International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

Cost Analysis for Irrigation Projects Using Solar Energy in Egypt

Ahmed W. Soliman, Ayman H. Nassar, Ahmed M. Sattar

Abstract— Local and global, general and specific photovoltaic irrigation projects are introduced. Brief information about solar panels, their different types, their manufacturing, functionality, efficiency, and design processes are also presented. Concentrated Photovoltaic (CPV) is also described thoroughly, which is a brand new technology in the field of solar energy, and its possibility to be introduced to the Egyptian market, replacing flat plate c-Si Photovoltaic and conventional diesel generated power systems. A previous case study is introduced for a project operated in an area that has a similar Direct Normal Irradiance (DNI) to that of Egypt. Furthermore, a composed case study is discussed in detail for a project to be implemented in the area of Alexandria, Egypt. Last but not least, a detailed cost analysis is then conducted for this exact project to demonstrate the economical difference between all the previously mentioned powering systems. Where Low Concentrated Photovoltaic (LCPV) was found to be the best alternative in terms of present and future value.

Index Terms— Concentrated Photovoltaic, Conventional Photovoltaic, Cost Analysis, Cost Reduction, Diesel Generators, Egyptian Irrigation Systems.

1 Introduction

Around 50% of the Egyptian population is engaged in the agricultural sector, making agriculture an essential aspect of economic development of the country. However, agriculture in Egypt is negatively affected by low rainfalls, relatively low humidity, hot climate and the fact that water quality and volume of the Nile is constantly decreasing. Moreover, 85 to 90 percent of farmers work on lands of maximum 5 Feddan (21000 m²). This has led to making the Delta region rather used to accommodate Egypt's rapidly growing population than to be used in agricultural. Thus, to meet the increasing crop demand; in the past decade, agricultural business was forced to restore uninhabited and desert lands for agricultural use, for example, the western and the eastern desert areas. The immense evapotranspiration - occurring due to extremely high temperatures – and the sandy soils usually require constant and persistent water application, making irrigation agriculture essential in Egypt.

Costs of diesel for irrigation systems are terribly inflating because of the absence of diesel in the markets. Furthermore, the use of diesel fuel is also more expensive when used in deserted lands due to their remoteness. Taking into consideration the transportation expenses of diesel, maintenance costs and overhauling of generators, using diesel will not anymore be economically feasible and attainable for those farms in the coming years. At the same time, Egyptian crop exporters are losing competitiveness in the international market due to crop losses that were caused by lack of irrigation. High carbon dioxide emissions, tremendous diesel discharges into the soil and precarious long distance transportation of diesel to the farms are just a few of many ecological disadvantages of diesel operated water pumping systems. Therefore, we have to find an alternative energy source in order to overcome the flaws of diesel powered systems and to enhance the growth and development of Egypt's agricultural sector.

With 90 % of desert land, higher possibilities of clear sky-days and solar radiations that reaches 2600 kW/h, Egypt is one of the most potential countries in the Middle Eastern and North African region for solar energy availability. The introduction of solar powered pumping systems presents a magnificent chance to overlook the usage of non-reliable and non-sustainable fossil fuelpowered generators. Moreover, the implementation of solar powered irrigation systems helps to conquer the risk from the variation and fluctuation in both fuel and supply prices, and instead ensures stable and reliable on farm energy supply. Thus, crop losses due to insufficient irrigation will never be a consequence.

In comparison with Diesel prices, solar energy is not yet a competing substitute considering the price of input only. This is due to the strong governmental financial support of diesel by the Egyptian government. Given the current economic situation, governmental financial support will decrease adequately within the next 2 years to make solar energy a competitive replacement. However, this is probably the case for remote desert farms. A simple cost analysis was carried out for a distant desert farm in Egypt showed that 1 kW/h generated from diesel energy will cost the farm 1.55 L.E. due to the cost of transportation, unlike energy generated from photovoltaic panels which will cost 1.05 L.E. for every single kW/h. With respect to irrigation, this means that one cubic meter of water costs the farm 0.45 L.E. when using diesel-powered pumps and 0.28 L.E. when using solar energy. Using a different energy source, such as Photovoltaic Systems, has proven to be much more cost-effective for isolated desert farms.

There are various numbers of different pumping systems that can be used in irrigation. The most popular photovoltaic

- *Ahmed W. Soliman is currently pursuing masters degree program in civil engineering in the German University in Cairo, Egypt, PH-+201122033459. E-mail: ahmed.wael-soliman@guc.edu.eg*
- *Ayman H. Nassar, Associate Professor, Faculty of Engineering at German University in Cairo, Cairo, Egypt. E-mail: ayman.hamdy@guc.edu.eg*
- *Ahmed M. Sattar, Associate Professor, Faculty of Engineering at German University in Cairo, Cairo, Egypt. E-mail: ahmed.abdelsattar@guc.edu.eg*

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

cells being used recently are the poly-crystalline and mono-crystalline cells. Different initiatives and sustainable energy firms has picked polycrystalline cells, though mono-crystalline cells are much most efficient. However, since mostly every single farm in Egypt is located in an isolated remote desert area, where on-grid systems and in-house cabling would barely be found, thus polycrystalline cells has proven to have a much better cost-efficiency ratio. Determining which solar pumping systems to be used depends on different factors. Standalone solar photovoltaic systems for direct irrigation offer a very simple solution. However, these systems do not provide a backup power supply. Therefore, 3 different and more sophisticated solar pump systems were widely available in the market, where we will be clearly illustrating each and every one of them in this paper.

