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Solar Systems Analysis and Estimation for Buildings in Bahrain and GCC Countries

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Abstract: The high electricity demand and consumption of in Gulf Cooperation Council (GCC) countries show that alternative ways of energy production have to be explored and developed. The renewable resources of energy applications should be addressed, tested and evaluated in the GCC region including the solar energy systems approach. In the present paper we identify and present the fundamental parameters for the solar systems installation in GCC, the influence of the local environmental conditions and the panels' characteristics and efficiency for this certain region. An extended investigation is presented concerning the characteristics of the panels' types, the orientation and tilt angle, the influence of dust, humidity and climate temperature and the real efficiency of the panels' estimation. The efficiency and power estimation is analysed by an alternative empirical approach, giving particular interest to the specific factors that are responsible for the efficiency drop. It is concluded that the solar systems application can be high beneficial for the Bahrain region, if the installation is developed according to the specific climate conditions as the dust precedence in the atmosphere or the temperature on the cells during the operation. This type of environmental power production solution can be cost efficient and sustainable, providing to the region an alternative solution for the electricity production.

Keywords: Renewable Resources, PV Systems, Solar Energy, Panels' Efficiency, GCC Countries

1. INTRODUCTION

As the global electricity demand is rapidly increased, alternative ways of energy productions are explored and developed towards to the goal of cost efficient and environmental friendly solutions.

The main operation and performance of the renewable solar energy sources is based on the sun existence and the energy of solar irradiance, which reaches the earth. The creation, development, and conservation of life on Earth are due to the sun. The sun provides the earth continuously large amounts of energy, which we utilize by a variety of ways. The sun maintains the known natural water cycle with direct heating and evaporation of the sea water, creating lakes and rivers and then chutes which it give us the necessary energy. The movement of the air masses in the atmosphere and the utilization of wind energy are observed again due to sun. The sun is also responsible for the creation of marine waves that provide to us the energy of waves. With the development of flora and the utilization of various plant products through a combustion process we have an additional energy. In recent decades, after the decline in stocks of oil and the environmental impact of traditional energy sources, the international community is trying to use more soft power based on utilization of energy provided by the sun.

The renewable resources of energy development seem to be more necessary than ever at the moment that the electricity consumption is growing rapidly. The European Union's energy consumption is expected to grow by 0.7% to an annual rate up to 2030 [1]. At the fourth annual report for 2013 the BP Energy Outlook 2035 reveals that global energy consumption is expected to increase to 41% from 2012 to 2035 [2]. Also in the world petroleum congress had been held in Moscow, they said through the report titled «BP Statistical Review of World Energy 2014» that renewable energy sources accounted for over 5% of global electricity generation for the year 2013, while the share of photovoltaic systems was 33% [3]. The greatest demand for electricity in accordance with BP expected from emerging economies of China and India. The demand of the renewable energy applications development or in particular the utilization of photovoltaic systems in the Middle East is quite high as energy savings can be achieved both in economy and geological level.

The Gulf Cooperation Council (GCC) Countries intent to invest even more to the renewable resources of energy to the near future, although the oil and gas production is still in a high level. However, they strongly believe that the

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environmental energy friendly solutions development is beneficial and essential for their countries and they intent to invest even more to this direction. The six GCC countries of Saudi Arabia, United Arab Emirates, Kuwait, Qatar, Oman and Bahrain cover their energy needs through the oil and gas production [4], while the electricity consumption in each country is comparatively high, mainly due to the air-conditioning function demand. The renewable energy projects development was not so encouraging due to the low price of electricity in this way that any investment to the wind or solar energy is not sustainable and not profitable at these countries. However, as the energy crisis receives high evolution through the entire planet, the GCC countries have been influenced and that is why, sustainable energy solutions have to be developed according to their particular environmental characteristics and geographical location.

The geographical coordinates - location of the GCC countries provide them a high solar potential and good solar energy exposure. Several projects have been developed in this area and it seems that the necessary conditions exist in order to invest in this type of renewable source. Many researchers have noticed the particularities of this area and they have studied the parameters of the solar energy systems applications, since long, as Patlitsianas [5], who tries to set the appropriate conditions of this type of projects according to the available companies, the policies and the cost. Chehid [6], even since 2003 focused on the need of the Arab Countries to invest in solar and wind energy presenting some basic relating data and showing that this investment will be beneficial and efficient enough.

As Alnaser [7] present the current situation in renewable energy projects in the region, it seems that the relating projects exceed 600MW, where Kingdom of Bahrain has its significant role. The development of the sustainable energy is proved by the CO2 emissions reduction in GCC which has to take place even further due to the rapid financial development of each country as well [8].

Most of the researchers try to set the current situation in solar and renewable energy projects in order to investigate the efficiency and the particular conditions or parameters with the most significant impact to the electricity production. Concerning the U.A.E. region, various research works have been done, as Chaar [9], who focus on the solar radiation in Abu Dhabi, or Islam [10], who present a measurement technique for the solar radiation in the same region and relating results with acceptable convergence. The data which are presented by Makri [11] prove that the electricity demand in U.A.E. has been increased significantly, while the high economic development of the country led also to CO2 emissions high precedence and the solar energy projects can be an effective solution due to the irradiation values in this country. Similar studies have been developed for Oman [12], Libya [13], Algeria [14] or North Africa [15], showing according to the particular parameters that the solar energy exploitation can be beneficial and sustainable for these countries as well.

The Kingdom of Bahrain is always open in the renewable resources of energy development following the GCC countries vision as some solar systems applications have been already developed in the country [16] in the last decade [17,18]. Due to the high electricity consumption rate the solar and wind energy applications have been done very popular for development and investment promising an even more energy efficient and sustainable country in the near future.

