Geographical and Climate Change Implications on Solar Photovoltaic Performance

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Abstract

The performance of a Solar PV system depends largely on the weather conditions at the system location. For a better understanding of the effect of weather conditions on PV system performance, the weather conditions at the PV system location and generation data must be considered. A number of correlations have been identified between the geographical location of the PV system, the degradation rate, the life span, and the system's performance. It is well established that a PV system's location strongly affects its degradation rate, life span, and performance.

Africa, Europe, Asia, and North America all showed similar findings based on data monitored across four continents. The performance of the PV system depends on UV radiation levels at the system location. UV radiation, however, contributes to the degradation of PV system performance. PV panels' performance drops over time as they are exposed to UV radiation for a longer period. By providing cooling around the PV panels, the effect can be mitigated, the system's performance will be improved, and its life will be prolonged.

The performance of PV systems is influenced by temperature management during their existence. There is strong evidence that some periods during energy generation experienced a cooling wind and therefore had less impact on performance than other areas where the system experienced a lot of cooling conditions during high-temperature periods. Wind speed can mitigate much of the heat generated by the PV panels during energy generation, which is particularly important to prolong the lifespan of the PV system. It shows that cooling methods have a high level of effectiveness in improving PV performance because they control the temperature.

The results of the data study provided clear-cut guidance to be able to write software programming to represent the findings. Neural networking programming has been developed to predict PV system performance based on wind, temperature, UV, and rainfall inputs at any location from the research findings.

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Abbreviations

PV … Photovoltaic

CSP … Concentrated solar power.

STC … Standard Test Condition

BIPV … Building Integrated photovoltaic.

UV … Ultraviolet

Tempt … Temperature.

EVA … Ethyl vinyl acetate

BAPV … Building attachment photovoltaic.

a-Si … Amorphous silicon cells

CdTe … cadmium Telluride cells

CuInSe2 … Indium Selenide cells

EIA … Energy Information Administration

BIPV … Building-integrated photovoltaics

BAPV … Building applied photovoltaics

PV … Photovoltaics

MPP … Maximum PowerPoint

ML … Machine learning

DL … Deep learning

STC … Standard Test Conditions

CIS … Copper-indium-selenium

CIGS … Copper-indium- gallium-selenide

CdTe … Cadmium telluride

FIT … Feed-in tariff

I-V … Current-voltage

P-V … Power- voltage

UV … Ultraviolet

EVA … Ethylene-vinyl acetate

CPV … Concentrated photovoltaic.

ECF…………………………………………………………… Embodied carbon footprint

CSP…………………………………………………………… Concentrated Solar power.

VRA……………………………………………………………Volta River Authority

PVSCs………………………………………………………... Perovskite solar cells

SO_2 .... Sulphur dioxide

NH_3 ....Ammonia

OSCs……………………………………………………………Organic solar cells

CO_2...Carbon dioxide

MPP ……………………………………………………………Maximum PowerPoint

MLP……………………………………………………………multi-layer perceptron

ReLU……………………………………………………………. Rectified Linear Unit

Units

Kwh ………………………...…………………………………… Kilowatt-hour

Kwp…………………………………………………………… Kilowatt peak

m^2……………………………………….……………….…...... Meter square

MVA ………………………………………………………….…Mega Volt Amp

MW…………………………………………………………..Megawatt

KW……………………………………………………………Kilowatt

m/s…………………………………………………………... Meter per second

℃……………………………………………………………..Degree Celsius

mW…………………………………………………………... Milliwatt

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Author’s Declaration

All the work presented in this thesis is mine, derived from my own original research and generated by me.

I confirm that.

1. Regulations for Staffordshire University and Buckinghamshire New University have been followed in preparing this thesis.
2. While pursuing a research degree at this institution, this work was undertaken totally or primarily.
3. In all cases where I have consulted the published work of others, I have clearly credited them.
4. The sources of references I have used are always given. Other than these references, this thesis was entirely written by me.

I can confirm that my thesis submission conforms to the regulations of Staffordshire University and Buckinghamshire New University.

1.0 Introduction

1.1 Background of solar PV technology

A solar power generation system uses different technologies to convert the sun's energy into electricity or heat that can be consumed by humans. The development of PV technology has evolved and is one of the fastest-growing green technologies in the world since Edmond Becquerel discovered it in 1839 (Arun & Kumar, 2017). It was during the oil crises of the early 1970s that the first commercial PV technology was developed (Pinkse & Buuse, 2012). The PV technology has progressed and improved since its invention, resulting in a reduction in cost and gradual improvement of energy conversion efficiency.

Although technology has advanced, renewable energy technologists are still among the least efficient in terms of efficiency. Although the cost of PV technology has decreased over the years, it is still considered one of the most expensive green energy generation technologies on the market today, compared to hydro, biomass, and wind. PV systems can be installed as stand-alone systems or integrated into building envelopes, which makes it easier for an individual to produce micro-electricity to supplement energy consumption. Due to its flexibility, PV technology holds enormous potential for contributing significantly to global energy security (Yiping & Yanqiang, 2013).

Solar panels today come in a variety of shapes and materials, dominated by silicon and thin-film materials, but the efficiency of performance is dependent on local weather conditions. (Audwinto, et al., 2015). Even though this technology has a low efficiency of energy generation, its efficiency is still improving with current conversion efficiencies around 15-20%, and solar cell efficiency can reach 42% in some instances (Aris Vourvoulias, 2022).The Environmental Protection Agency reported in 2021 that efficiency has now reached 20%, but experimental PV cells and space satellites have achieved 50% efficiency. (EIA, 2021). While performance efficiency has improved over time, it still is not as good as other renewables such as wind between 35%-45% (NSW, 2015) and hydropower can get up to 95% (Dpt, 2005).

Research has been undertaken to examine and investigate the capabilities and applications of various technologies in an effort to develop innovative ideas to make the technology more competitive by improving PV system energy efficiency. There have been many studies that have shown that PV performance is susceptible to local environmental factors, which can result in an increase in variability and uncertainty of the output power. (Tabone, et al., 2016). The outdoor PV system's performance can be affected by many factors, so a thorough understanding of degradation and failure is vital to accurate PV performance predictions (Arun & Kumar, 2017).

1.2 Types of solar plants.

The use of solar PV technology to generate electricity has progressed and is expected to continue in the foreseeable future. The market today is filled with numerous types of PV panels based mainly on silicon technology from different manufacturers. A solar plant can be classified into several types, and each of them has its own unique characteristics, requirements, and applications. The three most widely recognized categories of solar power generation systems are concentrated solar power (CSP), solar thermal collectors, and solar photovoltaic systems (PV). As energy demand grows around the world, solar power generation systems are being developed at a rapid pace to meet energy needs.

Environmental conditions can affect the quality and physical properties of these solar system components, affecting their efficiency and lifespan (Alpay, et al., 2015). There are a variety of solar thermal collectors, including unglazed plastic collectors, flat-plate collectors, and evacuated tube collectors, used to generate heat, electricity, and hot water. Since concentrated solar power has a low cost of generation, as well as a high conversion efficiency (42% compared to 15% for solar PV systems), it can be applied to a wide range of material processing applications (Farzaneh, et al., 2016).

1.3 solar PV panel’s Design structure.

Module materials include aluminium frames, glass layers, encapsulating layers of transparent ethylene-vinyl acetate (EVA) polymer, solar cells, junction boxes, and protective foil as backsheet (Fiandra, et al., 2019)**.** An aluminium frame that protects the edges of the glass and provides mounting points for the panels (Solar, 2017). A direct relationship has been established between the performance of a PV system and the environmental conditions such as temperature, humidity, and ultraviolet radiation (UV) intensity at the location**.** (Oliveira, et al., 2018)**.**

The materials used for PV panels present different geographical challenges, since they are susceptible to degradation based on weather conditions. The component’s materials are exposed to these vulnerable conditions throughout the entire system's operational life (Vellini, et al., 2017). For example, Considering the aluminium frame's expansion ratio is different from that of the glass material, these two materials are attached together to eliminate stress build-up and maintain insulation due to degradation (Solar, 2017). The degradation of solar photovoltaic modules (PV) can be classified into two categories: the premature degradation caused by light-induced degradation of the solar cells, discolouration, and delamination of the EVA materials, and the lengthy degradation caused by defects of field-aged conditions, such as corrosion, cracks in solder joints, and cell breakdown. (Han, et al., 2018).

1.3.1 Back sheet component

The backsheet consists of three layers of laminated polymer films, including an outer layer and an inner layer containing polymeric material for encapsulation protection and component insulation (Liu, et al., 2014). As for the outer layer, it is made up of fluoro containing polymers which provide weather invincibility. The inner layer of the structure is made up of ethylene-vinyl acetate and low-density polyethene, while the middle layer is made up of polyethene terephthalate to provide electrical insulation and mechanical strength (Liu, et al., 2014).

In order to minimize the effects of degradation on performance, the backsheet is designed to maintain the performance of PV modules in harsh environmental conditions. The components are isolated from potential stress conditions by the backsheet to minimize degradation caused by those conditions (Kempe, 2006). When the backsheet's tensile strength decreases, moisture can penetrate the PV module, allowing both water vapour and liquid to enter. This is the most common failure mode of the module and results in PV module failure (Kim, et al., 2014).

There are four main environmental conditions that can significantly affect the polymeric degradation of a PV module; temperature, humidity, moisture, and ultraviolet (UV) light (Fairbrother, et al., 2018). In addition to being ultra-violet-resistant, moisture-resistant, and temperature-resistant, the backsheet must also be able to withstand high temperatures. In order for PV power generation to operate reliably and securely over the long-term, the durability, and electrical properties of the backsheet are crucial (Zhang, et al., 2014). Increasing temperature accelerates degradation, but moisture and hot temperatures are the most significant stress factors (Kim, et al., 2016). Water vapour can permeate into the module, causing corrosion of the metallic components, as well as hydrolytic degradation of the encapsulant due to moisture acting as a hydrolytic catalyst with the back-sheet material (Pons, et al., 2014).

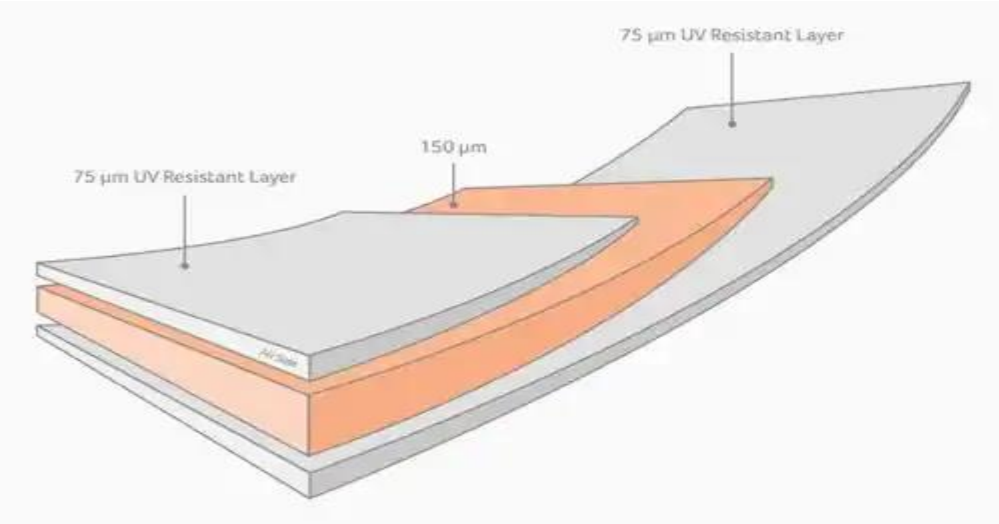


Figure 1 Schematic structure of PV backsheet materials *(PVT, 2016)*

Several studies have been conducted regarding the vulnerability of the backsheet to extreme weather conditions. Some of the study's results established and verified that the weather conditions at a PV system location are associated with the degradation of the PV components. Parameters, especially those related to components, should be investigated to determine how they might influence the module's performance outdoors (Oliveira, et al., 2018). When initial decision is made to install a PV system, it is imperative that the weather conditions at the system location be considered to improve efficiency and reliability. PV components materials are influenced by the local conditions, so it is imperative to investigate and consider the local conditions before installing a PV system.

Moreover, there are geographical implications for the reliability of PV system operation, since different locations have completely different weather conditions, and therefore the performance of the system is highly likely to be affected by the exposing conditions. The various results established by the researchers can be interpreted and concluded as stating that different locations exhibit varying weather conditions, which may indicate that system performance and operational period may vary from location to location. PV systems with similar specifications at different locations may exhibit different degradation rates of materials depending on how severe the weather conditions are. Therefore, operational periods may differ regarding the degradation level.

The goal of cheaper PV energy generation has not been achieved yet there needs to be a balance between improving the quality of PV component material and making the technology affordable to continually increase PV energy generation.

1.3.2 The Encapsulant component

The current solar PV modules available are expected to last between 25 and 30 years before deteriorating in performance (Richardson., 2018). It is important to note that the component's material is subject to differing geographical weather conditions that can affect the component's performance over its expected lifetime. PV panels are made of encapsulants made from ethylene-vinyl acetate (EVA), a very delicate material whose main function is to protect and preserve the modules' active components from mechanical and electrical degradation. It also acts as an optical interface between the cell and backsheet (Planes, et al., 2014).

Besides providing structural support, the encapsulant also maintains electrical insulation so that stressing and cracking of cells are prevented (Hirschl, et al., 2013). When the polymeric material of the encapsulating material degrades, the performance of PV panels drops at some point. EVA degradation rate and degradation mechanism are highly influenced by the chemical and physical conditions at the PV panel installation site. (Peike, et al., 2011).

1.4 Photovoltaic system location

There are many factors that affect the performance of a PV system, including factors such as the weather, the availability of solar energy, the orientation of the modules, and the durability of their components. The location of PV systems is often determined by an uncontrollable factor at the expense of performance. The performance of PVs is critically impacted by the local environment, which affects the variability and uncertainty of the output power of the panels (Tabone, et al., 2016). It is possible for geographical conditions to cause PV panel deterioration, which can have a negative impact on a system's performance and life cycle.

Even the United Kingdom has different weather conditions geographically throughout the seasons, with the East and South being mostly sunny, warm, and less windy than the West and North (MetOffice, 2017). Different conditions present different challenges to the PV system geographically, so performance will differ from one area to another. Weather conditions vary dramatically between the north and south of the equator on a continental scale which is more likely to reflect on PV performances in both north and south continents.

1.4.1 Potential factors that can influence a decision for PV system location.

When choosing a location for PV system installation, more considerations than economics must be considered. There is more than economic factors to consider when selecting a location for PV system installation. Globally, solar power generation's importance to the environment is still not well-understood.

In choosing a PV system location, several important factors, whether technical or financial, are crucial. In addition to education and culture, costs, technical requirements, and political matters are most often considered. The significance of these factors varies from one geographical location to another around the world. It is important to note that each factor has different influence levels in both developing and developed countries. However, many of these factors are often prioritized at the expense of making good technical decisions to improve PV system performance.

(i) Cost of PV system installation influence

With the largest share of investment among renewable energy technologists, PV systems continue to grow at a phenomenal rate (Trappey, et al., 2016).For technologists, accessing renewable energy around the world is difficult due to its high capital costs (Heydari & Askarzadeh, 2016). The capital cost of the PV installation is different in other markets which provide different challenges geographically. In the United States, the cost of installing a residential PV system is almost double that of a German (Moon & Baran, 2018).

The cost of PV power module accounts for 70-80% of the total system cost which has seen a significant reduction over the years (Sharma & Chandel, 2013). The PV system capital cost remains among the highest among renewable technologies despite all the cost reductions. There has been the introduction of Feed-in Tariff (FiT)systems in many countries in order to promote renewable energy generation and mitigate the high capital costs associated with it as well as attract investment through long-term subsidies in the kWh-price (Zhang, et al., 2014). In recent years, the FIT has been a catalyst for the growth of the solar PV market, but it is now at 3.62p/kW and will reach 3.55p/kW on 1st January 2019 (FITariffs.co.uk, 2018).

Investors now must find other alternatives to mitigate costs including system location therefore having a PV system closer to the grid can save costs and losses if the appropriate system conditions are met for the PV system performance to be optimal, it is more important to find the right location based on system requirement conditions. Therefore, PV system siting decisions based on system conditions requirements for performance improvement should be prioritised over the cost-cutting measure. Considering that PV systems have a 25-year life cycle, prioritizing cost over system performance is not a wise decision. Prioritizing system improvement, however, would provide long-term benefits on the system's output power generation.

(ii) Technical.

The PV panel modules has different designs from different manufacturers, each aiming to improve the technical capabilities of the technology to improve energy conversion. Various string arrangements are implemented using series-parallel and parallel processing capabilities for tracking the sun and maximum power point (MPP) (H.Gad, et al., 2017). Prior to installation, all these technical characteristics and technical requirements of PV panels should be assessed to ensure the system matches the site conditions.

Solar cells in PV panels are used to convert sunlight into electrical energy. The ability of solar cells' energy conversion can be influenced by solar radiation (Azzouzi, et al., 2011). The solar cells are composed of compound elements in groups III and V of the periodic table which has the potential to reach the highest efficiencies (Augustin, et al., 2012) under favourable conditions. Solar Photovoltaic energy generation is therefore highly dependent on weather conditions such as solar radiation and wind circulation at the location, which should also be considered before the system is installed. Different PV panels solar cells respond differently to solar radiation (Augustin, et al., 2012) and should be assessed to maximise the available condition to improve the system performance. Finding the right location for an installed PV system is important to maximise system efficiency.

PV panel surface can be subjected to shadowing caused by trees, buildings, clouds, pollution, and many others that can affect the output power of the system. The shadowing is caused by obstruction of the sunlight to reach the panel surface which must be well optimised before sitting and utilisation to minimise the effects (Hadwan & Alkholidi, 2018).

PV installations must also be considered in terms of the availability of transmission and distribution networks in and around the earmarked area. This has the potential to reduce power loss and increase the system cost of solar PV energy generation. Considering all the technical factors listed above can have an impact on the choice of a PV system location.

(iii) Political.

Both developed and developing countries have different approaches to acquiring land for projects. Political institutions have become a significant factor in promoting PV technology around the world. The United States got government's decision of promoting solar PV installations and other renewable technology in residential homes as micro-energy technology in the country's energy portfolio underpins the significance of political influence on PV system installation.

United States of America government increased investment in renewable energy such as solar PV because of the energy crises the country experienced in the 1970s and 2000s and the concern for the increasing threat of climate change due to rising carbon dioxide (CO_2) (Kwan, 2012). The incentives from the government made the public consider solar PV as the micro-energy source on their rooftop without considering the limitations of the area. Different mechanisms of incentives like Feed-in Tariff, Green Certificates and Net Metering depending on respective governments' mechanisms influenced the deployment and utilization of renewable energy producing different results. The government of Japan revitalised the PV system market after the national target for a PV system and other renewable technologies aimed to transform the whole nation into a low carbon society (Kaizuka, et al., 2009). The cumulative installed PV capacity in Japan increased because of the government's involvement in clean energy generation to reduce the country's emissions.

Many researchers have proved that different incentive mechanisms or combinations have led to an increase in PV capacity in countries like Australia, Italy, Greece, and others (Antonelli & Desideri, 2014). Political incentives have led to an increase in PV deployment however there was no effective policy to manage the risk and the investors took advantage to install many systems to make the payback period shorter. The surge had the potential to influence the sitting of solar PV systems since some investors see it as a money-making mechanism to make a profit from their investment.

(iv) Education and Cultural.

Culture is the way of life that can precipitate decisions for the installation of PV systems, especially in developing countries. Culture and education affect the way people perceive solar PV projects in the communities either by the government or individuals. There are different procedures involved in acquiring land in various parts of the world. In some developing countries like Africa and other developed countries traditionally earmarked lands for traditional purposes which many often become impossible to acquire even if the conditions are perfect for PV system installations. A typical example was a proposed solar project in the Mojave Desert in California. The Native American tribes that lived for generations have been proposed to be used for solar PV projects. The local people filed a lawsuit against the federal government to delay or prevent the land grant for the solar PV projects. Even though the condition at the site is exceptionally good for solar PV electricity generation for the community (Trinastic, 2015), objections by local communities can potentially prevent such a project or can well influence where the PV system project would be installed even if permission is granted for the project to go ahead.

2.0 Aim and objectives

In the past few years, more research has been conducted on the performance of PV panels, but their findings are more debatable because either overestimating or underestimating. As a result, solar PV performance and payback period have held back its popularity and applications (Tabone, et al., 2016). Most of the research work has been conducted in laboratory environments or climates, which is why their results and findings would not be accurate if they are generalized and used in a different climate (Han, et al., 2018).

The payback period for the PV systems mostly depends on their performance which varies from one geographical location to another one because of intermittent conditions. Consequently, the research aims to identify geographical climate trends that influence PV panel performance in order to provide significant information about PV panel performance across a variety of climates. By analysing the research results, manufacturers would be able to make the right predictions about the performance of their PV systems. In addition, the findings would help the manufacturers be confident in providing a warranty on their products. Moreover, the findings will provide customers with accurate payback periods for their PV systems, providing them with confidence and peace of mind.

Objectives

My goal is to identify geographical climate trends that will provide important information on PV panel performance in various climates. In order to accomplish the goal, data from PV systems in various locations are collected and analysed under different climate conditions. In order to achieve the research aim, the following objectives need to be taken to arrive at the research aim are summarised as follows.

1. **Existing PV system output data collection:** In order to analyse the effects of local weather conditions on existing PV system output data, a minimum of three years' live data will be collected from existing PV systems.
2. **Collecting weather condition data:** The local weather conditions of wind, rainfall, and temperature under which PV system output data is generated will be collected and analysed.
3. **Data Analysis Using Software (SPSS/Microsoft Excel):** This software provides a graphical representation of the collected data.
4. **Comparing results**: Data from literature reviews, interviews, and experiments will be compared using graphical views of the collected data.
5. **Corollate the Data**: Compare and analyse the data for the studied areas and make recommendations on the operation ad positioning of the solar systems.
6. **Creating a graphical view of PV performance**: Using the software (SPSS/Microsoft Excel) to create a graphical representation of the findings/trends. This will make manufacturers and customers understand the results better and easier, as a result, they would be able to assess the payback and period/performance of PV panels by themselves.
7. **Creating generation review**: Generation review of PV system performance against different weather conditions like low and high-temperature effect, wind speed effect, period of rainfall effect and other intermittent conditions interact and the effect on the efficiency.
8. **Discussions**: The result of the study may lead to one-on-one discussions with experts in PV panels and local environmental conditions. The use of different materials to design PV panels can provide a better understanding based on the reaction of PV panels to different conditions, for instance.

9. **Neural network program**: Using the results of this research, neural network application can be programmed to predict future performance of any PV system by using the weather conditions data.

3.0 Research challenges

Since most businesses and investors of solar PV projects treat data as confidential document, getting system empirical data is the biggest challenge. Shareholders are the only ones who can access such documents; therefore, trust must be built over time to allow outsiders access to such information. Since there is a time constraint, it is difficult to build such a relationship to gain the trust of the data handlers to release data to an outsider regardless of what the data will be used for.

Another challenge is a common language. It can be difficult to clarify what data you need when you do not have a common language. For instance, where data was provided in a foreign language, made it difficult for me to translate and use it. All this challenges together have made it difficult for me to acquire many data that I would have liked to have for this research study.

Research question: *What is the impact of geographic and climatic change conditions on the performance of PV systems as well as the lifespan of such systems?*

4.0 Literature review

The literature review examines existing data and scientifical publications to gain an understanding of PV panel types, their applications, issues around PV panels and barriers to their use, as well as any studies on geographical location and its impact on PV panel positioning. Additionally, temperature, humidity, dust, and sunlight have been discussed as factors that can affect PV panel performance. The review of relevant works will assist in developing a methodology for this research in addition to getting valuable information about these topics. In order to accomplish this, the following research topics has been researched and reviewed.

