FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE

ELECTRICITY COST FROM RENEWABLE ENERGY TECHNOLOGIES IN EGYPT

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SUMMARY

Electricity cost from Renewable Energy Technologies in Egypt
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This study is developed based on the methodology of the versions from December 2010 (Kost, Schlegl December 2010), May 2012 (Kost et al. 2012) and November 2013 (Kost et al, 2013) for Germany. The current study is done for the Egyptian market and takes into account current trends in cost development.

Levelized cost of electricity (LCOE) presents a basis of comparison for weighted average costs of different power generation technologies. This concept makes it possible to compare different technologies accurately and is not equivalent to the amount of feed-in compensation or serves as an adequate investment decision for individual power plants. The actual value of the electricity is determined by the daily and hourly variations and weather-related fluctuations in supply and demand conditions and therefore cannot be represented by LCOE. Information about the methodology for LCOE can be found in the Appendix.

In the current study, the levelized cost of electricity (LCOE) of renewable energy technologies in the third quarter of 2016 is analyzed and their future cost development predicted up to the year 2035 based on technology-specific, historical learning rates and market development scenarios.
The focus is on LCOE of photovoltaic (PV), concentrated solar power (CSP) plants and wind power plants in Egypt. As a reference, the development of the levelized cost of electricity for newly constructed conventional power plants (diesel generators and gas combined cycle power plants (CCGT) is studied. Figure 1 shows the calculated LCOE of renewable energy technologies and fossil fuel power plants if constructed in 2016.
PV plants achieve a LCOE of 0.079 and 0.181 US$/kWh in the third quarter of 2016, depending on the type of power plant (ground-mounted utility-scale or small rooftop plant) and received sunlight (1900 to 2700 kWh/(m²a) global horizontal irradiance (GHI) in Egypt). The specific power plant costs of PV are in the range of 1300 to 2000 US$/kWp. Ground mounted plants have a lower specific investment and therefore lower LCOE.
The levelized cost of electricity from CSP plants (spec. invest 4000 - 5200 US$/kW) are between 0.125 and 0.218 US$/kWh. A heat offtake is not included in the calculations.
Wind power at very good onshore wind locations already has lower costs than diesel generators or CCGT power plants. The levelized cost of electricity for onshore wind power (spec. invest from 1100 to 1500 US$/kW) are between 0.048 US$/kWh and 0.102 US$/kWh.

In the case of conventional power plants, the LCOE from CCGT range between 0.076 and 0.115 US$/kWh and between 0.072 - 0.094 US$/kWh from diesel-fired generator. The full load hours of conventional power plants are integrated into the calculation of the LCOE. The fuel cost is assumed to be increasing in the upcoming years. Values in Figure 1 reflect the level of the full load hours and a variation of the CAPEX for the year 2016.

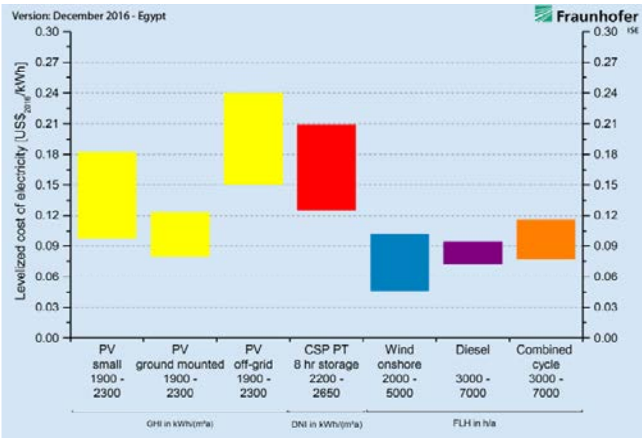

Figure 1: Levelized cost of electricity (LCOE) of renewable energy technologies and conventional power plants at locations in Egypt in 2016. The value under the technology refers in the case of PV to the global horizontal irradiance GHI in kWh/(m²a), for CSP the direct normal irradiance DNI kWh/(m²a), for the other technologies it refers to the number of full load hours for the plant per year. Specific investments are taken into account with a minimum and maximum value for each technology.

Forecast for the Levelized Cost of Electricity in Egypt until 2035

Figure 2 shows the result of the calculations for the future development of the LCOE in Egypt up to 2035. The cost ranges reflect the existing range of the calculation parameters (e.g. plant prices, solar irradiation, wind conditions, fuel costs, number of full load hours, etc.), which can be viewed in Tables 1 to 5. This method will be explained for the photovoltaic cost range: The upper limit of LCOE results from the combination of a PV plant with a high procurement price at a location with low solar irradiation (e.g. North Egypt). Conversely, the lower limit is defined by the favorable availability and low procurement price of plants at locations with high solar irradiation in South Egypt. Analogously, this process is applied with the corresponding reference values to CSP and wind plants as well as conventional power plants.

The usual financing costs in the market and the surcharges for risk are included in detail and are specific to the technology. This provides a realistic comparison of the power plant locations, technology risks and cost developments. The level of financing costs has a considerable influence on the LCOE and the competitiveness of a technology. Furthermore, all costs and discount rates are calculated with real values in US$ (reference year 2016) in this study.

The specific investments in the third quarter of 2016 are calculated based on market research and cost studies.

The development of the PV market leads to a progress ratio (PR) of 85% (corresponding to a learning rate of 15%) which will lead to further reduction in costs. By 2035, the LCOE of ground mounted PV plants will sink to 0.055 US$/kWh so that ground mounted and rooftop plants will be able to compete with onshore wind power and the increasing levelized cost of electricity from CCGT (0.078 to 0.087 US$/kWh) and diesel generators (0.090 to 0.094 US$/kWh). The diesel generator investments lie at 170 to 300 US$/kWp. PV ground mounted plants in Egypt will drop considerably below the average LCOE of all fossil fuel power plants by the year 2035.

The LCOE from onshore wind power today is already at a very low level and will only decrease a small amount in the future. Improvements are expected primarily in form of a higher number of full load hours and the development of new locations with specialized wind turbines. Thanks to the expected increase in prices for fossil fuel power plants, the competitiveness of onshore wind power will continue to improve. Starting 2027, the local conditions will especially decide if onshore wind power can produce less expensive electricity than PV plants.

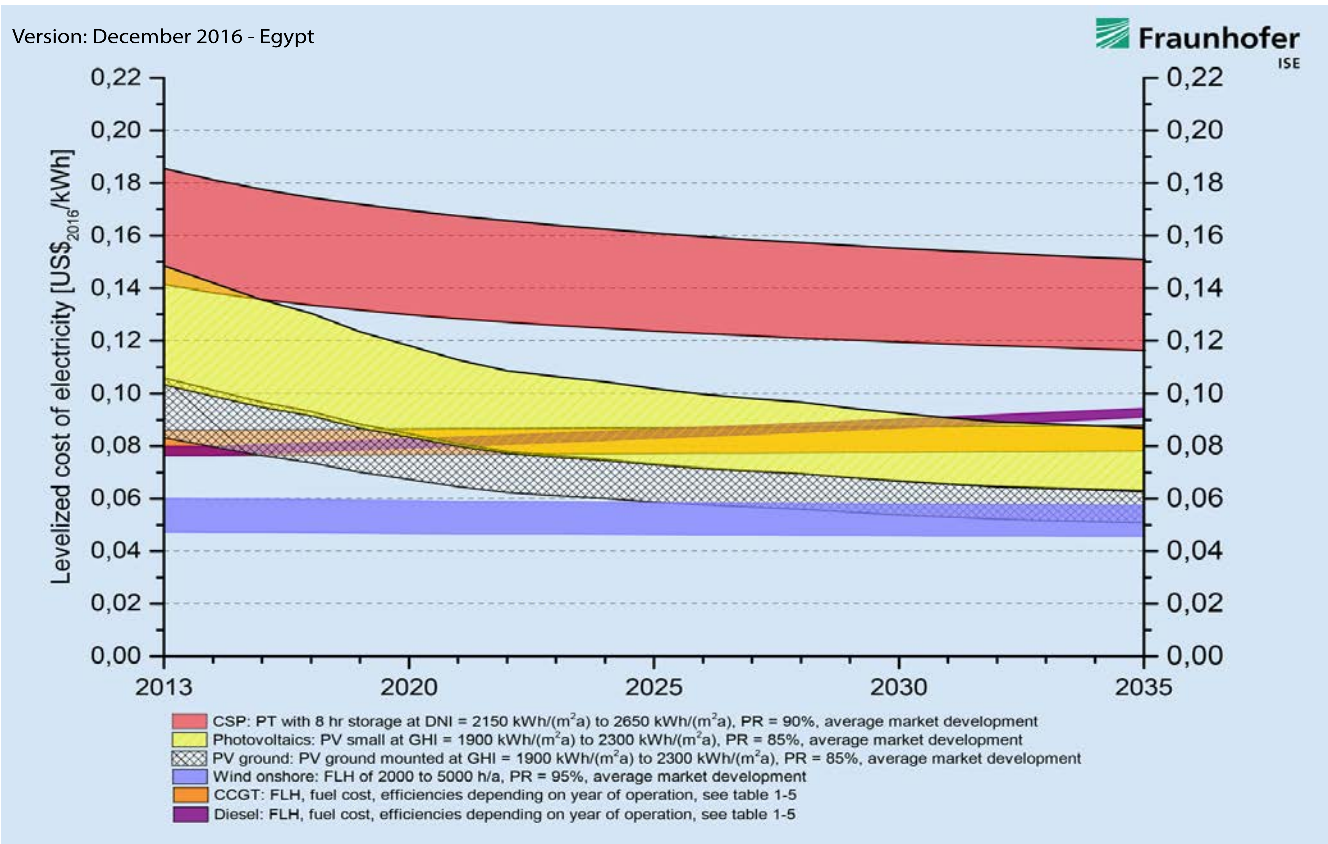

Figure 2: Learning-curve based predictions of the levelized cost of electricity of renewable energy technologies and conventional power plants in Egypt by 2035. Calculation parameters in Tables 1 to 5.

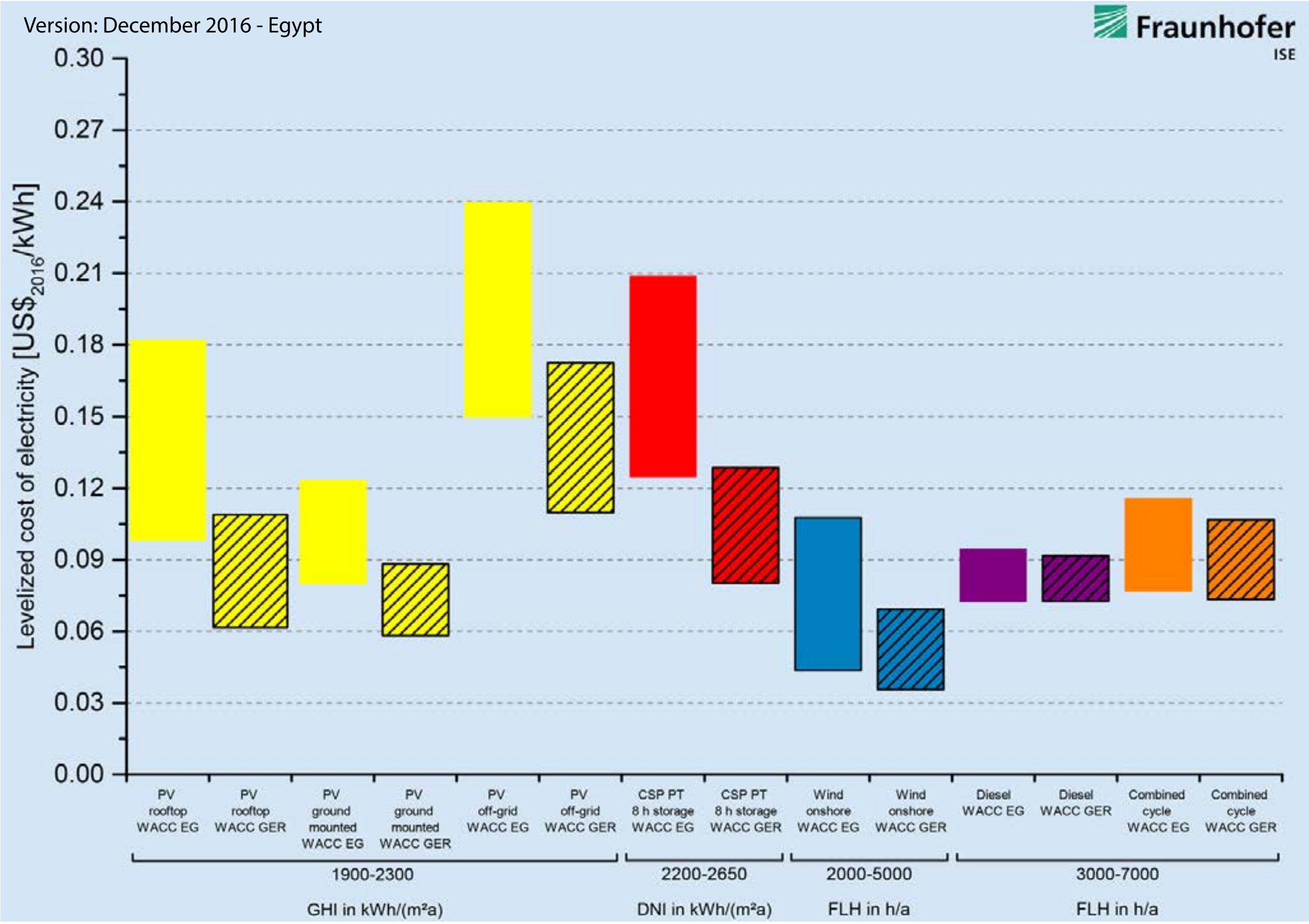

Figure 3: LCOE of renewable energy technologies and conventional power plants at locations in Egypt in 2016. The dashed bars show the level of LCOE under the assumption of financing costs like in Germany.

