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RESEARCH ARTICLE OPEN ACCESS

A critical review of solar energy and dust in Gulf Countries

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kuwait

ABSTRACT
Many studies took on the dust accumulation, analysing its frequency, density and material characteristics, yet, limited research took on the subject of its impact on the use of renewable energy systems within the Gulf Corporation Council GCC, specifically in Kuwait. The overall objective of this research is to encourage the use of alternative, renewable energy sources to fulfil the growing demands of electricity. The aim is to develop an understanding of weather and the climatic conditions of Kuwait, analysing the impact of dust on the efficiency of solar photovoltaic (PV) systems, as well as, the maintenance (cleaning) requirements, to ensure optimum level of Performance. The research study started with an extensive literature review, covering researches specific to the GCC countries as well as the work done globally. Moreover, weather and climatic data for Kuwait, detailing parameters like average temperatures, Precipitation levels, Sun radiation/daily hours and dust characteristics were analysed. PVSYST software was used to simulate the solar PV system output within Kuwait's weather parameters, evaluating multiple tilt angles, to understand the potentials and variables affecting its efficiency.
With the many researches and reports acknowledging the solar potential within the GCC region, along with the challenges facing climate change, the use of PV solar panels can be of a great value, meet the rising demand of electricity and power while sustaining the environment. However, Concerns such as the dust impact on performance must be taken into consideration while designing the overall system as well as planning its maintenance requirements. The Conclusion will include guidance for the cleaning patterns, established to maintain the efficiency in consideration of estimated monthly dust events.

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I. RESEARCH SCOPE

1.0 Introduction

Solar power, contrary to fossil fuels, is characterised as an inexhaustible and clean source of energy. The distribution of sunlight, its intensity and the hours of daylight are not even throughout the world. Due to the latest advancement in technology, many countries all over the world are trying to fulfil their need for energy with the help of solar energy by using photovoltaic (PV) and other/ different concentrated solar power (CSP) systems/ technologies. The deserts and other dry zones around the world have great potential for generating energy due to the abundance of sun and vast area availability. Such areas can be used to generate power that can support other power generation facilities, meeting electricity demands and reduce emissions. PV and CSP plants have faced many challenges, one of the main significant factors is the dust accumulation, resulting in damage to the panel's surfaces loss of inefficiency for PV/CSP modules.

Dust on the solar panels can be considered as the most significant and influential factor for its impact on its efficiency and potential damage, deteriorating the surfaces. The accumulation of dust can harm the performance of the collectors on the panels; Soiling is a more common term used for the solar panels. Soiling concerns are inclusive of the impact of dust, plant products, dirt, bird droppings, salt, and growth for different sort of organic species on the solar panels; All these accumulations result in an adverse impact/effect on the performance (optical performance) of the solar panels. Other than soiling, relative humidity, temperature effects, speed of the wind, delamination of different conversion devices within the solar panels, and corrosion are also significant factors that can harm the overall performance.

The two prime factors that can have a significant role in depicting the level of dust are the environmental conditions of the site and the location on which the solar panels are situated. It is also important to identify the properties of the dust. Dust particles might include organic or inorganic materials. To understand the impact of the dust, analysis of the biological properties, material composition, charge distribution, surface energy, and shape of the dust particles must be identified.

As well as, the climatic/ climatologically circumstances/ characteristics speed of the wind, the direction of wind, wind relative frequency, ambient temperature, Haze/ dust storms events, their frequency, and precipitation levels.

1.1 Background

The fast increase in the level of industrialization has been linked to the global phenomenon known as Climate Change or Global Warming. It resulted in an increasing overall negative impact on the environment, raising the levels of pollutants and greenhouse emissions. Nations all over the world have taken initiatives to overcome these negative impacts, making sure that all possible actions are taken to reduce the use of fossil fuels and to focus on new and alternative cleaner energy sources. Different nations had tried to mitigate the use of fossil fuels and actively utilise new renewable energy sources for their environmental and economic benefits, studying and optimizing their use to the fullest. The use of solar energy systems is most widely used to replace or support the power/electricity generation by fossil fuel.

Many academic and business researches explored the potentials of solar energy. Global efforts have been made to devise new and more improved electrical technologies to maximize the benefits and productivity of solar PV cells and solar panels. These studies are helping with the efficiency of renewable systems with the hope that in few years, these systems become more reliable, replacing fossil fuels.

According to a study by Mas'ud, Mu'azu, Albarracín, & Firdaus, (2018) The countries within the Gulf Cooperation Council (GCC) are naturally blessed with the abundance of solar irradiation that can be useful to generate/ produce the power and energy with the help of solar PV technology. But apart from the positive aspects of solar PV technology, there is a significant level of concerns and challenges in utilizing such technologies in an efficient and effective manner. Technologies depending on renewable resources are vulnerable to climatic/ atmospheric conditions, impacting the application or implementation of such technologies at some parts of the world. Despite the challenges, the GCC countries have invested and are willing to upgrade and implement renewable technologies, shifting/ limiting their focus from producing electricity through fossil fuels. Countries such as the Kingdom of Sudia Arabia, the United Arab Emirates and Kuwait have planned and aimed to increase the use of solar/ renewable energy sources to cope up with the demand for energy and power within the next decade.

The presence of large particles deposits (bulk of dust), frequent sand storms, and other climatic issues have resulted in a decline within efficiency and performance of the solar panels. It's one of the main reason's renewable resources (mainly solar) are not majorly used as these issues are regional and specific. The initiatives of the GCC governments are in line with the international commitments to ensure effective implementation of renewable applications and serious efforts are taken to reduce the industrial environmental impact. The challenges the GCC countries are working hard to overcome is moving towards alternate/ renewable energy sources to meet the increasing demand for power and also to reduce the dependence on fossil fuels. It is also noticeable that academic and research institutes (local and international) are supporting the use of renewable resources, arguing that regionally, solar energy can be the most promising and effective form of energy generation resource for the GCC countries.

Previous researchers Catelani, et al., (2012) stated that there is a limited number of studies that try to highlight the impact of dust on the efficiency of solar PV cells and also the continuous degradation in efficiency. The research limited its scope and is primarily devised to determine the impact of dust on the solar system's performance and efficiency. This is because there are other different environmental and climatic factors that can have an impact on the system. The researcher aims to use a systematic and schematic representation of different factors that set up the dust on different PV panels and uses an experimental approach to reach to the outcomes of the research. The influence of the dust on the PV panels is tested with the help of a detailed analysis of the system and the researcher aims to use the information to generalize the outcomes to other GCC countries. The electrical performance of the system and the prime impact of dust on the performance was highlighted within the research with the help of experiments on a solar panel system. The conditions of with or without the dust and the results of the performance are highlighted and compared and contrasted to get a more specific outcome.

Different previous research papers have highlighted the impact of different environmental influences on the efficiency of solar PV cells but the influence of dust is overall less acknowledged. This research study is carried out to determine the effect of tilt on the solar PV cells primarily focusing on the GCC country (i.e. Kuwait) and uses the literature review to depict and critically analyse the productivity of using the solar energy taking into account optimum potential for generating energy

and the dust accumulation rates corresponding to the PV angels.

1.2 Research Objectives

This study focuses on;

- Proposing the potential deployment/ installation of the PV solar panels concerning slope/ tilt to optimize the efficiency and manage the electricity demand for Kuwait.
- To evaluate the importance of Solar PV panels as a source of renewable energy for Kuwait and its long-term efficiency.
- Determining the efficiency of solar energy as the renewable source in the Gulf region (Kuwait) and evaluating the regional challenges.
- Proposing maintenance and cleaning plan for the PV panels to sustain their performance.

1.3 Research Questions

The research questions this study will answer are:

- What is the impact of tilt on the efficiency of the solar PV panels in Kuwait?
- What is the impact of dust on the solar PV cells located in Kuwait?
- Do Solar PV panels represent the potential to manage the increasing demand for electricity within Kuwait?

II. BACKGROUND AND LITERATURE REVIEW

The conversion of solar radiation from the sun into electricity is carried out with the help of Solar photovoltaic (PV) systems that are constituent of cells that help in the conversion. The overall system is a combination of the one or more than one panel, charge control, load, and the battery. Majorly, the solar panels are fitted on the ground or on building's roofs, connected with the help of wires with an inverter. The inverter helps to convert the solar energy into an alternate energy source.

Impact of dust on the solar PV cells

This section of the literature review helps to develop an understanding about the impact of dust on the solar PV cells. The aim is to gather enough information to achieve the research objectives evaluating research papers from all over the world that are focused on the subject topic then exploring more specific literature from the gulf countries. The studies will also be compared and contrasted to get a more comparative point of view on the subject.

Goossens & Kerschaever in the year 1999 carried out wind tunnel experiments to determine the impact of the wind velocity and airborne dust on PV cells performance resulting from an accumulation of dust within the region. The researchers make use of four different velocities of wind and accumulation of dust on the cells that allowed to carry out a more accurate outcome from the analysis. The examination of the open-circuit voltage, short circuit current, maximum power, fill factor variation and the reduction of the overall solar intensity of the cells were conducted. The researchers after a thorough examination of the different elements of the research methodology were able to conclude that the accumulation of dust and also the deposition of fine Aeolian dust was a significant factor that created a negative impact on the performance of the solar panels and the solar cells in specific. However, the researchers also determined that the velocity of wind also had a significant impact on the overall performance of the solar cells. The researchers claimed, that the impact of dust accumulation is considered more extreme compared to the impact of wind velocity on the cells. The researchers also share their opinion and findings that the speed of wind has no significant impact on the sediment logical structure/appearance of the dust.

Another study by Rachid & Hamid, (2017), in continuation to the outcomes presented by Sulaiman et al., (2011), stating that the accumulation of the dust on the PV panels have a negative influence on the efficiency, this impact gets worst as the dust build up increases. The research uses a quantitative methodology, analysing the results from the solar panels impacted by being exposed to dust. The researchers also concluded that the dust has a more negative impact on panels that are tilted on a 30-degree angle compared to the panels on a 50-degree angle. The impact is not only in the loss of efficiency but also in the form of financial losses and the researchers state that the outcomes of the study can be applied to all the other solar panels within the Jazan region of Saudi Arabia.

Sulaiman et al., (2011), help in providing a quantitative assessment, examining the performance impact of dust on the solar panels. The objective of the study is to provide details about the impact of dust on the solar panels. the researchers noted that the outcomes of most qualitative studies are not accurate and/or also not clear. Hence, the researchers used specific experiments to examine the dust particles with constant power light source and from that, the researchers aimed to evaluate the performance and the efficiency of the solar panels. The analysis of the experiments on the solar panels leads to a conclusion that the efficiency of the solar panels can be affected significantly with approx. 50% of the overall efficiency can be reduced.

Another study by Jan et al., (2014) provides a variety of information on the impact of

dust accumulation on solar panels. The researchers state that there is a decrease in the optical efficiency of the solar panels (PV System). The researchers make use of a variety of sources including the commercial sites, rain statistics and other events as per the nearby weather station as well as data from the satellite. The researchers find out that the accumulation of dust on the different solar panels during the summer period resulted in a decline of efficiency from a total of 7.2% to 5.6% that was normalized to 7.1% due to the rain. The researchers use the term soiling for the appearance of dust on the solar panels.

Monto & Rohit, (2010) in their research explained that the depletion of the oil reserves and different other factors within the global market have resulted in the encouragement of adopting sustainable/ renewable energy sources. Using solar Photovoltaics panels is one of the most common alternatives adopted throughout the world. The researchers also raise the point of that their research is required to determine the usefulness and impact of solar panels on energy production, they also provide details of the efficiency of the solar panels within commercial markets. They aim to evaluate the solar panels efficiency and finding out means to increase the overall effectiveness, as well as the efficiency of the panels including the geographic (i.e. selection of location, latitude and altitude) and the design of the solar panels including the level of tilt, altitude of the panel and the orientation as these, can help to improve the efficiency. The researchers clarify that other than these factors some elements can have a potential impact on the performance and including others, dust is a significant element/ factor that can have a negative impact. The objective is to help improving the long-term efficiency of the solar panels against dust accumulation.

Another research, focusing on the GCC region by Mu'azu et al., (2018) noted that the use of fossil fuels has enriched and have dominated the economy within the last few decades specifically in the countries associated with the Gulf Corporation Council. It is also noted that the current need for power production for the GCC countries has led to an increase in the use and development of alternative and renewable energy sources to cope with the increase in demand for the future. It is also important that the policies and regulations enforced, having a realistic approach to ensure that the future demands for the production units and divisions are met most effectively. The authorities must also provide a steady focus on the promotion of renewable to the general public and the overall state economy. For that reason, the researchers have provided with a recommendation that the investments in research and development must be done to make sure that technical know-how and significant application can be ensured and also mixed-initiative including the private and public investments, strict policies, regulations, and a regulatory framework are devised to make sure that the overall effectiveness of the system are improved and long term efficiency can be guaranteed.

The research study by Sayyah et al., (2014) is specific to the GCC countries. The researchers found that there is a huge potential for big-scale solar panels placed within semi-arid lands known as deserts. The prime reason is that the availability of sunlight is huge and there is a higher chance to ensure that the conversion of sunlight to power and electricity can be done in the most effective and efficient manner. the availability of sunlight is present but there are two main drawbacks for using these panels in such distinct areas including the dust, the humidity and the ambient temperature of the region. The researchers claimed that the impact of such environmental degradation can be a cause of the inefficiency of the plants/ panel and it can harm the production of energy and electricity. The major negative impact of the dust and other particles on the solar panel can result in transmission losses. The researcher's prime aim was to understand the reasons and evaluate the loss of energy by the solar panels due to the huge amount of dust on the panels with a specific focus on the flat panel PV systems within the region. Their literature review was focused to gain a better understanding of the different researcher's outcomes and findings on the subject matter throughout the world. Along with that, the outcomes of the studies performing laboratory soloing tests is also a part of the extensive literature review carried out by the researchers. These studies helped to support the outcomes of the previous researchers, that there is a negative impact of dust accumulation on the efficiency and performance of the solar panels. They also provided some recommendations on design, different effective and most comprehensive solar panels, cleaning processes of the solar panels and other information that is beneficial for the long-term success of the renewable energy extraction within the GCC countries.