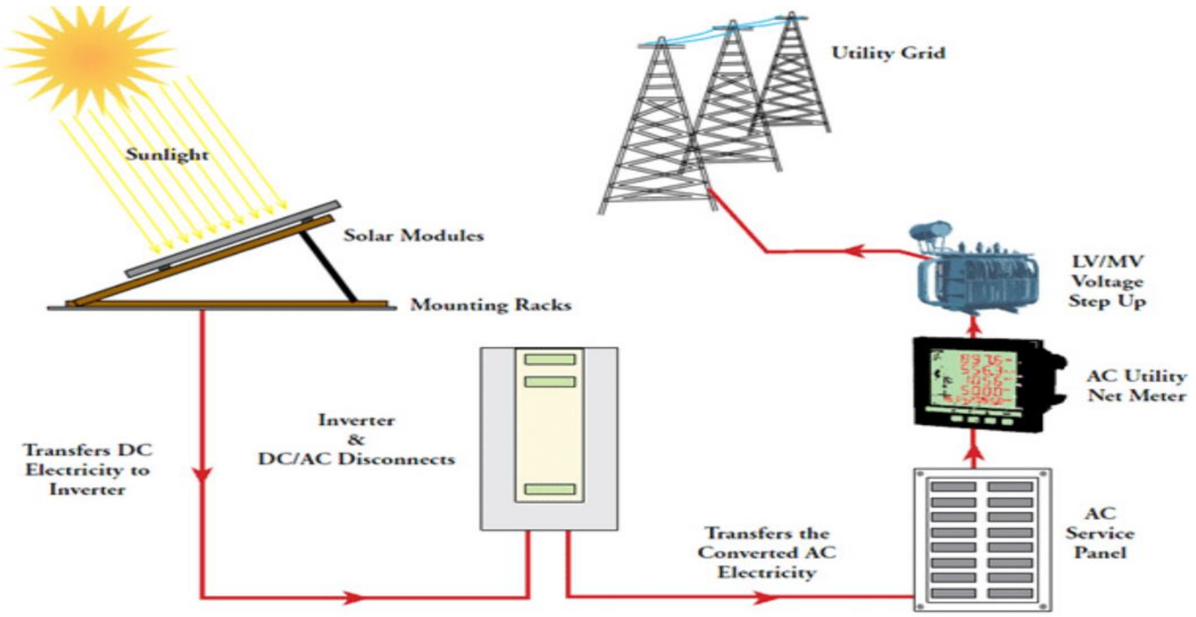


Figure 2 Structure of solar power plant *(Sweta & Hindocha, 2020)*

An example of a typical solar plant is shown in Figure 2. It consists of PV panels, inverters, meters, and transformers for generating solar power and delivering it to the grid or consumers. A solar power system produces electricity by using semiconductor materials that produce an electric current when exposed to sunlight, utilizing the photovoltaic effect. The sun's rays create an electric field when they shine on the solar panels, which causes the photoelectric effect to produce electricity.

Using an inverter, direct current electricity must be converted to AC (alternating current). Once AC electricity is converted, it passes through a meter and is transferred to the grid through a transformer.

4.1 Research knowledge gap.

Many studies have been conducted on PV power generation in order to develop a more efficient system. Most of these studies are done in the laboratory under standard test conditions of 25 °C(STC) based on simulation results. The system components are simulated before and after manufacturing, as well as other simulation test to predict the performance before installation. No matter where you are in the world, it is not possible to control the local environmental conditions in practice such as rainfall, wind, and temperature as is the case with tests and simulations. It is important to realize, however, that the performance of PV systems in practice is highly dependent on local weather conditions, which are often intermittent. Therefore, simulation results do not give a true reflection of the actual performance of PV systems.

How will this research provide a more accurate projection of performance than simulated projections?

A real live PV system empirical data will be gathered, examined, and analysed in the research studies. A minimum of three years of PV generation data will be collected from different geographic locations available for the study. The study will also collect existing system generation data and the actual conditions under which the output data is generated at the system location. Quantitative analysis of real-time data will provide close picture of information on system performance that is based on real-time data. Based on the information, it may be possible to get a closer prediction of the lifespan of PV systems, their performance, and their degradation rate in the future.

4.2 PV panels technology development.

Different PV panels respond differently to variable environmental conditions such as solar radiation, temperature, and wind speed, such as different temperature coefficients, voltage ratings, and current ratings (Elibol, et al., 2017). PV system electricity generation is dependent on weather conditions such as temperature, wind, and solar radiation. As the temperature of a solar cell increases, its performance decreases, which leads to a reduction in output power (Kant, et al., 2016). PV panels made from these materials respond differently to varying environmental conditions, such as solar radiation, temperature, and wind speed, due to different temperature coefficients, voltage ratings, and current and spectral reactions (Elibol, et al., 2017). There have been many studies identifying new enhancement materials for solar PV technology, such as organic solar, hybrid solar, PVSCs, and others. The technology identified here has a genuine possibility of improving PV energy generation efficiency. At the moment, no breakthroughs have been made in these identified technologies since they are still under investigation to ensure they will outperform existing ones. A few of the current ideas are discussed below.

4.2.1 Organic solar cell technology

Organic solar cells are an innovative technology that is mechanically flexible. Organic solar cell has low production costs, is environmentally friendly in that they can be easily disposed of and are made of lightweight materials (Saunders, 2012). Its potential speed and simplicity of processing make organic photovoltaic technology the best of its kind compared to other current traditional technologies (Wright & Uddin, 2012). In this technology, electrons (donor and acceptor) pair up to create holes when a photon of light excites the donor to transfer an electron to the acceptor (Arun & Kumar, 2017). Organic photovoltaic cells differ from silicon solar cells in that the incident photon breaks the covalent bond that forms electron-hole pairs (Wright & Uddin, 2012).

The organic solar cell technology aims to provide low-cost solar energy generation and has the potential to produce solar energy at a lower cost than traditional technologies (Hösel & Krebs, 2013) Their flexibility and lightweight characteristics make them competitive with silicon and thin-film technologies, opening up a wide range of applications (Anctil, et al., 2010). Mechanical flexibility and semi-transparent designs make this technology more appealing for building-integrated PV systems; however, low energy conversion ratios and long-term reliability issues have been major barriers to mass production.

In order for solar PV technology to become more affordable than it is currently in the market, the efficiency of solar cell technology must be improved closer to traditional technology. As a result of its lightweight characteristics, this technology could provide a better solution for solar energy production on residential roofs.

4.2.2 Concentrated Photovoltaic technology panel.

The concentrative photovoltaics (CPV), PV cells are combined with an optical device to absorb sunlight from a wide area and focus it on a specific area covered by PV cells (SISER, 2017). In general, solar power can be categorized as either concentrated solar power (CSP) or concentrated photovoltaic power (CPV). The technology works best in bright, sunny locations by reflecting or focusing the sun's energy onto a receiver that captures it and converts it to electricity (EERE, 2019).

To maximize the sun harvest, the technology applications require precise positioning of the focus using refractive and reflective devices like heliostats, parabolic collectors, and mirror dishes.

Several concentrated solar power technologies exist, including parabolic technology, solar tower technology, dish Stirling technology, and linear Fresnel technology (Kumar, et al., 2017). Depending on the local conditions, each type of CSP has different geographical advantages. As a result of the concentrated solar photovoltaic technology assessment studies, it was determined that parabolic technology has enormous potential in the South African economy and that this technology can be applied in naturally dry environments and in mid-latitude regions. (Kumar, et al., 2017).

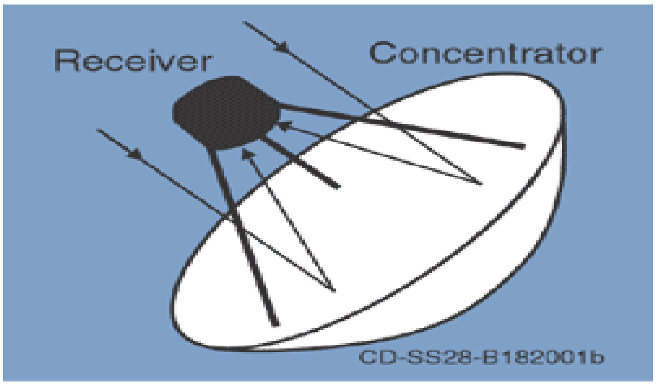


Figure 3 Dish CSP schematic *(EERE, 2019)*

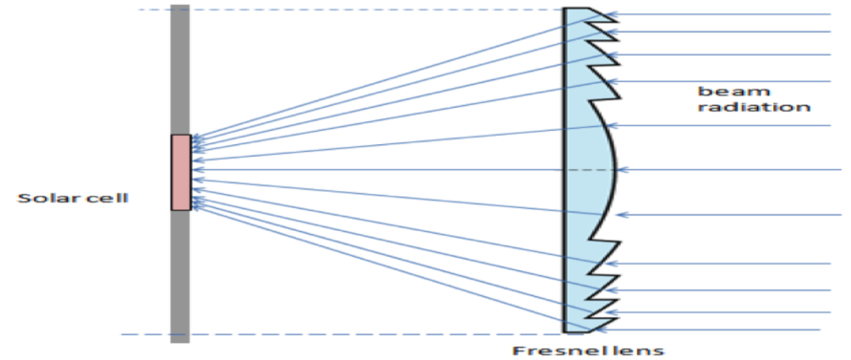


Figure 4 Linear Fresnel system *(Fedkin & John, n.d.)*

4.2.3 Hybrid solar cell.

Solar PV applications have taken up a great deal of interest in organic materials due to the exciting opportunities they can provide for improving the technology. In this technology, organic and inorganic semiconductor materials are combined into mixed nanostructures (Günes & Sariciftci, 2008). Using the combined benefits of both technologists, the technology becomes more efficient because organic solar cells have low production costs, whereas inorganic solar cells have high conversion rates but high costs. (Arun & Kumar, 2017). Compared to organic semiconductor electron acceptors, inorganic semiconductor electron acceptor materials give the system greater advantages in processability and environmental stability (Wright & Uddin, 2012).

Hybrid technology offers a cheaper alternative to conventional silicon solar cells, and its inorganic semiconductor nanoparticles provide a high absorption coefficient and size modulation (Günes & Sariciftci, 2008). Organic components in hybrid nanocomposite will make the technology more efficient than conventional semiconducting photovoltaics (Corneliu & Diacon, 2013).

4.2.4 Perovskite solar cells (PVSCs).

Perovskite solar cells are a promising photovoltaic technology that uses organometal halides to create dye-sensitized solar cells. (Park, 2015). In addition to its externally verifiable energy efficiency of 16%, this technology is expected to become more and more popular as time progresses (Snaith, et al., 2014).

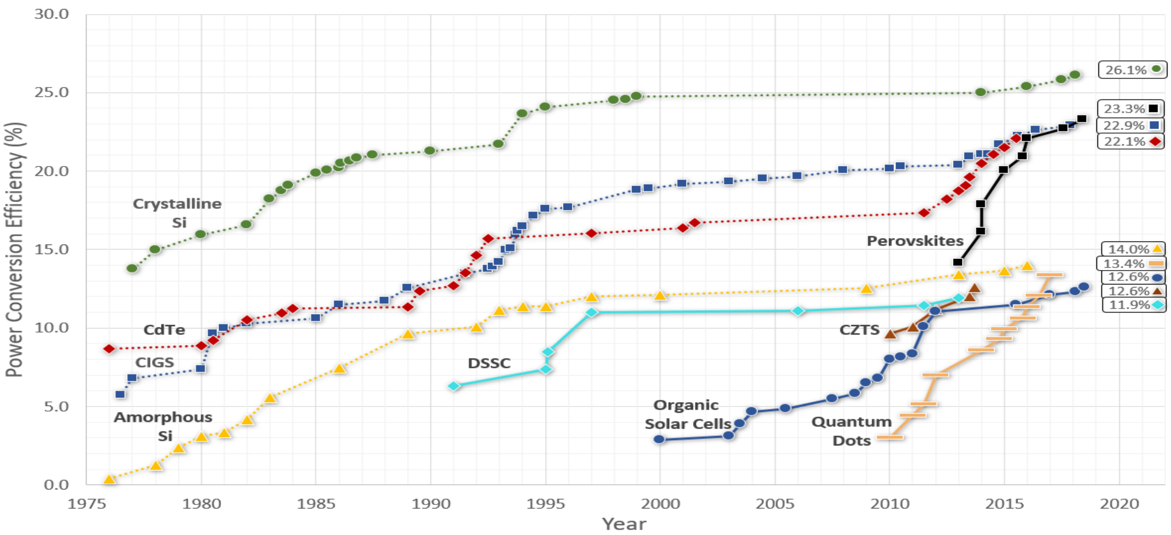


Figure 5 Perovskite solar cell power conversion efficiency compared to others *(Ossila, 2018).*

Perovskite solar cell efficiency potential since the invention is second to none of the traditional technology as seen in Figure 5. Due to a great deal of vulnerability to external degradable factors like water, light, and oxygen, the technology has a major problem in the long run. (Ossila, 2018). To make the technology more acceptable, more studies are needed to identify strategies for improving stability.

4.3 The existing solar PV panels technology.

Solar PV technology for electricity generation has evolved and this trend is expected to continue in the years ahead. Today, there are many types of PV panels on the market from different manufacturers, most of which are silicon-based. There are four main types of solar cells used for energy conversion: polycrystalline or multicrystalline silicon cells, amorphous silicon cells (a-Si), cadmium telluride cells (CdTe) and copper indium selenide cells ($CuInSe_2$) (Yilmaz, et al., 2015). A few other panels are not widely used; these include copper-indium-selenium panels (CIS), copper-indium-gallium-selenide panels (CIGS) and cadmium telluride (CdTe) panels and a few.

PV panels are normally tested in the laboratory under standard test conditions (STCs) of 25°C and 1000 W/m2. However, in the field they are exposed to different environmental conditions that are contrary to the standard test conditions. PV system performance is difficult to predict throughout its lifetime due to these differences between standard test conditions and real-life conditions. Copper-indium-selenium, copper-indium-gallium-selenide, and cadmium telluride are not cost-effective and new and fall behind due to their reliability and efficiency (Lee & Ebong, 2017). Other technologies are being explored by researchers that might improve the performance of PV systems.

4.3.1 Poly-crystalline.

Solar PV panels of this type are incredibly popular and widely used because of their good price-to-efficiency ratio. However, they are less efficient than mono-crystalline panels when it comes to efficiency (Arun & Kumar, 2017). Compared to monocrystalline modules, polycrystalline or polysilicon modules have low efficiency but are cheaper, so they are a better option when it comes to reducing PV technology costs. A polycrystalline PV system has less metal contamination than a monocrystalline system, which makes it a better option for long-term applications (Tyagi, et al., 2013).

4.3.2 Thin film.

A thin-film PV panel is not a popular technology, but it is based on copper, indium, and selenium (CIS) technology, which is more affordable, but less efficient. In thin-film technology, amorphous silicon is a well-known material whose cell efficiency ranges from 5% to 7%, however, this material shows a high level of degradation over time (Parida, et al., 2011). Thin-film PV material has a lower absorption coefficient than that of mono-crystalline and poly-crystalline PV technology (Lee & Ebong, 2017). The low efficiency return of this type of PV technology is still a concern, even though many researchers have proven it has the potential to compete with the more popular panels. Thin films are easier to integrate into building components due to their flexibility and the lightweight of the structures (Arun & Kumar, 2017). Additionally, improving PV performance is important for reducing head costs. Thin-film PV technology, however, is unattractive with its low efficiency, while crystalline PV provides a better alternative.

4.3.3 Mono-crystalline.

Mono-crystalline PV panels are efficient and have been around for many years. Solar panels made of monocrystalline crystals have a better efficiency, however they are more expensive than those made from polycrystalline crystals and thin films. This technology is based on crystalline Si p–n junctions (El Chaar, et al., 2011) which are mostly used materials in the PV industry. The mono-crystalline silicon material has been improved by using the Czochralski process (Tyagi, et al., 2013). The Czochralski process is using the crystal growth method to obtain a single crystal of semiconductors such as silicon, germanium, and gallium arsenide (Friedrich, 2016).

4.4 Types of Photovoltaic panel mounting.

PV systems can be mounted in a variety of configurations, including ground-mounted, building-integrated (BIPV), shade structures, floating photovoltaics, and roof-mounted. Roof-mounted PV can be retrofitted as a necessity. Each type of mounting design depends on the space, the area, and the system requirement. For smart cities like Masdar, PV arrays can be integrated with buildings as roofs or as structural support to improve sustainability.

4.4.1 Building-integrated PV system.

BIPV

BAPV

Figure 6 BIPV and BAPV system (
(Energypedia, 2014)

A mount of this type integrates into the building envelope and is most found in residential areas. Mounting can be classified into two types: BAPV (Building Applied Photovoltaics), which involves fitting solar modules to existing surfaces such as roofs and walls, and BIPV (Building Integrated Photovoltaics), which involves replacing the traditional building elements with solar panels shown in Figure 6. Since it is a separate structure independent of the actual building, the BAPV type does not directly affect its functions. The BIPV incorporated parts of buildings to replace some conventional building materials such as facades. Building structures of this type have a direct impact on the functionality of the building, so important considerations such as environmental factors, safety concerns, maintenance concerns, the durability of the structure, and others should also be taken into consideration. In buildings, BIPVs provide a principal source of electrical power and offer a means of reducing construction costs while using fewer building materials (ASCA, 2019).

4.4.2 Ground mount PV system

As the mount is easier to place and access, it provides a flexible solution for installing multiple rows of modules on the ground. There are two types of ground-mount PV installation: the pole mount and the original standard mount. PV system installation may vary according to regional and technological conditions, but it uses more land compared to other renewable-energy options, which critics argued were superior to traditional energy production methods. (Mohamed Amer Chaaban, 2017).

Figure 7 Ground mount PV system *(Mohamed Amer Chaaban, 2017)*

Standard ground mounts and arrays have a fixed angle. However, depending on the type of installation, this angle can be adjusted manually in seasons to follow the sun. The tilt angle of a pole mount system allows for an automatic sun tracking system that automatically adjusts the panels to maximize sunshine.

4.4.3 Pole mount PV system.

It is common to use pole mount technology of solar power installation in open areas or parks to maximize sunlight exposure; however, a large amount of land is required for the installation.

Figure 8 Pole mount PV system (Mohamed Amer Chaaban, 2017)

This system allows the use of tracking devices to improve modules exposed to solar radiation which is the most crucial benefit of this type of system installation. The pole mounts installation, aside from being simpler to install, allows for easier maintenance clean-up and improves performance by allowing airflow around the panels. Using this type of microgeneration is very convenient in situations where there is not enough roof space for roof installation to reduce our domestic energy bills and combat climate change.

4.4.4 Floating PV system.

Photovoltaic technology floating on water is a new technique for generating electricity on a water surface. Figure 9 shows an exceptionally good example of how a floating PV system is done on the surface of the water.

Figure 9 Floating solar plants *(Kim, 2020)*

Installation of solar photovoltaic (PV) systems requires intense use of local land, which sometimes leads to local protests. With floating PV technology, many of these obstacles to solar PV projects can be overcome. By installing solar PV systems on water bodies, valuable land can be conserved. In comparison to land installed solar panels, floating solar panels offer a number of advantages, including higher generation performance due to the cooling from the water underneath the panels, as well as fewer obstacles to block sunlight from reaching the panels. (Sahu, et al., 2016).

The floating PV system maintains the direction and position of the modules on the water very effectively. Even though the system is appealing there is a limitation to control such as wind and water current which may cause the modules to move out of position. Due to the possibility of solar radiation imbalances caused by floating panels, it is imperative for fixed mooring to implement directional control mooring systems. A monitoring system would create restoring force if the floating panels were detected to move on the surface (Kim, 2020).

4.5 Weather conditions effect on PV generation.

PV system performance of solar electricity generation is greatly influenced by local weather conditions. A variety of weather conditions can potentially impact energy generation, and this section discusses the different ways this can happened.

Climate change continues to exacerbate the uncertainty in solar PV system reliability in response to changing climate conditions. In some regions, the solar conditions are better than others, but these conditions are intermittent and seasonal, which can affect the performance and reliability of the PV system. It is found that PV systems perform better in the Mediterranean climate than in temperate climates since solar insolation plays a more important role in PV systems than operating temperature (Stazi, 2017). Climate change affects the solar irradiation of the PV system location, and the energy conversion ratio changes accordingly (Daher, et al., 2018). In a number of research studies, climate change has been linked to reduced solar irradiation, which negatively impacts PV system performance. (Ma, et al., 2016).

4.5.1 PV modules component materials under weather conditions

In order for PV modules to perform effectively and last for a long time, different materials are used in making PV panel components. This contributes to the performance and durability of the modules. PV panels use solar cells that work on the principle of photoelectric effect, which are made from semiconductor materials with an electric field due to their PN junctions (Saini, 2014).

Silicon is the most common semiconductor material used for the solar cells' construction (AZoOptics, 2008). Figure 10 illustrates the effect of light waves shining continuously on PV panels absorbing the incident light and gaining energy as a result of that absorption to be emitted from the panel surface. When sunlight reaches the surface of the PV panel, electrons in the material are triggered by the photoelectric effect to flow through it, generating an electric current (Yilmaz, et al., 2015).

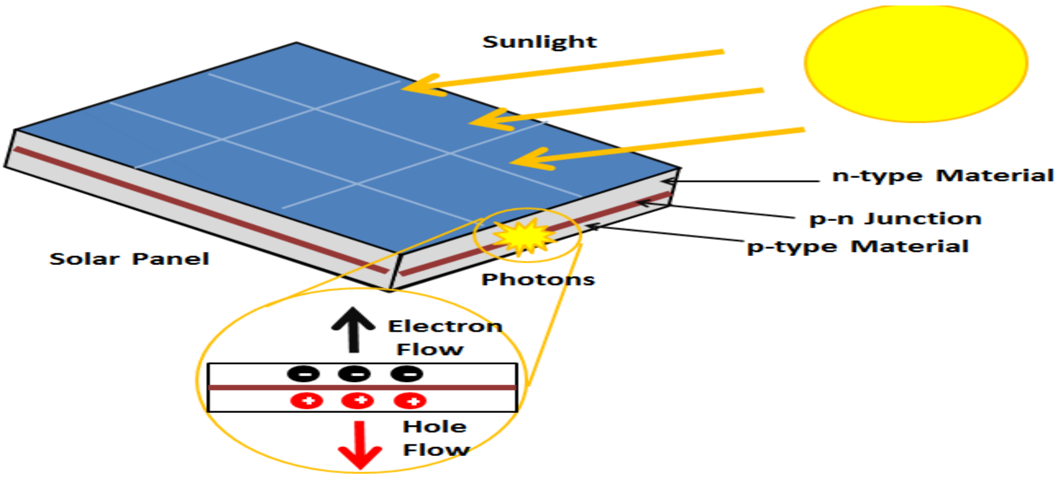


Figure 10 Schematic diagram of the photoelectric effect (Mamdouh, 2018)

The semiconductor diode consists of p-type and n-type semiconductors placed in a junction with each other. A p-type semiconductor has three valence electrons which leave an extra hole that is positively charged, and the N-type semiconductor has five valence electrons which leave one free electron called donor which is negatively charged. Doping N-type and P-type semiconductors results in extremely close electron energy levels, therefore, jumps between the conduction band and the bandgap require a small amount of energy. In P-type materials, the extra hole in the bandgap allows electrons in the valence band to move, leaving holes. These holes act as majority carriers for current to flow through the P-type semiconductors.

4.5.2 Effect of temperature on PV panel.

PV panels are affected by various environmental factors, including the ambient temperature. In this section, we examine how temperature affects PV panel performance. Ben Mahmoud, et al 2016, research study identified how PV panel performance can be affected significantly by the temperature and solar irradiation at the system location (Ben Mahmoud, et al., 2016). From other studies, solar radiation intensity and air temperature have a considerable effect on the output power of the solar cells (Xingcai & Kun, 2018) . According to these findings, temperature management of PV panels is crucial for improving solar cells' performance by mitigating their temperature effects.

Several studies have been conducted on how temperature impacts PV systems. Zaini, et al.2015, found that the temperature affects monocrystalline PV systems in Malaysia at an average ambient temperature between 21°C and 35°C. According to the results of this study, temperature increases also reduced the bandgap of the solar cell and changed its electrical parameters such as open-circuit voltage (Voc), short circuit current (Isc), and maximum power (Pmax) (Zaini, et al., 2015).

Using monocrystalline solar panels to demonstrate the dominant effect of increasing the panel's temperature resulted in a linear decrease in maximal power and open-circuit voltage with a slight increase in short circuit current and efficiency (Zaini, et al., 2015).