The LCOE is highly sensitive to the financial parameters in the identified locations and for the specific technology, respectively. The relatively high financing costs in Egypt lead to a high LCOE for PV and CSP despite the very high irridiation in Egypt. The values of the LCOE for PV in Egypt are surprisingly similar to those in Europe.

When assuming financing conditions which are feasible in a market which is mature for renewable energies, e.g. Germany, the LCOE is reduced substantially. Figure 3 shows the effect of enhancing the financing situation in Egypt when applying the financing conditions of a mature renewable energy market like Germany.

1. OBJECTIVE OF THIS STUDY

In contrast to the tendency of increasing energy prices for fossil and nuclear power sources, and the gradual removal of fossil fuel subsidies, LCOE of all renewable energy technologies have been falling continuously for decades. This development is driven by technological innovations such as the use of better and cheaper material, reduced material consumption, more-efficient production processes, increasing efficiencies as well as larger systems. For that reason, the objective of this study is to analyze the current and possible future cost situation mainly for renewable energy technologies and compare these to the conventional generation technologies.

Central content of this study

- Analysis of the current situation and future market deveopment of Photovoltaics (PV), Concentrated Solar Power (CSP) and wind power in Egypt.
- Economic modelling of the technology-specific LCOE (Status 3rd quarter of 2016) for different types of plants within the local conditions (e.g. solar irradiation and wind conditions) on the basis of common market conditions.
- Assessment of the different technology and financial parameters based on sensitivity analyses of individual technologies.
- Geographical presentation of the LCOE of exemplary plants in Egypt.
- Projection of the future LCOE of renewable energy technologies through 2035 based on learning curve models and market forecast scenarios.

The technologies are assessed and compared on the grounds of historically documented learning curves and conventional market financing costs. The current and future LCOE for new conventional power plants (diesel generators and gas combined cycle power plants) are calculated as a reference.

In order to be able to realistically represent the usual variations in market prices and fluctuations in full load hours within the respective technologies, upper and lower price limits are stated. Characteristics of individual techonolgies that cannot be represented in the LCOE such as advantages of FLH, decentralized power generation, load following operation capability, availability depending on time and easily integrated storage are not taken into account while the effect of varying the FLH or CAPEX or the financial conditions is presented in sesitivity analyses.
The level of levelized cost of electricity of renewable technologies depends significantly on the following parameters:

Specific investments
for the construction and installation of plants. Upper and lower limits are defined based on current power plant and global and local market data.

Local conditions
with typical irradiation and wind conditions for different locations and full load hours in the energy system.

Operating costs
during the plant's operational life time.

Operational life of the plant

Financing conditions
The calculations are based on specific, local market conditions. The technology-specific risk surcharges and financing conditions are based on thre respective shares of external and equity based financing.

The following power generation technologies are studied and assessed in various design sizes with respect to the current level of their levelized cost of electricity at local conditions in Egypt:

Photovoltaic plants (PV)
Modules based on crystalline silicon solar cells

Small rooftop plants (up to 10 kWp) – PV small
Large rooftop plants (10 - 100 kWp) – PV large
Ground-mounted utility-scale plants (larger than 1000 kWp) – PV utility-scale
PV off grid (typical sizes) – PV off grid

For the PV plants locations in Egypt with a GHI of 1900 to 2700 kWh/(m²a) are assumed.

Concentrating Solar Power Plants (CSP)

Parabolic trough power plants (100 MW) with and without thermal storage – CSP-PT

Power plants with Fresnel technology with thermal storage (100 MW) – CSP - Fresnel

Solar power tower plants (100 MW) with thermal storage – CSP - Tower

Of the various CSP plant technologies, three different technologies (parabolic trough power plants, Fresnel systems and solar power tower plants) that are currently being developed and built are studied.

Wind Power Plants

The operation of 2 - 3 MW wind turbines for high and low wind speeds in Egypt is analyzed. A range of 2000 to 5000 full load hours per year is considered. – Wind onshore

Conventional Power Plants

The LCOE of conventional power plants based on diesel and natural gas with different full load hours.

Diesel generators:
Diesel small (Generators < 50 kW)
Diesel large (Generators > 10 MW)

Gas and HFO/LFO power plants (CCGT):
CCGT- HE (High efficiency plants 50-60%)
CCGT- LE (Lower efficiency plants 40-50%)

2. HISTORICAL DEVELOPMENT OF RENEWABLE ENERGY TECHNOLOGIES IN EGYPT

The Egyptian economy is facing several challenges in general and in the power generation sector in particular. Most prominent is the failure of the installed capacity (28 GW) in meeting the current peak demand especially during the summer period is connected with a missing reserve margin (Egyptian Electricity Holding Company 2015a). Since the annual growth of the electricity demand over the upcoming five years is expected to increase at a rate of 5-6% further investment in the power generation sector have already been initiated and must be urgently issued (Mitscher et al. March 2015).

The degradation in the crude oil production over the last few years combined with high concerns about the depletion rate of the Egypt's natural gas reserves present a clear statement for the important role of renewable energy in meeting the growth of electricity demand (Patlitzianas 2011). The Egyptian government recognized this fact and approved an ambitious plan to produce 20% of the total generated electricity by renewable energy in 2020. This 20% is comprised of 12% (7200 MW) wind energy, 6% (2851 MW) hydropower, and 2% (1320 MW) solar energy (Razavi, Hosse in 2012). Due to the late political circumstances and development, the target was extended to 2022 (New & Renewable Energy Authority (NREA) 2015). Over the last decade, several projects were developed particularly in the wind and solar energy fields in order to meet the objectives of the Egyptian government on the renewable power development as shown in Figure 4.

The electricity generation from hydropower resources has played a vital role in Egypt for decades. In 1960, the Egyptian government commissioned the Aswan Reservoir Dam I with a capacity of 271 MW, followed by the High Dam with a capacity of 2100 MW in 1967, and the Aswan Reservoir Dam II with a capacity of 270 MW in 1985. In cooperation with the Ministry water resources; Esna hydropower plant with a capacity of 85.68 MW was constructed in 1993, and Naga Hamadi with a capacity of 64 MW in 2008 (Egyptian Electricity Holding Company 2010).

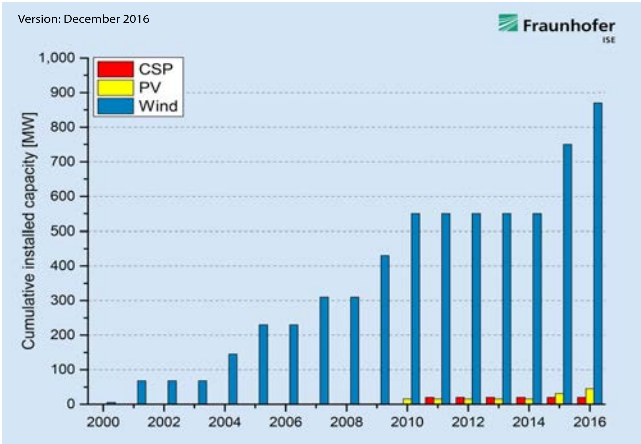

Figure 4: Egypt cumulatively installed capacity 2000-2016 of CSP, PV and wind power (Whiteman et al. 2015)

The Egyptian Wind Atlas states that Egypt has good wind potential, especially in the Red Sea coast region. The wind speeds in Egypt vary from 5 m/s until almost 11 m/s at the Gulf of El Zeit (Gylling Mortensen 2006). Given the high potential of wind power, Egypt started the wind energy program in 1993 through establishing a 5 MW pilot wind farm in Hurghada. The farm consists of 42 unit with various capacities ranging between 100 and 300 kW (New & Renewable Energy Authority (NREA) 2005). Egypt has crossed the experimental pilot project in Hurghada through a large scale grid connected wind farm (545 MW) in the Zafarana area along the coast of the Red Sea. The wind farm includes 700 turbines from different models (600 kW, 660 kW, and 850 kW). The Zafarana wind farm was implemented in several stages with various partners over ten years (2001-2010). The Zafarana wind farm stages can be summarized as following (New & Renewable Energy Authority (NREA) 2005), and (Fried, Qiao 2015):

- 140 MW wind farm within (2001-2004)
- 85 MW wind farm at 2005
- 80 MW wind farm at 2007
- 120 MW wind farm at 2010
- 120 MW wind farm at 2010

Additionally, the Egyptian government plans to build large wind farms with a total capacity of 1340 MW in the Gabal El Zayet, Gulf of Suez, and western Nile bank until 2018. The Gabal El Zayet wind farm includes three main stages, and it can be summarized as following (New & Renewable Energy Authority (NREA) 2015):

- The first stage with a capacity of 200 MW was officially inaugurated at 2015
- The second stage with a capacity of 120 MW will be finalized by the end of 2016.
- The third stage with a capacity of 220 MW will be finalized by the end of 2017.

The Gulf of Suez wind farm, with a total capacity of 600 MW, will be inaugurated by the end of 2018 in cooperation with the German Governmental KfW Bank, the European Investment Bank (EIB), Masdar, and the French Agency (AFD). Moreover, the western Nile Bank wind farm will be finalized in the same year in collaboration with the Japanese government (JICA) (New & Renewable Energy Authority (NREA) 2013).

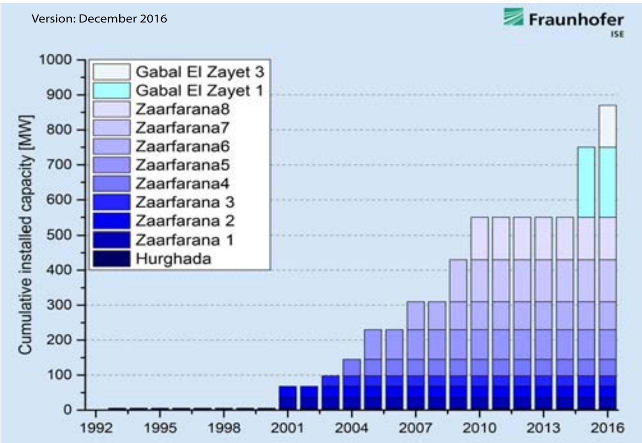

Figure 5: The cumulative installed capacity of wind farms in Egypt till the end of 2016

Even though the New & Renewable Energy Authority (NREA) owns the entire wind farm projects shown Figure 5, the Egyptian government encourages the private sector to participate by initiating incentives like the feed-in tariff or public tenders. In 2013, NREA announced a competitive tender under the framework of the "Build-Own-Operate (BOO) scheme for 250 MW of the wind farm (Fried, Qiao 2015). Furthermore, a usufruct agreement was signed with an Egyptian company in 2014 for constructing a wind farm with a total capacity of 600 MW (New & Renewable Energy Authority (NREA) 2015).

According to the Egyptian Solar Radiation Atlas (Shaltout 1991), Egypt has an abundance of solar energy since the global horizontal radiation varies between 1900 to 2700 kWh/(m^2a). The direct solar radiation is respectively high with 1970 kWh/(m^2a) to 2591 kWh/(m^2a), with an average sunshine of 10 hours and very few clouds. Therefore, Egypt has a great technical potential for widespread solar energy technologies and applications. Despite this fact, the development of solar energy utilization was limited till 2014 to a number of small-scale off-grid PV systems with a total capacity of 15 MW and a solar thermal plant with a capacity of 20 MW at Kuraymat (El-Khayat et al. 2012). The recent national ambitious plan of removing the electricity subsidies gradually within the upcoming five years amplifies the trend towards the expansion of PV systems (M. James April 2015). Within 2015 and 2016, Masdar established seven hybrid PV systems with a total capacity of 30 MW in the Red Sea and Al Wadi Al Jadeed governorates. The largest share of this capacity was a 10 MW plant in Siwa; this project generates over 175551 MWh/year which meets around 30% of the electricity demand in this area (New & Renewable Energy Authority (NREA) 2015). The details for the PV systems capacity in Egypt till the end of 2016 is shown in Figure 6.

In addition to the PV hybrid systems, the Emirati company has installed 7,000 off-grid PV systems in several remote areas of Egypt in cooperation with the Egyptian Ministry of Electricity. Each system consists of two solar panels with a storage capacity up to two days (Mancheva 2016).

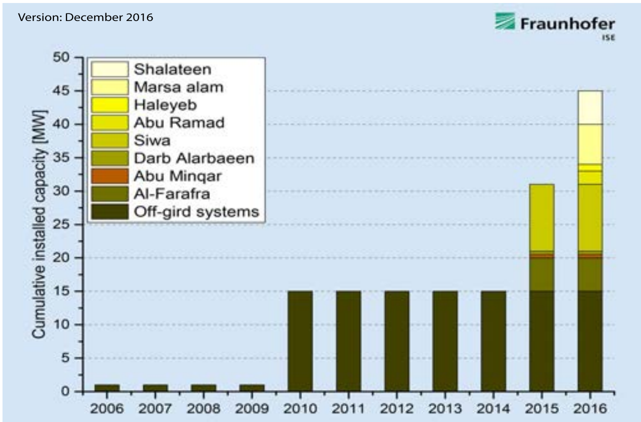

Figure 6: The cumulative installed capacity of PV systems in Egypt till the end of 2016

The program "Intelligent Energy Europe" of the European Union developed a scenario to predict the cumulative renewable energy technologies until 2050 in Egypt as shown in Figure 6 (Trieb et al. 2015). The proposed scenario reflects exponential growth in the renewable energy technology capacities over the next decades particularly CSP, PV and wind power. From 2010 to 2030, the growth in the renewable energy technology installation is slow where the CSP, PV and wind power will have a share of 2.3%, 12.4%, and 9.2% of the total installed capacity, respectively.