2 Photovoltaic Projects

In February 2008 the Supreme Council of Energy established the Egyptian Electricity Power Strategy, which aims to contribute 20% of the total renewable energy generated by 2022, including 12% solar energy by establishing solar stations linked to the grid with a total capacity of 7,200 MW.

Due to the subsidies and support given to the field of renewable energy projects by the government in the last 5 years particularly, public and private corporations related to this field have invested an enormous amount of money in renewable energy projects. Most of these corporations are national firms, not only contractors implementing the project in a site, but also manufacturers and maintenance firms. Table 1 shows a list of contractors, some key projects established by those contractors, and the technical details for these projects. These tables can give a slight idea on how important solar industry has become and how high of a potential it has to develop.

TABLE 1
PV Projects Implemented in Egypt & Africa

#	Contractor's Name	Corporation Type	Project's Location	Project's Description	Technical Specifications
1	LORENTZ	Multinational	Am Nabak, Chad	Implementing a drinking and sanitation water supply system to serve 13,000 displaced people in this area.	•Flow Rate:159 m3/day •Total Dynamic Head: 25m
			AinSfa, Oujda, Morocco	Replacing a fossil fuel powered pump with a 10KW solar energy pumping system in an agricultural area of 6 feddans for irrigation.	•Submersible pump (well):120 m3/day •Submersible pump (pool): 120 m3/day •Total Dynamic Head: 40 m
			Wadi El-Natroun, Alexandria, Egypt	Installation of a 34 kWp polycrystalline solar pumping system for irrigation usage.	•Flow Rate: 610 m3/day •Total dynamic head: 62 m •Pipe length: 80 m
			Al Minya, Egypt	Installation of a 6.9 kWp polycrystalline solar pumping system for irrigation usage.	•Flow Rate: 300 m3/day •Total dynamic head: 75 m
2	SEKEM	Local	Bahareya Oasis	60 kW Policrystalline stand-alone solar system, operating a 37 kW pump, irrigating 60 feddan of date palms.	• Flow Rate: 800 m3/day • Total Dynamic Head: 79m
3	PICO	Local	Mansoureya district	Implemented a hybrid central solar powered irrigation system with four pumps (288 kW) and a fuel saver system.	• Flow Rate: 3840 m3/day • Total Dynamic Head: 180m
4	KarmSolar	Local	Bahareya Oasis	**1.** Variable Speed Solar Water Pumping Pilot	-
				2. 7×40 KW Solar Water Pumping Stations	-
				3. 25 x 45kW Solar Water Pumping Stations	-
				4. 147kW Hybrid Pumping & Irrigation System: Drip Irrigation	-

3 Solar Panels

A solar cell is an electronic gadget or device that gets sunlight and transforms it straightforwardly into electrical power. It usually comes in the size of a compact disk, octagonal in shape, and colored dark blue. Solar cells are regularly packaged together to make bigger units called solar modules, themselves coupled into significantly larger units known as solar panels Just like the cells in a battery, the cells in a solar panel are intended to produce electricity; yet where a battery's cells produce electrical power from chemicals, solar panel's cells produce electrical power by capturing sunlight. They are scientifically named photovoltaic (PV) cells because they use sunlight - "photo" is a Greek word that means “light” in our dictionary - to make electricity - the word "voltaic" is a reference to Italian electricity pioneer Alessandro Volta.

3.1 Components and Functionality

A solar cell consists of two compressed upper and lower horizontal layers, n-type silicon and p-type silicon respectively. It generates electricity by allowing solar beams to stimulate electrons to jump across the junction between the different layers of silicon. When solar beams strike the cell, photons bombard the upper surface. The photons then carries their energy down through the cell. They then give up their energy to electrons in the lower p-type layer. The electrons use this energy to jump across the barrier into the upper n-type layer and escape out into the circuit. Flowing around the circuit, the electrons gives power to any connected instrument or machine. The below figure (Figure 1) clearly demonstrates the previously elucidated powering technique of solar cells, where subsequently; n-type silicon is the blue area, p-type silicon is the red area, photons are the yellow blobs, and electrons are the green blobs [1].

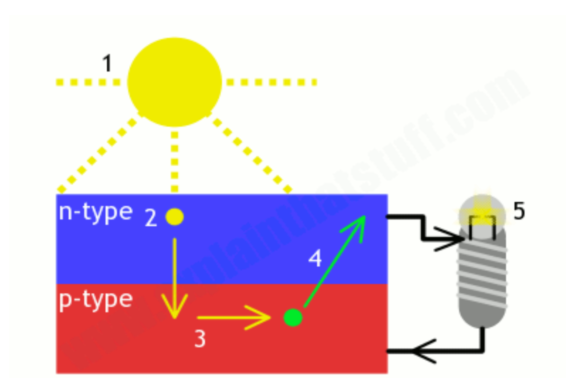

Figure 1. Demonstration of how a single-junction solar cell works[1].