A. Aim and Objectives

In the present paper we analyze the current situation in GCC countries and mainly in Bahrain concerning the possibility of efficient development of renewable resources of energy according to the amount of the electricity production as well as the cost of the investment. Current data are presented regarding the Bahrain weather and climate, as air humidity, dust precedence in the atmospheric air, average annual and monthly temperatures, purity of horizon and solar irradiance values, in order to identify the most appropriate proposal for solar systems development to the certain geographical location. In this way we set, select, propose and estimate the main solar systems parameters for GCC region as solar panels' type, orientation angle, tilt angle and real efficiency by an analytical and empirical way including the necessary adjustments according to the specific conditions. We based on recent studies in this field and extend their findings in order to set the appropriate parameters for a cost efficient solar energy solution proposal in the certain region calculating the expected electricity production in real conditions [17, 18, 19].

2. Photovoltaics System Data and Methodology

Renewable energy is on the rise, largely to reduce dependency on limited reserves of fossil fuels and to lessen effects of climate change (Fig. 1). The generation of electricity from sunlight directly (Photovoltaic "PV") over the last decade has been growing hugely worldwide. This is not surprising as the solar energy technologies are no longer expensive and the sun can produce greater than 2,500 Tera-watts (TW) of technically accessible energy over large areas of Earth′s surface. Solar energy has several positive aspects such as, reduction of greenhouse gases, increased energy independence, job opportunities and improved quality of life. Although the solar energy applications based on sun existence and simple physics properties, the efficient photovoltaic' s systems development and installation is a complicated study due to the demand of making the appropriate choices according to the geographical location, in order to achieve the highest panels' efficiency. Due to this reason an analytical study of certain environmental conditions is required in order to be able to identify and estimate the optimum solar systems values for installation and operation while certain exploration of relating data is necessary in order to present the specific regional characteristics and explore the need of renewable resources of energy development.

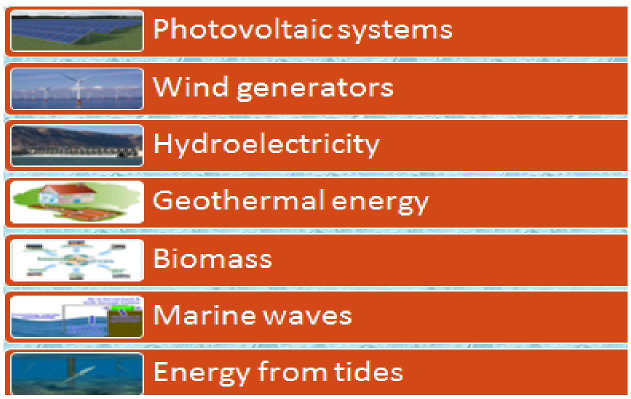

Figure 1. Renewable resources of energy

A. *Photovoltaic's systems development worlwide*

The European Union (EU) invests continuously with increasing trends in renewable energy over the last 15 years. Specifically in photovoltaic systems have been installed more than two-thirds of the global photovoltaic systems. The European Union has set an ambitious target, to reduce energy consumption to 30% by 2030 relative to 2007. Quite EU member states are approaching the target 20 20 20 or have already achieved (to reduce their collective greenhouse gas emissions by at least 20% in comparison to 1990 and increase renewable energy to 20% by 2020). However there are some Member States, which they haven't exceeded even 3%. In order to achieve this goal namely in the search electricity through renewable energy, the EU is based to a large extent to the usage of photovoltaic systems. In April 2014, a survey published by the Euroserver says that the installed photovoltaic capacity amounts in EU are up to 78,798 MWp at the end of 2013 while the electricity which is produced was equal to 80.2 TWh [20]. If we compare the map of solar potential of Europe with the countries that have the largest photovoltaic systems, we will find out that countries such as Germany, Denmark and Great Britain have very low solar potential in comparison with the countries of Southern Europe, which have much higher levels of solar radiation, however most of times the north countries have invested more in the photovoltaic systems installation and operation. At the following Table I, the watts per capita in Europe are presented, where it can easily be seen the intension of the European countries to increase the solar power production (Table I).

In the United States a great development of PV systems occurs as in the first half of 2013 more than 10 GW have been installed (Fig. 2). The 2012 US photovoltaic systems that settled were increased by 76% compared to 2011, namely 3,313 MWp were installed, and were added in the 4383 MWp which have been established in 2011 [22]. The new PV installations in the USA will be built mainly in southern and south-western regions where there are large areas of desert with high solar potential [23]. In the first quarterly report for 2013-2014 the SEIA / GTM Research US Solar Market stated that the increase of PV installations was 41% in comparison with 2012, reached 4751 MWp and was second after the source of natural gas in new power generation. At the end of 2013 the installation cost was reduced by 15% from the corresponding 2012 and reached 2.87 $ / W [24].

TABLE I. THE POWER FOR EACH EU CITIZEN FROM THE USE OF P/V SYSTEMS [21]

Country	**2011**	**2012**	**2013**
Germany	304.3	399.5	447.2
Italy	210.5	269.0	295.1
Belgium	165.5	240.0	267.3
Greece	55.8	136.7	233.7
Czech	186.0	192.5	202.8
Luxembourg	59.9	89.9	186.2
Bulgaria	17.7	127.4	139.9
Slovenia	44.1	105.7	123.8
Spain	91.3	97.8	100.7
Slovakia	89.8	95.7	99.3
Denmark	3.0	70.2	94.8
Austria	20.7	49.9	81.7
France	43.5	61.6	71.6
Malta	27.4	45.0	58.7
Romania	0.1	0.3	51.1
United Kingdom	16.2	26.3	42.9
Cyprus	12.5	19.9	40.2
Netherlands	7.1	19.1	39.6
Portugal	13.5	21.7	26.8
Lithuania	0.0	2.0	22.9
Croatia	0.1	0.1	5.1
Sweden	2.0	2.5	4.5
Finland	2.1	2.1	2.1
Hungary	0.4	0.4	1.6
Latvia	0.7	0.7	0.7
Ireland	0.2	0.2	0.2
Estonia	0.1	0.1	0.1
Poland	0.0	0.1	0.1
EU average	**102.2**	**136.3**	**155.8**

Having 300 days of sunshine on average every year and a high solar potential, India has begun to invest in the PV to meet its energy needs. The - dependent on coal - South Asian country making strides in the industry: in four years increased the power from solar plants connected to the grid from 161MW to 2.320MW and now aspires to build the largest solar park in the world, in the state of Rajasthan, power 4.000MW. It should be noted that India has as a goal to plant 10 GWp until 2017 and reach 20 GWp in 2020. Also investments in clean energy in India in 2011 reached $ 10.3 billion, which is an increase of 52% compared with 2010 [25].