Impact of dust on the solar PV cells within Gulf countries

The GCC (Gulf Cooperation Council) was founded with the objective of sharing regional experiences aiming for a stable and satisfactory regional collaboration and cooperation between the Arab countries within the Gulf. The authorities have helped to promote the need to make changes within the policies and procedures due to the challenges faced by the region such as financial instability,

currency sustainability and future strategies at times of peace or during wars. The GCC role is to ensure the sustainability, defence, and strategic development, taking specific measures to make sure that the wellbeing of the people living in different regions of the Gulf

Al-Maamary et al. (2017) helped to develop an understanding of the GCC challenges, facing the changes in climate (Climate change/Global Warming) within the region. These serious challenges are not only affecting the economy through industry, these are also going to affect all the individuals living within or near the region. Some of the main recorded changes in climate are higher levels of humidity averages, average ambient temperatures increase in summer, and a decrease in the level of precipitation. It references many supported claims that the climate change is majorly occurring due to the activities of the people throughout the years/ decades. The researchers state that the GCC countries exerted many efforts and aligned their agendas to ensure that issues like climate change are efficiently managed. Just like other developments by the authorities, the use and adaptation of means to develop sustainable sources of energy as an alternative are widely discussed. The GCC countries have developed a lot of strategies to focus on renewable energy production for securing the future energy needs. Mokri et al., (2013) provided details in their research paper regarding the development of the energy resources, its usefulness and other essential activities that are required to further promote the use of alternative sources of energy such as solar panels.

The use of solar panels has increased within the past two decades. The governments of the GCC countries had initiated several attempts, producing electricity using solar energy on a large scale. The climate challenges and the regional atmospheric conditions within the GCC countries had the inefficiency of the solar panels and their performance being questioned due to the dust accumulation. Some of the research studies undertaken, like one already discussed above by Rachid & Hamid (2017) help to understand the effect of dust and other atmospheric issues in the GCC, having a negative impact on the overall production and the energy generation process.

The study by Mu'azu et al., (2018) have helped to highlight the importance using solar energy in the current era, since the production of electricity can help to facilitate the future needs and demand of energy for the region. The researchers have a view pointed out that the governments and other authorities must take their contributions further with the overall effort to ensure that the long-term efficient policies and strategies are developed considering the issue of dust and how it can be mitigated for a long-term efficiency of the solar panels operation and maintenance.

Bardsley, (2017) also places forward his point of view, that the outcomes of the analysis have helped to proclaim that the dust within the Gulf region has a significant impact on reduction of the efficiency of the solar panels, even after their cleaning. This is due to the fact that the particles of the dust are decreasing the energy generation and therefore, specific strategies are needed to be counselled. The researcher states that the dust on cars and other areas is just like the dust on the solar panels. The presence of dust on a solar panel is however a much bigger concern for the user. It is noticeable that the government and other private investors in solar energy panels are spending millions of pounds to achieve their energy production targets and improve the environment; Therefore, the reduction of production and efficiency is a matter of great importance. The development of effective and energy contained machines for the cleaning of solar panels is available, but the cost of such heavy machinery and the damage it causes to the solar panel's surfaces are still a concern.

Many literatures have focused on the obstacles faced during the extraction and development of alternative resources for electricity and power. The use of solar panels for conversion from sunlight into electricity is one of the most widely used processes of sustainable energy generation. The GCC's geographical positioning make these countries a potential candidate as major users of the solar systems due to the abundance of sunlight throughout the year. The available technology has yet to address the far more sever climatic issues for the GCC, compared to other parts/ regions of the world. Dust and atmospheric issues have resulted in an overall decline in the production of electricity and power from the tested solar systems. The analysis of the current literature helps to provide details of what to be done in order to make sure that the future of solar panels can be maintained properly.

The efficiency of solar systems as a renewable source energy

As the carbon emissions are considered one of the most significant pollutants to environment, there has been a global awareness and control policies were put in place with the purpose of carbon emissions reduction. Accordingly, to many countries had evolved with their energy production, using renewable energy sources as an alternative or a supporting system to their current demands. With

that, the advancement in technology must keep up to make sure that innovations help to explore new means for producing energy, facing the new arising challenges.

Shahrouz et al., (2014) explained that there would be an increase in electricity demand as well as availability of new renewable energy systems over the next twenty years. In recent times, the rise in fossil fuel prices along with the negative effects of the fuels on the environment have resulted in an increase of study and research to utilize new sources of energy production that can replace the use of fossil fuels. To minimize the environmental consequences caused by the use of fossil fuels, the demand for renewable sources of power is considered as the most effective and efficient means for energy generation. The researchers stated that there is a need to develop specific and effective policies to ensure that the carbon emissions can be reduced significantly. Shahrouz et al., (2014) stated that the two most significant policies that can help to resolve these issues, first to make sure that the fossil fuels are replaced as much as possible with renewable energy sources and secondly to make sure that the efficiency of energy generated from renewable sources is improved.

Another research by Olusola et al., (2017) from Nigeria provides details of the importance of renewable energy sources; He stated that his country is considered to be one of the richest in fossil fuel reservoirs. With the available non-renewable (coal/fossil fuels) and renewable energy sources, almost 50% of population is been unable to receive electricity from the main grids. The researchers put forward the paper to provide details of renewable energy, its past, present and future perspectives. Statistics supporting the claim that if the government is able to facilitate the plans in the most effective manner, the population who has no access currently to the electricity can be able to use the facilities proposed. The author in his literature review supported by the cited journal articles and reports were used to explore the potential renewable energy sources including wind, biomass, solar energy, and the hydropower compatible with Nigeria's climate. All these possibilities were investigated to ensure that the population are able to get the power needed, improving their means of life. This is to address the energy supply challenge, considered as the biggest issue for Nigeria. It's important to understand the available renewable resources to select the most feasible and rewarding composition of solutions.

Turner, (1999) studied the possible resources to provide a description of renewable resources that might be best for his case in the United States. He used the details of different renewable energy sources, evaluating the energy payback period, energy storage capacity, and carbon dioxide emissions. For the location selected, he proposed the use of different hydron made/ composed energy sources, using different systems for the production to ensure that the demand internally can be met in the best feasible way. highlighting the drawbacks of using fossil fuels and carbon dioxide.

Panwar et al., (2011) studied the importance of renewable energy and different technologies to provide clean and environmentally friendly sources of electricity balancing the demand and supply. To help mitigating and minimizing the environmental effects, achieving the most effective alternative source of energy (other than fossil fuel), the researcher studied the potential renewable technologies aiming to sustain the highest efficiently.

It can be also concluded that the solar power can be used through its thermal and radiation (heat and light) energies, both can be transferred by technology to other energy forms. Wind energy as a dynamic force can also be transferred to energy. On the other hand, biomass as an organic material can as well be used to generate energy. All these studies are aligned in their conclusions and many other research works, emphasising that the use of renewable technologies help limiting the impact on the environment through the reduction of emissions. The researchers provided specific details to their location of study, and how carbon emissions can be mitigated using the available/feasible alternative sources for generating energy.

Carrasco et al., (2006) highlighted that the dependency on their central power plant can be reduced with the increase in the use of alternative renewable energy sources. Traditionally, the generated power is distributed and utilized to meet the demand of the energy within the region. Details are analysed of the latest solar photovoltaic power generation technologies and its efficiency in supporting the energy demand. For the location selected, the researchers reported that these can be considered as some of the most influential and important alternatives of energy. Considering the current and future prospects of the renewable energy sources and their importance of such technology on the environment.

Another study by Koroneos et al., (2003) explained the significance of the oil crises and the dependency on fossil for some countries and their economies. It stated that the oil crises led to an increased demand for alternate resources of energy in a more urgent and effective way. Most previous researchers claimed, the renewable energy sources are more as they are less likely to get exhausted and

also there are lower chances of having an inverse impact on the overall environment; Unlike the fossil fuels used in different regions of the world, being limited and having high emissions levels. The researchers also claimed that the current situation with the ongoing challenge in adapting renewable energy sources, not being used in full capacity, the fossil fuels usage is still dominating major areas and locations of the world. The researchers analysed the performance of three renewable sources of power, wind, geothermal and solar. The researchers provided a comparative analysis of the renewable and other non-renewable sources of energy based on the efficiency levels for each energy source.

Dresselhaus & Thomas, (2001) conducted a review of the current efforts using renewable and other non-renewable sources for the generation of power. The researchers support the points raised by Koroneos et al., (2003) that fossil fuels are currently the highest means of supplying and fulfilling the worlds/global demand for power. It also highlighted the long-term negative consequences and impact of the currently non-renewable means of power generation on the environment. It was emphasised that researchers and other analysts must make sure that the alternative suggested renewable sources of energy and their specifications are designed with knowledge of the main sources of renewable power generation, specific to the location of installation and are provided so that decision can be made to mitigate overall dependency of the world on non-renewable means of power generation (fossil fuels). The academics state that the renewable and other technological advancements are beneficial to make sure that the sources of power generation can be altered as well as can help to provide a more environmentally friendly means to generate power on a global scale.

From this literature review, the international interest in renewable energy is highlighted as well as the work determining the usefulness of the renewable energy sources and extracting the most efficient means of increasing the potential of the solar/ renewable energy sources used throughout the world.

A research study by Mekhilef et al., (2011) explains that solar energy is widely used throughout the world for the generation of heat and also in producing the electricity. The researchers quote the findings of the report by International Energy Agency that till the time (i.e. 2050) the worldwide production for power and energy would be almost half (i.e. 45%), generated with the help of solar natural power. The solar thermal energy source is considered to have a successful contribution to raise the overall level of energy demand. The academic uses the information of the industries and highlights the importance of the use of renewable energy sources. The researchers also state that the use of solar energy within the industries can help to improve the overall level of carbon emission and the negative impacts of the CO2 emission globally keeping them at minimum levels. The analysis helps to understand the importance of the global dependency on–renewable energy resources, noting that it has raised significantly and there are higher chances that other countries can align themselves strategically to improve the overall level of environmental efficiency.

The efficiency of solar systems as a renewable source energy in Gulf countries

The use of renewable energy sources throughout the world have been thourally studied. The outcome of these studies help to a light on the importance of such alternatives to fossil fules and how to improve the environmental conditions, reversing the polliotion issues raised by the use of fossil fuels.

Most of the literature found emphizise on the importance of the renewable energy sources and its major benefits, minimizing the current environmental issues. As the renewable sources of energy are highly linked to climate, the focus was to explore the renewable energy sources and efforts made by the GCC countries, and the initiatives taken by the governments (or other investmentors) to develop new alternatives for fossil fuel productio.

A study by Haris et al., (2006) evaluate the use of oil and gas resources for the production of electricity and other power resources majorly used within the GCC countries. In the study, it was noted that the governments and the general public are in full support of the alternative sources of energy generation systems as they are aware of the negative consequences for the use of oil and gas as the prime sources for generating electricity and other power industrial operations. As per the research, it was pointed out that it is up to the authorities and the governments of the GCC countries to make sure that effective and long term policies for renewable energy sources are devised. Along with that, the researchers state that the policies for rational use of energy are also important for the future of the use of renewable energy developments as it is considered to be the basis for the overall renewable power generation system planning and management.

Saima et al., (2014) highlight the dependency of the GCC countries on oil and gas as the commom (almost the only) means to generate energy. It was stated that countries are equally active in formulating and exploring the use of new renewable energy sources to make sure that the environmental impacts can be mitigated especially

in the Middle Eastern where the GCC Countries are located. GCC – (Gulf Cooperation Council) has provided a good platform to develop a strategic plan in order to invist in exploring the use of solar and other renewable energy solutions/ systems supporting the overall electricity demand over the period of next twenty years. The researchers enlisted details of the overall contributions and efforts of the GCC countries to increas the production of energy through renewable energy sources.

Zeineb et al., (2015) mentioned that the use of renewable energy and the decision to develop a more focused strategy, to ensure the use of such resources for GCC countries, require a very specific understanding when compared to the other regions of the world. Due to the fact that the GCC countries are rich with natural resources (oil and gas), they used to consider the investments within the renewable energy sources as less profitable and effective. But with the help of global and regional awareness, and specific focus on the development of the framework for the GCC countries, now the countries are able to take a step toward renewable energy for its effectiveness in the long term.

The analysis of the current potential of the solar power (considered the most rewarding renewable energy source within the region) within the GCC countries help to develop an understanding of the possible investments in renewable energy sources, making sure that the current and future demands for electricity and power are better met with the help of renewable energy sources.

There is also a point to be noted about the overall level of use of oil and gas being mitigated but not to be avoided completely as it would not be possible for GCC countries to fully meet the demands depending fully on the renewable energy sources. The investigation also raised the point that the governments and other authorities are trying their best to come up with the most effective and efficient strategic decisions for the GCC countries and to make sure that the benefits from the use of such renewable energy sources can be enhanced and improved. It was also noticeable that the overall efforts of GCC governments in maintaining and making sure that the majority of the production of new electricity is done by renewable sources are exceptionally supported by the global world and the public at large.

