MSc Program
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THE POTENTIAL OF USING PHOTOVOLTAIC TECHNOLOGY FOR ELECTRICITY GENERATION IN LIBYA

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
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Vienna, 11.10.2022

Affidavit

I, **FAISEL MOHAMED GIUMA GELIDI, BEE**, hereby declare

1. that I am the sole author of the present Master's Thesis, "THE POTENTIAL OF USING PHOTOVOLTAIC TECHNOLOGY FOR ELECTRICITY GENERATION IN LIBYA", 76 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract.

It is widely believed that the development of technologies that utilize solar electricity could be a significant step in alleviating the current issue in the world's power generation. Because of this, the world will be forced to discover a new alternative for the creation of power that is sustainable. In this paper, we will investigate the various ways in which solar energy has contributed to the production of electricity in Libya, including the numerous techniques and methods involved. In addition to conducting research on, reviewing, and keeping tabs on a variety of legal frameworks, legislative initiatives, and other activities carried out by different administrations across the nation.

Non-renewable energy sources such as crude oil and natural gas are plentiful in the country and considered as the backbone of the Libyan economy. Hence, the majority of power is generated using natural gas and heavy oil. Fortunately, the country is situated in a sunny zone, and due to the strength of the sun's radiation in nearly all regions of the country, the use of Photovoltaic (PV) technology to generate energy is economically possible and might result in substantial reductions in gas and oil consumed internally, reducing environmental pollution and, most significantly, conserving the cash from fossil fuel sales to modernize the country's infrastructure or for future generations which may be regarded as a very good cause to consider, given the world's behavior in terms of national resources and climate change.

The use of PV technology is advantageous, but all technical and economic aspects must be evaluated in order to obtain the most accurate results. This paper studies the economic and technical potential of using PV technology in Libya, especially in large-scale or utility-scale PV applications. Environmental concerns are ignored because the government lacks a clear policy.

CONTENTS

1 Introduction.

Energy, especially electricity has always played a very essential and significant roles in people's lives. Due to overpopulation and industrial revolution throughout the final quarter of the last century, global energy demanding, supply, investment and consumption has undergo tremendous changes over the years. A Significant structural change due to the excessive use of Natural resources, energy crises, growing impact of global warming and its implication on environment, and the recent Covid-19 global pandemic scenario.

In terms of power, there are three distinct options to relay on. Coal, oil, and natural gas are examples of fossil fuels, which fall into the category of non-renewable energy sources. The second category, renewable energy sources, includes options like solar, wind, hydropower, geothermal, and biomass that can be replenished naturally and do not cause any harm to the environment when used. The third category is nuclear fuel, which includes uranium and plutonium and gives us a lot of power.

North Africa, including Libya, is well-known for its abundance of renewable and fossil fuel resources. Oil and natural gas exports are a major industry for most North African countries, including Libya as well. The abundance of fossil fuels and gas resources is the primary difficulty in switching to renewable energy. In fact, both selling and importing oil and gas are heavily subsidized in Libya. This makes oil prices so low that renewable sources can't compete in the market.

Among the countries of North Africa, Libya is the second largest (1.76 sq.km). Solar, wind, and geothermal energy are all highly promising in the area. It has one of the longest periods of daylight on the globe. As the Mediterranean has a long coast of almost 2000 km, wind energy could be a great option. As the region has a massive deserted land area, it is ideal for large-scale solar energy plants, and the German Aerospace Centre estimates that each square kilometer (km2) of this region receives solar energy equivalent to 1.5 million barrels of crude oil annually. Unfortunately Industrial cultures here rely heavily on energy sources, mostly fossil fuels, and their high consumption rates use up the huge non-renewable resources that have been slowly building up in the earth's layers for thousands of years. Therefore, by adapting renewable energy technologies in this country, especially large-scale solar energy plants, renewable energy could deliver numerous benefits in terms of social, economic, and environmental factors. Advantages include fewer pollution and greenhouse gas emissions, smoother trade flows, a more secure energy supply, less reliance on foreign sources, more domestic jobs, and higher living standards.

Despite the large and extensive renewable energy resources in Libya, according to this research of the region, the vast majority of solar energy potential and untapped resources remain unexplored.

1.1 Motivation.

Solar photovoltaic (PV) installations in Libya are highly recommended due to the country's excellent annual solar irradiation. Although the country has a wealth of fossil resources (oil and natural gas), the government's subsidization of electricity generated from these sources means that its sale price is artificially low and has a significant impact on GDP.

The economy of Libya has been in crisis since 2011. The civil war and the ensuing instability in the political situation are major contributors to the current economic downturn. As with other industries, the energy sector has seen the effects of the ongoing economic downturn. In particular, the unreliable supply of power has been a problem because of rising regional demand and inadequate local generation. In recent years, the region has come to see power production as one of its most pressing challenges. As a result, the government of Libya is attempting to address the ongoing economic crisis by employing a number of initiatives, particularly within the petroleum industry. In order to make more energy, the government has recently taken important steps toward making a road map. For example, they are looking into whether or not it would be possible to upgrade power facilities and use renewable energies like solar electricity.

1.2 Core objective.

In the same vein as other forms of renewable energy, the primary motivation for studying photovoltaic systems is the potential to lessen the negative effects of carbon dioxide emissions and climate change. Although the effects of greenhouse gases and global warming are not prioritized in Libya and other developing nations that have faced enormous problems and conflicts, there are some reasons, such as oil price fluctuations, that increase incentives to invest in and develop renewable energy sources in those regions.

The primary goal of this research is to examine the viability of utility-scale solar technology for power generation in Libya. Review the current situation of the PV industry in the region and make suggestions for how to boost the sector's overall growth.

This study seeks to address some pressing concerns regarding Libya's photovoltaic potential as:

- How can PV technology be used in this area, and what keeps it from being used?
- What effect does the use of PV technology as a source of alternative energy in Libya have on the economy of the country and its neighbors?
- Is it economically viable to generate power with photovoltaic there?
- What initiatives are advised for promoting the PV market in the region?

1.3 Methodology of approach and work structure.

Numerous sources, including Internet research, books, journals, papers, and literature relevant to renewable energy and photovoltaic technology, have been used to demonstrate and indicate the quantity of energy that can be harvested from such a technology in order to provide the most correct response to the questions posed. These sources can be found online.

It is intended to learn more about the viability of photovoltaic technology as a domestic energy supply. To gain a complete picture of the state of technology in the country, we'll be running some calculations and doing some simulations. The National Renewable Energy Laboratory (NREL) developed software named SAM, which is used for the simulation in Sabha. Sabha is a major city in the desert, therefore it makes sense to set up the simulated PV farm there, close to the transmission lines serving the current electrical grid. The report should also include a brief feasibility analysis of the technology.

This study is structured as follows:

- CHAPTER 1 contains the purpose of the study, the key issue that needs to be addressed, the study's motivation, its central objective, and its technique will all be discussed after an introduction to renewable energy sources and PV technology in general.
- CHAPTER 2 provides context for Libya, with an emphasis on the energy industry, drawing from a wide range of reports, statistics, data, and in-depth academic research published in both regional and international journals. This chapter offers an in-depth examination of things as they are right now. Consider investment safety recommendations and trends, as well as policies and long-term objectives.
- CHAPTER 3 concentrates on the history of solar energy technology, the production process, the types of PV systems and their components, and the manufacturing process.
- CHAPTER 4 focuses on how feasible this technology is in terms of sunshine hours, operating and maintenance cost and how the government is reacting in terms of green energy.
- CHAPTER 5 will examine the photovoltaic industry's worldwide, continental, regional, and Libyan market trends, value sectors, and growth.
- Chapter 6 addresses the technical evaluation of a utility-scale solar power plant in Libya, including site selection criteria, energy production calculations, and simulation.
- Chapter 7 contains a summary and suggestions that should be considered.
- Chapter 8 consists of all the references that were used.

2 Region background.

Drawing from a variety of sources, this chapter presents background information on Libya, with an emphasis on the oil sector.

2.1 Demography and socio-Economic development in Libya.

The overpopulation and geometric growth rate within the last 20 years of the global population are one of the major driving factors for electricity demand in Libya and other selected North African countries. According to global population figures and demography reports, the population of Libya has grown from 5.358 million in 2000 to about 7 million in 2020 with an average growth rate of 1.32% (world meters info 2019).

On average, growth is 1.32 percent. Thus, in the last two years of global pandemic COVID 19, which caused over 5.8 million deaths globally, according to World Health Organization annual bulleting reports (W.H.O), the population growth has steadily slowed and the expected forecast should be 8.1 million in 2050. And the data shown here isn't captured and taken account of foreign labor and illegal immigrants that came into the country through deserts and unconstitutional means, irrespective of the political instability and security situation in Libya since 2011 (world population review, 2022).

The second main driving force for the country's electricity energy demand is economic growth and expansion in capital direct investments, as well as the relative stability in the global oil price outlook. In the year 2000, Libya's GDP was approximately $7142 USD per capita, reached 14382 USD/capita in 2008, and by the year 2020 had fallen to 3699 USD/capita. The long-term average annual growth rate for per capita GDP is 3.61 percent (World Bank date 2022).

Oil exports have been the mainstay of the economy since they began more than five decades ago; in 2019, they accounted for roughly 60% of GDP. After three years of growth from 2017 to 2019, the economy fell in 2020 due to a sharp decline in oil and gas output and exports. With hydrocarbons accounting for 95% of merchandise exports and 93% of fiscal revenues (excluding foreign exchange fees), the precipitous decline in hydrocarbon output in 2020 harmed the country's external balance and fiscal position, resulting in decreased government spending, decreased private consumption, and decreased imports (Libya economic monitor middle east and north Africa region,2021).

2.2 Energy sector overview in Libya.

The energy sector had undertaken various faces. The dynamics of climate change, energy shortage and energy retreat to support development and industrial support action plain which give birth to alternative option of renewables and related technologies as a possibility solution. Policy makers legislative and law promulgators, technology developments and international co-operation have moved these technologies and innovation to global top priority, particularly in the past 20 years. Despite of global uncertainty and crisis caused by the COVID-19 pandemic, renewables energy discovery systems which shown incredible resilience, and technical significant of renewables driving electricity method with share of solar and wind system (IRENA, 2021).

The General Electricity Company of Libya (GECOL) is the only legal entity and sole owner that controls, manages and is responsible for power generation, installation and maintenance with about 26 power stations and 85 generating units that come in different sizes and capacities scattered all over Libya, with the majority sited along the Libyan coast. Furthermore, the geographical locations and general electricity company of Libya assets generation is show and illustrated blow in Figure (1).

Figure 1: Location of GECOL generation plants 2017(Supporting electricity sector reform in Libya, 2017).

Lately, GECOL has evaluated and did a proper evaluation of power plants and it is classified as "in service", which authoritatively confirms an installed capacity of 10.238GW for the year 2017. Of this installed capacity, the actual available capacity is a fluid concept that varies continuously as maintenance, inadequate fuel, and other factors are responsible for reduction in some units' power capability, while other units are taken out of service or functionless because of inadequate or lack of maintenance and innovation. The differences in plant availability are clear from the data and information, which is derived from GECOL's General Control Department quarterly reports for 2015 and 2016. Figure (2) shows the available capacity by region during the last quarter of 2017 with a significant change in status of around 5.345GW, representing 52% of the installed capacity (Supporting electricity sector reform in Libya, 2017).

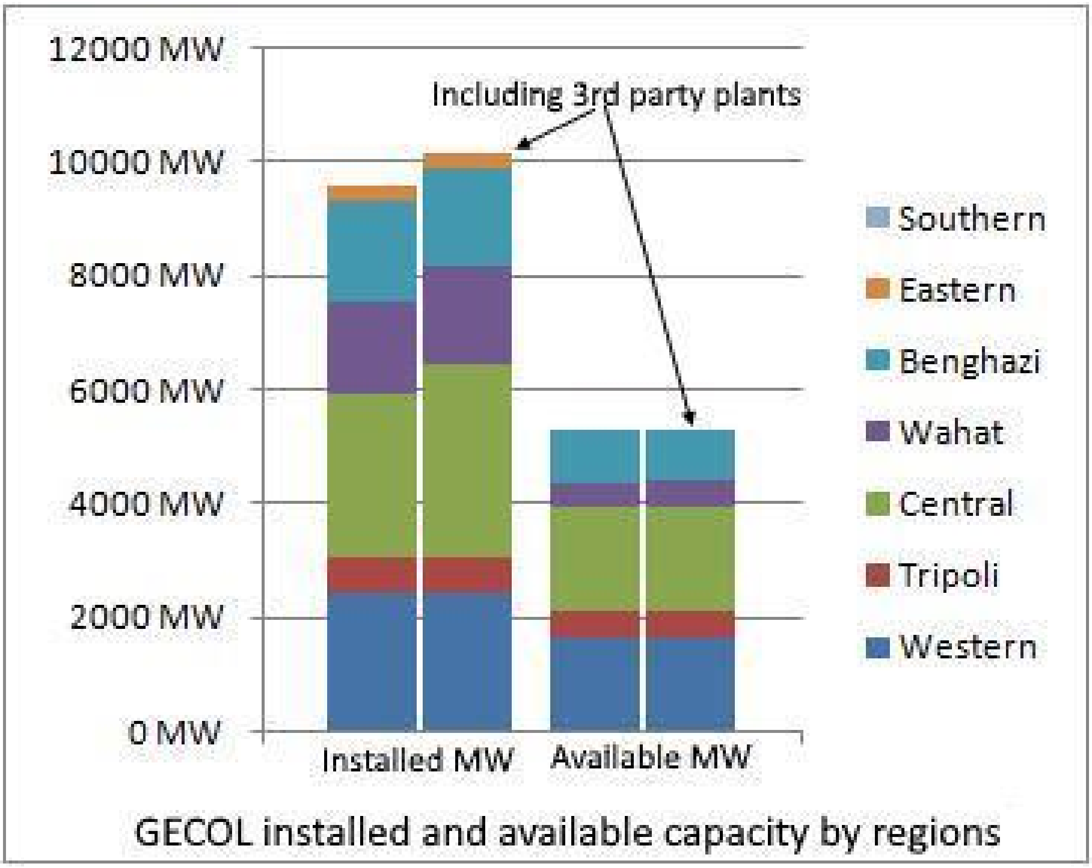


Figure 2: GECOL installed capacity and generation availability by regions till 2017 (Supporting electricity sector reform in Libya, 2017).

In addition, Figure (3) specifies the disparity in power generation units of the Libya network. Gas turbines are preferably by GECOL and have dominated other forms of power generation systems, regardless of their high operating costs and maintenance activities. Nowadays, GECOL has not carried on their upgrading plans, services and maintenance schedules as well. This has led to the elimination of some of the operating units out of service or a reduction in their power capabilities. Because of this, GECOL's network suffers regularly a drop in power generation level and blackouts on many occasions (Supporting electricity sector reform in Libya, 2017).

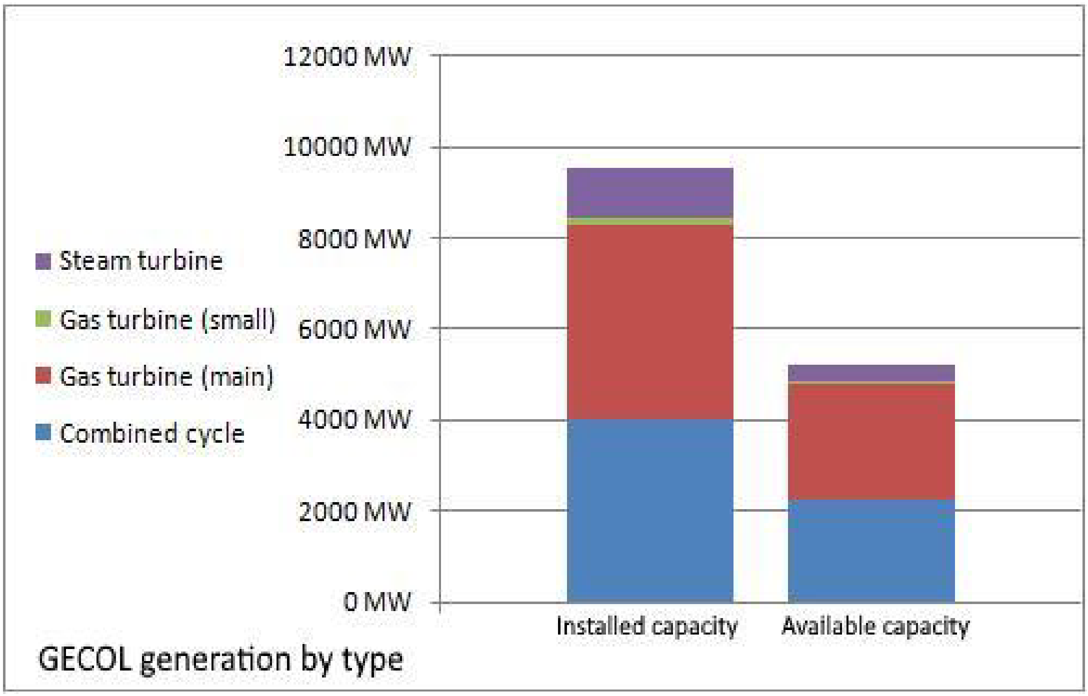


Figure 3: GECOL generation by technology in Libya 2017(Supporting electricity sector reform in Libya, 2017).