Within 2040 to 2050, the market demand for the CSP and PV will see a strong growth especially in 2050 where the CSP and PV will amount to 27.2% and 21.3%, respectively, while the wind power sector will have a share of 14% of the total installed capacity. According to the national objectives, hydropower will not be deployed any further. This is due to the limited resources. For this reason, the study does not analyze hydropower any further.

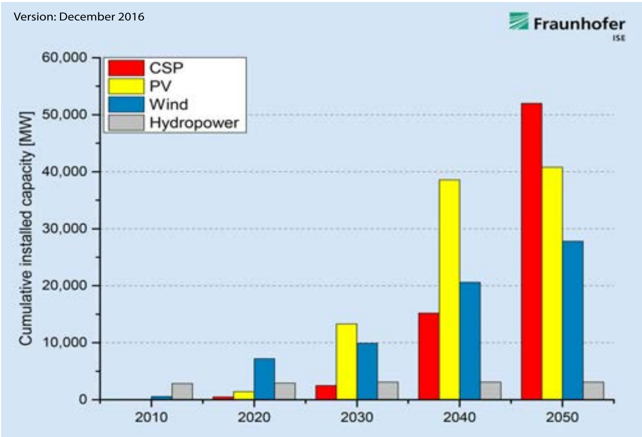

Figure 7: Market Forecasts for the cumulative renewable energy technologies in Egypt through 2010 and 2050 according to (Trieb et al. 2015)

3. BACKGROUND, APPROACH AND ASSUMPTIONS

Approach

The levelized cost of electricity (LCOE) is calculated for each considered technology, assuming an installation of the respective technology in Egypt today and for the future until 2035. In order to achieve that, the investment costs are determined: current investment costs are identified by a detailed market analysis, and future investment costs are calculated out of the respective historic learning rate and a forecast of the market development. The LCOE is calculated by applying specific technology and financing parameters.

Photovoltaics

Market Development and Forecast

The solar PV technology is globally one of the fastest growing renewable energy technologies over the last few years driven by the governmental incentive policies including the feed in tariff and the tax break (IRENA June 2012). Furthermore, solar PV has the centralization and decentralization feature which adds flexibility in the installation. The global PV capacity has been multiplied by a factor of 36 over the last ten years, and it reached 242 GW by the end of 2015 (Agora energiewende 2015) (Fraunhofer ISE October 2016). The rapid expansion of the PV capacity reduces the price dramatically where the manufacturing cost declines 20% for every doubling of installed capacity (Fraunhofer ISE October 2016).

By the end of 2015, the cumulative installed photovoltaic capacity increased by 26% in comparison to the previous year (REN21 2016). The European Union is still the most developed region with a total installed capacity of 96 GW (SolarPowerEurope 2016). However, there is a high growth rate of the PV installation in Asia and a stagnation in European PV market due to the reduced subsidies and incentive schemes and the difficulties in recouping the project costs in Europe (REN21 2016).

In 2015, China added 15 GW to a total capacity of 28 GW compared to the current 43 GW globally installed capacity, overtaking the long term lead of Germany. In Japan, 11 GW were added and connected to the electricity grid by the end of 2015 which raised the total PV capacity to 33.3 GW. Elsewhere in Asia, the Indian government added 2 GW as part of an ambitious plan of achieving 100 GW by 2022, followed by Korea which added 0.3 GW to a total capacity of 2.1 GW. Outside Aisa, North America added 7.8 GW where the United States of America accounted for 7.3 GW, and Canada accounted for 0.5 GW. In Africa and the Middle East, the deployment of solar PV is driven by the reduction of costs, the abundance of solar resources, and the rapid increment in the energy demand. Several off and ongrid projects were established in Africa. Algeria and south Afrcia are leading in adding capacities where Algeria added around 0.3 GW, and South Africa added 0.2 GW in 2015. However, the installed capacity is still limited in the Middle East. Jordan and the United Arab Emirates announced several tenders for solar PV installation with low bids rate in 2015 (REN21 2016).

The Fraunhofer-Institute for Solar Energy Systems ISE on behalf of Agora Energiewende (Agora Energiewende 2015) developed scenarios for the global PV market demand up to 2050 showing an exponential behavior in the upcoming years as shown in Figure 8. The three main scenarios include the Pessimistic, the Intermediate, and the Optimistic scenario. The Pessimistic scenario is developed based on a 5% Compound Annual Growth Rate (CAGR) after 2015. This rate is estimated based on a slow market development. The Intermediate and the Optimistic scenarios were built based on 7.5%, and 10% of CAGR, in the period between 2015 and 2035, respectively. The three forecast scenarios are lower than the historical development of the global PV market which was 50 percent between 2000-2013 since the high rate of development can only be sustained in relatively young markets. Based on the proposed scenarios, the deployment of PV capacity will vary between 3000 and 6900 GW by the end of 2035.

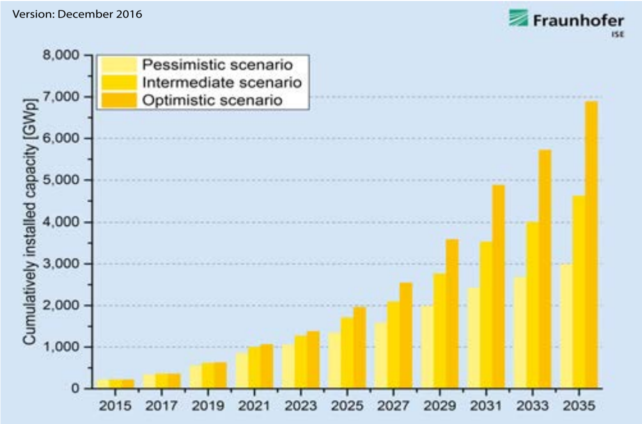

Figure 8: Market forecast for global cumulative power plant capacity for PV 2015-2035 according to Fraunhofer ISE

Market prices – Status quo and development

The solar PV industry continues a strong growth 2015 due to the strong global demand and the declination in the price of PV systems. The average PV module price dropped further in 2015 as shown in Figure 9, but at a lower rate compared to the period between 2008 and 2012 (REN21 2016). The price for the crystalline modules dropped by about 8% over the last few years to reach an average price of 0.53 US$/W in the 3rd quarter of 2016. The industry focussed on the soft costs improvement through enhancing the PV efficiency and developing an optimized output (Fraunhofer ISE October 2016). In 2015, the Asian continent continued to be in the leadership position for the global module production with 87% where China alone accounts for 67% of the total world production. This situation is the topic of an intensive debate within the international PV industry, since the Chinese manufacturers are being accused of being supported by the Chinese government and of price dumping in order to achieve a dominant position in the market after a period of market consolidation. In light of the current conditions, manufacturers are again able to manufacture cells and modules with positive margins. In addition, several countries (including Algeria, Brazil, Egypt, Iran, South Africa and Thailand) began to establish manufacturing facilities during 2015 to meet the growth in the global energy demand, and reduce the import of PV modules (REN21 2016).

The strong decline in the price of solar modules also led to a reduction in the prices for PV systems. The costs for inverters and BOS plant components (Balance-of-System components) such as assembly systems and wiring as well as for their installation did not drop to the same degree (Fraunhofer ISE October 2016). While in 2005, solar modules constituted a nearly 75% share of the system costs, today it is at around 55%. Based on these market data, and studies done at the Fraunhofer ISE, a progress ratio of 85% is assumed for all PV systems.

Table 1 shows price ranges for PV power plants of various sizes in Egypt. The prices for small PV systems (up to 10 kWp) are currently between 1700 and 2000 US$/kWp. For larger PV systems up to 1000 kWp, the prices currently range between 1300 and 1600 US$/kWp. PV utility-scale power plants (PV ground mounted) with capacities above 1000 kWp are achieving investment costs ranging from 1200 to 1500 US$/kWp. For the off-grid PV systems, the price currently ranges between 2400 and 2650 US$/kWp. These values include all costs of components and of installing the PV power plant.

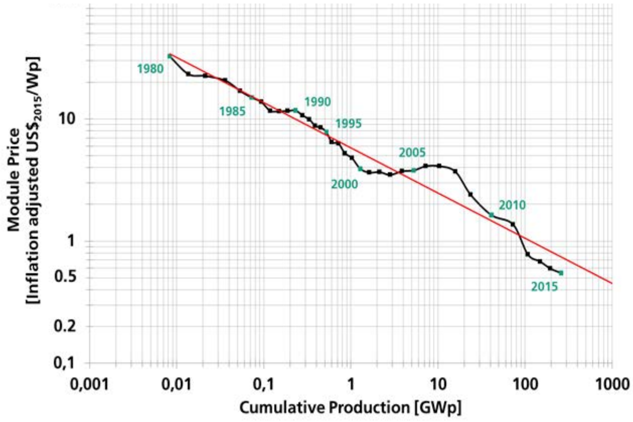

Figure 9: Historical price experience curve of PV modules since 1980. Source: ©Fraunhofer ISE: Photovoltaics Report, updated: 4 November 2016 Learning curve based on EuPD data (Fraunhofer ISE October 2016)

Concentrating Solar Power Plants

Market Development and Forecast

Due to its technological properties, CSP can be operated efficiently primarily in areas with excellent solar resources with an annual DNI of over 2000 kWh/(m²a) (Kost et al. November 2013). The privilege of utilizing thermal energy storage systems is essentially distinguishing CSP from wind power and PV. Therefore, this technology attracted e.g. the governments in Spain and USA to support several CSP projects.

The CSP deployment has started to grow at a high rate since 2004 where the annual global installed capacity increased by 50 percent per year over the last few years (REN21 2014). In 2015, the worldwide installation increased only by 6 percent or nearly 0.27 GW to achieve a total capacity of 4.65 GW. Spain remains in the leadership position for CSP with a total capacity of 2.3 GW, followed by the United States of America with a total capacity of 1.7 GW. Moreover, there is a notable growth of installations of CSP plants in other countries (Whiteman et al. 2015). Examples of the activities in the recent years are: Morocco established a CSP power plant with a capacity of 160 MW in 2015 as a part of a Multi-stage CSP plant with a total capacity of 500 MW. This project is expected to be finalized by the end of 2018. In Egypt a CSP combined cycle with a 50 MW capacity was installed in 2011. In South Africa, the first CSP plant was inaugurated in 2015 with a capacity of 100 MW, followed by another CSP project with a total capacity of 100 MW in 2016. In addition to the existing projects, several CSP projects are under way in North Africa. In Algeria, the government announced a plan for installing 2 GW of CSP by the end of 2030, whereas Egypt plans to add 50 MW by the end of 2020 (REN21 2016).

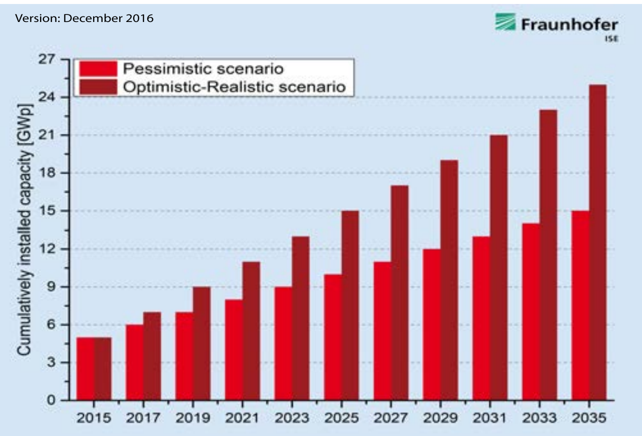

Figure 10 Global market forecast for cumulative power plant capacity for CSP 2015-2035 (Hashem 2015)

A market development forecast by CSP Today predicts a steady increase in the installed capacity starting from almost 5 GB in 2015 (Hashem 2015). Three main scenarios are presented in the study (a pessimistic scenario, a conservative scenario and an optimistic scenario). In this study the optimistic scenario is not included since the development of the technology is not likely to reach this scale. In the pessimistic scenario an almost linear increase of 500 MW is assumed, meaning that 15 GW installed capacity will be reached by 2035. Since the CSP Today forecast is presented until the year 2015 the values until 2035 are extrapolated. The conservative scenario assumes an annual increase of 1000 MW reaching 25 GW in 2035. A summary for the deployment of CSP until 2035 is shown in Figure 10.

The progress ratio assumed for CSP technologies is 90%. The specific investment for CSP technologies is shown in Table 1. Parabolic trough plants of 100 MW without thermal storage systems have specific investment of 2900 to 4450 US$/kW. Adding a storage system increases the cost of the plant reaching a range from 4600 US$/kWh up to 5850 US$/kWh (FRENELL 2016).

Wind Power Plants

Market Development and Forecast

Among all renewable energy technologies, wind power and PV are currently the leading technologies due to their competitive costs with conventional power plants (GWEC 2016). In the United States of America and Europe, wind power is the leading source of new power generation, whereas it is ranked as the second source in China (REN21 2016).

By the end of 2015, the global installed capacity of wind farms increased up to 432 GW, representing a cumulative market growth of more than 17% (GWEC 2016). Asia is the largest market for wind power since it accounts for 53% of the installed capacity, followed by the European Union (20.1%), and North of America (16%) (REN21 2016).

China has the leadership position in wind power installation since a capacity of 30.8 GW was added in 2015 reaching a total capacity of 145 GW. The Chinese wind power market is driven by the governmental subsidies for the purpose of energy security and pollution reduction. The European Union also had a tremendous progress in wind farm installations which is mainly due to the large amount of installed capacity in Germany. In 2015, Germany installed a capacity of 6 GW that brought the European Union to a total of 147.7 GW. The United States of America ranked as the second country in the wind power installation with a total installed capacity of 88.7 GW (GWEC 2016).

