] Table 11 shows performance data of different CSP technologies.
Table 11: Performance indicators of different CSP technologies [47]

<table>
<thead>
<tr>
<th>Technology</th>
<th>Capacity Unit [MW]</th>
<th>Concentration</th>
<th>Annual Solar Efficiency</th>
<th>Capacity Factor (solar)</th>
<th>Land Use m²/MWh/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trough</td>
<td>10-200</td>
<td>70-80</td>
<td>10-15% (d)</td>
<td>24% (d)</td>
<td>6-8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>17-18% (p)</td>
<td>25-90% (p)</td>
<td></td>
</tr>
<tr>
<td>Fresnel</td>
<td>10-200</td>
<td>25-100</td>
<td>9-11% (p)</td>
<td>25-90% (p)</td>
<td>4-6</td>
</tr>
<tr>
<td>Power Tower</td>
<td>10-150</td>
<td>300-1000</td>
<td>8-10% (d)</td>
<td>25-90% (p)</td>
<td>8-12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15-25% (p)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dish Stirling</td>
<td>0.01-0.4</td>
<td>1000-3000</td>
<td>16-18% (d)</td>
<td>25% (p)</td>
<td>8-12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18-23% (p)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(d) = demonstrated; (p) = projected
ST: Steam Turbine; GT: Gas Turbine; CC: Combined Cycle
Solar Efficiency: net power generation/incident beam radiation
Capacity Factor = solar operating hours per year/8760 hours per year
Performance data of different CSP technologies [47]

4.3.2. Process Heat
A very important outcome of CSP that is unfortunately seldom used is heat. Many industries need large quantities of heat for different stages of their processes. A study by the International Energy Agency (IEA) recommended the use of heat from CSP technology for industries such as food, textile, transport equipment, metal and plastic treatment, and chemical. Heat is especially needed for processes such as cleaning, drying, evaporation and distillation, blanching, pasteurization, sterilization, cooking, melting, painting, and surface treatment. This is because in these processes 27% of the heat required should be at medium temperature (100-400°C) and 43% should be above 400°C.

The study also noted that the most suitable technologies for extracting heat for industrial processes were parabolic trough technology and the fresnel system. [45, 50]

4.3.3. Water Desalination
Water scarcity is becoming a topic of increasing concern in these times. However one advantage for some countries facing the threat of water shortages is the high solar potential. The AQUA CSP study by the DLR (German Aerospace Center) has analyzed the potential for using the solar power in sea water desalination, and found the solar resource potential in the MENA region could easily cover the countries’ deficit in drinking and irrigation water. [20, 47]

The study notes that the potential annual water deficit in the region is 50 billion cubic meters, and is expected to grow to about 150 billion cubic meters a year by 2050. It predicts that energy from solar thermal power plants will become the cheapest option
in the next 20 years for both electricity at below 4 eurocents per kWh and desalinated water at below 40 eurocents per cubic meter. It would not be an exaggeration to say solar desalination could eventually produce around 50% of the regional water supply. [47]

CSP systems have the potential to operate cleaner desalination plants with extremely low environmental impacts compared to today’s conventional desalination systems. They do so at about 20% higher investment cost, but using a fuel that will be considerably less expensive than today’s fossil fuel sources. Individual plant locations would need to be chosen carefully to allow rapid discharge and dilution of brine, and subjected to a thorough environmental analysis to avoid impacting important marine life. [45]

DLR suggests that the most appropriate technology mix would be either the concentration of solar power providing electricity into a reverse osmosis process membrane desalination (RO), or the concentration of solar power electricity and heat into a thermal ‘multi effect’ desalination system (MED).

Reverse osmosis (RO) is a membrane separation process that recovers water from a saline solution pressurized to a point greater than the osmotic pressure of the solution. In essence, membrane filters hold back the salt ions from the pressurized solution, allowing only the water to pass. Pre-treatment of the feed water is an important process step and can have a significant impact on the cost and energy consumption of RO. [47] (Figure 28)

![Figure 28: Principle of Reverse Osmosis Desalination](image)

MED is a thermal distillation process. The feed water is sprayed or otherwise distributed onto the evaporator surface (usually tubes) of different chambers (effects) in a thin film to promote evaporation after it has been preheated in the upper section of each chamber. The evaporator tubes in the first effect are heated by steam extracted from a power cycle or from a boiler. The steam produced in the first effect is condensed inside the evaporator tubes of the next effect, where again vapor is produced. The surfaces of all the other effects are heated by the steam produced in
each preceding effect. Each effect must have a lower pressure than the preceding one. This process is repeated within up to 16 effects. The steam produced in the last effect is condensed in a separate heat exchanger called the final condenser, to be cooled by the incoming sea water, which is then used as preheated feed water for the desalination process. [47] (Figure 29)

![Figure 29: Principle of MED [47]](image)

The difference between CSP/MED and CSP/RO in terms of technical and economic performance is rather small. However, the specific water output per square meter of collector area of a CSP (Parabolic-Dish-Steam-Cycle) system coupled to RO is higher than that of a CSP to MED plant. This is because the electricity produced by the CSP plant will be fully used by RO, while MED will only use low-temperature steam extracted from the turbine and about 2 kWh/m³ of electricity for pumping, leaving most of the electricity generated by the CSP plant for other purposes. Therefore, a comparison on the basis of collector area only makes sense taking into account both products of the CSP plant (power and water).

There are other water desalination technologies such MSF (Multi Stage Flash). This is a thermal distillation process that involves evaporation and condensation of water. The evaporation and condensation steps are coupled to each other in several stages so that the latent heat of evaporation is recovered for reuse by preheating incoming water. (Figure 30) MSF process has the disadvantage that it requires a lot of energy and operates with high temperature steam, resulting in painfully reduced electricity output by the connected steam turbine. Therefore RO and MED are preferred. [14, 47]
According to the Aqua CSP study, CSP desalination will play a significant role in covering the water demand in Egypt, starting in 2030, as illustrated in the following graph. (Figure 31)
### 4.3.4. Cooling

Heat supplied by CSP systems can be used to drive heat-operated refrigeration systems, through the creation and maintenance of temperatures lower than the ambient. In order to achieve low (lower than the ambient) temperatures, a commonly utilized phenomenon is the change of phase of a material, such as when a liquid evaporates to a gas phase. [51]

![Figure 32: Simple single effect absorption refrigeration cycle](image)

*Left: schematic; Right: zero-order model*

Figure 32 is a schematic diagram of a typical absorption refrigerator in the simplest, single-effect configuration. In brief, this system employs the working fluid pair ammonia/water, in which the water serves as the absorbent and the ammonia as the refrigerant. In this cycle, heat is applied to both the generator and the evaporator and rejected in the condenser and absorber. The refrigerant vapor formed in the evaporator is absorbed to liquid form in the absorber. In the case of the ammonia/water solution the refrigerant (ammonia) is absorbed by chemical affinity into the water. The refrigerant is transferred to the condenser pressure in liquid form by means of a pump. In the generator the refrigerant is separated from the liquid solution by applying heat and boiling it out of the solution. Two steams leave the generator, one with vapor refrigerant that goes into the condenser, and other one with a weak solution that is returned to the absorber. In summary, an absorption refrigeration cycle pumps heat, $Q_e$, from the refrigeration temperature, $T_e$, to the heat rejection temperature, $T_c$. [51]
4.4. Local Manufacturing

The greater a local industries’ contribution to manufacturing parts for CSP plants, the bigger the impact on the cost of the energy produced. Therefore the more know-how, manufacturing capabilities, and components production is available in a country, the lower the cost per kWh of the CSP electricity – making it more competitive with other power-generation technologies. As previously illustrated, Egypt is one of the countries with highest CSP potential in the MENA region and worldwide. This represents a further motive for the industry to engage in CSP production (directly and indirectly) and CSP associated services. Figure 33 gives an overview of all the steps and value chain of CSP project installation from project development phase till the distribution of the power output.