As mentioned earlier, Libya's electricity network suffered a drop in power generation levels and the availability of fuel played a major role in it. The majority of GECOL's power plants are negatively affected by the fuel supply issue.

The power plants are affected by the availability of fuel in many ways. The most important area is the inadequate supply of fuel. The well-known political situation and civil war are responsible for the cuts off that regularly occur during the supply of power plants. Furthermore, the high demand for gas as a source of operating fuel is mainly because the majority of GECOL's generation units are gas turbines based on "both the gas pipeline infrastructure and the production of natural gas are unable to keep up with demand". On many occasions, the less vital (smaller) units are compulsorily disconnected from the network to guarantee enough gas pressure to supply other more important (larger) units. In fact, less vital units are converted to low fuel oil (LFO) operating mode, regardless of all the disadvantages of using this system (Supporting electricity sector reform in Libya, 2017).

2.3 Regulatory frameworks, future plans or visions and challenges.

With the political unrest and global pandemic in Libya, various governments in power were trying to improve the capacity of electricity generation in the last decade by reviewing and evaluating the numerous challenges that GECOL was facing. These challenges are visible to everyone who lives in the country and were reported by GECOL themselves (GECOL's report) as follows:

1. GECOL is forced to shut down its power plants for minor and large inspections because of the requirement to perform maintenance. A power outage arises as a result of this condition.
2. Building GECOL's capacity by improving:-

- Generation transmission project management.
- Integration of renewable energy sources.
- An asset management and conditional monitoring system that is accessible online.
- Both the end-user devices and the network operations must be energy efficient.

Furthermore, with the support of the current administration in the country, GECOL has announced various steps in order to improve the electrical network, such as the reconstruction and upgrading of the South-Tripoli power plant; the overhaul of steam units at the Zawiya and North Benghazi plants; and even more, they came to a mutual agreement with an Egyptian consortium to implement the Derna gas power plant project (Inside Libya, 2021).

The future vision of GECOL is to increase the capacity of energy exchange between Libya and its neighboring countries and the validity of the direct current (DC) cable interconnection project between Libya and Italy. A feasibility study suggested the possibility of exporting 1000MW. Finally, GECOL stated that a discussion between Libya and Greece is coming in the near future to build up an interconnection project targeting the export of 3000MW.

However, without an appropriate fund due to the instability in the political situation and security challenges, the above-mentioned plans and visions cannot be achieved.

3 Solar energy.

In searching for alternative clean energy, renewable energy is the best option to compliment the traditional source of power generation (fossil fuel energy).

Through the development of science and technology, it has been realized that the sunlight that Earth receives from the sun has adequate energy to meet the global demand. Every single hour, uncounted numbers of photons irradiate the Earth, giving enormous amounts of energy which can be beneficially used in daily life if converted to a useful type of energy. It has been estimated that this energy should be enough to meet the global energy demand for an entire year (interesting engineering website).

Sunlight, or solar radiation, is radiant energy (electromagnetic) from the sun, which provides light and heat. The amount of solar radiation in a location depends on many factors, including geographic location, landscape, and weather.

The technology that is currently available either transforms the radiation into electrical energy by solar cells (photovoltaic cells) or into heat energy by CSP (concentrator solar power), which can be used to generate electricity as well by fusing it with steam turbines to do so. The focus will be on photovoltaic systems in this paper.

3.1 Photovoltaic definition.

Photovoltaic is the technology that converts light from the sun into electricity by generating (DC) electrical power expressed in Watts (W) from semiconductors. As long as the sun shines and the light or radiation is observed by the solar cell, which is the name of individual PV elements, the DC current is flowing out of the cell, leading to the generation of power, and when the light stops or the sunsets, electricity stops (Luque and Hegedus, 2003).

3.2 Historical overview.

At the beginning of the 19th century, the photovoltaic phenomenon was discovered by a French physicist called Alexander Becquerel. In 1839, he detected this phenomenon, "the conversion of light into electricity." The function of solar cells is based on this phenomenon. Nikola Tesla and Albert Einstein were among the scientists who participated in the development of photovoltaic phenomena through their research in the following years (Čotar and Filčić, 2012).

Due to high manufacturing costs, major advancements in photovoltaic technology began concurrently with the rise of the semiconductor industry at the beginning of the second half of the twentieth century. Solar cells were used to power orbiting satellites around the Earth throughout the 1960s because they proved to be a very reliable technology. Due to the oil crisis in the beginning of the seventies and the improvement in solar cell performance, there was a huge focus on lowering the high costs of its manufacturing. This opened up new avenues for the implementation of this technology. Solar cells were the main source of electricity at various sites far away from the electrical grid, where the electricity was required in order to ensure energy supply to wireless applications, telecommunication equipment, and other low-power electricity-dependent equipment (Čotar and Filčić, 2012).

During the eighties, this technology became accepted and widely used. Well developed countries (USA, Japan, and countries in Europe) have started building up production lines to produce solar cells in order to keep up with the demand and the industry has become more mature. Solar cells are used in lots of devices such as calculators, watches, radios, lamps, and other applications with small batteries (Luque and Hegedus, 2003).

Furthermore, with the significant development in this technology, the main reason was to use solar cells for commercials. The independent system and connected systems were developed in the meantime. Even more, there was a focus on electricity provided in rural areas where electricity networks and infrastructure have not been developed in order to allow some applications to work, such as pumping water, cooling systems, and telecommunications (Čotar and Filčić, 2012).

In the last two decades, this technology and its market have tremendously grown as the developed countries are trying to meet 2030's renewable energy objectives. They are trying to reduce the dependency on nuclear power after the Chernobyl disaster (Ukraine) in 1986 and the Fukushima disaster (Japan) in 2011. Furthermore, they are trying to reduce CO2 emissions globally.

In fact, countries have implemented a legislative framework for the production of green energy and have motivated private sectors (power plant owners) as well as their populations (consumers) to be integrated into this system by securing subsidies for the energy produced by green technologies. The equipment has a growth rate of 40% per year for photovoltaic technology and it is noticeably one of the fastest rising technologies. In point of fact, by the year of 2010, the installed power capacity by this technology has surpassed the staggering milestone of 17.5 GW (Čotar and Filčić, 2012).

3.3 Photovoltaic cell Technologies.

The main factor in comparison between alternative power generation technologies is determined by the cost of energy provided per kilowatt-hour. In PV power, there are to main factors that determined the cost.

1. PV energy conversion efficiency.
2. The cost per watt of power generated.

Both factors indicate how the electricity provided by PV system economically valuable (Patel, 2006).

The conversion efficiency of the PV cell is defined as follows:

$$\eta = \frac{\mathrm{Voc} \times \mathrm{Isc} \times \mathrm{FF}}{\mathrm{Pin}}$$

Where:

Voc is the open-circuit voltage;

Isc is the short-circuit current;

FF is the fill factor and

η is the efficiency.

The input power for efficiency calculations is 1 kW/m2

The main objective of PV cells development is to moderate the cost of commercial solar cells by improving their conversion efficiency and increasing their other performance parameters. The other objective is to increase the earnings of PV cells production lines and simultaneously reducing the energy demanded for its manufacturing process and its cost, also reducing both impurities and defects. This only could be reached by expansion our understanding of how PV technologies works.

The improvement in producing an efficient low-cost and affordable cells have led to various forms of PV technologies which is available in present market regarding to the efficiency conversion and module cost. The following sections provide an overview of the most common types (Patel, 2006).

3.4 Single-crystalline silicon.

Single-crystal silicon also known as mono-crystalline cell, is being recognized not only as the best accessible raw material for cells industry but the most commercially used as well in present time. The energy conversion efficiency of this type varies between 14% and 18% and in a good weather condition with clear sky, a 1square meter surface of this type of cell is capable to convert solar radiation of 1000 W/m2 to 140 W (Čotar and Filčić, 2012). In its manufacturing process, a pure semiconductor material is needed. In order to reach this purity, first the silicon need to be melted, then a crystal has to be placed in this liquid silicon and slowly drawn. The outcome of this process is a solid single-crystal bars. This type of process is in reality slow with high energy demand which means high cost materials estimated between 20$ and 25$ per pound. Each bar is sliced into smaller wafers with diamond saw, their thickness varies from 200 to 400 µm. After that, the wafers needs to slice again into rectangular shape in order to make the most number of cells that can be joined together on rectangular panel. The wafers are sliced into another shape which is a square shape cell but nearly half of the silicon bar is wasted and In order to reduce this waste, the cell is formed from the hall silicon bar. Growing crystals on ribbons is another approach to save waste. Some producers are using laser beam to cut the wafers and minimize the waste.

This type of production has led the capability of use to a much higher level, thus the estimated life time of the cells is between 20 to 30 years nevertheless considering the level of degradation during their operations over the years (Čotar and Filčić, 2012).

Figure 4 shows a solar panel which was constructed from mono-crystalline silicon cell.

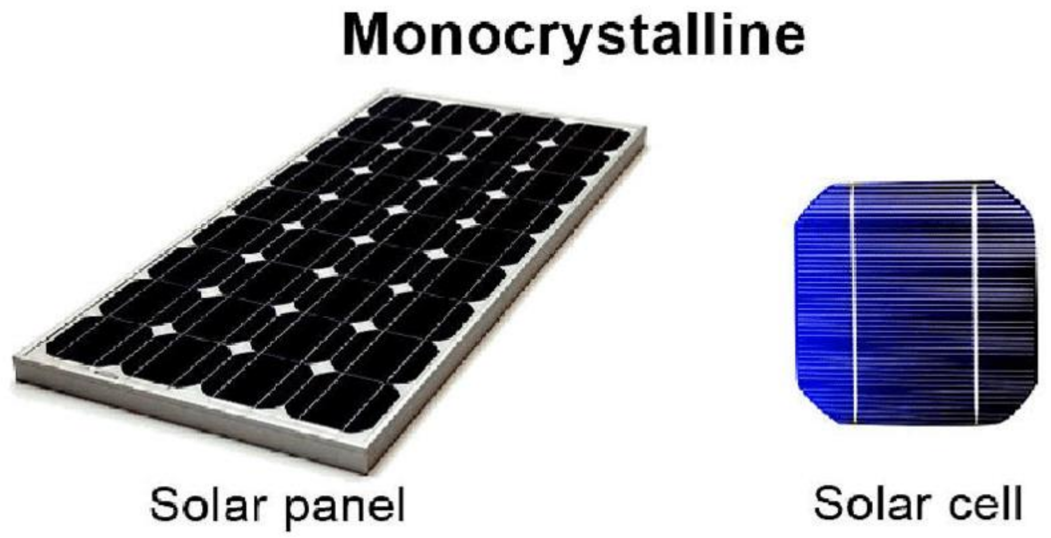


Figure 4: solar panel constructed from mono-crystalline cell (learn4electrical.altervista.org, 2022).

3.4.1 Polycrystalline and semi-crystalline silicon.

It is known as multi-crystalline cell as well. The way of manufacturing these types of crystalline cells is relatively fast and more efficient compared to mono-crystalline from economic point of view, which means higher profits as a results of low cost and less time required. The silicon needs to be purified first by molten it into liquid and instead of drawing single crystals, molten silicon formed into slabs and solidified, the outcome of this process is a multi-size of multiple-crystals whose boundaries may been imperfect and that lead to a lower conversion efficiency but it gives a lower cost of power per watt. The energy conversion efficiency of this type varies between 10% and 14% and in a good weather condition with clear sky, a 1square meter surface of this type of cell is capable to convert solar radiation of 1000 W/m2 to 130 W. It comes in both thick and thin-film cells and become a leading brand in the market with commercial usage. The estimated life-span is between 20 and 25 years W (Čotar and Filčić, 2012). Figure 5 shows solar panel constructed from polycrystalline silicon cell.

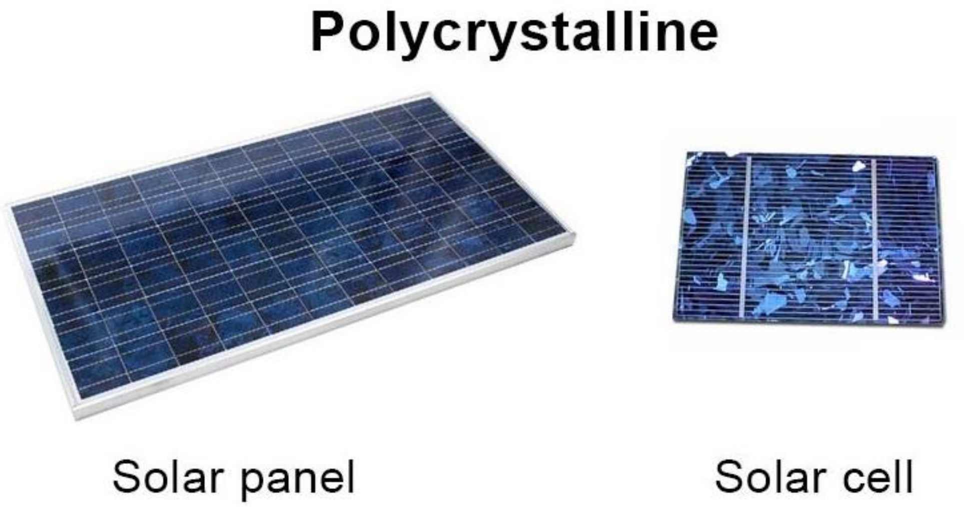


Figure 5: solar panel constructed from polycrystalline cell.

3.4.2 Thin-film cell.

In the last two decades, new types of technologies in terms of modules manufacturing have arrived into the market. Copper indium (CIS), cadmium telluride (CDTE), and gallium arsenide (GAS) are all thin-film materials. The module is manufactured by depositing a very thin layers of the above mentioned materials on a low-cost substrate such as glass, plastic, stainless steel and ceramic or any other valuable and compatible substrate material in the near future. This type of technology has reduced the cells production costs as much less material is needed to cover a square area of cell but in the opposite direction, they have a lower energy conversion compare to crystalline silicon which range from 5% to 13%.

- Copper indium (CIS) as shown in figure 6:

National renewable energy laboratory (NREL) has started the developing of an efficient and lower cost CIS cells, their aim was to reach an economical manufacturing process and maintaining their high performance at the same time. In fact, they (NREL) have reached a CIS sell efficiency of 18% in 2004, at that time this was a huge achievement and they called a world record.

This number has improved during the following years and has been estimated at 20%. A 1square meter surface of this type of cell is capable to convert solar radiation of 1000 W/m2 to 160 W inside laboratory conditions (Čotar and Filčić, 2012).

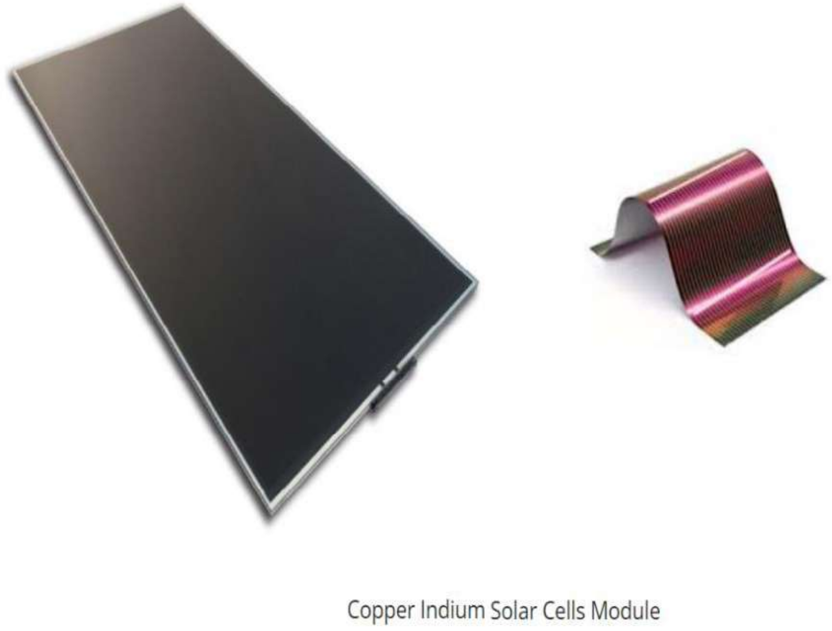


Figure 6: Copper indium (CIS) cell (www.solarfeeds.com, 2022).

- Cadmium telluride (CDTE) as shown in figure 7:

Cadmium telluride is a mixture of metal between cadmium and tellurium semimetal and it seems to be a very promising material to use in this technology due to its physical properties. The efficiency of this type of module is around 18%, in fact, a 1square meter surface of this type of cell is capable to convert solar radiation of 1000 W/m2 to 160 W inside laboratory conditions (Čotar and Filčić, 2012). Unfortunately, this module is not commonly used nowadays because of the toxicity in cadmium which can causes cancer.