Even though the Non-OECD countries have limited installations of wind farms, new markets are opening across Latin America, Africa, and the Middle East. By the end of 2015, in Latin

America, a total capacity of 12.2 GW was installed where Brazil share was 57 % of the total capacity (GWEC 2016). Due to the financial problems in Africa, a small amount of wind farms was reached where the total installed capacity was 3.29 GW. However, the 'pipeline' activities in Egypt and Morroco will enhance the share of wind power within the next few years. In the Middle East, the total installed capacity of wind power was around 244 MW with Iran and Jordan in the leading positions (GWEC 2016).
The Global Wind Energy Council and Greenpeace International (GWEC November 2014) present an outlook for wind power based on three main scenarios: New Policies scenario, Moderate scenario, and Advanced scenario. In the New Policies scenario, the market forecast is assessed based on the current trend of the national and international climate policy without dependency on formal laws. In the Moderate scenario, the proposed forecast model has the same characteristics as the New Policies scenario. However, this scenario accounts for all supporting policies for wind power technology. The Advanced scenario is considered as the most ambitious scenario where the governments enacts sympathetic laws and policies for the wind power installation in line with supportive policies on carbon emission reduction.
The current study predicts a future market with a total capacity between 1025 and 2506 GW in 2035 as shown in Figure 11. Based on the historical data a progress ratio of 95% is assumed for the study.

Table 1 shows price ranges for wind power plants in various locations in Egypt. The specific investment for wind power plants ranges between 1100 and 1600 US$/kW (Kost et al. November 2013). For locations with very high wind speeds and high full load hours a higher specific investment will occur.

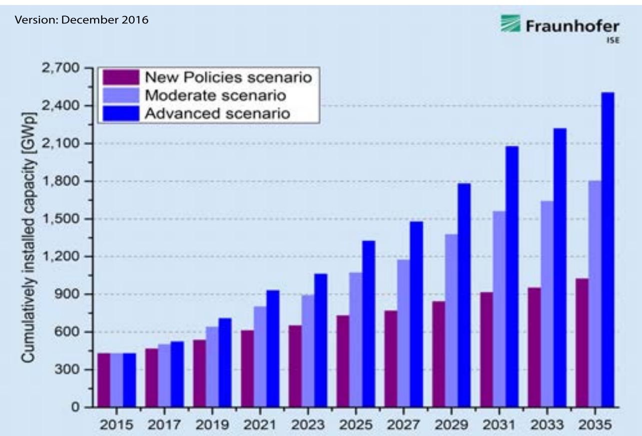

Figure 11: Global market forecasts cumulative wind power 2015-2035 according to GWEC (2015)

Conventional Power Plants

Market development and forecast

Electricity generation by the differnet fuel types has changed dramatically over the past few decades. However, coal continues to be the primary fuel to generate electricity for conventional power plants. Electricity generation from nuclear and natural gas-fired power plants continues to increase rapidly since the 1980s, whereas the use of oil for electricity generation declined sharply after the oil crisis in the 1970s. In the 2000s, the concern about global warming and the increment in the green gas emission spiked more interest toward the development of natural gas-fired power plants since it emits CO_2 at a lower level compared to coal and oil power plants (EIA May 2016).

Natural gas power plants have the second largest share of electricity generation worldwide after coal-fired power plants. Natural gas power plants produce 5155 TWh. 22% of the natural gas power plants are installed in the United States of America, followed by the Russian Federation with 10.3%, Japan with 8.16%, and the Islamic Republic of Iran with 3.8% (IEA 2016). The EIA forecast showes a continuous growth in the installed capacity of natural gas-fired power plants over the next decades reaching a share of 28 % of the total electricity generation by the end of 2040 (EIA May 2016). Based on the Natural gas report by IEA, natural gas will continue to increase its share until 2020. The annual increase lies at around 2% (IEA 2015).

The oil power plants play a minor role in the worldwide electricity production where it has a share of only 4.3% of the total electricity generation (IEA 2016). However, it still plays a vital role in several MENA countries since they still have large oil reserves. In Saudi Arabia, 54% of the total electricity generation is based on oil power plants (Aoun, Nachet March 2015). The EIA assumes that the electricity generation based on the oil power plants cwill continue to degrade over the next decades where it will only have a share only 2% in 2040. This decline will be associated with a significant increase in the oil price at the long-term projection compared to the other fuel resources used for electricity generation (EIA May 2016).

Egyptian market development and forecast

In Egypt, in 2015, the electricity production mainly depended on the conventional power plants where it represented 94% of the total electricity generation; this corresponds to 145 TWh. The conventional power plant in Egypt can be categorized based on the technology rather than the fuel type since most conventional power plants combine the usage of natural gas with heavy oil based on the market availability. Egypt is currently deploying 3 new CCGT plants of 4.8 GW each. The conventional power plants tend to display more dependency on the natural gas rather than heavy oil due to the large natural gas reserves in Egypt (SIEMENS AG 2016). The annual natural gas and heavy oil consumption in the thermal power plants is 21215 and 7760 Ktoe, respectively. Based on the technology classification, conventional power plants are categorized into combined cycles, steam cycle, and gas turbines power plants. Steam power plants produce the highest share of electricity (43%), followed by the combined cycles power plants (33%), and the lowest share is from gas turbines (14%) (Egyptian Electricity Holding Company 2015b).

The program "Intelligent Energy Europe" of the European Union proposed a forecast scenario for the electricity generation in Egypt (Trieb et al. 2015). In this scenario, a massive reduction in the dependency of utilizing conventional power plants is observed by 2040 where the conventional power plants represent only 37% of the total electricity generated. Furthermore, natural gas becomes the main fossil fuel source, whereas there is no more deployment for the heavy oil in conventional power plants. This scenario is driven by the annual decline in the crude oil resources combined with the significant concern about the present high level of natural gas consumption (Patlitzianas 2011) (Ibrahim 2011)

Technology and financing parameters

A detailed explanation of the methodology of LCOE is found in the Appendix on page 26. Since the Egyptian currency is currently undergoing very high inflation, the study is conducted in US$ to avoid inaccuracy by inflation rates. The conversion rate used in the study is dated from the first of October 2016 and is one US dollar to nine Egyptian pounds.

Upper and lower price limits that do not take outliers into account are calculated for all technologies based on the data collected; the regular market costs for installation of plants varies between these limits. Ranges of investment costs are assumed for all locations. In practice, one must take into account that the plant investments in markets that have not yet been developed can in some cases be considerably higher. Table 1 shows the amounts of investment in US$/kW (nominal capacity) for all technologies considered. The investment costs are determined based on market research on currently installed power plants in Egypt while considering external market studies at the same time. Inside the technologies, the system costs are distinguished based on power plant size and power plant configuration.

PV sytems are broken down into: small plants up to 10 kWp, large rooftop plants up to 100 kWp, ground-mounted plants up to 1 MW and off-gridplants. Each segment is assigned a range of investment cost. On the basis of these limits it is possible to calculate the LCOE of the investment date in 2016. The operational lifetime of PV plants is set at 25 years, which is a conservative assumption (Fraunhofer ISE October 2016).

	PV small	PV large	PV ground mounted	PV off grid	CSP PT	CSP PT with 8h storage	Wind onshore	Diesel small	Diesel large	CCGT-LE	CCGT-HE
Investment 2016 low [US $]	1700	1300	1200	2400	2900	4600	1100	170	150	600	900
Investment 2016 high [US $]	2000	1600	1500	2650	4450	5850	1600	240	170	900	1200
share of equity	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
Share of debt	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
Return on equity	13%	16%	16%	13%	18%	18%	18%	16%	16%	16%	16%
Interest rate on debt	8.5%	8.5%	8.5%	8.5%	9.5%	9.5%	9%	8.5%	8.5%	9%	9%
WACC nominal	9.8%	10.8%	10.8%	9.85%	12%	12%	11.1%	10.8%	10.8%	11.1%	11.1%
WACC real	8.8%	9.7%	9.7%	8.8%	10.9%	10.9%	10%	9.7%	9.7%	10%	10%

Tabele 1: Investments and financial parameters for current power plants

Onshore wind power is classified into plant types for locations with favorable and unfavorable wind conditions. This distinction is expressed in different assumptions with respect to the relationship between rotor and generator size and the associated full load hours at the respective location as well as in the cost assumptions for a plant. The data for onshore wind power is collected from completed projects in Egypt, such as the Zafarana project.

For CSP, this study investigates parabolic trough power plants (PT) of a size up to 100 MW that are designed with and without thermal storage (8 hours). Additionally, solar tower power plants (with storage) and Fresnel power plants (with storage) are modeled. Information about the reference power plants, location-specific solar irradiation and plant-specific capacity provide the basis for calculating the LCOE of CSP.

The discussed parameters are included in the calculation of the average LCOE for the third quarter of 2016 (Table 1 and 2). The financing parameters have been analyzed in detail and adapted to the risk and investment structure of the individual technologies in Egypt, since the selected discount rate has considerable influence on the calculated LCOE. In many studies, this aspect is not adequately investigated. Identical discount rates are often assumed for all technologies and locations investigated. This results in deviations from the actual LCOE.
The discount rates in this study are therefore determined for each technology through the usual capital costs in the market for the respective investment and are comprised in part of costs of debt and costs of equity (weighted average costs of capital - WACC).

Large power plants that are built and operated by large institutional investors have, due to the high return on investment required by the investor, a higher WACC than small plants or medium-sized plants that are constructed by private persons or business partnerships. The return on investment that investors require for these technologies with a short market history – like CSP is also higher than for established technologies. One can expect that the financing parameters will approach parity after a corresponding increase in the installed capacity, since the risk surcharges for new technologies will decrease with increasing experience.

Since the WACC is derived from the usual interest rates and expected returns on the market, which are given in nominal values. Accordingly, the nominal Value has to be calculated first. This nominal value is then converted into a real value by taking an assumed 1% p.a. inflation rate into account.
The decisive factor for the calculation of the LCOE is that all payment streams are assumed at either nominal or real levels. A mixture of real and nominal values is not permitted. To complete the calculation on the basis of nominal values, the annual inflation rate until 2035 must be predicted. Since the forecast for the inflation rate over the long term is very imprecise, cost predictions for the long term are generally completed using real values. Therefore, all costs stated in this study therefore refer to real US dollar values from 2016. The information about LCOE for future years shown in the figures for the various scenarios always refers to new installations in the respective years. In a plant that has been constructed, the average LCOE remains constant over its operational lifetime.

	PV small	PV large	PV ground mounted	PV off grid	CSP PT	CSP PT with 8h storage	Wind	Diesel small	Diesel large	CCGT-LE	CCGT-HE
lifetime [in years]	25	25	25	25	30	30	20	30	30	30	30
Annual operation cost [US$/kWh]					0.02	0.02	0.018	0.01	0.01	0.02	0.02
Annual fixed operation cost [US$/kW]	34	26	24	47	22	22		30	30	22	22
Degradation	0.9%	0.9%	1.0%	1.0%	0.4%	0.4%	0.2%	0.1%	0.1%	0.2%	0.2%
Fuel cost [US$/kWh]								0.018	0.018	0.019	0.019
Efficiency								30%	35 %	40 - 50 %	50 - 60 %
Progress ratio	85%	85%	85%	85%	90%	90%	95%	100%	100%	100%	100%

Table 2: Input parameters for calculation of economic efficiency

A second factor which influences the return on investment is the project-specific risk: The higher the risk by default, the higher the return on investment required by the investor. In order to keep the capital costs low, the highest possible amount of favorable external capital is desirable. It is, however, also limited by the project-specific risk: The higher the risk of default, the lower the amount of external capital that banks will provide.

When comparing global locations, one must keep in mind that the financing conditions differ, as do the environmental conditions such as solar irradiation and wind conditions. Especially in the case of renewable energy projects, whose economic efficiency is significantly dependent on state-controlled feed-in compensation, the country-specific risk of default of these payments, such as caused by national bankrupcy must be taken into account. Another factor is the availability of subsidized loans at favorable interest rates. Egypt does not yet offer very favorable framework conditions for investments in regenerative power plants. Locations in Egypt and in some of the MENA countries, admittedly, have considerably higher values for solar irradiation, but for a realistic comparison of the LCOE, the actually observed and less-advantageous financing conditions must be taken into account. Due to the high risk and the fluctuating rates of the Egyptian pound, the financial costs are tentatively very high.

Local Conditions Studied

Irradiation – Full load hours

The amount of electricity yield at the power plant location is an important parameter with a considerable influence on the LCOE of renewable energy technologies. In the case of solar technologies, the amount of diffuse or direct solar radiation plays a role depending on the technology (PV or CSP). For wind farms, the full load hours can be calculated from the wind conditions at the power plant location as a function of the wind speed.

For that reason, exemplary locations with specific full load hours for wind farms should be studied as well as locations with specific energy sources from solar irradiation (Table 3). At typical locations in Egypt, there is a global horizontal irradiance (GHI - consisting of diffuse and direct irradiation) in the range between 1900 and 2500 kWh/(m²a) onto the horizontal surface. This corresponds to a solar output between 1600 and 1800 kWh/kWp/a onto an optimally configured PV plant.

CSP plants concentrate only direct irradiation onto a focal point where it is converted into electricity or heat. For this reason locations with an annual direct normal irradiance (DNI) from 2000 and 2500 kWh/(m²a), such as found in Egypt, are favorable for CSP plants and should be taken into consideration.