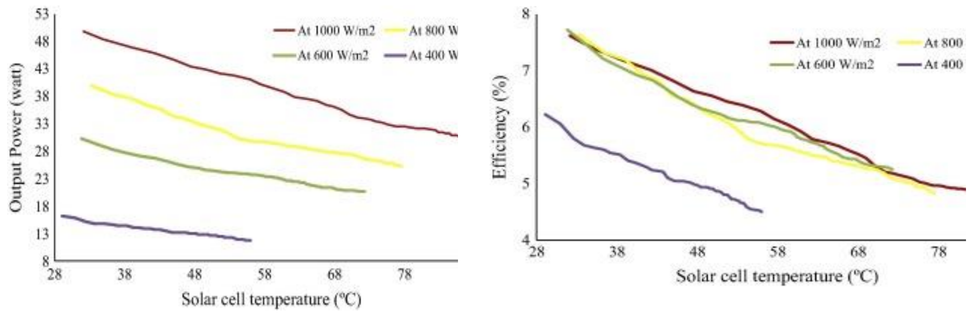


Figure 11 Effects of solar temperature on PV generation (Rahman, et al., 2015)

Rahman, et al, research findings in Figure 11 shows that the electrical efficiency of PV panels drops by 0.06% per a 1 °C rise in solar cell temperature (Rahman, et al., 2015). Siecker, et al.2017 shows that a 1°C rise in PV module causes a 0.5% decrease in efficiency (Siecker, et al., 2017). Also, a higher altitude with low temperature has the highest performance ratio compared with a low altitude (Dubey, et al., 2013).

There is no doubt that all the research findings are valid, however, there is a wide range of margins of percentage reduction due to a 1°C rise in temperature across many different locations. Therefore, it would be exceedingly difficult to estimate the percentage reduction for a 1°C rise in temperature at different system locations across the globe. Temperatures vary from one geographical area to another due to altitude and latitude differences. Temperature intensity depends on rainfall or temperature management of the location. Due to this, it would be difficult to determine the exact percentage drop in efficiency for a 1 °C drop or increase in temperature.

4.5.3 Temperature degradation.

PV system components materials are subjected to local weather conditions such as temperature on which the performance of the system depends. In areas of scorching temperature can make the PV panel vulnerable and degraded quicker than expected.

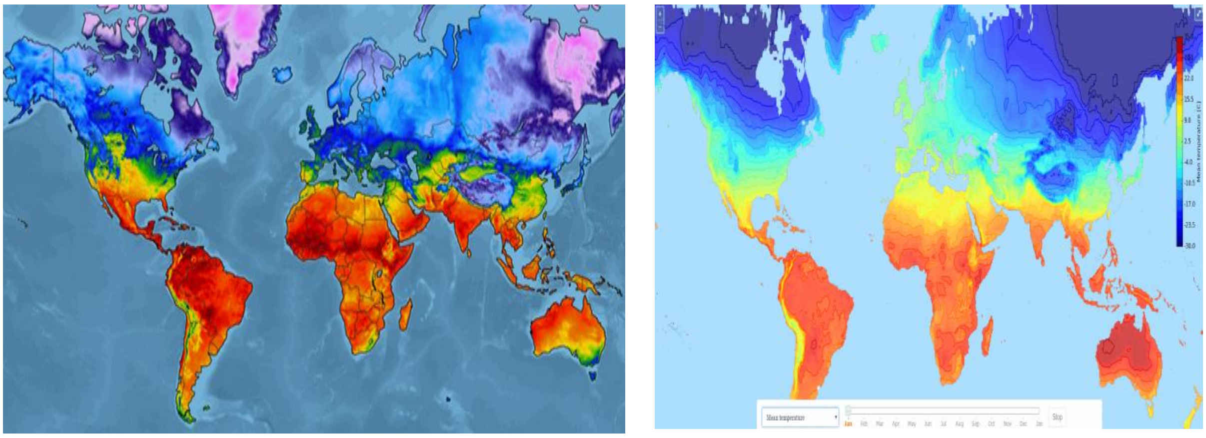


Figure 12 Temperature map of the world (imgur, 2018)

Temperature and UV radiation transmission through the EVA encapsulant are two major external parameters influencing PV panel materials (Oliveira, et al., 2018). The degradation of encapsulants could be accelerated by factors associated with their materials, including temperature, atmospheric gases, and pollutants (Zhang, et al., 2014). Figure 12 is a particularly good example of temperature variations across different locations around the world. According to this, the temperature at different places in the world constantly changes, leading PV panels to have varying levels of ultraviolet degradation and temperature changes as well. It is very crucial to mitigate the effects of rising temperature to minimise the degradation of component materials of the PV panel. To extend the panel's operational life and enhance performance, these current limitations need to be improved in order to prevent or minimised degradable conditions to prolong the module lifespan.

It is important for encapsulants to adapt to all conditions, such as temperature, humidity, and ultraviolet light, in order to reduce the degradation rate of the encapsulants (Zhang, et al., 2014). As the polymer material in the encapsulant is subjected to environmental conditions, it eventually deteriorates affecting the PV panel's energy output. Different polymer materials have been discovered by researchers capable of mitigating the effects of degradation. There is a concern that this polymer material will be more expensive than existing ones in the long run, which raises concerns about whether it will be possible to make solar PV energy generation more affordable in the long run.

4.5.4 Wind and temperature effect

The ambient temperature on PV panel installation can potentially affect the performance of energy generation. However, wind can act as a passive and natural way of cooling down PV panels which can increase their performance. Hence, wind accessibility on solar PV panels is crucial during high-temperature conditions (25°C) (Xingcai & Kun, 2018)**.** The degradation of PV panels contributes to a reduction in panel performance, so cooling methods should be utilized to reduce the rate of degradation and increase the efficiency of the panels. (Siecker, et al., 2017).

The annual output energy of the PV system can be improved by about 1% because of a 0.1%/°C reduction in temperature coefficient (Zaini, et al., 2015). It is an incredibly significant improvement for both microgeneration and commercial solar power generation to increase their annual output by one percent (1%). Many research outcomes have proposed several cooling methods for PV modules that can be executed actively or passively. There are different ways to implement a measure, and some are more effective than others in terms of cost. Hasanuzzaman, et al.2016, shows passive cooling achieved a 6-20°C reduction in PV module temperature with improved performance up to 15.5% with active cooling achieved a temperature reduction of up to 30°C with 22% improvement (Hasanuzzaman, et al., 2016).

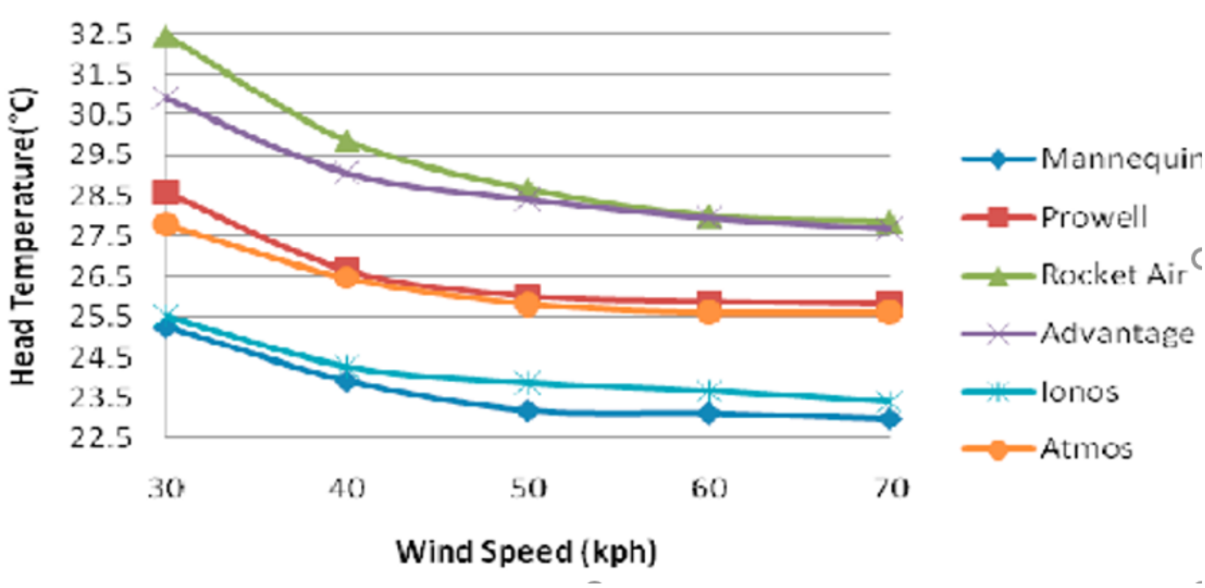


Figure 13 Wind effect on temperature *(Zakaria, et al., 2010)*

In general, when the wind increases, temperature decreases as shown in Figure 13. The use of passive cooling provides natural air circulation around the PV panels, which can be more effective on stand-alone systems.

A number of cooling methods have been proposed and proven effective by researchers, including water immersion cooling, thermoelectric cooling, forced air circulation cooling for solar PV systems, and photonic crystal cooling (Siecker, et al., 2017). Gao, et al.2018, also proposed two methods of cooling; solar photothermal conversion cooling and solar photoelectric conversion cooling (Gao, et al., 2018).

Most of the methods of cooling are highly effective in improving PV performance because of temperature control. Costs associated with implementing cooling technologies make the economic argument for cooling technologists impossible, but cooling does help reduce the temperature effect on performance. *What are the best times and locations to implement the cooling method without affecting performance*?? In this research, we hope to add to the knowledge already published some of these answers.

4.5.5 Dust conditions influence.

There is a possibility that dust can settle on PV panels, which is why it is important to investigate the effects of dust on PV panels. During the hot temperatures season in the sunniest part of the world, dust deposition on solar panels is a major problem in utilizing solar energy (Wang, et al., 2019). There are two factors that influence and dictate dust settlement levels on PV panels: local weather conditions and geographical climate characteristics (Mani & Pillai, 2010). There have been many research studies on the effects of dust on performance. The findings have proven that dust deposition causes a decrease in PV output.

Ketjoy & Konyu, studies findings show that PV performance degradation because of dust accumulation for unclean panels is around 6.9% (Ketjoy & Konyu, 2014). Also, Saidan, et al., experiment proved that efficiency degradation because of dust deposition on PV panels resulted in a 6.24% a day,11.8% a week and 18.74% a month decrease in output power (Saidan, et al., 2016). Another study by Maghami, et al., 2016 shows that the amount of accumulated dust on the PV panel surface affects the overall energy output daily, monthly, seasonally, and annual basis (Maghami, et al., 2016). According to Maghami, et al, dust accumulation is determined by geographical environmental factors like wind speed, rainfall, and wind direction. Saidan and Walwil, research shows that average degradation on the PV module due to dust deposition is not uniform as it depends on weather conditions at the PV system location (Said & Walwil, 2014).

Rao, et al conclude that higher wind speed promotes dust deposition on the PV panel surface and rainfall aid in cleaning the PV panel surface (Rao, et al., 2014)

The above-mentioned research results show that dust accumulation reduces PV system performance. Despite this, most of these experiments were conducted in middle eastern and Asian countries which normally experience more dusted winds during some seasons and have lower rainfall rates. Saidan, et al, experiment covered the entire year which includes rainfall seasons as well as dust seasons which are normally called the dry season. Since Ketjoy & Konyu's experiment data only covers a brief period of five months, this does not represent the performance of the PV system over a year. PV performance needs to be assessed year-round in all conditions, rather than just during a limited period, which doesn't capture the true effects of dust.

An investigation of the dust accumulation effect on system generation performance will last at least more than a year to give a good indication of the impact of dust accumulation on system performance.

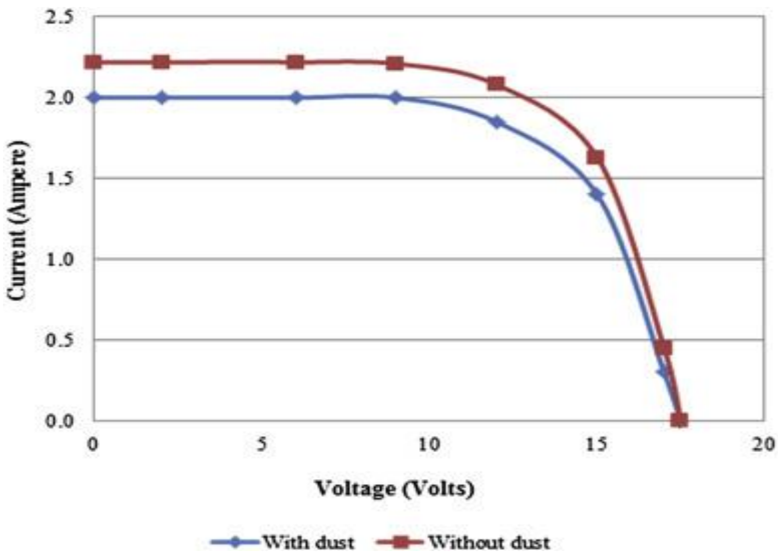


Figure 14 Dust effect on PV electricity generation (Motasem, et al., 2016)

Around the world, there are a variety of weather conditions. Since Europe has less dust than Asia, Africa, and the Middle East, the results may differ from continent to continent. A PV panel's size and tilt angle would determine how much dust would accumulate (Mekhilef, et al., 2012) therefore, different PV panels and tilt angle dust deposition may differ from one PV system to the other. An excellent example of how dust can affect PV system performance is shown in figure 14, and the smaller the tilt angle, the greater the chance of dust accumulating on the panel surfaces.

4.5.6 Ultraviolet (UV) degradation.

The prolonged exposure of PV modules to ultraviolet (UV) radiation from the geographical location is one of the main causes of PV module degradation (Dunn, et al., 2013). In PV component materials, ultraviolet degradation begins when oxygen is present as an oxidative component. This causes degradation of polymer materials such as ethyl vinyl acetate (EVA) through ultraviolet light action, which changes their primary structure (Oliveira, et al., 2018). According to UV degradation tests of PV backsheets exposed to UV sunlight, greater UV exposure can result in more severe chemical degradation, changing the colour of the backsheet (Liu, et al., 2014).

As oxidative degradation has been primarily occurring at the surface of the backsheet material due to greater oxygen availability and higher temperatures, the backsheet material has changed (SpecialChem, 2019). The ageing process of EVA under the influence of heat, humidity and ultraviolet radiation is not fully understood (Peike, et al., 2011). However, Oliveira, et al. established that ultraviolet radiation contributes to the rapid ageing of the ethylene-vinyl acetate material of the encapsulant. The ultraviolet radiation is in the range of 295nm-400nm and therefore very harmful to the polymer material because the wavelength has strong photon energy to cut the chemical bonds of the molecules of the polymer (Gu, et al., 2017)

The presence of free acetic acid contained in the encapsulant EVA polymeric material is linked to many failure mechanisms in PV modules (Oreski, et al., 2017). An increase in temperature and molecular oxygen can generate acetic acid and other unstable gases, resulting in the formation of bubbles, reducing solar module performance (Oliveira, et al., 2018).

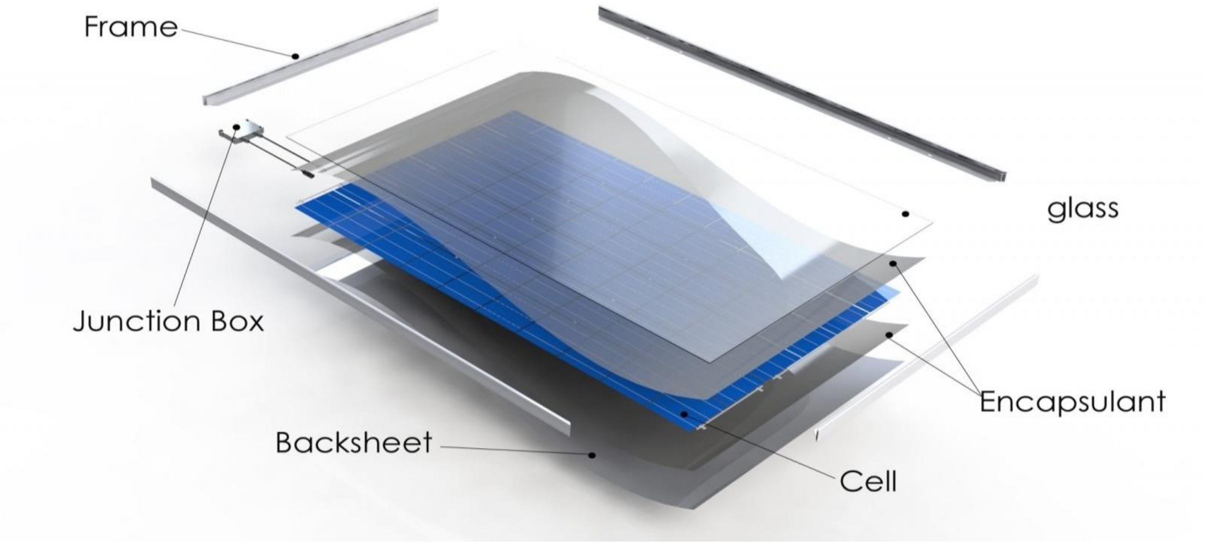


Figure 15 Degradation study based on ultraviolet exposure *(Braña, et al., 2015)*

Figure 15 illustrates a good example of UV effect on a photovoltaic module. The experiments showed that defects in EVA happen which is due to UV exposure over time. This condition affects the overall performance of PV panels (Braña, et al., 2015) .

4.5.7 Humidity

PV system performance and reliability are influenced by the humidity of locations determined by climate conditions. The system performance dependency on climate conditions continues to escalate the uncertainty in solar PV power. A number of parameters can influence performance, including gas pollution, humidity, and atmospheric parameters such as ambient particulates, aerosol composition, and solar radiation (Fountoukis, et al., 2018). As a result of increasing industrial activities, population growth along with emissions from automobiles, the level of pollution in the troposphere has increased considerably (Bukowiecki, et al., 2002) which affects local conditions.

The climate is affected by many pollutants like CO2, humidity, and noise, but most of these pollutants are invisible, but they can influence atmospheric absorption rates (Miller, 2017). Particulates settled on the solid surface attract water vapour and grow quickly to some small droplets under humid conditions (Morabet, 2018). Consequently, humidity can negatively affect PV performance by accelerating the degradation of the encapsulant, which is a crucial component of ethylene-vinyl acetate panels. It is the formation of acetic acid, oxidation, and breakdown of the main chain of ethylene vinyl acetate that causes the degradation of ethylene-vinyl acetate to begin (Oreski, et al., 2017)

Encapsulation for the solar cells is made from polymeric materials which provide insulation and protection against mechanical stress and environmental corrosion (Shamachurn & Betts, 2016). Additionally, humidity can cause water ingress degradation, which is the primary cause of degradation of solar PV panel components worldwide. Water ingress in PV system modules can result in water vapour entering the modules, affecting key components of the PV materials, and acting as a degrading catalyst.

Water ingress through rain can be a big hindrance, accelerating the degradation of the encapsulant, but it can also serve as a passive mechanism to facilitate dust removal from PV panels. (Rao, et al., 2014). Experiencing water ingress for prolonged periods of time can accelerate degradation of PV module components, which can be detrimental to PV modules The effects of water ingress on PV module performance have been established in Miami and Florida's humid climate conditions, resulting in an increase in failure rates (Kempe, 2006). Water vapour ingress on the PV module can accelerate the corrosion of the PV material and affects the resistance in solar joints (Park, et al., 2013).

4.5.8 Solar radiation.

Energy balance is represented by solar radiation that reaches the surface of the earth, and this leads to the emergence of physical, chemical, and biological processes (Wang, et al., 2016)**.** Energy emitted by the sun in the form of electromagnetic radiation that travels from its core to the earth's surface and is modified as the distance between the sun and the earth changes (Gutiérrez-Trashorras, et al., 2018)**.** There are three components of global solar radiation; direct and beam radiation, diffuse radiation, and reflected radiation (Kaddoura, et al., 2016). Radiation from direct beams is attenuated by the atmosphere and air molecules as it passes through the panels, with some of the radiation being absorbed or scattered by them (Zhao & Wang, 2010). The scattered radiation is the diffuse radiation, and the reflected radiation is the reflected radiation from the ground that only strikes the panel that is tilted at the correct angle (Kaddoura, et al., 2016).

An angle is calculated by taking the vector point between the earth's centre and the horizontal plane containing its orbit around the sun and determining the angle between them (Kaddoura, et al., 2016). Figure 16 shows the amount of solar radiation incident on a tilted module surface perpendicular to the module surface.

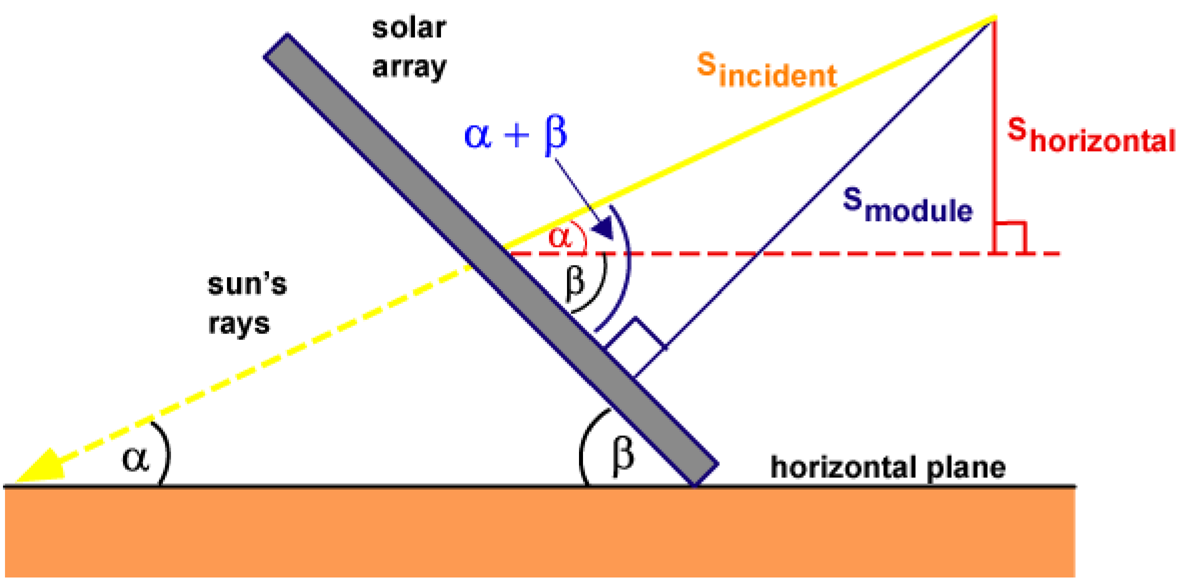


Figure 16 Solar radiation on a tilted surface (Bowden, 2020)

PV energy losses depend on a large variety of parameters which includes meteorological conditions (wind direction, wind speed, and humidity). In addition to ambient particulate matter and the chemical composition of aerosols, solar irradiance is also a factor in energy loss due to the atmosphere (Fountoukis, et al., 2018). In some areas, pollution has increased due to industrial activities, population growth, and road traffic emissions. These factors affect air quality at a tropospheric level considerably (Bukowiecki, et al., 2002).

Particulate matter is composed of small solid particles which can be in the form of chemical substances or energy carried by air currents into the natural environment (Morabet, 2018). There are many possible environmental pollutants like air (CO_2) and water that are invisible but can result in damage by a change in absorption rate and transmission characteristics of the atmosphere (Miller, 2017). Particulates settled on the solid surface to attract water vapour and grow quickly into some small droplets under humid conditions (Morabet, 2018).

As a result of vehicle exhaust pollution, ultrafine particles smaller than 100nm and solid particles other than ash are produced which are of great concern for the environment and contribute to global warming (Liati, et al., 2018). This study investigated how pollution from atmospheric particulates impacts PV performance due to climate change. The amount of air pollution in urban areas is more due to high population density, growth in industrial activities and ash emitted from vehicle exhaust. It is likely that the system performance will be impacted, and this can be monitored and examined if there is a correlation between energy production and the system performance.

