Feasibility Study of Photovoltaic Power Plant in Libya; Location, Technology and Economics

Ahmed S. Kagilik,
Faculty of Engineering, Sabratha University, Libya
as.kagilik@gmail.com

Khairy Agha
Faculty of Engineering, Tripoli University, Libya
k_r_agha@yahoo.com

Christian Bornhauser
GIZ Gesellschaft für Internationale Zusammenarbeit, Germany,
cb@bornhauser24.de

Abstract

Steeply falling installation costs during the last decade makes the Photovoltaic technology highly competitive particularly, of course, in a sunny region like the Libyan Desert. Photovoltaic power plants are easy to maintain and, once installed, consume practically no additional natural resources. New and innovative jobs will be created and local companies will take part in certain ways and benefit.
The aim of this paper is to demonstrate how efficient and cost-saving solar energy can be exploited in the deserts of Libya. A feasibility analysis to the large-scale grid connected PV project with total capacity of 14 MW is dedicated. The power plant delivers approximately 27 GWh of electrical power in one year. It is shown that the cost for one kWh is in the range of 0.08 USD, which is approximately four times less than the cost for electricity produced

with Diesel-generators in the same region. This leads to savings of Diesel (light oil) of approximately 6,400 tons per year. The value of the saved diesel is approximately 5.7 Million US Dollars (at a world market price of 900 USD per ton). Within its minimum lifetime of 25 years, the PV power plant saves 150,000 tons of Diesel or 133 Millions of US Dollars. Compared to the saved oil the break-even is within 7 years and the Return of Investment (ROI) is in the range of 14 %.

Keywords photovoltaics, electric power, fossil fuel, Return of Investment.

1. Introduction

Renewable energy sources are now seen as an important asset, in particular for the electricity sector, which is still entirely driven by fossil fuels. RE sectors are generally based on mechanical, technically-intensive production technology and are mainly labor-intensive. A domestic market for RE infrastructure acts as driver for manufacturing RE components domestically. Today, photovoltaics are well developed technology with fast growing market with highly competitive to fossils if one considers the world market prices for light oil. The world market for PV technologies and system components is mainly fully developed. Many PV systems have been applied in many countries and implemented successfully in different locations and environments throughout the planet. The compound annual growth rate of PV installations is up to 45 % during the period from 2006 to 2016 with annual installations in the range of at least 40 GWp and the total cumulative installations of about 300 GWp at the end of the year 2016 [1, 2].

Electricity demand in Libya is rising quickly, at an annual rate of more than 6 %. Oil consumption within the country is rising strongly too. Renewable energies for power generation are also expected to alleviate power supply bottlenecks, since the electricity consumption in Libya rapidly increases, with power supply shortages becoming more and more frequent. Libya is also endowed with an enormous potential for renewable energies (RE) and may enable Libya to diversify from its current strong reliance on fossils towards a more technology-driven model. However, Libya has fully recognized the potential of its excellent wind and solar conditions in combination with empty land in the South of Libya. But despite excellent solar radiation, wind conditions and an abundant availability of undeveloped land, renewable options have never been seriously considered in the past. Today, the new Libyan state is reconsidering its energy policies. Renewable power plants offer an opportunity to reduce the national consumption of domestic fossil fuel resources for electricity generation, thereby saving oil and natural gas for exports that are needed to sustain. By creating a domestic market for RE infrastructure, Libya will realize several advantages in its domestic employment market. The RE share in 2025 is expected to reach approximately 10 % [3].

In this work, a feasibility/pre-Tender - costs and benefits are getting estimated based upon industry proven data and experiences. The first milestone is “Feasibility confirmed” by assessing all relevant influences and judging the successfulness of the PV system at Hun. Numerous stakeholders are involved in the approach. Most important are Libyan governmental authorities, such as the General Electric Company of Libya (GECOL) and the Renewable Energy Authority of Libya (REAol), providing the necessary framework and empowerment to the project. An external drivers and supporters such as Gesellschaft für Internationale Zusammenarbeit GIZ and the Desertec Initiative Dii are providing strategic, structural and technological input for the project. On the other hand, an expert consultants (e.g. Fichtner GmbH, Wuppertal Institut, Dii) have to be involved which bring in additional expertise [4, 5].