A study by Ahmed et al., (2017) helps in the examination of the Energy execution, ecological effect, and cost evaluations of one MWp plant utilizing the principle 2017 market accessible photovoltaic advances under hot climatic conditions for the territory of Kuwait. Impact of climatic parameters on modules efficiencies, net Energy generation per unit zone and plant execution proportion with PV modules produced using crystalline silicon-based and dainty film advances put together was evaluated with respect to hourly, daily, monthly, and yearly premise individually. The PV modules utilized are the monocrystalline, polycrystalline, and flimsy film cadmium telluride (CdTe) and CdS/CdTe semiconductor. These systems are evaluated based on their manufacturere given attributes and a normal of 20 years hourly climatic information of the surrounding air-dry temperatures, horizontal sun based radiation, and normal wind speed for the state of Kuwait. The outcome demonstrates that the monocrystalline system has the highes production ability; Used as a base for being least land-requiring modules in the region, it is discovered that, the a polycrystalline plant requires an extra land of 19.33%, flimsy film cadmium telluride (CdTe) plant needs additional land of 8.39% and meagre film cadmium sulphide (Discs)/cadmium telluride (CdTe) (CdS/CdTe) plant needs an additional land of 39.76%. The region's net yearly Energy delivered per unit (specified land area) comparing the different systems off the the monocrystalline PV system as the optimum. The indicate that Polycrystalline system delivers less yearly net Energy by 10.54%, slight film cadmium telluride (CdTe) system deliver less yearly Energy by 6.07%, and slender film Albums/CdTe system generate less yearly Energy by 22.73%. The primary examination end is that the slender film cadmium telluride (CdTe) innovation has the yearly normal right Energy cost execution parameters with less Levelised Energy created and capital expense with least ecological destructive outflow and it tends to be prescribed for use under Kuwait atmosphere condition.

Different researchers all over the gulf countries have tried to determine the best possible means of renewable energy sources to keep up the pace of electricity and power demands for the countries within the region.

A study by Mejia et al., (2013) highlighted that the dust is considered as one of the most significant influencers that affect the efficiency of the solar PV cells of the CSP (concentrated solar thermal) systems. The research made use of the data gathered of a solar system from a large commercial site for the year 2010 and the weather/ rain events in the nearest area Also, the use of satellite data helped to determine the impact of soiling/ dust accumulation of the solar panel. The analysis of the data and the overall outcomes helped to conclude that the soiling resulted in a loss of efficiency equal to approximately 0.21% on a daily basis. The efficiency of the solar panel decreased from 7.2% to a total of 5.6% over a period of 108 days. The researchers also highlight that the efficiency was

further improved due to rain but it reached a maximum level of 7.1% after the rain.

The research paper by Monto & Rohit (2010), further points out the usefulness and importance of the geographic location including the latitude and solar insolation and the design of the installation including the tilt and altitude of the solar panel. The researcher's further state that these factors must be addressed and used efficiently to improve the overall performance and afterwards mitigate the other issues like soiling. The researchers also provided guidance on the possible levels of maintenance and cleaning of the solar panels as it can help to improve the overall efficiency of the system.

The study by Ali et al., (2017) help to raise awareness on the environmental, economic, and health-related impact of dust. The researchers use the data of dust storms for the period of 2009 till 2017 and related trajectories were plotted. The satellite images were used to derive information regarding the eight SDS trajectories and the researchers categorised the dust with respect to size and shape, and further 12 sub types were highlighted for the area. The researchers state that a total of approximately 89.1 million metric tons of dust is transported to the Arabian Gulf every year. The amount of dust deposits in the oceans and sea compared to any other region is the highest. The research paper helps to determine the types and level of dust that is transported to the Arabian Gulf region and the research would be beneficial for the future prospects including the management of environmental and also the occurrence of special events.

A study by Mizanur et al., (2012) mentioned that solar PV cells and their efficiency were tested almost all over the world. In the study, it is stated that energy is viewed as a prime operator in the age of wealth and a critical factor in the level of economic stability and development. Restricted fossil assets and ecological issues related to them have stressed on the requirement for new supportable Energy supply choices that utilization sustainable power sources. Among the accessible advancements for Energy generation from sunlight based source, the photovoltaic framework could give a noteworthy commitment to building up a progressively reasonable Energy framework. Sun-powered Panel has it's wide utilize beginning from a basic 5W diode light (semiconductor device with two terminals) to a couple of kW air conditioning drives. A sun oriented board with a battery and a charge controller and other assistant gadgets like DC to air conditioning converters establish a Solar Home System (SHS). Solar home framework (SHS) is getting to be well-known step by step and even poor family units are currently getting to be intrigued to buy sun based home framework because of its economical and environmental values. On the other hand, any sun based home frameworks (SHS) have a noteworthy issue that is low proficiency in maintaining a steady performance. It likewise diminishes yield step by step due to inappropriate systems for upkeeps, the impact of residue and shadow. Amassing of residue on sun-powered board of sunlight based photovoltaic (PV) framework is a known challenge. It was found from the investigation that the amassed residue on the outside of photovoltaic sun based board can diminish the framework's proficiency by up to 35% in one month. In this paper, we demonstrate the impact of residue aggregation on the sunlight based board normally and how it is conceivable to conquer this issue.

III. METHODOLOGY

3.1 Introduction

This section explains the methods adopted to analyze the PV's performance, determine the impact of dust on the Solar PV cells and evaluate the efficiency of solar energy as a form of renewable source within the Gulf region. Qualitative and quantitative data were collected during the research and analyzed. Multiple resources were used to validate the accuracy of data used, using only reliable reports by official publications and institutes, using systematic manner to ensure that generalized outcomes are be presented.

3.2 Research objectives

As mentioned in the introduction, with this study, the objectives are:

- Proposing the potential deployment/ installation of the PV solar panels concerning slope/ tilt to optimize the efficiency and manage the electricity demand for Kuwait.
- To evaluate the importance of Solar PV panels as a source of renewable energy for Kuwait and its long-term efficiency.
- Determining the efficiency of solar energy as the renewable source in the Gulf region (Kuwait) and evaluating the regional challenges.
- Proposing maintenance and cleaning plan for the PV panels to sustain their performance.

3.3 Research Philosophy

The start is with understanding the regional climatic challenges within the GCC by reviewing the meteorology yearly reports, published researches analyzing the weather behavior and the frequency of common weather events that might have an effect on the renewable energy system' performance. By establishing the effect of these regional parameters,

a strategy is set to assess the maintenance requirements (cleaning) and challenging the recommended (optimum) setting with the efficiency issues arising from the climate events.

The data for electric supply and demand along with the details of solar PV panels offered as an electricity alternate potential source for the GCC countries, their performances drop due to dust specifically are gathered and discussed to provide guidance toward better efficiency.

3.4 Research Design

The research uses statistical and scientific content to critically analyze and discuss the dust occurrence (including the dust storms, dust chart per year, rising dust levels and amount of suspended dust) and its influence on solar PV cells. The analysis would help to explain the possible means to overcome the issue of dust accumulation and possible means to recommend the cleaning of the solar panels. The local data used were mostly provided by KISR (Kuwait Institute of Scientific Research) (KISR, 2019), Kuwait's meteorology department and the Ministry of Electricity and water. The chart below details the structure of this research reaching the objectives decided:

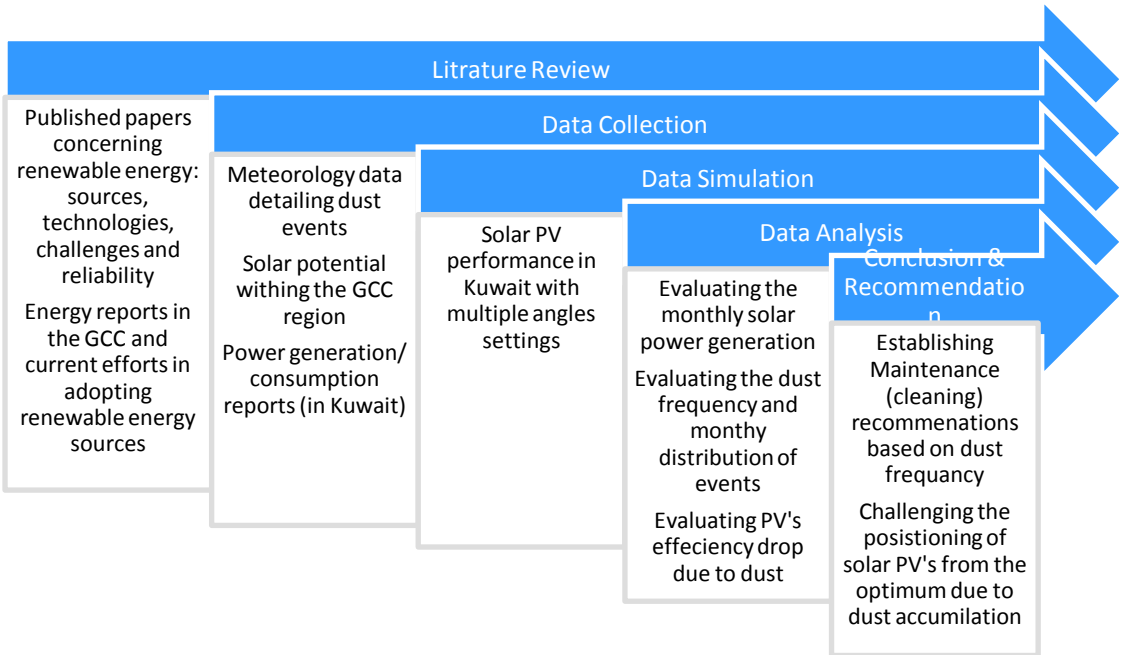

***Figure 1**: Research Structure*

3.5 Sampling procedure

- Thorough and in-depth exploration and comparing/ contrasting the findings of the research papers concerning:

1. Renewable (solar) systems productivity and efficiency.
2. Weather statistics detailing the monthly dust, haze, and dust storms events frequency and the amount of dust precipitation.

- The data of Kuwait's weather is analyzed, concerning the temperatures, wind and the amount of dust obtained from Kuwait's meteorology department and KISR.
- The use of simulation is done through *PVSYST* (PV Systems and Solar Software Development Services) and the information/ data for Kuwait is gathered with the help of internal links as well as internet sources including the angels of tilt for achieving best possible efficiency of the Solar Panels.
- Optimum angles for solar PV performance were obtained by the Solar Angle Calculator, derived from the Solar Electricity Handbook
- Solar energy generation potential was conducted through (Renewables.ninja), a simulation platform developed by Stefan Pfenninger and Iain Staffell, who both research the effects of integrating renewable technologies into our energy systems

IV. RESEARCH ACTIVITY: SIMULATION/MODELLING

In this research, simulations are used to evaluate solar PV' capabilities and the percentages as well as the days recommended for cleaning (monthly) of the Solar PV systems based on Kuwait's region climatic parameters. This is done with the use of simulation, graphical representations to visually explain the data and tables (as well as the ones a part of the appendix) displaying the statistics of the discussed parameters. The data for electricity

and weather and details for the best possible tilt concerning Kuwait region are evaluated. Details of dust including the suspended dust, rising dust levels, and several dust storms, explanation of the power potential for Photovoltaic systems, and the simulations for wind and solar PV farms are gathered and obtained to reach the conclusion for this research.

V. RESULTS & ANALYSIS

The analysis of the data specifically for Kuwait is analysed and interpreted to develop an understanding of the overall Renewables performance. The analysis performed is essential to build a solid base for the research study.

Figure 2: *Capital of Kuwait, Kuwait City*

5.1 Average Temperatures in Kuwait

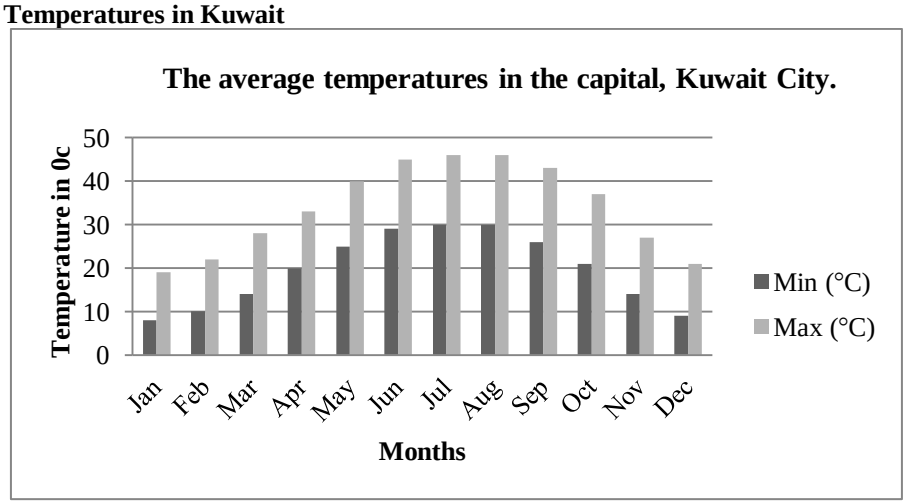

Figure 3: *The average temperatures in the capital, Kuwait*

Some data are available online and daily updated, concerning the weather averages hourly, daily, weekly, monthly, seasonally and yearly. Evaluating the weather parameters of Kuwait is the first step to build a solid base for this study. Many online providers are publishing weather statistics, the data used was obtained from (Climates to travel) for their clear and specific display of information. Details including the average monthly temperatures, precipitation levels, and average sunshine hours for Kuwait were of use. The analysis of solar radiation values for the year 2018 helps to develop an understanding of Kuwait's potential, using solar as a source of renewable energy. Kuwait's weather is mostly sunny and hot. The average temperatures for the month of Jan (winter's peak) reach a maximum of 19^0 whereas, the average minimum temperature is 8^0. The most sunny and hot months of the year are June, July, August and September out of which July and August for the year 2018 were the hottest, with temperatures reaching an average maximum of 46^0 and average minimum of 30^0.