Figure 33: Basic structure of the CSP value chain including cross-cutting activities [52]

According to the World Bank study, low-investment activities with low complexity could be implemented in the short term in Egypt and the MENA region. These include collector assembly, collector installation, civil work (including groundwork), as well as collector foundations, building and infrastructure. Those activities represent around 17% of plant investment. In the longer term and with more sustainable CSP markets, other contributions by the local market could be added, such as mirror and receiver production. Those represent 80% of plant investment. [15]

The study identifies four main pillars to facilitate local CSP manufacturing, namely:

1. **Ensuring a long-term market for CSP components**, through development of a government’s binding target for CSP projects. Other markets could also be developed through initiatives such as the Mediterranean Solar Plan or DESERTEC. Moreover the CSP industry could not only serve the local
market, but also the regional MENA market, and other markets in Europe and the United States.

2. **Awareness raising and information provision.** It is important to raise awareness of the importance of CSP and the potential benefits for investing in this field. Also higher transparency in information-sharing is required. This could be achieved through regular updates of countries’ economic data, electricity market overviews, and projects’ status.

3. **Enhancing infrastructure, trade and finance.** This includes physical as well as institutional infrastructure and international free-trade agreements. A further promotional aspect is creation of a favorable tax and trade framework for CSP components. The formulations of the legal framework for power production and the new electricity law for Egypt also have to be finalized. It is intended, but not specified in the proposed electricity law, that the domestic content will be a part of the criteria for selection among competing bids for power plant concessions. [34] This comes in addition to providing financial support for companies’ start-up and investment support mechanisms for production line upgrades and employee training.

4. **Strengthening absorptive capacity and innovation** systems by developing research facilities within the country. It is also important to introduce quality assurance certification/bodies to guarantee quality for the locally manufactured CSP components. This measure also involves knowledge transfer to the local workforce through training facilities as well as through joint ventures between local companies and experienced international CSP component manufacturers. [15]

There are different ways for Egypt to become involved in the process of installing CSP projects. The first steps in strengthening the local manufacturing sector for this purpose could be:

- Local assembly of a CSP plant
- The empowerment of local EPC (Engineering, Procurement, Construction) contractors.
- Mirror production through the development and production-line adjustment of glass industries. Egypt already has existing float glass production capacities, and already exports their products.
- Steel Structures, as Egypt already has a well-structured steel industry and is one of the most important steel producing countries in the region. Therefore, the current steel industry with some investment and effort could supply CSP plants with support structures.
- Piping and insulation are not CSP specific and are already being produced in Egypt.
The local pilot project -Kuraymat Solar Thermal Power Plant- initiated the process of familiarizing local industries with CSP technology, manufacturing components and processes. This site provides an ongoing example from which lessons could be learned for future projects.
CHAPTER FIVE
Feasibility of CSP Plants in Egypt
It is important to remember that incentives for Renewable Energy are justified in order to compensate for market failures, for instance externalities related to emissions and other environmental impacts. They are designed to help the market have a successful kick-off and to drive the transition towards large-scale investments. “Therefore, Renewable Energy incentive schemes must be transitional and decreasing over time, in order to foster and monitor technological innovation, and move towards market competitiveness.” [27]

In the third chapter, the importance of introducing effective incentive schemes in order to support and promote CSP in Egypt was discussed. Currently CSP plants need the support of the government in order to secure their competitiveness and profitability to investors. This should be only temporary because it is expected that in only few years this technology, after achieving the mass production level, would be able to compete with conventional energy production on peak and medium loads, and later with the base load. [30]

On top of the previously mentioned required incentive schemes is the feed-in tariff as it has proven successful examples in countries such as Spain and Germany. In this chapter, the feed-in tariff incentive will be studied and guidelines for its implementations will be proposed.

5.1. Designing Feed in Tariff

Currently the government of Egypt has decided to adopt the competitive bidding system with a PPA, as a first step, and then based on that experience to move to the feed-in tariff system. This is an acceptable first step; however the challenge will be how to design this tariff in a way that would guarantee its effectiveness and efficiency in order for it to meet its objective.

The feed-in tariff which is a contractual guaranteed long-term PPA regulated by the government -for the tariff and the associated technical and contractual conditions- serves two objectives, as discussed in chapter 3:

- Ensuring the economic and financial viability of the Renewable Energy project. In order for the feed-in tariff to constitute an incentive, it has to be above the opportunity cost of electricity from conventional resources. [12]
- Reducing the investment risk to a manageable level. The longer the guaranteed period, the lower the risk to the investor, as revenue for a longer period will be guaranteed. [27, 53]

It was also previously explained that feed-in tariff has two forms, either as a fixed tariff/rate, or as a premium added to the market rate. Each form has its advantages as well as its disadvantages. Table 12 draws a comparison between the two forms.
Advantages | Disadvantages
--- | ---
Fixed Feed-in Tariff | • Reduces price risks on investors and developers, therefore reduces financing cost.  
• Is based on the investment costs; therefore it should guarantee covering all the costs which is a good motive for investors.  
• Reduces market risks, because it does not only guarantee a long term PPA, but also with a predetermined price.  
• Does not encourage establishing the plants where they are needed the most, unless the feed-in tariff design is project/location specific.  
• Could be costly on the government if the feed-in tariff is set too high especially if the inflation is fully considered, if the feed-in tariff is paid by the government not the consumers.

Premium Feed-in Tariff | • Allows competition between generators.  
• Market oriented, and encourages generation according to demand (peak load).  
• More profitable if the plant is producing peak load electricity (because it is the most expensive electricity).  
• Very appropriate to liberated electricity markets.  
• Is based on the market prices, irrespectively of the generation costs.  
• Because of the lower predictability of the revenues, this system imposes higher risks on the investors.

Table 12: Comparison between fixed- and premium feed-in tariff designs [29, 30]

The fixed feed-in tariff is more appropriate to Egypt, putting in mind the current electricity market is monopolized by EEHC. Moreover the fixed feed-in tariff supports more the emerging technologies as it provides more stability. The disadvantages associated with the fixed feed-in tariff could be beaten with smart designing of the feed-in tariff. This makes it very appropriate for promoting the CSP industry in Egypt. The following analysis and discussion will focus therefore on the fixed feed-in tariff.

To achieve the effectiveness of the feed-in tariff, the scheme should meet some characteristics. The feed-in tariff design shall therefore define and give answers to the following questions and issues:

- *Taking account of the level of development of each technology.* A special feed-in tariff for each Renewable Energy technology should exist. For instance, the feed-in tariff for CSP should be different from the one of wind and photovoltaic. This is because each technology has a different investment cost, status of development and cost learning curve which require different support schemes from the government. CSP requires higher tariff than wind energy.
- *Defining eligibility criteria,* i.e. which types of installations (parabolic troughs, dishes, fresnel..) are covered by the tariff system and which prerequisites are
connected to the eligibility. For example, in order to promote local manufacturing, one of the eligibility criteria could be involving a local contribution with a minimum percentage. However this share should be realistic in order to avoid obstacles to investments.

- **Providing tariffs for all levels, from domestic to large-scale developments.** Also within the same Renewable Energy technology, there should be different tariffs for the different scale and usages. Installing a CSP component for a single factory, shall not be the same tariff as a large scale CSP plant. As proposed in chapter 3, the competitive bid system could be applied for large scale projects, while the feed-in tariff is to be dedicated for the medium and small scale ones (less than 100 MW). [53]

- **Guaranteeing long term investment security.** The feed-in tariff shall guarantee the purchase of the produced power for a long term (25 years recommended with a minimum to the loan period) in order to reduce the risks on the investors.

- **Being administratively simple.** Regulation of the procedures related to the tariff scheme should be simplified and designed efficiently to minimize the administrative costs. Bureaucracy should be decreased.

- **Being easy to explain in order to ensure public acceptance.** This is very important in order to promote CSP, especially for smaller investors.

- **Defining the duration of support and the tariff degression.** This is important for the investors to know in order to be able to plan their revenue and profitability. There are two types of degression: within the project life time and within subsequent projects.