2. Site Examination

In parallel the geographic and environmental conditions of Libya are almost ideal for PV, Libya provides vast areas of land with excellent solar (and wind) conditions. As a result many attractive sites can be identified providing excellent opportunities establishing a network of RE power plants [6]. In this work, the proposed site of the PV power plant will be close to the city of Hun (N29^{o}07`07``, E15^{o}56`12), located in the desert area of Libya. The area is flat, arid, highly exposed to the sun and no high mountains or buildings may influence the power system.

Solar irradiance is the single most important parameter for evaluation of PV system performance, so for simulation and evaluation purposes it is important to select the best possible data series. The global horizontal irradiation (GHI) is the most critical resource for solar PV plant. For optimum design of a PV plant, it is important to know the distribution on intensity and wavelength. Solar maps or irradiation tables are essential tools in planning and dimensioning of solar energy installations. In this study we have collected most of the available data sources for the solar climate of the project site in Hoon. However, we have to realize that all the data used in these studies were based on the satellite data. The general meteorological data at Hun site being used in this work for the yield simulations is being sourced via EMPower/NASA data, as shown in figure 1, [7]. One can see clearly that the desert conditions at Hun are very advantageous for PV power generation. If one compares the quality of the Hun location to other locations in Libya, such as al Kufrah, Sebha, Darnah and Tripoli. We can see that Hun is well positioned. Hun's average daily solar radiation (horizontal) is among the best in a set of excellent locations.

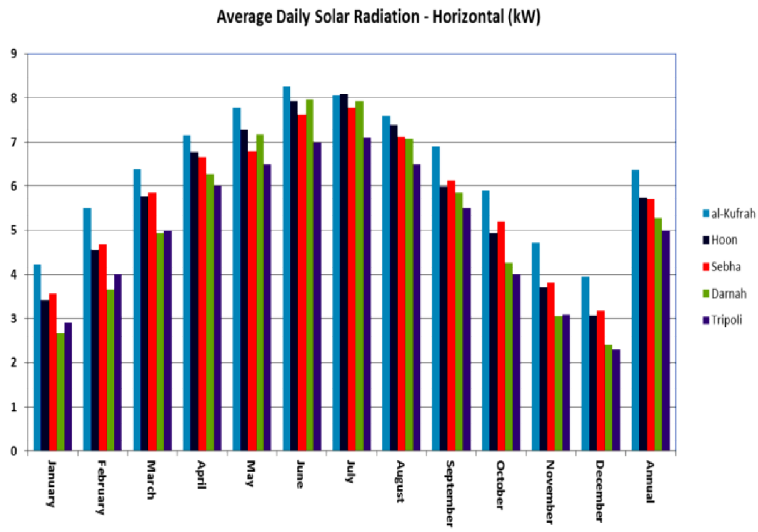

Figure 1: Hun solar radiation compared with other locations in Libya

The 14 MW PV plant shall be connected to the grid close to Hun. A substation is already in use at the construction site. It is obvious that PV power plant without additional power storage delivers electricity solely during daylight hours. Comparing the grid load in Libya with the daylight hours one can observe, that the maximum load is later in the day and sometimes (during summer) even after sunset. This means that PV cannot displace residual power generation, as shown in figure 2.