PV System	Irradiation (GHI)	Electricity output per 1 kWp
Northern Egypt (Alexandria)	2021 kWh/(m²a)	1600 kWh/a
Cairo	2070 kWh/(m²a)	1630 kWh/a
Sinai	2370 kWh/(m²a)	1820 kWh/a
East of Egypt (Marsa Alam)	2330 kWh/(m²a)	1800 kWh/a
Western Desert (Siwa)	2100 kWh/(m²a)	1650 kWh/a
Upper Egypt (Aswan)	2300 kWh/(m²a)	1790 kWh/a
CSP - Parabolic with storage (100 MW)	**Direct normal irradiation**	**Electricity output per 1 kW**
Northern Egypt (Alexandria)	2150 kWh/(m²a)	3900 kWh/a
Sinai	2600 kWh/(m²a)	4560 kWh/a
East of Egypt (Marsa Alam)	2650 kWh/(m²a)	4700 kWh/a
Western Desert (Siwa)	2300 kWh/(m²a)	4270 kWh/a
Upper Egypt (Aswan)	2500 kWh/(m²a)	4570 kWh/a
Wind power	**Full load hours of wind**	**Electricity output per 1 kW**
Low (Hurghada, wind speed 6.7 m/s))	2000 h	2000 kWh/a
Medium (ZRas Sudr, wind speed 7.3 m/s)	3000 h	3000 kWh/a
High (Gulf of El Zeit, wind speed 11m/s)	4000 h	4000 kWh/a
Max	5000 h	5000 kWh/a

Table 3: Annual yields at typical locations of PV, CSP and wind power (source: Fraunhofer ISE)

The wind conditions are also location-dependent. Onshore wind power can evince full load hours of only 2000 hours at poor locations. The level of full load hours, however, can reach values of up to 3000 hours at selected locations near the Red Sea coast in Egypt. In order to complete a plant specification, plants are calculated up to full load hours of 4000 hours per year with a plant design for locations with very favorable wind conditions (Gylling Mortensen 2006). Locations with higher average wind speeds and the respectively resulting higher full load hours are calculated using the data for plants with favorable wind conditions (high wind speed plants). The average value for all onshore wind power operated in Egypt in the years 2000 – 2016 was between 2000 and 3000 full load hours per year (high average fluctuations are possible). However according to the New & Renewable Energy Authority wind onshore plants with up to 4000 and 5000 full load hours are in the pipeline in Gulf of El Zeit (New & Renewable Energy Authority (NREA) 2015).

In comparison to most renewable energy technologies, the annual power production and full load hours for a conventional power plant depends on the particular demand, the costs for fossil fuels and the competitiveness of the technology in the energy system. Presently, full load hours for CCGT power plants in Egypt lie at an average of 5200 hours (Breyer 2012). For diesel generators, the range is very wide depending on the application of the plant. If the diesel generator is used for domestic applications the full load hours are minor compared to the full load hours of a large diesel generator for example for a hotel. Based on this information, the study shows a wide range of full load hours for both technologies. Diesel generators are divided into two types (small and large) with efficiencies from 30 to 35% respectively. The full load hours are represented accordingly (Table 4). The same applies for CCGT plants. To cover all the possible ranges of the technologies, thje technology is divided into two ranges. One is for high efficiency plant, with an efficiency of 55% and full load hours of 5000 – 7000. The second range is for lower efficiency plants with an average efficiency of 45% and a full load hour range from 3000- 5000 hours.
Higher full load hours can reduce the LCOE of fossil fuel power plants, if the competitive environment and demand situation permits this, and correspondingly lower full load hours will lead to an increase in the LCOE.

	Full load hours (FLH) conventional power plants	Diesel	CCGT
2016	High	7000	7000
2016	Low	3000	3000

Table 4: full load hours of conventional power plants

Fuel Costs

The Egyptian government deployed large subsidies over decades in the energy sector, targeting the low income and middle class households. The burden of these subsidies has grown dramatically over the last few decades due to the increase of the international energy prices. In 2013/2014, energy subsidies reached US$21 billion which accounts for 8.5 % of the total Gross Domestic Product (GDP). Egypt's energy subsidies were particularly wasteful and inefficient because below-market clearing controlled prices provided producers with below-cost inputs, resulting in overconsumption, distorted commodity markets, and unreliable services as well as enormous claims on public resources. In July 2014, the Egyptian government has introduced a major plan to reform the energy prices for fossil fuels and electricity through several stages. This plan was supported by the sharp fall of the international oil price. The oil price is currently 40% below the price in the last few years. This declination substantially reduces the gap covered by the government and subsequently creates a supportive environment for the Egyptian energy reform plan.

Based on the governmental reform plan, the official prices increased significantly. The largest price increment was the price increase of natural gas with 122% for transport, 100% for residential users and 79% for electricity generation, whereas the diesel prices also increased by 55%. In some cases such as the heavy fuel oil, the official prices were left unchanged. A summary for the fuel prices based on the governmental reform plan is shown in Table 5. Even with this governmental plan the energy subsidies are reduced to US$14 billion, which represents 6% of GDP. The energy subsidies still remain substantial.

Fuel price [US$2016/kWh]	2016		2020		2025		2035	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Natural gas	0.0102	0.0273	0.0140	0.0283	0.0205	0.0307	0.0242	0.0427
Heavy oil	0.02197		-	-	-	-	-	-
Diesel	0.01803		0.0351	0.0442	0.0407	0.0542	0.0553	0.0829

Table 5: Assumptions about fuel prices (World Bank Commodities 2015) (CEDIGAZ Februrary 2015) (Egyptian Ministry of Petroleum and Mineral Resources 2014)

4. RESULTS - CALCULATION OF LEVELIZED COST OF ELECTRICITY

General comparison

For the comparison of technologies carried out in the current study the LCOE of renewable energy technologies for PV, CSP and wind power at various locations in Egypt is determined based on market data, specific investments, operating costs and other technical and financial parameters.

The reference calculations for conventional power plants (Diesel and combined cycle (CCGT)) provide comparative values which are also investigated for various plant configurations as well as different assumptions for the construction and operation of these power plants as shown in Figure 12.

The LCOE of small PV plants (PV Rooftop) is calculated for locations with different values of solar irridiation and a CAPEX variation between 1300 US$/kWp and 2000 US$/kWp. Based on these assumptions, the results show that the LCOE for PV rooftop lie between 0.098 US$/kWh and 0.181 US$/kWh. At locations with high GHI (2700 kWh/(m²a)) in Southern Egypt the LCOE of small rooftop plants lies between 0.098 US$/kWh and 0.141 US$/kWh. In Northern locations with lower irradiation (1900 kWh/(m²a)) the LCOE ranges between 0.126 US$/kWh and 0.141 US$/kWh.

Ground-mounted utility-scale plants are already achieving values between 0.079 US$/kWh and 0.095 US$/kWh in Upper Egypt and 0.102 to 0.123 US$/kWh in Northern Egypt, since the CAPEX varies between 1200 US$/kWp and 1500 US$/Wp. This means that the LCOE of all types of on-grid PV plants (PV Rooftop and PV ground-mounted) in Egypt lies almost within the current national price of electricity for the high tariff of the residential sector and commercial sector (0.107 US$/kWh) (Egyptian Ministry of Electricity and Renewable Energy 2016).

For the off-grid PV systems, the LCOE vary between 0.149 to 0.186 US$/kWh in Upper Egypt (Aswan) and from 0.192 and 0.239 US$/kWh in Northern Egypt. The results are estimated based on the specific investments which were assumed to be between 2000 US$/kWp and 2600 US$/kWp.

For the CSP with a thermal energy storage system which is able to provide 8 hours of operation by using energy from the storage only, the LCOE varies between the 0.124 US$/kWh and 0.152 US$/kWh at locations with DNI of 2600 kWh/(m²a), while at locations with DNI of 2100 kWh/(m²a) the LCOE lies between 0.169 and 0.208 US$/kWh.

Wind power with average installation costs between 1100 to 1600 US$/kW reveals, among the renewable technologies, the lowest LCOE at 0.047 US$/kWh at onshore locations with very high annual full load hours of 4000; however, these sites are limited in Egypt. For this reason, the costs for plants at poorer locations vary in the proximity of 0.079 US$/kWh (see Figure 12), depending on the specific investment as well as the annual full load hours achieved on site (see Table 1and Table 3).

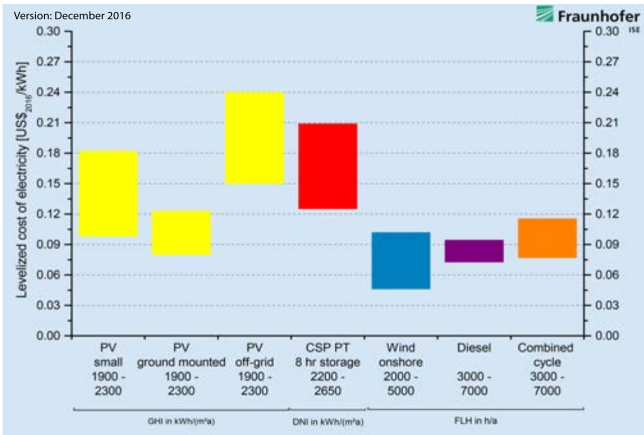

Figure 12: LCOE of renewable energy technologies and conventional power plants at locations in Egypt in 2016. The value under the technology refers in the case of PV to global horizontal irradiance (GHI) in kWh/ (m²a); for CSP to the DNI, in the case of other technologies it reflects the number of full load hours of the plant per year. Specific investments are taken into account with a minimum and maximum value for each technology. Additional assumptions in Table 1-5

Under the current conditions for conventional power plants in the electricity market with the respective full load hours and fuel prices, the following LCOE of each technology are calculated: Diesel can reach LCOE from 0.093 to 0.105 US$/kWh for the selected operational parameters for small generators. The LCOE of larger diesel generators is lower and lies between 0.072 US$/kWh and 0.075 US$/kWh. Today, CCGT power plants achieve values between 0.077 and 0.115 US$/kWh, which explicitly reflects the current trend toward idling CCGT power plants, caused by the subsidized costs of energy in Egypt, which are difficult to refinance.

One must keep in mind that the calculation of the LCOE does not include the possible flexibility of a power generating technology or the value of the electricity generated. For example, seasonal and daily generation differs significantly for the individual technologies. Furthermore, differences arising from the flexible operation of power plants or the supply of system services are not taken into account in the calculation for the LCOE.

As discussed in the previous section the LCOE is highly sensitive to the financial parameters in the defined locations or for the regarded application. When assuming financing conditions which are feasible in a market, mature for renewable energy, technologies, e.g. Germany, the LCOE is reduced substantially as the results show in Figure 6.

The LCOE for PV is similar to the results in Europe. Even though Egypt has a much higher irradiation, the PV systems are not more cost effective than those in regions with less irradiation in Europe.

In the UAE, having similar natural resources, a new project reaching 2.99 US$ct/kWh is announced. This is due to a competitive bidding process as well as governmental support for the solar projects and enhanced support schemes. In the case of Egypt and as discussed in the assumption section, the WACC is very high since the cost of debt and cost of equity are respectively high. Figure 13 shows the effect of enhancing the financing situation in Egypt. If more incentives and better boundaries are set, e.g applying the financing conditions for Germany, see Table 6, the LCOE of PV can be almost reduced by half.

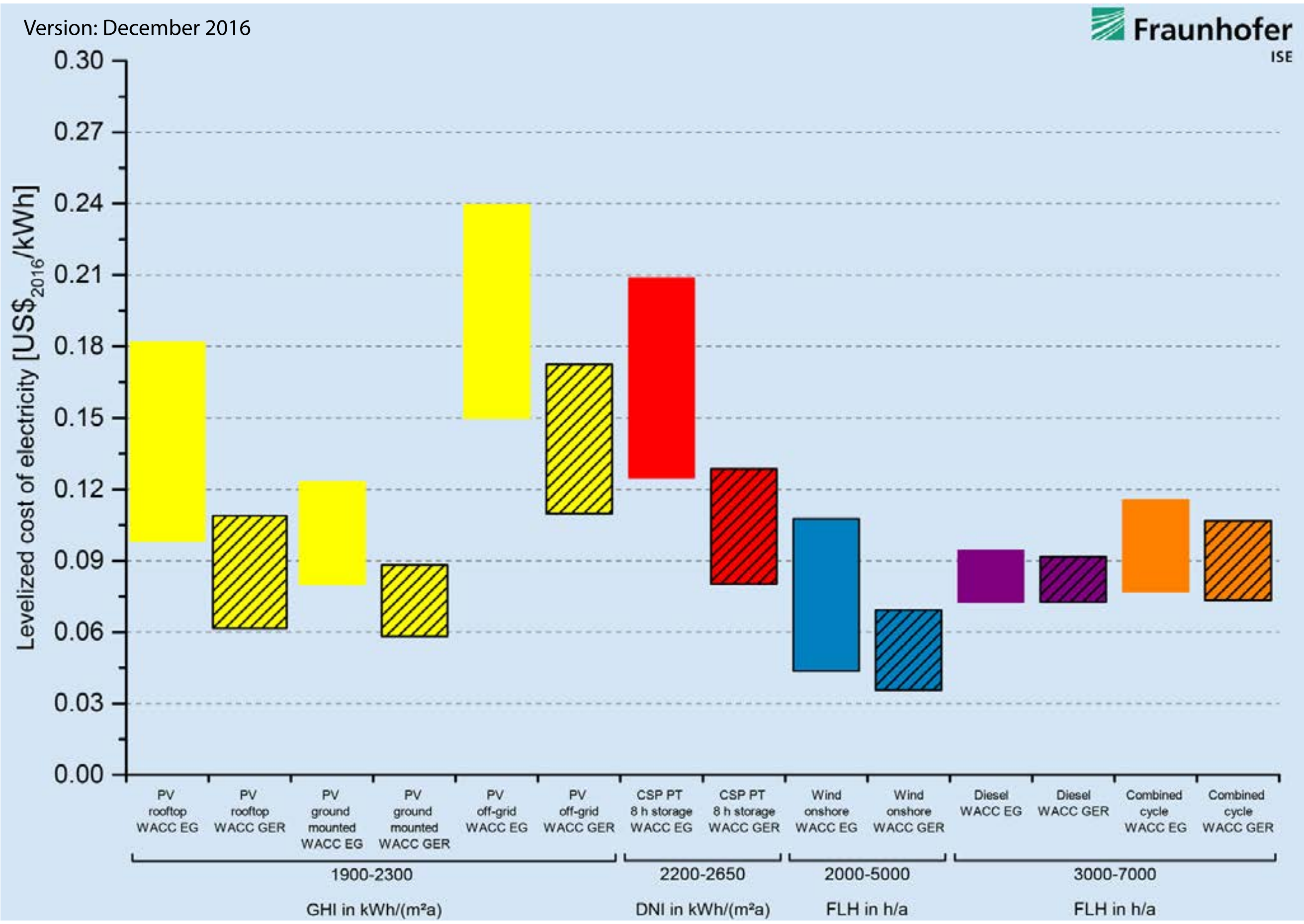

Figure 13: LCOE of renewable energy technologies and conventional power plants at locations in Egypt in 2016 in comparison to Germany

Photovoltaics

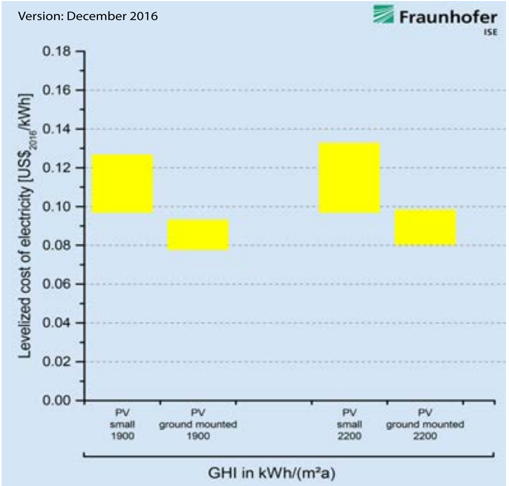

Figure 14: LCOE of PV plants in Egypt based on varying irradiance (GHI in kWh/(m²a)) in 2016.