***Table 1**: Average Temperatures, Kuwait City*

Kuwait City - Average temperatures	Min (°C)	Max (°C)
Jan	8	19
Feb	10	22
Mar	14	28
Apr	20	33
May	25	40
Jun	29	45
Jul	30	46
Aug	30	46
Sep	26	43
Oct	21	37
Nov	14	27
Dec	9	21

5.2 Average Precipitation Levels in Kuwait

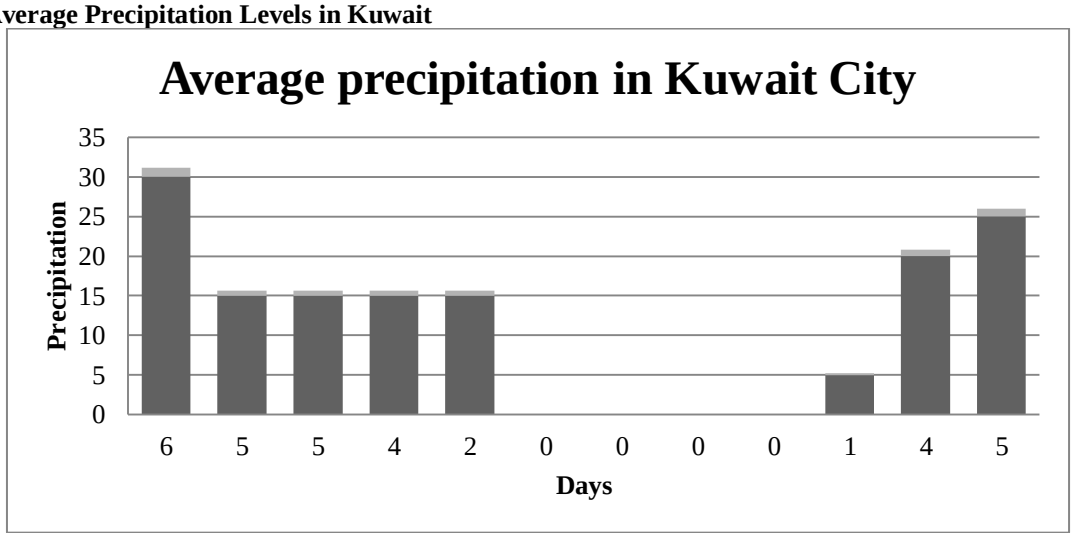

Figure 4:** Average precipitation in Kuwait City **(Climates to travel , 2019)

The data for precipitation summarising the total monthly rain levels (in mm) that took place in Kuwait for the year 2018. In the year 2018, Kuwait precipitation levels were the highest in the month of January with 30 mm. While in June, July, August, and September the precipitation levels were 0 (no rain events at all). The table below breakdown the rain precipitation monthly levels for the year 2018. This is important in pointing out that the rain frequency is not sufficient at all to be relied on for cleaning the solar PV panels as some other regions do.

***Table 2**: Kuwait City - Average Precipitation Levels, Monthly*

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prec.(mm)	30	15	15	15	15	0	0	0	0	5	20	25
Days	6	5	5	4	2	0	0	0	0	1	4	5

5.3 Solar data for Kuwait

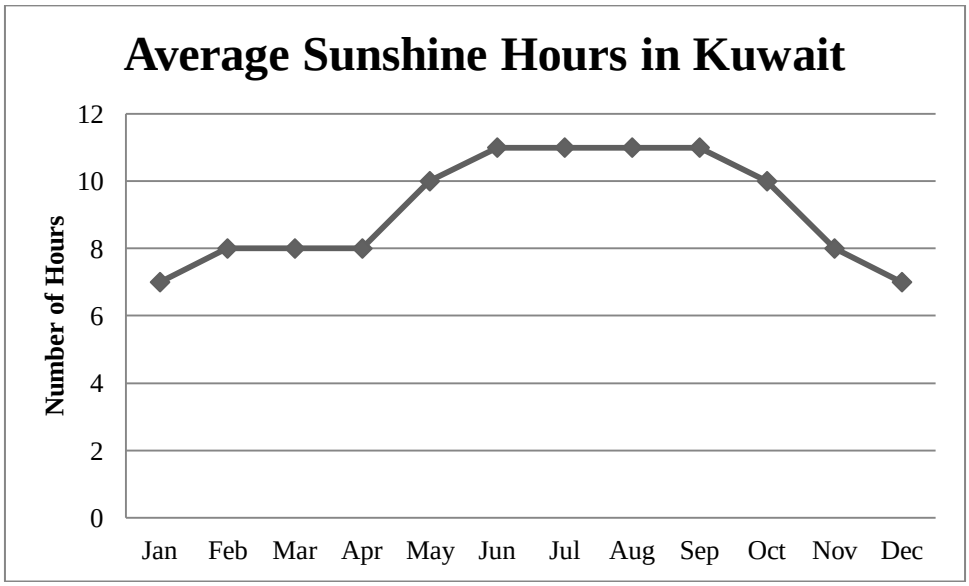

Figure 5: *Average Sunshine Hours in Kuwait* ***(Climates to travel , 2019)***

With the use of PVSYST for the evaluation of sun data, it was shown that the positioning of the sun in Kuwait is above 30^0 and is less than 90^0. The average sunshine hours per month are also studied, and the analysis of the data help to develop a more accurate understanding of the higher potential for Kuwait to use the alternate energy sources majorly the Solar PV systems. There are higher levels of solar radiation, in values adequate to be considered as important resources available to the country. The results in (Figure 5) supported by the table below helps to identify that the highest average sunshine hours in Kuwait are 11 hours in the month of June, July, August, and September. Followed by 10 hours in the month of October and May, 8 hours of sunshine in the months of February, March, April, and November, and seven hours in January and December.

Table 3*: Average Sunshine Hours, Monthly*

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prec.(mm)	7	8	8	8	10	11	11	11	11	10	8	7

These parameters have a significant role in determining the potential of renewable systems in Kuwait as well as the factors impacting their performance. In the following sections, recommendations for the maintenance will rely on the weather parameters as much as the guidelines defined by the manufacturers.

5.4 General Weather in Kuwait

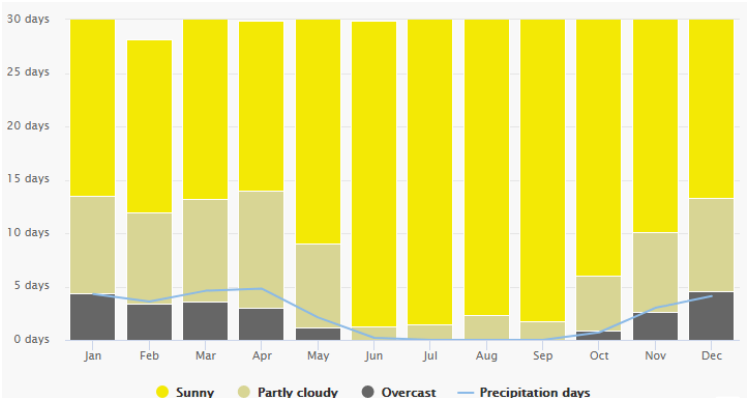

Figure 6: *Cloudy, sunny, and precipitation days*

Figure: 6 represents the sunny, cloudy, and precipitation days for Kuwait, the days in specific with lower than a total 20% cloud cover are presented as cloudy days, with clouds from 20-80 per cent are cloudy, and days with more than 80 per cent clouds are presented as the overcast. The figure above shows the weather for Al Wafrah, Kuwait, 28.554° N 48.053° E, 110 m asl. Showing that the region is mostly cloudy with June, July, August, and September as the sunniest months of the year and April as the cloudiest month of the year with 11 partly cloudy days. The analysis of the climate of Kuwait helps to understand that the level of sunshine in the region is high and therefore, there is a huge possibility to use the solar PV panels to get the most efficient means of energy. It can also help to identify that the amount of rain is limited and therefore, there is a need to evaluate the overall cleaning policy to ensure the efficiency of the solar panels are managed.

Further data, detailing the sun parameters are included in appendix A. These parameters are the key in estimating the daily potential of energy calculations and simulations. The data was obtained from KISR and it includes: the sun's declination yearly pattern, the sun's altitude yearly pattern and sun's altitude vs. azimuth.

5.5 Electricity Peak Loads

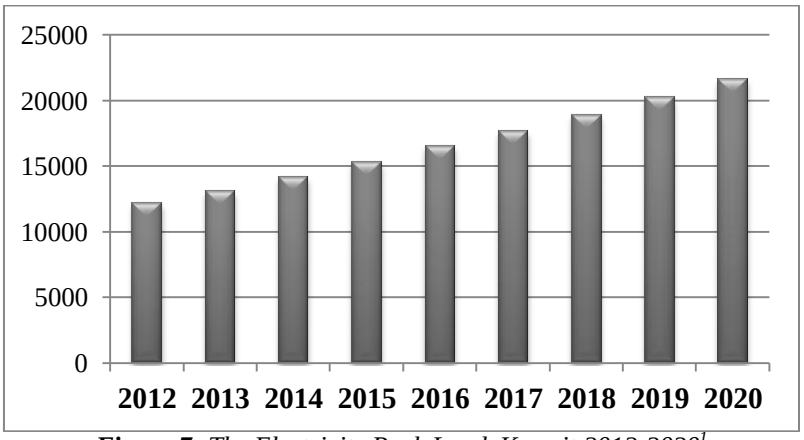

Figure 7: *The Electricity Peak Load, Kuwait 2012-2020*[1]

The electricity peak load for Kuwait is showing consistent growth. From the year 2012. Figure 7 shows the steady increases, and forecasting that it will keep on the same trajectory, pushing the electricity sector to upgrade and expand in order to meet the growing demand for electricity. Kuwait's consumption of electricity per capita, compared to the average made by the Organisation for Economic Co-corporation (OECD) countries, is 2.3 times greater. The main sources of electricity generation in Kuwait is through water desalination plans, fuelled by oil and gas. The growing production and internal consumption of crude oil, gas, coal and other hydrocarbon fuels coupled with the fluctuating prices, has resulted in a decline in income and affected in the economic growth activity for the country. It's worth mentioning that the ministry of electricity and water aims to decrease the values or to maintaining them by advising the public on the latest low consuming appliances as well as publicising the global challenge of climate change.

The analysis of the current and future electricity needs for Kuwait as well as the continuous growth in demand support the need for new applications, using renewable energy sources as one of the most effective means to cover/fulfil the demands while being mindful about the environment[2].

[1] Sreekanth, K.J., Ruba, A.-F., Abdulrahman, B. & Ahmad, A.M., 2016. *Potential of Energy Storage Technologies for Electrical Power System in Kuwait*. Westminster: Energy Systems Conference Energy Systems Conference.

[2] Zeineb, A., Adel, G. & Rashid, A., 2015. Recommendations on renewable energy policies for the GCC countries.. *Renewable and Sustainable Energy Reviews*, 50(2015), pp.1181-1191.

5.6 Photovoltaic Power Potential

5.6.1 Optimum Yearly Energy Generation

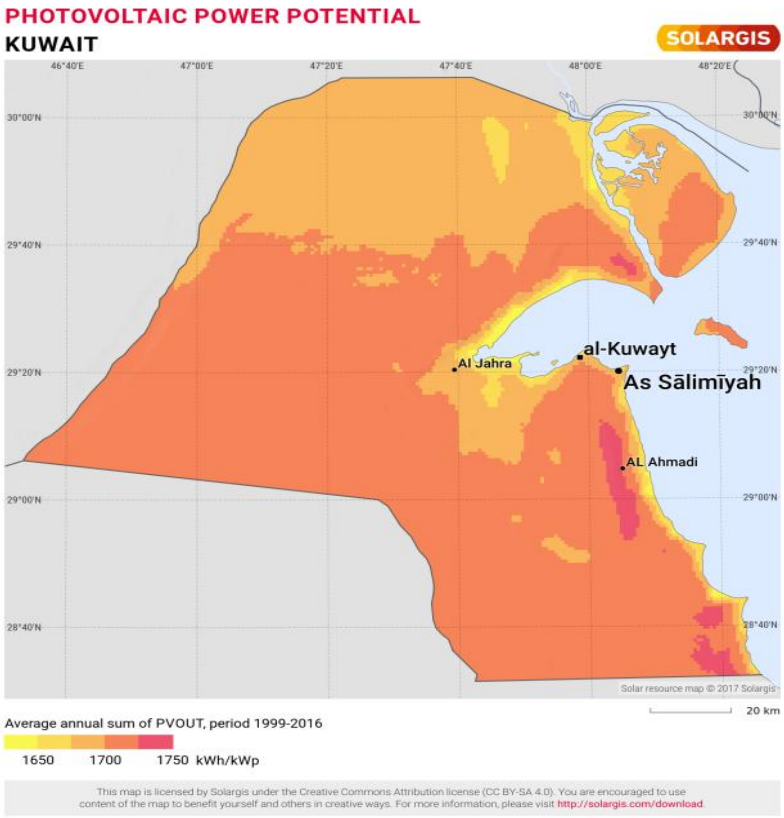

Figure 8: *Photovoltaic Power Potential* ***(Solargis, 2019)***.

Figure 8 provides a graphical representation of the potential photovoltaic power generation within Kuwait. The website (https://solargis.com) provides several images including the representation of global horizontal irradiation and the direct normal irradiation. These figures help to support the use of renewables and that there is a satisfactory level of potential for the photovoltaic power within the region with a higher range in some regions between 1700 to 1750 KWH/KWP and a lower range in other regions with potential between 1650 KWH/KWP [3]. These rates shall be very encouraging for the government and concerned authorities to devise the future strategies in support of using renewable energy sources, mainly the use of Solar Photovoltaic Systems.