3.2 Efficiency

According to the law of conservation of energy, energy cannot be created nor destroyed, it can only be converted. If this implies a thing, it is that a solar cell doesn't create energy, but it can only change light energy from its form into electrical energy. According to previously conducted statistical analysis, in practice, most cells convert about ten to twenty percent of the energy they receive into electricity. The typical market-found flat plate c-Si solar

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

cell has a theoretical maximum efficiency of around thirty percent (Shockley-Queisser limit). This is due to the presence of different wave lengths in a light ray, and conventional flat plate c-Si cells are only capable of capturing photons that have a certain frequency band. Furthermore, most photons either have plethora of energy when striking the solar cell which leads to wasting the excess energy or some doesn't even have enough energy to penetrate and knock out electrons, thus are also effectively wasted. However, at the very best scientists have manager to reach a 46% efficiency in perfect laboratory conditions using multi-junction solar cells which is capable of collecting photons of different wavelengths [1].

Figure 2 shows a set of different efficiency values for different types and generations of solar cells. Where the very first solar cell invented had an efficiency of only 6%, the highest achieved efficiency was 46%, and the efficiency for the daily seen conventional 1st generation PV cell had an average efficiency value of 15%, and that's unlikely to get much better.

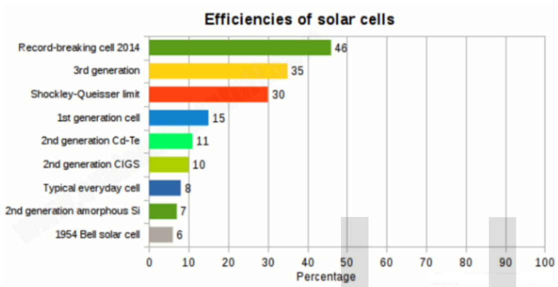

Figure 2. Bar chart comparing the efficiencies of different types of solar cells [1].

Moreover, there are numerous troublesome aspects that considerably affect the efficiency of the whole solar system negatively. Such aspects includes; the construction of the panels, their positioning and angle of inclination, the DNI (Direct Normal Irradiance), the temperature they are subjected to - temperature and efficiency have an inversely proportional relation, and their surface neatness.

4 Concentrated Photovoltaic

Concentrated Photovoltaic (CPV) is gradually being seen as a revolution in the field of photovoltaic since it holds the best guarantee in addressing the vitality complications antagonizing the world. A CPV system has a similar purpose to that of the conventional PV system, which is to convert light energy into electrical energy. The distinction between both technologies lies in the addition of an optical structure that focuses a considerable area of sunlight rays onto every cell. CPV has been established in the late 1970s and has been going through a rapid process of development since then, yet is just now achieving business practicality. It is the most updated technology to enter the renewable energy sector generally and the solar sector specifically [2].

CPV technology uses optical lenses and mirrors to concentrate solar beams onto high-efficiency photovoltaic single or multi-junction cells. The combination of optics and solar cells thus results in the highest commercial efficiency obtainable. The main concept behind CPV is using cheap but efficient concentrating optics that intensely reduce the cell area, allowing for the use of high efficiency, more expensive cells and potentially a LCOE (Levelized Cost of Electricity) competitive with standard flat-plate PV technology in certain sunny areas with high DNI (Direct Normal Irradiance) [3].

CPV is best suited for sunny regions where the DNI values are 2000 KWh/ (m^2a) and above. Concentrated photovoltaic systems are classified into three different categories according to the concentration factor of the technology configuration (See Table 2). Almost more than 90% of the CPV production up till late 2016 are assorted as HCPV (High Concentrated Photovoltaic) having a dual-axis tracking system. For HCPV systems, where concentration ranges from 300 times to 1000 times on an insignificant cell area, allows the use of highly sophisticated, efficient, but rather expensive multi-junction solar cells. These solar cells are based on III-V semiconductors (e.g., triple-junction solar cells made of GaInAs/GaInP/Ge). Furthermore, LCPV (Low Concentrated Photovoltaic), CPV with a concentration ratio below 100 times, has started to be commonly deployed. Since they primarily use crystalline silicon solar cells and a single-axis tracking system, ending up with a less complicated system than HCPV that has a considerably pleasing efficiency [4].

TABLE 2
Description of CPV Classification

Class of CPV	Typical Concentration Ratio	Tracking	Type of Converter
HCPV (High Concentration Photovoltaic)	300 - 1000	Two - Axis	III-V multi-junction solar cells
LCPV (Low Concentration Photovoltaic)	2 - 100	One or two - Axis	Mostly c-Si and sometimes other materials used

A crucial motive for large-scale power plants using high concentrated photovoltaic is the substantial increase in the efficiency of single modules. Higher cell efficiency means less area required for the same outputs, which allows a massive reduction in land-related system costs. In the recent four years, CPV efficiencies have reached 26-29% on site in real life conditions. Scientists and R&D sectors in reputable companies still predict a further increase in efficiency of over 32% in the next decade due to predictable improvements in not only the efficiency of the cell itself but also in the effectiveness of the optics. Furthermore, tracking systems in CPV help to optimize the energy production rate throughout the daytime of a sunny region, in particular on the late part of the morning when electricity demand peaks. However, in contrast to concentrated solar power, the range of power output of a project is vast, varying from a kilowatt range to a multi-megawatt range, which makes it a better alternative when comes to adapting to the local demand. Some CPV systems also inhabit a smaller area of land, since the tracking systems, with quite narrow bases, are not tightly packed. In several cases, this could allow

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

for continued use of the land for different purposes, for example, agriculture - which is the case of this study. Finally, HCPV could provide an advantage over traditional c-Si technology in hot climates, because of the lower temperature coefficient.