The current LCOE values of PV are shown in Figure 14 for various plant sizes and costs at different irradiance values (according to Table 3). The calculation is done for the Egyptian market and hence with the Egyptian WACC calculated according to Table 1. The number in the graph (Figure 12) following the plant output stands for the annual irradiance at the plant location in kWh/(m²a). The CAPEX is also varied based on the market analysis done for Egypt. Plants in the Northern Egypt produce approximately 1400 kWh/(m²a) of electricity, while plants in Upper Egypt supply up to 1800 kWh/(m²a).

The strong decline in prices for these plant investments has a substantial influence on the development of the PV LCOE. Even in Northern Egypt, it has already been possible to achieve a LCOE of under 0.077 US$/kWh. Consequently, the costs for photovoltaically generated electricity from all types of PV plants in Egypt would be beneath the average household cost of electricity (the high tariff of the residential sector). At locations in Upper Egypt, small PV plants have LCOE between 0.112 and 0.124 US$/kWh. If better financing opportunities or incentives are introduced into the Egyptian market, further decline in the LCOE is expected (see forecast optimized). Today, many module manufacturers are already offering guarantees on the performance of their modules that exceed 25 years. In the event that the operational lifespans of plants increase from 25 to 30 years, the LCOE of these plants will sink by another 7%.

A sensitivity analysis for a small PV plant in Egypt demonstrates the strong dependency of the LCOE on irradiation and specific investments (see Figure 15 and Figure 16). This explains the abrupt decrease in the LCOE in the last year owing to the decline in module prices. The CAPEX and WACC have an influence on the LCOE which is not to be underestimated since a 20% of decline in one of these parameters reduces the LCOE to around 0.08 US$/kWh. Moreover, the full load hours of the system have also a strong effect on the costs. If longer lifetimes of power plants that have already amortized are realized, the power plants will continue to produce electricity at very low operating costs. The lifetime that varies slightly has a smaller influence on the LCOE of PV plants since discounting of values in the future li

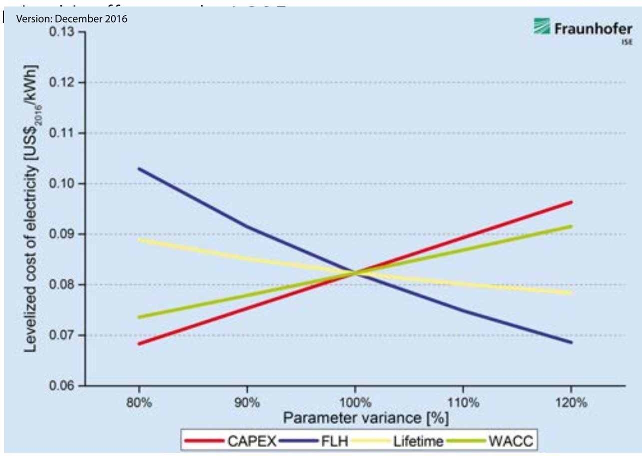

Figure 15: Sensitivity analysis of a ground mounted PV plant with a GHI of 2300 kWh/(m²a) and investment of 1300 US$/kW

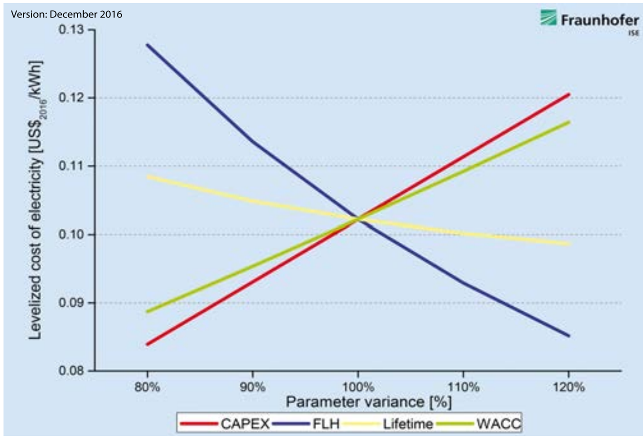

Figure 16: Sensitivity analysis of a rooftop PV plant with a GHI of 2300 kWh/(m²a) and investment of 1500 US$/kW

The figure on the right represents the sensitivity of a ground mounted plant with the same variables. It is evident that the FLH plays a major role in the LCOE of a PV system. Additionally, the CAPEX and WACC have similarly effects on the cost as for the small rooftop system. If CAPEX or WACC are reduced by 20%, the LCOE would decrease to 0.07 US$/kWh.

LCOE map for PV

If in the base case a specific investment of 1350 US$/kW is assumed. The map shows the results for LCOE depending on solar irradiance and extra costs due to distance from the markets and infrastructure. E.g. sites in the western desert with high solar irradiation do not necessarily have the lowest LCOE, since they are far from infrastructure and from any major cities. For the base case of a specific investment of 1350 US$/kW and added extra costs, the LCOE ranges between 0.110 US$/kWh and 0.140 US$/kWh, as shown in Figure 17.

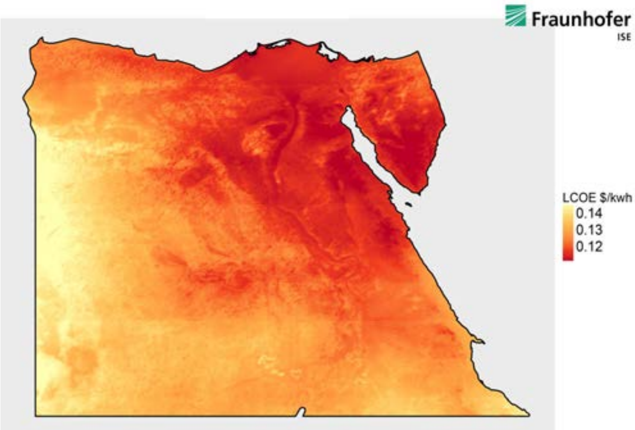

Figure 17: Geographic presentation of LCOE for a ground mounted PV plant with an investment of 1300 US$/kW

Concentrating Solar Power Plants

The analysis of the LCOE of CSP plants is based especially on market data of realized power plant projects with parabolic trough and tower technology in many different countries.

The analysis of the LCOE of CSP plants is based especially on market data of realized power plant projects with parabolic trough and tower technology in Morocco, South Africa, Spain and the USA on whose basis it is possible to develop the power plant parameters and investment information for parabolic trough power plant projects with power plant capacities of 100 MW. Cost data for Fresnel technology is taken from the PE2 power station and for tower technologies plants like Crescent Dunes in the USA and Abengoa in RSA. The size of the thermal energy storage is indicated by the number of full load hours for which the turbine can be supplied with energy from a fully charged storage without solar irradiation present (Kost et al. November 2013).

The LCOE of the analyzed CSP-PT (Parabolic Trough) plants with thermal storage and with a DNI of 2000 kWh/(m²a) is between 0.160 US$/kWh and 0.207 US$/kWh (Figure 18). This means that they frequently perform better than power plants without storages, whose values are up to 0.314 US$/kWh. The reason for this is that a larger solar mirror field combined with molten salt thermal storage provides for a better utilization of the power plant turbine and therefore higher numbers of full load hours.

Solar power tower plants with thermal storage (with a specific investment of 5500 -7000 US$/kW) tend to have a higher LCOE (0.205 - 0.256 US$/kWh) compared to parabolic trough power plants with thermal storage. Linear Fresnel power plants with thermal storage (0.166 - 0.237 US$/kWh) are in the same range. In regions with higher solar irradiation of up to 2500 kWh/(m²a), such as in Upper Egypt (Aswan), and Marsa Alam, LCOE of 0.118 US$/kWh can be achieved for CSP technologies without thermal storage and 0.137 US$/kWh for technologies with thermal storage.

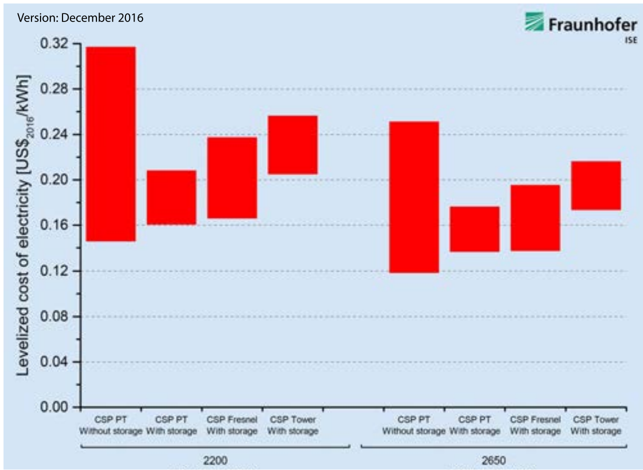

Figure 18: LCOE of CSP plants with a nominal capacity of 100 MW, by plant type and irradiance (DNI in kWh/(m²a)) in 2016

The sensitivity analysis shows that CAPEX and WACC reduced by 20% would, compared to the reference case, lead to a LCOE of 0.143 US$/kWh and 0.148 US$/kWh (see Figure 19). The higher full load hours have a similarly strong, positive influence on the LCOE.

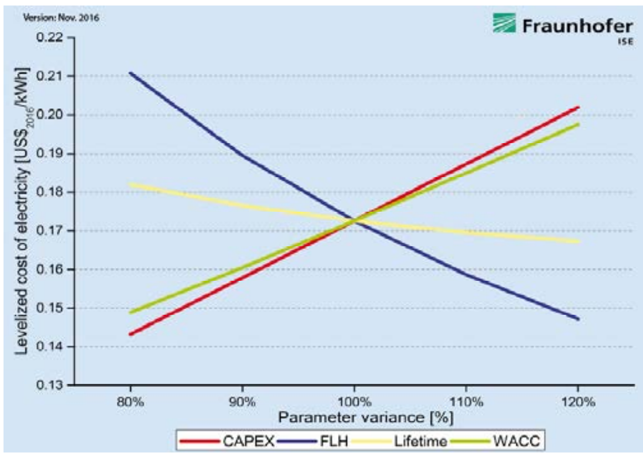

Figure 19: Sensitivity analysis for CSP (100 MW with thermal storage) with annual DNI of 2500 kWh/(m²a) and specific investment of 5250 US$/kW

Wind Power Plants

The LCOE of wind power is highly dependent on local conditions as well as the achievable full load hours. In general, it is distinguished between locations with favorable and unfavorable wind conditions through the average wind speed. But in general the layout of the wind farm and its specific wind turbines have also a huge impact as the technology, size, height or overall structure influence cost, operation and generated electricity.

Locations with average wind speeds of over 9 m/s are referred to as locations with favorable wind conditions, while the average annual wind speeds at locations with unfavorable wind conditions are lower than this. In Egypt, the favored locations are often located in coastal areas, where the average annual wind speed is often above 8 m/s (Gylling Mortensen 2006).

Currently, it is observed that manufacturers of wind power plants increasingly advance the refinement of their plant designs to increase yield at locations with unfavorable wind conditions. This is done in part through tower height or through increasing the contacted rotor surface in proportion to the generator capacity which makes it possible to achieve around 2000 full load hours at locations with an average annual wind speed of around 6.3 m/s. Greater tower heights and longer rotor blades, however, lead to higher material and installation costs that can only be justified by a significant increase in full load hours compared to a conventional wind turbine at locations with favorable wind conditions and therefore making the investment profitable. Thanks to ongoing technical refinement, one can expect that full load hours of future plants will be increased.

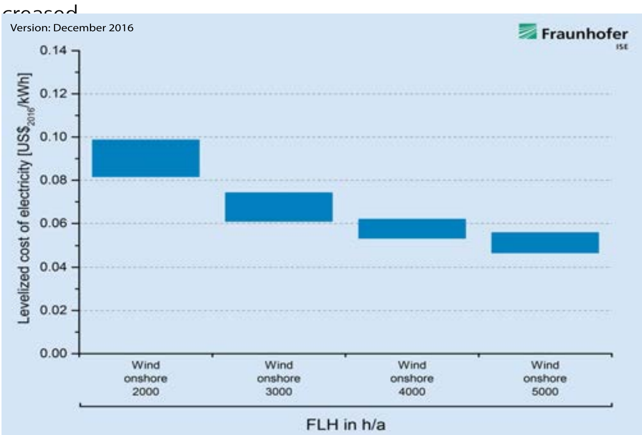

Figure 20: LCOE of wind power by full load hours in 2016

The LCOE of wind power plants for two locations with unfavorable wind conditions is calculated. The locations have an average annual wind speed of 7 m/s and 8 m/s respectively. At the first location 2000 full load hours and at the second 3000 per year are achieved with this method. Exquisite locations for favorable wind conditions on the coasts are available with wind speeds of 10.5 m/s and 5000 full load hours. These locations have not been exploited yet and hence the sensitivity calculation is done based on existing plants with full load hours of 3000 hours per year.

