# Using solar energy in Kuwait to generate electricity instead of natural gas

by

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#### A REPORT

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## **Abstract**

Solar energy is the energy that is basically obtained from the sun. It is used for purposes of generating electricity by using solar thermal systems of photovoltaic panels. This report discusses the utilization of solar energy in Kuwait for purposes of generating electricity. The report is divided into six chapters. Chapter 1 discusses the introduction, which will be limited to the use of electricity in Kuwait and the possibilities of utilizing solar energy as a renewable source of energy to generate electricity. Chapter 2 discusses the background of the use of solar energy, where the reasons and the advantages of using solar energy are analyzed. Chapter 3 gives an in-depth discussion on solar energy. The generation of electricity from photovoltaic solar panels and solar thermal electricity systems are presented. Chapter 4 discusses the comparison between solar power farm and natural gas with the aid of data from Kuwait. Chapter 5 gives a discussion on the use of solar energy in Kuwait. Chapter 6 includes the conclusions and recommendations for future work.

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# Chapter 1

# INTRODUCTION

# 1.1 History of Kuwait

Kuwait is a small country located in northwest corner of the Arabian Gulf with an area of 17,820 square kilometers. The population of Kuwait is 4.2 million. The climate in the summer is hot and dry within an average temperature of 42 to 48 °C and in the winter it is warm with a low chance of precipitation. Oil is the main source to generate electricity in Kuwait.

Electricity started in Kuwait in 1934 by the Electricity National Company and the first power plant had two generators. Each generator had a capacity of 30 kilowatts. In 1951, the Electricity National Company started to use a generator of a capacity of 500 kilowatts. By that time, the demand for the electricity was increasing and expanding. Therefore, the government decided to have a new ministry and called it Ministry of Electricity and Water (MEW), which is responsible of providing Electricity and Water to consumers. Nowadays, Kuwait has six power plant which are Al-Shuwaikh Plant, Shuaiba North Plant, Shuaiba South Plant, Al-Doha East Plant, Al-Doha West Plant, and Al-Zour South Plant.

# 1.2 Kuwait Generating Electricity using Natural Gas Fired Generators

Kuwait consumes energy which is obtained from fuel as a major source of energy. The crude fuel is made up of liquid oil, natural gas and other related products. To convert the natural gas into electricity, a number of procedures are taking place in the power plants and in the water desalination power stations. There are huge boilers that burn abundant amounts of natural gas into chemical energy and ultimately convert the gas into thermal energy. This produces a high pressure,

super-heated steam, by which the turbines are driven to convert the thermal energy generated into mechanical energy. The chemical energy is used to rotate the electrical generators to create electrical energy. The electricity that has been generated is transferred to a given electrical network, where it is transmitted, distributed and delivered to various consumers.

# 1.3 Cost and Price of Electricity

The price of electrical power in Kuwait changes depending on its usage. The Ministry of Electricity and Water in Kuwait has identified the following tariffs for electricity. Residential, industrial, chattels and chevron (neutral zones) places cost 2, 1, 10, and 12 in Kuwaiti Fils, which is the sub-division of Kuwaiti Dinar, per kilowatt, respectively. However, these rates are expected to rise due to the ministerial considerations in the Law numbered (20 of 2016) that requires increases in the prices of both water and electricity.

# 1.4 Ministry of Electricity and Water in Kuwait

It is important that Kuwait's Ministry of Electricity and Water consider alternative and novel methods of providing energy to citizens. This is particularly due to the ever-growing demand for electricity in the country and the need to obtain a safe sustainable development. Currently, Kuwait Institute of Scientific Research has plans underway through which electrical power can be obtained from the use of renewable energy sources. Some of the projects that have been established include thermal power stations with a capacity of at least 50 Megawatts, a wind power station that has an estimated capacity of 10 Megawatts, and a photovoltaic solar power station that has an approximated capacity of 10 Megawatts. Thanks to the use of these three stations, the Ministry is able to generate enough electricity for all citizens because the power generated is fed directly to the national grid system for electricity.

By considering new methods of generating electricity, the Ministry of Electricity and Water will support easing the pressure that is presently witnessed on the conventional power stations, particularly during summer season. In addition, the Ministry will be saving on the costs that are

incurred in generating electricity. It is a well-known fact in Kuwait that the cost of producing electricity is quite high, notwithstanding the ever-increasing demand from the citizens for electricity. By using clean energy sources such as the wind and the sun. Expenses can be saved and channeled into other important projects in the country.

The Ministry of Electricity and Water can work hand in hand with the Kuwait Institute of Scientific Research to identify the most feasible options in generating electricity. Also, to encourage and enlighten the citizens to use renewable energy sources, it can act as a role model by emphasizing the use of such important sources of energy in buildings as solar panels in new or existing buildings.

Renewable sources of energy will also help decrease the electricity grid loads that are presently connected. It will also preserve the oil reserves, and decrease the environmental effects that are often generated as a result of greenhouse gases emissions which will lead to reduce pollution and decrease the environmental impacts. Also, The Ministry of Electricity and Water can partner with the Kuwait Foundation for the Advancement of Science in conducting some of these projects. According to the Foundation, the use of solar panels in various residential buildings can save up to 7,027 oil barrels each year. These barrels of oil are estimated to cost KWD 221,000 and this amount of money can be channeled to other projects in the national economy.

By exploring these new options of energy sources, the Ministry of Electricity and Water, and the country in general, will benefits from three major things. First and foremost, the high demand of electricity in the country will be effectively catered for. Secondly, there will be an optimal environment in setting aside funds for alternative sources of energy due to the fact that Kuwait is endowed with lots of wind and sun. Finally, the high price of oil will be managed as it will not be the only source of electricity.

# 1.5 Solar Energy is a Renewable Source

The sun is one of the principal sources of renewable energy. Solar energy is basically the direct conversion of sun's energy into electrical power with the use of solar panels and collectors (Goetzberger, 2006). Solar energy is heavily reliant on power known as nuclear fusion that is generated from the sun's core. The energy obtained from the sun is gathered and the conversion into electricity can be done in diverse ways such as the use of solar collectors to heat water and the use of solar attic fans to cool the attic for domestic purposes (Goetzberger, 2006). There are also complex technologies that can be employed to carry out the conversion such as photovoltaic cells, reflectors and boilers. However, our modern day society cannot be solely powered with the use of solar energy as it is entirely dependent on the sun.

Apart from the sun energy, there are other alternative and renewable sources of energy such as wind power, hydroelectric energy, biomass, geothermal power, and hydrogen and fuel cells (Papageorgas, 2013). The wind power can be utilized for purposes of pumping water or creating electricity. However, it is important to note that it requires far-reaching areal exposure to generate noteworthy energy amounts. The sun is an important element in the generation of wind power as the atmospheric movement is highly driven by temperature variations at the surface of the earth when lit by sun rays.

Hydroelectric energy utilizes the gravitational potential of elevated water that has been lifted with the aid of sunlight from the oceans and other water bodies (Papageorgas, 2013). Biomass is the energy that is obtained from plants. Geothermal power is the energy that is generated from the initial earth accretion. It is augmented by the use of heat that is available from a number of radioactive decays present in the earth.

As a renewable source of energy, solar energy can be used either through the utilization of photovoltaics or solar thermal systems. It is renewable meaning that one needs not purchase the solar energy before using it. It is just available in natural form for use by each and every person who is willing. In the production of electricity, solar energy does not cause any form of pollution. It reduces the cost of electricity as one does not have to pay utility fees for electricity if they have their own solar panels. Its maintenance level is equally quite low and no obstructions are caused

while using solar panels. In addition, the value of any residential building increases when installed with a solar panel.

# 1.6 Conversion of Sunlight into Electrical Power

The energy obtained from the sun can be converted into electricity and this is termed photovoltaic (PV). The photovoltaic cells generate direct-current electricity that is passed through a power inverter and ultimately converted into alternating-current electricity (Papageorgas, 2013). This form of electrical power can be used in both residential and commercial buildings as it is more or less similar to the one generated by utility power companies. There are grid-connected and stand-alone systems that are used in the generation of electricity from sun energy. The systems that are connected to the grid are mainly utilized in commercial infrastructures. Systems that are off-grid are used for purposes of feeding electricity directly to facilities in order to be utilized immediately, or into a battery system so as to be used in the future (Papageorgas, 2013).

# Chapter 2

# **BACKGROUND**

# 2.1 Reasons for Using New Sources of Energy

There are many reasons to use new sources of energy. Following are the main reasons why we need to use new sources of energy.

# 2.1.1 Global Warming and Pollution Levels

Currently, the world is experiencing an increase in the levels of global warming and environmental pollution especially due to the release of the greenhouse gases into the atmosphere (Papageorgas, 2013). Some of the components that are used in the generation of electricity, such as fuels, account for the increase in the levels of global warming and pollution. They do undermine the possibilities of having sustainable development in the world. As such, people have resorted to the use of renewable and clean sources of energy that do not pollute the environment. Some of these sources include the sun and wind. Being clean sources of energy, they do not release greenhouse gases into the atmosphere. Hence, the levels of global warming are reduced (Beran, 2013).

## 2.1.2 High Demand

The world pollution continues to grow at very high rates each year. In addition, people have developed innovations that require the use of energy to be managed. Therefore, there is a high demand for electricity as shown in Figure 2.1. As such, people have decided to use new energy sources to supplement on the already available electricity. By using such sources, they will be able to meet those demands.