The total share of thin-film cells in the market is around 15% and it keeps increasing. Due to the innovations and developments of other thin-film materials, this increment is expected to continue as there will be much more compatible materials in the market with less effects on human's health and our environment, the Lifespan is around 15-20 years (Čotar and Filčić, 2012).

Figure 7: Cadmium telluride (CDTE) cell (www.justdial.com, 2022).

3.4.3 Amorphous silicon.

When a thin layer of silicon placed on glass or any other cheap substrate then it called amorphous cell as shown in figure 8. This type of cell could be placed in the thin-film cells group but the used material is silicon. The way of manufacturing this type of cell is to place a very thin layer of silicon in the range of 1-2 µm on glass or stainless-steel roll or other substrate. By comparing this technology to crystalline silicon technology, the material used in this type is around 1%, therefore the cost of production is fairly low and it offer a significantly lower cost of energy per watt. However, the conversion energy efficiency of this type is relatively low and it is almost around 6% (more or less the half efficiency of crystalline silicon technology) but the development in this technology had seen lots of progress and it focuses on stabilizing the module efficiency by improving the depositing techniques, balancing photon utilization by lowering band gaps in materials and developing low-temperature epitaxy. The efficiency is expected to reach a higher level in the near future. The efficiency of this type of module is low as mentioned above.in fact, a 1square meter surface of this type of cell is capable to convert solar radiation of 1000 W/m2 to 50 W, and therefore it is mainly used in low power equipment such as watches (Čotar and Filčić, 2012).

Figure 8: amorphous panel (wikimedia.org, 2022).

Table 1 shows a comparison of Amorphous Silicon and other crystalline silicon technologies.

Table 1: Comparison of Crystalline and Amorphous Silicon Technologies.

	Crystalline Silicon	**Amorphous Silicon**
Present Status.	Workhorse of terrestrial and space applications	New rapidly developing technology, tens of MW of yearly production facilities were commissioned in 1996 to produce low-cost cells.
Thickness	200-400 µm (0.004–0.008 in.)	2 µm (less than 1% of that in crystalline silicon).
Raw Material.	High	About 3% of that in crystalline silicon.

Module costs (2004).	$3–5 per watt, expected to fall slowly due to the maturation of this technology.	$3–5 per watt, expected to fall rapidly to $2 per watt due to substantial DOE funding to fully develop this new technology.

3.4.4 Spheral cell.

It is another technology which has been discovered inside labs by using a low grade silicon crystalline beads as raw material. The manufacturing process is done by placing the beads on a thin layers of perforated aluminum. During the manufacturing process, all impurities which occur are pressed out to the surface in order to be properly disposed. Because each sphere functions separately, a single sphere failure has a minor impact on the bulk surfaces of overall performances. It was found that a 100-ft2 spherical panel could generate 2000 kWh per year in an average Southern California climate by the US Company Southern California Edison Company. Figure 9 shows spheral cell.

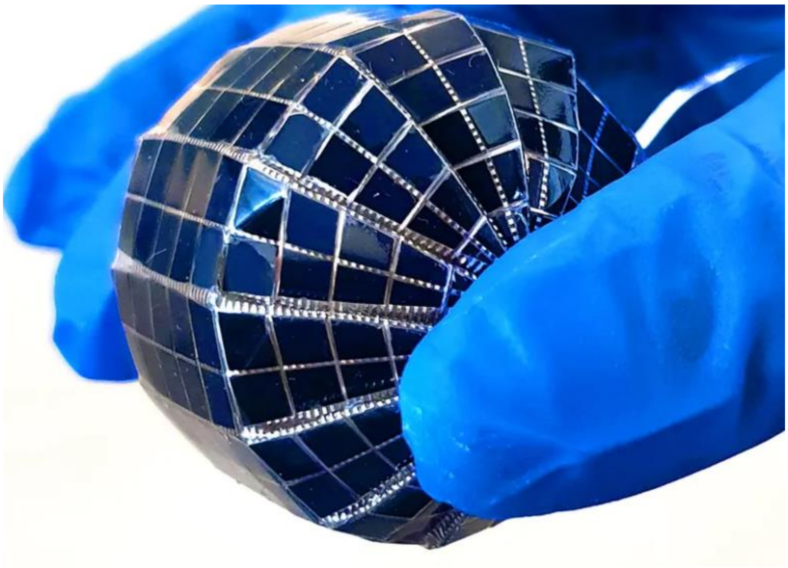


Figure 9: Spheral cell (spectrum.ieee.org, 2022).

3.4.5 Concentrator cell.

It is known as Concentrator PV (CPV). Many developer around the world are making lots of effort in order to reach a high conversion efficiency in this industry. In this electricity technology generation made directly form sunlight by focus it into a relatively small and high efficient solar cell (multi-junction cell) using low cost lenses or curved mirrors. Figure 10 shows the difference between CPV technology and the regular cell.

The result of using such technique is a high intensity sunlight dropped into the cell causes high amount of heat. Therefore a cooling system needs to be installed to reduce it and protect other system components. The main advantage of this technology is the amount of cell area that used, it needs a smaller area (small active cell area) than normal cell for similar power output. In addition to reduce the size of cell and increase the power output, the conversion efficiency increases under high intense lights and much easier to reach high levels with smaller size cells than normal type. In fact, some producer has already reached a 37% efficiency cells in their development in space application industry.

Furthermore, the researchers are still ongoing in order to increases the capability of using this technology in utility sector and in areas with high insolation. High concentration PV systems (HCPV) have a remarkable chance to become a dominant technology in energy sector, they hold much higher efficiency than other existing PV technologies with lower cost system components By the mid-2020s, the International Energy Agency predicts that commercial HCPV systems would have instantaneous efficiencies of up to 42% under conventional test settings with concentration levels of 400 or higher (El Bassam, 2021).

The efficiency of this technology has already surpassed 33% in outdoor normal conditions and some of the installations are currently running in different countries such as China, United States and some parts of Europe. In the present time, concentration PV is competing concentrated solar power (CSP) as they are both suitable for regions with high direct normal irradiance. There is a discrepancy between these technologies, the deference between the two technologies is that CPV generate electricity directly form sunlight while CSP uses heat that generates form the sun's radiation to produce steam which runs a turbine that connected to a generator then produces electricity. Until 2012, CSP possess a much higher level of the share market in this sector than CPV (El Bassam, 2021).

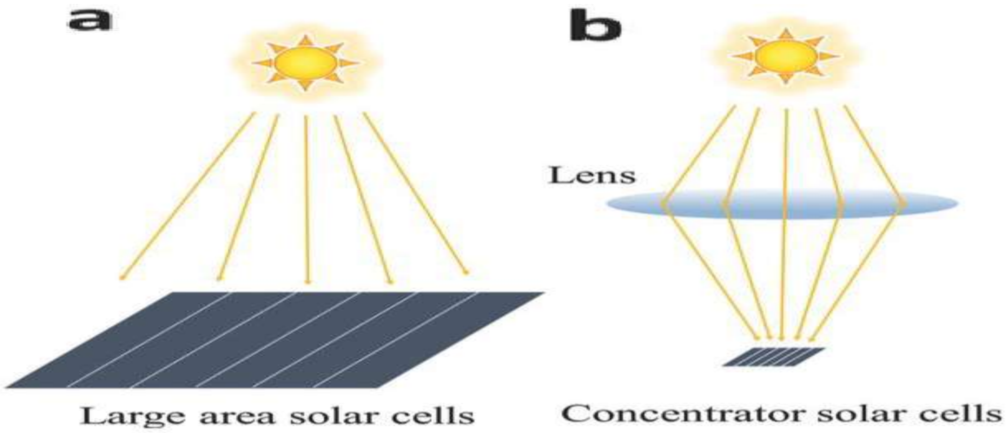


Figure 10: a- regular cell mechanism. b- Concentrated PV mechanism.

3.4.6 Multi-junction cell.

Only red and infrared light, but not blue or ultraviolet, are converted into electricity by the single-junction n-on-p silicon cell. When the energy level of the light matches the energy level of the semiconductor, which is known as the band gap, the PV cell transforms light into electricity most efficiently. In multi-junction cells, layering several semiconductors with a wide range of band gaps in order to converts more light energy levels (wavelengths) into electricity. Two or more cells are stacked on top of each other to accomplish this, the top cell has the largest band gap in order to absorb and convert short wavelength (blue) light while The bottom cell has the lowest band gap, allowing it to absorb long wavelength (red and near infrared) light. Converting a wide range of sunlight into electricity by this type of cell has been the key for increasing the conversion energy efficiency. In 2000, national renewable energy laboratory (NERL) in cooperation with NASA have developed dual-junction solar cell for space power systems and that led to the foundation of triple-junction solar cell which has reached 34% efficiency under concentrated sunlight.

3.5 Energy depreciation of photovoltaic cells.

The energy depreciation of photovoltaic cells refers to the amount of time it takes for the energy gained from utilizing a PV system to equal the amount of energy lost during its construction and eventual breakdown.

Of course, the energy depreciation period varies depending on the location of the system for instance, in areas with a lot of irradiated solar energy, it can be up to 10 times shorter than the lifetime of the system (Čotar and Filčić, 2012).

3.6 PV systems.

Because solar generators are made up of photovoltaic modules, energy supply systems can be designed for a very wide power range. The power spectrum extends from a few mill watts for watches or calculators to kilowatt systems in remote area power supplies, such as street lights or water pumps, to megawatt-scale central photovoltaic (PV) power facilities. The fundamental construction components are PV modules, which may be structured into arrays in order to increase electric energy generation.

There are two major types of photovoltaic (PV) systems:

3.6.1 Stand-alone systems (off-Grid).

In these systems, the electric distribution grid is not accessible. The most common system configuration is shown in Figure 11. The system shown in Figure 11 is one of the most complicated since it has all of the components required to power AC equipment in a typical house or apartment. System components will vary depending on the type of load they are being used to handle. If the PV modules are to supply exclusively DC loads, an inverter could be omitted or substituted by a DC to DC converter. When other means of energy storage are employed if operation schedules are unimportant, it is also possible to connect a PV array directly to a DC load.

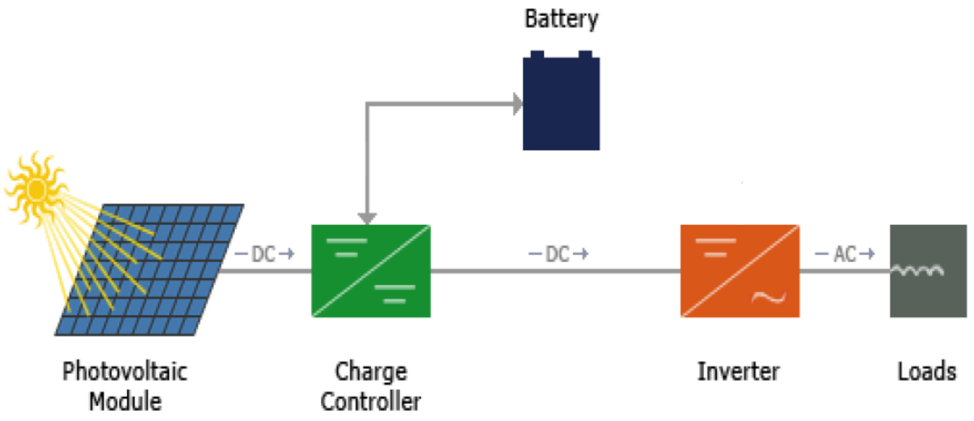


Figure 11: Stand-Alone Photovoltaic System (basic solar PV system types, 2015).

3.6.2 Grid-Tied systems (on-Grid).

These systems are directly connected to the electric distribution grid and hence do not need battery storage. Figure 12 illustrates the system's fundamental configuration. This mode of operation requires an inverter to convert DC currents to AC currents, based on the local energy load variation and the solar resource change during the day. Electricity is either sold or purchased from the local electric utility. There are numerous advantages to employing grid-connected PV systems as opposed to the conventional stand-alone systems. These advantages are:

1. Smaller PV arrays can consistently deliver the same amount of power as larger ones.
2. Less balance of system components is required.
3. It is possible to achieve comparable emission reductions by utilizing existing infrastructure.
4. Energy storage and battery replacement and recycling expenditures for individual customers are no longer necessary.
5. Effective utilization of available energy Contributes to the necessary electrical grid generation when the client's demand is lower than the PV output.

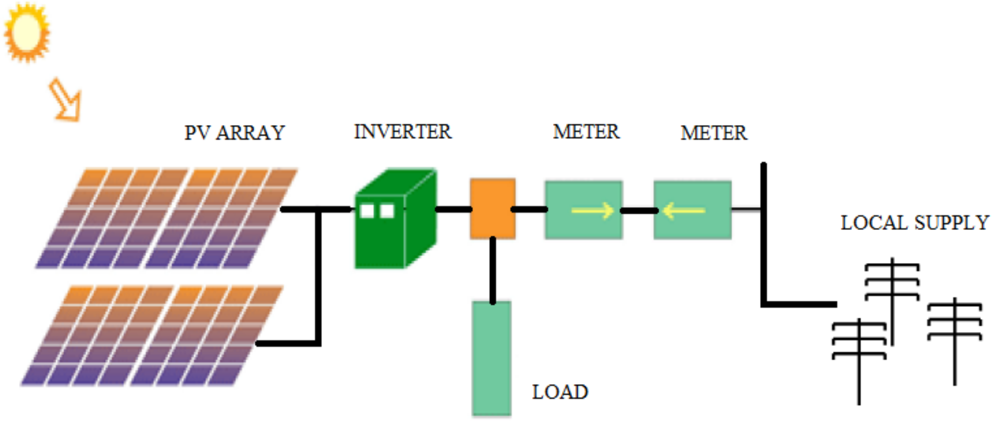


Figure 12: Grid-Tied Photovoltaic System (basic solar PV system types, 2015).

3.6.3 PV power plant (Farms).

Photovoltaic installations on a localized area as shown in Figure 13 produce a great amount of electricity for these systems, which are also connected to the network. There are several hundred kilowatts of photovoltaic power generated and available, and it has lately reached several hundred megawatts. It's not uncommon for these installations to be situated on major industrial sites and terminals. Using existing infrastructure to generate electricity, these large-scale projects help to meet a portion of the region's electricity needs.

A large-scale solar farm in Germany's former military airfield serves as a good example of how enormous solar farms may be. 40 MWp, thin film technology, 110 hectares of surface area (equal to 200 football stadiums), 40 million kWh of annual electricity output, 25.000 metric tons of CO2 reduction, and a price tag of 130 million euros (Čotar and Filčić, 2012).

Figure 13: PV farm in India (www.constructionworld.in, 2022).

A list of the PV system's individual components, along with a brief description of each, is provided below.

3.6.3.1 Photovoltaic (PV) Modules.

The photovoltaic cell is the fundamental component of a photovoltaic module, which is a collection of solar cells electrically coupled to one another and fixed on a support structure that may convert solar radiation into electricity. A typical photovoltaic module is made up of a series circuit of cells that are enclosed in a glass and plastic casing for the purpose of providing protection from the outside elements as shown in Figure 14. Modules are intended to provide power at certain DC voltages, such as 12, 24, or 48 volts. The produced current is directly proportional to the amount of light striking the module. Multiple modules may be interconnected to create an array. A module or array with a bigger surface area will generate more electricity. PV modules are rated based on the power generated under Standard Testing Conditions (STC) of 1 kW/m2 of sunlight and 25 degrees Celsius (°C) PV cell temperature. Their measured output under STC is expressed as "peak Watt" or Wp nominal capacity (Government of Canada, 2003). Even though PV modules are warranted for 10 to 25 years of power output, they can be expected to deliver 40 to 50 years of energy (voltage and current) with much higher operation and maintenance costs (Wiles, 2010). The product's maker typically provides the following kinds of electrical data:

1. Polarity of the output terminals is an important consideration.
2. For module protection, the maximum series fuse should be used.
3. Open-circuit voltage rated at.
4. Voltage at which a module can operate at its maximum efficiency.
5. The maximum allowable current in a given environment.
6. Rated short circuit current.
7. Rated maximum power.
8. Rated system voltage.

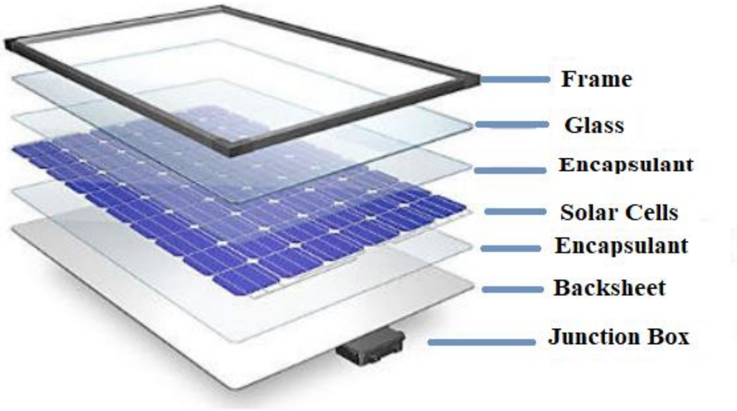


Figure 14: PV module structure (www.researchgate.net, 2019).