As shown in Figure 20, the LCOE of wind power at the coastal locations with favorable wind conditions with 5000 full load hours was between 0.046 US$/kWh and 0.055 US$/kWh. Locations with less favorable wind conditions achieved a LCOE from 0.052 to 0.059 US$/kWh, depending on the specific investments. If it is possible to reach 2000 full load hours at the location in question, the LCOE reaches values between 0.081 and 0.098 US$/kWh.

A sensitivity analysis for the wind power plants in Egypt illustrates a strong dependency of the LCOE on the CAPEX and WACC (See Figure 21). This explains the strong decrease in LCOE with the continued enhancement of the wind turbines price. Again, a significant influence of the full load hours is noticed. Both effects reflect a significant dependency of the local weather conditions and the wind turbine layout size. The size and layout of the wind turbine change cost and the amount of the electricity output strongly. The lifetime parameter has a slightly small influence on the LCOE of the wind farms.

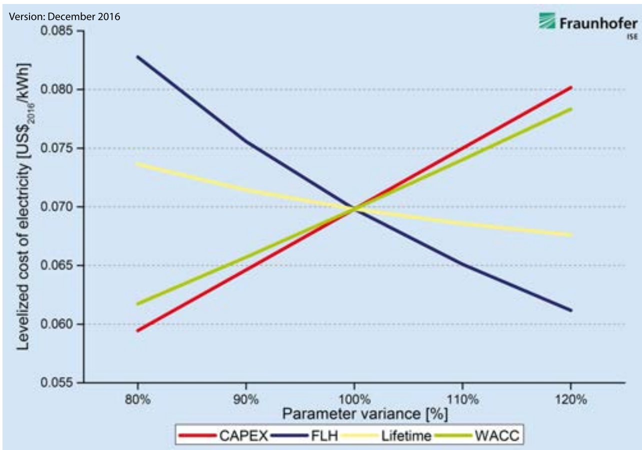

Figure 21: Sensitivity analysis of onshore wind power with 3000 full load hours, specific investment of 1500 USD/kW

Conventional power plants

The LCOE of diesel generators or combined cycle (CCGT) power plants, mainly operated with natural gas, are highly dependent on the fuel price and specific investment. In Egypt, the thermal power plants currently achieve an average of 3000 and 7000 full load hours. The full load hours that a power plant can achieve are dependent on the market demand. Therefore a wide range of typical operation / full load hours is assumed in this study.

Figure 22 shows the LCOE of 2016 of diesel generators and CCGT power plants, for each case for the spectrum of full load hours from Table 4, the power plant scale and efficiency from Table 2, the fuel prices from Table 5 as well as the minimum and maximum specific investments from Table 1.

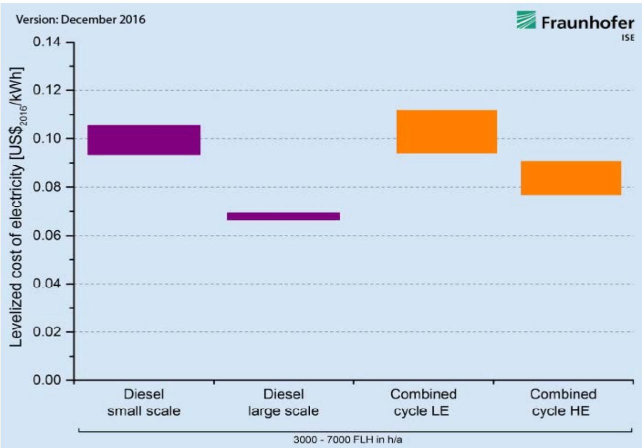

Figure 22: LCOE conventional power plants in 2016 with specific investments in 2016

Large diesel generators currently have the lowest LCOE, which lies between 0.066 and 0.069 US$/kWh. This is considerably lower than small diesel generators which lie between 0.093 and 0.105 US$/kWh. The LCOE of CCGT power plants has a range between 0.077 and 0.111 US$/kWh and is more expensive in Egypt under the current fuel prices (which are partly subsidized). Advantages of CCGT power plants are their greater flexibility and lower CO_2 emissions compared to the diesel-fired technologies. By comparison, admittedly, the LCOE from onshore wind plants at locations with 5000 full load hours lies at 0.047 US$/kWh below the cost of most conventional power plants.

To be able to compare the results to the global market, the following graph presents the local LCOE once with the current fuel prices and once with the International Fuel Price (IFP). The international fuel prices assumed are 0.037 US$/kWh for crude oil and 0.024 US$/kWh for natural gas (World Bank Commodities 2015). It can be observed that due to the very high subsidies in Egypt, the LCOE for the conventional power plants is misleading. While bearing in mind the governmental plans to remove the subsidies in the near future, it is important to identify the LCOE from conventional power plants at this point. As seen in Figure 23 the large diesel generators as well as small ones will have much higher LCOE. The LCOE is raised by 4.5 US$cents/kWh reaching an average of 0.119 US$/kWh for small plants and 0.166 US$/kWh for large plants. CCGT plants will also experience a rise in the LCOE, however not as strongly. Since the international and the local fuel price are not as far apart, the LCOE of low efficiency plants will rise from an average of 0.103 US$/kWh to 0.112 US$/kWh. The LCOE of high efficiency plants will rise from an average of 0.084 to 0.094 US$/kWh.

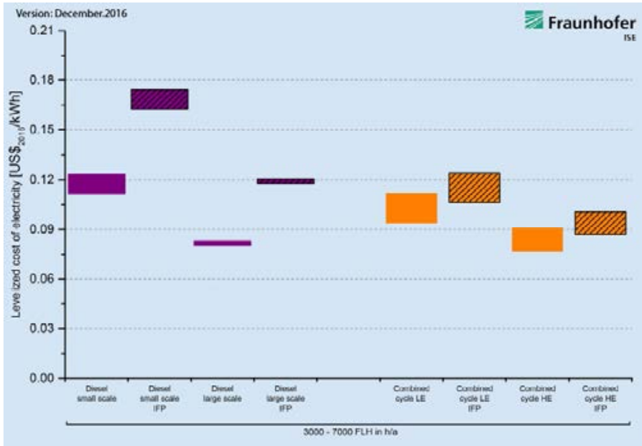

Figure 23: LCOE conventional power plants in 2016 with specific investments in 2016 and international fuel prices of 2016

Forecast for the Levelized Cost of Electricity through 2020 and 2035 in Egypt

For renewable energy technologies, cost forecasts can be generated based on historically observed learning curves whose progress over time builds on the different market forecasts for the period of 2020 to 2035. The forecasts are highly dependent of the boundary conditions and assumptions made in the calculation. If certain boundaries like incentives, prices, market development etc change, the forecast will be altered.

The learning curve also plays a major role in calculating the forecasts. For photovoltaics and wind technology, it has been possible to describe an average learning rate and/or progress ratio (PR= 1-learning rate) in the last 20 years. The investments per Watt of PV modules sank in the past following a PR of 80%. For the forecast of future development in the LCOE of PV systems, a PR of 85% is used, as suggested by Wirth April 2016. By comparison, the costs of wind power in recent years followed a PR of 95%, it has earlier been between 87 – 92% (Fraunhofer ISE 2010).

The forecast for the levelized costs of electricity up to 2035 is likewise completed for the CSP technologies. Studies by the German Aerospace Center (German: Deutsches Luft- and Raumfahrzentrum, abbreviated DLR) yield different PRs for the individual components in CSP plants (solar field, thermal storage, power block) with values between 88% and 98% (Viebahn 2008, Trieb 2009). This yields an average PR of 92.5%, which refers to the entire power plant. Other studies assume PRs with values of 90% (Greenpeace, 2009) or 92% – 96% (Sarasin, 2009). In this study a PR of 90% is chosen.

Modelling the future LCOE shows a variable development dynamic for the individual technologies, depending on the parameters discussed here, the financing conditions (WACC), market maturity and development of the technologies (PR), current specific investments (US$/kW) and local conditions (Figure 24). Today, in 2016, the calculations show that PV plants in Egypt can generate power for 0.103 – 0.148 US$/kWh from rooftop plants. The costs will fall to an average of 0.100 US$/kWh in 2020. By 2025 and 2035 the LCOE of small rooftop systems will continue to decrease from an average of 0.087 until 0.074 US$/kWh respectively.

For ground mounted PV plants the LCOE already lies between 0.083 US$/kWh and 0.105 US$/kWh today. The suggested development shows that the price will decrease to an average of 0.075 US$/kWh in 2020 and will continue to drop until it reaches 0.055 US$/kWh in 2035. Today, wind power in Egypt generates electricity at very low cost compared to PV. With average costs of 0.055 US$/kWh wind power is already competitive to CCGT and diesel-generators. According to the forecast calculated the LCOE will sink until 2035 but with a smaller declination than PV. This is due to the progress ratio assumed for wind power. In 2035 the average LCOE of wind will reach 0.051 US$/kWh and end up with almost the same in 2035.
For CSP the current LCOE is very high compared to the other technologies. It lies at 0.163 US$/kWh in average. By 2035, the LCOE of CSP (PT) can sink to values between 0.116 US$/kWh and 0.150 US$/kWh under the given assumption (interest rate, etc.).
With the current gas and diesel price, status October 2016, the conventional plants are competitive with ground mounted PV plants at good locations and have higher costs than wind power. The LCOE of CCGT plants and diesel generators is currently at an average of 0.077 US$/kWh and 0.081 US$/kWh respectively. In the case of the conventional plants and as discussed in the previous sections, the Egyptian government is subsidizing fossil fuels to a great deal.

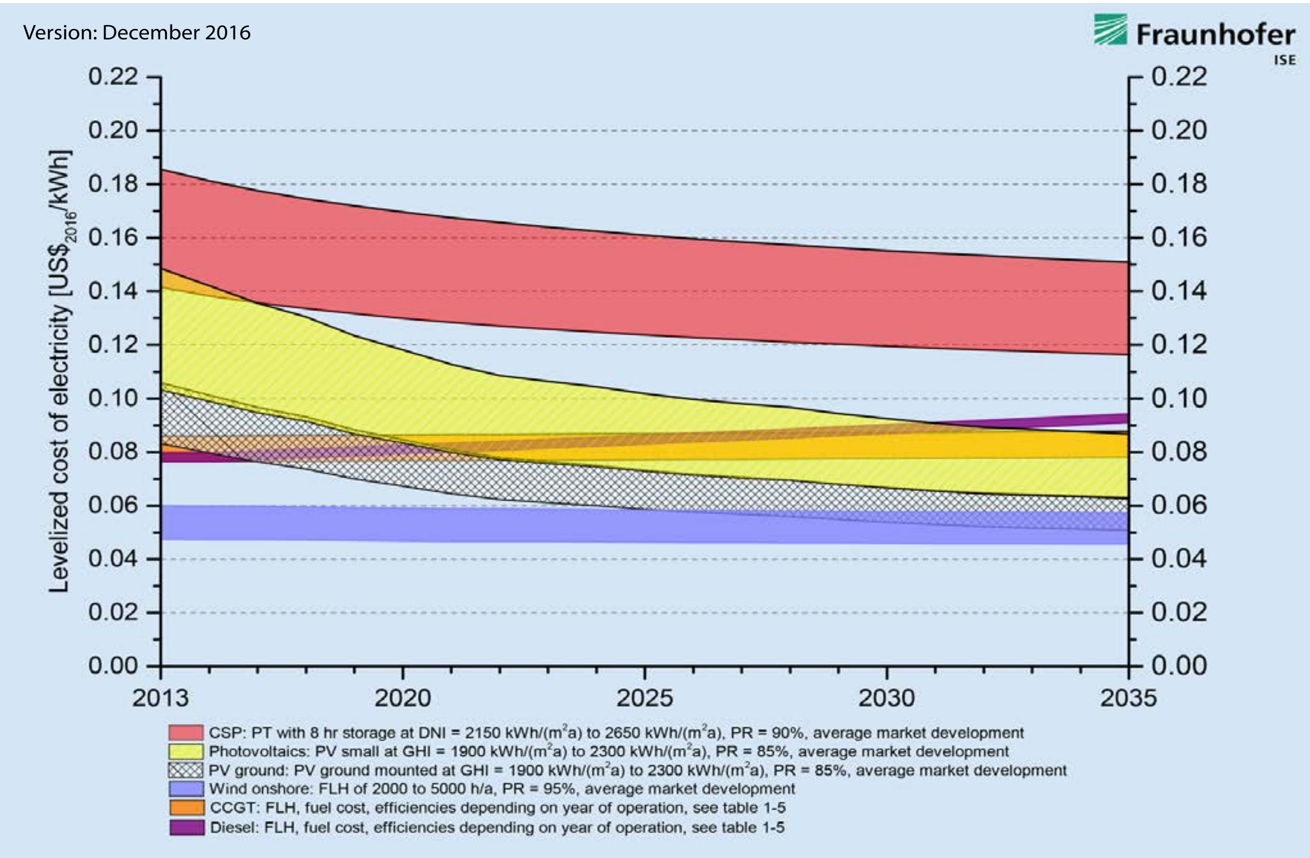

Figure 24: Forecast for the development of LCOE of renewable energy technologies as well as conventional power plants in Egypt by 2035

However, since the governmental plan is to gradually remove these subsidies, it is assumed for the forecast that in the year 2035 fuel prices will be at international prices, hence it increases in the LCOE. By the year 2025 the LCOE of CCGT will be at 0.081 US$/kWh and reach 0.082 US$/kWh in the year 2035. For diesel a more progressive increase can be observed. By the year 2025 the LCOE will be at 0.084 US$/kWh and reaching 0.092 US$/kWh in 2035.