Usually the investment is financed by equity and debt. Therefore the tariff required at the beginning of the projects lifetime is higher than after the repayment of debt. After the debt has been fully financed lower subsidies are needed. A degression within the project lifetime could be only applied, after that the loan on equity costs are paid back. In the case of flat tariff, the feed-in tariff would need to be set high which could be an avoidable burden if financed by the government. There are three common different forms for the tariff definition of the same project over time, shown in figure 34.
The second degression type is a tariff decrease for the subsequent projects, i.e. the project installed this year is rewarded a higher tariff than project installed a year later. This has two advantages. The first is to encourage the investors to start their projects instantly and not one year later as the tariff will decrease. Also because by time and by new installations, the investment cost decrease with the learning curve, therefore the required support decreases. The International Energy Agency (IEA) clearly states that “Feed-in tariffs which do not foresee a clear incentive reduction over time may be effective for the kick-off deployment stage of Renewable Energy, but are clearly not economically sustainable in the medium- to long-term.” [27]

- **Considering inflation.** Since the feed-in tariff agreement is designed to be a commitment over a long term, it is recommended to adjust the feed-in tariff value to the inflation rate. This decreases the risk on investors particularly for investors in big installed capacities and especially in a country like Egypt with high inflation rates exceeding sometimes 10%. On the other hand imposing this inflation adjustment, represent an extra cost on the feed-in tariff financer. [28, 29, 53]
- **Risk level on the investment.** The higher the risk in the country, the higher should the feed-in tariff be. Moreover, the higher the feed-in tariff, the shorter the pay-back period, and thus the lower the investment risk. As a result, lower interest rates could be granted to the project loan. Thus higher tariffs will result in lower investment costs, or at least better utilization of the investment money as less will be paid on interest to banks.

It is important to work on all dimensions simultaneously because missing one dimension could lead to failure of the policy.
Determining the value of the tariff depends on different measures, the most important of which are:

- Investment cost of the plant per MW
- Other associated costs, e.g. land acquisition costs, licensing procedures
- Operation and maintenance costs
- Acceptable premium required by the investors
- Site quality of the plant. The LCOE (levelized cost of electricity) differs with the DNI intensity. The higher the DNI, the higher is the capacity factor, the lower the LOCE, accordingly the lower is the feed-in tariff required. Therefore feed-in tariff should be site-specific. This is a very complicated procedure however. On the other hand applying a uniform feed-in tariff will lead to exploiting the sites with highest DNI because they offer a higher power therefore higher return on investment, which is a good outcome for all stakeholders. [53]

5.2. **Feed in Point**

The DLR has developed a concept proposing a strategy for introducing CSP in the MENA region “that will not require considerable subsidization and will not constitute a significant burden for electricity consumers in the region”. In this section the general concepts developed for the MENA region will be applied to Egypt in order to “present a strategy for the market introduction of CSP [...] removing the main barriers for financing and starting market introduction in the peak load and the medium load segment of power supply” to be followed later by the base load. [54]

This will be applied on three steps. First is calculating the cost of generating power from conventional sources and its development in the future. Then will be followed by identifying the cost of CSP and its development in the future due to the economies of scale after its projected expansion. Finally, after putting together the outcome of the first two steps through comparing the cost of conventional electricity with the cost of CSP throughout the years, the economical feasibility of the CSP will be evaluated.

5.2.1. **Calculating LCOE (Levelized Cost of Electricity) in Egypt**

The LCOE is important to have an indicator for the costs of generating electricity from conventional energy sources. This model should distinguish between electricity generated to cover the peak, medium and base load, as each has usually a different energy mix with a different efficiency and capacity factor.

The parameters used for this model are as follows:
Table 13: LCOE for conventional power in Egypt parameters

The LCOE estimation follows the following calculations:

**Equation 1**

\[ F = \frac{\text{CoF} \times E}{\eta} \]  
[13, 48, 54]

**Equation 2**

\[ \text{Inv} = \text{Inv}_{\text{specific}} \times C \]  
[13, 48, 54]

**Equation 3**

\[ FCR = \frac{(1+i)^n \times i}{(1+i)^n-1} \]  
[13, 48, 54]

Assuming the interest rate is 9% /year and the lifetime is 25 years, then the FCR according to equation 3 will be approximately 10.18% /year.

The LCOE is calculated according to equation 4, for each segment (peak-, medium- and base- load) separately.

**Equation 4**

\[ \text{LCOE} = \frac{\text{Inv} \times FCR + \text{O&M} + F}{E} \]  
[13, 54]

Where:

- CoF: Cost of Fuel [$/kWh]
- E: electricity generated per year (=installed capacity (kW)*annual full load hours (h/y)) [kWh/y]
- \( \eta \): Efficiency [%]
- Inv: Investment Cost [$]
- Inv_{specific}: specific Investment [$/kW]
- C: Installed Capacity [kW]
- FCR: fixed charge rate as function of interest rate (i) and economic lifetime (n) [% of Inv/y]
- O&M: Operation and Maintenance of annual operation and insurance [$/y]
- LCOE: Levelized Cost of Electricity [$/kWh] [13]
As for the annual increase of the CoF, 1.5% was assumed as the model study.

This LCOE shall be determined for each load segment (peak, medium and base). The weighted average cost of electricity is to be determined through equation 5:

\[
LCOE_{average} = \frac{LCOE_{peak}E_{peak} + LCOE_{medium}E_{medium} + LCOE_{base}E_{base}}{E_{peak} + E_{medium} + E_{base}} \tag{5} \text{[48, 54]}
\]

The resulting cost structure for the new plants in Egypt, considering the input data including capital cost, operation and maintenance, fuel costs and return on investment (from table 13, is shown in table 14 and demonstrated in figure 35:

<table>
<thead>
<tr>
<th>LCOE [ct$/kWh]</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Load</td>
<td>2.07</td>
<td>2.21</td>
<td>2.36</td>
<td>2.70</td>
<td>3.09</td>
<td>3.54</td>
</tr>
<tr>
<td>Medium Load</td>
<td>2.93</td>
<td>3.11</td>
<td>3.30</td>
<td>3.74</td>
<td>4.25</td>
<td>4.84</td>
</tr>
<tr>
<td>Peak Load</td>
<td>4.44</td>
<td>4.68</td>
<td>4.95</td>
<td>5.55</td>
<td>6.24</td>
<td>7.04</td>
</tr>
<tr>
<td>Average</td>
<td>2.39</td>
<td>2.54</td>
<td>2.71</td>
<td>3.08</td>
<td>3.51</td>
<td>4.01</td>
</tr>
</tbody>
</table>

Table 14: LCOE for conventional power in Egypt

This graph represents the business as usual case of producing energy, i.e. keeping the same energy mix for power generation with a fuel cost escalation.
5.2.2. Drawing the CSP Cost Curve

In the previous chapters, the large potential of the CSP cost reduction was mentioned. As explained before, this is mainly because of the economies of scale and learning opportunities associated to the growing installations of CSP plants. With doubling the production, the investment costs decreases by a factor, this is the learning rate. [26] Experience curve is a more general term than the learning curve, and is used to refer to the “cost reductions for non-standardized products produced globally, nationally, or by an individual company.” [26] In this context, cost is the total cost including labour, capital, raw materials, administration, and marketing. Reducing the cost could be achieved through reducing the price of input materials, developing the product and its production methods, product redesigning, product standardization, learning and scaling effects in the production process. This shows that the cost reduction depends to a large extent on the increased demand, while the demand depends also to a large extent on the investment cost and thus on the product cost. [26] Several studies -e.g. DLR, World Bank and others- have studied this cost reduction potential and tried to estimate it in figures. In the following section, projection for the CSP experience cost curve for Egypt will be estimated; taking into account the future global installed capacity development as well as the DNI in Egypt.

Many studies and papers have expected different scenarios to the development of the CSP in the future, varying from too conservative estimations that predict only 850 GW instalments by the year 2050 and other very optimistic that expect the CSP to reach 1,500 GW worldwide. The two extreme scenarios are shown in table 15. For the calculation of the CSP cost development a moderate scenario will be used referring to the reference paper, also shown in table 15.