3.6.3.2 **Inverters**.

Figure 15 depicts an inverter, an electronic solid-state device used to convert DC electricity into AC electricity. An inverter as basic as the one shown in Figure 16 can be constructed. The manufacturer can use MOSFETs, IGBTs or bipolar transistors as ideal switches in the circuit (depending on the power and voltage requirements). Figure 17 shows how a square wave voltage can be generated if the switches are cycled on and off at the desired AC frequency (S1&S3 and S2&S4). No load voltage can be controlled, and excessive harmonic currents and voltages are generated as a result. Harmonic distortion can be reduced and load voltage can be controlled using high-frequency pulse width modulation. Overheating in motor loads can be caused by harmonic content because of greater copper losses and uneven magnetic fields that affect overall operation. Shockingly unpredictable behavior is also possible in sensitive electrical loads. Accurate AC can now be produced using advanced control techniques and imaginative topologies; three-phase systems are also possible by including additional switches.

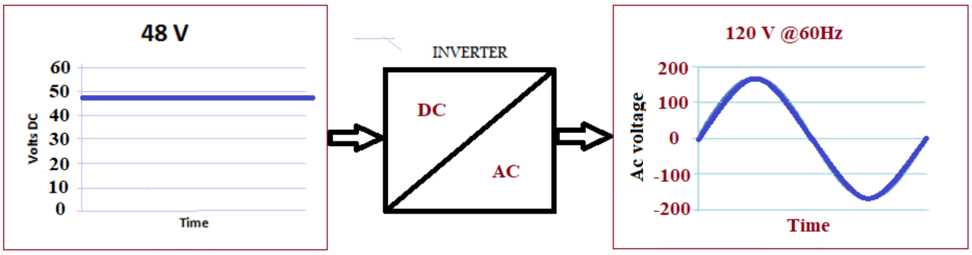


Figure 15: DC to AC conversion through Inverter.

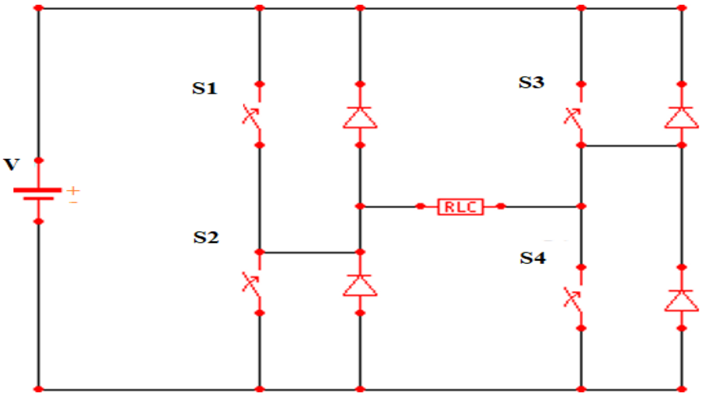


Figure 16: Circuit Diagram of an Inverter.

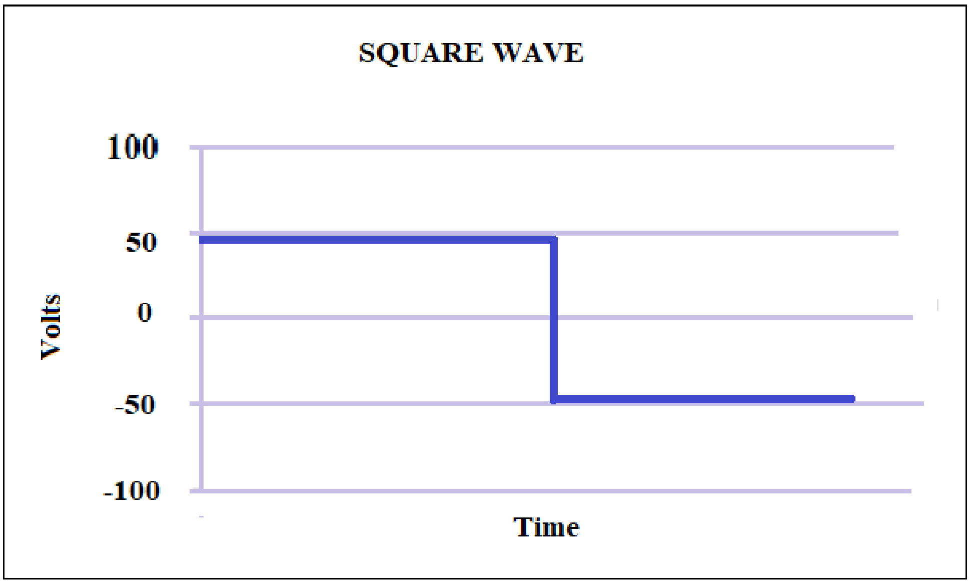


Figure 17: Square Wave Voltage.

Because of the wide range of uses for inverters, design criteria tend to be tailored to meet the individual needs of each industry. In order to meet the needs of the relatively new solar sector, an entirely new industry has emerged around the need for an appropriate inverter, with both large and small producers joining the market. DC outputs from PV modules are influenced by a variety of factors, including irradiance, temperature, and the presence of a load. In stand-alone systems, Inverters functioning with energy storage or batteries require a modest DC voltage operating range to accommodate voltage changes caused by the battery's state of charge, as well as surge capacity for safe, uninterrupted operation during transient events. The operational requirements for Grid-Tied inverters differ significantly from those of stand-alone inverters since they are connected to the electric distribution network. Most grid-connected applications do not take energy storage into account, however it could be an alternative if the owner has dependability requirements. The maximum power point tracker (MPPT), inverter, galvanic isolation (optional), and protection and control features) can all be classified as part of the power conditioning equipment. A frequent practice in the PV industry is to combine these components into one enclosure or unit in order to save manufacture and installation costs; thus, it has been referred to as the "inverter."

Grid-connected PV systems are frequently said to be only as good as their coupling between the DC and AC power sectors. For example, even the greatest solar modules in the industry will be ineffective if the electricity is not converted effectively and safely to usable levels at the load side. Allowing the integration of distribution power generation systems that could affect the quality of electric power in the distribution network is pointless for utilities. The following components are essential for effective inverter systems:

3.6.3.3 Maximum Power Point Tracker (MPPT).

Due to the fluctuating nature of the sun's irradiance, the PV array will never provide constant nominal voltage and current conditions. Figure 18 shows the I-V curves for a PV module under various operating conditions. MPPT is able to guaranties that the PV modules will always provide the maximum amount of power possible, regardless of the operating conditions. There are a variety of MPPT control algorithms available, some of which are capable of controlling over 98 % of the PV array's output capacity. P&O, the most widely used algorithm, works by gradually increasing or decreasing voltage and then monitoring the power output until a maximum power point is reached (Esram and Chapman, 2007).

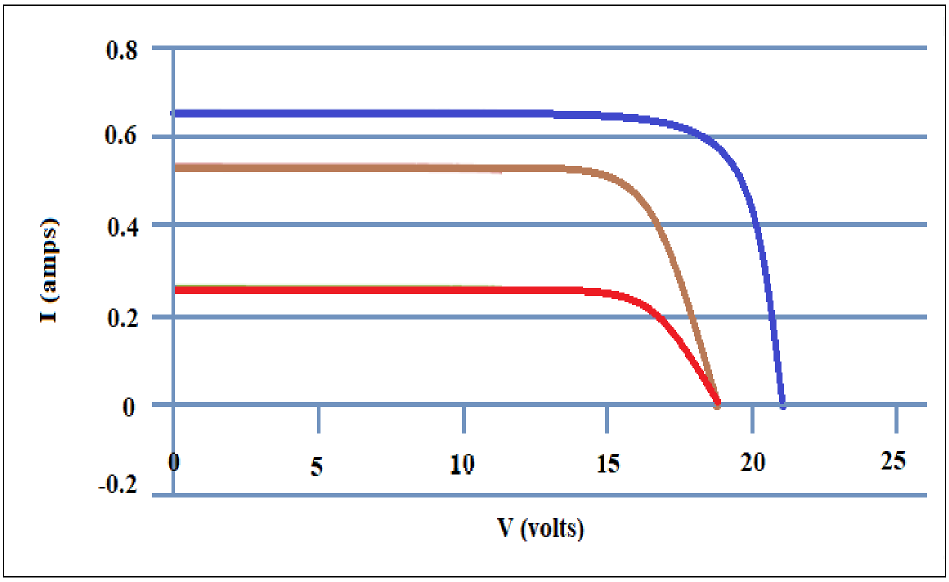


Figure 18: I-V Curves for a PV Module.

3.6.3.4 Inverter.

Inverters as mentioned before have the task of DC/AC conversion. Grid-tied inverters can be divided into two broad kinds. A line-commutated inverter which gets its switching signals straight from the grid's currents. Harmonic currents are generated by the low switching frequencies and must be filtered out. For small single-phase inverters, bulky and expensive filtering networks are impractical. A multi-phase isolation transformer at the utility output could be used to connect numerous big three-phase inverters to filter any unwanted currents; the transformers should be qualified to resist additional heating due to harmonic current copper losses (IEEE, 2003). Self-commutated inverters, which use internal control units to monitor grid conditions, such as frequency and voltage, to determine their switching frequencies. There are two types of self-commutated inverters: voltage-source and current-source.

3.6.3.5 Voltage and Frequency Synchronization.

When the utility grid's voltage and frequency fluctuate normally, inverters shouldn't have any issues working. Devices that constantly monitor the grid voltage and frequency must be included in controllers. Tolerable ranges have been determined for these and the unit should trip within an appropriate period of time while allowing the inverter to operate through short-term voltage fluctuations. The current injected by an inverter must be in phase with the voltage supplied by the utility.

3.6.3.6 Islanding Protection.

The term "islanding" refers to a situation in which a DG continues to supply power to a distribution network that would otherwise be de-energized (e.g., breaker opening because of a fault). Islanding poses a risk to utility employees, who may be unaware that a circuit is still energized. DG's have been determined to have a very low probability of continuing to operate, especially for home grid-tied PV systems that are unable to do load-following in the event of an outage. However, islanding is a safety element in the event of a load balance. All distributed generation that is connected to the grid must have islanding protection (Saleh et al., 2016).

3.6.3.7 Inverter Reaction to Faults.

Inverters operate using solid-state technology and, unlike generators and motors, have no inertia or significant amounts of energy stored within them, allowing them to respond to faulty situations extremely rapidly. The inverter's response will be determined by what it "sees" as terminal voltage and apparent load impedance during a malfunction. If the detection technique takes longer than expected or simply fails, fault contributions, if any, will still be fairly minor when compared to utility short-circuit currents. The condition will force the device to disconnect because inverters cannot supply currents substantially more than the rated load current. The majority of grid-connected inverters are designed to function on current control. These inverters require the utility voltage as a reference to provide the PV current and cannot operate as an island (Ishikawa, 2002).

3.6.3.8 Power Quality.

Local distribution grids are most concerned with harmonic and DC current injection. Harmonic injection levels can be kept below 5% by most PWM inverters, according to an IEA report (IEA, 2004). Harmonics cannot be totally avoided because of the PWM switching process however high switching frequencies and filtering are utilized at the AC output to minimize total harmonic voltage distortion (THD). When it comes to inverters, flicker isn't a big deal. The inverters will operate as current sources at unity power factor, and reactive power consumption in dwellings isn't very high, so flicker shouldn't be a major concern.

3.6.3.9 DC Isolation (Galvanic Isolation).

There is still a low-frequency transformer present in the output of most three-phase inverters from the early days of inverter design. External transformers may be necessary in specific instances. It is possible to use standard Δ-Y distribution transformers when connecting a three-phase output or a low voltage single-phase isolation transformer with a 1:1 ratio. A typical purpose of transformers in inverter harmonic filtering networks is to prevent possible by-product DC currents from being injected into the distribution network (DC currents may induce saturation of distribution transformers). While maintaining electrical separation, the transformer provides a safe grounding point. However, utility laws no longer mandate the use of an isolation transformer. Designers of inverters have come up with creative solutions to the issues outlined above. The usage of high frequency (HF) transformers incorporated in an internal high frequency converter stage can be done with ease. The isolation provided by line frequency (LF) transformers is provided by these compact, lightweight devices. With a typical line frequency transformer causing roughly 2% loss, the inverter's weight and cost can be significantly reduced. To ground both sides of a full-bridge inverter, specific circuit topologies are required because the ordinary inverter cannot be used as a suitable grid connection. The transformer less designs are more cost-effective, more efficient, and lighter than their traditional counterparts. The silicon content in power electronics has risen dramatically in recent years, compared to the iron content. In most cases, the local utility sets the operating parameters for these sorts of inverters (Wall, 2001).

3.6.3.10 Energy Storage.

In a PV system, the energy generated by PV modules does not necessarily correspond to the energy demand. A PV installation that is not connected to the grid must store that extra energy produced by solar cells. Frequently, electrical storage batteries are used in stand-alone PV systems. The key roles of a PV system's storage battery are as follows (Guinée et al., 2011):

1. Using PV modules to generate electricity, store the energy and supply it to the load as needed.
2. Providing consistent voltages and currents to electrical loads at all times.
3. Provide some electrical loads (mostly motors) with high peak operational currents (starting current).

The energy storage system (mostly batteries) needs an extra device, which called charge controller and it is considered to be a member of the balance of system components. Their primary job is to regulate the amount of electricity flowing from the solar module array to charge the batteries. Even when the battery is fully charged, the majority of these devices will not overcharge it or discharge it below the minimal design charge.

3.6.4 Balance of System Components (BOS).

It's common for BOS components to account for 30–50% of total system expenditures. They're all the extras needed for a proper PV system installation. A BOS's components may include the following:

1. Conductors, Conduits, and Boxes.

2. Overcurrent and ground-fault protection devices.
3. Metering Equipment.
4. Support structure.
5. Charge Controllers.
6. Battery Housings and Enclosures.

3.7 Advantages and disadvantages of PV systems.

Sunlight energy is a typical example of renewable sources of energy generation, with hugs amount of advantages and disadvantage in searching for clean and CO2 free emission society.

These are the most common advantages and benefits:

- A clean and green energy sources

The most prominent and significant advantage of PV technology is clean and CO2 emission free source of energy, there is no fear or worry about any harmful greenhouse gases generating into the air as carbon dioxide.

- Free raw materials or cost free power generating

Another advantage is that you don’t have to pay for additional raw materials. PV cell depend on solar and renewable energy to produce electricity, which is naturally free and unlimited supply.

- Flexibility.

That is PV cells can generate electricity and power anywhere, all it requires is availability of sunlight.

- Cost Reduction and Value for Money.

Cost affordability compared to other sources of power generation method, PV costs much less than other technologies in terms of MWH/$ as well as capital cost.

- Low and Easy To Install & Maintenance.

Solar PV cells are known for their low maintenance and operating cost compared with other renewable and Non -renewable ENERGY system.

- Noise free and silent.

Solar PV is suitable for urban areas and residential application because it doesn't produce and generate huge noise.

Despite the numerous advantages of PV, some factors are remain bottleneck and shortcoming for successfully implements and operating system in our environment. Includes the follow:

- Intermittency issue

Unlike other renewable energy sources, PV technology have intermittency problems. Which means that it's not continuously available for converting into electricity like during night-time, rainy weather .in such condition PV cells will incapable of meeting electric power demand.

- Unreliable power option

Due to unpredictability of sunlight and other natural occurrences factors which the PV cells depends for sources of powers to generate electricity.

- Durability and sustainability

The life-span of PV cells and its required additional cost or fund to maintain and sustain the PV panel from damage and safeguard investment in power generating sector.

- Inadequate and lack of personnel

The PV technology required skill and technical men power for installation, funding the investment and maintenance, therefore adequate provision should provide for training individuals to meet shortages of manpower in industry.

4 PV feasibility in Libya.

This chapter analyzes the practicality of solar power in terms of available sunlight, the cost of operation and maintenance, and the government's stance on renewable power.

4.1 Sunshine hours and radiation in Libya.

Libya as mentioned above is located in North Africa. A large portion of the population is located along the coast and in the immediate hinterland of the country, which is mostly covered by the Sahara desert. Thus, it is an optimum location with a very high potential for PV installation.

In the next two figures, the direct normal irradiation and the PV power potential in the period between 1994 and 2018 will be shown.