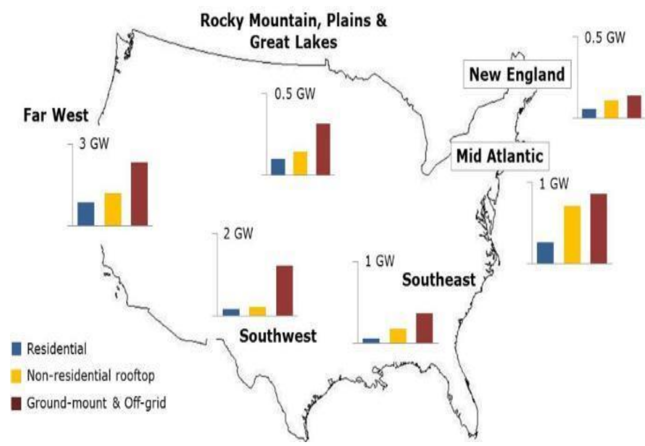

Figure 2. GW of PV systems in USA [21]

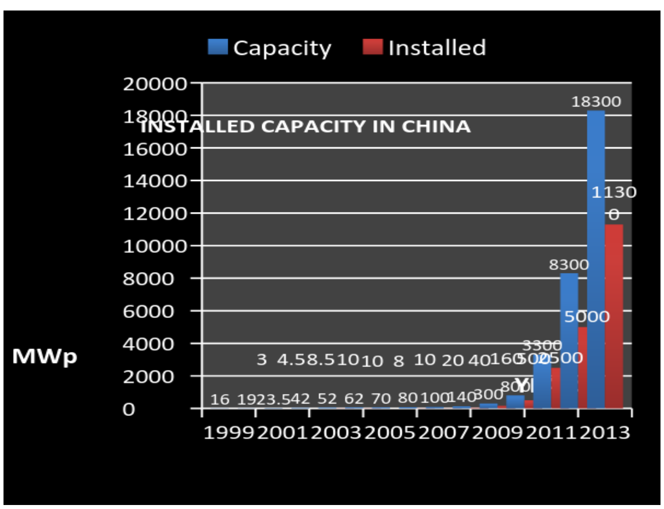

Figure 3. PV systems installed in China

China is now the world's largest country solar PV market, according to the World Exhibition of New Energy Development 2014, having recently overtaken Germany. The China with more than 400 manufacturing PV companies has become the most dynamic industry in the world in this area [26]. With very strong solar capacity in most of the country and high dependence on coal, China aims to depend as little as possible by the minerals fuels. The PV systems installation in China began in 1999. According to the World Development Report 2014, New Energy [27] China overtook Germany as the largest PV market in the world (Fig. 3).

B. Photovoltaic's systems development in GCC

The Arab Gulf has already begun important efforts to use the solar energy for electricity production and it seems that according to several studies can be an efficient and sustainable solution for the near future. The installation of PV systems is environmental friendly approach and if we consider the high solar potential in the region, PV systems installation can be the alternative way in order to reduce the energy consumption using mineral fuels. As it is expected due to the know climate conditions and it is depicted in the solar radiation map of the Arab Gulf (Fig. 4), the Gulf Area is annually exposed to a significant amount of irradiance from the sun, with a range between 1400-1700 kWh/m^2/year. The average daily irradiance in Middle East and Gulf Area fall in the "red zone" worldwide, as the highest areas exposed to the sun with an average of 6 kWh/m2/day [28]. Furthermore, viewing the global solar radiation in GCC countries, it is shown in the graph below that the peak daily irradiance in Kuwait reaches over 8kWh/m2 in June, followed by the UAE at about 7.5 kWh/m2 in May, while KSA and Bahrain are exposed to a peak irradiance of approximately 7 kWh/m2 [29].

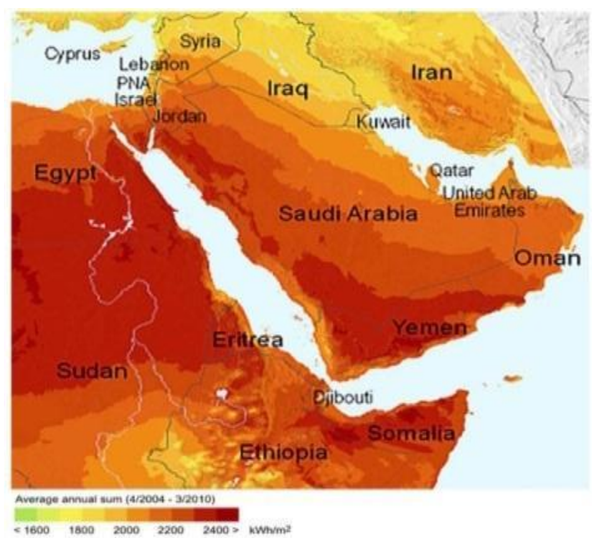

Figure 4. Solar radiation in Middle East countries [29].

C. Kingdom of Bahrain – PV systems progress

Bahrain and the remaining GCC countries have huge resources of crude oil and natural gas about 478 billion barrels of crude oil and 41.92 billion cubic meters of natural gas representing about 42 % and 24 % of the world's total resources respectively (estimated in 2004). In year 2000 the United State Geological Survey (USGS) estimated that the GCC countries have undiscovered crude oil potential about 162 billion barrels (about 17 % of the world's total) and 23.3 trillion cubic meters of natural gas (about 16 % of the world's total). These facts explain why the development of renewable clean energy is still relatively low in spite of GCC region and especially Bahrain has access to one of the world's most abundant solar resources. [30].