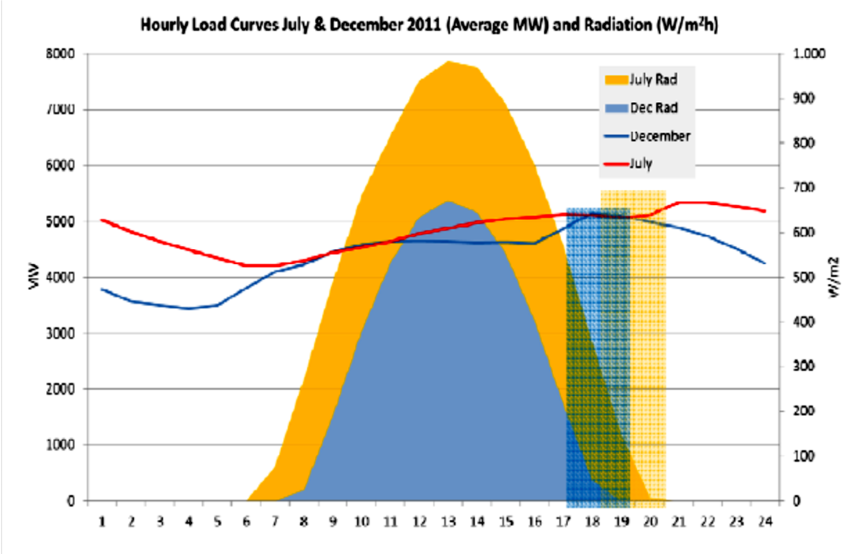

Figure 2: Exemplarily grid load and solar radiation in July and December

3. Yield Assessment Check and Cumulated power output during 25 years:

Solar photovoltaic PV modules are divided into two main categories: crystalline (mono- and poly-silicon) and thin film. Mono-silicon PV modules are the most efficient but also the most expensive. Poly-silicon PV modules are slightly less efficient and less expensive. Thin film PV modules are cheaper and consume much less silicon. In addition, thin film PV modules are less sensitive against high temperatures and more sensitive at ambient/diffuse light. This might lead to an overall higher output of electricity, but there are shortcomings as well. Most of the photovoltaic modules currently in the field are either mono-silicon or poly-silicon and have a proven track record for long lifetimes. Thin film PV modules are gaining market share; however, there are only little experiences for operating times of 10 years or more yet. In this work, technical design of the solar PV system and an exemplary assessment for the Hun location based upon their CdTe (thin film) technology and the meteorological site conditions in Hun has made by Calyxo company in Germany. The results are determined by a mathematical model calculation. The actual yields of the photovoltaic system can deviate from these values due to fluctuations in the weather, the efficiency of modules and inverters, and other factors. Table 1shows the main Hoon project design characteristics and yield assessment check results for 1MW AC variant ground mounted rack PV system.

Table 1: Main Hun project design characteristics and results

Project Block:	1MW (AC) System Variant ground mounted rack system	
Climate Data Record:	Hun (1986-2005)	
Gross/Active PV Surface Area:	92,228.20 / 94,051.09	ft^2
PV Array Irradiation:	21,391.580	kWh
Energy Produced by PV Array (AC):	1,902.986	kWh
Grid Feed-in:	1,902.986	kWh
System Efficiency:	8.9	%
Performance Ratio:	87.0	%
Inverter Efficiency:	98.1	%
PV Array Efficiency:	9.1	%
Specific Annual Yield:	2,131	kWh/kWp

The table above does not represent a full technical design of the solar system. However, these results show the huge potential of solar energy investment in Libya [8].

Most important for the evaluation of the power plant is the electrical output during its expected lifetime of at least 25 years. Using data provided by the Hun mast and meteorological data one can simulate different module technologies with regard to the actual electrical power fed to the grid. Figure 3 shows the calculated output amount of electricity produced for three different module technologies (Mono-silicon, poly-silicon and CdTe thin film) within the first year of operation. The diagram shows a certain advantage of the thin film technology that little higher electricity production of thin film modules, mainly caused by differing sensitivity of crystalline and thin film modules at higher temperatures and ambient light. Nevertheless, there is a considerable error margin slightly higher compared to the silicon modules. The error margin is relatively high and there are some drawbacks of the thin film technology, which outweigh the higher power production. Specifically the cumulated output over 25 years is of critical interest as this is the expected minimum lifetime of the PV solar plant. Differences of the three technologies (Mono-Si, Poly-Si and CdTe) are within the range of 5%, which can be assumed to be within the error margin.