4.5.9 Water ingress degradation.

Throughout the world, water degradation is the most common degradable factor for solar PV panel components. Water ingress in PV system modules can result in water vapour ingress, which affects various components of a PV system. The magnitude of this impact depends on the geographical location, which changes over time. Water ingress from rainfall can be a significant hindrance since it accelerates the degradation of the encapsulant, but it can also be used as a passive mechanism to cleanse PV panels (Rao, et al., 2014). Long-term water ingress can accelerate the degradation of components materials in PV modules, resulting in serious effects on their performance. It has been established that water ingress affects the performance of PV modules, which contributes to the increased failure rates in hot and humid conditions in Miami and Florida (Kempe, 2006). Water vapour ingress on the PV module can accelerate the corrosion of the PV material and affects the resistance in solar joints (Park, et al., 2013). A very good example of the water vapour ingress effect on solar PV panels is shown in Figure 17.

Figure 17 PV panel water vapour ingress effect *(Review, 2018)*

PV module degradation is caused by water vapour ingress into the PV module material, which causes a hydrolysis reaction that causes degradation of the material (Oliveira, et al., 2018). It is possible that this can cause a physical and chemical reaction between the PV components, especially EVA, that can lead to corrosion, which can be a major hindrance to the performance of PV systems.

Although water degradation is common in many geographical regions, ingress degradation is expected to be greater in areas with frequent and continuous rainfall than in areas with little rain. In areas with abundant rainfall activities like Europe, water ingress into the EVA is more likely than in desert countries without much rainfall. A PV panel encapsulant should provide mechanical support and protect against corrosion and degradation, but water vapour ingress can compromise this characteristic affecting the PV panel's performance and reducing the lifespan of the PV system.

Another important task for the encapsulant is to act as a water vapour ingress limiting layer in the PV module (Kim & Han, 2013). However, the encapsulant can not stop the ingress completely which allows low moisture permeation through the module to cause degradation. In order to minimize the effects on PV panels and improve the operational life of PV panels, the current encapsulant material should be improved to be more resistant to water vapour ingress.

4.6 PV installation design

The purpose of this section of literature is to consider the technicalities of installing PV systems for electricity generation, including the tilt angle requirement based on the location, the angle of the PV panels, and any other limitations associated with the panels. Degradation of components materials caused by local environmental and climate conditions can cause the PV module to perform poorly, resulting in intermittent failures and decreased output efficiency (Badiee, et al., 2016).

The ethylene-vinyl acetate material is expected to have increased electrical resistance, low water absorption ratio, and is cost-effective, which makes it an ideal material for use as an encapsulant material for PV modules (Badiee, et al., 2016). It is important to note, however, that polymer-based materials and solar cells can only be used for a certain period of time due to the degradation caused by environmental conditions, such as humidity, temperature, oxygen, and ultraviolet light. (Endale, et al., 2014). There are several types of degradation effects that occur more frequently in hot and humid climates, including junction box failure, glass breakage, defective cell interconnects, and delamination (Dhoke, et al., 2018). A thin-film PV module is particularly vulnerable to water vapour ingress which has cast doubt on the long-term reliability of the module (Kim & Han, 2013). The PV cells are protected against environmental degradation by encapsulating and sealing them in a package to ensure a long operating life (Liu, et al., 2014).

4.6.3 PV panel components.

The current solar PV modules in the market are expected to last between 25-and 30 years before decommissioned of the PV system (Richardson., 2018). However, the component's materials are subject to different geographical weather conditions which affect the performance over the expected lifetime. The encapsulant is a particularly important part of the PV panel and is made from a very delicate material of ethylene-vinyl acetate (EVA). The basic function of the EVA is to shield and preserve the active parts of the PV modules from mechanical and electrical degradation as well as acting as an optical interface of the cell and back sheet (Planes, et al., 2014). The encapsulant also provides structural support and maintains electrical insulation to prevent stressing and cell cracking (Hirschl, et al., 2013). However, at some point in the PV panel lifespan, the performance drops because of the degradation of the polymeric material of the encapsulant. The rate of degradation of polymeric material of the EVA and degradation mechanism is strongly dependent on the chemical and physical conditions at the PV panel location (Peike, et al., 2011).

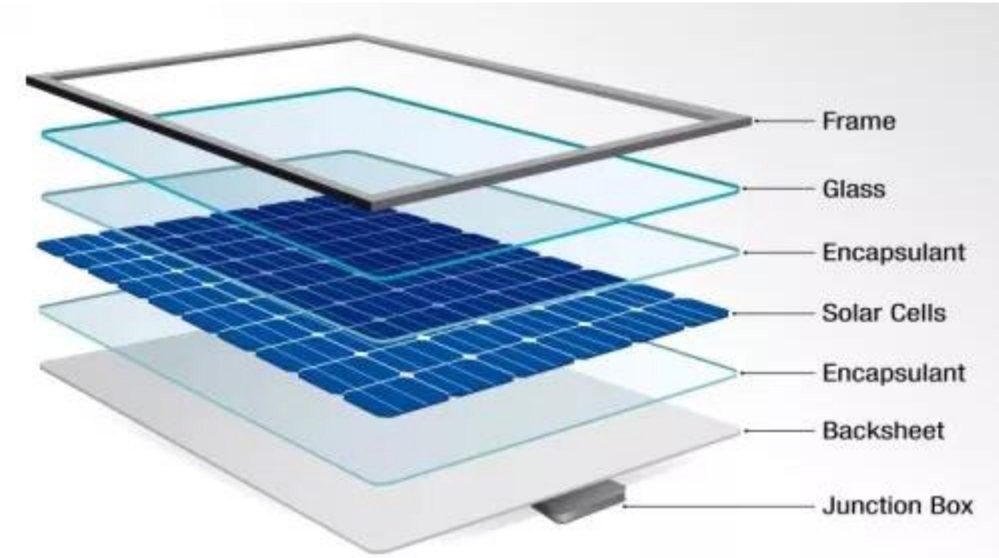


Figure 18 Material components of solar PV panel (Solar, 2016)

4.6.4 The effect of tilt angle

PV panels' tilt angle has a significant impact on their performance and cannot be ignored (Xu, et al., 2017). It is important to have all this information at hand before installing a solar PV system, since the latitude varies from one geographical area to another.

When it comes to solar PV energy generation, tilt angle and orientation are crucial because they can affect the efficiency of solar surfaces on how to optimize solar radiation. (Jafarkazemi & Saadabadi, 2013). Studies have shown that tilt angle can also affects dust accumulation, plate transmittance and solar radiation absorption (Xu, et al., 2017). According to most studies, dust on PV panel surfaces, or dust scattered in the atmosphere around PV panels, can cause up to 15% further degradation of power efficiency (Zaihidee, et al., 2016). Based on this data, it is likely that the tilt angle of the panels is directly related to the volume of dust accumulated (Kaddoura, et al., 2016) was verified by Abdeen, et al., in the experiment in the desert environment (Abdeen, et al., 2017).

Research studies have demonstrated tilt angles are particularly important in mitigating the effects of dust accumulation on PV panels. Tilt angles also vary from geographical area to geographical area (Abdeen, et al., 2017). There is also evidence to suggest that a tilted solar panel collects less dust than one oriented horizontally, and that you should avoid putting solar panels in this position (Xu, et al., 2017). The accumulation of dust on PV panels is also reduced by increasing the angle at which the PV module is angled during rainfall (Tanesab, et al., 2017).

The various researchers' outcomes signify the enormous effect dust can have on PV performance, but dust pollution varies according to the climate conditions. Although most research has been conducted in desert countries, where dust is abundant naturally, areas with regular rainfall or minimal dust circulation might have different effects on the output performance. There should be a balance between the optimum tilt angle and geographical conditions to improve PV system performance.

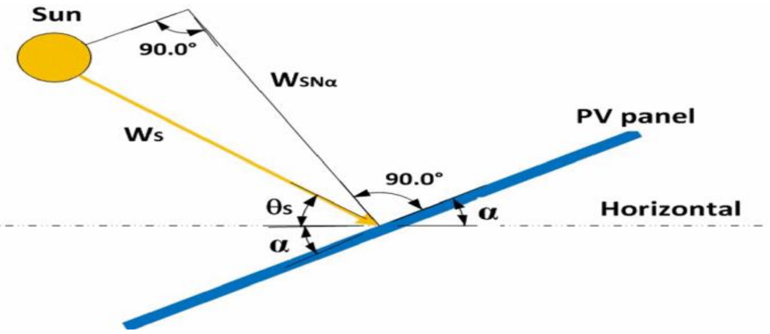


Figure 19 Schematic view of tilted PV panel (Bostan, et al., 2017)

4.6.3 PV technology market development.

The development of solar panels has evolved into one of the fastest-growing green technologies in the world, with tremendous potential for the future as the photovoltaic effect was discovered by Edmond Becquerel in 1839 (Arun & Kumar, 2017). The first commercial solar PV technology was developed during the oil crisis in the early 1970s (Pinkse & Buuse, 2012). As the technology has evolved and cost has been reduced, energy conversion ratio has gradually improved. However, the efficiency of performance is still among the lowest among renewable energy technologies available today.

Though PV technology has become more affordable over time, it is still considered one of the most expensive green energy generation technologies today compared to other renewable technologies like hydro, biomass, and wind. The flexibility of the PV technology has given it enormous potential to make a significant contribution to the world's energy security (Yiping & Yanqiang, 2013). There are different varieties of PV panels in the market today dominated by silicon and thin-film materials, but performance depends on the intermittent weather conditions at the system location (Audwinto, et al., 2015).

The technology has become popular and easy to install, but low efficiency of energy generation has remained and continues to be a major concern. However, technology conversion efficiency is continuing to improve with current efficiencies above 20%. (EIA, 2021). Considering the cost of the technology, PV power generation will be a cost-effective method based on reliability, performance, and life expectancy of the PV modules, which are related to the payback period.

4.6.4 Shading

Shading is a widespread problem globally that affects solar PV performance, and the severity of the system depends on how often the system is exposed to a frequently intermittent shade. The shading on PV panels is usually partial, which is one of the major drawbacks that degrades the maximum power the array can produce (Sai Krishna & Moger, 2019).

The amount of shade on panels varies by location due to several factors, such as trees, pollution, nearby buildings, and sometimes sun movement**.** In the solar PV system, several PV panels are connected either in series or parallel to form a solar array for desired voltage and current. The efficiency of PV systems depends on the operating temperature of the cells and the amount of solar radiation hitting the cells. Shaded arrays can impair solar irradiation. A shaded PV panel absorbs a large amount of power generated by the cells receiving high insolation and converts it into heat, causing damage to the cells (Abdulazeez & Iskender, 2011).

Shading on solar PV panels cells will cause a reduction in the total output power of the system because of increasing energy losses in the shaded cells. It is due to the fact that shaded cells may become reverse biased, draining power from unshaded cells, which might lead to hot-spot problems (Ramabadran & Mathur, 2009). In order to reduce the effects of shading on PV panels, many researchers recommend a bypass diode across the modules in order to monitor the multiple peaks in the power-voltage characteristics under non-uniform isolation (Abdulazeez & Iskender, 2011).

4.6.5 PV Panel carbon footprint assessment.

As a result of climate change, people are more aware of reducing their carbon footprints to minimize the effects of it on the planet. A PV system's carbon footprint is determined by the amount of energy used to manufacture its components and modules (Irvine & Rowlands-Jones, 2016), which involves the emissions throughout the supply chain from extraction of material to the decommissioning of the PV system. PV panels are one of the cleanest energy technologies available today, but the processes required to make them require the collection and assembly of various raw materials. PV panel components are made by preparing these raw materials at some point in the process leading to a carbon footprint resulting from individual component processes prior to assembly into a PV panel.

Solar panels have embodied carbon footprints through the mine and refinement of raw materials, which include components like silicon, encapsulant material, and aluminium, each of which has a carbon footprint associated with its production (Pal, et al., 2017). In order to calculate the carbon footprint of solar panels, we must consider the mass and energy involved in the entire production process, from when the material is extracted to the point when the panels are assembled and ready to use. In addition to the carbon footprint, the carbon footprint highlights the possible negative environmental impacts caused by the preparation of component materials for making PV panels, as well as potential environmental hazards from decommissioning solar PV technologies.

To minimize potential environmental impacts, investors and manufacturers should take part in lifecycle management of PV panels. This involves ensuring sustainable performance from the point of production of material to the eventual dissipation or disposal of the panels (Ciacci, et al., 2014). PV panel is made from dissimilar materials with an individual embodied carbon footprint during the material preparation process combined before assembling into the PV panel. In order to understand the significant impact on the PV module in general, it is necessary to discuss some of the important components.

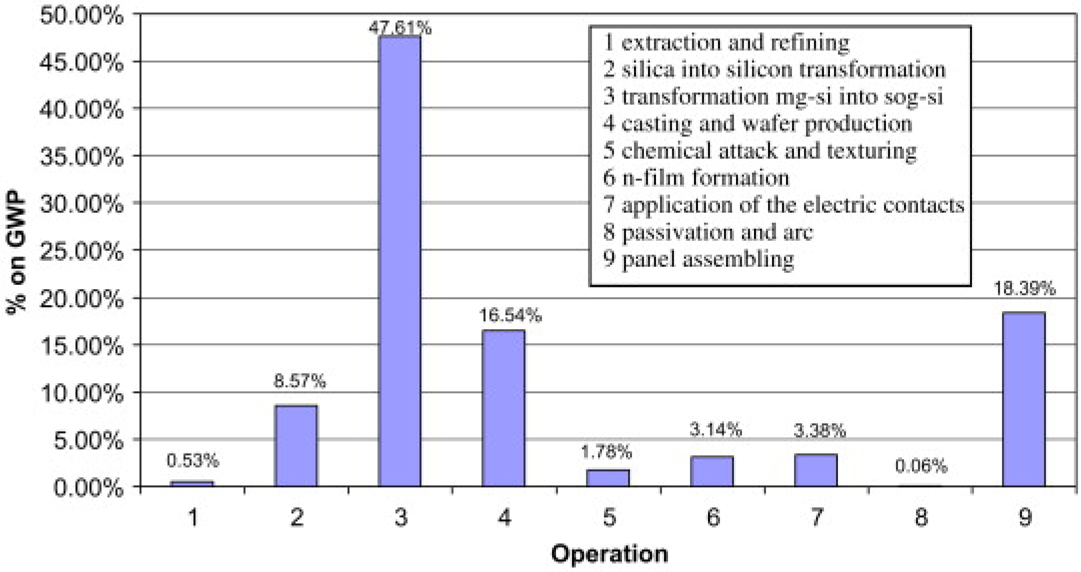


Figure 20 Contribution of a unit operation to the GWP in percentage GWP= 80kgCO_2/panel (A.Stoppato, 2008).

(i) Aluminium material.

The most used materials in solar power systems are aluminium and steel. Aluminium has high strength, machinability, and corrosion resistance in outdoor environments (Farzaneh, et al., 2016). The aluminium part of the PV panel is a particularly important part of the PV panel. The aluminium is used to cover the edges of the PV panel to provide secured support for the panel to the roof. The primary production of aluminium material requires energy intensive processes from extraction and refining to usable product, so the carbon footprint associated with PV panel assembly also includes transportation costs. In the aluminium industry, we have adopted alternative routes for processing raw materials, improving emission control processes during the production and increasing recycling as a greener practice at different stages of the production process (Ciacci, et al., 2014). Using alternative processing procedures is expected to minimize PV panel manufacturing's overall carbon footprint.

(ii) Silicon material.

Solar system modules require silicon as one of the most important components. Due to the high energy requirements for the extraction and refinement of silicon material for PV panels from silica compounds, it is the most important component material. The silica is refined to silicon by carbon in the form of charcoal (Stylos & Koroneos, 2014). The reduction process is carried out by fusing ground quartz with coal in the crucible with an electric arc (A.Stoppato, 2008). Based on studies by A. Stoppato (2008), the product of chemical processes and the by-products generated by individual components embodied carbon footprints as shown in Figure 20 and the chemical equation [$SiO_2 + 2C \rightarrow Si + 2CO$.]. 8.57% of the carbon footprint of a PV panel assembled as shown in Figure 20 is attributed to by-products of silica transformation.

(iii) Inverter material

The inverter is a power electronics application for converting direct current produced by solar panels into alternating current for use. The inverter contributes to the carbon footprint of the PV system throughout its lifespan. The inverters are often replaced during the life of a PV system before decommissioning, so each inverter contributes a certain amount of carbon dioxide to the overall system's carbon footprint (Irvine & Rowlands-Jones, 2016). Most of the inverter's warranties currently are between 10-and 15 years (Ilumen, 2019).

Due to the relatively long lifespan of PV systems, inverters usually require replacement after 10-15 years, which would triple the amount of carbon footprint produced by them. As a result, inverters should have a lifespan that matches the running period of the PV system in order to reduce their carbon footprint, which contributes to the total footprint of the PV system.

4.6.6 PV system and Environmental risk control.

Even though more sustainable scientific processes are being implemented to reduce the embodied carbon footprint contribution from individual PV panel components, PV panel disposal after use poses precarious environmental risks. Population growth will result in a waste generation increase from 1.7 to 8 Mt in 2030 to 60 to 78 Mt in 2050 in the PV sector (Contreras-Lisperguer, et al., 2017). Embodied carbon footprints are not just a function of emissions from manufacturing components, but also of energy generated over the course of the system's life (Irvine & Rowlands-Jones, 2016). Longer system operation contributes to reducing the carbon footprint, but pernicious indications about disposed of PV panels envisage an adverse environmental impact, which could negatively affect the value and importance solar power has for the environment. While recycling waste PV panels could be the best approach, the process would be challenging for treatment plants in the future due to dismantling, collection, and transportation difficulties (Latunussa, et al., 2016).

It may be necessary to adopt a recycling system that requires an energy-intensive process and adds more carbon footprints to the original footprints of individual components to minimize the impact of predicted environmental catastrophe from disposed of PV panels. PV systems have less or negligible carbon footprints depending on the type of maintenance system used, unless active methods such as cleaning or cooling are used, which require additional equipment. Currently, PV manufactures use fewer materials, which is a very strong indicator of sustainability, since less material is being used, which reduces the material carbon footprint. Considering PV panels are made from varied materials, it is highly unlikely to have components with zero carbon footprints, but there are methods for minimizing individual component footprints during preparation, thereby minimizing the overall footprint of the PV panel. A system's carbon footprint is expected to increase in distance from the source of manufacturing, depending on the distance between the system location and the source of manufacturing. Due to the transportation required to transfer components from one country or continent to another, the carbon footprint of the PV system increases geographically.

4.6.6 Scientific networking intelligence to improve PV system performance.

In the world of artificial intelligence, deep learning relies heavily on the use of neural networks in order to make predictions based on data analysis (Pratik Shukla & Iriondo, 2021). The neural network is the fundamental unit of deep learning, and it mimics the behaviour of the human brain in order to solve complex data-driven problems. A deep learning technique lets neural networks figure out which features matter for themselves instead of engineering them. As artificial neural networks, also called neural networks, have been around since the 1940s, and have seen many ups and downs, most notably when compared to support vector machines (SVM) (Harrison, 2022).

A number of other approaches to problem solving are also available, such as machine learning and deep learning (DL). The idea behind machine learning is to train the system to solve a problem rather than to directly program it (Mesquita, 2021). Machine learning (ML) tasks are aimed at making predictions about new, unknown data. In order to accomplish this, you assume that the unseen data follows a distribution similar to the training dataset's (Korab, 2021).

Figure 21 illustrates how data and machine learning algorithms combine to create a model, which can then be used to predict new data. In this way, neural networks can be used to collect and analyze network data in order to improve the network's performance, reliability, visibility, and security.

Information technology is enabling scientists to conduct better research, make findings more accurate, and make research more meaningful. In the past few years, there has been a significant increase in the use of networking intelligence programming to give accurate scientific results (Korab, 2021). This results in researchers having to make manual predictions of performance or performing increasingly complex tasks without scientific tools to validate their accuracy.

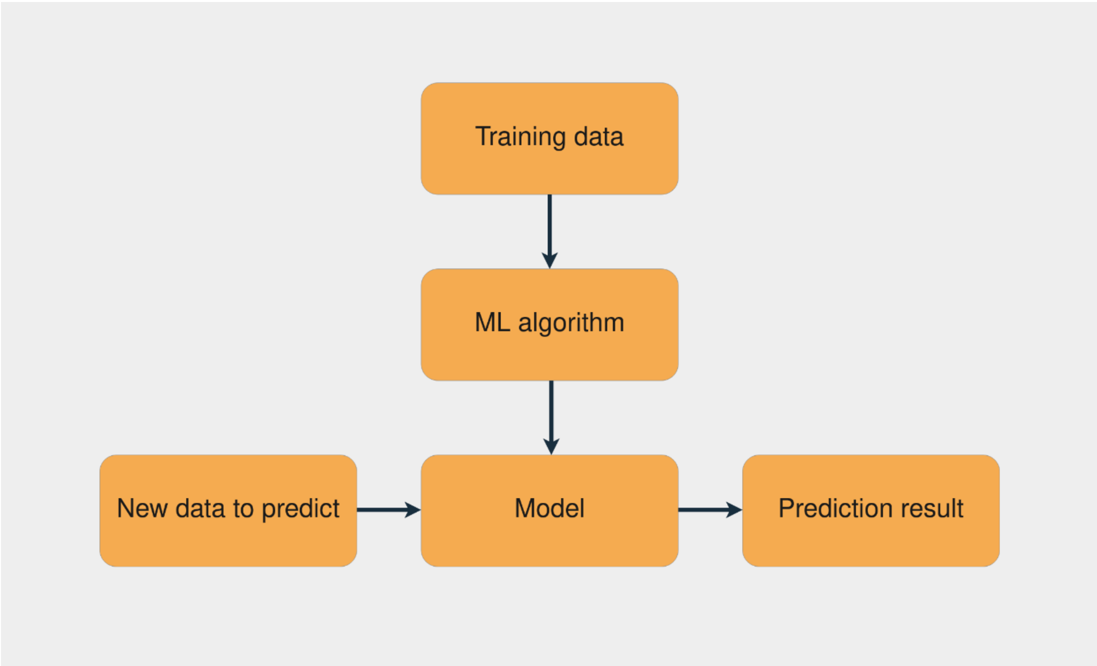


Figure 21 Schematic representation of networking approach (Mesquita, 2021)

Using networking intelligence, researchers can obtain more convincing results in a complex situation where there is a large amount of data to predict expected meaningful outcomes. Network analytics involves comparing data with pre-programmed models to make decisions about the network's performance. The data is fed into a model of the ideal network performance to improve operations. When the performance of a data source is less than ideal, the analytical network recommends adjustments before results are validated.

In this project, the data collected in relation to the performance of solar panels at several locations in India, England, USA, Ghana, and Wales, and using Neural Network, the network program will predict the performance of solar panels installed in any other locations in the world.

4.6.8 Summary

In order to ensure a successful installation of solar power, the geographical area where the PV system is installed must be given the necessary attention as the PV system is affected by the weather. Despite this, weather conditions are largely intermittent and seasonal, which has a significant impact on the performance and reliability of PV systems. PV systems perform better under Mediterranean climate conditions than temperate climate conditions. This is because solar insolation rather than operating temperature plays a significant role in the system's performance (Stazi, 2017).

The goal of every investor in solar power is to make economic gains. By investing in a location with optimum climate conditions, you may enhance the efficiency of your investment, and therefore decrease the payback period. As a result of this research, we will be able to add to the knowledge base of PV optimisation and assist investors in making informed decisions based on geographical and climatic factors.

5.0 Methodology

In an ideal world, all PV panels would be equipped with electronic devices that measure the amount of energy they generate. The collected data can be presented in Excel sheets on an hourly, daily, monthly, or yearly basis. Additionally, a PV system's performance can be estimated by knowing the environmental conditions in which it will be installed. Based on irradiance, and ambient temperature, PV panel manufacturers and installers estimate PV system performance. This estimation is done under standard test conditions (STC). However, in practice, it's impossible to control the environmental conditions, resulting in large uncertainties in the results (Tabone, et al., 2016). Generally, PV system performance will be affected by climate conditions like rainfall, wind speed, and temperature as well as other technical specifications.

The purpose of this research is to determine how, and which geographical climate trends can affect the performance of PV panels in a solar panel system. By analysing these geographic trends, manufacturers and installers could accurately estimate the performance of their PV systems and design PV panels before installation. A number of steps must be taken to achieve the results, including examples, data collection, data simulation, and data analysis.