[3] Solargis, 2019. *Solar resource maps and GIS data for 180+ countries | Solargis*. [Online] Available at: https://solargis.com/maps-and-gis-data/download/kuwait [Accessed 19 August 2019].

5.6.2 Monthly Tilt Angles

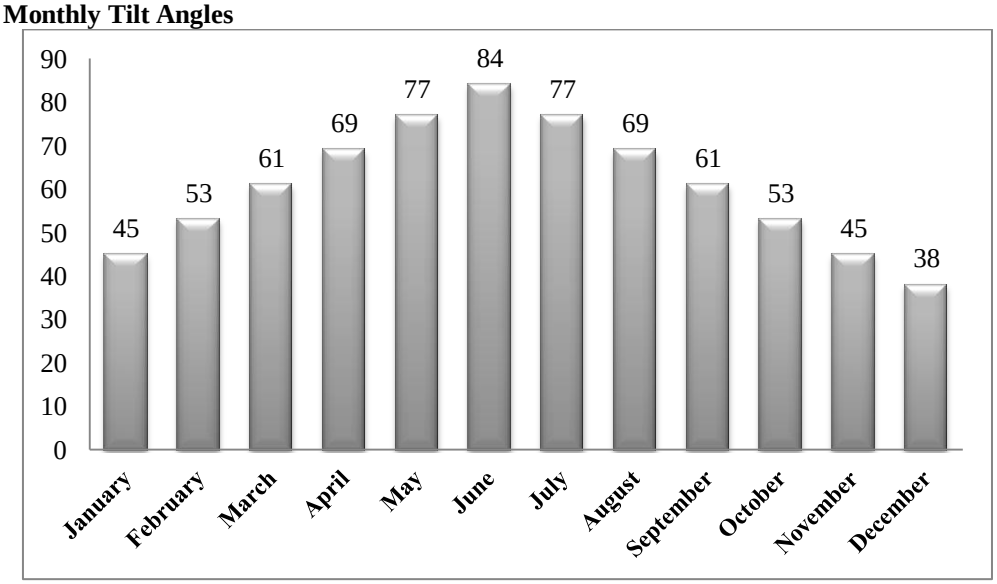

Figure 9: *Al Wafrah, Kuwait Optimum Monthly Tilt Angles* ***(Solar Panel Angle Calculator, 2019)***

Figure 9 highlights the optimum tilt angles per month. These angles are obtained with the help of the Solar Panel Angle Calculator. This calculator was developed to take on the climatic characteristics of a specific location and calculates the optimum angle of placing solar PV's to harness the largest amount of energy. The data for Tilt Angles mentioned are specifically for Al Wafrah, Kuwait. These are meant to guide the energy generation levels to the highest efficiency the Solar PV panels can achieve. The highest angle of 84^{o} is recommended for the month of June whereas, the lowest angle of 29^{o} is for the month of December. Apart from that, a more general approach, would be using specific tilt angles for each seasons[4].

5.6.3 Tilt Angle with Respect to Seasons

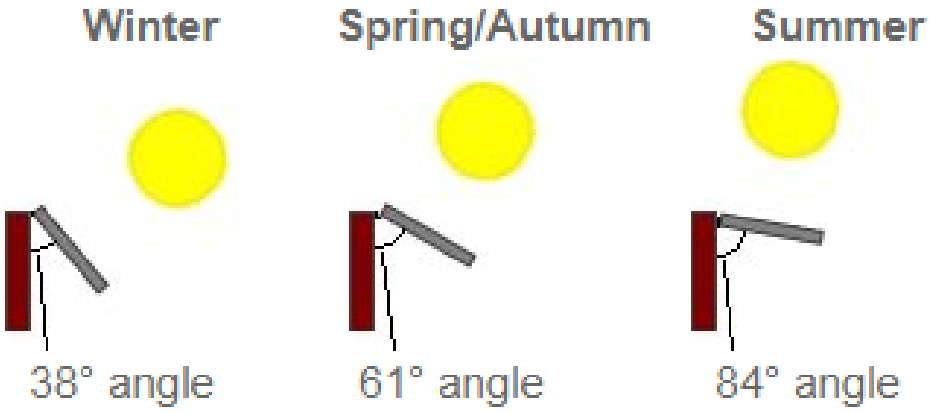

Figure 10: *Tilt Angle with respect to Seasons* ***(Solar Panel Angle Calculator, 2019)***

[4] Solar Panel Angle Calculator, 2019. *Solar Angle Calculator | Solar Panel Angle Calculator*. [Online] Available at: http://www.solarelectricityhandbook.com/solar-angle-calculator.html [Accessed 27 July 2019].

Figure 10 provides a generalized Tilt angle for the four seasons in Kuwait. The recommended installation angles were data a 38^o angle for winter, 61^o angle for spring and autumn and 84^o angle for summer, to reach to the maximum level of efficiency for generating power with Solar PV system. The analysis of the tilt or best tilt angle for the solar panel in Kuwait should also consider the accumulation of dust. As explained in the literature review section, surfaces closer to the horizontal level accumulate more dust. Hence, affecting the efficiency of the overall system. The tilt of the panel along with the design (marital) of the solar panel can have a direct impact on the output or performance, taking into account the weather impact on the performance not just the potential of measured solar radiation.

With the simulations of solar potential in Kuwait, using the recommended 3 angles as well as 3 additional angles were conducted. This is to analyse the performance and validate those suggested optimums. The graphical representations of the following section display the monthly patterns and behaviour.

5.7 Solar Energy simulation with different angles (Kuwait)

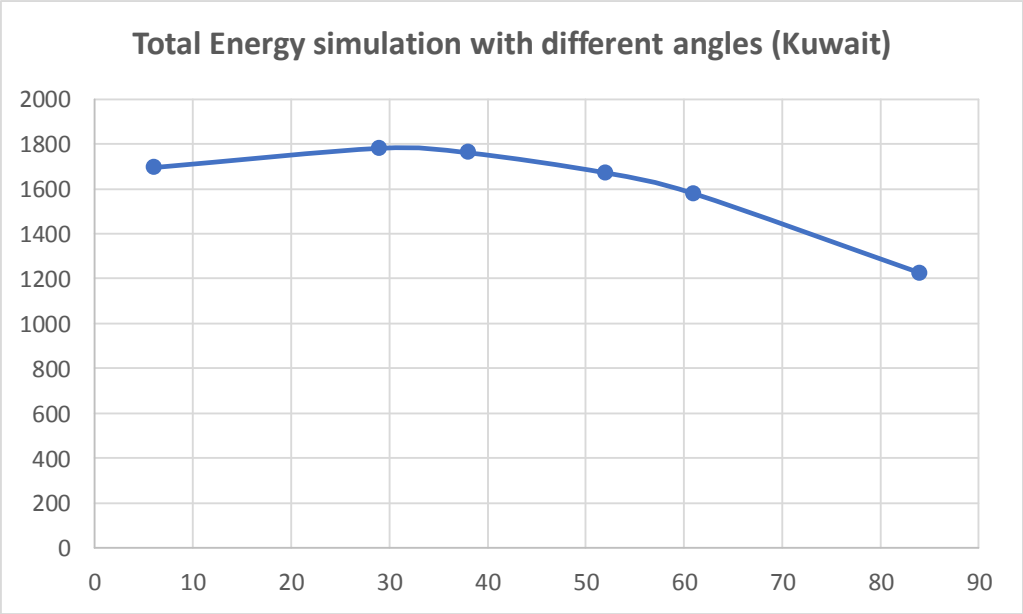

Figure 11: *Annual Solar Power Generated (Kw) using different tilt angels- Based on Kuwait's 2014 solar radiance data (collected through* ***(Renewables.ninja, 2019)****.*

Six different Solar PV angles were simulated to understand the impact of tilt angle over the annual power generation capacity. Three of the six angles simulated were the seasonal optimums (the optimum summer, optimum spring/autumn, and optimum winter). The optimum angles mentioned before were measured from the vertical level. Since the simulation module input the tilt angles from the horizontal level, these optimums become (6^o optimum summer, 29^o optimum spring/autumn and 52^o optimum winter). The other three additional angles were selected to be (38^o, 61^o and 84^o) from the horizontal level as well. Figure 11 above helps to highlight the total level of energy generated by the systems with respect to the selected different angles. The graph shows that the optimum angel for Solar PV systems calculated for Kuwait is almost 30^0, matching the recommended Spring/Autumn optimum of 29^0 with a total yearly energy of 1780.664 Kw.

Table 4*: Energy Simulation for Solar Panels at Different Angles, Kuwait*

Angle		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Energy
6	Optimum Summer - 6	103.388	121.593	140.283	148.612	160.688	174.326	175.697	167.903	152.18	131.348	111.827	106.766	1694.611
29	Optimum Spring - 29	127.147	142.545	149.437	147.593	150.697	157.458	160.96	162.544	159.513	148.413	136.938	137.419	1780.664
38	additional - 38	132.375	146.277	148.769	143.09	142.61	146.138	150.372	155.616	157.649	150.6	142.332	144.748	1760.576
52	Optimum Winte - 52r	135.856	147.038	143.019	131.619	125.82	124.016	129.1	139.633	149.453	148.943	145.681	150.776	1670.954
61	additional - 61	135.089	144.263	136.33	121.498	112.51	107.5	113.115	126.363	140.826	144.632	144.588	151.191	1577.905
84	additional - 84	122.525	125.681	108.992	86.728	72.155	60.079	65.5	82.898	107.294	122.181	130.197	139.849	1224.079

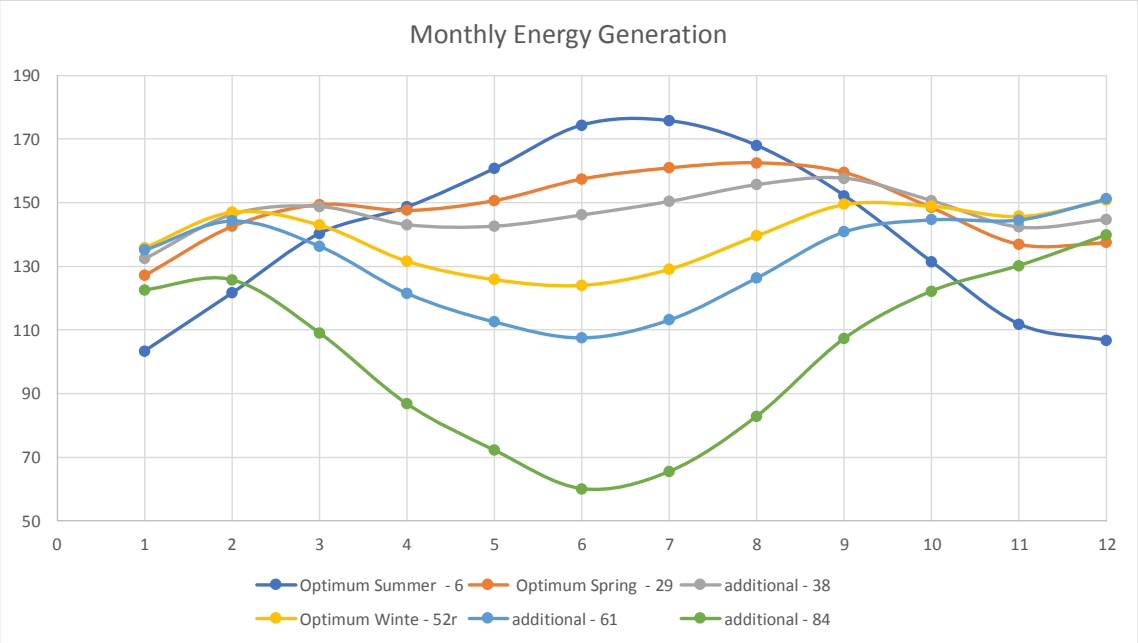

Figure 12: *Monthly Energy Generation*

Using (https://www.renewables.ninja/), 6 different angles were simulated to analyse the monthly power generation. With the proposed optimum angles by the solar electricity handbook and the selected additional angles, the data above is generated Table: 4, Summarising the simulation results of monthly energy generation using solar PV's in Kuwait.

5.7.1 Dynamic System of Composed Tilt

Table 5*: Composed Angles, and multiple seasonal setting for Solar PV's*

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Energy
Composed 3 angles	**Optimum 6 - 29 - 52**	**135.856**	**147.038**	**149.437**	**148.612**	**160.688**	**174.326**	**175.697**	**167.903**	**159.513**	**148.943**	**145.681**	**150.776**	**1864.47**
Composed 2 angles	**52 - 6**	135.856	147.038	143.019	148.612	160.688	174.326	175.697	167.903	152.18	148.943	145.681	150.776	1850.719
Optimum 1 angle	**29 - Optimum Spring**	127.147	142.545	149.437	147.593	150.697	157.458	160.96	162.544	159.513	148.413	136.938	137.419	1780.664

Table 5 represent the composition of multiple angles throughout the year, from the identified seasonal optimum angles (6, 29 and 52 degrees), that if the user chooses to have a dynamic system with the possibility of alternating the angles seasonally. If the user wishes to change in PV angles between the four seasons, optimum energy of 1864.47 Kw can be produced. If the user wishes to limit the change in PV angles between two seasons, the total power generated would be less, but only by 0.7%. Meanwhile, if the PV system is chosen to be with a fixed angle, the optimum would be installing the surfaces at a 29°, less than the optimum by 4.5% (Table 6).