Figure 5. Solar potential in Bahrain [31]

In Bahrain the annual average temperatures is about 30 ^{o}C to 32 ^{o}C and presents a very high solar capacity of 2,300 kWh / m^2 The country has already started to invest in the exploitation of solar energy in recent years and it seems that a lot of progress may follow as Bahrain and the Gulf Cooperation Council countries (GCC) have some of the highest levels of solar radiation in the world [32] (Fig. 5)

The County makes the first steps to exploit renewable energy sources and various proposals have been submitted by the academic and industrial sector. Today in Bahrain have been completed the procedures for installing a pilot system for the production of electricity. The project is based on the installation of PV systems that will produce 5MW per year, and it will be installed in three different areas; in Awali 1,6 MW, in the refinery park of BAPCO 3 MW, and in the University of Bahrain campus 0,5 MW [33]. This project will provide more than 8,000 MWh of electricity, which is attributable of high savings as 67.000 MCF (thousand cubic feet) of gas and 6,900 metric tons of carbon dioxide each year [34]. Also in the Al Door area, an area of approximately 12 hectares, has decided to be installed a hybrid system consisting by PV of power 3 MW, and wind power equal to 2 MW. In the Juffair district the lamps for lighting have been replaced by LED lamps and it can decrease the electricity consumption in this road by 25% (Fig. 2). In 2013, in Hidd area they have installed solar lighting where the electricity reduction has been followed in order to draw in reliable conclusions [35]. In 2008, the building of the World Trade Centre have been adapted and the three wind turbines can achieve a total power output of 0,66 MW, or 11% to 15% of the total capacity building needs [36].

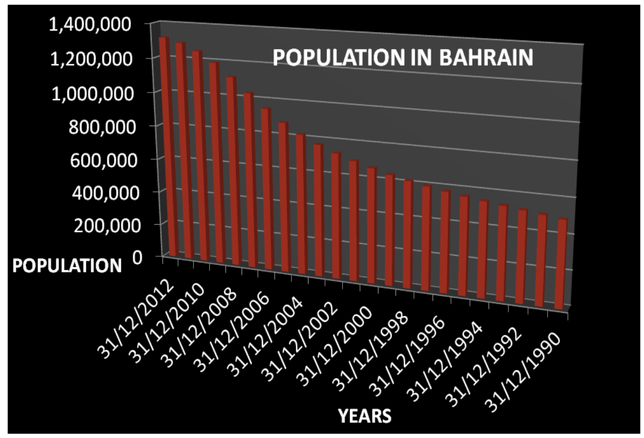

Figure 6. Population growth in Bahrain [37]

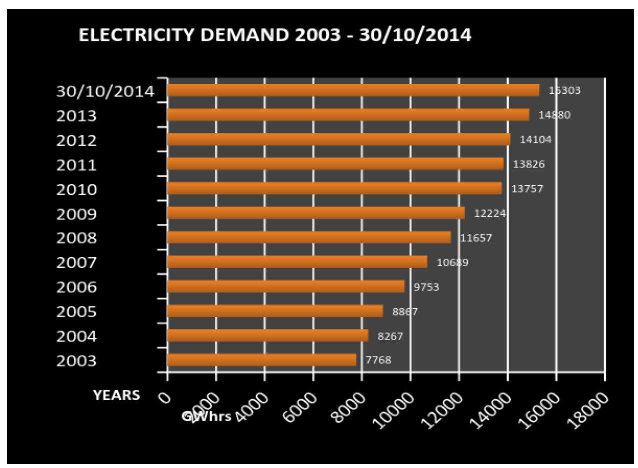

Figure 7. Electricity demand in Bahrain [34].

D. Kingdom of Bahrain – Energy demand and solar data

The Kingdom of Bahrain has a continuous population growth mainly from economic immigrants, (Fig. 6) thus is observed a corresponding continuous increase in demand for electricity (Fig. 7).

Annually the period from April to November the people in Bahrain spend most of their time inside buildings in which the electricity consumed per house typically becomes three times in comparison with the winter months.

As shown on picture 8, and according to Electricity and Water Authority (EWA) statistics, the highest amount of electricity load in Bahrain is consumed by the residential sector about 56 % followed by the commercial sector 28 % and then the industrial sector 15 % (Fig. 8). The air conditioning systems for residential and commercial buildings in Bahrain consume about 65 % of electricity. The mechanical cooling systems and the buildings in Bahrain are not energy efficient, and Bahrain needs to have sustainable building designs that can reduce the use of fossil fuels [38].

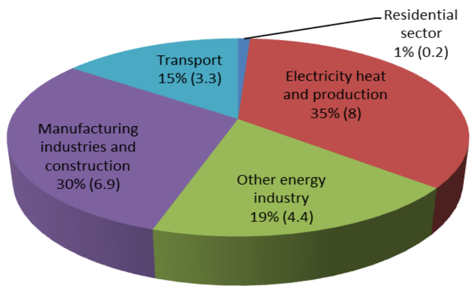

Figure 8. Electricity Consumption by Sector (2007) [39]

The average monthly temperatures in Bahrain in a year are divided into two categories. In the first category mild temperatures are included ranging from an average of 14,4 ^{0}C to 30,7 ^{0}C from November to April and in the second one is comprised of the average temperatures from 26,9^{0}C up to 40^{0}C, which are usually developed among May to October (Fig. 9) [40].

One more positive parameter for Bahrain is the duration of sunshine during the day which seems to be one of the largest worldwide. In the winter season as well as in the autumn months, the average daily of sunshine range is 7.13 hours to 10.05 hours, while in the spring and summer months the average of sunshine range is 7.20 hours to 10.12 hours approximately**.** The monthly hours of sunshine present a range of 211.4 hours in February to 315 hours in June (Fig. 10 and 11). In general, in Bahrain, the annual hours of sunshine approach 3190 hours per year [41].