5.1 Method of data collection.

A mixture of primary and secondary data would be used for the research. Primary data will be collected from a monitoring instrument installed at Bucks New University. In addition, secondary data would be collected from businesses and organizations who own or invest in solar energy systems. Solar research institute of Singapore, the solar world, the Volta River authority of Ghana, domestic owner from Wales, Chennai School of Technology in India, and the solar world are just a few good examples. At least, a minimum of three continents will be considered in this analysis, depending on the availability of the data from different countries.

The natural weather conditions (Geographical conditions) such as ambient temperature, wind, rain, and other weather conditions which can adversely affect the PV performance. Other conditions that can lead to degradation of the PV panels and obstruction of solar radiation will also be considered. To complete the analysis, the data on weather conditions in the locations where the PV panels operate will be also collected. To gather this information, individuals and organisations will be contacted for relevant meteorological data or an organisation which operate the PV panels to get the data on weather conditions. In order to extrapolate key information regarding the weather conditions in which PV systems are operating, three quantitative research methods are used for data analysis.

5.2 Data Analysis:

The main data analysis research method to be used is quantitative data analysis. An empirical analysis of the data collected will be carried out quantitatively in order to extract any meaningful pattern of conditional influence on the system's performance. The findings would provide a meaningful information needed to predict future performance.

The performance measure is the rate of energy generated by the PV system in each amount of time. It is usually measured in terms of output per unit time. The performance equation is given as: Performance = Output / Time (Firth, et al., 2010).

Efficiency is the ratio of the output to the input of the PV system; this gives an indication of how well the system converts inputs into useful outputs. The performance is usually measured in percentage. The efficiency equation is given as; Efficiency = (Output / Input) x 100%, (Firth, et al., 2010). Where the Output is the useful output of the PV system, and Input is the total input to the PV system.

5.3 Quantitative Research Method:

A correlational research method is the first method of quantitative analysis. The goal of this method is to correlate the performance of PV systems (output) with the weather conditions (input) under which these data are collected. Each month, wind, rainfall, temperature, and solar radiation data are gathered and analysed in conjunction with PV system energy generation data. The purpose of this analysis is to determine whether there is any correlation between the input and output data. MATLAB or SPSS will be used for this analysis.

***A causal-comparative* research** method is the second quantitative analysis method to be used for data analysis. In this method, correlated trends between input and output data are analysed to identify or investigate the cause-and-effect relationships of correlated trends via correlational research. (The first method). The results of this analysis will significantly contribute to understanding how environmental factors impact on PV panel performance. The findings from this analysis will help improve the performance of PV systems and will enable us to make some recommendations to the users and manufacturers accordingly.

The third quantitative analysis method is the experimental research method. Using a laboratory setting, a scientific investigation will be conducted to determine whether input and output data are related. To undertake the experiment, the method recommended by relevant British standards (BS EN 62446-1: 2016, A1:2018) is followed using a solar panel unit and a solar simulator. An electronic data acquisition system (Volt101A) will be used to monitor and collect data. The purpose of this investigation is to compare experimental results obtained under controlled conditions with experimental results obtained under different weather conditions at separate locations. By using this method, we will be able to confirm the authenticity of data collected for this research, especially the secondary ones, which in turn will allow us to confirm or deny the correlations identified in this study.

5.4 The In-depth discussion.

Using data collected from the Buckinghamshire university solar power system, my primary source of data, will help to estimate the relationship between input and output data using university monitoring tools. The measurement of environmental parameters, such as temperature, wind speed, and solar radiation, is achieved with the help of an environmental monitoring instrument, however, to validate the data readings PV system experts in the field were consulted. Additionally, contacted was made with the local weather experts in order to confirm the data collected from New Bucks University monitoring instrument. Several open questions were posed to experts including local Met-Office data monitors for feedback which was essential in writing the programming for the findings.

In order to understand how PV panels are used in the domestic sector around the world, a number of interviews with PV panel users have been conducted. Primary data and some parts of the secondary data were collected from different locations across the globe, so householders in all regions were chosen. The questions were related to their experience in using PV panels such as payback period, PV performance under different weather conditions, maintenance, and the issues they have had with PV panels. This interview provided us with more realistic, honest, and unbiased information on the performance of PV panels under different weather conditions.

The PV panel manufacturer for the PV system used for the study was contacted for technical information about the panels' capabilities in an experiment or at home. As part of the interview with the manufacturers, questions were asked about the performance and limitations of their products in varying weather conditions. Users of such panels for residential microgeneration was also contacted for their experience of using the panel and to verified information gathered from manufacturers, this helped to access the performance of their products against weather conditions in particular locations. The results from different areas will be compared with all data accumulated from different regions to be analysed and extrapolated to identify geographical climate trends concerning the performance of PV panels. The results from this study will provide meaningful information for manufacturers and users of PV panels to have a clear idea about what effect the geographical and climatic conditions have on the performance of their PV panels.

5.5 Using Neural Network intelligence application.

Neuronal networks (also known as artificial neural networks) are adaptive programs that learn by using interconnected nodes or neurons in a layered structure that closely resembles the structure of the human brain. In neural networks, patterns can be recognized, data can be classified, and future events can be predicted by learning from data.

A neural network is an ideal framework for modelling non-linear relationships, and many speech, vision, and control systems employ them to recognize patterns or classify objects or signals. Input layers, hidden layers, and output layers make up the network. Each layer contains several nodes, or neurons, and the neurons of each layer use the outputs of all the nodes in the previous layer as inputs, resulting in interconnectivity among neurons. It has become well known that neural networks, especially deep neural networks, are extremely proficient at complex identification tasks to generate more accurate scientific result. Figure 22 is good example of interconnected nodes in neural network intelligence programming to produce one single output.

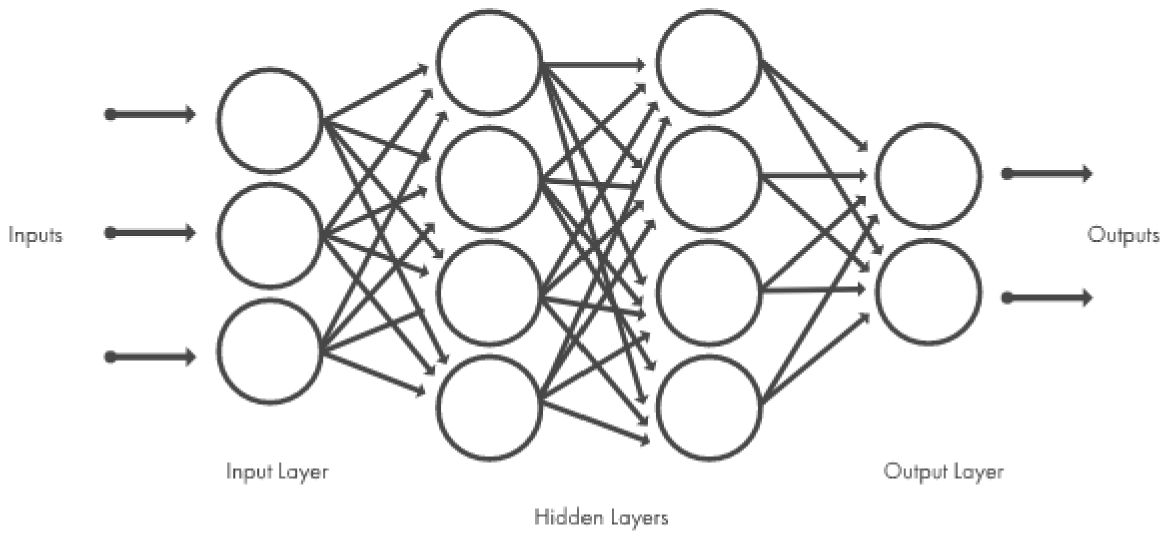


Figure 22 An example of neural network parameter (Toyoizumi & Wang, 2022).

Neural networks are created by adding layers of perceptron together, creating a multi-layer perceptron model (Portilla, 2017) where your data will be entered into an input layer, and your output layer will generate the output. To produce an output, the perceptron receives inputs, multiplies them by a weight, and then passes them into an activation function (Portilla, 2017).

To improve the accuracy of the predictive model of neural networking, we must also add a bias to the perceptron or inputs, such as a constant weight independent of the inputs. As a result, it will be easier to predict the outcome of more inputs with a greater level of variation. In this project, the data collected from different locations (five sites out of four continents) will be used as input layers and nodes and using Python I will program the entire layers.

5.6 Research impact.

There have been many studies on improving solar power performance, as reviewed in many journals, conference papers, and by a number of organizations. Performance is examined in the context of different geographical implications since climate conditions vary from one region to another. Even though there is a significant difference in climate conditions, the same module of PV panels is used across the world. As a result of this research, other researchers will be able to gain a better understanding of PV performance in this context.

The collected data from different regions around the world, including Africa, Asia, Europe, and north America, the Mediterranean and the Middle East and Americas. As these areas have different climate conditions, we will be able to obtain different information on PV performance from different regions, which can be extrapolated into meaningful conclusions. Using the information gathered from different regions, it is possible to identify limitations that are specific to certain regions.

6.0 Analysis

A review of PV system energy generation performance data collected around the world will be analyses in this section of the research. As a result of monitoring and analyzing this data, analytical information will be extrapolated for an investigation to provide credible answer to the research question. A comprehensive analysis of the PV energy generation performance will be conducted against the weather conditions under which the data was collected from the existing system. The recorded PV system data will be compared against the weather conditions collected as the input parameter for the research. The input parameters used, wind speed, ultraviolet radiation, temperature, and rainfall.

Wind speed around a PV system refers to the velocity of the air in the immediate vicinity of the solar panels. it is very important to monitor the wind speed around a PV system to ensure that it remains within safe and optimal ranges for efficient and reliable operation.

Ultraviolet (UV) radiation refers to the electromagnetic radiation with a wavelength shorter than that of visible light but longer than X-rays, typically between 10 and 400 nanometres. The UV is one of the components of sunlight that reaches the earth's surface which is measured in mW/cm^2 and can affect the performance and efficiency of photovoltaic (PV) systems.

The temperature (expressed in ℃) around a photovoltaic (PV) system is the ambient temperature in the vicinity of the solar panels and associated equipment. The temperature can vary depending on factors such as the time of day, season, geographic location.

Rainfall around a photovoltaic (PV) system refers to the amount of precipitation that falls on or near the system. PV systems are typically installed outdoors and exposed to rainfall expressed in millimetres.

A comparison of the various weather conditions has the potential to yield significant information regarding the location and performance of the system, which can then be extrapolated into meaningful trends. By analysing the current PV system performance levels, we can build a meaningful countermeasure to reduce the effects. The results will help us assess whether the system will perform well in the years to come.

6.1 Navrongo, Upper East Region, Ghana

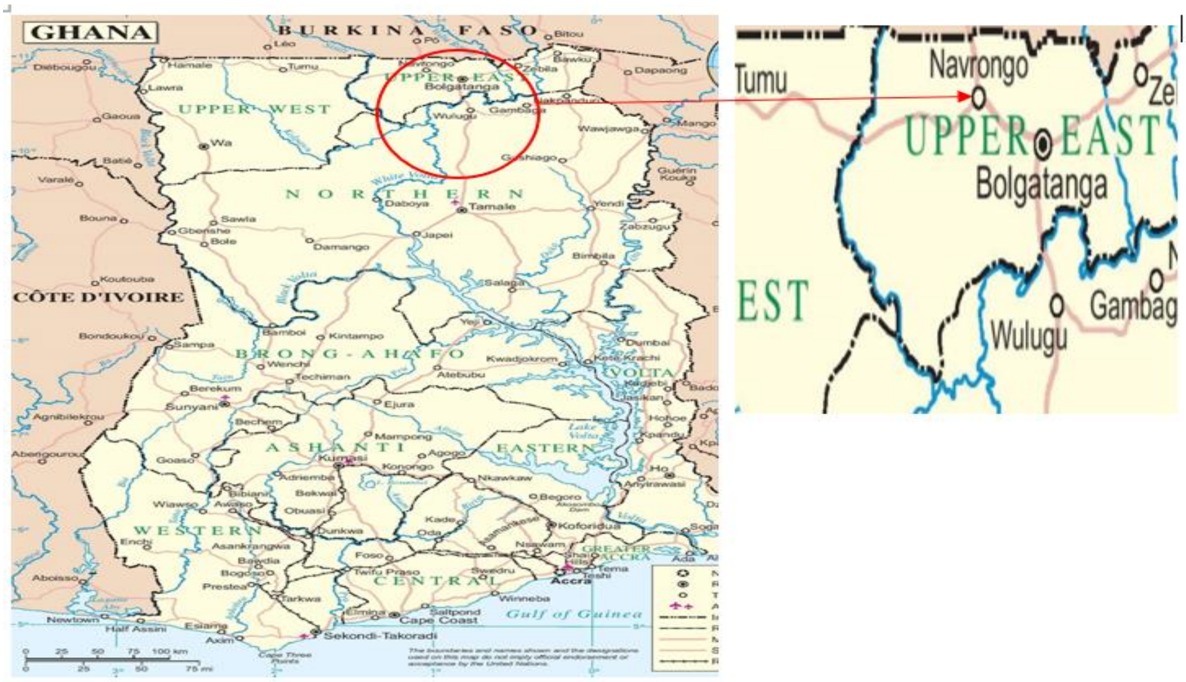


Figure 23 Ghana *map showing the PV system location (King & Cole., 2017)*

The city of Navrongo is in the upper east region of Ghana in West Africa and experiences desert-like conditions most of the year. The Upper East region shares boundary with Burkina Faso to the north and Togo to the east and lies between longitude 0° and 1° West, and latitudes 10° 30'N and 11°N. In Ghana, where the PV system is located, the rainy season begins in April and ends in September, and the dry season begins in October (GhanaMet, 2017). The harmattan, a desert wind, blows from the northeast from December to March, lowering the humidity and creating hot days and cool nights in the north. A majority of the time, March is the hottest month, and August is the coolest month.

Figure 24 2.5MW Navrongo Solar Power Plant (VRA, 2018)

Under Section 46 of the Volta River Development Act 46 of the Republic of Ghana, Volta River Authority (VRA), an electricity provider in Ghana that is responsible for generating, transmitting, and distributing electricity. Therefore, PV system data was provided by the VRA for the research (GhanaWeb, 2019). Ghana's government's plan to reduce its carbon footprint has led to the VRA drafting the Renewable Energy Policy to develop 10% from renewable energy sources.

The main objective is to help minimize pollution and provide sustainability to the environment which led to the installation of a 2.5MW Solar PV power Plant at Navrongo in the Upper East Region of Ghana (VRA, 2015). The PV array consists of 8622 panels that cover 4.77 hectares of land and is connected to a data logger on-site to monitor the distribution of energy across the country. The polycrystalline PV module system with a rated efficiency of 15.2% and an expected annual generation of 3.7Gwh. Wind speed, wind direction, temperature, and rainfall data were obtained from Ghana meteorological services station in Accra- Ghana. The Ghana Meteorological Service uses the latest equipment and has a proven track record of producing reliable data.

6.1.1 Solar potential for Navrongo.

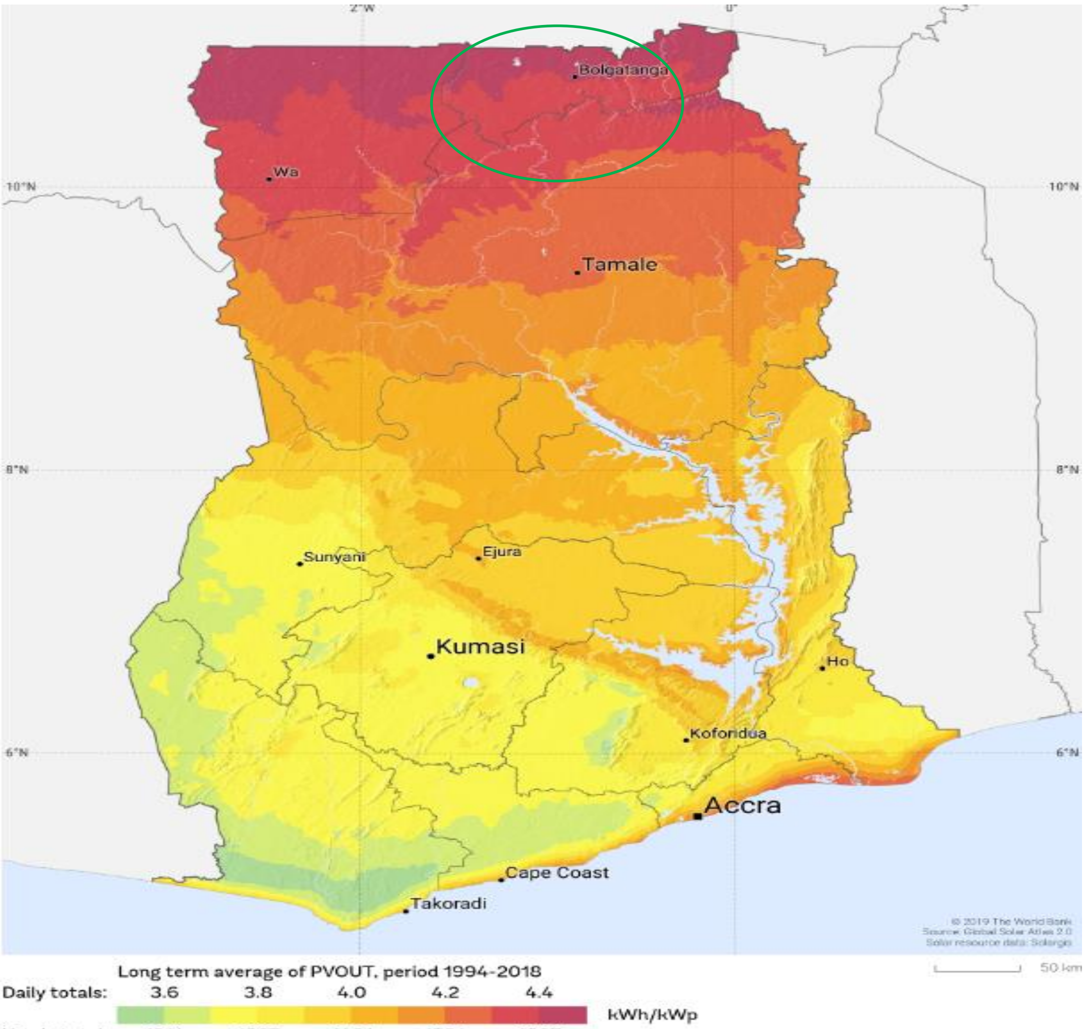


Figure 25 Solar potential map for Ghana (Solargis, 2019).

Thesolar radiation data are used as the primary source of solar energy potential analysis which includes locally available measurements and identification of regions with the highest solar potential, seasonal and inter-annual variability of solar resources (Solargis, 2019). Putting the geographical data into consideration adds value to the solar capacity information and information regarding weather conditions that determine the operational environment of the solar system. The Navrongo in the Upper East region is highlighted in figure 25 where the system location is endowed with 4.2kwh/kwp to 4.4kwh/kwp daily levels of solar power potential, therefore, it is the expectation that systems, in general, should perform better. It should be noted that solar technology also relies on weather conditions, and has not demonstrated a significant solar potential, so upgrading the system won't guarantee better energy performance. By analysing weather condition data with system performance, we can carefully judge the long-term viability of the system either to confirm design rating performance or to guide investors to make the right investment decisions. It is a good thing to have some helpful information about the expected location to help enhance system performance and lifespan.

6.1.2 Climate seasons of the location.

There are two distinct seasons in Navrongo Ghana over the course of a calendar year: the wet season and the dry season. The wet season lasts from April to September, and the dry season, lasts from October to March, and each season brings different levels of climate conditions. The wet season is the time for heavy rainfall and during this period temperature falls but is still above the standard test condition temperature (25℃) for PV panels as shown in figure 26. There was little ultraviolet radiation during the wet season, and the wind speed was consistent throughout the period. Furthermore, the dry season is characterized by high temperatures as well as a dusty atmosphere due to the dry atmosphere and the high temperatures. Ultraviolet radiation (UV) often peaks during the dry season and also there is a slight increase in wind speed from November to February.

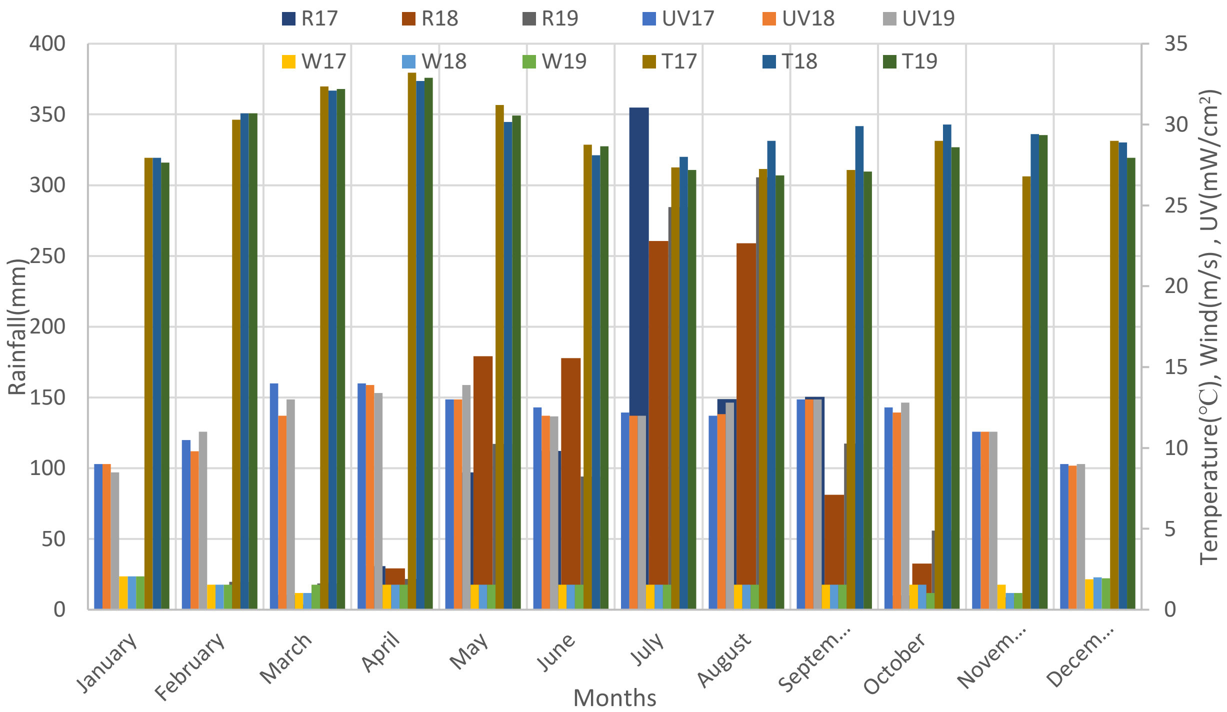


Figure 26: Climate condition for the two seasons

Graph definition of terms.

- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019

- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019

6.1.3 Weather conditions effect on PV system energy generation.

In this section is to investigate the conditions under which the PV system performs by examining the weather conditions data and the actual energy generation data of the PV system. Figure 27 gives a general view of the PV system energy generation performance under different weather conditions. Maximum energy generation occurred at the peak of ultraviolet radiation levels and with a minimum change in wind speed. Similarly, the energy generation performance peaks as soon as the temperature starts to rise after the rainfall has stopped, as can be seen in Figure 28. During the rainfall temperature drop to a minimum of 27.2℃ and the performance of energy generation increases as rainfall tail off for the dry season to begin as shown in Figure 28 and figure 27.