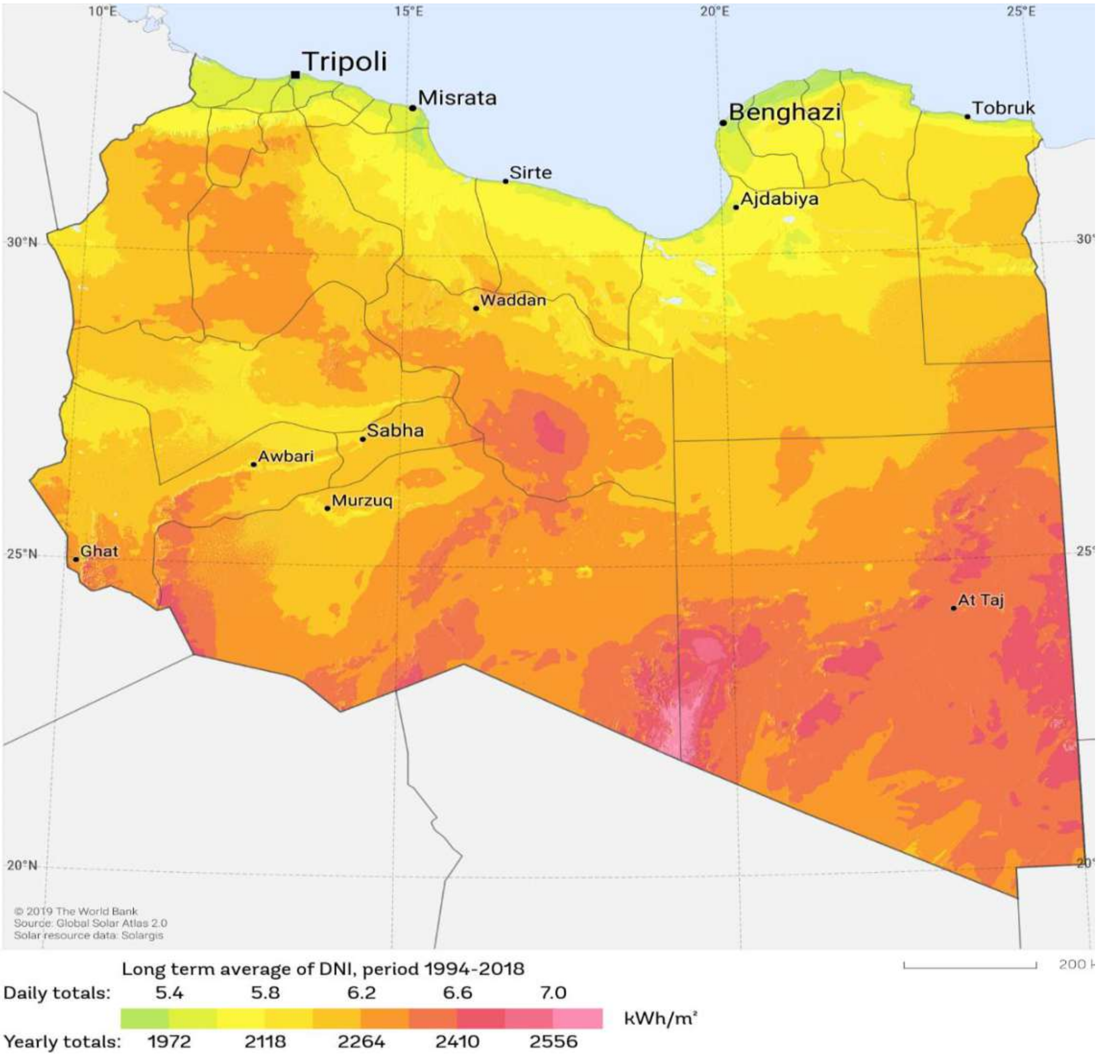
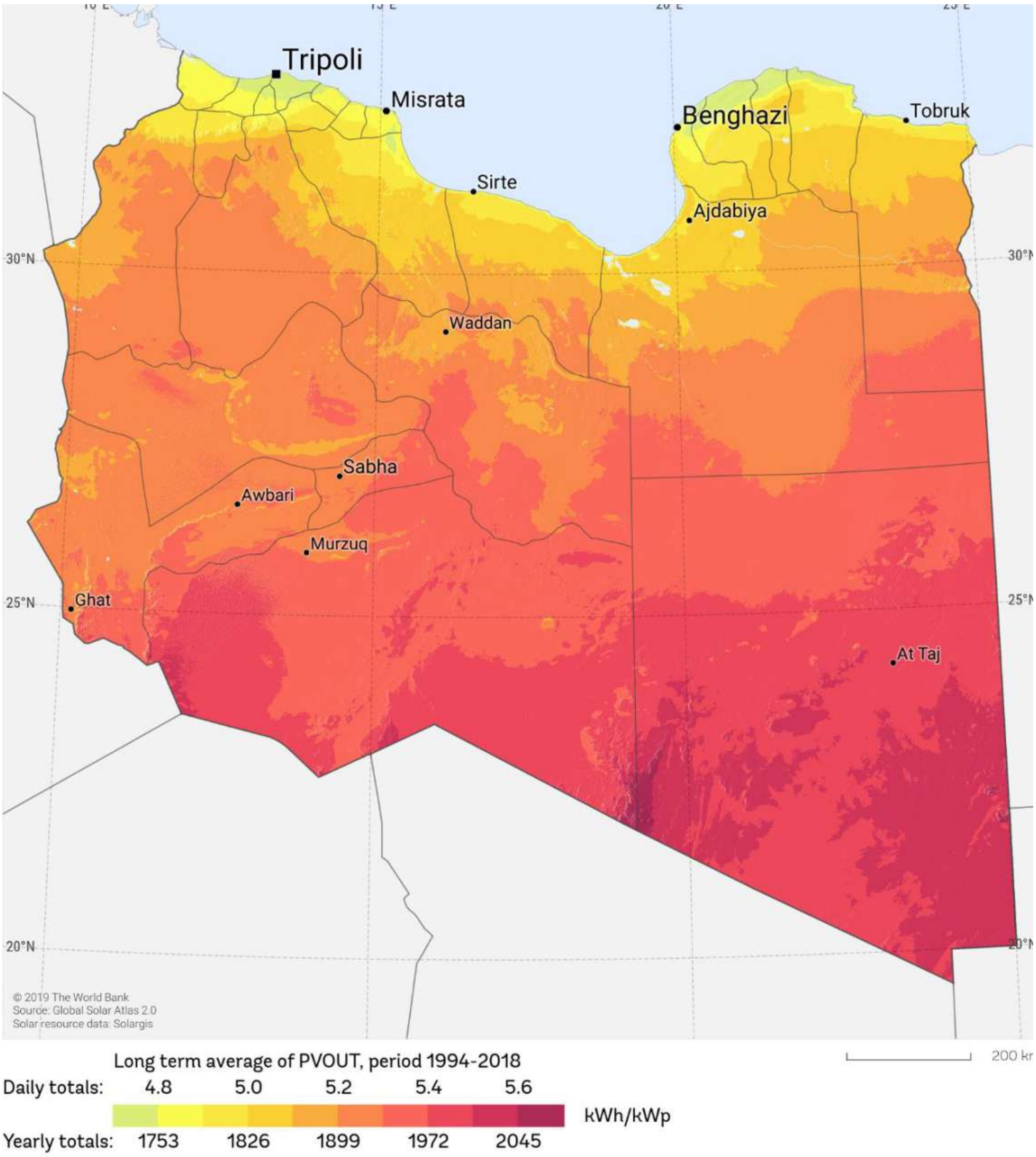


Figure 19: the direct normal irradiation (kwh/m²), period 1994-2018 (Global Solar Atlas, website).



© 2019 The World Bank
Source: Global Solar Atlas 2.0
Solar resource data: Solargis

Figure 20: PV power potential (kwh/kwp), period 1994-2018 (Global Solar Atlas, website).

Three major cities in the country was chosen for date preview in this study. Tripoli, Libya's capital and largest city, having a population of over 1.1 million people in 2019. It is located in northwest Libya, on the outskirts of the desert, on a rocky outcropping jutting into the Mediterranean Sea and forming a bay (Major Urban Areas - Population). Benghazi, located on the Gulf of Sidra in the Mediterranean, is a significant seaport and the country's second-most populated city, as well as the largest city in Cyrenaica, with an anticipated population of 807,250 in 2020 (Population of Libyan Cities 2020 - The Bureau of Statistics and Census Libya). Sabha is a city in southwestern Libya around 640 kilometers (400 miles) south of Tripoli. It was originally the capital of the Fezzan area and the Fezzan-Ghadames Military Territory, and it is presently the capital of the Sabha District (Malcolm and Losleben, 2004).

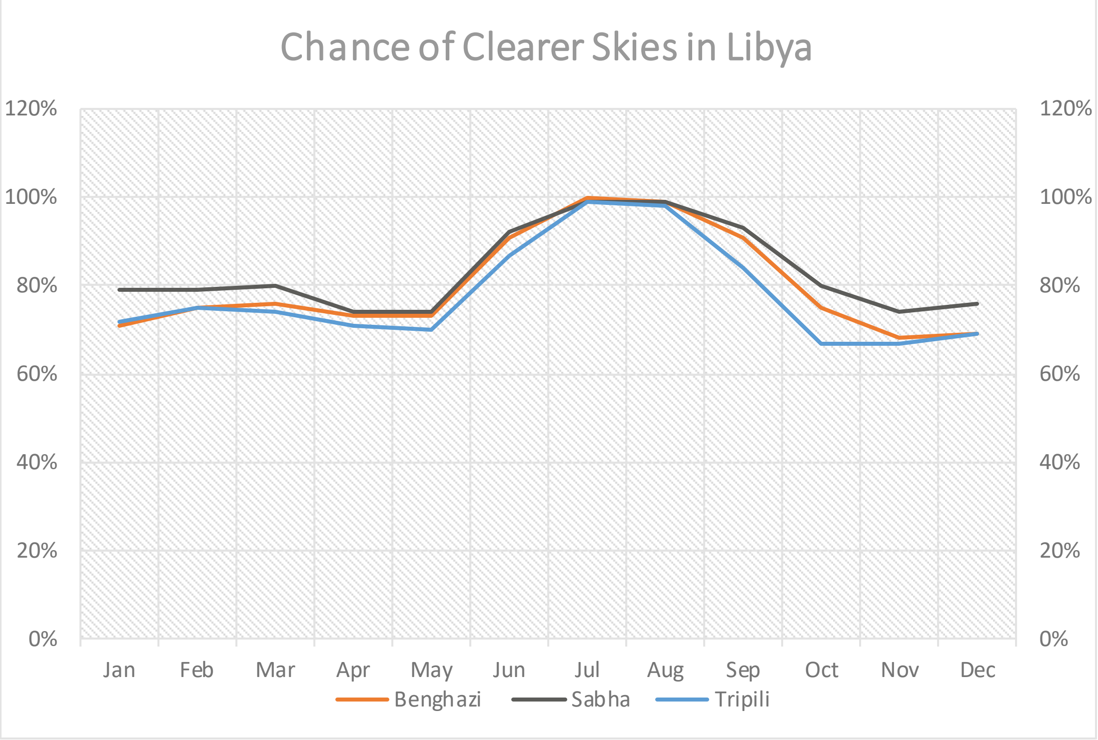


Figure 21: Percentage chance of clearer skies in Libya (weatherspark.com).

Table 2: The percentage of time the sky is clear (weatherspark.com).

Months	Tripoli	Benghazi	Sabhā
January	72%	71%	79%
February	75%	75%	79%
Mars	74%	76%	80%
April	71%	73%	74%
May	70%	73%	74%
June	87%	91%	92%
July	99%	100%	99%

August	98%	99%	99%
September	84%	91%	93%
October	67%	75%	80%
November	67%	68%	74%
December	69%	69%	76%

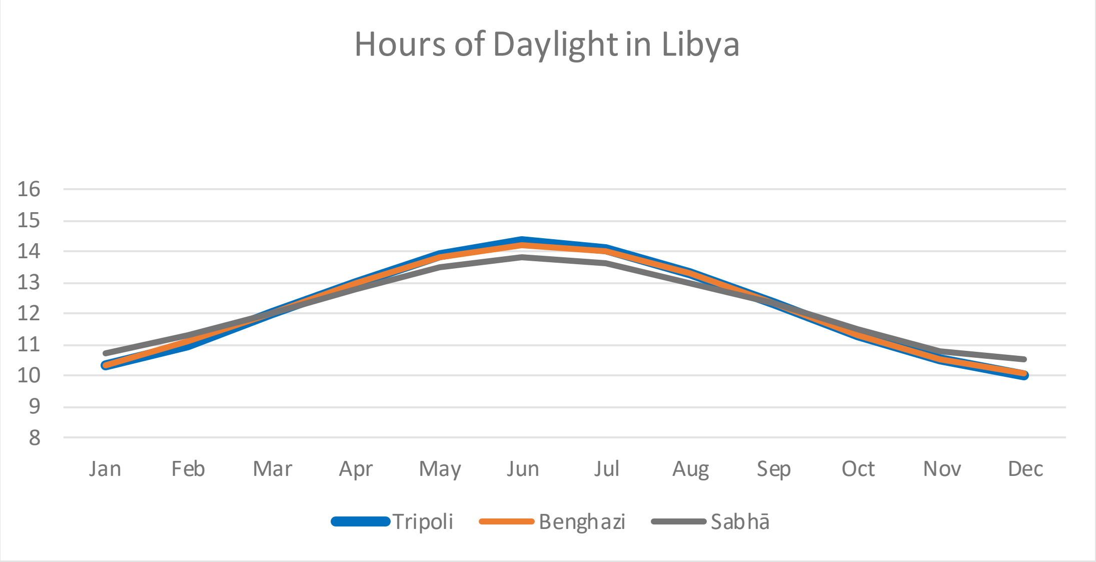


Figure 22Libyan sunshine hours (weatherspark.com).

Table 3: The number of hours during which the Sun is at least partly above the horizon (weatherspark.com).

Months	Tripoli	Benghazi	Sabhā
January	10.3h	10.3h	10.7
February	11.0h	11.1h	11.3h
Mars	12.0h	12.0h	12.0h
April	13.0h	13.0h	12.8h
May	13.9h	13.8h	13.5h
June	14.3h	14.2h	13.8h
July	14.1h	14.0h	13.6h
August	13.3h	13.3h	13.0h

September	12.3h	12.3h	12.3h
October	11.3h	11.3h	11.5h
November	10.5h	10.5h	10.8h
December	10.0h	10.1h	10.5h

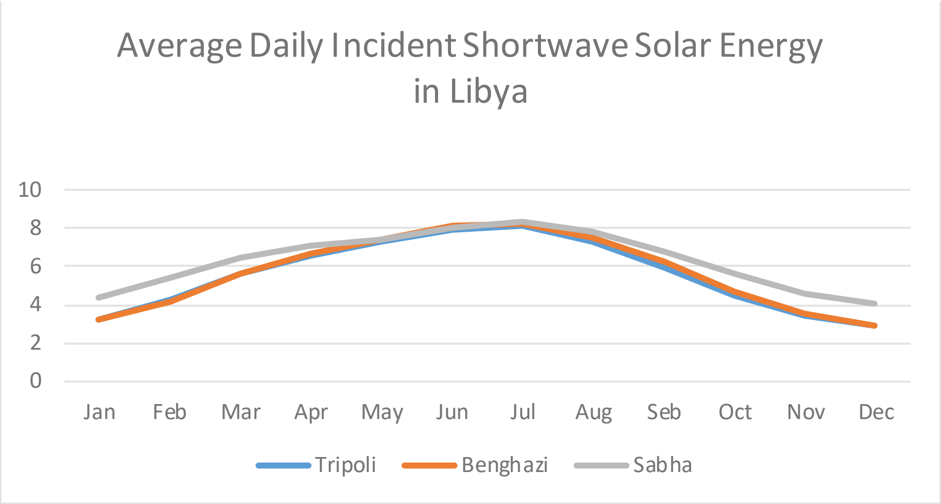


Figure 23: Libya's average daily incident of shortwave solar energy kWh/ m² (weatherspark.com).

Table 4: The average daily shortwave solar energy reaching the ground per square meter kWh/ m² (weatherspark.com).

Months	Tripoli	Benghazi	Sabhā
January	3.2 kWh/ m²	3.2 kWh/ m²	4.4 kWh/ m²
February	4.3 kWh/ m²	4.2 kWh/ m²	5.4 kWh/ m²
Mars	5.6 kWh/ m²	5.6 kWh/ m²	6.5 kWh/ m²
April	6.6 kWh/ m²	6.7 kWh/ m²	7.1 kWh/ m²
May	7.3 kWh/ m²	7.4 kWh/ m²	7.4 kWh/ m²
June	7.9 kWh/ m²	8.1 kWh/ m²	8.0 kWh/ m²
July	8.1 kWh/ m²	8.2 kWh/ m²	8.3 kWh/ m²

August	7.3 kWh/ m^2	7.5 kWh/ m^2	7.8 kWh/ m^2
September	5.9 kWh/ m^2	6.2 kWh/ m^2	6.8 kWh/ m^2
October	4.5 kWh/ m^2	4.7 kWh/ m^2	5.6 kWh/ m^2
November	3.4 kWh/ m^2	3.5 kWh/ m^2	4.6 kWh/ m^2
December	2.9 kWh/ m^2	2.9 kWh/ m^2	4.1 kWh/ m^2

4.2 PV initial and maintenance costs.

Definition of cost: in accounting or finance, cost is relative monetary value of expenditures for raw materials, equipment's, supplies, services, labor, products and others forms of expenses incur in production, distribution and exchange of services.