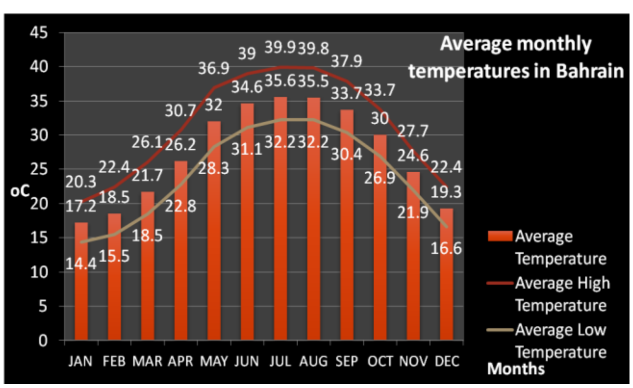

Figure 9. Average higher and lower monthly temperature in Bahrain.

Bahrain and particularly its capital, Manama has latitude 26 ° 12'36 "N and longitude 50 ° 34'48" E as geographical coordinates. According to the NASA Langley Research Centre Atmospheric Science Data Centre the intensity of solar radiation is between 3.59 $\frac{KW}{m^2}/day$ and 8.21$\frac{KW}{m^2}/day$, while the purity of the horizon on a scale from 0 to 1 varies between 0.59 to 0.73 [41], as it is shown in Fig. 12.

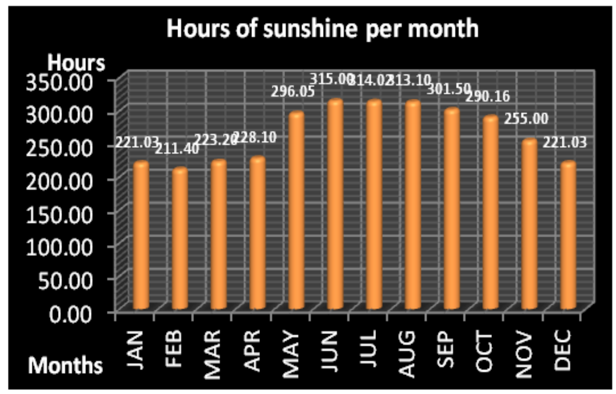

Figure 10. Average sunshine hours in Bahrain.

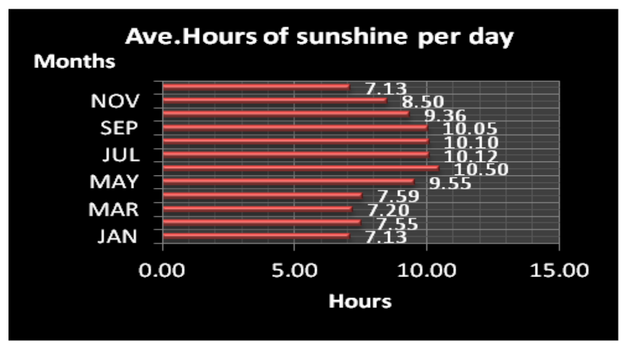

Figure 11. Total average sunshine hours per year in Bahrain.

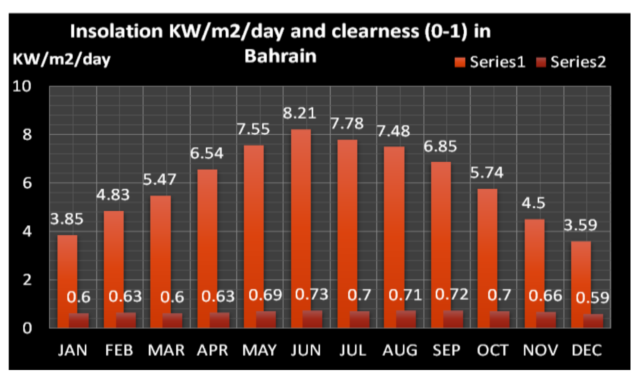

Figure 12. Solar insolation and purity of the horizon in Bahrain

3. RESULTS

Considering the above data, it seems that the solar energy potential in GCC countries is high and photovoltaic systems installation can be profitable if necessary requirements are followed according to fundamental parameters in order to maximize the panel's efficiency. Apparently, although there are common methodologies that can be followed for PV selection, based on the previous experience in this field, the location, the climate conditions are well as the electricity demand have to be considered in order to modify the proposed solution and achieve the best possible electricity production in combination with the optimum life span and maintenance cost deduction. The following estimation has been considered for Bahrain territory but these can be applied for all GCC countries due to certain similarities. It is an acceptable accurate approach, trying to investigate the influence of the location parameters and environmental conditions to solar panels' installation and efficiency in GCC countries.

It is recommended to be followed for solar panels' installation where the land area is limited, as in buildings. However most of the data can be used for any solar application according to the nature of the project.

A. Types of PV panels for Bahrain and GCC

The photovoltaic solar cells can be classified based on the way of manufacturing to Silicon wafers (manufactured through cutting the wafers from a solid ingot block of silicon), and thin film technologies (a thin layer of a semi-conductor material is put on a low cost substrates). The Crystalline wafers have high efficiency, but they are relatively costly to manufacture. Thin film cells are cheaper because the materials used are inexpensive and the manufacturing process is simpler. However, thin film cells are less efficient. The most common solar panels types which are widely used in most of the commercial applications are single crystalline and polycrystalline types. In order to make the appropriate choice, we will assume the following parameters and criteria: efficiency in real conditions, heat resistance, durability, the availability in the market and cost. In general the single crystalline panels operate with higher efficiency than the other type in SCT conditions. According to the literature an average value for their single-crystalline efficiency can be 15-20% at STC while for the polycrystalline 12-15% [42].