According to a study conducted by VasilisFthenakis, senior scientist at Brookhaven National Laboratory, he concluded that post-concentrating solar energy on a mono-crystalline solar cell over a broad range of concentrating rates results in an output variation of a non-linear curve. Which means that the higher the multiplier of solar energy, the greater the CPV efficiency was. Until the range of 500 suns which is the efficiency peak for the mono-crystalline silicon material. Refer to figure 3, which is a chart that illustrates the relationship between concentration rates and efficiency [5].

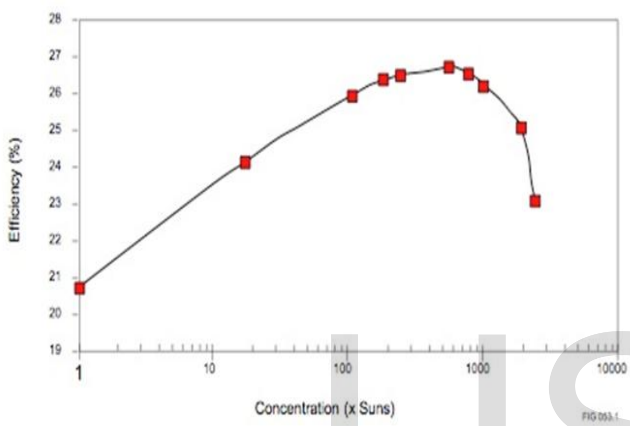

Figure 3. Demonstration of how a single-junction solar cell works [4].

4.1 Low Concentrated Photovoltaic (LCPV)

LCPV (Low Concentrated Photovoltaic) systems have a concentration ratio of – as mentioned above – 2 to 100 times [Mostly 5x – 10x]. Examples of these systems include prism-based concentrators, V-troughs, and compound parabolic concentrators. They typically use single junction silicon solar cells, have quite simple designs and often employ concentrating optics made of cheap plastic or glass. LCPV are easier and less expensive to manufacture and maintain than HCPV systems as they do not require dual-tracking or active cooling systems. Moreover, in addition to the direct component, LCPV are also capable of capturing an extensive amount of the diffuse solar radiation, making them particularly suitable for almost any climate [6].

Cost Advantage of LCPV

As indicated earlier, the aim of pursuing the LCPV design is to reduce the installation cost of a solar PV system. It is therefore important to predict theoretically the cost reduction that can be achieved by creating an LCPV module. According to Sarmah et al. The typical conventional PV module is made of silicon solar cells coated between two thick glasses. Therefore, the cost comparison of the LCPV module should be compared with the commercially available glass-coated PV module. To simplify the analysis, other costs such as the inverter, external wiring from the modules to the inverter and overall PV system installation cost are not considered in this analysis. The concentrating and non-concentrating PV modules used for the calculation here have dimensions of 111 cm x 85 cm x 4 cm. The breakdown cost for the conventional PV module and the LCPV module are presented in Table 3. From the table, the LCPV module could reduce the manufacturing cost by 31.75% when compared with a traditional solar PV module [7].

TABLE 3
THEORETICAL COST OF FABRICATING A 111CM X 85CM MODULE (EGP)

Item	Conventional Solar PV Module	LCPV Module
PV	703.00	174.00
Concentrator	0.00	254.00
Glass	120.00	60.00
Encapsulation	83.00	111.00
Frame	73.00	73.00
Wiring	30.00	17.00
Labor	141.00	96.00
Total	1,150.00	785.00
Cost Reduction (%)	-	31.75

4.1 High Concentrated Photovoltaic (HCPV)

HCPV systems use concentrating optical Fresnel lenses or dish reflectors that focus sunlight to concentrations of a thousand times or even more. The solar cells require a high quality active cooling system to assure high-temperature related performance and prevent thermal damage. Passive heat sinks are additionally recommended than active cooling systems for an enhanced overall efficiency and project economy. Multi-junction solar cells are presently preferred over single junction cells, due to lower temperature coefficient, which is the ability to maintain effectiveness at an increased temperature, and higher efficiency.

According to the standard test conditions, Multi-junction has reached an efficiency of 46% for production cells. The standard test conditions are the best case scenarios for a solar cell to generate electrical power, where for example, the incident optical power is optimized to 850 W/m² and the cell temperature to 25 °C. However, in real life, an HCPV cell will usually operate under conditions of an inconstant spectrum and higher temperature. Correspondingly, the optics used for solar beam concentration have an efficiency of around 70 to 90 percent themselves. Taking these factors into consideration would possibly cause an efficiency drop to about 36% of direct current power. Whereas under similar circumstances, a c-Si panel would have an efficiency of maximum 18%.

5 CASE STUDIES

5.1 Previous Case Study

According to the construction firm "LORENTZ" which is a multinational firm known for implementing PV systems all

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

over the world, they conducted a case study for a PV system they implemented later in Am Nabak, Chad for drinking water supply, Chad is a country in central Africa that is known for its desert climate and it has a similar solar irradiance as that of Egypt. Thus, it was essential to study their case and analyze the difference in cost between using PV system, diesel system, and water transport for this project. Tables4 & 5 gives detailed data of initial costs, operational costs, total costs, and total savings respectively. Assuming a daily water requirement of 160 m^3, an annual general cost increase of 3%, and an annual 10% increase on fuel.