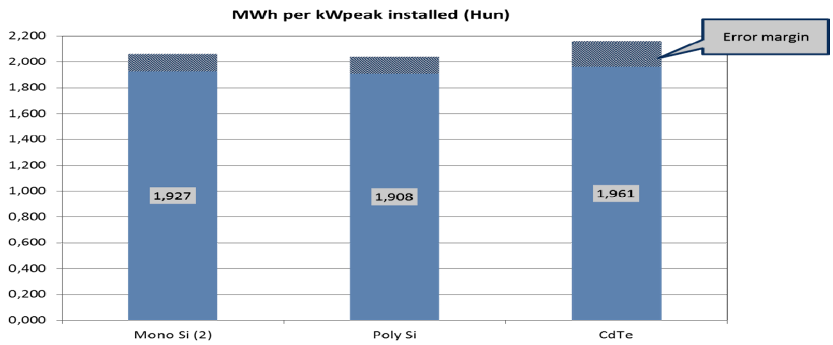

Figure 3: Calculated electricity output within the first year of operation for Poly-, Mono- and CdTe modules considering high temperature degradation

The long-term degradation of PV modules is an important parameter for the calculation of the cumulated power fed to the grid during the expected minimum lifetime (25 years) of the power plant. The expected (calculated) cumulated amount of the supplied electricity for 5, 10 and 25 years is shown in figure 4. The total output of the 14MW power plant in Hun can be expected as approximately 600 GWh over 25 years under the premises that the power station is operated and maintained in an orderly manner. During the minimum of 25 years, operating phase of the PV system, the output has to be measured and compared regularly to the guaranteed value. Degradation is assumed to occur in a linear way over time, which makes yield calculations rational. However, significant parameter to be taken into consideration for long-term operation of a PV power plant is the temporal degradation of efficiency. Silicon cells as well as thin film modules loose efficiency caused by chemical aging effects. These ageing effects lead to a temporal degradation of efficiency.

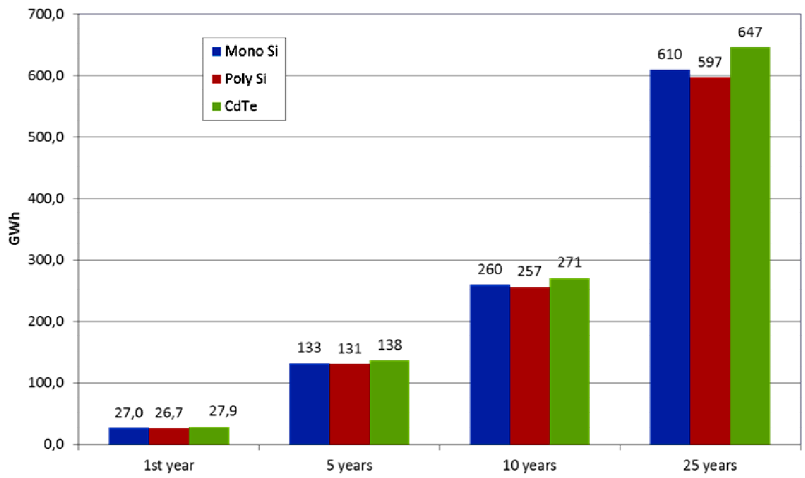

Figure 4: Yield. Calculated electricity output within 25 years of operation for Poly-, Mono- and CdTe modules considering degradation effects (temperature and ageing)

There are only less verified long-term data for thin film. Nevertheless thin film manufacturers (e.g. calyxo, first solar and others) guarantee a degradation of not more than 10% over 10 years and not more than 20% over 25 years for their modules, equivalent to crystalline module manufacturers [8]. Thus, the degradation factors for crystalline and thin film modules can be assumed to be on the same level. The degradation factors need to be specified in the contract with the supplier of modules. Degradation also occurs due to various other reasons and it is possible to diminish some of them by a suitable design, proper operation and consequent maintenance of the PV system during its lifetime. Figure 5 illustrates a relatively high degradation generated by e. g. dust from sand or damage. As a consequence implementation of frequent cleaning devices and trained operation personal is mandatory. There are different methods in place; but mainly cleaning by water gets applied to avoid touching the surface of the modules. In the arid desert area of the PV plant the amount of water needed is an important factor. Thin film technology needs more labor and more water as the surface needed for 14 MW is significantly higher.