As we have seen by the above graphs, the GCC region is characterized by high temperatures all year. Due to this factor, panels efficiency drop is developed when the total temperature of the cell is higher than 25 ℃. This factor seems to be higher at the polycrystalline panels (approximately experimental values 0.45% to 0.5%). In some experiments, single-crystalline panels have performed in a very good efficiency rate even in 50 ℃ surface temperatures. Finally, if we assume the same characteristics and quality, the cost is 5-7% higher in single-crystalline panels, which seems not to be so important disadvantage due to the longer life of the product and the less demand in regular maintenance. For this reason, in this paper we choose single-crystalline panels. It is worth to be mentioned that both of the panels' types have been used in GCC countries with good power production and efficiency in most of the times according to the project and what is more important to be considered. Sometimes the current availability in the market is important as well.

B. Azimouth, Tilt angle and Orientation

The efficiency of the certain panels is not only depended on their type or the solar irradiance but also to the certain inclination angle which can be modified or the orientation. Major role for these selections play the geographical coordinates and determine the optimum location and inclination for each application. Consequently the tilt angle and orientation have to be selected according to the geographical coordinates, location height (roof of buildings or ground) and azimuth. As we have already mentioned, in order to achieve the maximum electricity production by the solar panels, the solar irradiance incidence angle to the panel has to be as close as possible to 90 deg. This can be arranged according to the tilt angle as well as the azimuth angle of the panel. If we want to install photovoltaic systems in Bahrain or in a GCC country, as we are at the north hemisphere, the optimum inclination angle of the panel should be equal to the geographical latitude and the azimuth angle equal to approximately zero (0) with south direction.

As the location geographical coordinates for Bahrain are latitude 26 ° 12'36 "N and longitude 50 ° 34'48" E, the optimum tilt angle for the panels should be equal to 26 deg while the ideal azimuth equal to zero with south orientation (Table II).

TABLE II. OPTIMUM PANELS' TILT ANGLE AND ORIENTATION IN BAHRAIN

Characteristic	Value
Bahrain Geographical Coordinates	26 ° 12'36 "N 50 ° 34'48" E
Optimum Tilt Angle	26 °
Optimum Azimuth	0 °
Optimum Orientation	South

However sometimes, due to the specific location characteristics, maybe it is not possible to follow and apply the above values. In such cases we may follow the below rules:

- The tilt angle should be in the range of 0 to 50 deg
- The azimuth angle cannot be more than 70 deg by the south direction
- Whatever combination it is applied the final solar panel efficiency shouldn't be less than 90% of the maximum one.

There are several software than may support the above calculations as the Google Earth, which produces certain indications about shadows, useful for photovoltaic panels' installation in buildings.

It is worth mentioning that the possible shading on the solar panels has negative impact to the panel's efficiency and these have to be avoided through the initial installation study, even for the possible future shading.

Using relating software it is possible to calculate the optimum above combinations of angles in order to achieve the maximum panels' efficiency. The below figures have been extracted by the Sun Earth Tools data and the official Bahrain Weather data bases [38,43], for the most crucial dates which are 21 December, 21 June and 21 September, due to the characteristic highest, average or lowest duration of day and night (Fig. 13, 14, 15). The first one has been generated for south orientation while the followings for south-southwest and southeast.

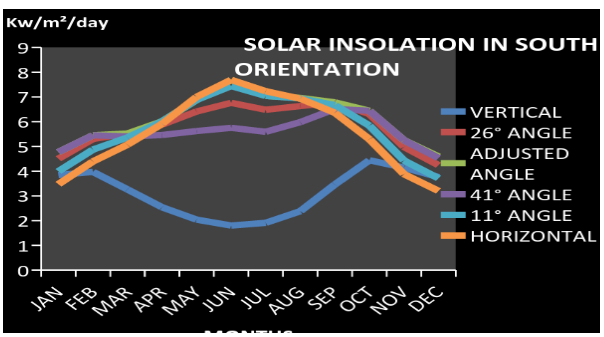

Figure 13. Solar Insolation in Bahrain for various tilt angles in south orientation

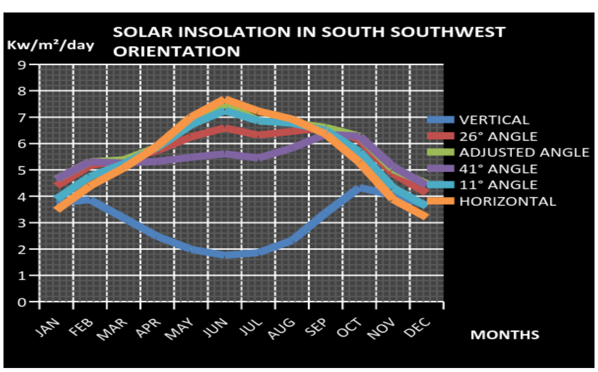

Figure 14. Solar Insolation in Bahrain for various tilt angles in southwest orientation

By these figures it can be easily seen, that if a tracking system is possible to be mounted and adjusted to the solar panels, we will be able to achieve maximum values of the panels' efficiency during all the year. However if not, the optimum tilt angle is 26 deg as the maximum average performance is developed.

C. Tracking System

If the desired solar applications will be installed in buildings for residential purposes the photovoltaic modules are usually mounted on the structure to keep them oriented in the desired direction. The mounting system for solar structure can be fixed (the most common design used) or dynamic (tracking system which is rarely used).

The fixed mounted designs keep the rows of modules at a fixed angle of orientation (azimuth) and at a fixed tilt. As explained above, the location of the sun varies during the course of the day and during the course year. Using the fixed mounting system will not collect the maximum sunlight from the sun because the module should be perpendicular to the sun to collect the maximum amount of energy. For this purpose a tracking system can be used [44, 45].

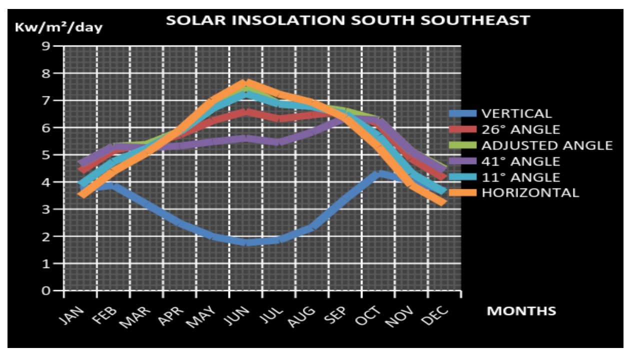

Figure 15. Solar Insolation in Bahrain for various tilt angles in southeast orientation

Adjusting the tilt angle led to increase the power output of the module by 3.61 %; this would provide meaningful boost in energy [46, 47].