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>lowest expectations</td>
<td>1,000 MW</td>
<td>2,900 MW</td>
<td>31,000 MW</td>
<td>230,000 MW</td>
<td>540,000 MW</td>
<td>850,000 MW</td>
<td>0.88</td>
<td>[8, 66, 67]</td>
</tr>
<tr>
<td>optimistic expectations</td>
<td>1,000 MW</td>
<td>29,000 MW</td>
<td>150,000 MW</td>
<td>340,000 MW</td>
<td>920,000 MW</td>
<td>1,500,000 MW</td>
<td>0.88</td>
<td>[8, 66, 68]</td>
</tr>
<tr>
<td>CSP expected expansion</td>
<td>1,000 MW</td>
<td>8,250 MW</td>
<td>39,000 MW</td>
<td>240,000 MW</td>
<td>595,000 MW</td>
<td>950,000 MW</td>
<td>0.88</td>
<td>[8, 50]</td>
</tr>
</tbody>
</table>

Table 15: Expected worldwide CSP future expansion [55, 56, 7, 54]

*assumption
The cost experience curve function is

**Equation 6**  
\[ C_x = C_0 \left( \frac{P_x}{P_0} \right)^{\frac{\log PR}{\log 2}} \]  

Where:
- \( PR \): progress ratio = \((1 – \text{learning rate})\); the learning rate is an indicator that shows by what percentage does the cost decrease with every time worldwide installed capacity is doubled.[40]
- \( C_x \): specific investment at point \( x \)
- \( C_0 \): specific investment at reference point 0
- \( P_x \): cumulated capacity at point \( x \)
- \( P_0 \): cumulated capacity at reference point 0

In order to determine the value of the current specific investment \((C_0)\) for Egypt, we need a reference country. Spain is one of the countries that has realized good progress in the CSP field in Europe and worldwide; therefore is a good indicator to estimate the specific cost in Egypt.

As previously illustrated in Figure 9, Egypt has a technical potential exceeding 2800 kWh/m²/y, while the new identified site for the coming project (Kom Ombo) has an average DNI of 2500 kWh/m²/y [2]. Therefore this DNI value could be used as an indicator for the DNI in Egypt in this model. Spain with only a DNI level of 2090 kWh/m²/y (southern Spain) had a feed-in tariff of 27ct€/kWh in 2010, which was sufficient to stimulate the CSP industry in Spain [7, 54]. These data could be used for calculating \((C_0)\).

**Equation 7**  
\[ C_{0\ Egypt} = C_{Spain} \times \frac{DNI_{Spain}}{DNI_{Egypt}} \times \$ / \€ \]  

Accordingly \( C_{0\ Egypt} \) – assuming an USD to EUR exchange rate of 1.19 – is equal to 26.86 ct$/kWh. \((C_{0\ Egypt} = 26.86 \text{ ct$/kWh})\), which is on the lower half of the worldwide estimated CSP costs by the IEA for 2010 of 20-30 ct$/kWh [7]. The reason for this figure is that the cost depends on the annual solar radiation and Egypt is one of the countries with high DNI.

The analysis starts with the year 2010, although in practice no CSP plants will be actually working in Egypt before 2014 at soonest. This is because the construction only needs 2-3 years, and till now we are still in the studying phase of possible plants (Kom Ombo). Since that costs and tariffs should decrease by time

Applying equation 6 to the following data (table 16), results to the CSP experience cost curve for Egypt, which decreases from 26.86 ct$/kWh in 2010 to 7.58 ct$/kWh in 2050 (figure 36):
CSP Progress ratio \([54]\)  
Reference DNI for Egypt \([\text{kWh/m}^2/\text{y}]\)  
Reference LCOE for CSP in Egypt in 2010 \([\text{ct$/kWh]}\)  

Table 16: LCOE for CSP in Egypt parameters

![CSP experience curve on Egyptian Site (DNI 2500 kWh/m²/y)](image)

Figure 36: CSP experience curve for Egypt 2010-2050

Other studies have estimated experience curves for the different Renewable Energy technologies in Egypt (figure 37):

![Experience curves for different Renewable Energy technologies in Egypt][3]

Figure 37: Experience curves for different Renewable Energy technologies in Egypt [3]

(CSP plants are hybrid solar with fuel fired plants with 8000 full load hours per year)
The CSP experience curve shows that CSP can be a significant component in the future electricity mix of Egypt. CSP can represent a hedge against the volatility of the fuel costs and external oil markets. Moreover it adds to the economical development of local industries and aggregate economic development of the country, as well as having environmental advantages. It is important now to determine when this will be feasible, which will be discussed in the following section. [54]

As explained before, both cost reduction and demand increase rely on each other; therefore in order to start this vicious cycle, the cost should decrease. To help moving along the experience curves, some policy measure should be implemented in order to give an incentive to start the CSP market deployment and expand the market, to help reduce the cost for the investors. To sum it up, the progress of the experience curve depends on the policy instruments. [26]

Germany for example has applied several measures to develop the wind power, directed towards improving the technology and expanding the market. The main programmes were: Research and Development programs since 1975 onwards, Subsidies during 1986-1996 and Feed-in Tariffs since 1991 to date. These instruments had a significant effect on increasing the number of units installed as well as on decreasing the cost of wind turbines and the specific cost of electricity, showing a progress ratio of 88%-94%. [26]

Spain has also introduced some instruments that helped the development of the wind market. In the late 1970s, Spain started to introduce Research and Development programmes, as well as investment subsidies on the early 1990s and a premium electricity price to wind power generated since the mid 1990s. Those measures as well as others have helped the wind industry to achieve a progress ratio of 90%. [40]

5.2.3. **LCOE in Egypt- CSP vs. Conventional Power**

It is to note that Egypt is one of the countries with high increase in electricity demand exceeding 6 %/a [1]. Moreover the experienced electricity outages in summer 2010, will force the installation of new capacities. Accordingly it is expected during the coming years to increase the investments in power plants installations. This could represent an opportunity for CSP.

Putting figure 35 and figure 36 together, will allow us to compare between the LCOE of the CSP and the conventional power plant for the different segments. The result is plotted in figure 38.
As shown in the graph, the CSP cost is decreasing significantly, however this decrease does not allow it to be economically competitive with the cost of the electricity from conventional sources. Till 2050, given the previously mentioned parameters - fuel prices, fuel escalation, investment cost - the CSP cost is higher than the average electricity cost and even higher than the cost of the peak load power. This is definitely an important barrier that will be facing the attraction of the desired investments towards CSP. The main challenge is also represented in the fact that, the investment cost is high, and needs to be paid up front, while the profit is not guaranteed. Therefore it is important to secure the revenue by introducing long-term PPA that was discussed in chapter 3. Adequate tariffs for CSP need to be introduced and a feed-in tariff according to guidelines described at the beginning of this chapter should be designed. As a possible and recommended tariff for the strategy development of the CSP deployment in Egypt, is to design the tariff to start covering the peak load first, to be followed by meeting the demands of medium load and base load. It is to note that “the high avoided cost of peak load electricity allows for a much higher tariff in that segment and as a consequence will require lower subsidies” [54].

The main reason behind this case is the extremely low fuel prices available in Egypt (because of the energy subsidy). An important question is how long will the primary energy be available to cover the supply? Could they be sustained till 2050? For how long will the government be able to subsidize the energy that intensively to reach these prices? How much is the government loosing by burning the fuel domestically at very low prices instead of exporting it at international price levels?
5.2.4. Sensitivity Analysis

Changing some parameters could have effects on the economical feasibility of CSP in Egypt. Many of these parameters are in the hands of the government and could be changed in order to increase the attractiveness of the CSP for the investors. In this section, some parameters will be changed and their effect on the model will be examined.