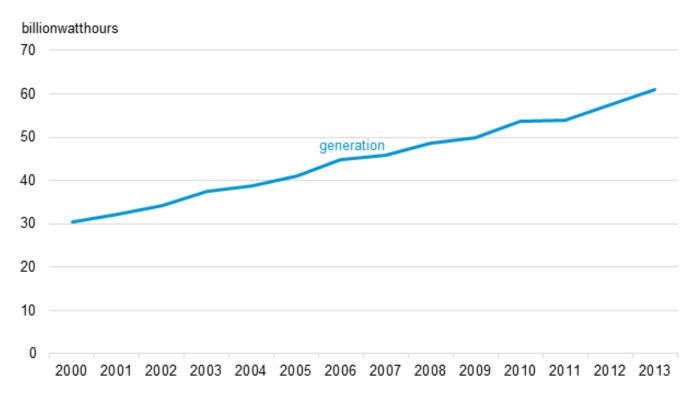


Figure 2.1: Kuwait electricity generation (U.S. Energy Information Administration)

# 2.2 How People Took Advantage of the Sun

The benefits of the sun are countless; it provides many advantages to our life. However, we rarely think it has such an importance. Following are ideas about how people took advantage of the sun.

## 2.2.1 Heating of Water

The energy obtained from the sun can be used to heat water. Figure 2.2 shows the solar water heater. The heating can be done either indirectly or directly. In an indirect water heating system, a fluid that transfers heat, known as ethylene glycol, is utilized (Beran, 2013). It transports the heat into a designed tank from a solar collector. The system is basically resistant to freezing. As such, the water that is heated cannot be possibly frozen. However, it is quite expensive when compared to a direct system of solar water heating. In a direct system, the water that is stored or consumed from water heater is the one that is heated (Beran, 2013). It is quite effective in warm weather conditions as the pipes of the system are culpable to freezing. If freezing continues for a long time, the pipes are likely to be destroyed, and hence, interfering with the process of heating the water.

Once the water has been heated in a direct system, it can be circulated to various points through either an active or passive system. In an active transfer system, there is a circulation pump that is utilized to transmit the heat obtained from the solar collector to a storage tank in which the heat is stored for use. In a passive solar system, there is neither a pump nor a control system through which the heat obtained from the solar collector can be transmitted to a given tank for purposes of storage (Beran, 2013).

The solar collectors used in an active system can be either a flat panel or an evacuated tube system. The flat panel is basically a box that is covered with a glass material. Inside the box, there are numerous copper fins and copper tubes that are attached. The box has a selective surface that is made up of a dark substance that aids in the collection of the sun energy. The sunrays heat up the water which then moves from the solar collector to an insulated tank. From this point, it is ready for use.

The evacuated tube system has numerous glass tubes which are evacuated with materials known as solar absorbers. These materials are used to gather the heat obtained from the sun. To reduce the heat that is lost in the process, there is a vacuum that is strategically placed in the outer and inner side of the tubes. The radiation from the sun is absorbed and the fluid that is contained in the copper pipe is heated up. The reflectors which are located at the back of the tubes also offer extra radiation. Using the sun to heat water in the homes has helped people over the years to save

on the costs incurred in paying for electricity. In addition, it promotes sustainable development as the environment is not affected.

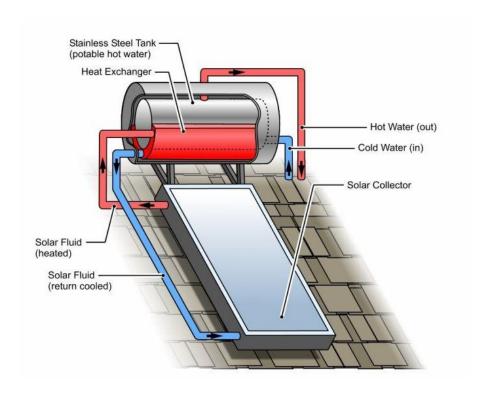


Figure 2.2: Solar water heater (Chua, 2013)

# 2.2.2 Generation of Electricity

Apart from heating water, people have taken advantage of the sun to create electricity for use in both residential and commercial buildings. Electricity can be generated from the sun through the use of concentrated solar thermal-energy systems or photovoltaic solar panels. The generation of electricity using solar energy is discussed in detail in this report.

# 2.3 Determinants of Solar Energy

The determinants of solar energy depend on several factors, which are:

## 2.3.1 Geographical Location

The region in which the solar power plant is located can be a great determinant in the amount of electricity that is generated. For instance, in Figure 2.3 shows the areas with high sunlight levels that have the capacity to generate a lot of electricity whilst regions with low sunlight levels can only generate little electricity which is not sufficient for use. In addition, areas that are clouded or have a lot of shade may not be able to receive a lot of sun rays and hence, the amount of electricity obtained is quite low. In the event that any part of the solar panel is placed under a shade, it will have a negative influence on all the other parts by reducing the electrical output. Hence, it is important for one to associate with the production before establishing a solar power system in any given region. The area chosen should be in a position to receive maximum sunrays that can be utilized in the generation of electricity. To avoid any shadows in the regions, one can opt to trim down any tall trees that are likely to have an adverse impact on the solar panel.

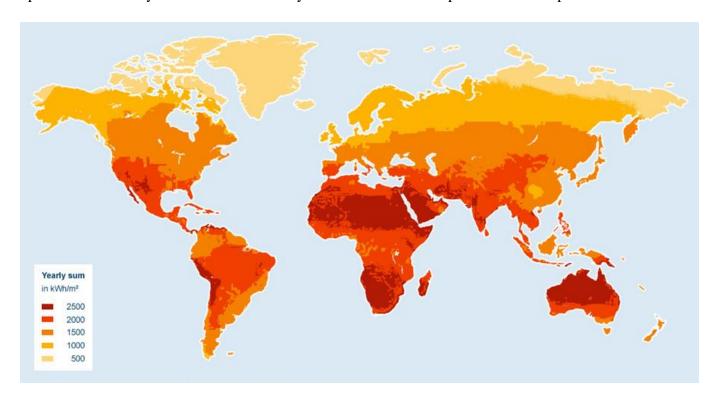


Figure 2.3: Global solar energy

## 2.3.2 The Quality and Efficiency of Solar Panel Materials

Variations in weather and seasons can affect the efficiency and quality of the materials that are used in solar panels. The pitch of a house roof and the orientation in which the solar panel is placed into can also affect its quality. Hence, it is advisable that the solar panels are adjusted at least two times in a year. During winter days, the sunrays are received into the solar panels from a very low angle and this can affect its efficiency. Therefore, tracking systems are needed to manage the tilt and follow the angle of the sun at all times.

However, in as much as a lot of sun rays are good in the production of energy, high degrees of temperatures beyond the recommended levels can have an adverse effect on the solar panels. This is due to the fact that they enhance the conducting capacity of the semi-conductors, making the charges that are inside the solar panel materials to be balanced. Such a process significantly decreases the electric field magnitude. It also does not allow the charges to separate from each other and ultimately, reduces the cell's voltage. Depending on the region in which the solar panel is situated, the temperature levels can decrease the electrical power output to between 10 and 25 percent.

The efficiency and the quality of the solar panel materials can be also reduced if there is soiling on the front parts of the panel. Soiling can occur through either pigeon droppings or dirt. Such soiling becomes quite cumbersome to be washed away by the rain. To avoid this, it is recommended that a regular physical examination of the solar panel is conducted from time to time. The front surface of the panels can be also washed manually if there are any droppings or dirt on it.

# Chapter 3

# **SOLAR ENERGY**

## 3.1 Introduction

Solar energy is basically the radiant light and heat obtained from the sun. It is harnessed with the aid of various technologies including, but not limited to, solar thermal energy, photovoltaic systems, artificial photosynthesis and solar heating. These technologies can be either termed as active or passive solar and this is largely dependent on the mode of capturing and distributing the solar energy. It also depends on the method utilized in converting the solar energy into electrical power. Solar energy is one of the renewable sources of energy that is available for use worldwide. Photovoltaic systems are widely recognized as active solar techniques whereas solar thermal energy is generally a passive solar technique (Goetzberger, 2006).

# 3.2 Types of Solar Energy

Many techniques are used to gain the desired solar energy. The photovoltaic cells and solar thermal electricity will be the two main subjects to be discussed in this report with a comparison between them.

## 3.2.1 Photovoltaic (PV) Cells

A photovoltaic solar cell is generally a device used in the direct conversion of light energy into electricity with the aid of semi-conductors of electricity that unveil a photoelectric impact. A characteristic system of a photovoltaic utilizes solar panels, each made up of various solar cells that generate electricity. The installations of photovoltaic cells can be mounted on the rooftop, ground or the wall of buildings. The mounting can be done through fixation or simply through the employment of a solar tracker that follows the direction of the sun. No form of pollution is produced into the environment with the use of solar photovoltaic cells as there are no moving parts.

### 3.2.1.1 History of PV Cells

In the last two decades, solar photovoltaic cells have advanced from a pure strong market of lesser scale applications to a conventional source of electricity. The use of photovoltaic cells to generate electricity dates back to the 1880s when Charles Fritts constructed the very first solar cell. In 1931, one of the engineers in Germany known as Dr. Bruno Lange established a photo cell with the use of silver selenide as opposed to copper oxide. The prototype containing the silver selenide was not very effective as its conversion rate of solar energy into electricity was less than 1 percent. Nonetheless, the significance of such a discovery was highly recognized and put into use by James Clerk Maxwell and Ernst Werner von Siemens. In the 1940s, Russell Ohl conducted a lot of research in methods that could be employed in the conversion of solar energy into electricity. His research work was utilized by Daryl Chapin, Calvin Fuller and Gerald Pearson in 1954 to create a solar cell known as crystalline silicon. These initial solar cells were worth United States Dollars 286 per watt. Their efficiencies were approximately 4.5 to 6 percent.