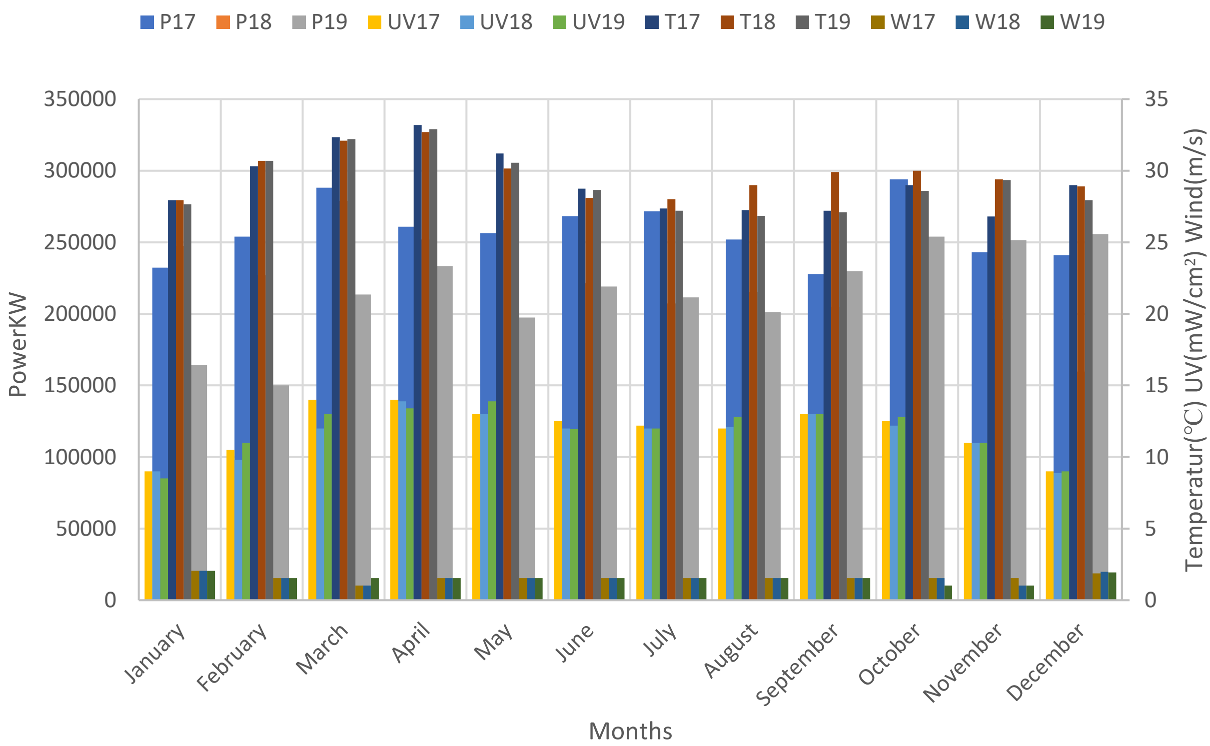


Figure 27 Performance against temperature, ultraviolet radiation, and wind speed

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.

- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

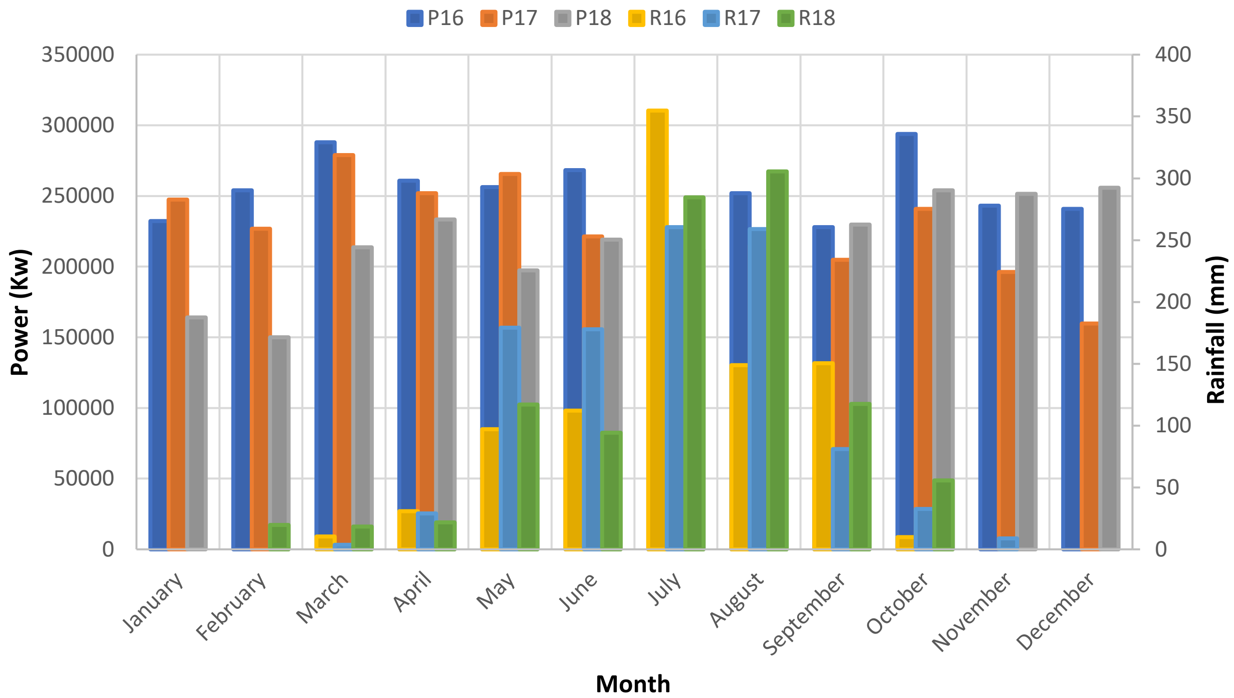


Figure 28 Performance under rainfall conditions.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019
- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019

6.1.4 Seasons breakdown of PV system energy generation performance.

(i) Wet season

In Navrongo in the northern region of Ghana, there are two seasons. The first season data to be used for the of the analysis is the wet season. The performance of the PV system from 2017 to 2019 is shown in figure 29. All conditions data collected during generation will be considered in order to determine performance under each of them.

It is noted from Figure 29 that the wind speed remained constant at an average of 1.5m/s during the wet season. The amount of ultraviolet radiation (UV) increases with increasing temperature, but during the rainy season, both UV and temperature decrease. In Figure 30, the ultraviolet radiation and temperature both increases before and after rainfall period. A look at the performance pattern shows that peak performance occurs during and after the wet season when ultraviolet radiation is at its highest.

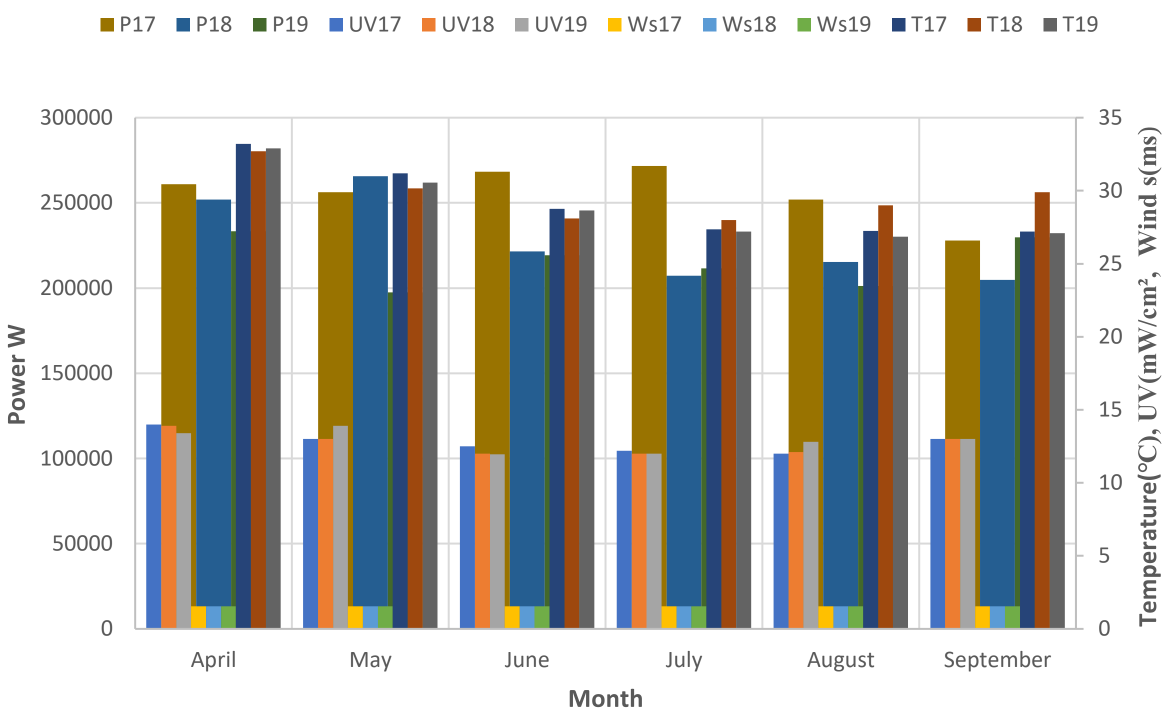


Figure 29 Performance under temperature, UV, and wind during the wet season

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

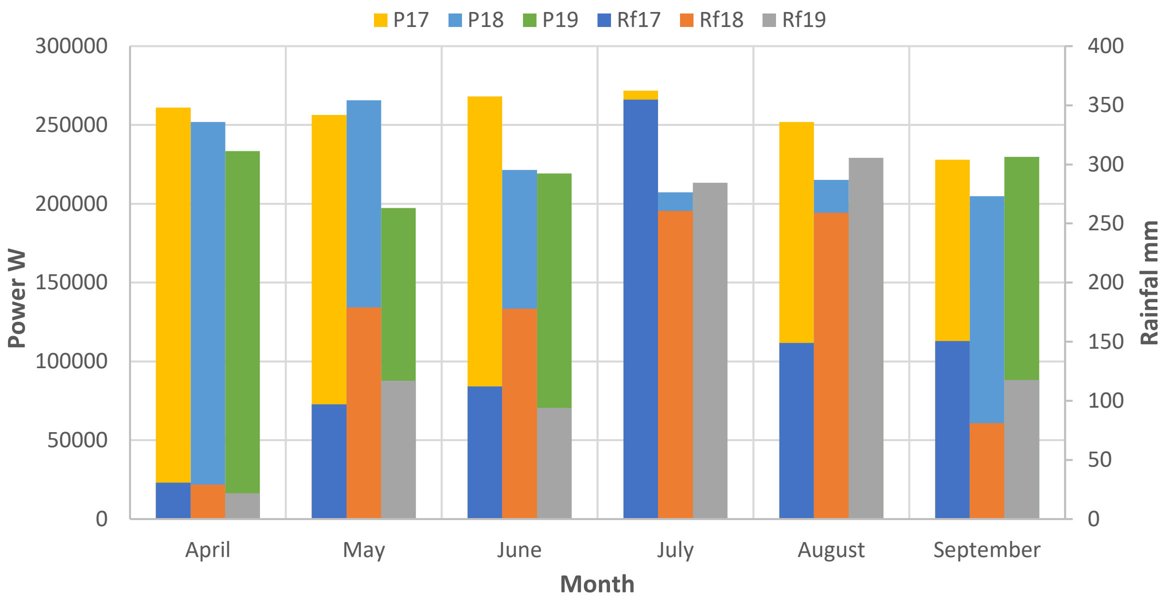


Figure 30 Performance under rainfall during the wet season

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019.

(ii) Dry season

Within the calendar year, the dry season begins in October and ends in March. The performance of the generation system is to be evaluated based on data collected on weather conditions over an extended period. According to figure 31, energy generation during the dry season is affected by the levels of UV, temperature, and wind speed. When temperature increases ultraviolet radiation also increases and when wind speed drops by 0.5m/s and performance improved. While the season began with better performance, performance begins to drop as UV and wind speed decreased. A strong correlation noted between system performance, temperature, and ultraviolet radiation during both wet and dry seasons.

According to figure 32, rainfall ceases during the dry season, and a gradual warming begins during the wet season. The performance during the dry season is much better between 26kW - 29kW compared to the wet season which is around 25kW-27kW. The performance of the system decreases significantly between November and February when rainfall was very low.

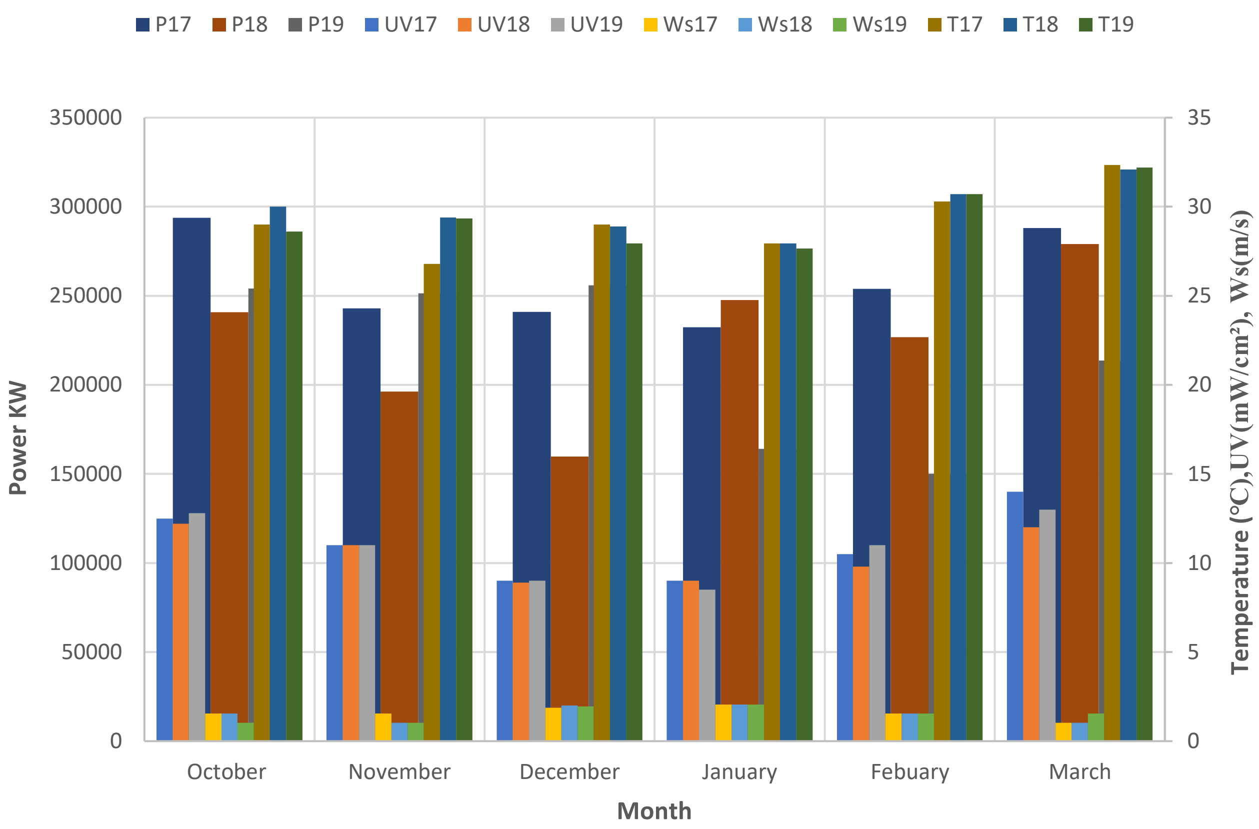


Figure 31 Performance under temperature, UV, and wind during the Dry season

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

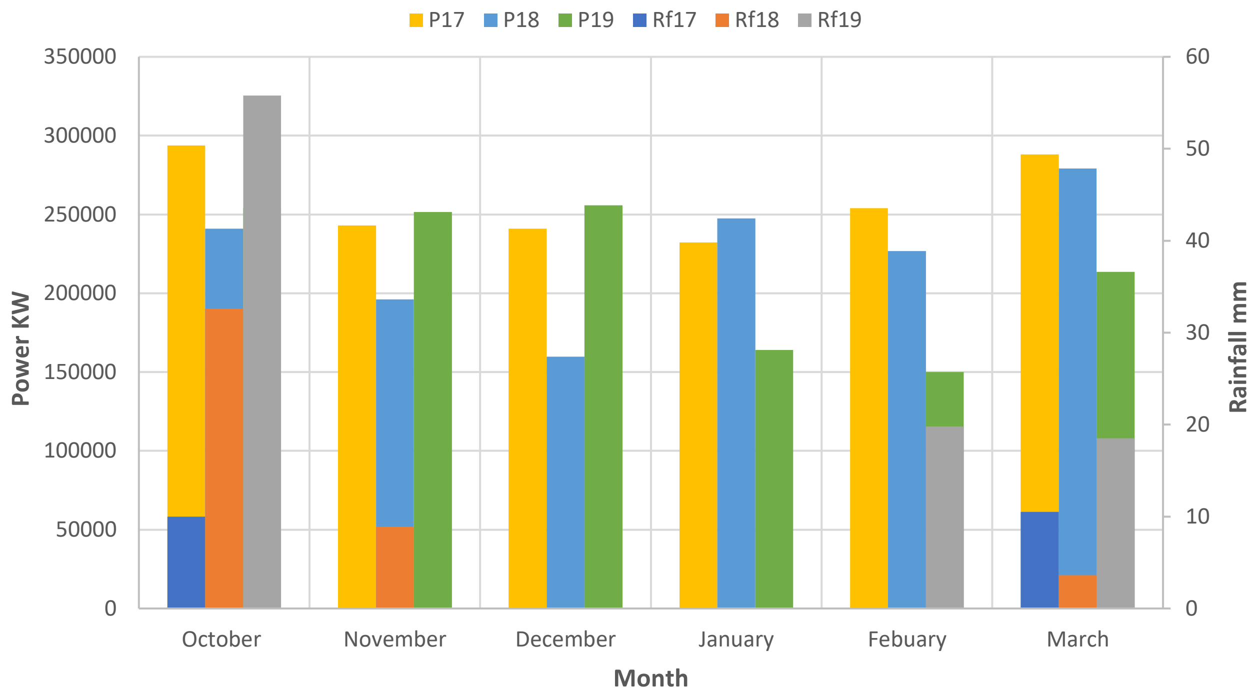


Figure 32 Performance under rainfall during the Dry season

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019.

6.1.5 Discussion of Results.

As a result of differing weather conditions, the two seasons' performance results in different readings. Solar potential in the region is particularly high, at 4.4 kWh/kwp daily, with an annual total of around 1607 kwh/kwp. Due to this, it is evident that both seasons of the year are suitable for the system location to produce decent output power.

An average wind speed of 1.5m/s can be observed during the wet season. In the wet season, due to rainfall, the minimum temperature is 27.1°C; however, the amount of ultraviolet radiation increases with temperature. The figure 27 shows that performance increases with increased ultraviolet radiation regardless of the season, however in the wet season, ultraviolet decreases by an average of 1.2mW/cm2 as a result of the rain.

There was an increase of 0.6m/s in wind speed during the dry season compared to the wet season performance. An increase of 0.6m/s wind speed resulted in decreasing temperatures and ultraviolet radiations in figure 31. Wind speeds in January and February caused a decrease in ultraviolet and temperature to the minimum levels; 8.5mW/cm² for UV and 28.6°C for temperature, causing a decrease in performance.

A comparison of performance over the two seasons will be made using the first season (2017) as a reference as shown in figure 34. Furthermore, according to the readings, the dry season's performance in 2017 was 1.01% higher (15066.9kW) than the wet seasons. Throughout the years, the performance of generation decreases, but the extent of that decrease varies with the seasons and weather. The overall performance during the dry season is better than the wet season, even though the percentage drop is 1% higher than in the wet season. From figure 34, we can see that performance drops by 15066.9kW (1%) during the dry and wet seasons.

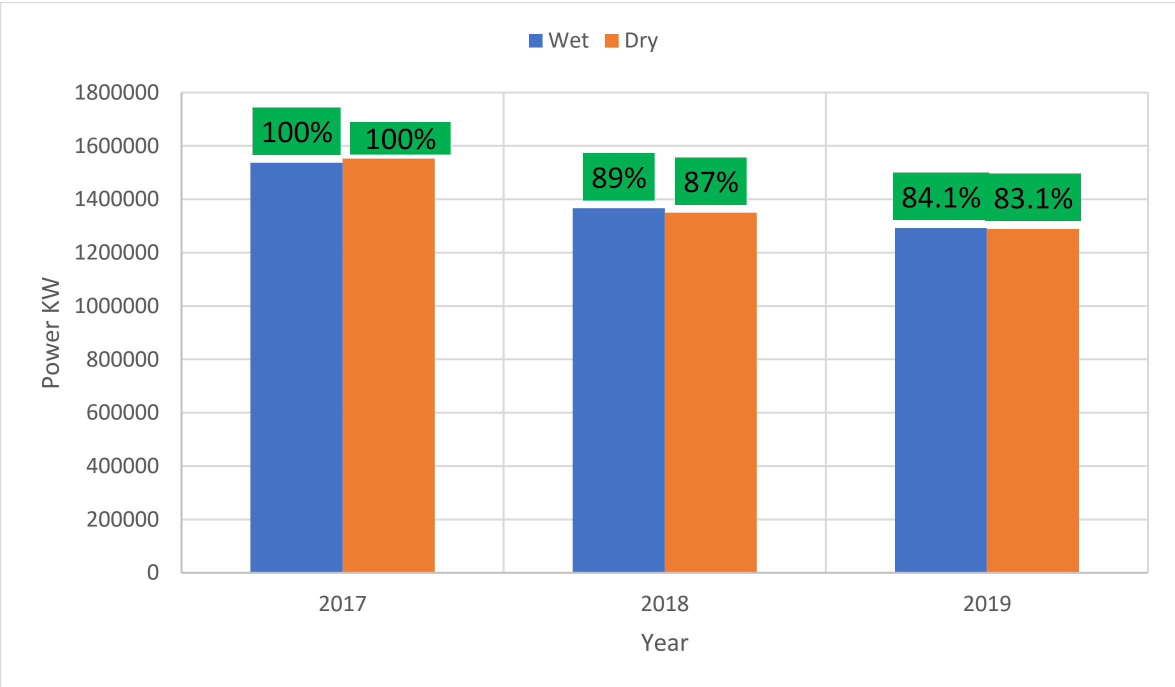


Figure 33 All-season performance drops in percentage.

It was observed from the data during the Dry season UV levels reached up to 14Wm/cm², temperature values reached as high as 32°C and wind speeds reached as high as 2.05m/s. From other researchers, a key factor responsible for PV module degradation has been proven to be prolonged ultraviolet radiation exposure (Dunn, et al., 2013) and also long UV exposure leads to more severe chemical degradation which can affect performance (Liu, et al., 2014). The combination of UV and hot temperatures can cause damage to modules' components, accelerating the rate at which PV systems degrade their performance (Zhang, et al., 2014). However, it has also been proven that higher wind speed promotes a dusty which is one of the key features of conditions associated with the dry season.

In the wet season, UV levels, temperatures, and wind speeds were less than in the dry season, resulting in a slower rate of deterioration per year than in the dry season. In general, in terms of performance deterioration, the wet season is 15kW a year slower than the dry season, meaning that PV systems under dry conditions deteriorate quicker to underperform.

6.1.6 Future projection

From the first monitoring year [2017] for both seasons, the percentage drop in subsequent years can be used as reference point to predict future performance. An analysis of the PV performance trend over the first three years is shown in figure 33, resulting in a projection of future generation patterns. Using 2019 performance as a reference, it is projected that by 2035, which is 15 years from 2019 data shown in figure 34, the dry season performance would drop by 94% and the wet season performance would drop by 78%. This means for the full year; the PV system would only be operating at 14.6% of its expected performance from 2019. When a PV system can only operate at 13.6% of original capacity then it is at the end of the lifespan and need to be replaced because it is wasteful of resources and space.

There is a major downside to having such rapid deterioration of PV system performance depending on the initial performance. Maybe if the PV system performance had been good before then, you wouldn't have had to rely on the feed-in tariff for payment or able to pay the cost of the system.