As mentioned in chapter 2, energy is highly subsidized in Egypt. These subsidies represent a high threat on the CSP deployment as it will always be relatively expensive. This is just an artificial cost difference, as only the consumers pay a lower value while the conventional power production represents a burden on the government’s budget. The cost of fuel as calculated in the previous sections is around 7.2 USD/MWh for the base load, 8.22 USD/MWh and 9.59 USD/MWh for the medium- and peak load respectively. If these costs were replaced by the international energy prices (base load: 15 USD/MWh, medium load 35 USD/MWh and peak load 60 USD/MWh [54]), the CSP will be much more competitive with the conventional power production. CSP will have the same cost as the peak load by 2013, the medium load by 2022, and the average load by 2035. By the end of the study period 2050, CSP could satisfy the total Egyptian electricity production. Figure 39 compares the LCOE for Egypt with LCOE from conventional energy at the international energy prices. This case is also valid for all sites that are not connected to the energy grid in Egypt and have to buy their energy at the international market.

Figure 39: LCOE (CSP +conventional) in Egypt with international fuel prices
Another important point posed for discussion is the annual fuel price increase. In CSP, the fuel cost is represented in power block of solar collectors’ investments. Since the total investment cost for CSP is paid at the beginning, the CSP LCOE is not subject for cost escalations. Therefore, if the estimated yearly fuel price change is increased from 1.5% to 3%/a, this will allow the CSP to have the same cost as the peak load power before 2040 and as the medium load power around 2050. This is displayed in figure 40:

On the other hand, there are other measures that could affect the LCOE of the CSP. These are mainly the measures that are influenced by the worldwide conditions such as the progress ratio. The lower the progress ratio the more competitive does the CSP technology becomes. For instance if the progress ratio decreases just by 1%, the CSP LCOE intersects with peak load LCOE curve -which means they have the same cost- before 2050. If the progress ratio reaches 0.8, the CSP technology will be able to satisfy all segments of power in Egypt with more competitive prices than the conventional sources. (Figure 41)
As discussed earlier and summarized in table 15, there are different forecasts for the worldwide CSP installations in the coming years. If the most optimistic scenario is considered while keeping all other parameters constant, CSP will be able to provide Egypt with power for peak load at same price of power from conventional sources by 2050 (figure 42).
If we consider changing different parameters at the same time such as considering the achievement of the optimistic scenario or CSP installations worldwide, at the same time increasing the fuel prices in Egypt by 20% and considering a yearly increase for the fuel by 2%, CSP will be able to compete with the power for the peak load before 2040 and the medium load power by 2050. (figure 43).

Figure 43: LCOE (CSP+conventional) in Egypt with CSP optimistic scenario, fuel price increase 2%, fuel prices 20% higher

To conclude, there are different parameters included in the CSP strategy planning that affect its economic feasibility. Some of them are concerned with the CSP behaviour while others are the reflection of changes in conventional energy parameters. Not all changes have the same effect, therefore it is better to start with the ones that have more significant ones.

All these parameters allow the CSP to be economically feasible without a subsidy; it is even considering a 10% return on investment.
CHAPTER SIX
CONCLUSION
This study has tackled the development of CSP mainly from a market perspective - focusing on the potential of this green energy in Egypt and the ways the government can aid the development of this treasure. The Egyptian CSP framework has been analyzed and recommendations were suggested for the promotion of CSP in Egypt. The different facets involved in harnessing CSP have been discussed in order to paint a clear picture of its pros and cons. An overview of the different applications of this energy has also been offered with a description of how these technologies could fit into the Egyptian context. This context is key to choosing and designing an energy portfolio that could meet the country’s needs. In order to plan such a portfolio the local manufacturing capacity must be taken into account as well as measures to encourage their involvement in the production of CSP parts. Moreover the study included guidelines for designing a feed-in tariff as well as comparisons of investments in CSP plants vs. conventional power plants. These could offer policy makers some parameters for strategic planning.

CSP helps achieve environmental security by offering power generation with reduced greenhouse gases. This is thanks to a CSP life cycle of GHG (greenhouse gases) emissions of only 15-30g/kWh. In contrast to nuclear power, CSP avoids the risks of nuclear contamination. Even during the installation of CSP plants, pollution from combustion products is below the amount registered in conventional plants. The only source of pollution from CSP occurs at the manufacture of equipment and components. But CSP technology is based on recyclable material. Naturally there are some environmental drawbacks, but they are minimal compared to its advantages. For example the cooling towers –like those of any other steam cycle- produce noise. The heat transfer fluid (HTF) used is a hazardous material that could lead to the pollution of the soil and water if spilled. Moreover the synthetic HTF oil has an unpleasant smell. In conclusion the negative effects of CSP plants are minimal. This technology instead has a net positive impact on the environment. [48]

The peak load of the Egyptian load curve in 08/09 was 21330 MW [1], with a significant increase in summer. This is due to the operation of countless numbers of electric cooling devices to make Egyptian summer temperatures bearable. In the summer of 2010, the country witnessed electricity outages during the summer, the result of supply failing to meet peak demand. It is evident that the installed capacity needs to be increased.

The price of energy is a hot topic in Egypt as it is one of the sectors that receive high subsidies. These are expected to reach 67 billion EGP in 2009/10 representing 16.85% of the government’s budget. Because of this, several energy tariff adjustments were planned after 2004. Initial plans were for this tariff to be steadily increased on yearly basis, but they were frozen due to events such as the global economic crisis. In total, average electricity prices increased 32% from 2004 till 2008, reaching 0.187 EGP/kWH in 2008. This average tariff is still very low compared to the international energy prices. The subsidy on energy prices should be reduced, but with care and the
deliberate consideration of all aspects (mainly social and economic aspects). Ideally, subsidies would be reduced first for the wealthy, then for the working class. The subsidy should also be eliminated gradually in order not to disturb the economy. It is a fact that increased energy tariffs will have an effect on the end product costs.

Egypt’s impressive CSP potential exceeds 73000 TWh/year - one of the highest in the region. Other promising characteristics are a high DNI (1970-3200 kWh/m²/year), high sun duration hours (9-11 hours), few cloudy days, large expanses of unoccupied desert land, and an extended national electric grid. All these factors make Egypt a perfect location for CSP projects worldwide. It is expected that CSP will become a striking contributor to the Egyptian electric and water supply in the medium term. CSP is the most important future power source for Egypt as it has the highest potential of all the Renewable Energy sources. Because of this, it deserves government efforts to promote and encourage investment in this technology. In the five-year plan to implement the Egyptian Energy Strategy (2012-2017), 100 MW of CSP are planned. This is a small target compared to its huge potential, but it is a good first step. Another step was a feasibility study of different locations for CSP plants, with the district of Kom Ombo selected for the first pure CSP project. This area is located in Upper Egypt and has an average DNI of 2515 kWh/m²/year. It also has access to the Nile – access for cooling water- and could easily be connected to the grid. A 100 MW capacity is planned, subject to increase; with stored energy this could reach 150 MW. Until now, there is one installed hybrid power plant with a solar component at the Kuraymat (140 MW capacity with solar share of 20 MW).

Over the past few years Egypt has cooperated with other countries by extending its regional network to different nations with the goal of ensuring energy security and enhancing energy reliability. These networks connect Egypt to countries such as Jordan, Syria, the western borders of the Maghreb countries through Libya, and Gulf Countries through Saudi Arabia. These connections can even reach Europe through two paths reaching Spain and Turkey. These connections prepare Egypt to become an electricity exporter, especially to Europe. [48] However these interconnections are of limited capacity, <500 MW.