Table 6*: Percentage Difference in PV Performance for Different Tilt Composition*

PV Tilt		**Total Energy**	**Diff.**
Composed 3 angles	**Optimum 6 - 29 - 52**	**1864.47**	**Optimum**
Composed 2 angles	**52 - 6**	1850.719	-0.7%
Optimum 1 angle	**29 - Optimum Spring**	1780.664	-4.5%

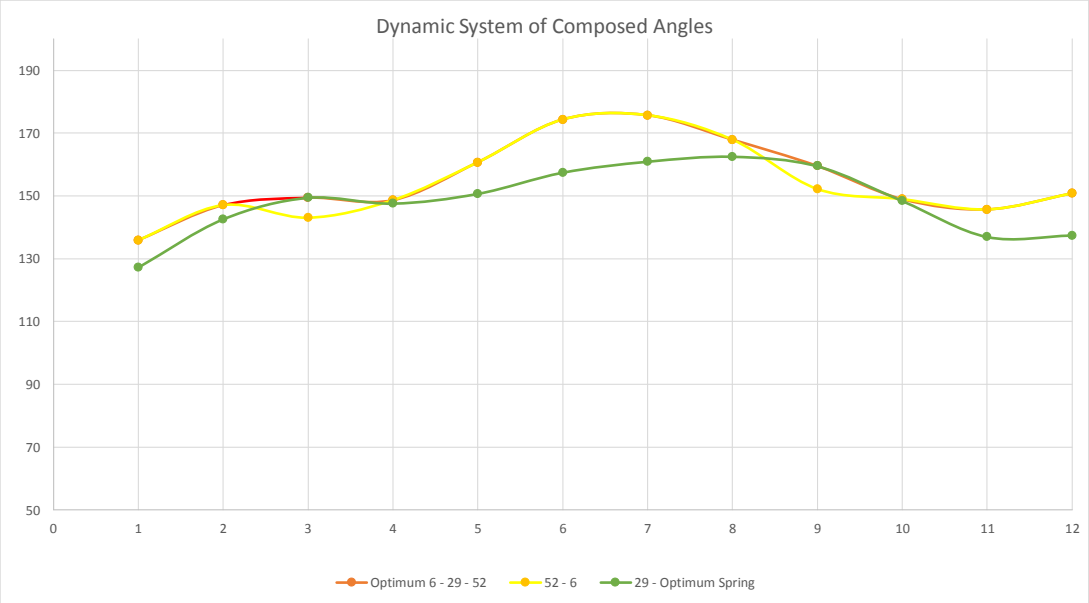

Figure 13: *Dynamic System of Composed Angles*

Thy dynamic PV system (allowing tilt variation) of composed angles can be used to achieve optimum energy generation. Figure 13 shows the monthly energy levels with a composed 3 angles system (optimum 6^0-29^0-52^0), a composed 2 angles system (optimum 52^0-6^0) and finally using a single optimum angle (i.e. 29^0 Optimum spring). The analysis of the angles for the whole year with the different variation help the user understanding the potential and making an informed decision.

5.7.2 Fixed Tilt System

If a system with a fixed tilt is being considered, table 7 provides details for the level of energy generated throughout the year with the simulated six angles (6, 29, 38, 52, 61, and 84) and the difference percentage in performance, compared to the optimum calculated with seasonal change of tilt.

Table 7*: Solar Power Generated (Kw) & Differences in Performance (%)*

Angel (^{0})		Total Energy (Kw)	Diff
6	**Optimum Summer**	1694.611	-9.1%
29	**Optimum Spring/Autumn**	1780.664	-4.5%
38	**Additional - 38**	1760.576	-5.6%
52	**Optimum Winter**	1670.954	-10.4%
61	**Additional - 61**	1577.905	-15.4%
84	**Additional - 84**	1224.079	-34.3%

The percentages highlighted in Table 7 are calculated based on the total energy simulated for every angle in Table 4 and compared with the optimum energy from the dynamic system using 3 composed angles (i.e. Optimum 6-29-52) for the whole year (i.e. 1864.47) in Table 6.

When we include the dust as a factor, knowing that dust disposition on surfaces with angles closer to the horizontal level increases, the selection of angles would be recommended with an angle closer to the vertical level. hence, it become a compromise having lower energy generation vs. lower amounts of dust disposition. The following section on this research details the dust parameters (frequency, intensity, distribution... etc.). Combining the knowledge of Solar PV's system capability and the performance hindering factors is the way leading to optimised performance.

5.8 Dust Storms, Dust Fallout and Rainfall, and Analysis of Dust

5.8.1 Dust Fallout and Rainfall

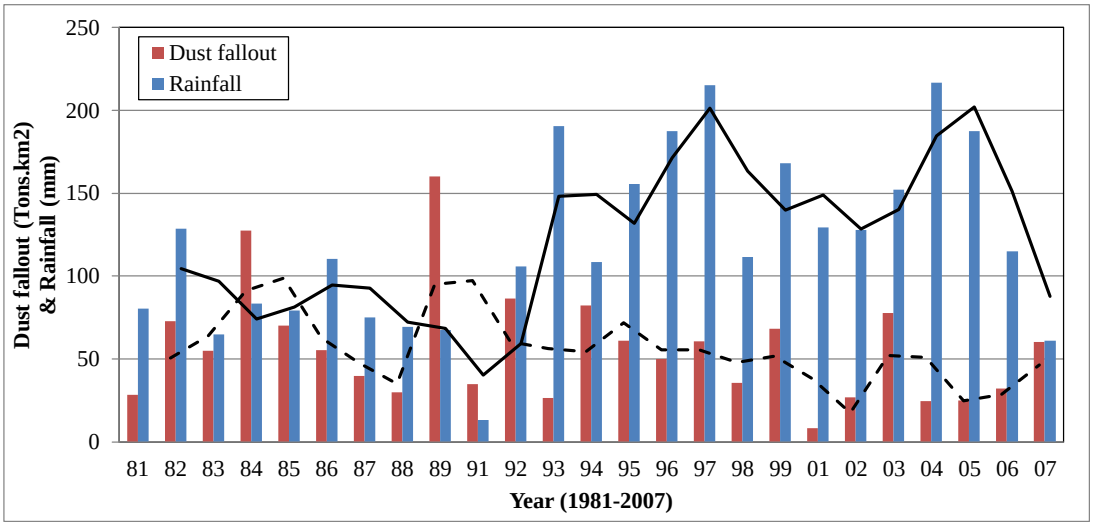

Figure 14: *Dust Fallout and Rainfall (1981-2007 - KISER)*

The Dust fallout and the yearly Rainfall levels between the years 1981 and 2007 is shown in Figure 14. Understanding these trends is important to evaluate the intensity of the dust accumulation that can lead to an overall efficiency loss of solar panels. The Dust fallout has some unpredictability and a lack of a systematic pattern. The lowest level of dust fall out in Kuwait is noticed in the year 2001 whereas, the lowest level of rainfall is noticeable in the year 1991. These are not in contradiction with figure 13 marking the year of 2002 with the lowest number of Dust storms as the representation in figure 14 marks the dust fallouts in Tons/Km^2.One pattern might be noted though, the average of rainfall after the year of 1993 became higher, still not reliable enough for cleaning surfaces such as solar PV's.

Dust is not just defined by the occurrence of Dust storms. Dust storms are events where the intensity of wind carry solid particles (mostly sand) to the point it hinders the visual capabilities, and in most cases shutdown the transport sector. Dust also occur suspended in the atmosphere, on an elevation higher from the ground, effecting the intensity of solar radiation reaching the surfaces. When the intensity of wind and the size of particles are low, its mostly referred to as Haze.

5.8.2 Dust Storms

Weather data, recording major and minor events such the dust storms, dust fallout and rainfall, suspended dust, and rising dust is gathered to develop a profile for Kuwait climate. Specifically for this research, the details of the level of dust can help to develop basis for the maintenance (cleaning) frequency of the solar panels. Figure 15 summarise the number of dust storms recorded between the years 2001 and 2014.

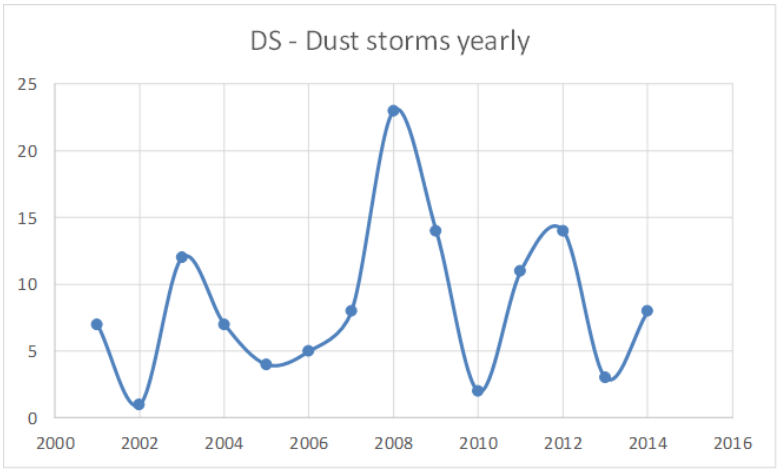

Figure 15: *Dust Storms (2001-2014)*

The varying trend of Dust storms reached a maximum in the year 2008 a total of 23 dust/sand storms. The lowest number of dust storms in Kuwait was recorded in the year 2002. The yearly variance shows that there is no clear trend for the number of yearly dust storms in Kuwait. This randomness in the frequency make the future forecasting of dust storms event very hard. The average between these years is 9 dust storms per year.

5.8.3 Analysis of Dust

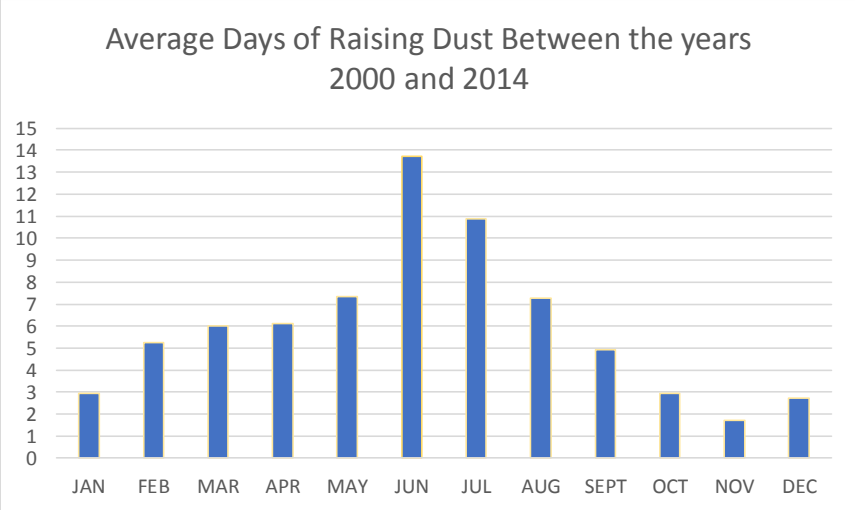

***Figure 16**: Average Days of Raising Dust Between the years 2000 and 2014, (**KISR**)*

Figure 16 summarises the average number of monthly rising dust events (i.e. the sum of monthly events in the defined years divided by the total number of years). The monthly pattern helps to understand that summer months have higher occurrence frequency than other seasons. The normal distribution-shaped like pattern reaches an average maximum of more than 13 rising dust days in June, while the pattern is at its lowest on November at an average of less than 2 raising dust events. The data provided by KISR (Kuwait Institute of Scientific Research) record the rising dust events from the year 1962 till the year 2014. It's worth mentioning that the months of June, July and August recorded a maximum number of rising dust events (18 rising dust events) in the years 2000, 2013 and 1968 consecutively.

5.9 Simulation of Wind and Solar PV

The data for this research's expanded further than quantifying and analysing the dust events. A range of statistics and useful data for the overall weather, including the values of average temperature, average irradiance cloud cover, and air density are worth noting for developing a comprehensive profile for the weather in Kuwait. These are essential to conduct hourly simulations for wind and solar PV systems. The results include details for electricity generated in "kW", the level of irradiance direct and diffuse levels in "kW/m\u00b2", and temperature in "\u00baC"

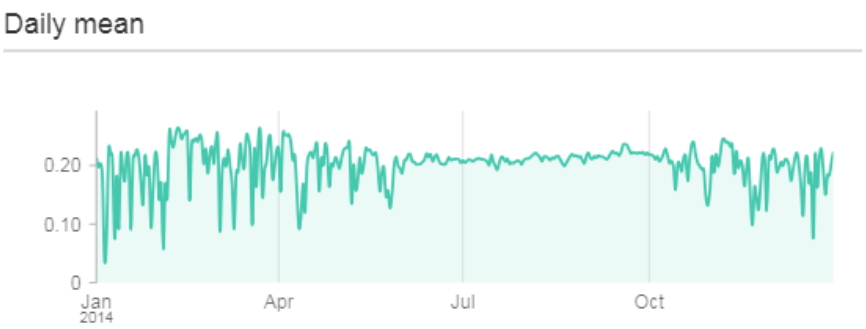

***Figure 17:** Solar PV - Daily Mean*

The daily mean values for the PV simulation within the region are presented in Figure 17. In the year 2014, a PV system with a capacity of 1 kW, with a system loss fraction of 0.1, none tracking, on a tilt of 35^0, and Azimuth of 180^0 is used to run the simulation. The results of the daily mean value for the PV simulation helps to predict that the average of the daily mean Solar PV generation falling mostly between 0.1 and 0.2. Especially between the months of June and October, the value is almost steady above 0.2. The fluctuation is mostly falling between November and May, reaching a lower point less than 0.05. This simulation does help to identify the potential and the overall level of efficiency for the daily mean values as it can help to better fulfil the electricity and power requirements of the future. But it does not take into account the events of dust and accumulated particles on the solar PV's. As it has been previously proven that within the simulated steady performance in solar capabilities shown in Figure 12 in summer months, those same months mark the highest occurrence and quantity of dust events and accumulation levels.