TABLE 4
INITIAL OPERATIONAL & TOTAL COST COMPARISON BETWEEN DIFFERENT SYSTEMS. AM NABAK, CHAD. JULY, 2017

	Water Transport	PV	Diesel
Initial Costs			
Well building	0 USD	49,000 USD	49,000 USD
Pumps and installation	0 USD	27,500 USD	10,000 USD
Additional Infrastructure	0 USD	27,500 USD	27,500 USD
PV modules	0 USD	16,500 USD	0 USD
Diesel generator	0 USD	0 USD	14,000 USD
Initial system costs	**0 USD**	**120,500 USD**	**100,500 USD**
Operational Costs			
Energy required per day	-	29 KWh	29 KWh
Tank/truck cost per day	1,200 USD	0 USD	13.70 USD
Diesel cost per day	542 USD	0 USD	16.75 USD
Maintenance/ Servicing per year	0 USD	500 USD	3,500 USD
Yearly operational cost	**635,830 USD**	**500 USD**	**14,612 USD**
Total Cost			
1 year cost	635,830 USD	121,500 USD	115,112 USD
5 year cost (no cost increase)	3,179,150 USD	123,000 USD	173,560 USD
5 year cost (cost increase)	3,533,172 USD	123,155 USD	182,939 USD

TABLE 5
PROJECT'S TOTAL SAVINGS. AM NABAK, CHAD. JULY, 2017

Total Savings		
Number of years	PV / Water Transport	PV / Diesel
1 year cost	514,330 USD	-6,388 USD
5 year cost (no cost increase)	3,056,150 USD	50,560 USD
5 year cost (cost increase)	3,410,017 USD	59,784 USD

5.1 Previous Case Study

Diverse maps and set of data were retrieved from different Egyptian authorities such as; Ministry of Water Resources & Irrigation, National Water Research Center, and the Research Institute for Groundwater. These data showed the locations of water wells and groundwater tables for the whole city of Alexandria, and other technical specifications for this specific geographical area. Concerning these data and some irrigation systems design techniques, a case study for an irrigation system in El-Hammam, Alexandria was composed, where this area had 91 wells, with an average depth of groundwater of 11 meters, average discharge of 50 m^3/h and an irrigation demand of 30 m^3/h. Also, taking into consideration that the average pump efficiency is about 80% and the total working hours per day for the system is 12 hours.

6 COST ANALYSIS

The previously mentioned case study is theoretically implemented using five different powering systems; diesel generators, conventional photovoltaic, low-concentrated photovoltaic, and high-concentrated photovoltaic. A cost analysis is then conducted and all five systems are compared in terms of present worth and future worth.

1) Conventional PV Pumping System

After using several solar demand and pumping system calculators, solar irrigation system's components quantities are thoroughly obtained for El-Hammam, Alexandria's project. Moreover, according to highly qualified technical supervisors and environmental engineers from Tiba Solar and Cairo Solar, who are pioneers in the field of solar manufacturing, data about prices and availability of the system components are also attained.

Prices of Components for a Conventional PV System

- Solar module (STC 250 watt) = 2,400 L.E.
- Steel frame price for 2 solar modules = 2,500 L.E.
- Battery 100 ampere = 1500 L.E.
- Charge controller = 800 L.E.
- Water pump inverter = 120,000 L.E.
- Submersible pump 3kw = 26,856 L.E.

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

Components needed for El-Hammam's Project

- 1022 Solar module (250 watt)
- 511 Steel frame
- 1022 Battery (100 ampere)
- 1022 Charge controller
- 1 Inverter (250 hp)
- 91 Submersible pump (3kw)

According to the given data about the prices and quantities of the solar irrigation system's components, the total initial cost for the project is **8,644,796 L.E.**, and could be calculated as follows:

$$Total\ initial\ Cost = \sum(No.of\ Units\ \times Cost\ per\ Unit) \quad (1)$$

The photovoltaic system uses no fuel, which means that there are no operational costs, and has very low maintenance costs. The only maintenance for the photovoltaic system is the replacement of inverter, controller and batteries,which costs 120,000 L.E./unit, 800 L.E./unit, and 1500 L.E/unit respectively, on a 10 year basis. Adding these costs up to the initial cost, gives a total project cost of **12,052,996 L.E.**

2) Diesel Generator Pumping System

For diesel generator systems component costs were obtained from Egypt Power Group and are as follows:

- Diesel generator (200kw) = 1,058,238 L.E.
- Diesel generator fuel consumption full loaded = 53.5 liters/hour
- 1 liter diesel = 2.35 L.E.
- De-carbonization = 5500 L.E.
- Oil / Change = 2400 L.E.
- Oil Filter = 510 L.E.
- Air Filter = 600 L.E.
- Estimated Overhaul Cost per Year = 10,000 L.E

By using Eqn. 1, the total initial project cost if diesel generators were used is **3,622,134 L.E.**

The diesel generator requires constant maintenance on a regular basis. Where according to Egypt Power Group employees,for a diesel engine set that is continuously running, the standard require 35 oil changes, 6 de-carbonizations and 1.5 overhauls per year. The life cycle cost different levels of diesel engine maintenance requirements. By adding the operation and maintenance costs to the initial cost, the summation of the project's cost using diesel generators is **21,660,272 L.E.**

3) Low Concentrated PV Pumping System

The total cost of the irrigation system calculated, including the water pump inverter cost and the submersible pumps cost, was $\mathbf{8,644,796}$ **L.E.**, this price excludes maintenance costs. By subtracting the costs of water pump inverter and submersible pumps, which is common for all the systems being compared in this analysis, the total cost of the conventional PV system will be:

$$PV_{total\ cost} = 8,644,796 - \left(120,000 + (91 \times 26,856)\right) = 6,080,900\ EGP$$