Photovoltaic (PV) systems are a significant financial commitment that will have an impact on the long-term viability of the PV industry. A solar system purchase is analogous to buying new gear in that prospective buyers research numerous models, choices, and costs before settling on a final choice. PV solar systems are a good option if you want to get the most bang for your buck by balancing performance and cost. When contemplating a photovoltaic (PV) solar power system, prospective investors should thoroughly assess multiple estimates or project ideas. PV solar proposal evaluation can feel like comparing apples and oranges because of the many variables and assumptions that go into developing a proposal. Combining the total system cost with various savings, tax credit, loans, financial grant and subsidiary with further distant the actual investment. Also, the cost format and bulleting will help the investors, installers and readers to understand the major components of photovoltaic solar technology including initial capital cost, operational and maintenance cost.

- INITIALS CAPITAL COST

Initial or direct capital costs are those expenses and expenditures that associated with the PV solar technology and clearly assigned to a specific piece of equipment or components related to installing that involved in the project. Capital expenses, also known as starting costs, are included in the overall cost, which is an upfront cost incurred in year zero of an analysis. Typical examples of PV solar system direct capital expenditures include solar panels, inverters, and other components such as racking, wires, and monitoring equipment.

In addition, the original cost includes indirect costs such as personnel and technical know-how, grid interconnections, engineering, permits, environmental studies, sales taxes, and import customs.

- OPERATION AND MAINTENANCE

Operation and maintenance costs, unlike direct and indirect capital costs, are the recurring annual expenses required to maintain, repair, and replace crucial components of a PV solar system. Restoring or replacing inverters and modules is among the most common PV solar system operations and maintenance expenditures. Re-torqueing electrical connections, changing fuses, repairing broken or crushed wiring conduit, and finding ground problems also fall into this category. Proposals can report operation and maintenance costs in a variety of ways, including as a simple annual fixed cost, an annual fixed cost proportional to the system size (nameplate capacity), an annual fixed cost proportional to the overall capital investment, and an annual variable cost proportional to the projected annual electrical production of the system. NREL recommends a fixed annual operating and maintenance cost of $19 per kW for mid-sized PV solar systems (10–100 kW). If a 20-kilowatt PV solar system costs $19 per year to operate and maintain, then the annual operating and maintenance budget would be $380 per year. Operating and maintenance expenditures may be subject to annual inflation and annual escalation under some ideas (Hay, 2016).

4.3 Government incentives of green applications.

As global demand for consumption of energy increase, the government of Libya had made tremendous effort to diversify its sources of energy to meet every demand increase in energy sector which has been severely hit by civil war and political crisis and that erupted the country since 2011.

The Libyan government is making effort to diversify its energy mix and to harness the countries solar and wind power potential. By 2050, Libya aims for 22% of electricity generation to come from renewable energy sources. Libya is also in the process of implementing its initiatives and incentive known as NEEAP. (NATIONAL ENERGY

EFFICENCY ACTION PLAN) under the supervision of Renewable energy authority of Libya (National Plan for developing The Renewable Energy in Libya, 2012).

Furthermore, ministry of electricity and renewable energy established the renewable energy authority of Libya (REAoL) in 2007. A statutory body established by act of parliament or law to carry out national plan for developing the renewable energy alternative sources in Libya between 2013 and 2050. The plan action was divided into short term (2013-2015), Medium term (2015-2025) and finally long term (2025-2050).

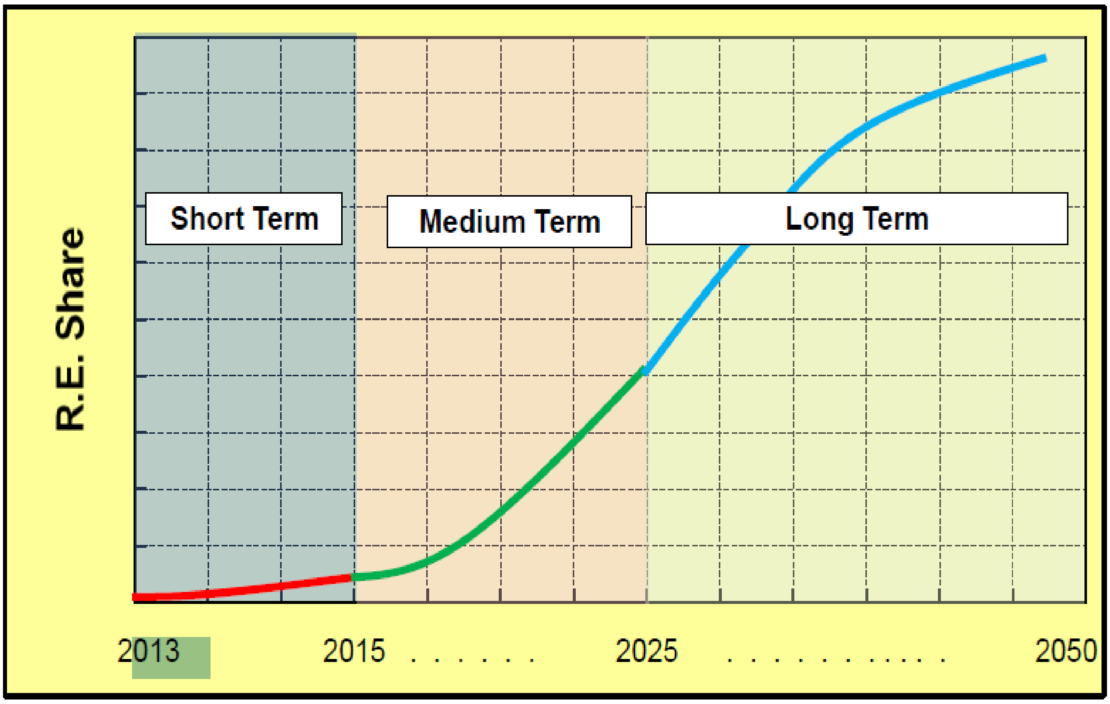


Figure 24: Libyan renewable energy development plan (National Plan for developing The Renewable Energy in Libya, 2012).

The following are the primary goals of REAOL (Libya national plain, 2012):

- A complete mapping of Libya's renewable energy sources, followed by the carrying out of studies to ascertain both the existing market and its potential in the future.
- The completion of a variety of projects involving renewable sources of energy.
- Increase the percentage of the national energy mix that is comprised of renewable sources of energy.

- Promote and bolster the sectors that are associated with renewable energy sources.
- Put forward the necessary legislation to boost renewable energy sources.
- The execution of the initiatives that are concerned with the conservation of energy.

5 PV market in Libya.

This chapter shall review the global, continental, regional and Libya market trend, value segments and development of photovoltaic industry. The global study of how global energy and social economic affect the photovoltaic demand and general acceptability in around the world and Libya.

5.1 International PV market situation.

As a result of the COVID-19 epidemic that impacted worldwide energy consumption, market data shows that the global PV market rose dramatically in 2020 and 2021, with an estimated market value of USD 170.55 billion. By the year 2020, the total installed PV capacity will have risen to at least 760.4 GWdc. Some trends can already be discerned from this data despite its need to be confirmed in the future year.

After two years of market decline, the Chinese PV market has rebounded to its 2017 levels. As of 2020, (48.2 GW) of PV had been installed, compared to (43.4 GW) in 2018 and (31.10 GW) for 2019. Almost one-third of the world's PV capacity is currently installed in China, making it the most populous country in the world in terms of installed capacity. Market share review in other countries outside china indicated that, the global PV market grew from (79.2 GW) in 2019 to at least (90 GW) in 2020/2021, a 14% increased yearly. The European Union market segment and share valued index number close to (19.6 GW) and the rest of Europe added around (2.6 GW). For the year 2020, German (4.9 GW), followed by the Netherlands (3.3 GW), Spain (2.83 GW) and Belgium (1.76 GW) were the top five European markets for solar power (0.9 GW). Utility-scale installations made up 73% of the new additions to the U.S. market, which is a new record for the market as a whole Other Asian countries like Vietnam (11 GW) and Japan (8.1 GW) round out the top five, respectively, with outstanding annual installations India (almost 5 GW but in severe fall from prior years), Australia, Korea, Brazil, Taiwan and Mexico all contributed considerably to new additions in 2020 to 2021 growth, followed by the Philippines and South Africa. Six countries in Asia-Pacific, two in Europe, and two in the Americas make up the top 10, according to a detailed review of the data gathered from a variety of sources (Brazil and the USA). The installed capacity needed to enter the top 10 global market was around (3 GW) in 2020, a stable capacity compared to 2019 and twice the capacity needed in 2018. In addition, the top 10 nations accounted for approximately 78% of the global annual PV market share in 2013. More than 5% of the world's annual electricity needs might theoretically be met by solar power in the countries listed below. Honduras, Australia, Germany, Greece, Chile, Spain, Netherlands, Italy, Japan, Belgium, India, China, and Turkey are among the countries on this list. In conclusion the contribution of PV technology, application and market segment's to decarbonizing the energy mix and clean energy is progressing, with PV saving as much as 875 million tons of CO2. However, much remains to be done to fully decarbonize and PV deployment should increase in order to cope with the targets defined during the united nation agreement of CO2 emission free society (Fortune Business Insights & International Energy Agency, 2020).

5.2 PV market condition in Libya.

With current energy challenge globally, which Libya is included, there is opportunity and potential to diversify its domestic energy consumption and decentralized power solution, with 22% of the country electricity generation intended to be derived from renewable energy sources by 2030. This objective was in agreement of Renewable energy authority of Libya 2030 vision, which was established to grow the renewable energy capacity and diversify energy supply, particularly from solar and wind. While Libya currently produce (33TWH) of power to justify and meet high electricity demand as a result of this the sector required large inflow of private investment (local or foreign) and policy support service from government to fostering competitiveness and long and short time purchase agreement for renewable energy developers or investors.

Government in its endless effort is working hard to bring investors both local and foreign alike, to develop the renewable energy sources to foster and increase electricity generation mostly solar and implementation of photovoltaic plants with power storage facilities within the remote –communities and selected cities and to reduce emission of CO2 being generated by fossil energy technically.

These are the various projects embarked by difference administration in Libya in order to sustain and diversify energy consumption in the country (energycapitalpower.com, 2021):

- Renewable energy plant in Bani-Walid (50 MW).

It was revealed in August 2021 that Libya's renewable energy administration was planning to build a 50 MW renewable energy plant in Bani-Walid in order to alleviate the country's power shortfall, expand the national grid, and deliver power to the region.

- Solar power plant in Tejoura (62 kW).

The Tripoli-based center for solar energy and research, Tejoura, has been established in an effort to increase electricity production. When the project is finished, it will be automatically connected to the national grid, relieving the present power deficit.

- Solar PV plant Kufura (100 MW).

Another grand-stone project that will added to market value coverage to Libya photovoltaic and solar electricity power facility is construction of power plant in kufura, with planned capacity of 100mwp, it will facilitate and help to provide energy security for rural population of kufura and its environment, Libya is accommodate and inhabitant of daily solar radiation of 7.1 kwh per m^2 in its southern region.

- Assorted public-private partnerships renewable project (2000 MW).

Renewable energy agency of Libya, recently announced significant and mega project with total valuation of power electricity of 2,000 mw, by depend and pv technology advancement in coming years. The model of project shall be public-private partnerships business system or arrangement.

This system will eliminate state control power generating system, it will encourage private investment and other stakeholders to harness potential and mechanism in renewable energy sector participation.

Finally, after review global market share and its potentiality it can be concluded that Libya, Africa and Middle East only contributed and installed nearly 1.5GW of solar PV project in 2020/2021.

6 Power plant simulations.

The technical assessment of a utility-scale solar power plant in Libya is discussed in this chapter. This covers topics such as site selection criteria, energy production calculations, and software modeling.

6.1 Site selecting criteria.

To identify the optimal sites for PV power plant, it is required to establish an effective criteria, taking factors such as the feasibility of solar energy systems in the area into account. The factors employed in this study fall into three categories: economic, environmental, and climatic. Multi-criteria data analysis is a set of mathematical tools and procedures used to assess multiple ways of making judgments and factors based on diverse criteria, some of which are in conflict with one another, to determine the optimal option. It can be advantageous in a range of human infrastructure sectors.

For the construction of a PV power plant, a comprehensive analysis of solar radiation is essential. An increase in the output of a solar cell module is directly proportional to the intensity of the incident solar radiation. Photovoltaic systems typically require 1100 kWh m2 of annual sun irradiation in order to be economically viable (Kereush and Perovych, 2017).

When it comes to slope, flat land is the most ideal for solar installations. It is difficult and expensive to build on steep slopes. The intricacy of the design rises as the slope gets steeper, which can contribute to an increase in expenditures. Erosion, drainage, and foundation stability can all be affected by the placement of solar panels on steep slopes (Brewer et al. 2015).

The optimal orientation and inclination of PV modules, as well as the technical components of all photovoltaic power plant installations, are influenced by the earth's slope. It is widely accepted that the highest slope that is technically viable for installation is 15%. If the slope is small, orientation isn't a big deal because photovoltaic panels can be supported by structures on the other side of the hill, but if the slope is steep, it's impossible to build a solar power plant because the slope orientation is a deterrent (the steeper the slope, the less desirable the location is for erecting a station). In this regard, there is a wide range of slope values that have been shown to be suitable: some studies have restricted slopes to less than 3%, some to between 5% and 15% (Castillo et al. 2016).

The efficiency of solar power plants and the duration for which they potentially generate electricity are closely related to the air temperature. The ideal air temperature ranges between 15 and 40 degrees Celsius (Kereush and Perovych, 2017).

Considering an economic element is the accessibility of a PV farm site to an electrical transmission line which supply power. When the transmission lines are close to the PV farm, the costs associated with installation and the development of a new infrastructure are minimal. The closer a project is to existing power lines, the less expensive it will be to connect it to the grid and the lower the line-loss will be [Castillo et al. 2016, Charabi et al. 2011]. If a solar PV utility has a capacity of less than 15 MW, it needs a nearby 35 kV power line, but if it has a capacity of more than 15 MW, it needs high-voltage transmission lines that are higher than 35 kV (Kereush and Perovych, 2017). According to some research, it is more cost-effective to locate solar PV farms closer to places with high energy demand, such as towns, cities, and businesses, because the distance electricity must travel and the associated line-loss and transmission costs are reduced (Tahir et al. 2015).

Construction of new roads has a significant negative influence on the environment, which can be mitigated by choosing sites that are near to existing roads (Janke 2010). Transporting construction materials for a solar power plant necessitates a well-maintained road system. The farm should also have access to roads that are at least 3 meters wide so that they can be maintained properly. Infrastructure, such as noise barriers around roads, could be integrated into PV systems.

Both the location of the PV plant and the main interconnection route may be affected by land usage and availability. This list of concerns must be addressed far in advance of the operating period if any troubles are to be avoided. Land acquisition or leasing can be complicated by the fact that the transmission line must cross land owned by several owners. As a result, properties along the desired path may see some changes in terms of accessibility or availability. Hence, it is essential to carefully investigate the surveying records, ownership titles, and property use agreements (Kereush and Perovych, 2017).

When it comes to land cover, a prospective ideal location should be devoid of mountains, trees, and riverbeds; it should have low or medium grassy vegetation or scrublands as a preferred preference.

On the basis of the preceding information, the province of Sabha was selected. It is a densely inhabited city in the south of the country, surrounded by a vast quantity of desert and unoccupied territory. The evaluation of solar radiation is a crucial step in the development of solar projects, and even during the winter months, this technology is ideally suited for use. The average daily solar radiation ranges from 4.1 kwh/day in December to 8.3 kwh/day in July. Temperatures range from 6 degrees Celsius in the winter to 40 degrees Celsius in the summer, even exceeding 45 degrees Celsius (47.5 degrees is the heat record in the area). The planned site for the building of a large-scale PV plant is situated in a region with easy access to a well-developed road network. It is entirely possible to transfer the components of a solar power plant without any significant delays. As the available information indicate, there is an abundance of workers in the area who can perform the necessary civil engineering and plant installation, meaning that there is less of a possibility that the process of establishing a solar power plant in the area would be slowed down or disrupted. Figure 25 shows the transportation network in the country.

Figure 25: Main roads in Libya (Urban transportation in Libya, 2020).

Coming to electricity network, medium voltage transmission circuits of 30kV and 66kV connect the high voltage (220kV and 400kV) networks to the low voltage (11kV) networks in Libya as shown in figure 26. There are approximately 2225 kilometers of power transmission cables and overhead lines, as well as 355 substations for the 30kv network and 175 substations for the 66kv network, in addition to low voltage substations and transformers. The electricity network in Libya is among the most advanced in the region of North Africa. Regular updates and renewals occurred up until 2010, well before the outbreak of war in Libya.