5.10 Analysis of Dust and PV Cleaning

Using the data of haze dust and blowing dust in Kuwait for last three years (i.e. 2016, 2017, and 2018), to estimate the expected number of days for cleaning the Solar PV systems. Figure xx show the monthly averages of haze dust and blowing dust events.

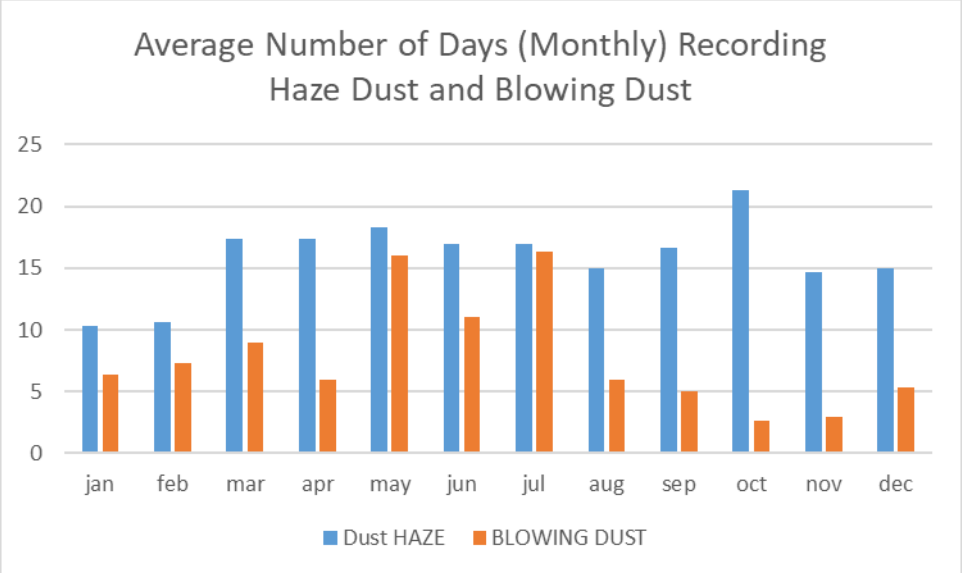

Figure 18**: Average Number of Days (Monthly) Recording Haze Dust and Blowing Dust for the past 3 years **(KIAS)

The average number of haze dust and blowing dust for the past three consecutive years will be used to estimate/recommend the most suitable number of days for cleaning. From Figure 18, its noticed that the number of dust haze is almost consistent (mostly between 15 and 20 days) throughout the year except for the months of January and February. While the days of blowing dust are peaking during the summer months (consistent with Figure 14). It's also worth mentioning that the total number of dust haze occurrence for the year 2016 was 139 days, followed by 174 days in 2017 and reaching to the highest value of 259 days in the year 2018. It cannot be assumed that the trend would move forward (i.e. the occurrence of haze in the year 2019 would keep on increasing) but, some might interpret this as a sign of climate change and assume an ascending pattern. For this research, the average of dust haze days for the defined three years is calculated as well as the average days of blowing dust. The average number of days recording dust haze for the three years was 15.9 days and the average number of days recording blowing dust was 7.8 days.

***Table 8**: Average Monthly Dust Haze and Blowing Dust for the Years (2016, 2017 and 2018), KIAS*

Month	DUST HAZE	BLOWING DUST
Jan	10.3	6.3
Feb	10.7	7.3
Mar	17.3	9.0
Apr	17.3	6.0
May	18.3	16.0
Jun	17.0	11.0
Jul	17.0	16.3
Aug	15.0	6.0
Sep	16.7	5.0
Oct	21.3	2.7
Nov	14.7	3.0
Dec	15.0	5.3
Average	15.9	7.8

The analysis helps to determine the number of days that is required to ensure that the PV systems are working at their level best throughout the year. The outcomes of the analysis are beneficial to highlight the number of days required for cleaning for Kuwait only and therefore, to determine the best possible time in days for the PV cleaning in the year 2019.

VI. DISCUSSION

The literature reviewed, the data collected, the simulation processed and analysis performed were all planned to help determining and evaluating the research subject chosen in detail. The objective is to reach specific recommendations at the end of the research answering the question stated in the research scope. Critical understanding of the research history done on the subject was essential before attempting any analysis. The potential energy within the GCC and specifically for Kuwait was investigated, their efforts toward the use of renewable resources was assessed as well. It was found in many sources that the GCC has a great potential for using renewables.

With the growing population and along with it the growth in power demand, the use of renewables might become necessary rather than an option. As stated by Mas'ud, Mu'azu, Albarracín, & Firdaus, (2018), the use of fossil fuel has been so far the main source in meeting the energy requirements. Their study introduced the concept of renewable energy sources, and the use of these sources to benefit the environment, and their significance to overcome the negative impact of fossil fuel power generation[5], using such alternatives being the most effective and efficient means to cope up with the growing needs. Those were all supported by the analysis of the climate within the GCC and by understanding the current power and electricity systems used in Kuwait, aligned with the studies that highlighting the importance of the growth in energy infrastructure. With that, industries, governmental and private investments took actions to help find the alternate for fossil fuel over the next decade.

The analysis of the weather in Kuwait and power potential for photovoltaic power was carried out to identify the compatibility for the use of Solar PV systems. The data obtained supported the used of solar systems as there is abundance of sunshine and longer hours of sunshine throughout the year[6]. From The analysis of the data, evaluating the Solar potential, multiple tilt angles for Kuwait were simulated to provide support for selecting the best tilt in the first steep to maximize the overall level of performance of the Solar PV Panels. The analysis of the tilt angles simulated was found in support of the guidance provided by Solar Panel Angle Calculator, the Solar Electricity Handbook (2019), marking the

[5] Mu'azu, M.A., Albarracín, R., Mas'ud, A.A. & Firdaus, M.-S., 2018. Solar Energy Potentials and Benefits in the Gulf Cooperation Council Countries: A Review of Substantial Issues. *Energies* , 11(2), pp.1-20.

[6] Solargis, 2019. *Solar resource maps and GIS data for 180+ countries | Solargis*. [Online] Available at: https://solargis.com/maps-and-gis-data/download/kuwait [Accessed 19 August 2019].

seasonal optimum tilt angles (i.e. 6^0 in Summer 29^0 for Spring and Autumn and 52^0 durring Winter.

The data used with the intention of improving the efficiency of current solar panels and to make sure that the panels are fitted with optimum tilt(s) that can allow it to work properly with highest level of efficiency. The simulations were to test the solar PV for Kuwait, summarising the yearly and monthly energy generation capacities. I was used to identify the different possible operation set up using different tilt angels to maximize the power generation. It was shown that a dynamic system with the possibility of alternating the tilt angles seasonally, optimum yearly power generation can be achieved. If the PV tilt angles between the two main seasons (Summer and winter), the total power generated would be less than the optimum by 0.7%. Meanwhile, if the PV system is chosen to be with a fixed angle, the optimum would be installing the surfaces at a 29^0, less than the optimum by 4.5%.

As pointed out by Monto & Rohit, (2010) that the tilt of the PV panels, the altitude, the design and orientation are very important factors in the performance of solar PV's [7] ., researchers like Sulaiman et al., (2011), challenged the recommended optimum installation of tilt of the solar panels, highlighting that the tilt angle can be the main factor increasing the dust accumulation rate[8]. From the simulation performed in this study, it was derived that the most effective angle for the solar PV panels for the summers (i.e. current seasons is 6^0 and for the coming season that is winter the level of PV tilt can be set to a 52^0 to reach to maximum level of efficiency. Those did not take into account the dust frequency and quantity affecting the performance.

The data for dust offered an insight into the frequency and significance of dust events (Dust storms, Dust Haze and Blowing Dust). The data showed that the level of dust (both suspended and rising dust) have an in consistent pattern throughout the years. However, it was noticed that the dust events were higher in frequency during the summer months. When we include the dust as a factor, knowing that dust disposition on surfaces with angles closer to the horizontal level increases, the selection of angles would be recommended with an angle closer to the vertical level. hence, it become a compromise having lower energy generation vs. lower amounts of dust disposition. For example, as per the simulation conducted, if a tilt angle of 52^0 is chosen, the energy production would be less than the optimum by 10.4%. However, such tilt being higher than 45^0, guarantees less dust accumulation leading to higher energy generation during dust events and until the cleaning of system is completed.

With the frequent occurrence of dust events, systems/policies must be devised to ensure that cleaning practices are sustaining the Solar panels performance, achieving maximum efficiency. It is important to consider the factors like cost, damage, and time linked to cleaning prior to deciding on the cleaning procedures and duration[9]. The data presented about dust in Kuwait helped in providing guidance about the need and frequency of Solar PV panels cleaning. The monthly/yearly cleaning days were identified based on the average occurrence of dust haze and blowing dust data. The data used was selected based on the meteorology reports of the past 3 years (2016, 2017, and 2018) to reflect recent averages of occurrence.

VII. CONCLUSION AND RECOMMENDATION

Conclusion

This study primarily aims to evaluate the current practices in power generation and highlight the importance of renewable sources of energy. The previous literature helped to conclude that the rise in electricity using fossil fuels is affecting the climatic conditions and environment (accelerating climate change). The governments within the GCC have invested in renewable sources of energy such as Solar power and Wind for the generation of electrify. The use of renewable energy can help to shift the reliance on fossil fuel, providing an economic value added to the benefits on the whole environment. By exploring the performance of Solar power in the GCC, the impact of dust as well as the amount of cleaning required for the removal of dust were analysed. The objective was to understand the solar system potentials and address the concern of dust occurrence, coming up with possible improvement in efficiency and performance of the solar PV panels. The analysis is carried out with the help of previous literature, data sources both

[7] Monto, M. & Rohit, P., 2010. Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations. *Renewable and Sustainable Energy Reviews*, 14(9), pp.3124-31.
[8] Sulaiman, S.A., Hussain, H.H., Leh, N.S.H.N. & Razali, M.S.I., 2011. Effects of Dust on the Performance of PV Panels. *International Scholarly and Scientific Research & Innovation*, 5(10), pp.2021-26.

[9] Bardsley, D., 2017. *Dust can dramatically reduce effectiveness of solar panels in Arabian peninsula, US study finds.* [Online] Available at: https://www.thenational.ae/uae/science/dust-can-dramatically-reduce-effectiveness-of-solar-panels-in-arabian-peninsula-us-study-finds-1.664896 [Accessed 10 June 2019].

international and local (specific to Kuwait) and the use of online simulation platforms for solar power capacity calculations.

The tilt angle for solar panels play a vital role in its overall performance and efficiency. To identify the best tilt angel, the simulation was made with multiple tilt angles. The results led to a verity of options:

I. Using a dynamic PV system with seasonal (Spring, Summer, Autumn and Winter) adjustable tilt gave the optimum energy production.
II. Using a dynamic PV system, varying the tilt at the major 2 seasons (Summer and Winter) had a lower energy production capacity of only 0.7%
III. Using a fixed tilt system, the optimum would be installing the PV's at 29^0, offering an energy production capacity lower than the seasonal optimum by 4.5 %.

Further to that simulation, the analysis of dust frequencies and quantities showed that dust haze, blowing dust, and dust storms are events occurring at a significant rate, having a significant impact on the solar PV's performance. Based on the analysis of dust, it was emphasised that the cleaning strategies for the solar PV system are needed in frequencies associated with the frequency of dust accumulating on solar panels surfaces, to make sure that the level of efficiency is maintained and insure the longevity of the system's performance.

Recommendations

With the conclusion made, based on the analysis of the research data and simulations explained, the following recommendations might be worth considering:

- Solar PV panels can be considered still one of the most effective and efficient means/way to produce energy within the GCC. However, the dust factor must be highly considered for the design of tilt angle and the maintenance/cleaning plans.
- Optimum tilt angle that can produce the highest potential out of a solar PV panel 29^0 can be challenged, if dust accumulation on the surface is being considered leading to a drop in the efficiency.
- If a solar system is being considered, flexibility in the cleaning schedule is required. As stated about the dust events, as much effort put in estimating the number of days for cleaning, dust events are quite un expected. Therefore, any cleaning contract/agreement shall include some sort of unit-price option to provided the cleaning services when needed, exceeding the estimated values.
- The research study explored two options in choosing the solar PV system, dynamic tilt setup or fixed tilt setup. Economic benefit analysis would be needed to evaluate the cost of both options and comparing the amount of energy produced, validating its feasibility.
- The analyses of dust data derived the estimation of cleaning for the PV system, specifically based on the data for Kuwait. Therefore, it is only applicable to the PV systems within Kuwait. Similar approach can be used to evaluate the conditions at other locations, provided the availability of the weather profile.
- Finally, further research (lab experiments and real life data) is needed, estimating the drop of efficiency resulting from dust accumulation on different tilt angles; This, combined with the simulation of potential PV production for energy would lead to optimum tilt installation for energy production.

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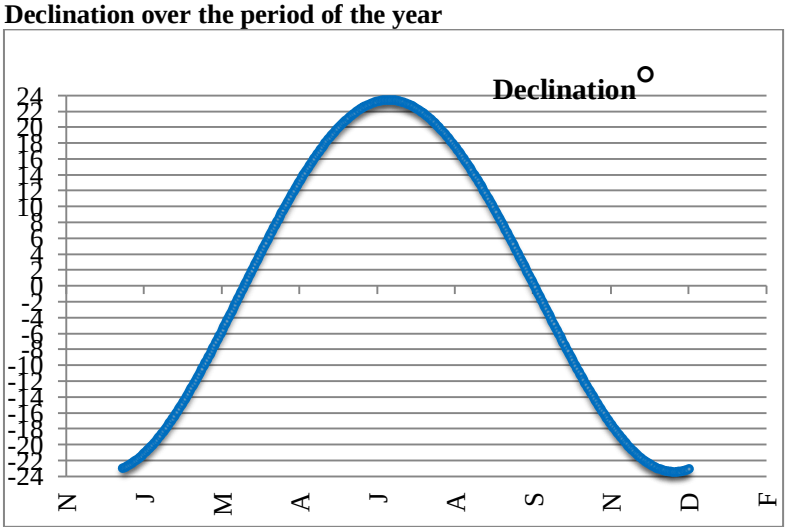
APPENDICES
Appendix A:
1.0 Sun Data

In association with KISR (Kuwait Institute of Scientific Research), the data for the sun characteristics was gathered. It's essential to understand the parameters influencing the productivity of solar PV's; Hence, this section details the patterns and recorded measures pertaining the sun in respect to the location of Kuwait.