In 2000, there was a mass production of the photovoltaic systems. Figure 3.1 shows the layout of photovoltaic farm. That year was critical in the way people responded to solar energy. For instance, the Eurosolar organization in collaboration with the environmentalists from Germany received funding from the government for 10,000 projects for the roofs. The photovoltaic systems

were utilized in standalone systems, specialized applications and grid-connected systems of photovoltaic. In 2012, the existing efficiencies of such solar cells were more than 20 percent. The maximum efficiency of photovoltaic cells was estimated to have exceeded 40 percent.



Figure 3.1: Photovoltaic farm

## 3.2.1.2 Elements and Components of PV Cells

#### • The Inverter

The electric current generated from the solar energy is basically direct current. Hence, for it to be used domestically in homes, it has to be converted into alternating current using an inverter. The inverter uses a series of solid-state switches to generate alternating current. A special type of inverter known as a grid-tie inverter is required if the electricity generated is to be utilized by the grid. Its main purpose is to match the electricity phase generated to the grid phase in order to avoid possible mismatches of the phases and hence, cancellation (Einav, 2004). In addition, the grid-tie inverter works as a safety measure. For instance, in the event there is a power blackout, it

immediately switches off the supply line to the solar panel so as to avoid causing any harm to persons working on the power lines.

#### • The Battery

Some of the photovoltaic solar cells have an installed battery that is used to store the excess electric energy generated from the sun. This energy is put into use when the solar panels do not provide sufficient energy; for instance, during rainy or dark days. Hence, the battery is generally utilized off-grid. The connection of the battery system can be either serial or parallel. The flooded battery, which is a lead-acid battery system, is the most preferred in photovoltaic cells as they neither require distilled water nor electrolytes.

#### • The Distributor

The distributor is used to distribute the AC power that has been generated by the inverter into the electric grid (Einav, 2004). At times, it can be used to distribute the electric energy generated not only to the grid but also the home that has been fitted with the solar system.

#### PV Generator

PV generator is used to convert the energy obtained from the sun into electrical energy. Its efficiency is currently estimated to be 15 percent. The device requires optimum conditions and environment so as to work efficiently and effectively.

#### • Charge Regulator

The charge regulator offers protection to the battery system by monitoring the charging process to either slow down or halt the process to avoid overcharging (Einav, 2004). It increases the life of the batteries to effectively store the energy generated. However, if the solar panel does not use batteries, then there is no need for a battery regulator. The charge regulators are of different types

and sizes depending on the photovoltaic system in use. It is important to note that the stability of the regulator should be reached at the maximum current (Einav, 2004).

### 3.2.1.3 Different Types of PV Cells

#### • Crystalline silicon (c-Si) PV cells

Crystalline silicon (c-Si) is a module that is established from the technology industry of microelectronics. The cells have a relatively high level of efficiency as compared to other PV cells. The crystalline silicon PV cells are basically bound together and afterwards laminated with the aid of glass that is both of high transmittance and toughened. This process gives rise to modules that are weather resistant and reliable. For purposes of ensuring utmost solar radiation going into the crystalline silicon PV cells, the glass contains a coating that is anti-reflecting and toughened (Torres et al., 2016). Either a rolled or flat low iron glass can be used such as Pilkington Sunplus and Pilkington Optiwhite, respectively.

Currently in the market, there are two different kinds of crystalline silicon PV cells: monocrystalline silicon and multi-silicon silicon, as shown in Figure 3.2. The mono-crystalline silicon is established through wafer slicing from a solitary crystal ingot that is highly pure. On the other hand, the multi-crystalline silicon is created by sawing a silicon cast block into bars and afterwards into wafers. The efficiency of the mono-crystalline silicon is higher as compared to that of the multi-crystalline silicon.

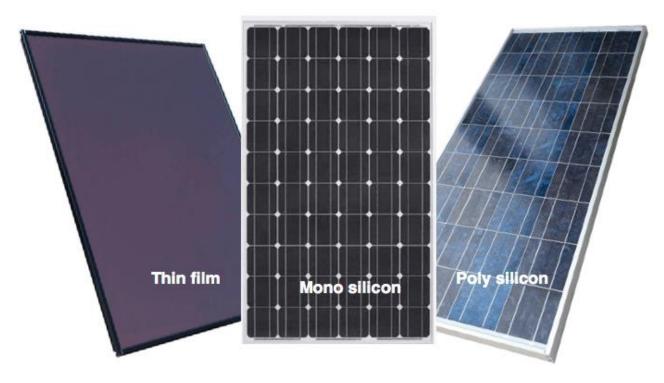


Figure 3.2: Types of PV cells (Newkirk, 2014)

The mono-crystalline silicon PV cell is one of the highly effective forms of technology for the photovoltaics. Typically, it has the capacity to convert approximately 15% of the energy obtained from the sun into electricity. However, its process of manufacture is quite complicated. As such, much higher costs are incurred in the manufacturing process as compared to other technologies. The multi-crystalline PV cells are relatively cheaper as its manufacturing process is quite simple. Nonetheless, they are relatively ineffective. Their efficiency is estimated to be 12% (Torres et al., 2016).

#### • Amorphous Silicon (a-Si) PV cells

These cells are prepared by putting silicon in a lean homogenous coating onto a substrate as opposed to establishing a stiff crystal structure. Unlike crystalline silicon PV cells, amorphous silicon PV cells have an effective mode of absorbing the sunlight. The cells are quite thin. Both flexible and rigid substrates can be utilized for purposes of depositing the silicon. Accordingly, it becomes an ideal PV cell to be employed in surfaces that are curved. It can be also bonded directly

on materials used for roofing in buildings. However, it is important to note that the technology used in these PV cells is relatively less effective as that utilized in crystalline silicon PV cells. Its typical efficiency is at least 6 percent (Torres et al., 2016). This is notwithstanding its production process that is both cheaper and easier. These PV cells are particularly useful if there are no restrictions on the roof space that is to be used.

## 3.2.1.4 Incident Radiation (Light) on PV Cells

There are three types of radiations that can be received by the surface of PV cells, Figure 3.3.

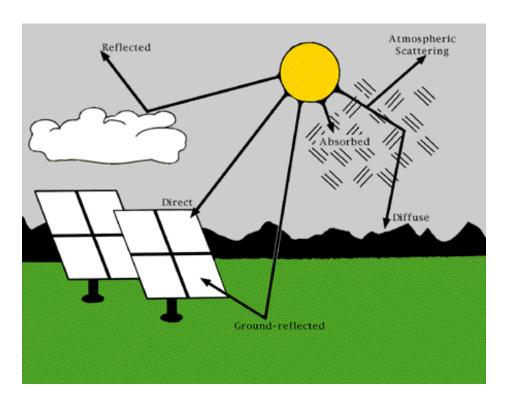


Figure 3.3: Radiation on PV cells (Houtz, 2014)

#### Direct Radiation

Also known as beam radiation, it is a form of solar radiation that travels on a straight line down to the earth's surface from the sun (Kamanga, 2014). The rays of the sun travel in a similar radiation. As such, it is possible for all the rays to be blocked at the same time and shadows created.

#### Scattered Radiation

This is the form of sun rays that have been scattered by atmospheric particles and molecules. However, it manages to reach the earth's surface. The total insulation is significantly decreased if the percentage of the scattered radiation is increased. In high areas, the percent of scattered radiation is quite high.

#### Reflected Radiation

This is a form of sun rays that are reflected off non-atmospheric surfaces, for example, the earth. It is estimated that asphalt and lawns reflect at least 4 and 25 percent of light, respectively (Kamanga, 2014). However, the PV solar panels are tilted away from reflecting materials and hence, reflected radiation does not cause an obstruction. The rays hardly strike the surface of the solar panels. Nonetheless, it is possible for the reflected radiation to be significantly great especially in snowy weather conditions. Fresh snow, for instance, reflects 80 to 90 percent of the radiation that strikes it.

## 3.2.1.5 Connecting the PV Cells

#### Series

A series connection is whereby voltage of the solar arrays is increased by connecting one solar module's positive to another solar module's negative. It is more or less like the connection done in batteries. Figure 3.4 shows the PV Cells that are connected in series (Kamanga, 2014).

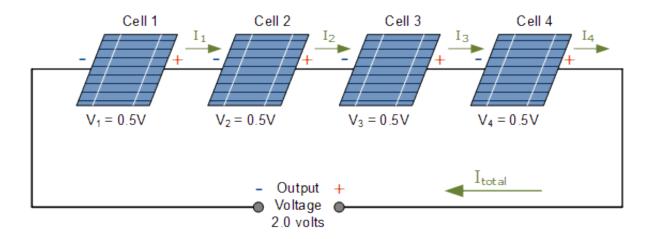


Figure 3.4: Series connection of PV cells

From Figure 3.4, the output voltage V<sub>out</sub> and the current I are given by:

$$V_{\text{out}} = V_1 + V_2 + V_3 + V_4$$
  
 $I = I_1 = I_2 = I_3 = I_4$ 

#### • Parallel

A parallel connection is whereby the current output of a solar array is increased whilst the voltage is kept similar (Kamanga, 2014). The positive modules are connected to each other whereas the negative modules are also connected to each other. Figure 3.5 shows the PV Cells that are connected in parallel.