The existence of a regional partnership between the MENA region and Europe - known as EUMENA- is important as it guarantees economic as well as political stability. One manifestation of these partnerships is the DESERTEC concept. One of the economic benefits is the trend towards a decrease in the cost of electricity and reduced price volatility which can lead to energy cost stabilization -especially with investment in new sources. This will also result in the reduction of energy subsidies in the MENA region. Increased electricity exports to Europe can lead to increased GDP (Gross Domestic Product) and local development due to the participation of the manufacturing sector in the development of Renewable Energy power plants. The partnership will also allow EUMENA to achieve energy security to guarantee energy supply resources to meet growing demand. This also opens new channels of energy
supply. This diversification reduces dependency on Europe in respect to energy. For the MENA countries this partnership solves its electricity shortage and water scarcity problems. [48]

While DESERTEC is a very important initiative, it is moving slowly. Therefore Egypt should start promoting and investing in diversified Renewable Energy power plants, especially CSP, until DESERTEC becomes more dynamic. These power plants could then be connected to the grid to satisfy both the local and regional demand. Unfortunately, critical challenges face this partnership, as there are many stakeholders involved. The establishment of this partnership requires a paradigm shift in the thinking of policy makers and the restructuring of the system. Consumer awareness of the initiative and its benefits is important to guarantee public acceptance. Differences within EUMENA countries cannot be ignored, be they cultural, economic or political. A harmonization of interests to establish common ground is a necessary first step prior to trade agreements. Financing the investments remains an important issue, as long-term financing schemes are required to support high investment costs that have longer payback periods. In order to overcome these challenges, strong lobbying is needed and solutions to these problems determined and implemented, while considering the time factor. [48] Another important challenge is the transmission of electricity to Europe, as it is much more complicated than the easy stored/transported fossil energy sources. It is very difficult to transport electricity through long distances overseas, especially from Egypt to Europe, where the distance is far and the sea is deep. The best solution turned out to be High-Voltage, Direct-Current (HVDC) transmission lines between countries, while using AC (Alternating Current) grids within the country.

The electricity market in Egypt is managed and regulated by the Egyptian Electricity Holding Company (EEHC), which supervises a range of entities with different specializations. Among them is the New and Renewable Energy Authority (NREA), the authority responsible for all issues related to the Renewable Energy in Egypt and its regulation. Its scope is broad, ranging from assessing Renewable Energy resources, fostering Research and Development, rendering consultancy services, providing training, managing information dissemination, and implementing Renewable Energy projects. NREA is a key player in the market but its role needs to be amended. It currently functions as a Renewable Energy project developer as well as market regulator – two roles that are in conflict. To function efficiently, NREA should redesign its role and split into three independent arms -- each with its own management and budget. The first one should be the regulatory body; the second to be responsible for research and Renewable Energy promotion; and the third as the commercial developer of Renewable Energy projects. Both the second and third arms could be either state-owned or privatized.

More attention should be given to CSP by creating a special sub-authority to promote this sector. This entity could prepare DNI measurement campaigns, identify specific sites for CSP power plants and prepare feasibility studies. They would also allocate and acquire land for projects, provide technical support, identify business partners,
facilitate the project establishment process, and support the local manufacturing industry.

Other important players in the Egyptian energy market are the Supreme Council for Energy, the Egyptian Electric Utility Regulatory Authority, and the Egyptian Electricity & Consumer Protection Regulatory Agency.

Aware of the need to take prompt action, the Egyptian government drafted a new electricity law, which is expected to be discussed in the new parliament. This proposed law is the first step towards the promotion of Renewable Energy through two main articles that establish the legal framework for Renewable Energy plants. This law would oblige the Egyptian Electricity Transmission Company (EETC) to purchase all energy generated from renewable sources at a price determined by EEHC. The proposed law describes mechanisms to control power generation from Renewable Energy sources, competitive bidding based and BOO (Build, Own, Operate) based on PPA agreements. The competitive bidding based on a Power Purchase Agreement (PPA) occurs between the investor and EETC according to a price approved by the cabinet. The time frame of the PPA is proposed at 15 years. It is important to ensure that it at least covers the debt period. In order for EETC to be able to buy Renewable Energy electricity according to the PPA, the law proposes the establishment of a “Fund for Development of Power Generation from Renewable Energies.” The budget for this fund comes from three main sources: allocation from the government budget, donations and grants, and proceeds from fund investments. It is important to ensure that this law is made effective as soon as possible, as it provides the needed framework for the CSP plants, which is crucial for investors.

CSP deployment faces some challenges in Egypt, such as highly subsidized conventional energy, non-ambitious government strategies for that sector, lack of financing methods for CSP, lack of information and transparency, undeveloped local manufacturing market, and high risks. It is important to overcome these challenges in order to attract private investment in this sector. A more ambitious target should be set for the medium and long term in order to create a market. Without an existing market, no investments can be created. Moreover, mechanisms should be developed to enforce this plan. In addition to large scale plants, the government should promote smaller scale investments to satisfy their own need for large factories or compounds, the so-called “Auto-Producing.”

CSP requires high investments, especially because this technology is still at the beginning of the experience curve and thus has high investment costs. In addition, there are challenges with investments, legality and logistics since this technology is considered a long-term one (20-40 years). The costs are of special concern as their value is known, while the potential profits are not well-known, thus increasing the risk. There is no feed-in tariff until now and the current PPA is of very low value, since it was the result of an agreement between two governmental bodies – the EETC.
and the NREA as the developer. Moreover, revenue is based on output, which can be unstable. An additional challenge is the high subsidy on electricity from conventional sources, which makes the CSP investment a difficult business case to present positively. [48]

In order to overcome these challenges, a set of policy instruments must be established immediately to create a favourable climate for investment and industry. One of the decisions should be the reduction of the subsidy on conventional energy. This would be a critical move because of its multiple effects on other political and economic decisions. Another measure to encourage CSP development is to make long-term financing available. It is important as well to shorten the bureaucratic procedures for investors to initiate their projects and facilitate plant permits. Conducting DNI measurement campaigns and identifying possible project locations will decrease the risk on investors and make it easier for them to decide whether to invest. An idea would be creating a 20 year Solar Atlas for Egypt.

The currently installed Renewable Energy projects (Wind or ISCCS) in Egypt were mainly financed by international donors. The Egyptian framework for Renewable Energy, especially CSP, lacks incentive schemes to promote private investment in this field. There are different types of investment schemes adopted by many countries that could be categorized as financial and fiscal incentives. These could include any combination of feed-in tariffs or premiums, binding Renewable Energy portfolio standards with solar targets, direct subsidies, quota obligations and fiscal incentives (tax and customs reductions). [7]

Providing long-term power purchase agreements (PPAs) is important to guarantee stable revenue to investors. A CSP field represents the fuel for a conventional power plant for its entire lifetime. Instead of being paid on installment according to usage as in the traditional case, this fuel is paid as a lump sum up front at the time of investment. This adds to the investor’s risk, a risk which can only be taken if a guaranteed long term income is secured at a price which covers the costs, risks and an acceptable premium/profit margin. [54] In this context, the feed-in tariff appears as a recommended option, with two types: fixed tariff or premium.

The feed-in tariff system reduces the investment risk of the CSP project as well as ensures the economic and financial viability of the project. The two types of feed-in tariff have their advantages and disadvantages. Since Egypt has highly-subsidized electricity market with fixed prices that are monopolized by the government, the fixed feed-in system is recommended more. However this needs to be well-designed to effectively guide investors toward activities which can help the government meet its strategic goals. Designing the tariff includes steps such as defining eligibility criteria, verifying the level of technology development, providing tariffs for the different production scales, defining the duration of the support -the longer the time frame the better for the investor- and guaranteeing public acceptance. Tariff degression must be determined with care. Within a project lifetime it is important to keep the tariff constant at least until debt is paid back. Once this stage is reached, a tariff decrease
can begin as no more money will be needed to pay the banks. The tariff on new projects should also decrease from year to year. This is because product costs steadily decrease as well, so such a move could encourage investors to initiate CSP projects immediately. Feed-in tariffs reduced from year to year encourage competition and cost reduction through experience, competition and economies of scale. These steps should be taken while bearing in mind the level of technological development. CSP is still at the beginning of worldwide adoption, and therefore requires higher tariffs than more mature technologies such as wind energy. Inflation might be an issue, as it discourages investors from taking risks and drives costs up for the government. The long-term PPA should be tailored to desired parameters in order to control the expansion. The overall goal is to “achieve a well-balanced mix of power sources that combined are able to supply base, medium and balancing power on demand” [54].

International guarantees on PPAs are recommended, especially in countries with low credit ratings, to overcome country-specific investment risks. [54] As noted earlier, such a feed-in tariff should decrease over time as technology continues to develop. The tariffs are designed to help the launch of new technologies such as CSP. All regulations should be transparent and reliable and the tariffs effects on industry and economy should be continuously monitored. The effect of the incentives on the industry and economy should be continuously monitored for adjustments and fine-tuning as the need arises.