As per the above equation, the cost of the conventional PV system is **6,080,900** stand-alone, for a project that has a power demand of 186 kWp. Thus, the cost of each watt in EGP can be calculated as follows:

$$\frac{cost}{watt_p} = \left(\frac{6,080,900}{186}\right) \div 1000 = 32.69\,\frac{EGP}{watt_p}$$

According to the breakdown cost analysis conducted by Sarmah et al, in table 3,the analysis arrived to a conclusion that the percentage of cost reduction between conventional PV and LCPV is approximately 31.75%. Which means that the cost per watt power of electricity for LCPV is:

$$\frac{cost}{watt_p}(LCPV) = 32.69 \times \left(\frac{100 - 31.75}{100}\right) = 22.31\,\frac{EGP}{watt_p}$$

Thus, the total cost of LCPV system for the El-Hammam, Alexandria irrigation project will approximately be:

$$LCPV_{total\ \ cost} = 22.31\ \times 1000 \times 186 = \mathbf{4,149,660}\ \boldsymbol{EGP}$$

Adding to this value the water pump inverter cost and the submersible pumps cost, should give a grand total cost of:

$$LCPV_{project\ \ cost} = 4,149,660 + \left(120,000 + (91 \times 26,856)\right) = \mathbf{6,713,556}\ \boldsymbol{EGP}$$

This concludes that the percentage of cost reduction for the whole project is:

$$\%\ Cost\ Reduction_{LCPV} = \frac{8,644,796 - 6,713,556}{8,644,796} \times 100 = 22.34\%$$

Maintenance costs for LCPV cannot really be obtained through previous experiences, since there is generally not a single LCPV system in the world that has been implemented 25 years ago – the expected lifetime of a PV project -. However, since LCPV usually uses the same materials and components used in a flat plate c-Si conventional PV system, it can be deduced that the maintenance costs for LCPV and conventional PV will roughly be the same. N.B. Taking into consideration that lens costs will be compensated in the difference in the amount of charge controllers and batteries.

$$\begin{aligned} Total\ cost\ for\ LCPV\ after\ 25\ years\ (With\ Maintenance) &= 6,713,556 + (120,000 \times 2) \\ &+ (800 \times 1022 \times 2) + (1500 \times 1022) \\ &= 10,121,756\ L.E. \end{aligned}$$

4) High Concentrated PV Pumping System

According to the ECA (Egyptian Customs Authority) clause (70/20/00/00/90) and (81/12/99/00/00), the customs and VAT (Value Added Tax) of almost all types of fabricated glass – to be used as concentration lens – and for III-V multi-junction cells are 10% and 13% respectively. That makes a total of 23% on the total prices of the items. Taking into consideration an additional 25% as a further approximation for trans-

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

portation and miscellaneous costs. This sums up to a total of 48% customs and VAT on the imported materials. Thus, the total cost of HCPV per watt is to be multiplied by 1.48 for a rough estimate when comparing the costs of other systems to HCPV.

All the costs used in the imminent analysis will be neglecting maintenance costs for HCPV. Since maintenance costs for HCPV is very hard to obtain due to the limitations and restrictions on the research in this section of the Egyptian market.

NREL (National Renewable Energy Laboratory) has derived an equation to calculate the cost per unit watt of HCPV power in USD, the equation is as follows [8]:

$$\frac{\$}{W_{p(DC)}} = \frac{cost\ /area}{power\ \ output\ /area} = \frac{1}{\eta_S P_\chi}\left[\frac{\phi_S}{C} + \frac{\phi_\chi}{\eta_\chi}\right] \tag{2}$$

Where:

ϕ_S = Cell costs in $\$/m^2$

ϕ_x = Primary optic costs in $\$/m^2$

C = Effective (or optical) concentration ration

η_χ = throughput efficiency of the concentrator

η_S = Cell efficiency

P_χ = 1,000 W/m^2 and corresponds to the CSTC incident DNI solar resource.

According to data from NREL's recently published research papers, the actual average cost of III-V cells are $2100 per square meter, the cell efficiency is approximately 36%, and the Fresnel lens efficiency is 80%. Furthermore, the DNI can be identified from the contoured DNI map from SOLARGIS, which in the case of El-Hammam, Alexandria, Egypt is 2200 kWh/m^2. According to a very well-known Chinese manufacturer and supplier in the field of lens fabrication, Fujian Fran Optics Co., Ltd., the average price of $1m^2$ of Fresnel lens is approximately $720 per square meter. Last but not least, the effective concentration ratio was assumed 500 suns, which is a moderate and reasonable value that won't require a massive cooling system.

$$\frac{cost}{watt_{HCPV}} = \frac{1}{0.36 \times 2200} \times \left(\frac{2100}{500} + \frac{720}{0.80}\right) = 1.142\frac{\$}{watt_p}$$

The cost of HCPV will be multiplied by 1.48, where 48% additional importing fees where added into consideration, since no manufacturers in Egypt is probably capable of fabricating the multi-junction cells or the required lens. This surmise to a cost of:

$$\frac{cost}{watt_{HCPV}}(Post\ Customs) = 1.142 \times 1.48 = 1.69\frac{\$}{watt_p}$$