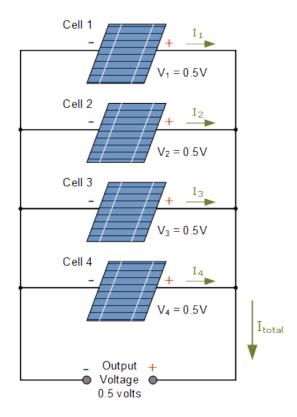


Figure 3.5: Parallel connection of PV cells

From Figure 3.5, the output voltage  $V_{\text{out}}$  and total current  $I_{\text{Total}}$  are given by:

$$V_{out} = V_1 = V_2 = V_3 = V_4$$

$$I_{\text{Total}} = I_1 + I_2 + I_3 + I_4$$

#### Compound of Series and Parallel

This form of connection is largely employed in huge solar panel systems (Kamanga, 2014). Both the series and parallel connection systems are utilized at the same time to improve efficiency. The compound series and parallel connection is shown in Figure 3.6.

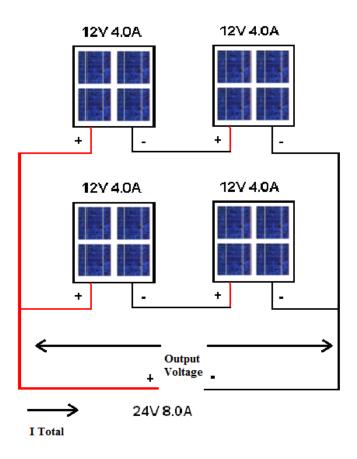


Figure 3.6: Compound of series and parallel connection of PV cells

From Figure 3.6, the output voltage  $V_{out}$  and total current  $I_{Total}$  are given by:

$$V_{\text{out}} = (V_1 + V_2) \parallel (V_3 + V_4)$$
  
 $I_{\text{Total}} = I_1 = I_2 + I_3 = I_4$ 

#### 3.2.1.6 PV Panel

A photovoltaic panel, which is shown in Figure 3.7, is comprised of a number of solar cells that are employed for the purposes of converting the energy obtained from the sun into electricity. More often than not, the photovoltaic panel is made from a semi-conductor of heat known as silicon. This is the same material that is utilized in the manufacturing of computer chips. The energy from the sun is absorbed by such materials in the form of photons. Also, electrons, which are basically minute particles that have been fully charged, and go through the photons in order to generate the required electricity.

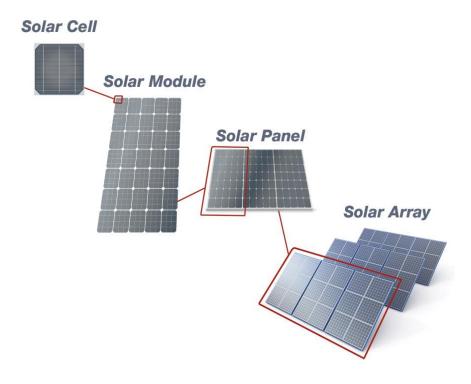


Figure 3.7: PV panel (Vijay, 2014)

### 3.2.1.7 How The PV Panel Works

The photovoltaic panel works by converting the energy obtained from the sun into electrical power (Tang et al., 2016). It solely relies on sunlight. Basically, the photovoltaic panel works by allowing light particles or photons to free electrons from any atoms that they are attached to (Tang et al., 2016). This process creates electricity. The photovoltaic cells that are inside the photovoltaic panel are employed for purposes of conversion of the energy obtained from the sun into electricity as it is shown in Figure 3.8.

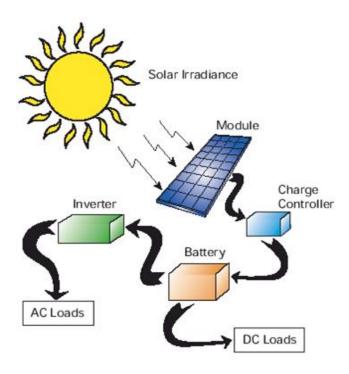


Figure 3.8: How the PV panel works (Green Energy, 2012)

#### 3.2.1.8 The Installation of the PV Panel

There are six major steps that are involved in the installation of the PV system; first, one must have a pre-installation plan (Tang et al., 2016). In this step, one carries out an inspection of the photovoltaic panel that has been purchased. Before the start of the installing, the purchased equipment is stored in an environment that is not only secure but also dry. Second, one is required to read the installation guidelines that are indicated in the equipment. The guidelines help in determining the correct measures that are to be undertaken while installing the equipment. Third, a safety plan is devised. This is to cater for possible dangers and harm that can arise during the installation process of the panel. Fourth, the area in which the photovoltaic panel is to be installed is staged and the logistics put into place. Fifth, all the tools that are needed for the process are assembled into one central location. Finally, the area for installing the panel is measured out and the mounts of the photovoltaic panel are mounted on it following the guidelines that had been set out (Tang et al., 2016).

#### 3.2.1.9 PV Panel Can Generate Electricity

Each and every photovoltaic panel is made up of two kinds of layers of semi-conductors, negative and positive. The light from the sun shines on the semi-conductors and causes the flow of electric current between the positive and negative points of the semi-conductor. The positive type of the semi-conductor eliminates the electrons that it comes into contact with. On the other hand, the negative type of the semi-conductor gathers all the electrons that have been eliminated by the positive type. It is the light from the sun that offers the necessary energy for the electrons to move from one point to another. Ultimately, this gives rise to the generation of electrical power. A large current will flow if the light intensity is quite high, whereas little current will flow if the light intensity is low. Hence, a lot of electricity can be produced during the sunny days, whereas little electricity is obtained during the cold days.

## 3.2.1.10 PV System Efficiency

In order to obtain the most power out of sunlight, calculating the efficiency of the PV cell system is required. However, the efficiency is not consistent due to variable factors such as the climate changes. The amount of sunlight being absorbed by the panels is affected by the weather fluctuations. For instance, the efficiency is going to increase in sunny days while cloud shades are most likely going to decrease the system's efficiency. Hence, before calculating the efficiency, the incident radiation flux should be determined along with the maximum desired power output. Moreover, the main factor in determining the efficiency is the area that the panel is occupying (Zakzouk,1984). The maximum efficiency of a solar PV system is given by:

$$\eta = \frac{P_{max}}{P_{in}} = \frac{V_{oc} * I_{sc} * FF}{P_{incident} * A}$$

where,

η: Maximum efficiency

• P<sub>max</sub>: Maximum output power (Watts)

• P<sub>in</sub>: Input power

• V<sub>oc</sub> : Open – cricuit voltage

• I<sub>sc</sub> : Short – circuit current

• FF : Fill Factor

• A: Surface area of the cell (m<sup>2</sup>)

• P<sub>incident</sub>: Light incident solar intensity (Watts/m<sup>2</sup>)

The fill factor is a measure of the quality of the PV cells. Fill Factor can be calculated as:

Fill Factor (FF) = 
$$\frac{I_{m} * V_{m}}{I_{sc} * V_{oc}}$$

where,  $I_m$  and  $V_m$  are the peak current and voltage, respectively.

#### 3.2.1.11 PV Installed in Global Market

The global market regarding the sale and purchase of solar photovoltaic panels is set to be higher. In 2015, the global market was utilizing at least 225 Gigawatts, which increased to 294.69 Gigawatts in the year 2016. China is currently the leading global country market in the installations of the solar photovoltaic panels. In 2015, China was able to install an approximate of 15.13 Gigawatts of photovoltaic panels. At the end of the year 2015, it is estimated that China has installed at least 43.48 Gigawatts. This is a significant increase as compared to the previous years, for example in 2011 when the installation capacity was quite low. The installations of solar power plants in China are done with the principal objective of boosting the use of green energy and to make adjustments to the energy mix that is currently dedicated to the use of coal. By promoting green energy, the country is able to achieve its goals and objectives in so far as sustainable development is concerned.

#### 3.2.1.12 PV Price

Photovoltaic solar panels cost between \$2.87 and \$3.85 per watt. A power plant that has a capacity of 5 kilowatts costs approximately \$10,045 to \$13,475 after tax. However, most of the companies that aid in the provision of solar energy do provide the consumers with incentives. The subsidies that are provided would be as much as 50 percent.

## 3.2.1.13 Methods of Improving the Efficiency of PV Cells

#### • Solar Cells Glazing

To ensure high level of efficiency, the photovoltaic solar panels need to be protected against harmful elements such as snow, rain, droppings of birds and hail. It is recommended to make use of either a low-iron glass or polycarbonate in offering such protection, as shown in Figure 3.9. This is because the two materials have at least 90 percent optical transmissivity (Goetzberger, 2006). Ordinary glass, on the other hand, decreases the electrical output by about 40 percent and thus it is not recommended.

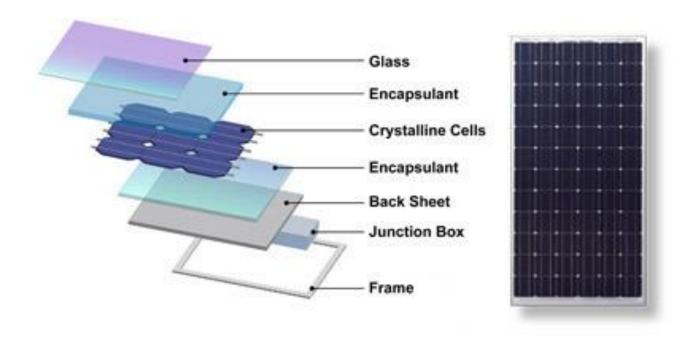


Figure 3.9: Solar cell glazing (Silicon from Dow Corning)

#### • Solar Panel Orientation

To obtain the greatest output, photovoltaic solar panels need to be positioned in a manner that is perpendicular to the rays of the sun (Goetzberger, 2006). Nonetheless, it is common knowledge that the solar panels installed on the top of the roofs follow the orientation and pitch of the roof. In other solar panels, the azimuth can be oriented southwards and its tilt can be adjusted accordingly so as to benefit from the sun available during winter periods. However, it is important to note that the energy from the sun is reduced during the winter due to the decreased sunlight period. This default is purely due to the fixed mode of orienting the solar panels. Hence, to improve efficiency, the solar panels can be designed in a manner that allows them to tilt freely and follow the direction of the sun, as shown in Figure 3.10.