A fixed tracking system can be finally used according to the type of application and surrounding areas because they are simpler, cheaper and have lower maintenance requirements compared to tracking systems. Adjusting the arrays manually two to four times per year would be costly. However, if the solar system is installed in building the tracking system application is not recommended as the structure of tracking systems contain more parts (especially moving parts), and hence require more maintenance. Some of the moving parts would fail eventually and the initial capital costs would be higher (extra component). Furthermore, the tracking systems require more land (space between the PV modules) to avoid shade compared to fixed types where less number of modules can be fixed for structures with tracking systems if the land area is fixed, and hence less energy would be produced [43,47].

D. STC and NOCT

Standard test conditions (STC) are the usual normal laboratory conditions which all the solar panels manufacturers use in order to perform the panels' tests. In this way, the comparison in various panels' parameters is easy performed and the selection process is easier. By the other hand the efficiency which is measured is not applicable for all areas as the conditions are set without taking into consideration the geographical location or other climate parameters. According to the SCT conditions an irradiance of 1000 Watts per square meters is considered, the light spectrum as 1.5G while the temperature of the cell is taken as 25o C. As it is obvious the estimated values for the panels in STC are ideal enough and sometimes are far from the real values. By the other hand the Nominal Operation Cell Temperature (NOCT) is defined as the temperature reached by open circuited cells in a module when irradiance of 800W/m2 is applied, the air temperature is 20 ℃ and the wind velocity 1m/s (Fig. 16).

As we have already mentioned, the panel's efficiency is decreased according to the cell's temperature and it is influenced as well by various climate conditions. In addition most of the panels operate in 48oC average and this depends on the weather conditions as well. Due to this reason the NOCT indications are more reliable for the GCC region as the high cell temperature development is certain during their operation. Better indication can be given under NOCT to the engineers that they want to choose the type and the manufacturer of the panel.

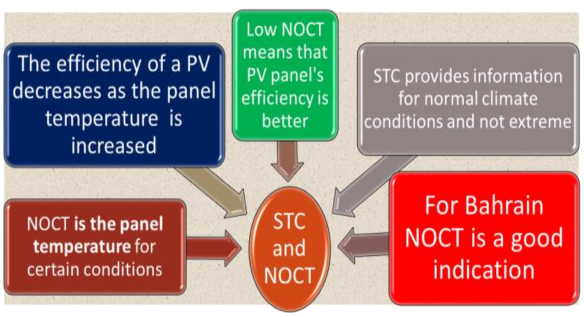

Figure 16. SCT vs NOCT

E. PV systems efficiency

The efficiency calculation for the PV panels is a challenging procedure as the SCT estimation is only an approach to the maximum one and various environmental parameters have to be considered according to the geographical location of each are or country. Several proposals can be considered by the literature which can support an accurate enough estimation for the real efficiency of the panels in Bahrain. As we focus on this region (although our approach can be easily applied in the GCC region) there are several parameters that should be addressed as purity of the air, daily temperatures, humidity, electricity demand, electricity cost etc, as we have already mentioned to the above paragraphs. However two conditions are playing major role in this study: the range of daily temperature as well as the dust precedence in the atmospheric air. These parameters can reduce the efficiency of the panels even in half according to certain values.

The daily temperature range is wide, from 14oC to 40oC for Bahrain. The efficiency will present an important drop from the SCT values, especially if the temperature is more than 35oC and that is why this parameter has to be considered if we estimate the approximated real panels' efficiency value.

In addition, one of the important issues and maybe one of the major concerns about the solar panels development in the GCC and Middle East region is the existence of high precedence of atmospheric dust. This dust has several effects on the panels operation such as the decrease of the amount of sunlight reaching their surface or the reduction of the transmission of the solar radiation that reaches the solar [48]. The most accurate way in order to define the reduction of the panels efficiency and the general influence is the experimental measurement of the relating variables in a daily bases for at least one year, providing by this way certain results for the specific region. However, although this is our near future research objective, several studies have been done for other GCC countries with one important for the Saudi Arabia, where the reduction is approximately 11% [48]. The calculation differences according to the experimental or analytical calculations that are presented are sometimes high as in Alamoud's approach [48], who claims that the reduction in the efficiency may reach 20%. According to the literature, to the specific Bahrain climate conditions we choose a 10% efficiency reduction due to the atmospheric dust.

In order to estimate the efficiency of a solar panel the panel's power and the solar radiation have to be considered, as we can see below:

$$n = \frac{P}{SR * A} \tag{1}$$

where P is the panel's power, SR the solar radiation and A the panel's area [49, 50].

The extracted value by the above formula is ideal and it cannot be reached in real conditions due to various environmental and climate parameters that haven't been considered to the above calculation. These conditions vary for each month or even each day of the year in Bahrain. If we want to estimate an approximate difference drop due to the developing temperature on the panel's surface during operation, the below formula can be used:

$$\Delta n = C_{temp}(25 - T_{mod}) * n \qquad (2)$$

where Δn is the efficiency drop, C_{temp} the temperature coefficient which is given for each panel by the manufacturer, T_{mod} is the panel's temperature in real conditions n the efficiency of the panel in SCT conditions (maximum possible efficiency value) [45].

As we have already assumed that a good panel type choice for Bahrain is the single-crystalline ones, the usual C_{temp} value is equal to 0.45% [35] while for all the panels' types this type of values are available. By the other hand the value of the panel's temperature depends on the monthly temperature in each region and it can be estimated by the below experimental formula providing a good approach:

$$T_{mod} = Monthly\ Ave.Temp. + 28°C \qquad (3)$$

The panel's temperature is estimated for each month, which means that the efficiency of the panels is not a constant value. The relating average temperature values are presented in Table III.