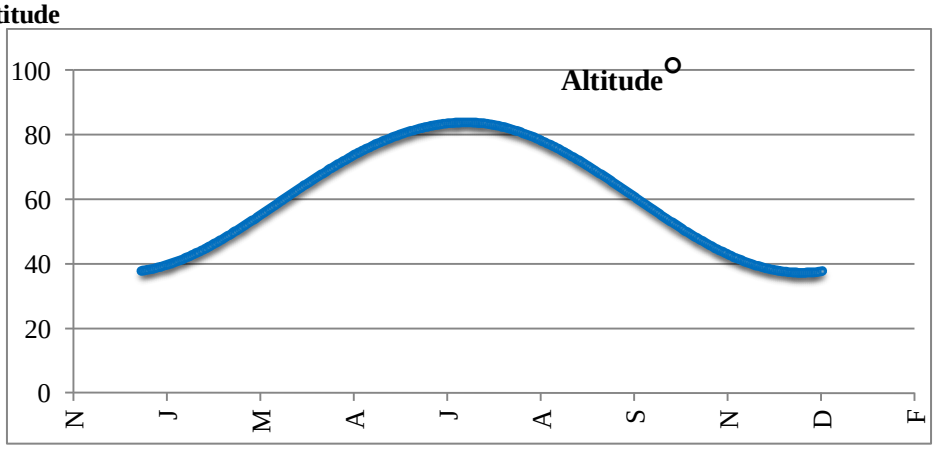
1.1 Variation in Declination over the period of the year



Variation in Declination over the period of the year

The analysis of the declination over a year helps to determine the changes within the tilt of the earth's respective axis. The graph shows the values of declination from -23.5 to +23.5 (-24 and +24) respectively. The astronomical formula is used to derive the graph as it helps to provide details for the analysis. The graph shows that the rays of the sun have a declination from +23 to -24 as the line is reaching the -24 mark and extending to reach under the +24 mark.

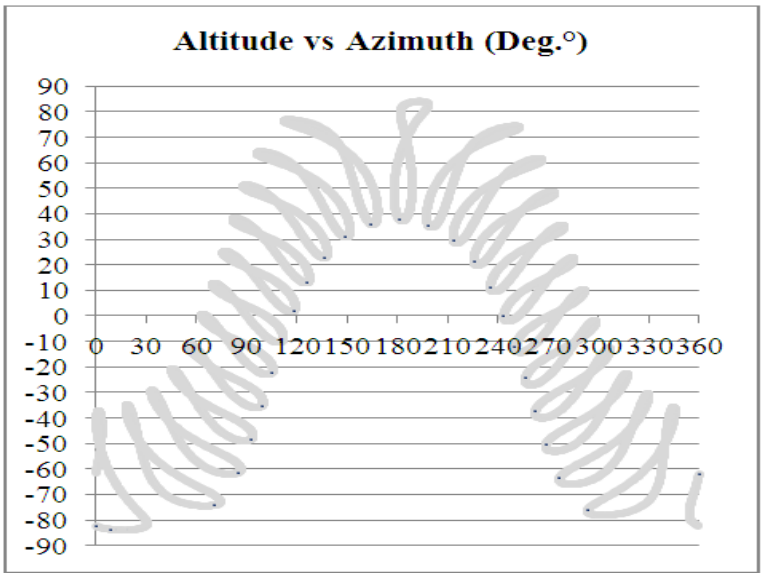
1.2 Altitude



Altitude

The representation of the Altitude helps understand the relative position of the sun with the relative month in a year. above can be used to identify that the altitude of the sun over the period of one year is 37.3^0, and the highest level of altitude of the sun is 83.8^0. The data presented in the graph is for the period from the 1st of January, 2017 till the 31st of December, 2017.

1.3 Altitude VS Azimuth

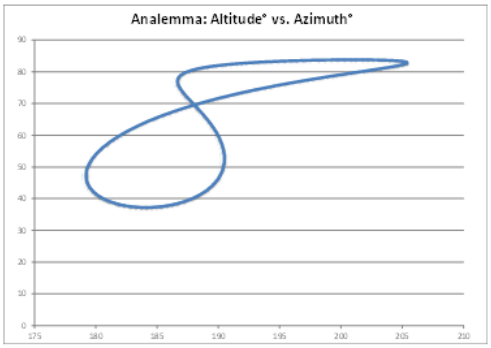


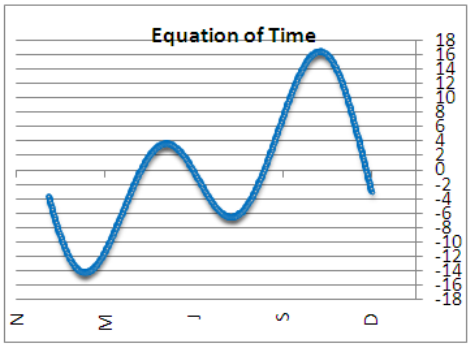
Altitude VS Azimuth (Deg.°)

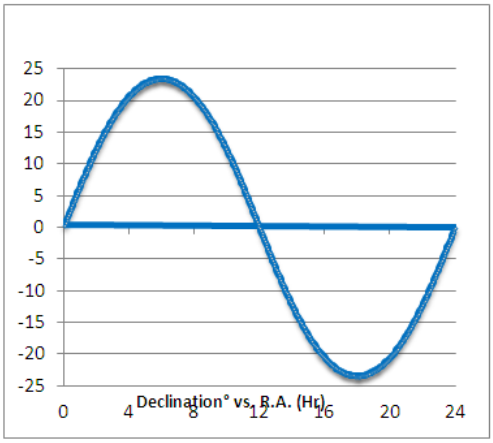
The data for Azimuth and altitude can display more details, analysing the position of the sun over the period of one year. The analysis helps to predict that the overall values for Altitude and Azimuth from January to December 2017 showed a varying trend. The maximum and minimum values for value for Azimuth are 360 and 0.10 whereas, for Altitude the values are 840 and -83.950 respectively. It is to be noticed that the Geographic Latitude of 29.20, Geographic Longitude of -47.060, Time zone difference of 3.0, and Height of the building (m) was selected to be 100 meters for the entire calculations.

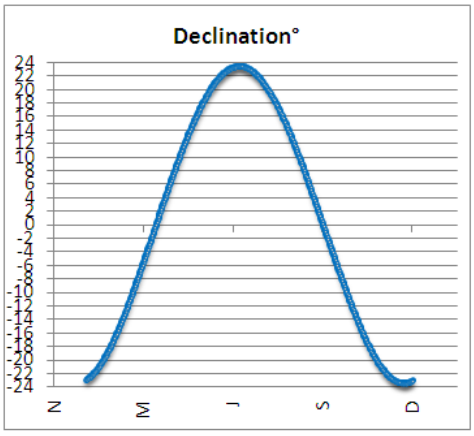
Appendix B:

2.0 Further Sun Parameters and Patterns (KISR)

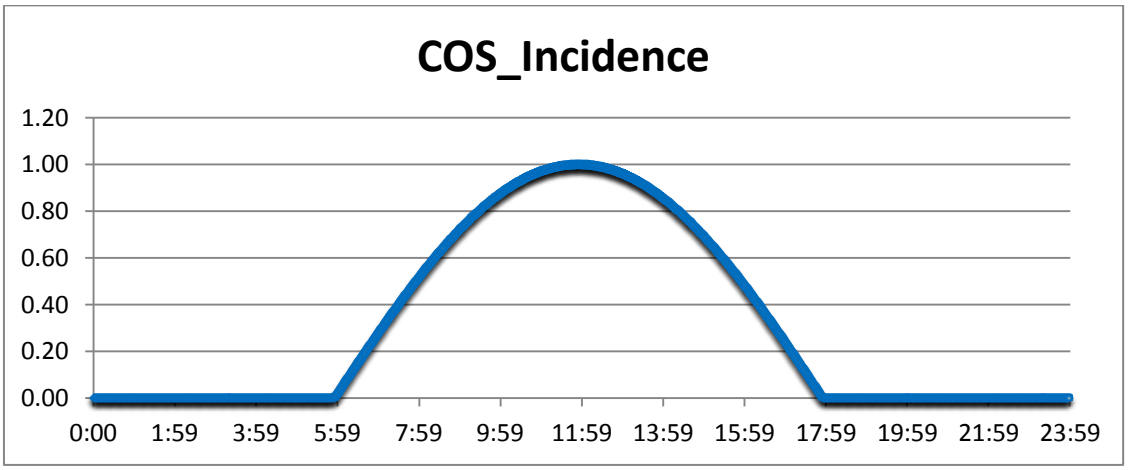


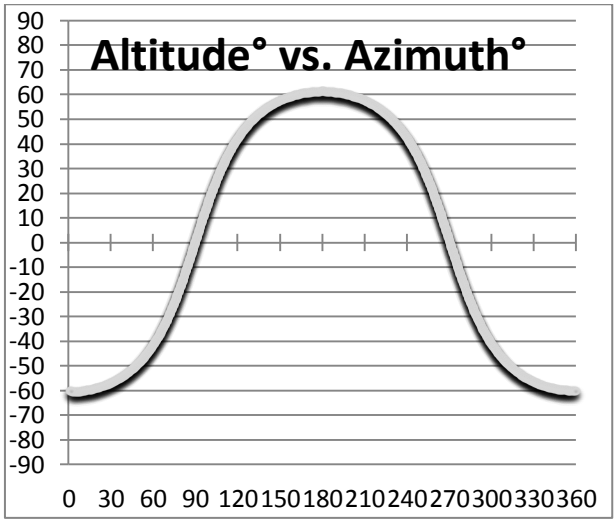


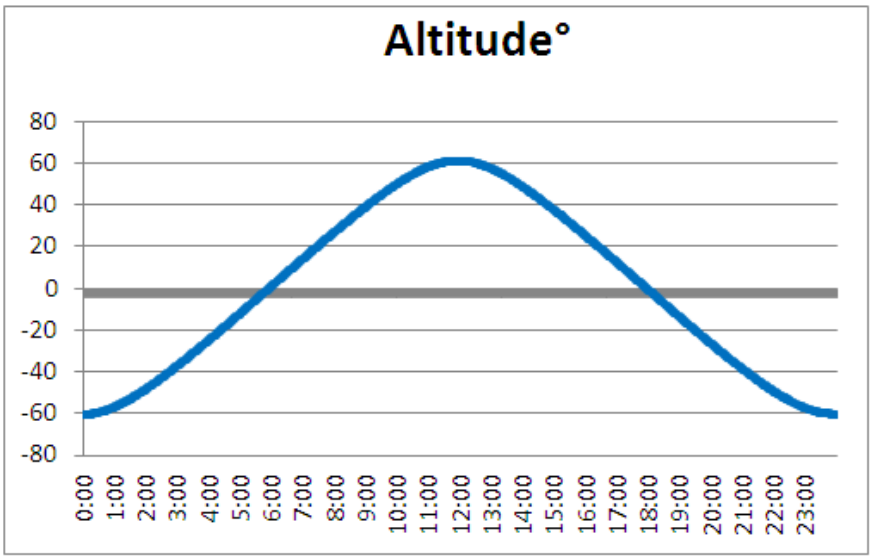


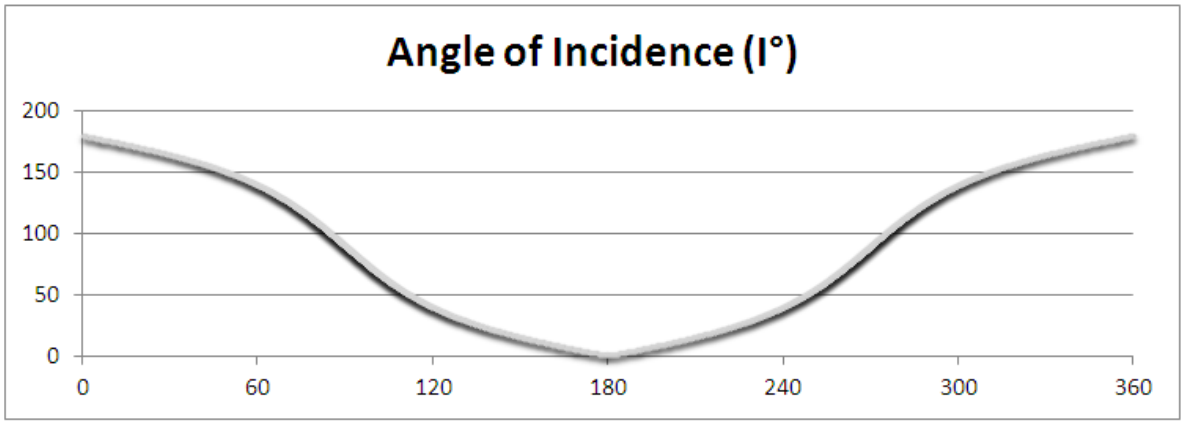


2.1 Sun Calculator Tilt









Sun Calculator Tilt Skew