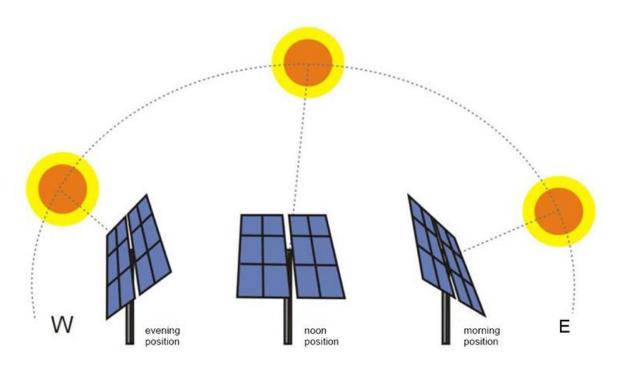


Figure 3.10: Solar panel orientation (Loeffle, 2013)

#### Solar Tracker

Solar tracking has been proven to be one of the effective modes through which the electrical power output can be enhanced. The principal objective of the tracker is to tilt the solar panel to ensure that they constantly face the direction of the sun. However, if the solar panels are quite huge, then it will be difficult for this task to be accomplished. This, therefore, means that the solar panels need to be of a manageable size so as to be easily rotated towards the sun to obtain heat from the sun energy. If the optimum tilt is not achieved, one can tilt the solar tracker as is shown in Figure 3.11 using manual means in order to attain the desired results.



Figure 3.11: Solar tracker (Bavaria Solarpark, 2004)

## • Solar Charge Controls

For the solar panels that make use of a battery system, it is important to have a solar charge control system to prevent the possibilities of overheating. The controller will be in a position to record the right ratio of voltage to charge in a battery and hence, enhance efficiency (Pathak et al., 2012). It ensures that no power is wasted so that the unutilized power is conserved for future use. This not only improves efficiency but also reduces the cost of using electricity.

## • Maximum Power Point Tracking Controller

This type of control system converts the excess power that is not in use into extra charge current (Pathak et al., 2012). The controller makes appropriate adjustments in order to maximize the amount of power that is transferred. The type of technology that it employs in carrying out this process is known as switch mode technology. Once the battery is fully charged, this control system turns off the photovoltaic panel, in Figure 3.12. Through such processes, the efficiency of the solar panel is greatly enhanced.

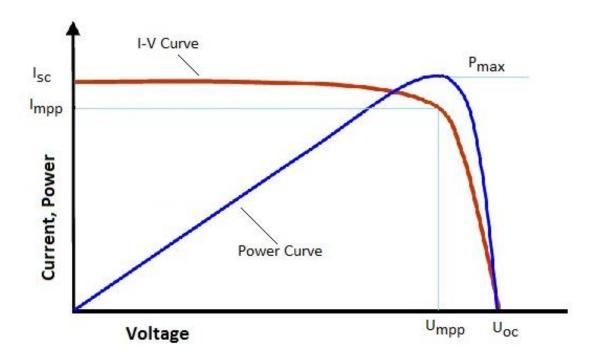


Figure 3.12: Solar PV characteristics (McFadyen, 2013)

#### 3.2.1.14 Problems of PV Cells

## • Probable Array Problems

Externally, the energy output of the PV cells can be reduced greatly by external problems such as module soiling and/or shade from huge trees. Module soiling is basically the dust that comes from air pollution locally. If the PV cells are not properly cleaned and maintained, at least 5 percent of the arrays can be lost daily. To solve this problem, one will be required to clean the arrays and trim the nearby vegetation from time to time. Animals can also cause external problems to the PV cells. For instance, rodents may damage the wires of the PV cell, birds can drop feces on the PV cells modules, and weeds can shade the PV cells. A solution to this is to install barriers that would prevent the rodents from reaching the PV cells. However, one should make sure that air is allowed into the PV cells in as much as there are attempts to keep the critters at bay.

Internally, there can be damage to the PV cells or module and as such, decreasing the output of the PV system. To avoid such kind of problems, one needs to visually inspect the array of the PV system at least once each year. Some of the problems that one can look out for include but are not limited to glass cracks, module burn spots, cell solder joint burns, and cell damage

#### Troubleshooting Tools and System Evaluation

In the event that the damage to the PV cell or module is invisible, it is important to evaluate the performance of the system with the aid of the built-in meter in the PV system's inverter. Through such a measure, it will be possible to identify any upcoming problems. Inefficiencies can also be detected by comparing the output of the system with the size of the array. The efficiency is often estimated to be between 70 and 80 percent. The remaining percentage is accounted for in the power losses as a result of module heating, module tolerance in production, and mismatch of the module. At other times, there can be also a drop in the wiring voltage, inverter inefficiency, and dust that can cause the drop in the system efficiency.

## 3.2.1.15 Advantages and Disadvantages of PV Cells

#### • Advantages of PV Cells

First, PV cells generate clean and silent electricity as no fuel is utilized. The absence of fuel from the system ensures that no harm is posed to the environment. It does not cause water or air pollution and hence, natural resources are not depleted, and neither human health nor animals are endangered. Second, PV systems are quiet, and they do not cause any form of noise pollution. Third, small scale PV systems can fit perfectly well in unutilized roof spaces of the already existing houses and buildings. Fourth, PV systems are quite reliable as they operate for long periods of time with little or no maintenance (Sayyah et al., 2014). It is for this reason that most of the satellites in the world are powered by PV systems in order to ensure constant efficacy. Fifth, sunlight is a reliable source of energy as it is both renewable and locally available. There is no need of incurring costs in importing the sunlight. As such, it decreases the environmental effects that are related to transportation. Additionally, it decreases our reliance on imported oil and its products. Solar energy cannot be simply depleted or altered unlike fuel that is either harvested or mined. Finally, the size of the PV system differs depending on the amount of energy need in any given circumstance. Therefore, the system can either be enlarged or made smaller depending on the amount of energy that one requires.

#### • Disadvantages of PV Cells

The process of production of PV systems utilizes some toxic chemicals such as arsenic and or cadmium. Nonetheless, the effects of such chemicals can be reduced by a proper recycling and disposal system. Second, unlike conventional energy sources, solar energy is relatively expensive to obtain (Sayyah et al., 2014). The high cost relativity is mainly due to the high costs incurred in manufacturing the devices used in PV systems. Equally, higher costs are incurred in the system's conversion efficiencies. However, with the ever-changing increase in the conversion efficiencies of the PV systems and the reduction in the costs of manufacturing the PV cells, it is possible that PV will develop a higher competitive advantage in the market as compared to the existing conventional fuels. Finally, the energy produced from the sun varies depending on the amount of sunlight that is available (Sayyah et al., 2014). For instance, during dark or cloudy days, the solar

systems may not be able to produce any form of power. This will cause energy shortages especially in regions where people rely solely on solar energy.

## 3.2.2 Solar Thermal Electricity

A solar thermal power system collects and concentrates sun energy to generate high temperature heat that is necessary to create electrical power. The system contains two main devices: reflectors and receivers (Latunussa, 2016). A reflector is basically utilized in capturing and focusing the sunlight into a given receiver. There is also a heat transfer fluid which is put under heat and then distributed in the receiver for the purpose of producing steam. The steam is later transformed into mechanical energy with the aid of turbines that power generators to create electricity as it is shown in Figure 3.13. It is important to note that there exists a tracking system that basically focuses the sun energy onto the receiver during the day, keeping in mind the changes in the position of the sun. A storage system known as thermal energy can also be utilized to store excess energy during hot days so as to be used during the night or cloudy days.

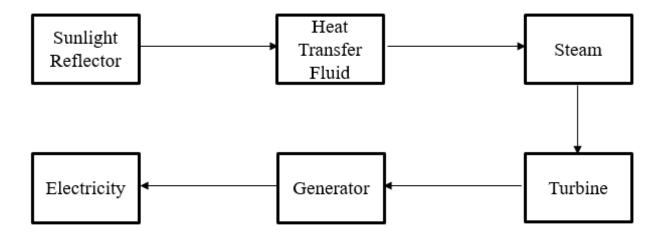


Figure 3.13: Solar thermal electricity system

## 3.2.2.1 Types of Solar Thermal Energy

## • Linear Concentrating System

This type of system collects the sun energy with the aid of U-shaped, curved, rectangular and long mirrors. Inside the mirror there is a long tube/receiver that covers the entire length of the mirror and onto which the sunlight is focused. The concentrated sun energy heats a fluid that is freely flowing inside the tubes. The fluid is later transported to a designed heat exchanger for purposes of boiling water in a modern-day steam-turbine generator. The end result of all this is the production of electricity (Latunussa, 2016).

The shape of the system allows the mirrors to follow the movement of the sun in all directions through the entire day and concentrate the sun energy continuously onto the tubes. Its large field of collectors positioned in parallel rows allows for the maximization of the energy collected from the sun.

The linear concentrating system can either be a parabolic trough or a linear Fresnel reflector. The former is characterized by the positioning of the tubes along the focal line of each and every parabolic mirror. On the other hand, the latter has one tube located above a number of mirrors to create room for the mirrors to easily move in tracking the movements of the sun throughout the day.