It is also important to continuously monitor incentive programs to ensure they are aiding in the realization of targets and following the government’s plan.

Morocco is one of the countries in the MENA region that has taken serious steps to start the deployment of CSP. The Moroccan Solar Plan involves installing 5 main stations that by 2020 will represent 14% of the installed capacity. This plan contemplates the use of 10,000 hectares with an estimated 9 billion USD budget. The first station is the Quarzazatte, which will have 500 MW installed capacity distributed over different phases. In order to promote CSP in Morocco and ensure the realization of the solar plan, the government created a special agency: the Moroccan Agency for Solar Energy (MASEN). The bidding system is the legal basis for the CSP projects, with the use of a PPA as in Egypt.

To increase financing options, the support of international donors is very important, particularly during the initial stages before the investment cost decreases.

There is currently about 1 GW CSP installed capacity worldwide, distributed among countries such as Spain, the United States and Italy. One of the biggest and most famous power plants is Andasol in Spain, consisting of 3 phases with a net solar electricity output of 150 GWh/year.

The possibility of integrated thermal storage is one of the main advantages of CSP. This storage capability allows it to offer firm and flexible production capacity to utility and grid operators. This is one of the main advantages of CSP vs. other Renewable Energy sources such as photovoltaic and wind. In addition to thermal
storage, CSP plants also have fuel-power back-up in order to offer the firm capacity as well. [7] In Egypt, it is possible to design CSP plants to match peak, medium and base load since solar energy is almost evenly distributed throughout the year. The winter CSP yield is estimated to be only 25% less than the summer one. There is good seasonal correlation between the energy demand in the country and the availability of solar power, since the higher peak in Egypt is reached during the summer when the higher solar energy is available. [54]

CSP technology also offers outputs other than electricity that can meet firm capacity. These could have a significant impact on meeting other power demands and solving other problems. CSP can produce significant amounts of high-temperature heat needed for industrial processes. Output temperatures of CSP can reach 400°C, compared to 90°C from flat plate collectors. One of the most important applications is water desalination through different technologies which can meet the growing demand for water in Egypt. It is forecasted that by 2050, CSP water desalination will satisfy around 50% of the water demand in Egypt. [47] CSP can also be used for cooling purposes. [7]

To encourage the growth of CSP technology in Egypt, it must be actively promoted. One important step that can be taken is the development of the local manufacturing capacity for CSP components, as this will increase the availability of essential parts and decrease the investment cost. There are four main prerequisites/measures that need to be adopted to develop the local manufacturing industry for CSP components. These are guaranteeing a market for these components over the long term; increasing awareness and making CSP information more available; enhancing the infrastructure as well as facilitating trade and finance; and increasing research and development. The first step towards local manufacturing in Egypt could be assembling the CSP plant locally, then taking over the Engineering, Procurement and Construction (EPC) by producing the mirrors and steel structures. Industries already exist in Egypt with the potential to fill this role; they only need to understand CSP and its specifications to be able to tailor their products to meet plant needs.

The development of CSP plant installation as well as the component manufacturing industry will boost the Egyptian economy in the form of employment opportunities. According to a survey of European companies, every 100 MW installed will “provide 400 full-time equivalent manufacturing jobs, 600 contracting and installation jobs and 30 annual jobs in Operations and Management.” A ripple effect would also be seen in other sectors of the economy, as it is widely accepted that with each “construction job, four service jobs are created to support it.” [6, 58] CSP would also open the door to energy exports, which would represent a new source of income and increase profits. In addition to the direct profit, the Clean Development Mechanism market will develop because of the saved Greenhouse Gases, and subsequently CERs (Certified Emissions Reduction) will be traded.
The CSP currently has a high investment cost, but fortunately there is still potential for improving the technology, which would increase its efficiency and decrease its cost. This is applicable to almost all CSP technology components; all component parts (mirrors/heliostats, receivers, heat transfer and/or working fluids, storage, power blocks, cooling, control and integration); all applications (power, heat and fuels); and at all scales (bulk power and decentralized applications). Examples of technology improvements could be new designs and structures, improvements in mirror reflectivity, an increase in the aperture size of the solar collector, improvements in receiver characteristics (especially at high temperatures) and research for new working fluids. In order to achieve improvements in technology, high investments in Research and Development are required. Storage options would increase capital costs by at least 30% but reduce energy generation costs by about 5-6% per kWh. [6]

CSP has a very promising experience curve, especially in Egypt given its high DNI. According to the forecasted worldwide expansion of CSP, its Levelized Cost of Electricity (LCOE) is decreasing yearly. The downside is that Egypt continues subsidizing conventional electricity production. A comparison of the LCOE from conventional sources and CSP over the next 40 years concluded that CSP cannot compete under current conditions. A valid threat is the scarcity of primary energy resources, like natural gas. How long will energy be available at these low prices? And how long will the government be able to continue the electricity subsidy, especially when it represents a continuous strain on the budget? Unfortunately the strategy adopted does not shield the country from the threat of energy scarcity. The current strategy instead is providing loss of opportunities as the government fails to save energy resources for the future or export them at higher prices.

Accordingly Egypt needs to start moving towards CSP implementation as fast as possible while saving the other conventional resources in order to prolong their availability over time. The saved primary energy could then be restored for the future or sold to other countries at international prices, allowing the country to make a profit. This profit could be used to finance the long-term PPA/feed-in tariff. This strategy is a win in all cases; if the fuel prices rise, then the country will have additional funds for implementing the strategy, if they drop, then primary energy could either be saved for future use or consumed at conventional or hybrid power plants. If this strategy is adopted now, Egypt could become the CSP market leader in the MENA region over the medium term.

This strategy was proven by the model, which used international fuel market prices for the calculations. It demonstrated that in these conditions, CSP will be able to supply Egypt with power for the peak load at the same cost as conventional power before 2015, and with power for the medium load around 2022. The LCOE for CSP and conventional power will have the same approximate cost in 2035. Added CSP
capacity will first replace peak load, then medium load and finally base load plants, leading to immediate savings in those supply segments.

Furthermore, these calculations were assuming a project rate of return of 10%, which means that it does not require a subsidy, only a guaranteed PPA/feed-in tariff. This strategy also offers a logistical advantage. The main barriers facing electricity transport to Europe are the connection and transmission lines. Since primary energy is more easily transported (i.e. Liquified Natural Gas), it could be then exported directly to Europe through pipelines. This could be a good solution until the funding for the electric transmission lines is available or other transmission options are found.

Replacing fuel (in case of conventional power plants) with capital goods (for CSP plants) is, in principle, favourable for a national economy, as it creates jobs and foments industrial activity.

The CSP investment cost could be viewed as an advantage as well. Since the whole cost is paid at the beginning and no fuel costs are required, the capital return to the investors is known. It eliminates the risk of fuel price increases. Therefore the LCOE of CSP is not subject to escalation, which represents an indirect cost hedge in contrast to conventional energy. [54] The only sources of price increases are spare parts and inflation.

It is important to note that as a developing economy with high population growth, Egypt should maintain its strategic reserves of energy sources for a longer time period. Primary energy (e.g gas) is also needed for the country’s development. So even if exporting primary energy will increase national income, care should be taken that strategic reserves are not affected. According to BP, Egypt has natural gas reserves of 2190 billion m³. The production of natural gas in 2009 totaled 62.7 billion m³ and consumption reached 42.5 billion m³ [59]. According to this production rate - even if kept constant- the natural gas reserves will only last the next 34.9 years, which would be 2044. This also underlines the importance of CSP and other Renewable Energies. The goal is to combine primary energy and Renewable Energy in a way that would support and lead to the secure and sustainable development of the country. This could be done by introducing CSP and other Renewable Energy technologies as quickly as possible, with small shares of the market increasing until 2050, according to a set strategy. The only condition is that tariffs need to be high enough to attract investments.

As Egypt’s recent “revolution” promises changes in all government ministries, new opportunities abound to reframe the issue of Renewable Energy and CSP development. Energy will have to figure prominently on the agenda of any new government. The new government and policies have within their priorities the promotion of private and international investments, big opportunities exist to promote CSP.
Outlook

This thesis addresses the feasibility of CSP in Egypt from different points of view and recommends strategies to promote this technology, using the maximum amount of research possible during the available time frame. However there are still some topics that need to be studied further and others that should be tackled.