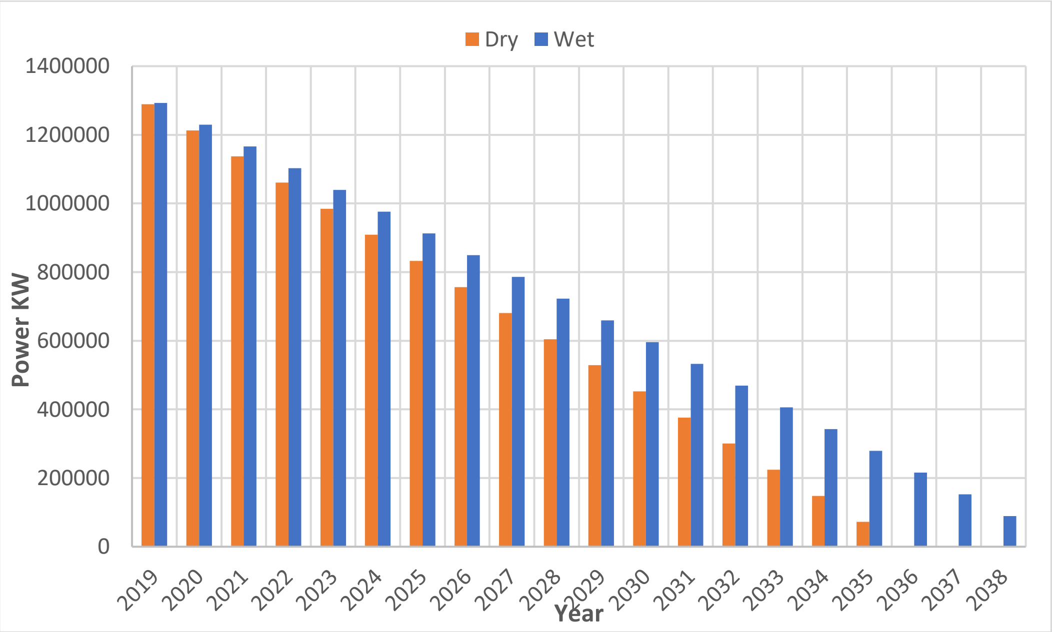


Figure 34 Performance projection of the PV system.

The 86.4 % performance reduction represents the minimum drop in performance in 15 years of the PV system lifespan. It is possible, however, that the reduction could be even greater due to prolonged exposure of PV modules to hot temperatures and UV light that could further impair the performance. The reason for this is that long-term UV exposure can cause more serious chemical degradation of the backsheet of modules that can affect the support structure and performance (Liu, et al., 2014).

With continued operation, there is a greater likelihood of water vapour ingress during the wet season, which can accelerates the corrosion of PV materials and alters performance for longer periods (Park, et al., 2013). On the basis of three years' data, the 86.4 % drop in projected performance which represents the least amount of deterioration in system performance expected over the 15 years.

6.2 High Wycombe -England.

Over the year calendar, the United Kingdom experiences variable weather conditions. High Wycombe is located on the edge of the Atlantic Ocean, with warm waters near the continental influences of mainland Europe, this is a mid-latitude westerly wind belt (MetOffice, 2017). As compared to the west and north of the UK, the east and south are generally drier, warmer, sunny, and less windy than the north and west, with most of these favourable conditions taking place more often during spring and summer (MetOffice, 2017).

High Wycombe is an English town in the northwest of London with an altitude of 204 meters Latitude = 51:68N Longitude = 00:81W. The wind direction, wind speed, temperature and rainfall data are collected monthly from 2015-to 2018. On the campus of Buckinghamshire New University in High Wycombe, three solar PV systems each rated 50kw are located on the roofs of three separate buildings. The university installed the system as part of the carbon reduction commitment started when it published its first Carbon Reduction Implementation Plan back in 2010. The goal was to reduce the University’s carbon footprint (from gas and electricity) by 50% by 2020 from a 2005 baseline (Jack, 2010).

The three systems located on the campus are embedded in figure 36 with South Wing in inserted figure 3, Timberlake in figure 1 and Gateway in figure 2. The systems were installed to supplement the University’s total energy requirement as part of many measures to reduce the carbon footprint. Every system is connected to a data logger that records output power generation on monthly basis. The logger is connected to the computer in the energy manager’s office for remote monitoring. University PV generation data is the primary data source, but additional data is obtained from UK Met Office. This represents the PV system primary data collected for the research.

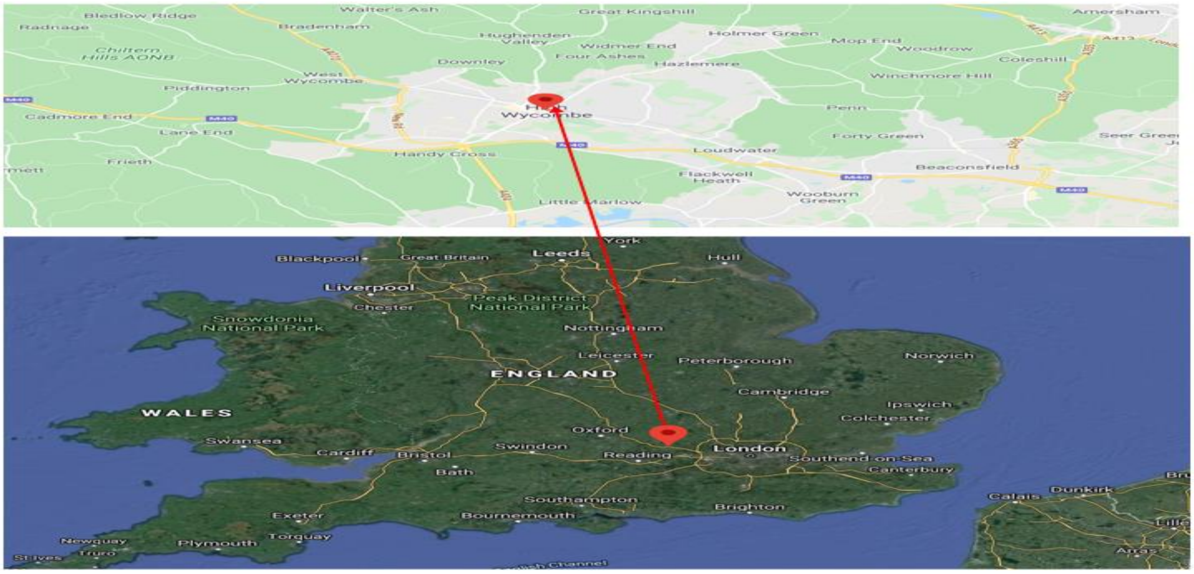


Figure 35 Map of High Wycombe England (Country, 2019)

A meteorological dataset of wind speed, temperature, wind direction, and rainfall were obtained from the United Kingdom Meteorological Office upon request (Met Office). Data represents the weather condition data for High Wycombe, a town in the northwest of London in the UK, as illustrated in figure 35. As a well-known, accurate, and quality source of weather data, the United Kingdom meteorological service can be trusted with this information. In their capacity as a world-leading scientific organization, they are equipped with modern scientific instruments for measuring weather and climate.

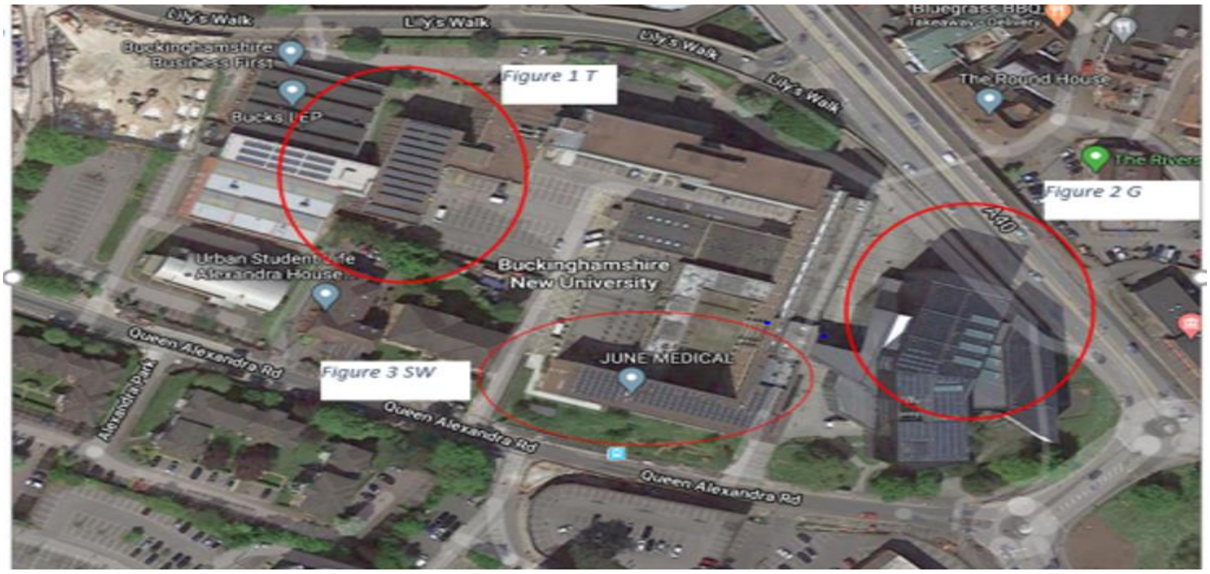


Figure 36 High Wycombe map showing Bucks university layout (map, 2020)

Figure 36 shows the satellite map for High Wycombe town with the University in which the PV system location is highlighted. The geographical layout of high Wycombe is unique due to the general layout of the area which is a vital detail to take into consideration in the analysis. The three systems on campus, each of which is located at a different location and experience different conditions owing to the environment in which they are located.

6.2.1 Solar potential for high Wycombe.

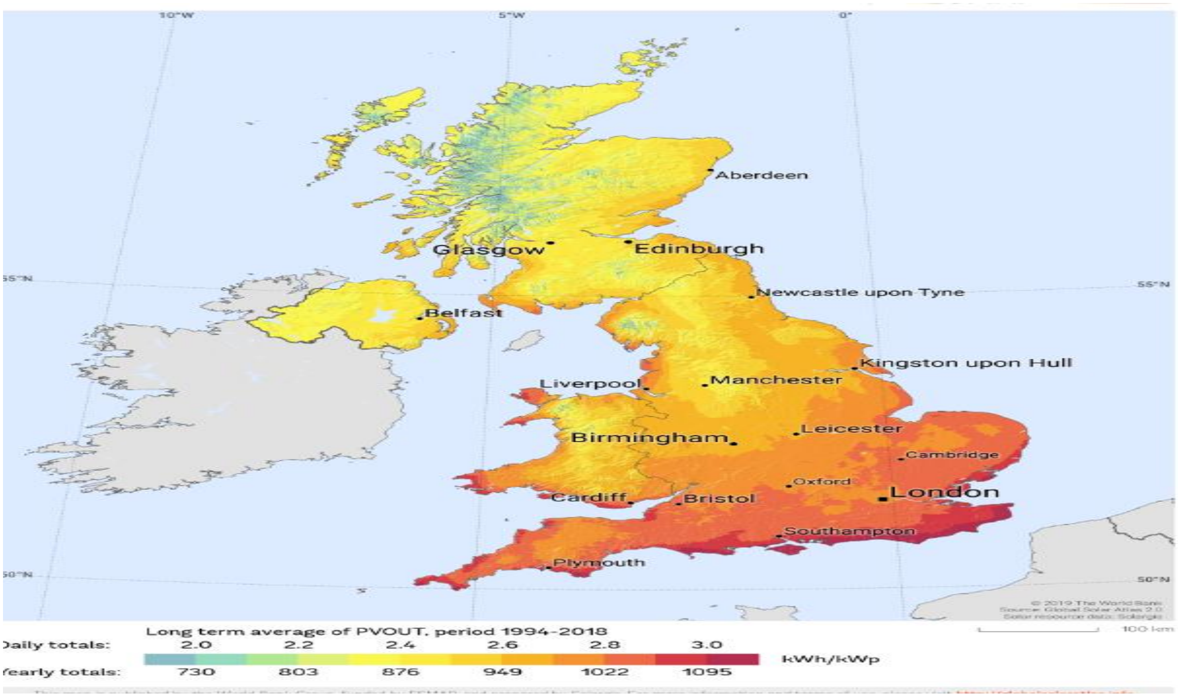


Figure 37 Solar potential map for the United Kingdom (Solargis, 2019).

Solar power potential shows counties in southern England have led the way in terms of the level of solar potential. A map of the United Kingdom's solar potential is shown in figure 37, which shows some counties are using their solar power options to the fullest, while others are not yet taking advantage of the available capacity (Whitlock, 2018).

High Wycombe located in the south of England with between 2.8 kWh/kwp to 3.0 kWh/kwp daily and 1022kwh/kwp to 1095kwp/kWh year levels of solar potential in the county as shown in figure 37. The level of solar potential, however, is subject to daily weather conditions, which is one of the reasons for the difficulty in predicting or estimating solar PV performance accurately during the day. Due to the higher solar potential in the south of the United Kingdom than the north, performance variations may exist between a system in the northern and southern regions.

6.2.2 Climate seasons of the location.

As its name suggests, High Wycombe is found on the northwest side of London in the region of hilly terrain. The town was once famous for its char-making industry and was named the furniture capital of England. As a thriving market town, High Wycombe has Tuesday as market day, which attracts traders and buyers. It is true that there are four seasons in England, and High Wycombe is no different from the natural seasons of the UK; the four usual seasons are summer, winter, autumn, and spring. During the summer months, the temperatures tend to be the highest, and it can also be the driest of the seasons with sporadic rainfall.

Winter starts from December to February; this is the coldest month of the year with shorter daylights. It can be a mixed bag of conditions in United Kingdom during winter, where areas near the coast tend to be warmer than those away from it (MetOffice, 2022). A spring season begins in March, when the days become longer, warmer, and the weather becomes quite calm and dry. There is much difference in temperature between the day and night. Autumn from September to November, with shorter daylight hours and stormier weather conditions, the temperature gets cooler.

Figure 38 shows the weather conditions pattern for High Wycombe for three years consisting of rainfall, ultraviolet radiation, wind speed and temperature during the system generation data. It can be seen that the overall pattern shows that most of the rainfall over the three years has been under 120mm, with wind speeds increasing and decreasing.

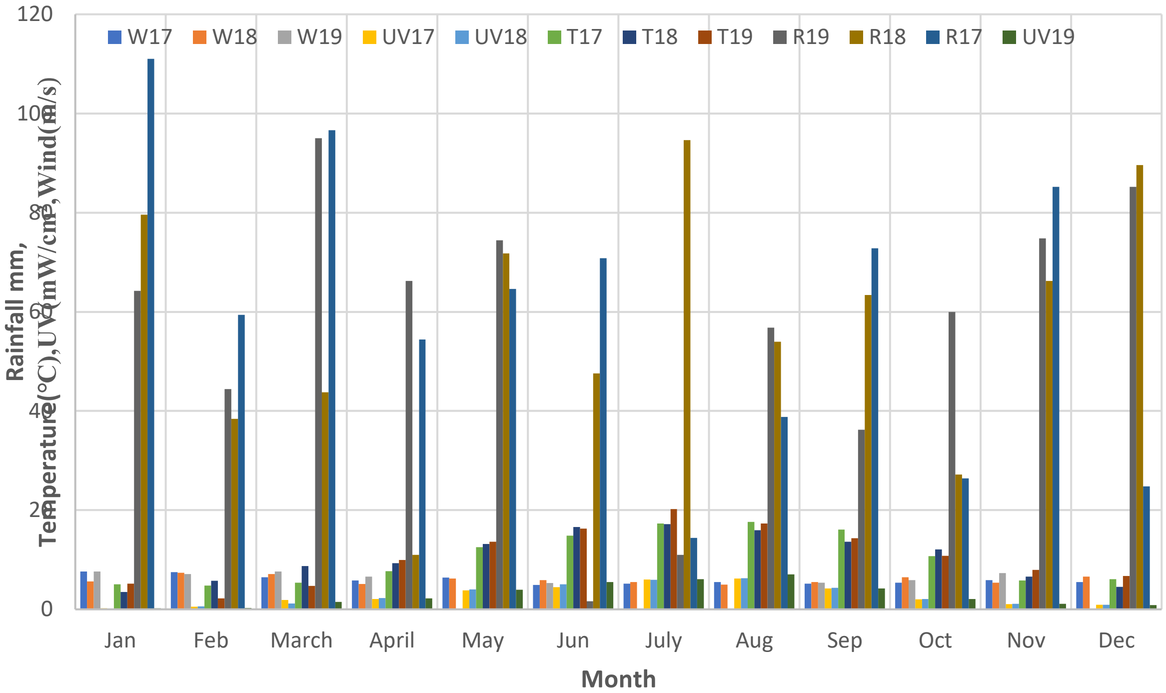


Figure 38 Climate condition for all season

Graph definition of terms.

- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019

6.2.3 Weather conditions effect on PV system energy generation.

The PV system performance over three years under different conditions is shown in figure 39. Different conditions associated with different seasons affect performance over the different seasons. The peak performance occurs when rainfall was low(14.4mm), at the peak of ultraviolet radiation (7mw/cm²) and a minimum wind speed (0.1m/s).

The rainfall, wind, temperature, and UV are correlated. Throughout the calendar year the ultraviolet tend to increase with increasing temperature and decreasing rainfall. A peak wind speed occurred in March and November when rainfall was at its peak.

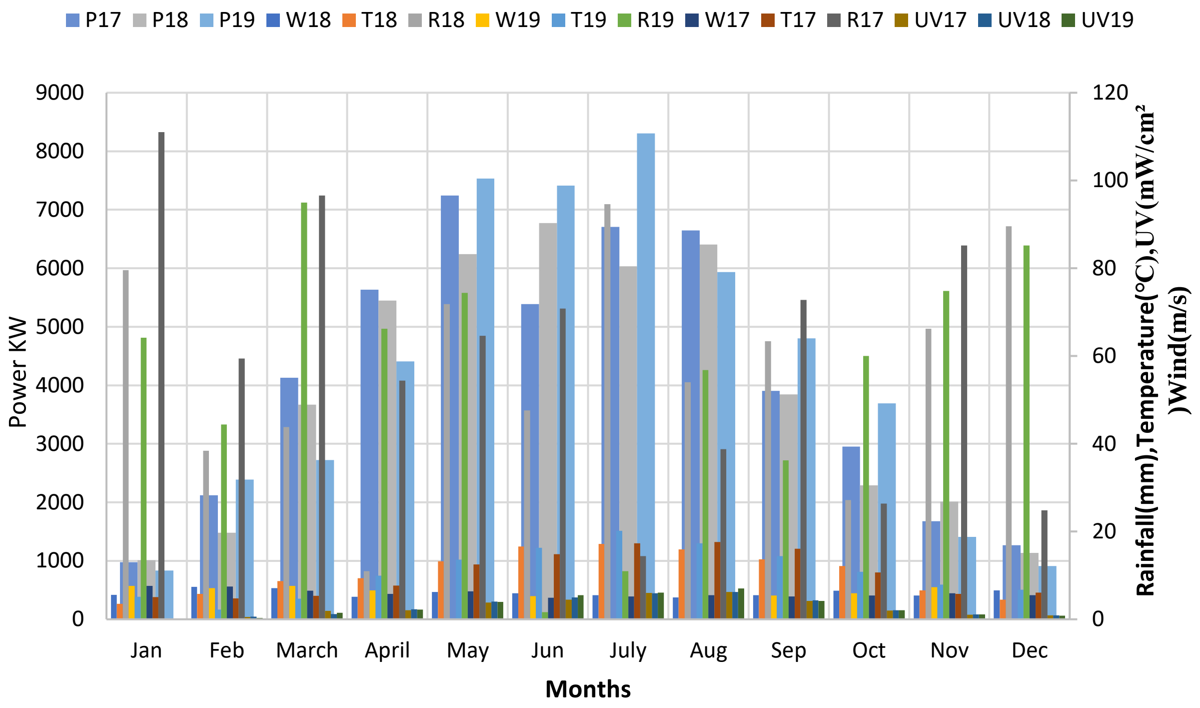


Figure 39 Performance against temperature, UV, rainfall, and wind speed.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- R17= Rainfall 2017, R18=Rainfall 2018, R19= Rainfall 2019
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

6.3.4 Seasons breakdown of PV system energy generation performance.

In this section of the study, the four natural climate seasons of the United Kingdom are used to investigate the performance of PV systems in each season and the effects of seasonal conditions on their energy production. Below are the analyses of the seasons which are spring, summer, autumn, and winter.

(i) Spring season

The spring weather can vary from warm and sunny to cold and rainy. Temperatures in the spring season can rise as high as 18°C during the day and drop as low as 6°C at night (MetOffice, 2022). A heavy cloud cover often covers the sky in March, and the season is characterized by short rainstorms and bright sunshine.

In figure 40, the higher temperature for the spring season ranges from 9°C to 13°C with intermittent rise and fall of rain activities. The minimum rain activities often happen in April. In this season, wind speeds can reach as high as 6.4 to 7.6 m/s due to the regular rainfall. This results in lower temperatures and UV radiation. The system performance for the spring season improved towards the end of the season, which is the transitional period into the summer. At this point, the ultraviolet radiations begin to increase while wind speed and rainfall dropped.

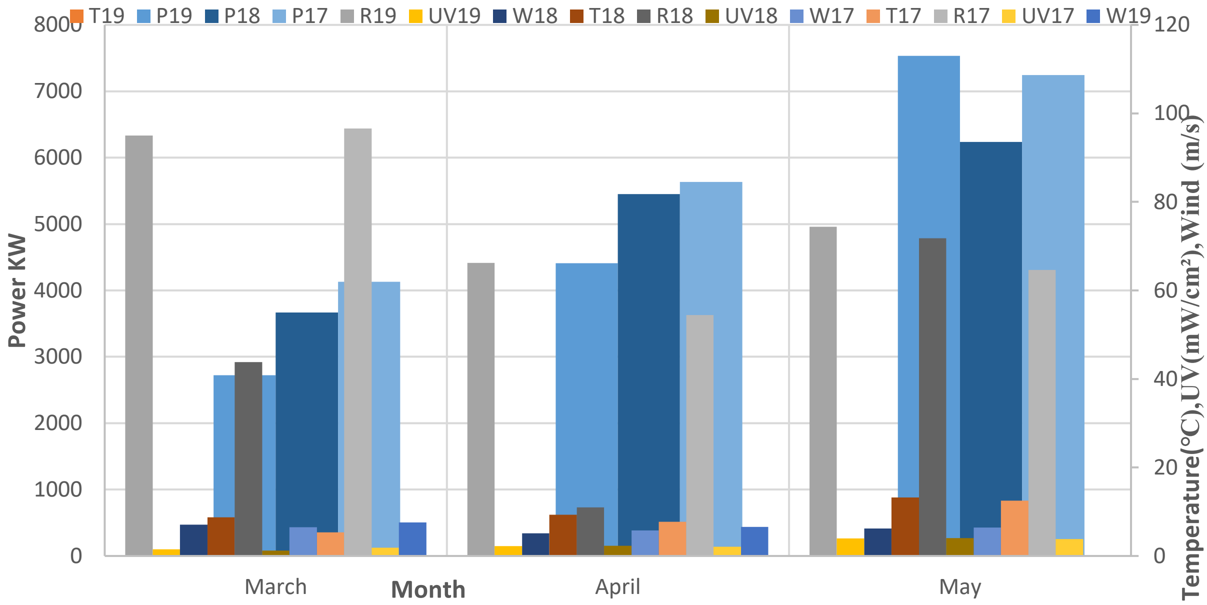


Figure 40 Performance under temperature, UV, rainfall, and wind during the spring season.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

(ii) Summer season

The summer season is the peak of sunshine, with long days and temperatures between 15°C and 23°C when the wind speed is calmed and there is little or no rainfall. The warmest month of the summer is July during which the temperature peaks, but the temperature normally decreases in August by a couple of degrees (MetOffice, 2020). As can be seen in figure 41, the PV system performs well under different weather conditions, ranging in temperature values from 16°C to 21°C under various weather conditions.

Consequently, this condition may result in an increase in ultraviolet radiation from 5.5mW/cm2 to 7.0mW/cm2. The summer experienced slight rainfall activity just above 90mm, with an exceptionally low wind speed of 3m/s descending to zero. Throughout the three-year period, the system performed best during July when ultraviolet radiations were high, rainfall was low, and wind speeds were low as observed in figure 41.