Figure 26: The division of Libya's geographical regions (Libyan electric network requirement, 2016).

A central dispatch connects and coordinates the four main circuits (East, West, South, and South-east), and each circuit has its own control unit. An effective SCADA system links and controls all circuits, allowing the grid to be automatically managed. Figure 27 also displays the national high-voltage network and the quality of the site connection to it across the country.

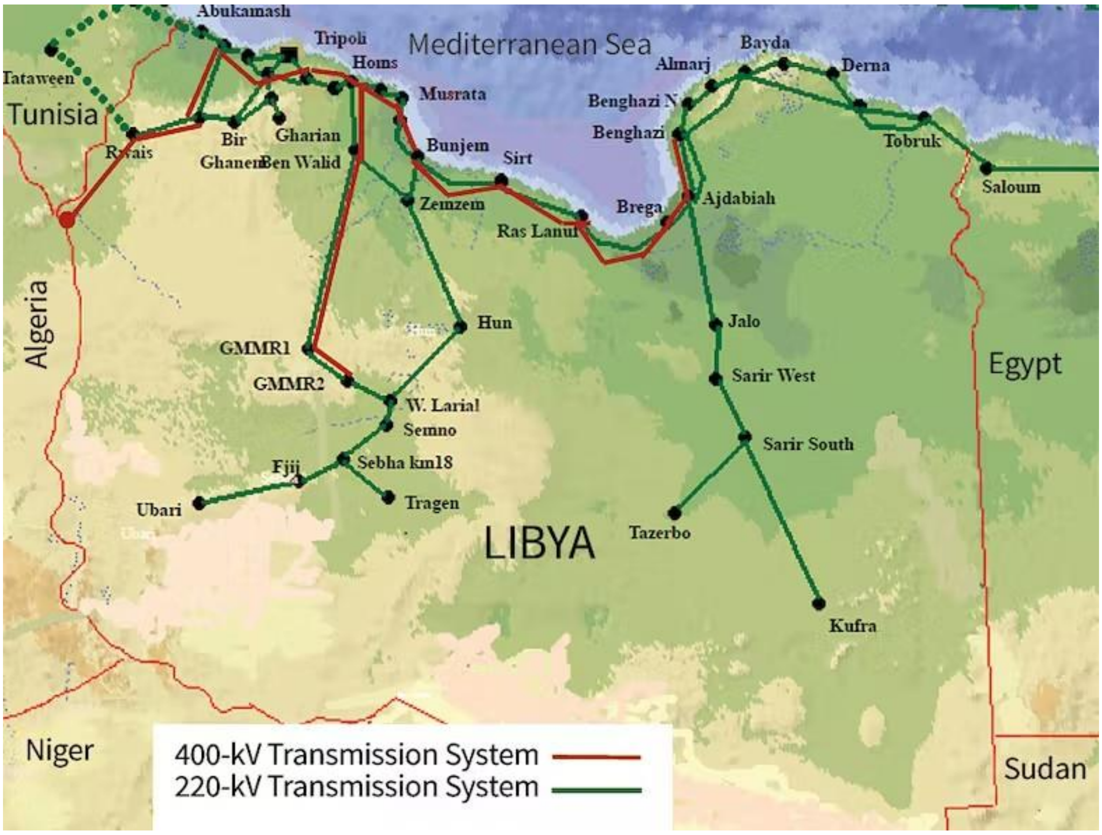


Figure 27: High voltage network in Libya (Conflict Damage and Reconstruction, 2017).

6.2 Data assessment of the utility- scale PV power plants.

Obtaining data from a reliable government source was challenging for this study since some of the information being sought is either classified or otherwise unavailable to the general public. The evaluation is based on information from international sources and some official sources that have been approved.

When considering the technical feasibility of the proposed PV power plant, an efficiency rating of between 12 and 19 percent for the solar panels is acceptable, and it's assumed to be 15%. For the purposes of this study, and since there is a lot of space available at the chosen site, a 5 MW power plant is assumed. During real operation mode, some losses may occur, and they are called "system losses," which account for performance losses and should be expected in a real system and it's assumed to be 12%.

The system size could be either estimated based on the area available for the array, or calculated from the module nameplate size at STC and the number of modules in the array:

$$P = A \times Is \times \eta \qquad [kW] \qquad \text{(Equation 2).}$$

P is the Power of plant (kW).

A is the Array Area (m²).

Is is the Maximum insolation (kW/m²).

η is the Module Efficiency (%).

In the case of a 5 MW power plant, the total array area (collector area) could be calculated by the equation 1.

5000 kW = Array Area (m²) × 1 kW/m² ×15%

Array Area (m²) = 33,333.3 m²

This array area is the total module area, not the total area required by the system. The total area of the system should include space between modules, space for inverters, and other parts of the system.

The nominal plant output (kWh), which is also called the target yield (kWh), is the system's theoretical energy output and could be calculated by the following equation:

$$E = A \times Ir \times \eta \times Pr \qquad [kWh] \qquad \text{(Equation 3).}$$

E is the nominal plant output (kWh).

A is the Array Area (m²).

Ir is the total solar insolation (kW/m²).

η is the Module Efficiency (%).

Pr is the Performance ratio (%).

The performance ratio is the coefficient for losses, and it is equal to [1-system loses], and in this case, it is [1-12% = 0.88].

Based on the available data for solar insolation in Sabha (the chosen location), which was mentioned in table 4, and by applying (Equation 3 to the array area, solar panel efficiency, and the performance ratio, the calculation would be as follows:

- In January, with 4.4 kWh/ m²/day for 31 days, the total solar insolation for this month is 136 kWh/ m².

Electricity generated in January kWh = 33,333.3 m² × 136 kWh/ m² × 15% × 88%.

Electricity generated in January kWh = 600,159.4 kWh.

- In February, with 5.4 kWh/ m²/day for 29 days, the total solar insolation for this month is 156.6 kWh/ m².

Electricity generated in February kWh = 33,333.3 m² × 156.6 kWh/ m² × 15% × 88%.

Electricity generated in February kWh = 689,039.311 kWh.

- In March, with 6.5 kWh/ m²/day for 31 days, the total solar insolation for this month is 201.5 kWh/ m².

Electricity generated in March kWh = 33,333.3 m² × 201.5 kWh/ m² × 15% × 88%.

Electricity generated in March kWh = 886,599.113 kWh.

- In April, with 7.1 kWh/ m²/day for 30 days, the total solar insolation for this month is 213 kWh/ m².

Electricity generated in April kWh = 33,333.3 m² × 213 kWh/ m² × 15% × 88%.

Electricity generated in April kWh = 937,199.063 kWh.

- In May, with 7.4 kWh/ m²/day for 31 days, the total solar insolation for this month is 229.4 kWh/ m².

Electricity generated in May kWh = 33,333.3 m² × 229.4 kWh/ m² × 15% × 88%.

Electricity generated in May kWh = 1,009,358.99 kWh.

- In June, with 8 kWh/ m²/day for 30 days, the total solar insolation for this month is 240 kWh/ m².

Electricity generated in June kWh = 33,333.3 m² × 240 kWh/ m² × 15% × 88%.

Electricity generated in June kWh = 1,055,998.94 kWh.

- In July, with 8.3 kWh/ m²/day for 31 days, the total solar insolation for this month is 257.3 kWh/ m².

Electricity generated in July kWh = 33,333.3 m² × 257.3 kWh/ m² × 15% × 88%.

Electricity generated in July kWh = 1,132,118.87 kWh.

- In August, with 7.8 kWh/ m²/day for 31 days, the total solar insolation for this month is 249.6 kWh/ m².

Electricity generated in August kWh = 33,333.3 m² × 249.6 kWh/ m² × 15% × 88%.

Electricity generated in August kWh = 1,098,238.9 kWh.

- In September with 6.8 kWh/ m²/day for 30 days, the total solar insolation for this month is 204 kWh/ m².

Electricity generated in September kWh = 33,333.3 m² × 204 kWh/ m² × 15% × 88%.

Electricity generated in September kWh = 897,599.102 kWh.

- In October, with 5.6 kWh/ m²/day for 31 days, the total solar insolation for this month is 173.6 kWh/ m².

Electricity generated in October kWh = 33,333.3 m² × 173.6 kWh/ m² × 15% × 88%.

Electricity generated in October kWh = 763,839.236kWh.

- In November, with 4.6 kWh/ m²/day for 30 days, the total solar insolation for this month is 138 kWh/ m².

Electricity generated in November kWh = 33,333.3 m² × 138 kWh/ m² × 15% × 88%.

Electricity generated in November kWh = 607,199.393 kWh.

- In December, with 4.1 kWh/ m²/day for 31 days, the total solar insolation for this month is 127.1 kWh/ m².

Electricity generated in December kWh = 33,333.3 m² × 127.1 kWh/ m² × 15% × 88%.

Electricity generated in December kWh = 559,239.441 kWh.

By adding the energy produced each month through the 5MW power plant, the annual energy generated is 10,236,589.7 kWh ≈ 10,236.5897 MWh as shown in figure 28.

The monthly electricity output measured in kilowatt hours is shown in Figure 28.

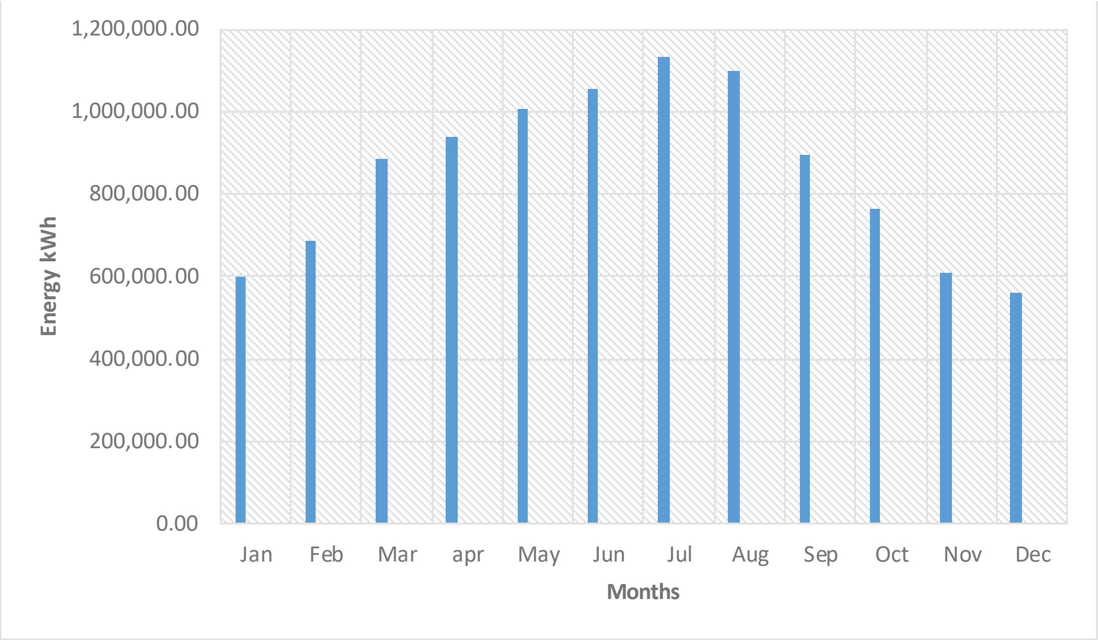


Figure 28: Electricity generated in kwh each month.

In a study conducted by The Cadmus Group on three different types of Libyan housing (public houses, flats, and villas), it was found that public houses had a daily consumption of 0.173 kWh per m2(Design and analysis of an isolated PV system for a house in Libya, 2020). In this case, a home with an area of 150 square meters would need 25.95 kilowatt hours per day of energy, which is 9,471.75 kWh annually. The number of consumers that could be supplied by this 5MW power plant can be determined by dividing its annual energy production by the amount of energy each home is expected to consume:

Number of consumers = total produced energy ÷ consumed energy by each home.

Number of consumers = 10,236,589.7 kWh ÷ 9,471.75 kWh.

Number of consumers that could be supplied = 1,080.

Since renewable energies have not yet been developed in Libya, there is no obvious capital cost associated with them. There is currently no defined price for PV technology on a utility scale, but Libya is a free market for any new technology and the government provides many opportunities to investors in order to invest in the region. In 2020, utility-scale projects across the world had an average total installed cost of USD 883/kW. (IRENA, 2020). The average cost to install a solar farm is between $0.89 and $1.01 per produced watt. These costs are estimated using data from the SEIA's 2021 report. Also, the investor is presumed to be the landowner of the site for the solar farm. Building and maintaining a solar farm is far more cost-effective than installing individual solar panels on homes. Costs for operations and maintenance at the utility scale in Europe have been estimated at USD 10 per kilowatt per year (IRENA, 2020). Land is priced at about $10 per kilowatt (personal estimation based on the local market).

Calculating the total cost of implementing this power plant from the mentioned information would be as follows:

Construction cost = 1.01$ × 5,000,000 W = 5,050,000 $.

Land cost = 10 $ × 5,000 kW = 50,000 $.

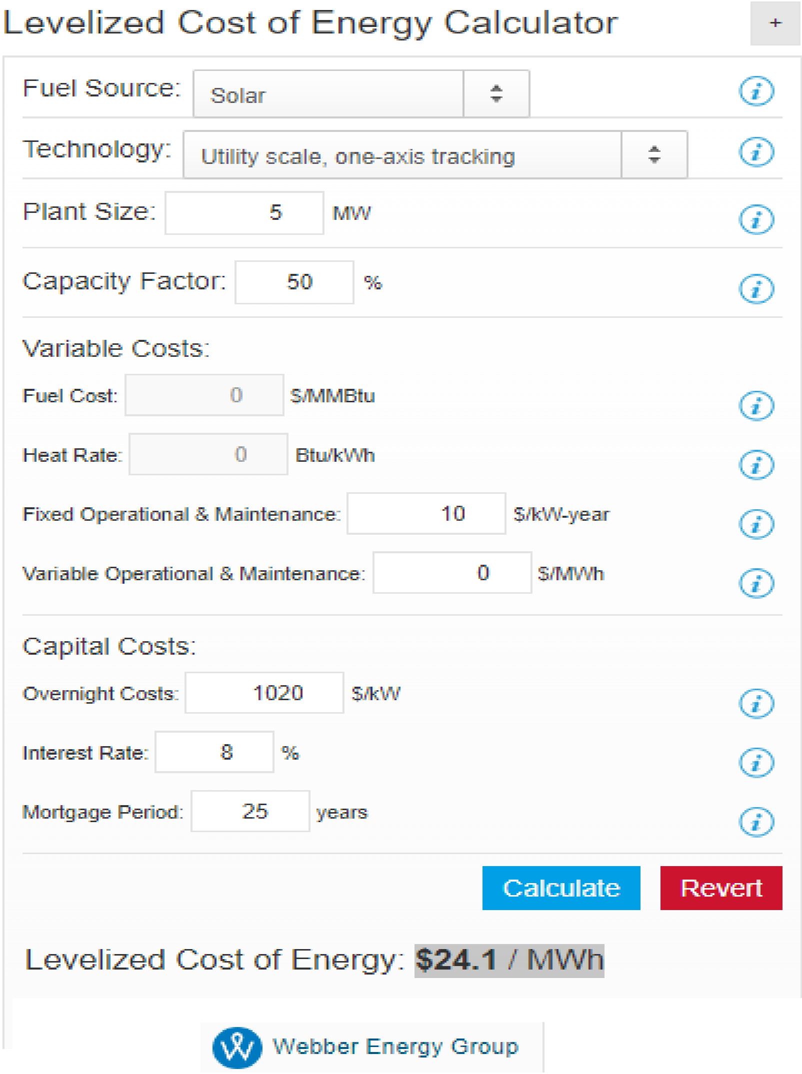
The total cost of the PV power plant = 5,050,000 $ + 50,000 $ = 5,100,000 $

There has to be a team of operators and a regular maintenance program established for this power facility. The annual price for both of them is $10.0 per kilowatt per year, known as O&M costs.

O&M costs = 10 $ × 5,000 kW = 50,000 $ per year.

As a following step, such a project would need to determine its Levelized cost of electricity (LCOE).The LCOE is the price at which the electricity produced by a system must be sold over its lifetime in order for it to breakeven. Since calculating the payback time or the net present value requires assumptions about the price at which the power can be sold to the grid or an end user, the levelized cost of electricity (LCOE) is a more accurate indicator of cost-effectiveness. This cost fluctuates considerably (by a factor of 10 or more) between markets or over time, and it has a direct bearing on an investment's feasibility. Levelized cost of electricity (LCOE) is a useful measure for making technology comparisons across different contexts. By directly comparing the LCOE with the price at which electricity may be sold, the monetary feasibility in a given situation can be revealed through the usage of LCOE. If the levelized cost of energy (LCOE) is less than the price at which electricity can be sold, the project is at least somewhat profitable and should be further investigated to determine if it is a feasible investment. The project is not economically viable if the levelized cost of energy (LCOE) exceeds the price at which power can be sold (Tamburini, Cipollina and Micale, 2021).