The main challenge for this study, and others focusing on Egypt, is the availability and accuracy of data. This, however, can only be solved by the respective authorities.

Financing the feed-in tariff is a critical question. In some cases the extra cost is assumed by the consumers and in other cases by the government. Each system has its pros and cons. This needs to be further investigated and analyzed.

It would definitely be useful to have more specific feasibility studies, which offer a more solid picture of the practical and associated costs for CSP in Egypt. These would offer investors a more comprehensive picture, and facilitate the investment decision. A detailed feasibility study is planned for the new CSP plant in Kom Ombo, which shall be very useful for the Egyptian CSP market. These feasibility studies should also include the different output options of CSP -process heat, water desalination and cooling- so investors can better evaluate them.

In this study the most common incentive schemes used around the world were presented with a special focus on the feed-in tariff. Further studies could discuss in detail other incentives and demonstrate their applicability and importance in Egypt. As for the feed-in tariff, it still needs to be further studied for Egypt with suggested values for the different segments and cases. The annual decrease should also be determined. Funding the feed-in tariff needs to be further studied and discussed.

The local manufacturing industry for CSP components is very important and will play a significant role in CSP deployment. Egypt has the potential to play a regional role in this respect. The World Bank has been studying this issue in depth for several MENA countries. Detailed studies in this field, which explore its effect on the Egyptian economy, should be interesting.

An economic and technical study of the possible ways of connecting Egypt directly to Europe is important, as well as a feasibility study for this investment.

This thesis focused on CSP from a market perspective rather than technical one. Different technical issues regarding CSP in Egypt need to be addressed, such as plant optimization, and the best CSP technologies for the country at the different locations.

Undoubtedly CSP has the potential to play an enormous role in reducing Egypt’s dependence on conventional energy. Timely investments in this technology today can ensure a steady and reliable energy source in the future.
APPENDICIES
Appendix A: Assuming the Electricity Output per Segment

For the model the electricity output per segment is needed, while only the value of total electricity output is known, which is 101,898 GWh/a [1]. From the reference model for the MENA region, the share of each segment could be calculated and assumed to be the same distribution in Egypt. Multiplying this share by the total annual electricity output will give us the electricity output per segment as shown in table 17.

<table>
<thead>
<tr>
<th>Study [54]</th>
<th>Egypt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed capacity [MW]</td>
<td>Electricity [GWh/a]</td>
</tr>
<tr>
<td>Peak Load</td>
<td>1,000</td>
</tr>
<tr>
<td>Medium Load</td>
<td>2,500</td>
</tr>
<tr>
<td>Base Load</td>
<td>4,000</td>
</tr>
<tr>
<td>Total</td>
<td>7,500</td>
</tr>
</tbody>
</table>

Table 17: Derivation of the electricity output per segment
*reference [1]
Appendix B: 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 [1]. (table 18)

Equation 8

\[
\text{specific fuel cost} \left[ \text{EGP/toe} \right] = \frac{\text{fuel cost} [\text{EGP}]}{\text{fuel} [\text{k toe}]}.
\]

<table>
<thead>
<tr>
<th>2008-2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel [K toe]</td>
</tr>
<tr>
<td>Total fuel Cost [ EGP]</td>
</tr>
<tr>
<td>Specific Fuel Cost [EGP/toe]</td>
</tr>
</tbody>
</table>

Table 18: Reference case to determine specific fuel cost [1]

With this value in mind, as well as knowing the total fuel consumed in conventional power generation in Egypt (22,179 k toe) [1], total electricity generation (101,898 GWh/a) [1] and assuming an exchange rate of the USD towards EGP of 0.181, the cost of fuel could be calculated according to equation 9. (Table 19)

Equation 9

\[
\text{specific fuel cost} \left[ \text{USD/MWh} \right] = \frac{\text{fuel consumption} [\text{toe}] \times \text{fuel cost} [\text{EGP/toe}] \times \text{USD/EGP}}{\text{Electricity Output} [\text{MWh}]}
\]

<table>
<thead>
<tr>
<th>2008-2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Consumption [ToE]</td>
</tr>
<tr>
<td>Fuel Cost [EGP/ToE]</td>
</tr>
<tr>
<td>Electricity Generation [MWh]</td>
</tr>
<tr>
<td>EGP/USD</td>
</tr>
<tr>
<td>USD/EGP</td>
</tr>
<tr>
<td>Cost of Fuel [$/MWh]</td>
</tr>
</tbody>
</table>

Table 19: Cost of Fuel

This is the fuel cost for the base load, the one with the highest efficiency assumed to be \( \eta = 40\% \). The efficiency plays a significant role in the fuel consumption and thus the fuel cost. Therefore in order to estimate the cost of fuel for the medium- and peak load, with a fuel efficiency of 35% and 30% respectively, equation 10 will be followed:

Equation 10

\[
\text{COF}_{\text{medium/peak}} = \text{COF}_{\text{base}} \times \frac{\eta_{\text{base}}}{\eta_{\text{medium/peak}}}
\]

This will result in a COF of 8.22 USD/MWh and COF peak of 9.59 USD/MWh.
Appendix C: Investment Cost of a Conventional Power Plant

The thermal plant investment cost is important to determine the LCOE. In Egypt there are three main types of power generation, Combined Cycle, Gas Turbines-, and Steam Turbine Power Plants. Knowing the installed capacity of each type, the share of the production can be calculated with the results shown in table 16. As well knowing the investment cost of each generation type, i.e. Combine Cycle 800 USD/kW, Gas 500 USD/kW and Steam 1400 USD/kW [40] then by multiplying these costs with the share of the installed capacity we calculate the weighted average for the thermal plant investment cost of 1114.77 USD/kW. (Table 20)

<table>
<thead>
<tr>
<th>Type of Generation</th>
<th>Installed capacity [MW]</th>
<th>Share of Installed Capacity</th>
<th>Total Investment Cost [$/kW]</th>
<th>Weighted Average Investment Cost [$/kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Cycle</td>
<td>7,178</td>
<td>35%</td>
<td>800</td>
<td>283.19</td>
</tr>
<tr>
<td>Gas</td>
<td>1,641</td>
<td>8%</td>
<td>500</td>
<td>40.46</td>
</tr>
<tr>
<td>Steam</td>
<td>11,458</td>
<td>57%</td>
<td>1,400</td>
<td>791.10</td>
</tr>
<tr>
<td>Total</td>
<td>20,277</td>
<td>1</td>
<td>1,114.77</td>
<td></td>
</tr>
</tbody>
</table>

Table 20: Determining thermal plant investment cost [40]
Appendix D: Operation and Maintenance Cost

The fixed O&M costs vary between the different types of generation, as Combined Cycle charge 2 USD/kW, Gas 13 USD/kW while the most expensive ones are the Steam Power Plants with 28 USD/kW. Using the weighted average according to the respective installed capacity, the average fixed O&M cost could be calculated as shown in table 21 as 17.58 USD/kW/year.

<table>
<thead>
<tr>
<th>Type of Generation</th>
<th>Fixed O&amp;M cost [$/kW/a] [40]</th>
<th>Installed capacity [MW] [40]</th>
<th>Share of Installed Capacity [%]</th>
<th>Weighted Average Fixed O&amp;M Cost [$/kW/a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Cycle</td>
<td>2</td>
<td>7,178</td>
<td>35%</td>
<td>0.71</td>
</tr>
<tr>
<td>Gas</td>
<td>13</td>
<td>1,641</td>
<td>8%</td>
<td>1.05</td>
</tr>
<tr>
<td>Steam</td>
<td>28</td>
<td>11,458</td>
<td>57%</td>
<td>15.82</td>
</tr>
<tr>
<td>Total</td>
<td>20,277</td>
<td>1</td>
<td>1</td>
<td>17.58</td>
</tr>
</tbody>
</table>

Table 21: Determining of fixed operation and maintenance cost [40]
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