Converting this value from United States Dollars to Egyptian Pounds gives:

$$\frac{cost}{watt_{HCPV}}(Post\ Customs) = 1.69 \times 18 = 30.42\frac{EGP}{watt_p}$$

The total cost of powering 186 kWp (El-Hammam project's demand) submersible pumps excluding the costs of the pump inverter and the pumps themselves are:

$$HCPV_{total\ \ cost} = 30.42 \times 1000 \times 186 = \mathbf{5,658,120\ EGP}$$

If pump inverter cost and pumps cost are included in this calculation, it will give a grand total project cost of:

$$HCPV_{project\ \ cost} = 5{,}658{,}120 + 120{,}000 + (91 \times 26{,}856) = \mathbf{8,222,016\ EGP}$$

This concludes that the percentage of cost reduction for the whole project if HCPV is to be used will be:

$$\%\ Cost\ Reduction_{HCPV} = \frac{8{,}644{,}796 - 8{,}222{,}016}{8{,}644{,}796} \times 100 = 4.89\%$$

6.1 Future Value

By taking a general look on the total costs of all four different types of pumping systems, it is notable that in this specific project diesel generator pumping system is by far the most expensive system and the least beneficial of all, in terms of sustainability and surely environmental impact. However, since these types of projects is usually meant to function for a 25 year period at least, Therefore all the amounts paid throughout the whole period will most likely be affected by inflation rates. In order to calculate the total future value for the different pumping systems, the interest rate from the Central Bank of Egypt needs to be known – 18.75% for September 2017. Also a set of different economics equationsare to be used, such as the compound value for the initial cost and the future value of annuity for operation and maintenance costs. Their equations are as follows:

- Compound Interest Formula:

$$M = p(1+i)^n \tag{3}$$

Where: M = Final Amount Including Principal

P = Principal Amount

i = Interest Rate per Year

n = Number of Years Invested

- Value of Annuity Formula:

$$FV = PMT\left(\frac{(1+i)^n - 1}{i}\right) \tag{4}$$

Where: FV = Future Value

PMT = Periodic Payment Amount

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

n = Number of Compounding Periods

I = Interest Rate per Year

The rates of interest according to the Central Bank of Egypt is rapidly ascending and descending each and every month. This is due to the difficult economic situation Egypt is going through in the last couple of years. Thus, conducting a cost analysis based on an absolute percentage of interest rate, will probably be invalid. However for the worst case scenario, the highest rate of interest - which is also the most recent value - will be taken into consideration throughout the analysis.

1) Diesel Generator

- $Future\ Value\ of\ Initial\ Cost = 3{,}622{,}134 \times \left(1+\frac{18.75}{100}\right)^{25} = \mathbf{265,953,047\ L.E.}$
- $Future\ Value\ of\ Operation\ \&\ Maintenance\ Cost =$ $[(53.5 \times 2.35 \times 12 \times 365) + (5500 \times 6) +$ *2400+510+600×35+15,000×1+18.7510025−118.75100=**278,698,974 L.E.***

- $Total\ Future\ Value =$ $265{,}953{,}047 + 278{,}698{,}974 = \mathbf{544,652,021\ L.E.}$

2) Photovoltaic

- $Future\ Value\ of\ Initial\ Cost = 8{,}644{,}796 \times \left(1+\frac{18.75}{100}\right)^{25} = \mathbf{634,739,034\ L.E.}$

Since maintenance costs for PV systems are paid in a 10 year intervals, thus, the Future worth of maintenance cost will be calculated in a different way than that of the annually paid diesel generators maintenance costs. In this case, the compound interest equation will be used. Refer to figure 4 for further illustration.

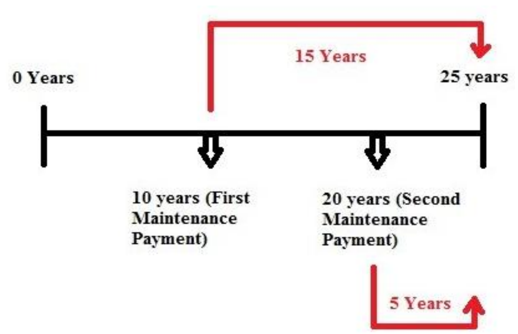

Figure 4. Method of calculating future worth of maintenance cost

- $Future\ Value\ of\ Maintenance\ Cost =$ $(120{,}000 + (800 \times 1{,}022) + (1{,}500 \times 1{,}022)) \times \left(1+\frac{18.75}{100}\right)^{15} + (12{,}000 + (800 \times 1{,}022) +$ *1,500×1,022×1+18.751005=**38,365,752 L.E.***

- Total Future Value $= 634{,}739{,}034 + 38{,}365{,}752 = 673{,}104{,}786$ L. E.

3) Low Concentrated Photovoltaic

- $Future\ Value\ of\ Initial\ Cost = 6{,}713{,}556 \times \left(1+\frac{18.75}{100}\right)^{25} = \mathbf{492,938,879\ L.E.}$
- $Future\ Value\ of\ Maintenance\ Cost =$ $\mathbf{38,365,752\ L.E.}$
- $Total\ Future\ Value = 492{,}938{,}879 +$ $38{,}365{,}752 = \mathbf{531,304,631\ L.E.}$

6.2 Comparing Results

As noted from the previous analysis, the percentage of cost reduction from using LCPV was calculated to be 22.34%. While the percentage of cost reduction from using HCPV was calculated to be 4.89%. This means that LCPV in this case study was actually 17.45% more cost efficient than HCPV, though HCPV is the more recent technology of the two. However, that doesn't make LCPV an absolute better alternative. LCPV was found to be better in this case study due to its simplicity that makes it manufacture-able in Egypt, thus, avoiding additional costs like customs and VATs. Moreover, if HCPV components started to get manufactured and fabricated in Egypt in the near future, this will make it a tough competitor, even better than LCPV. The below graph, Figure 5, shows a cost comparison between the flat plate c-Si system, the LCPV system and the diesel generated system in terms of installation, operation, and maintenance costs.