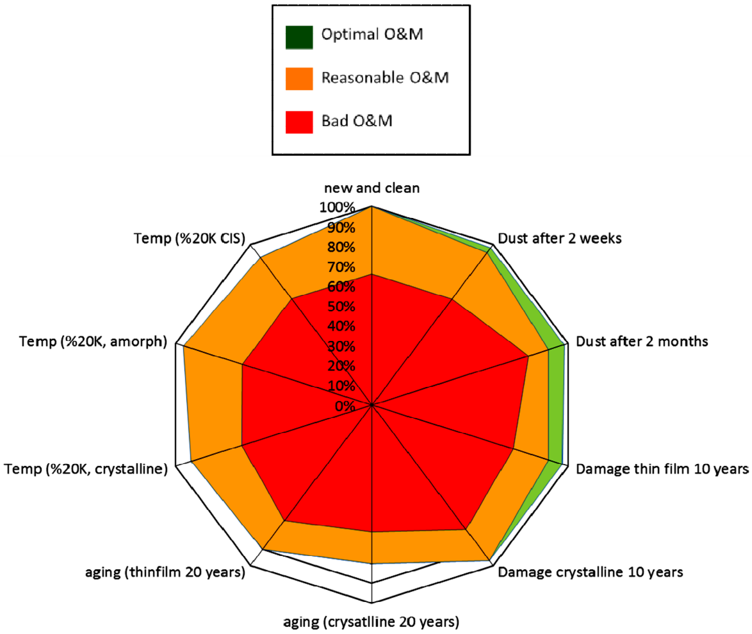

Figure 5: Degradation effects cumulated. The impact of good and bad maintenance

4. Economic Feasibility: Costs, Earnings, ROI and Break Even

Currently there is no open market for electricity in Libya. Both electricity production and distribution are operated and owned by the state. In principle, new power plants have to be benchmarked against the most expensive power production facilities which can be replaced by the new power plant. In the south of Libya (e.g. Hun. Sebha, Ghat) mobile Diesel generators support the security of electricity supply. These generators can be replaced by PV power generation or, at least, the Diesel consumption can be reduced drastically. Therefore, all calculations are based on the savings of Diesel and the actual world market price for Diesel. Thus, we have to calculate the savings induced by the 14MW PV power plant multiplied by the estimated world market price of 900 USD per ton average which is the lower average world price within the time period 2011-2013. In the next 25 years, it is expected that the world price rather rises or stays steady instead of declining. Table 2 shows how the cost for one MWh can be calculated on basis of the Diesel world market price. These values are taken from the Sebha Diesel generator station. Taking the numbers from the yield estimation, we have the electricity produced by 1 MW installed capacity of 1,927 MWh per year and the production of the 14MW PV power plant in Hun accordingly within a time period of 5, 10, 15, 20 and 25 years is determined. The electricity produced within 25 years period is about 625,890 MWh at 87% performance ratio including all system losses and module degradation.

Table 2: Diesel consumption and USD cost for one MWh (1MWh = 284USD)

Electricity Production Cost – Diesel Generator in Sebha	
Generator Consumption equals to equals to	0.283 liter Diesel per KWh 3.54 KWh per liter Diesel 4.21 MWh/ton Diesel
1 ton Diesel =	1,190.5 liter
Diesel WM Price: equals to	900 USD/ton 0.756 USD/liter
≈ Generator rent & OH +	0.214 USD/KWh (Diesel) 0.070 USD/KWh
Generator Electricity Cost total	0.284 USD/KWh (Diesel)
Generator Electricity Cost total	284 USD/MWh (Diesel)

Assuming that 1 ton of diesel produces approximately 4.21MWh and 1 ton of diesel costs 900USD, the diesel savings from the 14MW PV power plant in tons within a time period of 1, 5, 10, 15, 20 and 25 years are calculated. For example, the diesel saving within 25 years is about 148,573 tons which is equivalent to about 133,715,885 USD.

Fully in operation the PV plant delivers power compared to approximately 6,400 tons of Diesel per year which is equivalent to 200 truck-loads. In 25 years – the guaranteed system lifespan - approximately 150,000 tons of Diesel will be saved. If the world market price is 900USD per ton, this correlates to more than 130 mio USD. To calculate the production cost for the 14 MW PV plant we assume a minimum life time of the plant of 25 years and an investment of 2.70 USD for 1Wpeak. The annual cost of operation and maintenance is set to 1% of the total investment, as shown in table 3. The calculations clearly show that the production of electricity with Diesel generators in the region of Sebha is four times more expensive than production with PV.