[US$/kW]	PV small	PV ground mounted	Wind onshore	CCGT
share of equity	20%	20%	30%	40%
share of debt	80%	80%	70%	60%
Retun on equity	6%	8.0%	9.0%	13.5%
Interest rate on debt	4.0%	4.0%	4.5%	6.0%
WACC nominal	4.4%	4.8%	5.9%	9.0%
WACC Real	2.4%	2.8%	3.8%	6.9%

Table 6: Financial cost based on Germany (Kost et al. November 2013)

To illustrate a comparison between markets with lower financial costs, a direct comparison to the German market is illustrated in the following graph (see Figure 25). The assumptions in the following forecast present all the technical and local data of Egypt, however with financial costs like in Germany. See Table 6.

A general conclusion is that the financial costs have a huge influence on the feasibility of a technology. With the right regulatory framework for investors and for renewable energy technologies, Egypt can have competitive prices of renewables as of today. Starting 2025 even CSP technologies can be competitive to CCGT plants. In 2035 PV can reach LCOE of 0.049 US$/kWh for rooftop plants and even 0.042 US$/kWh for ground mounted PV systems. These costs will be lower than both CCGT and diesel generators.

Over the long-term, PV plants in Egypt and wind power at onshore locations with favorable wind conditions have the lowest LCOE. Both technologies have considerably lower LCOE compared to fossil plants by 2035. The technology and cost developments of recent years have considerably improved the competitiveness of wind power and PV.

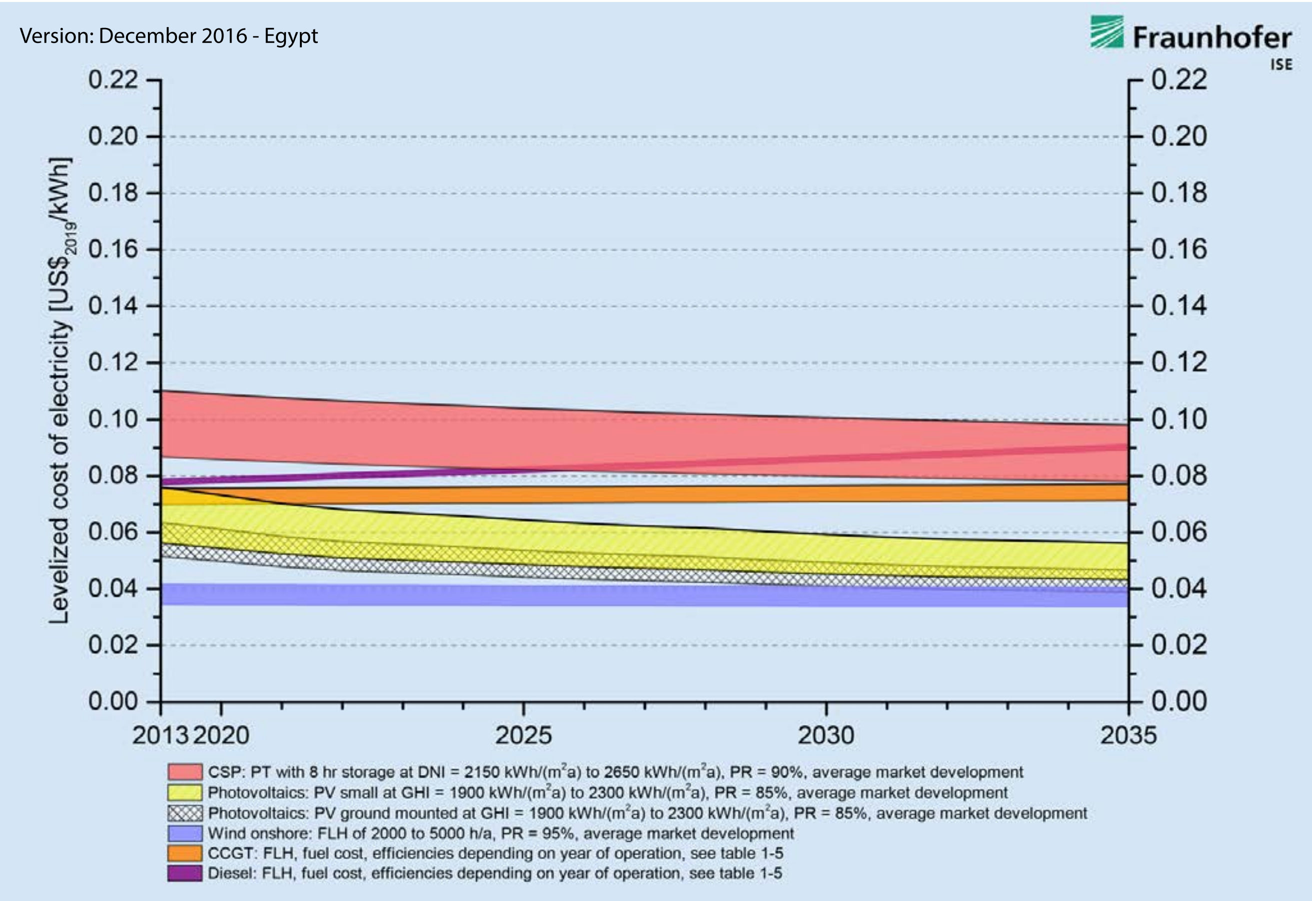

Figure 25: Forecast for the development of LCOE of renewable energy technologies as well as conventional power plants in Egypt by 2035 assuming German financing costs

5. APPENDIX

Calculating the LCOE

The method of levelized cost of electricity (LCOE) makes it possible to compare power plants of different generation and cost structures with each other. The basic thought is that one forms the sum of from all accumulated costs for building and operating a plant and comparing this figure to the sum of the annual power generation. This then yields the so-called LCOE in USD per kWh. It is important to note that this method is an abstraction from reality with the goal of making different sorts of generation plants comparable. The method is not suitable for determining the cost efficiency of a concrete plant. For that, a financing calculation must be completed taking into account all revenues and expenditures on the basis of a cash-flow model.

The calculation of the average LCOE is done on the basis of the net present value method, in which the expenses for investment and the payment streams from earnings and expenditures during the plant's lifetime are calculated based on discounting from a shared reference date. The cash values of all expenditures are divided by the cash values of power generation. Discounting the generation of electricity seems, at first glance, incomprehensible from a physical point of view but is a consequence of accounting transformations. The idea behind it is that the energy generated implicitly corresponds to the earnings from the sale of this energy. The farther these earnings are displaced in the future, the lower their cash value. The annual total expenditures over the entire operational lifetime are comprised of the investment expenditures and the operating costs accumulating over the operational lifetime. For calculating the levelized cost of electricity (LCOE) for new plants, the following applies (Konstantin 2009):

LCOE Levelized cost of electricity in USD/kWh
I_0 Investment expenditures in USD
A_t Annual total costs in USD in year t
$M_{t,el}$ Produced quantity of electricity in the respective year in kWh
i Real interest rate in %
n Economic operational lifetime in years
t Year of lifetime (1, 2, ...n)

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

The annual total costs are comprised of fixed and variable costs for the operation of plants, maintenance, service, repairs and insurance payments. The share of external financing and equity financing can be included in the analysis explicitly through the weighted average cost of capital (WACC) over the discounting factor (interest rate). It depends on the amount of equity capital, return on equity capital over lifetime, cost of debt and the share of debt used.

Also applicable to the formula for the annual total costs in the calculation of the LCOE:

Annual total costs A_t =
Fixed operating costs
+ Variable operating costs
(+ residual value/disposal of the plant)

Through discounting all expenditures and the quantity of electricity generated over the lifetime to the same reference date, the comparability of the LCOE is assured.

The LCOE is therefore a comparative calculation on a cost basis and not a calculation of the level of feed-in tariffs. It can only be calculated by using additional influence parameters. Rules governing private use, tax law and realized operator earnings make the calculation of a feed-in tariff based on the results for the LCOE more difficult. An additional required qualification is that a calculation of the LCOE does not take into account the significance of the electricity produced within the energy system in any given hour of the year.

Learning Curve Models

Cost and price dynamics of technologies can often be quantified following the »learning curve« or »price experience curve« approach which relates the cumulative produced quantities of a product and the sinking unit costs (production costs), as figure 22 shows for PV modules. The concept is based on learning effects. Its central empirical observation is that the costs (price) of a specific product decreases by an individual percentage-number (called »learning rate (LR)« or »price experience factor (PEF)«) every time the cumulative produced volume doubles.
Mathematically this is expressed by

$$C(x_t) = C(x_0)\left(\frac{x_t}{x_0}\right)^{-b} \quad (1)$$

with the cumulated production x_t and cost $C(x_t)$ at time t in relation to the corresponding produced quantity x_0 and the corresponding costs $C(x_0)$ at an arbitrary starting point. The central parameter b is called learning parameter. When plotted on a log-log scale it appears as a linear function.
The price experience curve usually refers to the market price of a product, whereas the term learning curve is used when the concept is applied on cost. The main outcome of this analysis is usually the learning rate (LR) or the progress ratio (PR), which is defined as (e.g. (G. F. Nemet, 2006))

$LR = 1 - PR = 1 - 2^b$

For example, if the cumulated produced volume doubles and the costs (price) sink by 25%, one speaks of a learning rate of 25% (or a progress ratio of 75%).

The price dynamics of PV modules have followed a price experience curve since 1980 (Figure 22). Oscillations around the trend line are not uncommon and have been observed for various technologies. PV module oscillations around the learning curve were for example caused by material scarcity and scarcity in production facilities along different parts of the module production value chain or overcapacities in production.

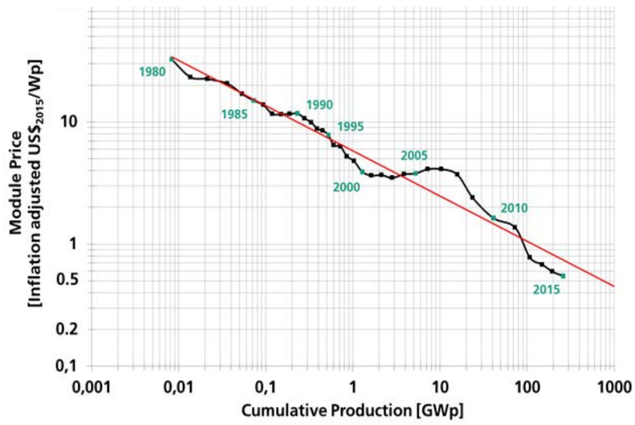

Figure 22: Historical price experience curve of PV modules since 1980. Source: ©Fraunhofer ISE: Photovoltaics Report, updated: 4 November 2016 Learning curve based on EuPD data (Fraunhofer ISE October 2016)

It is important to note that the learning rate depends on the time period, which is used for fitting the trendline. The starting year for PV module experience curves is 1980 in our analysis. Figure 22 shows learning rates depending on the date until which the data is fitted, the values vary around an average learning rate of 21 (Fraunhofer ISE, November 2016). For this study, we apply a learning rate of 15 percent for the PV system.

The price experience curve is a function over cumulated production volume. The correlation with time is done through scenarios for the market development: This allows statements about the future development of plant prices on a chronological index and therefore about the levelized cost of electricity as well. Changes in the terms of financing on the basis of changing framing conditions in the national economy are difficult to predict and are therefore not considered in this study. This would load the forecast for the development of the LCOE up with an additional, not-technology-specific uncertainty.

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BUSINESS FIELD ENERGY SYSTEM ANALYSIS AT FRAUNHOFER ISE

In recent years, renewable energy technologies have undergone a vertiginous development: The prices have dropped starkly, while at the same time the installed capacity of renewable energy technologies has increased terrifically. Worldwide, renewable energy technologies, especially photovoltaics and wind power have not merely developed into an important sector of the energy industry but are, through their growth, contributing to major changes in the energy system.

New, interesting questions arise from this change, questions primarily focused on the integration and the interaction of the renewable energy technologies in the system: How is a cost-effective use of renewable energy technologies to be achieved in various regions? How can different technologies be combined with each other in order to optimally cover the need for energy? How will the energy system as a whole develop? At what points must this development be supported by the state? What is the most cost effective path for the further development of an energy system, under consideration of the creation of local jobs?

Fraunhofer ISE offers a variety of responses to these questions that are covered in the following business topics:

- Techno-economic assessment of energy technologies
- Market analysis and business models
- Planning use of power plants and operating strategies
- Modelling energy supply scenarios
- National and regional energy supply concepts

At Fraunhofer ISE, we analyze various energy technologies from technical and economic viewpoints, such as on the basis of the LCOE. Furthermore, it is possible to optimally design the use of renewable energy technologies for a power plant park or a state by studying the interaction of the components with respect to specific target criteria.

The business field of energy system analysis studies the transformation of the energy system with the aid of very different methodological approaches: On the one hand, one can identify a multi-sector target system for a specific CO2 reduction goal according to minimum costs to the national economy. On the other, one can use investment decision models to show how the system will develop under certain framing conditions and how the interaction of the components in the energy system functions. This allows our models to offer a solid foundation for the decision concerning the framing conditions of any future energy supply.

An additional building block of the business field of energy system analysis is the development of business models that we offer under consideration of the changed framing conditions in different markets. We develop options for how renewable energy technologies can be used more frequently in the future, even in countries where they have not been widely disseminated to date. In this way, Fraunhofer ISE offers a comprehensive method of analysis as well as research and studies on technological and economic issues, in order to master the challenges presented by a changing energy system.

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