#### • Parabolic Trough

A parabolic trough is composed of a huge parabolic-shaped tube whose main purpose is to focus the rays of the sun onto a given receiver pipe that is strategically positioned at the parabola's focus (Latunussa, 2016). To ensure that the sun is continuous being focused, the trough tilts its angle with the change in direction of the sun. Figure 3.14 shows a parabolic trough. Its configuration allows to focus the rays of the sun 30 times above its normal levels of intensity. Hence, its temperatures of operation are estimated to be 750°F or higher. All this occurs inside the receiver tube that is stationed along the trough's focal line. This type of system is the largest in the world and is utilized in California's Solar Energy Generating System that was constructed in 1984. The system is also in use in three other large thermal power systems as follows: California Mojave solar project, Arizona Solana generating station, and California genesis solar energy project.

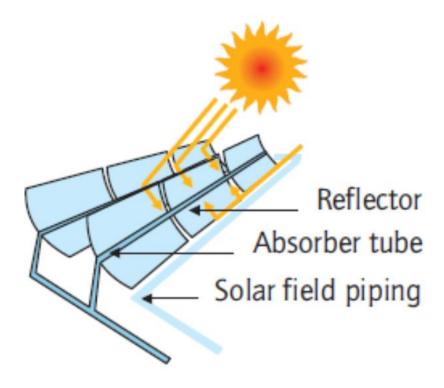


Figure 3.14: Parabolic trough (Concentrated Solar Power, 2013)

## • Linear Fresnel Reflector System

A linear Fresnel reflector system is more or less similar to the parabolic trough system. It has reflectors that focus the rays of the sun onto a certain receiver that is positioned on top of the reflectors as shown in Figure 3.15. The reflectors utilize the Fresnel lens impact. Such an effect allows for a focused reflector containing a huge aperture and diminutive focal length. The system has the capacity to concentrate the rays of the sun at least up to 30 times their normal power. The numerous receivers contained in the system make it possible to alter the inclination of the mirror in order to reduce their possibility of blocking access to sun rays by the neighboring reflectors. As a result, it enhances the efficiency of the system and decreases both the costs and requirements of the materials that are used (Latunussa, 2016).

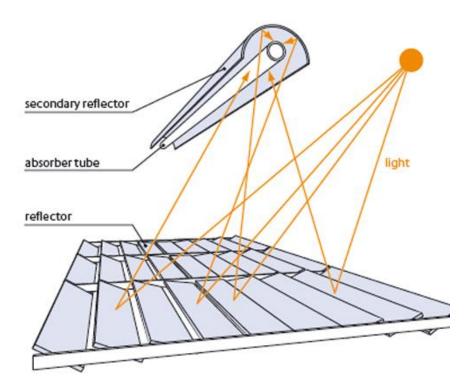


Figure 3.15: Linear Fresnel reflector (Dinter, 2013)

#### • Solar Power Tower

The solar power tower has a huge field composed of flat mirrors that track the sun and are known as heliostats. Reflection and concentration of the sunrays onto the receiver is done by the mirrors on the tower's apex. The solar power tower is shown in Figure 3.16. Water is the main element that is used in the heat-transfer fluid. However, molten nitrate salt can be also used due to its superior modes of transferring the energy and its large capacity to store the energy generated. In the United States, the following solar power towers are currently in use: Ivanpah solar power facility, Crescent Dunes solar energy project, and Sierra sun tower (Latunussa, 2016).

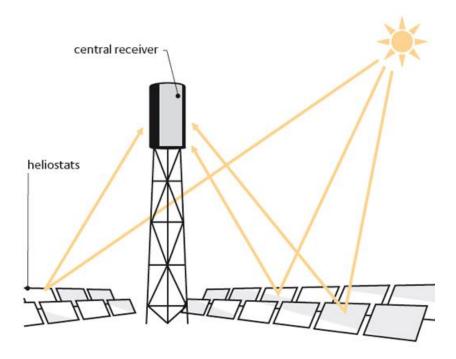


Figure 3.16: Solar power tower (Information for Renewable Energy Sources)

#### • Solar Dish System

The solar dish system resembles a huge satellite dish. It is composed of a number of minute flat mirrors that are shaped into a dish in order to decrease the costs that are incurred (Latunussa, 2016). The surface of the dish directs and focuses the sunrays onto a receiver that absorbs and accumulates the heat as shown in Figure 3.17. It later transports the heat into an engine generator. The fluid inside the receiver is heated to allow for the movement of the pistons and hence, generate mechanical power. The power is used in running a generator and ultimately generating electricity.

A solar dish system is endowed with the capacity of pointing directly to the sun. The solar energy is then concentrated at the central point of the dish. It is estimated that its fluid temperature is approximately 1,380°F. It has a concentration ratio that is much higher as compared to concentrating systems that are made in a linear manner. The dish can be easily used in remote areas due to the ability to mount the power-generating device of dish at the focal point. It is also possible to gather energy from various points so as to convert it into electrical power.

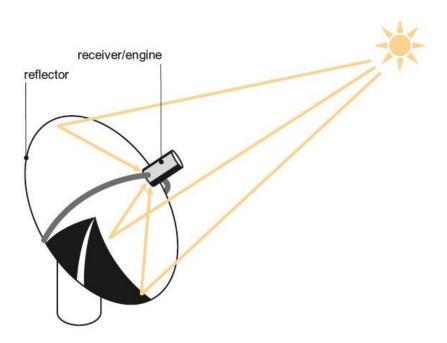


Figure 3.17: Solar dish (Dinter, 2013)

# 3.3 Comparison between Photovoltaic System and Solar Thermal Electricity

It is important to report the differences between the Photovoltaic system and Thermal electricity. A discussion of this follows,

## 3.3.1 Technology

The solar thermal electricity and photovoltaic systems have different operating principles. The photovoltaic system is basically dependent on the photovoltaic effect whereby a photon impacts a designed surface generating electrons. On the other hand, solar thermal electricity makes use of the sun energy for purposes of heating a fluid (Labouret, 2010). Either water or a different fluid can be used taking into consideration the specific application.

The photovoltaic effect is only available in semi-conductors after the production of an electric current on exposure to light. This occurs after specialized chemical procedures. The configuration of the semi-conductors is such that they are thin layers that match the principal component of the solar cells. It is the core element of the PV cell system that generates direct current electricity. The PV cells are incorporated into solar panels so as to attain the desired voltage and current. The grid-connected systems make use of an inverter aiming at of converting the alternating current into direct current.

The operating of the solar thermal electricity working principle is not as sophisticated as that of the PV cells. Nonetheless, its significance is more or less the same photovoltaic effect. The sun energy is used to directly heat water or other fluids that are used. The conversion of the energy into electricity occurs at diverse devices and this is only dependent on the temperature ranges of heating the water or fluids. Collectors that utilize medium or low temperature can be either evacuated tubes or panels made up of flat panels. Collectors that utilize high temperature have intense solar systems, for instance a solar tower, parabolic trough, dish or Fresnel reflector.

## 3.3.2 Utilization

The PV cells that are used in residential places generate direct current electricity directly from the sun energy. Currently, there exist three different types of PV systems that are used in residential areas as follows: "Stand-alone", "Grid-connected", or "Off-grid". Off-grid and Stand-alone PV cells are only utilized for domestic consumption, for example water heating and lighting (Labouret, 2010). A battery system is necessary for them to work efficiently. The battery system separates the generation of electricity from the consumption of electricity. Grid-connected PV cells are used for feeding the grid through the use of inverters (Labouret, 2010).

Solar thermal electricity systems that are used in residential places are mostly utilized for heating water. They work together with other heating systems such as fuel or gas. The working mechanism begins once the water temperature falls below a given value. This is especially the in countries that experience a cool type of climate throughout the year. In addition, these systems can be utilized for purposes of space heating, for example as is done in Sweden.

## 3.3.3 Design

The design of the PV cells system is much simpler as compared to that of the solar thermal electricity system. The PV cell system makes use of numerous solar panels that are either arranged in a parallel or series manner (Labouret, 2010). For the solar thermal electricity system, energy has to be transmitted into a generator from hot water or hot fluid. Accordingly, it is bound to have a complex design.

# 3.3.4 Versatility and Lifespan

The PV cell system is known to be highly versatile as compared to the solar thermal electricity system. The PV cell can power numerous appliances. However, the solar thermal system is restricted to only the heating of water and space. The lifespan of the PV cells is also known to be longer as opposed to that of the solar thermal electricity system (Labouret, 2010).

# 3.3.5 Storage

When using the solar thermal electricity, it is possible to store the excess energy that is generated. This is mainly due to the fact that solar thermal electricity systems have no capacity of converting the energy of the sun into electrical power directly. Additionally, the system has a water tank in which heat can be stored for future use. On the other hand, the PV cell systems have no capacity to store the sun energy (Labouret, 2010). As such, it leads to inefficiencies as it depends on the patterns of the sun. Hence, it would be proper to argue that the thermal power plant is reliable and uniform as compared to the PV cell power plant.

# Chapter 4

# COMPARSION BETWEEN SOLAR POWER FARM AND NATURAL GAS IN KUWAIT

# 4.1 Cost of Energy

A finding has been made that using natural gas as a power source may be a more conventional and quicker way of obtaining energy for Kuwait, yet there is sufficient evidence showing that converting to Solar Power Farms that operate using the photovoltaic technology will provide a better result in the long-run, cost wise.

## 4.1.1 Solar Energy

The cost of solar energy in Kuwait is subject to discounts that are offered by the providers of the solar panels. This is equally in the objective of the government of Kuwait to establish a long-standing plan in which discounts can be provided at a percentage of 6.7. The current discount when one purchases solar panels is between 0 and 20 percent. However, if the government was to offer the 6.7 percent discount, then the people in Kuwait will be in a position to save reduce expenses each year.