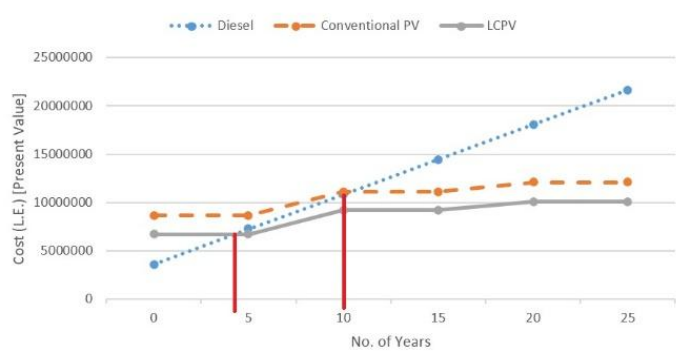

Figure 5. Comparison between different energy source types (maintenance included)

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

TABLE 6
COST COMPARISON BETWEEN DIFFERENT IRRIGATION SYSTEMS

	Initial capital cost (L.E.)	Total cost after 25 years (ignoring maintenance) (L.E.)	Total cost after 25 years (including maintenance) (L.E.)	Future Worth (After 25 Years) (L.E.)
Diesel generator Pumping System	3,622,134	17,389,022	21,660,272	544,652,021
Conventional Photovoltaic Pumping System	8,644,796	8,644,796	12,052,996	673,104,786
Low Concentrated Photovoltaic Pumping System	6,713,556	6,713,556	10,121,756	531,304,631
High Concentrated Photovoltaic Pumping System	8,222,016	8,222,016	---	---

7 SUMMARY AND CONCLUSION

After a simple mathematical calculation, conventional photovoltaic would seem the better alternative when being compared to diesel generators; however, this turned out not to be the case. Though Diesel generators have a much higher operation and maintenance costs, yet the enormous initial cost of the conventional photovoltaic system and the exceptionally high rate of interest in Egypt has led to a gigantic future value for PV. This exceeded the future value of the summation of the initial costs and M&O costs of the diesel generator. On the other hand, the extremely low initial cost of LCPV has allowed the system to remain the cheapest of all, even in the future value. Where, as deduced from the analysis, the percentages of cost reduction for LCPV when compared to diesel and c-Si PV were approximately 2.5% and 21% respectively, in the future value. Moreover, LCPV is a very simple upgrade regarding components used, which means that introducing such technology to the market would be accepted by solar powering systems stakeholders. And subsequently, the Egyptian government would allow subsidies to such sustainable projects. This brings the conclusion that LCPV is by far the most cost-efficient system.

Furthermore, HCPV is a very promising technology that will most likely prove to be the best alternative in Egypt probably in the next decade. However, it needs more acknowledgement in terms of research and development, for better understanding about its possible compatibility with the Egyptian market.

ACKNOWLEDGMENETS

The writers would like to thank the technical support departments of Tiba Solar, Cairo Solar, and Fujian Fran Optics Co., Ltd., for their valuable help in giving real-time data about needed components in the design process of the different power-generating systems.

REFERENCES

[1] Woodford, C. (2017, May 15). *Solar cell.* Retrieved from http://www.explainthatstuff.com/solarcells.html

[2] Imhamed Saleh M Ali, Tadhg S O'Donovan, K S Reddy and Tapas K Mallick (2013). *"An optical analysis of a static 3-D solar concentrator."* Solar Energy 88:57-70.

[3] Georgios E Arnaoutakis, Jose Marques-Hueso, Tapas K Mallick and Bryce S Richards (2013). *"Coupling of sunlight into optical fibres and spectral dependence for solar energy applications."* Solar Energy 93:235-243.

[4] R Wehrspohn and A.Gombert (2012). *"Propagation of White Light through Optical Fibres for CPV Systems."* Proceedings of SPIE series, volume 8438.

[5] R Setchi, I Jordanov, R J Howlett and L C Jain (2010). *"Optimised Dielectric Totally Internally Reflecting Concentrator for the Solar Photonic Optoelectronic Transformer System: Maximum Concentration Method."* Lecture Notes in Artificial Intelligence series, volume 6279, pages 633-641.

[6] NabinSarmah, Bryce S Richards and Tapas K Mallick (2011). *"Evaluation and optimization of the optical performance of low-concentrating dielectric compound parabolic concentrator using ray-tracing methods. Applied Optics"*50(19):3303-3310.

[7] Sarmah N., et al. (2014), *"Design, development and indoor performance analysis of a low concentrating dielectric photovoltaic module,"* Sol Energy, vol. 103, pp. 390–401.

[8] Fahrenbruch, A.L.; Bube, R.H. (1983). "*Concentrators, Concentrator Systems, and Photoelectrochemical Cells.*" Fundamentals of Solar Cells Photovoltaic Solar Energy Conversion. Elsevier.