The LCOE was calculated to be $24.1/MWh, or 2.41 cents per kWh, using an LCOE calculator developed and presented by The Webber Energy Group, a research group in the Mechanical Engineering Department at UT Austin that focuses on critical energy and environmental issues at the intersection of engineering (see Figure 29).



Levelized Cost of Energy Calculator

Fuel Source: Solar

Technology: Utility scale, one-axis tracking

Plant Size: 5 MW

Capacity Factor: 50 %

Variable Costs:

Fuel Cost: 0 $/MMBtu

Heat Rate: 0 Btu/kWh

Fixed Operational & Maintenance: 10 $/kW-year

Variable Operational & Maintenance: 0 $/MWh

Capital Costs:

Overnight Costs: 1020 $/kW

Interest Rate: 8 %

Mortgage Period: 25 years

Levelized Cost of Energy: $24.1 / MWh

Figure 29: The calculated Levelized cost of electricity.

6.3 Software simulation and results.

The System Advisor Model (SAM) is the software used in this simulation.

6.4 SAM overview.

Project managers, engineers, economists, policy analysts, technologists, and academics can all benefit from using SAM, as it is a computer model developed to aid in decision-making in the renewable energy sector.

For a renewable energy project to be modeled in SAM, the user must select a performance model and a financial model to represent it, and then supply values for input variables that describe the project's location, equipment type, cost to build and operate, and financial and incentive assumptions. After settling on appropriate values for the input variables, simulations are run and the outcomes are analyzed. Photovoltaic systems with optional battery storage, concentrating solar power, industrial process heat, solar water heating, wind, geothermal, biomass, and conventional power systems that deliver electricity directly to the power grid, or interact with the electric load of a grid-connected building or facility, could be covered by SAM's performance models.

As the code for SAM is freely shared with the community, anyone can use it. Software developers can add their own models and improvements to the project, while researchers can use the code to better understand the model methods. Furthermore, the SAM website includes downloadable reference guides detailing the model's algorithms.

6.4.1 SAM Input Values.

For SAM to work correctly, the actual equipment in the system, as well as the costs and financial assumptions, must be described as inputs. For SAM to give an accurate description of the site's renewable energy resources and climate, it needs a weather data file. The weather file could be either picked from a list of available weather data files, downloaded from the internet, or created out of available raw data.

In this simulation, the weather file for the chosen location (Sabha) was downloaded from the internet (Climate.OneBuilding.Org).

6.4.2 Simulation runs and outcomes.

The simulation was done for a 5MW power plant with an array type of 1 axis tracking, 1.2 DC to AC ratio, and 12% of total system losses and the results were as follows:

Table 5: Monthly data by Simulation.

	Daily average solar irradiance (kwh/m2/day)	Plane of array irradiance (kwh/m2)	Electricity production (kwh)
Jan	5.52	170.95	719,490
Feb	6.86	192.07	778,224
Mar	8.20	254.32	1,029,460
Apr	9.35	280.54	1,099,040
May	9.75	302.13	1,166,600
Jun	9.84	295.12	1,110,960
Jul	9.78	303.16	1,142,750
Aug	9.44	292.67	1,098,640
Sep	8.57	256.97	975,073
Oct	7.24	224.56	882,099
Nov	5.89	176.86	721,728
Dec	5.20	161.30	673,264

Table 6: Simulation summary.

Metric	Value
Annul AC energy in year 1	11,397,321 kwh

DC capacity factor in year 1	26%
LCOE levelized cost of energy real	3.42 cent$/kwh
NPV net present value	4,592,968 $
Year IRR Achieved	25
Net capital cost	5,644,918 $
Equity	6,637,760 $

The total energy generated in a year is more than 11 Gwh by the 5MW plant which is very impressive and convincible.

7 Conclusion and recommendations.

With its high yearly sun irradiation, Libya is considered an attractive location for PV installation. Those environmental and technical potentials are further heightened by the expanding energy demands in the region. Renewable energy technologies, notably PV systems, could be employed as alternative energy sources.

Low levels of public education and technical expertise, prohibitive upfront costs for solar modules, the lack of a valid FIT (Feed-In-Tariff) in the region, and a lack of government backing for this technology in Libya are the primary challenges to PV deployment in the region. In terms of solar energy, the country has a lot of untapped potential, however it's not easy to put to use.

Taking into account all capital costs, O&M costs, and a 25-year investment horizon, the results show that installing a utility-scale PV power plant is economically not feasible, although it is definitely the best option for the lack of electricity and the increase in demand in Libya because of the low price of electricity, which is subsidized by the government (0.002/kWh), and the high investment cost. Furthermore, there is a need for long-term research on the complexities involved in building a solar PV plant to generate power at a utility scale.

Here are some suggestions for how the country should promote the use of PV technology:

1. To encourage investors to develop PV power plants (on a small, medium, or large scale) and to make them economically viable, the government must adjust energy pricing (FIT), which was already announced by the government recently and will take place starting in September 2022.
2. As technology is still costly in the country in terms of standalone systems, more government financial assistance to citizens in the form of bank loans is required.
3. In order to boost the PV sector, it is suggested that more public solar systems be installed and that people and commercial customers be educated on solar energy, particularly in regards to finance.

Finally, Libya is currently in a developmental stage in which it must increase electricity production to meet rising demand and a growing population. Any of the renewable energy technologies, but especially photovoltaic technology, can help achieve this goal by increasing power generation and decreasing reliance on fossil fuels like natural gas, which have an adverse effect on the environment but will be secure in the future if conventional fuel sources in the region are depleted. This research makes it clear that Libya has a sizable solar resource that should be taken into account.

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List of abbreviations and symbols.

Δ-Y	Delta to Star connection.
°C	Degrees Celsius
A	Array Area.
AC	Alternating current.
BOS	Balance of System Components
CDTE	Cadmium telluride.
CIS	Copper indium.
CPV	Concentrator PV.
CSP	Concentrated solar power.
CSP	Concentrator solar power
DC	Direct current
E	Nominal plant output.
FF	Fill factor
Ft2	Square feet
GAS	Gallium arsenide.
GDP	Gross Domestic Product
GECOL	General Electricity Company of Libya
GW	Giga watt
HCPV	High concentration PV systems.
HF	High frequency.
Ir	Total solar insolation.
Is	Maximum insolation.
Isc	Short-circuit current.
Km	Kilometer
Km2	Kilometer square

Kw/m2	Kilowatt per square meter
KWh	Kilowatt-hours
Kwh/ m^2	Kilowatt hours per square meter.
Kwh/day	Kilowatt hours per day.
LCOE	Levelized cost of electricity.
LF	Line frequency
LFO	Low fuel oil.
MPPT	The maximum power point tracker.
MW	Megawatt.
MWp	Megawatt peak.
O&M	Operations and Maintenance.
P	Power of plant.
Pr	Performance ratio.
PV	Photovoltaic
PWM	Pulse with modulation.
REAoL	Renewable energy authority of Libya
SAM	System Advisor Model.
Sq-km	Kilometer square.
STC	Standard Testing Conditions.
THD	Total harmonic voltage distortion.
TWH	Terawatt hours.
USD	United states dollar
Voc	Open-circuit voltage;
W	Watt.
W.H.O	World Health Organization
W/m2	Watt per square meter

Wp	Peak Watt.
µm	Micrometer.

List of figures.

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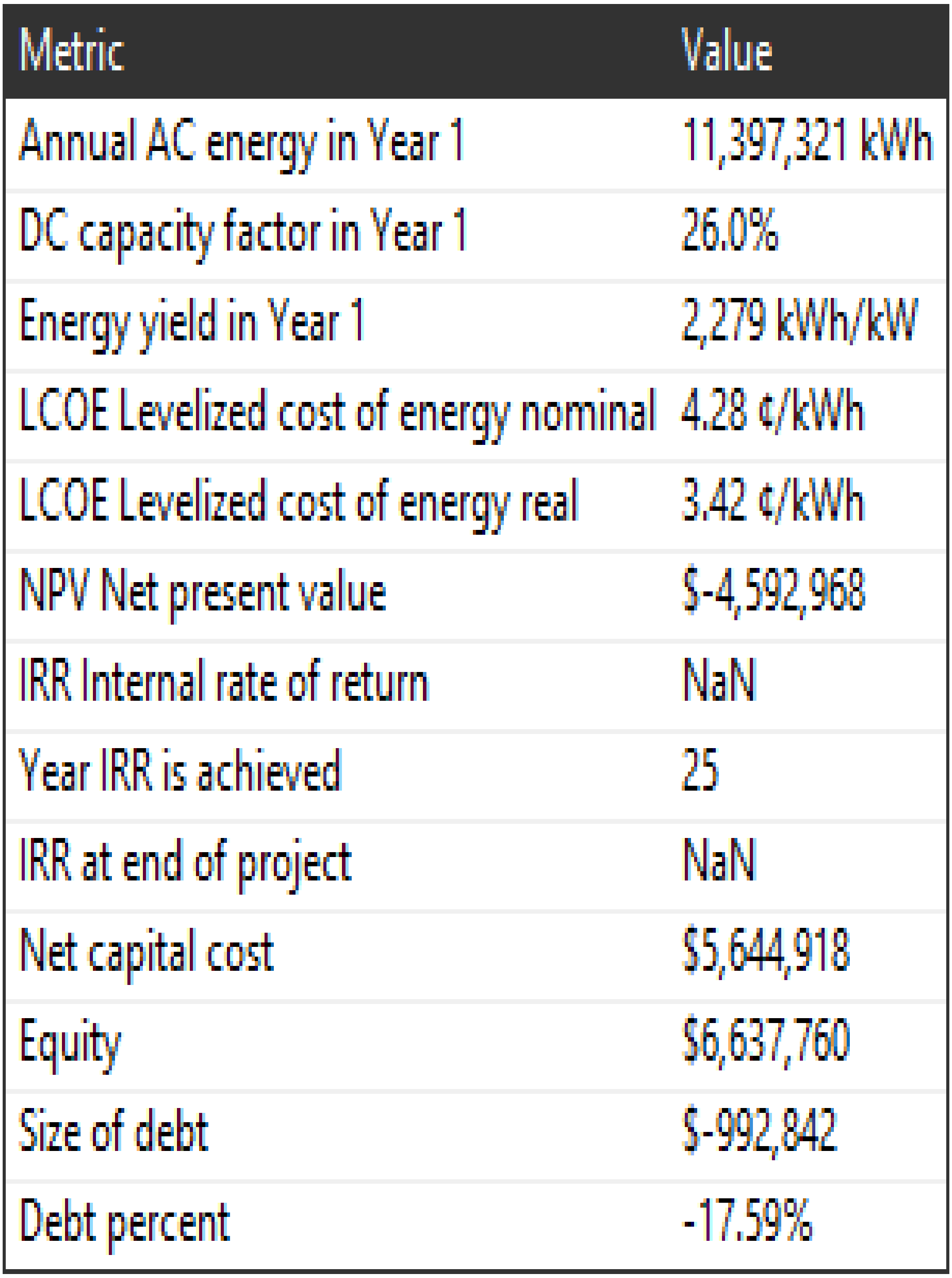
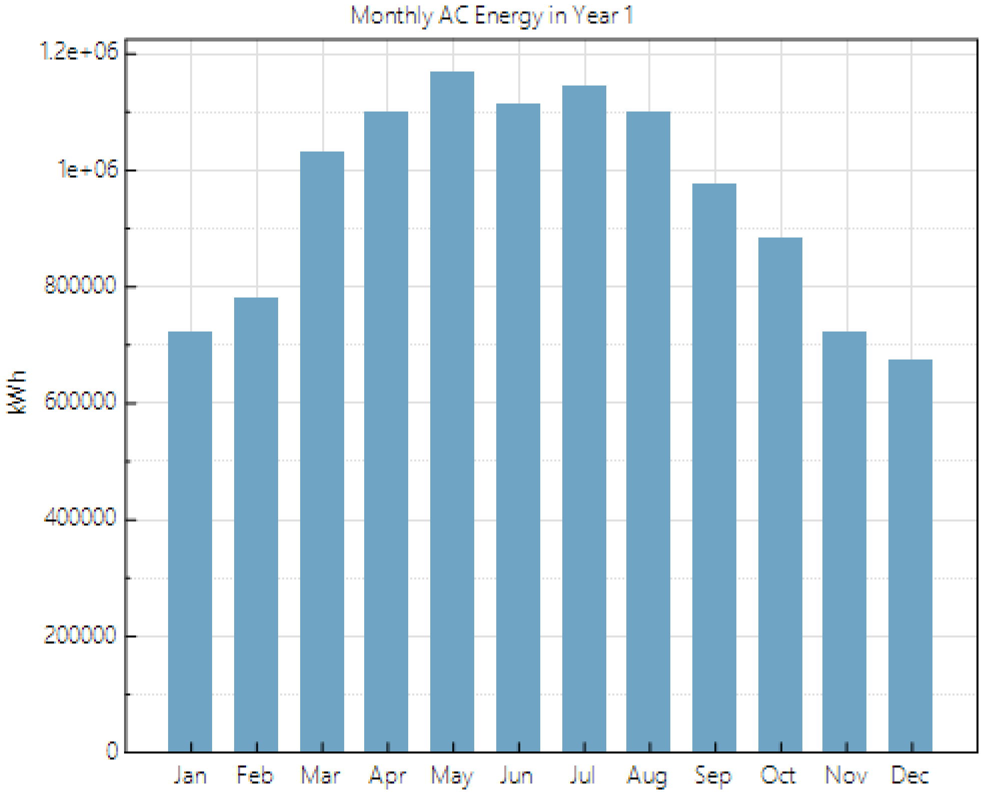
Appendixes.

Appendix 1: Simulation summary.

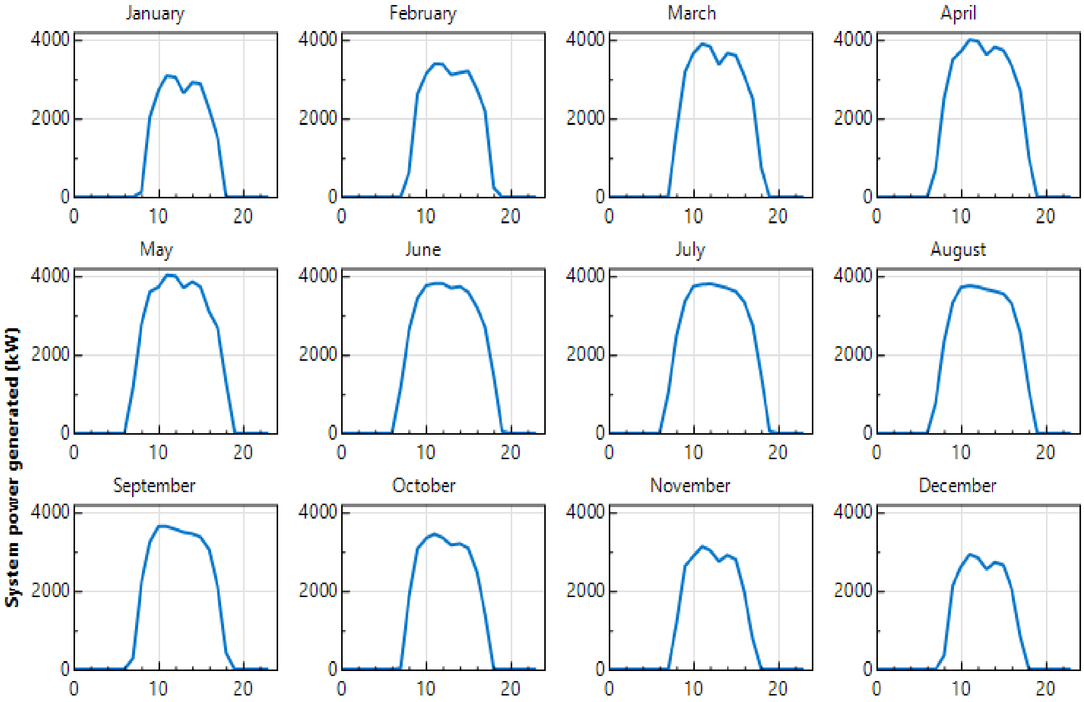


Metric	Value
Annual AC energy in Year 1	11,397,321 kWh
DC capacity factor in Year 1	26.0%
Energy yield in Year 1	2,279 kWh/kW
LCOE Levelized cost of energy nominal	4.28 ¢/kWh
LCOE Levelized cost of energy real	3.42 ¢/kWh
NPV Net present value	$-4,592,968
IRR Internal rate of return	NaN
Year IRR is achieved	25
IRR at end of project	NaN
Net capital cost	$5,644,918
Equity	$6,637,760
Size of debt	$-992,842
Debt percent	-17.59%

Appendix 2: Monthly energy production in year 1.



Appendix 3: average system production each month.



Appendix 4: Daily average solar irradiance.