## 4.1.2 Kuwait Natural Gas

Natural gas in Kuwait is relatively expensive as compared to the solar energy. This report shall make use of the Kuwait Dinar per one million thermal units in Britain. In August 2016, the cost of the natural gas was KD 0.84. In September 2016, the cost was KD 0.90. This was a change

of 6.46 percent from the previous month. In October 2016, the cost was KD 0.89 and a change of -0.31 percent. In November 2016, the price was 0.76 and a change percentage of -14.95. In December 2016, the cost was KD 1.09 and a change percent of 44.12 percent. Finally, in January 2017, the cost was estimated to be KD 1.00 and this was a percentage change of -8.99 from the previous month. From these figures, it is evident that the price of natural gas is very high, and probably beyond the affordability of some members of the public. Equally, the figures are not constant so that someone can determine the exact amount of money that he or she is likely to put into use in any given year. This occasion challenges especially in budgeting for the same as the prices are ever changing. It would be recommended that the utility companies in Kuwait come up with at least an estimate figure that the people can rely on in making a decision whether to use natural gas or solar energy as a form of electricity. It will also aid in the making of sound financial decisions. This is not only useful in Kuwait but also in other parts of the world that intend to make a comparison between the use of solar energy and natural gas.

## 4.2 Effect of Kuwait Natural Resource

# 4.2.1 Solar Energy

The energy obtained from the sun is a renewable form of energy. It is clean and not easily depleted. The sun rays are freely available for use in the natural world. Kuwait has an abundant amount of solar energy that it can use each and every year without depleting this natural resource. Its availability makes it possible for Kuwait to establish a number of solar plants through which electrical power can be supplied to all residents instead of simply relying on natural gas. It is important to note that Kuwait is a relatively desert region and hence, lots of sunlight is available in it.

With the use of the correct technology and proper solar panels, the country can be in a position to harness the sunlight and generate enough electricity. This is particularly useful due to the fact that the demand for electricity in the country has been growing at a tremendous rate. The natural gas currently available is not adequate to serve the needs of all the people in the country. It needs to be supplemented and sunlight seems to be a very viable option in doing so. In addition,

the use of solar energy in Kuwait will not take up much space and hence, lots of profits can be made whilst using minimum resources. In so far as sustainable development is concerned, solar energy has no impact on the environment. It does not cause any form of pollution, and does not lead to global warming. As such, it can be utilized to attain the goals and objectives of the nation for sustainable development. It will aid the country in enhancing its profitability and competitive advantage among other global players.

## 4.2.2 Kuwait Natural Gas

The natural gas that is available in Kuwait is a non-renewable form of energy. Once it has been utilized, it cannot be renewed. Additionally, a lot of costs are incurred in the process of production and distribution of the natural gas. As the population grows, the demand for electricity also grows at a high rate. Hence, constant use of the natural gas will deplete this natural resource completely from Kuwait. In as much as Kuwait has a number of oil fields, they are culpable of being depleted if the current mining is continuously taking place. In the future, it is possible that the upcoming generations in Kuwait may not have in their possession any natural gas that they can benefit from. To ensure that the future generations are equally catered, as far as the natural resources are concerned, it is the responsibility of the present generation in Kuwait to ensure that the available natural resources are utilized in an effective manner so that no form of wastage is done. It is through such measures that the future generations can also have natural resources to make use of for carrying out their various activities.

# 4.3 Capacity

Capacities may vary depending on the type of power, which the plant is using to generate electricity.

## 4.3.1 Solar Energy

Presently, the supply for solar energy in Kuwait is 2 Gigawatts. This is despite the demand for such energy that is estimated at 12 Gigawatts and is set to rise to 30 Gigawatts by the 2025 year. However, the Ministry of Electricity and Water in Kuwait has proposed plans through which it would be able to create a minimum of 4.5 Gigawatts of solar energy by 2030. This will supplement the available capacity of the natural gas in order to meet the demands of Kuwait residents regarding the distribution of electrical power.

## 4.3.2 Kuwait Natural Gas

Power plants are considered part of the individual power producers; which means that the plant is capable of increasing or decreasing its power output at any time. Those kind of power plants have a few factors that affect their capacity. That includes the ability of their internal parts to sustain continuous energy output for a period of time. Also, factors like lack of fuel or maintenance are contributors to reducing the capacity factor of the plant. In addition, the components that are inside the station require energy for them to operate, resulting in a lower actual output supplied to the electrical grid than both the rated output and the generator capacity. The current capacity of the natural gas in Kuwait is 14 Gigawatts. However, the government intends to develop at least 31 Gigawatts of natural gas by the year 2030.

# Chapter 5

# USING SOLAR ENERGY IN KUWAIT

Among all the countries of the world, Kuwait can be said to have one of the greatest demand for electrical power. Its per capita rate of energy consumption is quite high owing to four major factors. First and foremost, Kuwait has a combination of weather conditions that are very extreme. Second, the government of Kuwait offers its citizens high subsidies in so far as electricity is concerned. Third, the general population of Kuwait has been constantly growing over the years and hence, the great demand. Last, the plants available in Kuwait for desalination of water make use of a lot of energy and as such, their energy-intensive status can only allow them to function properly if there is a lot of electricity.

Kuwait witnessed an increase in the demand for electrical power up to two times its normal demand between the years 2003 and 2013. To cater for this increase, the government of Kuwait has a plan in which it considers entering into a partnership with global energy companies in a three-phase energy project. Its principal objective in doing so is to generate at least 2,000 Megawatts of electricity using renewable energy sources. The stated two thousand Megawatts is just a fraction, approximately 15 percent, of the total needs of energy that the country requires. In the initial phase of the process, Kuwait intended to establish an energy park of at least 70 Megawatts and the same was to be completed in 2016. The process was undertaken in one of the deserts in Kuwait known as Al-Shagaya as shown in Figure 5.1 and the area of the power facility is 39 square miles (or rather 100 square kilometers). The desert is on the west side of Kuwait City, approximately 100 kilometers away. It borders the Kingdom of Saudi Arabia and Iraq. In the second and third phases, the country intended to establish projects that will have the capacity to generate 930 Megawatts and 1000 Megawatts of electrical energy, respectively. Plans are underway to ensure that solar projects are completed.



Figure 5.1: Al-Shagaya project (Reve, 2014)

Using solar energy in Kuwait will require collaboration between various bodies of the government and other private bodies. The said bodies will work hand in hand towards achieving similar objectives of supplying enough solar energy to all the residents of Kuwait. They will also establish goals and objectives to the effect that sustainable development will be upheld in all the processes of generating energy from the sun. Some of these bodies are as discussed below:

## • Kuwait's Ministry of Electricity and Water

Currently, Kuwait's Ministry of Electricity and Water is the only body that supplies electricity and water to the people residing in Kuwait. In addition to this, it is given the mandate of being the central body to regulate and manage both the demand and supply of electricity in the nation. Considering the ever-increasing demand for electricity in the country, it would be appropriate to argue that the country is bound to face a number of challenges if only the Ministry has the mandate. It needs to partner with other bodies present in the country who share the same objective of offering clean sources of energy and meeting the demand for electrical power by supplying adequate

amounts of electricity. It is only through such partnerships that the nation can enhance its profitability globally and develop a competitive advantage over other nations.

In establishing solar power plants in the government of Kuwait, the Ministry of Electricity and Water is one of the government bodies that can significantly aid in ensuring that the projects are established. It is the ministry that will determine the energy needs of the individuals and endeavor to meet them from time to time. Being a body of the government, it can also assist in entering into negotiations with like-minded companies that are willing to offer solar panels to the residents of Kuwait.

#### Kuwait Institute for Scientific Research

The above institute came into being in 1967. The Arabian Oil Company Limited based in Japan played a major role in establishing the institute. This was mainly done to fulfill various obligations that had been bestowed upon it under a given concession agreement that it had entered into with the government of Kuwait. The institute is a self-governing public institute and it received this status through the 1981 Amiri Decree, which is the higher authority in Kuwait. Its main objective is to conduct applied scientific research for purposes of aiding in the development of the national industry. Some of the studies that it carries out include - but are not limited to - environmental preservation measures, discovery of resources available naturally in the country, methods of exploiting various agricultural activities, methods of promoting wealth of water in the nation, and energy and water sources.

As regards to the provision of solar energy in Kuwait, this institute would be quite helpful. It can do in-depth research specifically focused on how Kuwait can make use of the solar energy to offer sufficient electrical power to its residents. In doing this research, it can enter into a partnership with the Ministry of Electricity and Water so as to make viable plans in which its research can be utilized. The institute can also identify regions in which the equipment and materials for generating solar energy can be stationed so as to generate electricity. The electricity generated from such solar plants can be fed into an established national grid to feed the citizens of Kuwait in various parts of the country.

#### • Al-Kharafi National

Al-Kharafi national is a high-standing infrastructure developer in Kuwait. Some of its projects include, but are not limited to, water; reclamation and treatment of wastewater; cooling of the district, managing solid waste and high-end recovery of oil. Additionally, it is one of the most employed contractors and service provider for the management of infrastructural facilities in so far as water, electrical power, chemicals and petroleum are concerned. It not only works in the government of Kuwait but also in other states in Africa and the Middle East. The ministry of electricity and water, can employ the services of Al-Kharafi national so as to better manage its facilities of solar energy. Al-Kharafi national can also advise the government on the viable equipment and other materials that it can invest in so as to establish sufficient solar energy to meet its energy demands. By partnering with Al-Kharafi national, the government can be able to establish numerous grids and power stations specifically set aside for solar energy production.