As we have already mentioned the efficiency n of the panels in SCT is provided by the manufacturer and for the specific type of panels is usually 15-20% (average value equal to 17.5%) according to the brand and quality of cells.

The real efficiency due to the panel temperature and other various conditions can be finally depicted by the below formula according to the relating coefficient:

$$n_{real} = (n - \Delta n) * C_{tot} \qquad (4)$$

where C_{tot} is the total dimensionless coefficient of losses due to the local environment and other operational conditions. The C_{tot} coefficient comprised of several sub-components and it cannot be higher than 1 [49,50].

TABLE III. AVERAGE MONTHLY TEMPERATURE AND SOLAR IRRADIANCE FOR BAHRAIN [38].

Months	Av. Temp (^{0}C)	Sunshine h/day	Av. Solar Irradiance kW/m^2/day	Average Solar Irr. kW/m^2/day South Orientation and 26^0 tilt angle	Average Solar Irradiance kW/m^2/day Southeast orientation, azimuth 20^0 and 26^0 tilt angle
Jan	17,2	7,13	3,85	4,50	4,39
Feb	18,5	7,55	4,83	5,30	5,17
Mar	21,7	7,20	5,47	5,52	5,38
Apr	26,2	7,59	6,54	5,88	5,73
May	32	9,55	7,55	6,41	6,25
Jun	34,6	10,50	8,21	6,76	6,59
Jul	35,6	10,12	7,78	6,48	6,32
Aug	35,5	10,10	7,48	6,63	6,46
Sep	33,7	10,05	6,85	6,78	6,61
Oct	30	9,36	5,74	6,31	6,15
Nov	24,6	8,50	4,50	4,98	4,86
Dec	19,3	7,13	3,59	4,24	4,13

For Bahrain and for GCC countries we choose to calculate C_{tot} by the following way:

$$C_{tot} = Co_1 . Co_2 . Co_3 . Co_4 . C_{O_5} . C_{O_6} \qquad (5)$$

where:

Co_1: Coefficient of dust = 0.9
Co_2: Coefficient of inhomogeneity panels = 0.98
Co_3: Coefficient of panels connecting cables = 0.98
Co_4: Coefficient of energy transfer losses from the output PV system to consumption = 0.92
Co_5: Coefficient of inverter efficiency = 0.96
C_{O_6} : Coefficient of aging=0.90

Applying this formula we have already considered the most important environmental conditions and we approach a more realistic efficiency values for the GCC territory. However the selection of the coefficient values can vary according to more specific indications if these are provided.

In addition, if we want to estimate the total solar energy which is received by the panel the following empirical formula can be used:

$$E_{total} = H_d * A \qquad (6)$$

where E_{total} the relating energy, H_d the solar irradiance per month and A the area of the panel. The solar irradiance can be received by various literature sources. However at the

Table IV, we present the most recent data by the official Bahrain Weather data base [40]. The produced energy by each panel (E_p) will be given then by:

$$E_p = E_{total} * n \quad (7)$$

while the real efficiency (n_{real})of each panel according to the specific location, geographical position and environmental conditions is the one by the equation (4).

TABLE IV. EFFICIENCY AND RELATING VARIABLES APPROACH FOR PV PANELS OPERATION IN BAHRAIN

Variable	Value
Efficiency STC (n)	17.5%
A	1.70 m^2
C_{temp}	0.45%
T_{mod}	45.20 ℃
C_{tot}	0.69
Co_1	0.9
Co_2	0.98
Co_3	0.98
Co_4	0.92
Co_5	0.96
Co_6	0.90
Δn	1.22
H_d	4.5 kWh/m^2
$(n - \Delta n)$	16.28%
n_r	11.18%
E_{total}	7.52 kWh/day
E_p	1.17 kWh/day

For a typical solar single-crystalline panel operating in Bahrain an approximated estimation has been attempted concerning the relating variables and values and it is presented to the Table IV. It can be seen that the efficiency drop is highly influenced by the certain environmental and climate conditions as the drop is from 17.25% to 11.18%.

4. CONCLUSIONS

The photovoltaic system applications and development in Bahrain and GCC countries has been addressed in this paper trying to define the appropriate parameters for the installation and estimate the approximated efficiency according to various reduction factors. By the above analysis, it seems that the solar systems applications can be beneficial enough for these countries as in this region the solar potential is high and the solar irradiance receives very high values in most of the time of the year, in comparison with the other countries. By the other hand the electricity demand is very high though all the year in comparison with other countries, which means that this can be an efficient and sustainable solution concerning the electricity production. There are several proposals concerning the panels' types and although none of these can be excluded, the single-crystalline (mono-crystalline) ones seem to be more efficient in this region according to the location and specific characteristics. Several parameters have to be considered in the solar systems installation, with the most important one for this region, the dust precedence and humidity inside the atmosphere as well as the high cells surface temperature which is developed in most of the time of the year during operation. Both of the factors have as results to reduce the real efficiency of the panels up to even 37% and reduce in addition their life span, reduction which is usual in most of the countries for various other reasons. For this reason also the NOCT indication can provide more useful data rather than SCT for GCC countries as the SCT conditions are based on 25℃ cell temperature only. Tracking system can be efficient if the land area is not limited for the system installation, however is not recommended for buildings applications as the shadows will be very difficult to be avoided. There is no objection that a tracking system adjusting the tilt angle of the panels would produce more efficiency according to the monthly solar irradiance Due to the high dust precedence in the atmospheric air, a periodically cleaning system is necessary to be included to the photovoltaic system,. By the above estimations it seems that the solar systems applications can be quite beneficial for Bahrain and GCC countries, offering a sustainable solution for the power generation and facing the high demand for electricity consumption simultaneously. These can be durable and efficient enough, if certain local and operational parameters are considered through the installation analysis and implementation.

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