Table 3: PV plant production cost

Production Cost Breakdown		
Invest for 1 Wp PV (estm.)	USD	2.7
Total investment 14 MWp	USD	37,800,000
Minimum operation period	Years	25
Annual depreciation	USD	1,512,000
Annual cost of operation	% of invest	1.0 %
Annual cost of operation	USD	378,000
Annual production cost		1,890,000
Production cost 1 (net)	USD/KWh	0.070
Production cost 1 (net)	USD/MWh	70.06

A sensitivity analysis shall demonstrate the variance of the production cost when input parameters vary, as shown in figure 6.

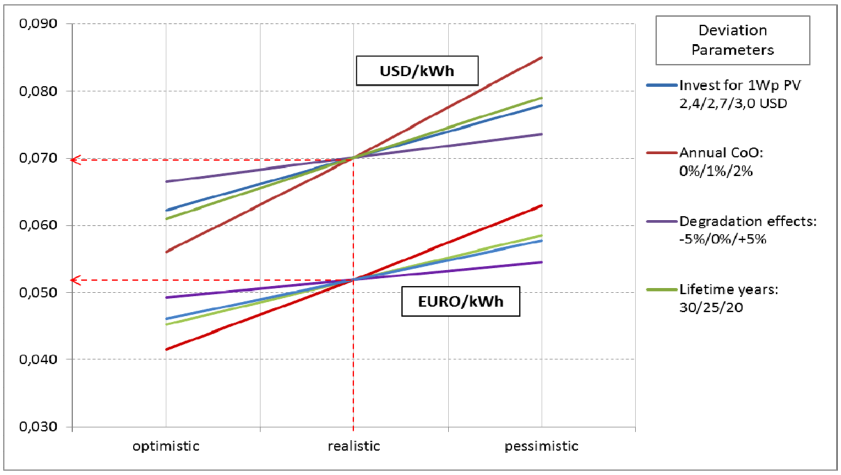

Figure 6: PV plant production cost sensitivity analysis for different input parameters.

Two categories of costs occur in the upfront investment costs and the ongoing maintenance / operating costs. As described above "income" in this project gets defined as avoided tons of diesel multiplied by expected diesel world market price. The point in time "break even" when the cumulated income exceeds the sum of costs is of particular interest for the bankability. Additionally the "pay-back-percentage", called Return on Investment (ROI), makes transparent the profitability of the PV plant and can be compared to the profitability of other projects in the investment market. Of course the calculation is dynamical due to deviation and other effects [9]. In this project, number of financial elements such as, system procurement and installation, site preparation, project office and logistics (1.5-2.5 % of System) are used for ROI calculation. Ongoing costs and income during operation phase (Maintenance/Operation, Insurance, Diesel saved etc.) are also included. It has found that the ROI for the first year is equal to about 14 % while the break even is about 7 years at degradation of about 0.8% year.

5. Conclusions

The experiences with PV power in Libya are limited, in particular, there are no large-scale PV power plants installed yet. Recently, the promotion and development of renewable energies has recently become an important priority for Libya. Therefore, the electricity from the PV power plant offer an attractive platform for the future to achieve long□term energy independence and can help to stabilize the power supply, while reducing environmental impact and sustaining a strong economy and society for future generations. In this direction large scale grid-connected PV projects will be established as a national plan to improve the diversification of the Libyan energy production portfolio. To verify the feasibility of PV power systems, the first project with 14 MW grid-connected PV system which will be executed in Hun city was presented and a comprehensive study including the plant design and its performance analysis and behavior was performed. The 5, 10 and 25 years analysis performance was investigated and the final yield assessment, cumulated power output and performance ratio considering the degradation effects and system losses for three different module technologies were calculated. Our results revealed that the differences of the three technologies (Mono-Si, Poly-Si and CdTe) are within the range of 5%, which can be assumed to be within the error margin. The 14 MW PV plant production cost, assuming a minimum life time of the plant of 25 years was calculated. The calculations clearly show that the production of electricity with Diesel generators is more expensive than production with PV with the ROI for the first year is equal to about 14 % at degradation of about 0.8% year, demonstrating the benefits and challenges associated with facilitate increasing the penetration levels of PV systems in the electric network in Libya.

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