## • Solarity Company in Kuwait

Solarity company was principally established with the objective of spreading the innovation that has been brought about by the modern-day world. It aims to ensure that whilst spreading the innovation it maintains an eco-friendly environment throughout the Middle East and particularly the country of Kuwait. In the sector of provision of solar energy, Solarity Company in Kuwait is involved in three major streams as follows. First, there is a retail stream that is managed through the company's showrooms. Plans are underway to ensure that the said showrooms are covered throughout the Gulf Cooperation Council region within the shortest time possible. The showrooms are basically retail stations that aid consumers to identify a number of products as regards to solar energy and choose the most convenient and affordable for them. The solar accessories available in these showrooms are designed for pumping, heating, cooling and lighting. So far, Solitary company has been in partnership with high-end manufactures of solar equipment and devices. As such, it has been able to offer the consumers high quality products that meet their needs and wants at any given point in time. By doing so, it has been able to attain customer satisfaction and fulfillment. The customers have gained a lot of trust in its capacity to offer all the needed solar equipment.

Second, there is a stream that acts as a wholesaler. It sells solar products for its partners in wholesale not only in the private but also in the public sector. It carries out the process of distribution of the products to all the destinations in which they are required. This is a strategic move that is aimed at increasing the number of sales that the company does in any given day. In addition, the move aids in the promotion of innovative products that preserve the environment at all times. This ensures that no harm is posed into the environment and hence, helping in attaining sustainable development in Kuwait.

Third, it is the installation of the projects. The company is well equipped with skilled and experienced human resources, particularly solar energy engineers who help it in meeting its goals and objectives. The engineers have in-depth knowledge in the manufacturing of solar equipment and other related solar power plants. The engineers also have the ability of designing and implementing power systems for solar energy. Hence, the government of Kuwait can make use of these engineers to widen the scope of its solar energy provision in the country as it will be working with the best human resources available.

#### Kuwait Solar Industry Association

The Solar Gulf Cooperation Council Alliance has plans underway for the purposes of establishing an affiliate body in Kuwait known as the "Kuwait Solar Industry Association." The main objective of the association is to create novel business and job opportunities regarding solar energy in the country of Kuwait. It is also intended to aid in collaboration opportunities in all the nations in the Gulf Cooperation Council. This is a great association that Kuwait can use in its endeavor to provide solar energy to the citizens and residents of Kuwait at all times of the year.

## • Al-Abdaliyah Intergraded Solar Combined Cycle Plant

Apart from the above-mentioned public and private bodies that have the potential of providing solar energy in Kuwait, the country has already established one of the largest solar power plants in the country known as Al-Abdaliyah integrated solar combined cycle plant as it shown in Figure 5.2. To ensure that the power plant is successful, Kuwait has signed a consultancy project with HSBC company. The contract was entered into on behalf of the government of Kuwait by the "Technical Office for Examining Development Projects and Initiatives" in Kuwait.



Figure 5.2: Al-Abdaliyah ISCC plant (Printing 3D Today, 2013)

The above-mentioned solar power plant is estimated to be 60 Megawatts. The total cost of building the same is approximated at KWD 926.75 million. The technology that has been employed in establishing this power plant is known as parabolic trough. The entire project, once completed, it will account for at least 60 Megawatts of the whole amount of electrical power that is used in Kuwait.

The solar power plant has been established by Kuwait's private sector and it is recorded in Law 2008/7. At the national level, the company that initiated the project has put on record various feasibility studies of the unparalleled venture. The project's technical team will work in close cooperation with the Ministry of Electricity and Water in Kuwait so as to float the solar power venture for purposes of tendering. This is done in accordance with the government of Kuwait's regulation regarding public private partnership programs.

At the point of completion, it is indicated that the solar power plant will contribute to most favorable use of the natural resources available in Kuwait. Some of the share-holding companies in Kuwait will be utilized for purposes of executing this project so as to reap the benefits associated with it. Additionally, it is important to note that such a measure is intended to be in tandem with the approach taken by the government of Kuwait in granting various incentives for purposes of private-public partnerships. Ultimately, this will be quite significant in meeting the ever rising demands for energy in Kuwait.

# Chapter 6

# CONCLUSIONS AND RECOMMENDATION

## 6.1 Conclusions

From the foregoing analysis, it is evident that solar energy, as a renewable source of energy, is an alternative and novel option that the government of Kuwait can put into consideration to meet its demands for energy. Using a natural resource such as natural gas, it cannot be depleted and hence, can be available for use as needed. Solar energy is obtained directly from the sunlight during the day and the excess can be stored in an established battery system for later use. Apart from the provision of electricity, the above report has noted that solar energy can be also utilized for the purposes of heating and sea-water desalination.

The energy obtained from the sun is not only clean but also renewable. It does not cause any form of pollution into the environment. All what that needed is the correct equipment such as solar panels that can be used to convert the rays of the sun into energy and ultimately electricity. For one to make maximum use of the solar energy, a battery system is equally needed as the sun is only available during the day. The energy stored in these batteries can be utilized at night or during the cold seasons. Basically, solar energy will be here with us for a long time to come. The Kuwait government needs to establish a viable plan through which it can harness the energy from the sun to meet the country's demands for energy.

## 6.2 Recommendations

The consideration of switching to a new renewable energy source is strongly advised. Investing time, research and money in Photovoltaic (PV) Solar Farms and scattering them around the unpopulated desert areas would be a smart move for a nation that is considered to be one of the biggest in oil production. A team of solar-panel experts should be hired to educate engineers about the technology and help draw out plans for future projects. It would cut costs down and act as an economical booster, creating more jobs and introducing a new field, diversifying the

country's energy options, increasing its resource stability and availability. That will lead to a decrease in consumer waste, increase the volume of resources for sale and it will slowly but surely decrease fossil fuel emissions, making it environment-friendly.

# References

- Beran, M., "Can Photovoltaic Solar Panels Be Calibrated To Monitor Solar Radiation?," Weather, Vol. 68, No. 6, pp. 157-161, 2013.
- Boxwell, M., Solar Electricity Handbook. 1st edition, Ryton on Dunsmore, Warwickshire, U.K., Greenstream Publishing, 2014.
- Chua, G., "Sunny side up for solar hot water," Architecture And Design. N.p., 2013.
- Crystal, J., "Kuwait: The Transformation of an Oil State," Vol. 11, Routledge Publishing, 2016.
- Dinter, F., "Solar Thermal Power and Their Advantages" Stellenbosch University, 2013.
- Einav, A., "Solar Energy Research and Development Achievements in Israel and Their Practical Significance," Journal of Solar Energy Engineering, Vol. 126, No. 3, p. 921, 2004.
- Goetzberger, A., "The Global Significance of Solar Energy Supply," Energy Materials, Vol. 1, No. 1, pp. 20-21, 2006.
- Houtz, B., "What is Solar Tracking?," About Solar Tracking, 2014.
- Kamanga, B. et al. "Optimum Tilt Angle for Photovoltaic Solar Panels in Zomba District, Malawi," Journal of Solar Energy, pp. 1-9, 2014.
- Labouret, A., Solar Photovoltaic Energy. 1st edition, Stevenage, IET, 2010.
- Latunussa, C. et al, Analysis of Material Recovery from Photovoltaic Panels. 1st edition, Publications Office, Luxembourg, 2016.
- Loeffler, M., "Orientation of Solar Panels." One Fridge off the Grid, 2013.
- McFadyen, S., "Photovoltaic (PV) Electrical Calculations," My Electrical Engineering, 2013.
- Newkirk, M., "What are Mono silicon, Poly-Silicon and Thin-Film Solar Panels?," Clean Energy Reviews, 2014

- Papageorgas, P. et al, "Smart Solar Panels: in-Situ Monitoring of Photovoltaic Panels Based on Wired and Wireless Sensor Networks," Energy Procedia, Vol. 36, pp. 535-545, 2013.
- Pathak, M., Pearce, J., and Harrison, S., "Effects on Amorphous Silicon Photovoltaic Performance from High-Temperature Annealing Pulses in Photovoltaic Thermal Hybrid Devices," Solar Energy Materials and Solar Cells, Vol. 100, pp. 199-203, 2012.
- Reve, "Kuwait: A Concentrated Solar Power (CSP) Market Worth Entering?," Wind Energy and the Electric Vehicle, 2014.
- Sayyah, A., Horenstein, M., and Mazumder, M., "Energy Yield Loss Caused by Dust Deposition on Photovoltaic Panels," Solar Energy, Vol. 107, pp. 576-604, 2014.
- Tang, W., Wu, J., and Chao, X., "Power Supply System Based on Photovoltaic Solar Panels and Current Transformers," Advanced Materials Research, Vol. 816-817, pp. 1235-1238, 2013.
- Torres, N. et al. "The Effect of Shading on Photovoltaic Solar Panels," Energy Systems, pp. 400-410, 2016.
- Vijay, G., "Construction of Solar Panel," 2014.
- Zakzouk, A., Mujahid, A., and El-Shobokshy, M., "Performance Evaluation of Photovoltaic Silicon Cells Under Concentrated Sunlight," IET Journal & Magazines, Vol. 131, No. 2, pp. 66-72, 1984.
- "Bavaria Solarpark," Direct Industry, 2004.
- "Green Energy How Solar Panel Works," Energy Solutions, 2012.
- "Information for Renewable Energy Sources," EAC Electricity Authority of Cyprus, 2012.
- "Kuwait," U.S. Energy Information Administration Marcon International, Inc.
- "Kuwait Signs Contract with HSBC for Consultancy for Al-Abdaliya CSP Plant," Printing 3D Today, SACM, 2013.

"Concentrated Solar Power," The Energy Backyard, 2013.

"The Science of Solar: Solar Energy – The Basics." Silicon from Dow Corning.