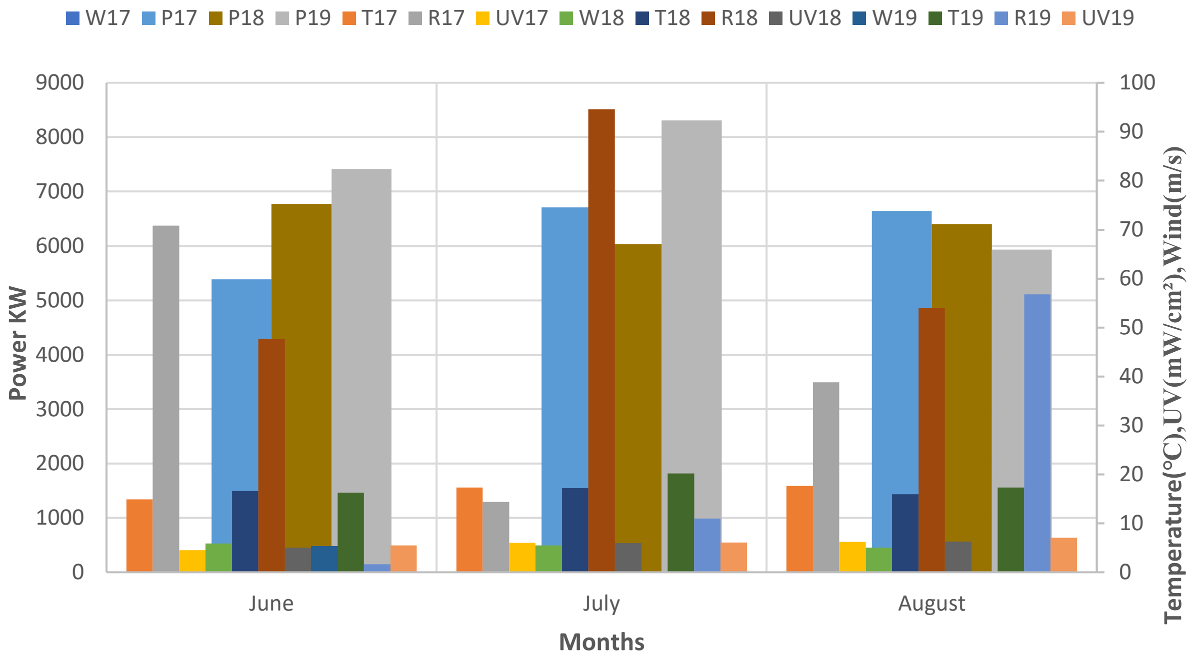


Figure 41 Performance under temperature, UV, rainfall, and wind during the summer season.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

(iii) Autumn season

This period is a good time to enjoy the warm summer weather during the first month of autumn, before the temperatures begin to drop sharply in October. There is a tendency for Autumn to be a rainier season, with temperatures starting high (20°C) and dropping to lows (10°C) during this time period.

A general increase in rainfall from the start to the end of the season can be seen in figure 42 during the course of energy generation. The rise in rainfall resulted in a decrease in temperature levels from 15°C to 8°C and ultraviolet radiation levels from 4.2mW/cm² to 1.09mW/cm². In spite of this, wind speed has continued to increase from 5m/s to 8m/s over this period. Due to increased rainfall and decreasing ultraviolet radiation, performance during the season continues to drop towards the end of the autumn season.

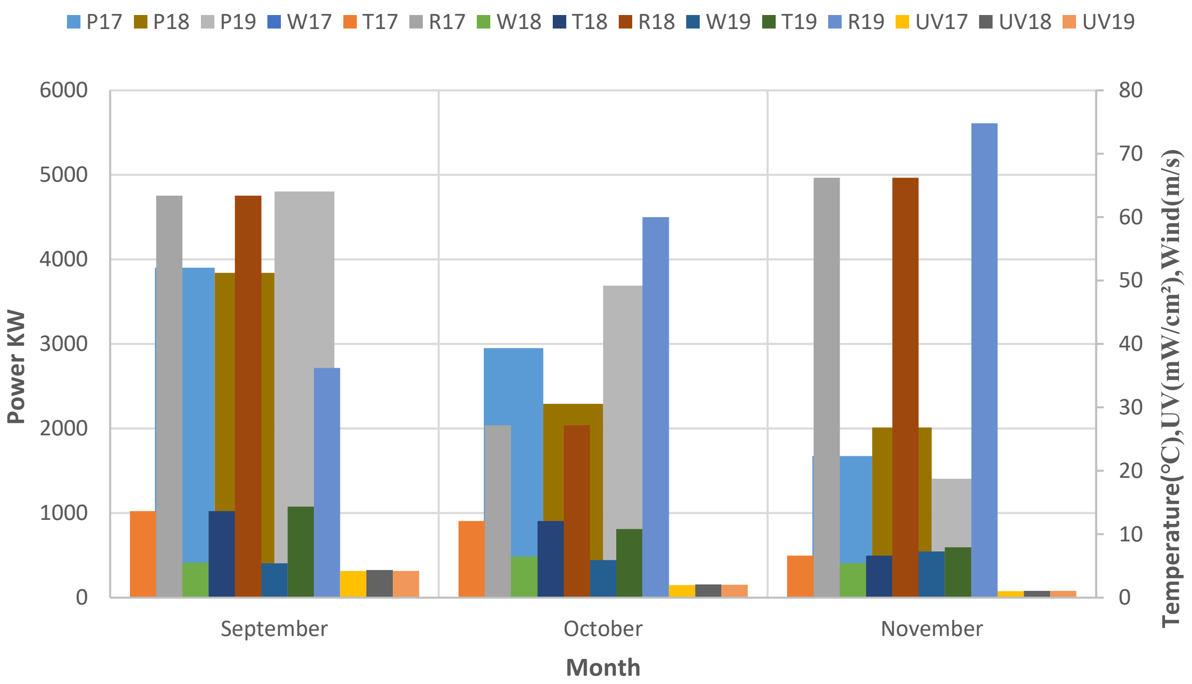


Figure 42 Performance under temperature, UV, rainfall, and wind during the autumn season

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

(iv) Winter season

There are periods of cold weather and sometimes rain in the United Kingdom during the winter. The average temperature ranges from 9°C to 5°C and it is also possible to experience freezing temperatures and snow during the winter season.

Based on the three-year measurements of the system's energy production, figure 43 shows the actual weather conditions for each period of time. Temperatures of under 7°C were recorded at the beginning and end of the winter season, when transitioning between seasons. Over the course of the year, the low ultraviolet radiation levels were recorded, ranging from 0.1mW/cm2 to 0.89mW/cm2 during this season which is the minimum levels over the calendar year.

As a result, the performance of the system across the winter season continues to drop from the transition period between autumn and the mid-season. When rainfall dropped from 90mm to under 40mm at mid-season, performance improved, and ultraviolet radiation levels increased by 0.4mW/cm2.

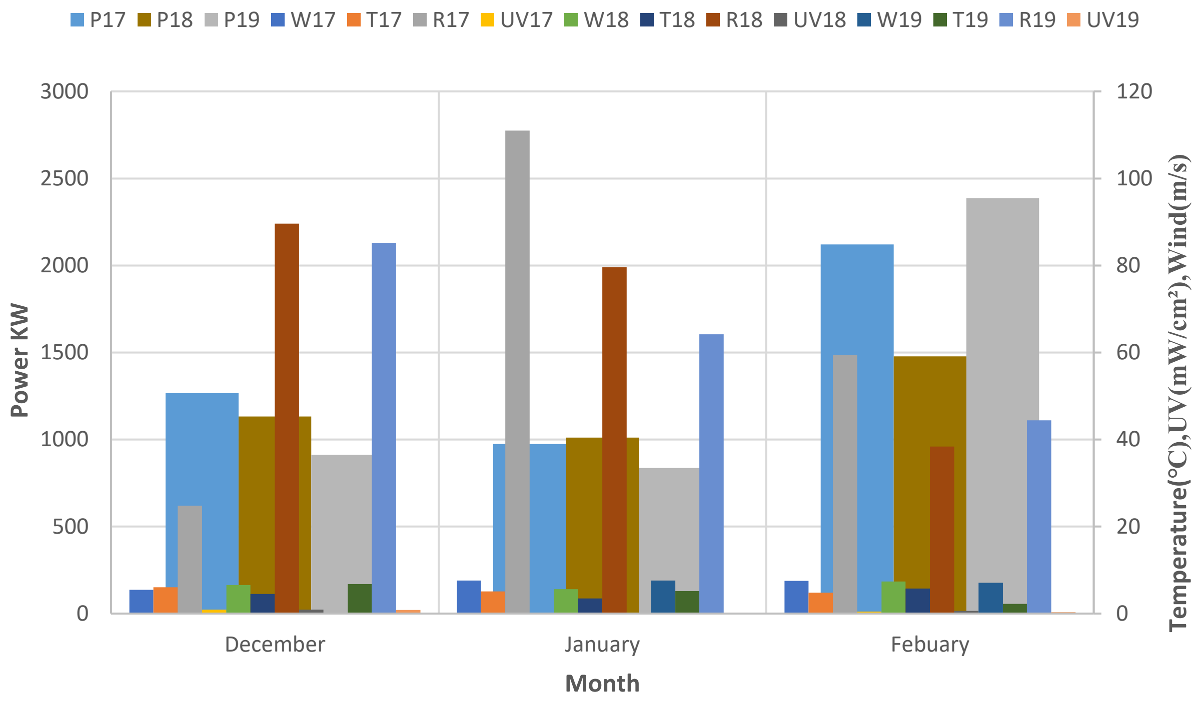


Figure 43 Performance under temperature, UV, rainfall, and wind during the winter season

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

6.3.5 Discussion of Results.

The solar potential for high Wycombe in the United Kingdom is between 2.8 kWh/kwp to 3.0 kWh/kwp daily and 1022kwh/kwp to 1095kwp/kWh yearly. Comparatively speaking, the solar potential of this country is decent, but it's not quite as good as in other hot countries like Ghana or India.

As shown in figure 40, the spring season has continued to improve since March as rainfall dropped from 96.6mm to 54.4mm and wind speed followed the same pattern during the same period of time. In addition, the continuous decrease in rainfall causes the temperature to rise from 9.34°C to 12.53°C. In accordance with the correlation between ultraviolet radiation and temperature, UV values increase from 2.1mW/cm2 to 3.8.1mW/cm² as temperature rises.

The performance peaked at the end of the spring before it transitioned into summer. The last half of the spring season saw increased ultraviolet radiation levels as wind speed dropped to near zero; from six meters per second (6m/s) to 0.1 meters per second (0.1m/s) as energy generation increased. There is an average drop of 8.35% per year in performance compared to the 2017-year performance.

The summer started with different variations of rainfall patterns for different years. Despite the irregular rainfall levels in 2018, 94mm of rain was recorded in 2018 than the previous year (47mm). Overall, performance has improved with an increase in UV levels from 5.5mW/cm² to 6.1mW/cm² and a continued drop in wind speed from 4m/s to 0m/s into the mid-season as shown in figure 41. After July, rainfall increases with wind speed and ambient temperature drops with UV levels affecting performance as summer ends and autumn begins. During the summer, the average performance dropped by 2.5%.

Figure 42 also shows a continuous fall in performance as rainfall increased to 74 mm and the temperature dropped from 10.81°C to its low of the season (7°C). The ultraviolet radiation levels continue to fall with decreasing temperature; however, wind speeds continue to rise up to 6.6 meters per second(6m/s). Compared to initial values of system generation in 2017, the performance has dropped by 4.5% per year for the three years.

Winter started with the continuous falling of rain from 89mm to 38mm throughout the period as shown in figure 43. The wind speed peaked at 7m/s during this period and plateaued up to the mid-season as the temperature remained at lower levels (below 6°C). The performance continues to drop until halfway through the season (January). Weather conditions improved in the second half of the season as rainfall decreased and ultraviolet radiation slightly increased from 0.2mW/cm² to 0.3mW/cm², with minimal changes in temperature and wind speed. The average performance drop for the winter season over the three years is 6.5% per year.

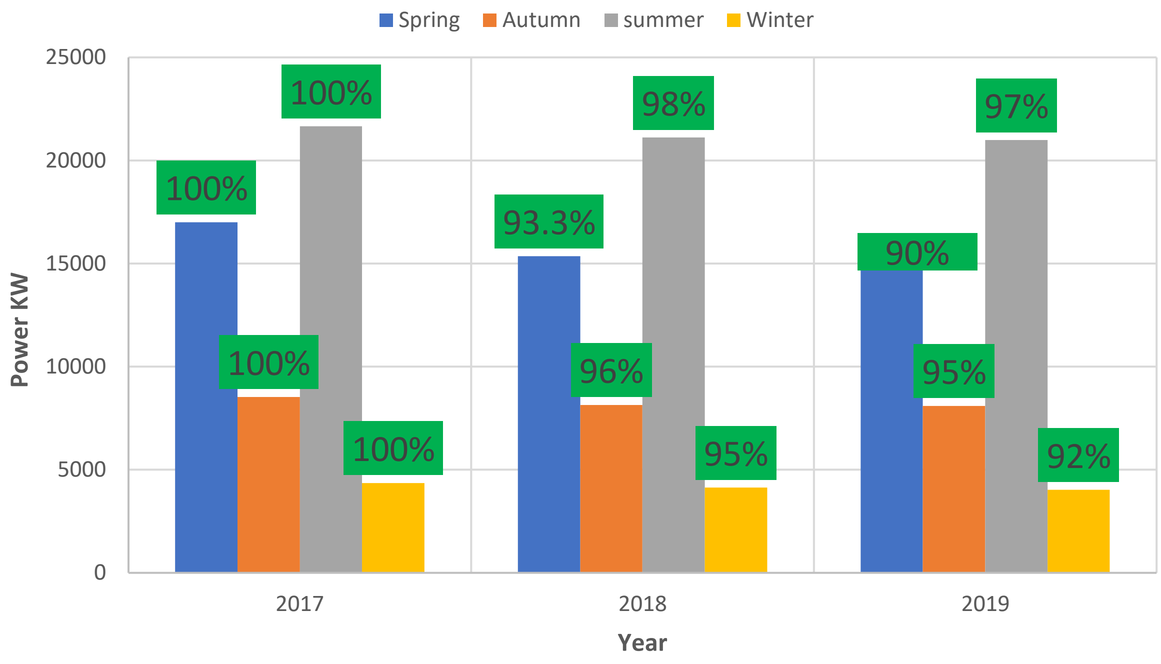


Figure 44 All-seasons performance drops in percentage.

6.3.6 Future projection.

The results of the activities in weather conditions can be used to predict the performance of the PV system in subsequent years based on the percentage drop for each season from the first monitoring data [2017]. An illustrated projection of PV generation patterns for individual seasons is generated in figure 45 based on the first three years of PV performance data.

Performance projections from the last data monitoring (2019) suggest that by 2034, or 13 years from now, the spring season performance would reach near 0%. The performance for summer would drop to 62.5%, autumn would drop to 32.5% and winter would drop to 2.5%. This means that the PV system would operate at 47.9% capacity from the 2019 performance levels.

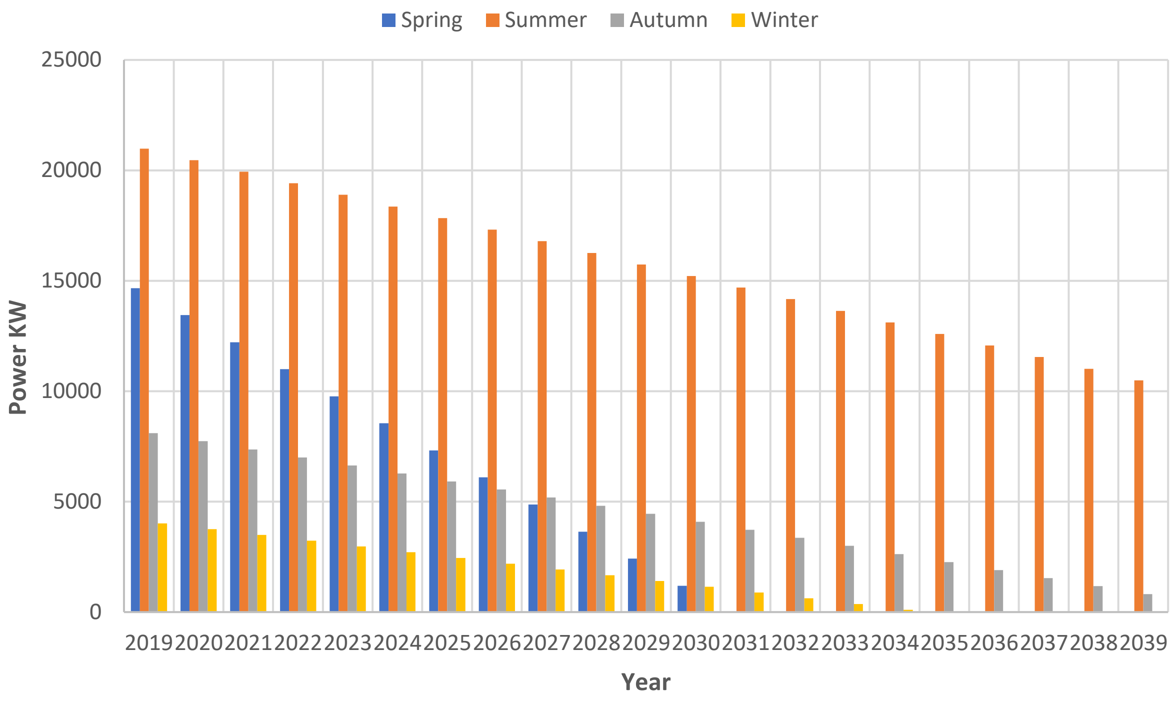


Figure 45 Performance projection of the PV system.

The 2034 projection performance means that the PV system performance would have dropped by 52.1% in 15years According to the first three years of performance projection. The performance drop is the least expected, but the extent depends on the levels of variance in input conditions. Compared to the summer and autumn, high-level rainfall is expected to cause most deterioration in performance during the spring and winter.

The rainfall levels for the spring reached a maximum of 96.6mm to a minimum of 64.6mm with an extremely high wind speed up to 4m/s. The winter also experienced similar rainfall activities up to 111mm with high wind speed up to 3.7m/s. The rainfall and wind speed are the most dominant conditions during the spring and the winter. From other studies wind speed can provide some cooling around the PV panels for temperature management; In the spring and winter, however, there is the least levels of temperatures, so high wind speeds can have a detrimental effect on system performance.

Several studies have found rainfall to be the main source of water ingress into PV panels. This can be detrimental to performance by accelerating the degradation of the encapsulant to affect PV system performance (Rao, et al., 2014). Water vapour ingress on the PV module can accelerate the corrosion of the PV panel material (Park, et al., 2013) which tend to affect the module materials. During the winter and spring season, these conditions were evident and can consider as key factors resulting in an increasing deterioration of performance.

6.3 Chennai- Goomudipoondi- India

Goomudipoondi is a village in Chennai the capital city of Tamil Nadu state in the south of India on the coromandel coast of the Bay of Bengal. Goomudipoondi which is the PV system location is 45 km from Chennai. Goomudipoondi is 11m above sea level and located at 13.40° N 80.15° E (Meteo365, 2020). According to Mete365 which is a local weather reporting paper. The entire year, the rain can fall for several days (59) and collects up to 1391.5mm with the lowest rainfall month. February and November are the months with the most rainfall for over eleven days and accumulates 407.4mm (16") of precipitation. As a natural hot climate, Chennai has an average temperature of 36.9℃ in June and around 27.5℃ in December, while its coldest month is December with an average temperature of 28.5 to 21.9℃.

The 500MW solar power at Goomudipoondi village, at Tiruvallur district and in the state of Tamil Nadu, India. The ground-mounted PV system was inaugurated in November 2016 and the monitoring of the system began in 2017. The system has an estimated performance ratio of 71.30% but in practice, the actual performance of 73.13% represents 1.83% better performance than expected. According to current practice, the plant in practice is performing slightly better than estimated, indicating exceptional performance during its first three years.

Figure 46 The ground installed system (VE, 2020)

The system is made up of 15560 modules of Trina polycrystalline with a total area of **27269m^2** and three Gamesa Inverter E-1.3MVA/E-1.4MVA with a rated voltage of 570V -920V. There are two arrays of PV modules in the plant, the first of which has 10680 modules made up of 20 modules executed in series and 534 modules executed in parallel. The second array of 4880 consists of 20 modules in series and 244 parallel strings with array operating characteristics of 50º.

6.3.1 Solar potential for Chennai.

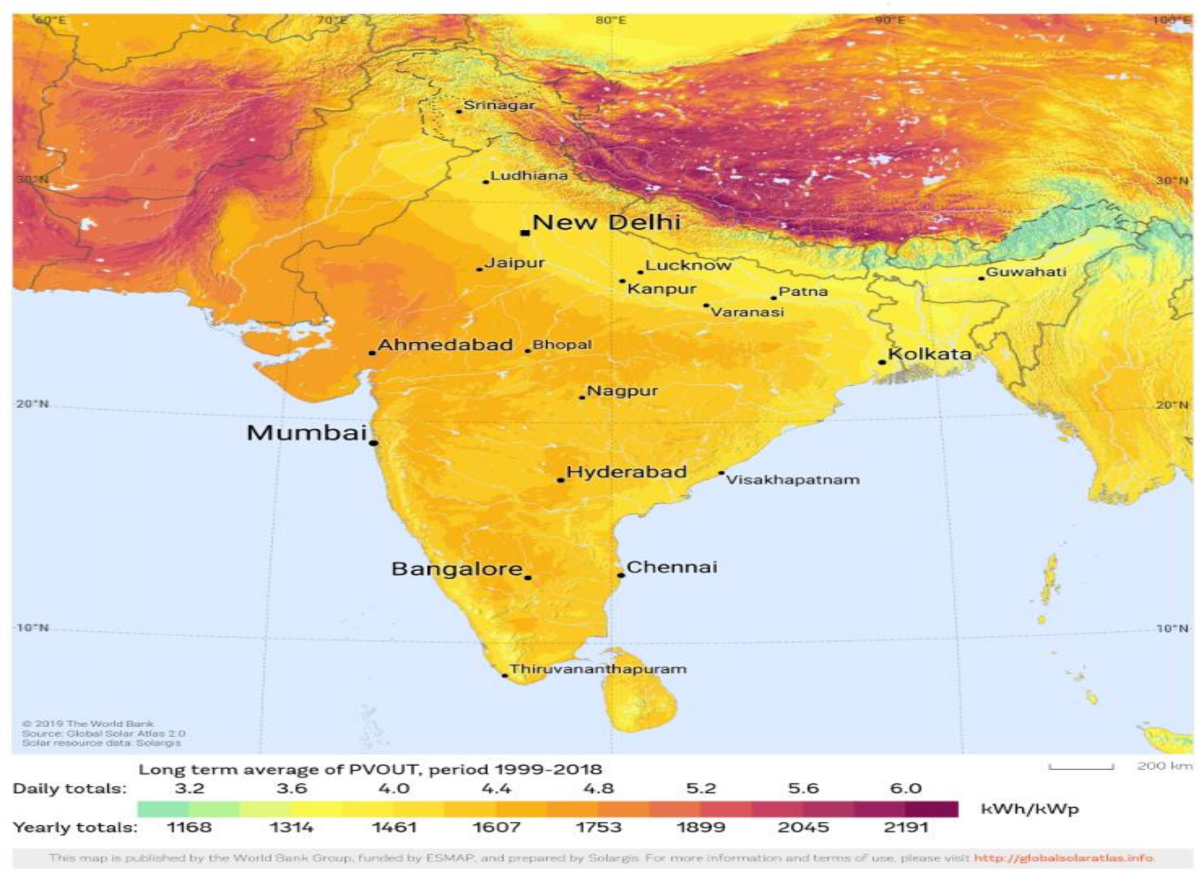


Figure 47 Solar potential map for India (SOLARGIS, 2019)

As compared to most Western countries, India's solar potential is exceptionally good than most countries. The solar potential for the system location in Chennai-India from figure 47 of the solar potential map from solargis shows a satisfactory level of solar potential. The good solar potential levels range between 4.0 kWh/kwp to 4.4kwh/kwp daily and 1461kwh/kwp to 1607kwh/kwp per year but this is subjected to daily weather conditions, however, it is not guaranteed. As a result of this, Chennai has a consistently high solar potential throughout the year, which manifests in the higher level of irradiance and actual PV performance for the first three years following the installation of the solar PV system.

6.3.2 Climate seasons of the location.

Goomudipoondi is a town in Chennai which is located on the coast. The general climate associated with this part of India is often hot and humid. Chennai has three major seasons: winter, summer, and monsoon. The winter months are November through February, the summer months are March through June, and the monsoon season runs from July to October.

As shown in figure 49, PV energy generation data were generated under a variety of weather conditions. While there is a minimum rainfall period between January and May, temperatures rise in the middle of May before the rain begins as seen in figure 48. After reaching its peak in April, the UV experienced a slight decrease between April and August, followed by intermittent rises and falls until the end of the year. As a result of the increased in rainfall, temperatures and UV radiation levels decreased.

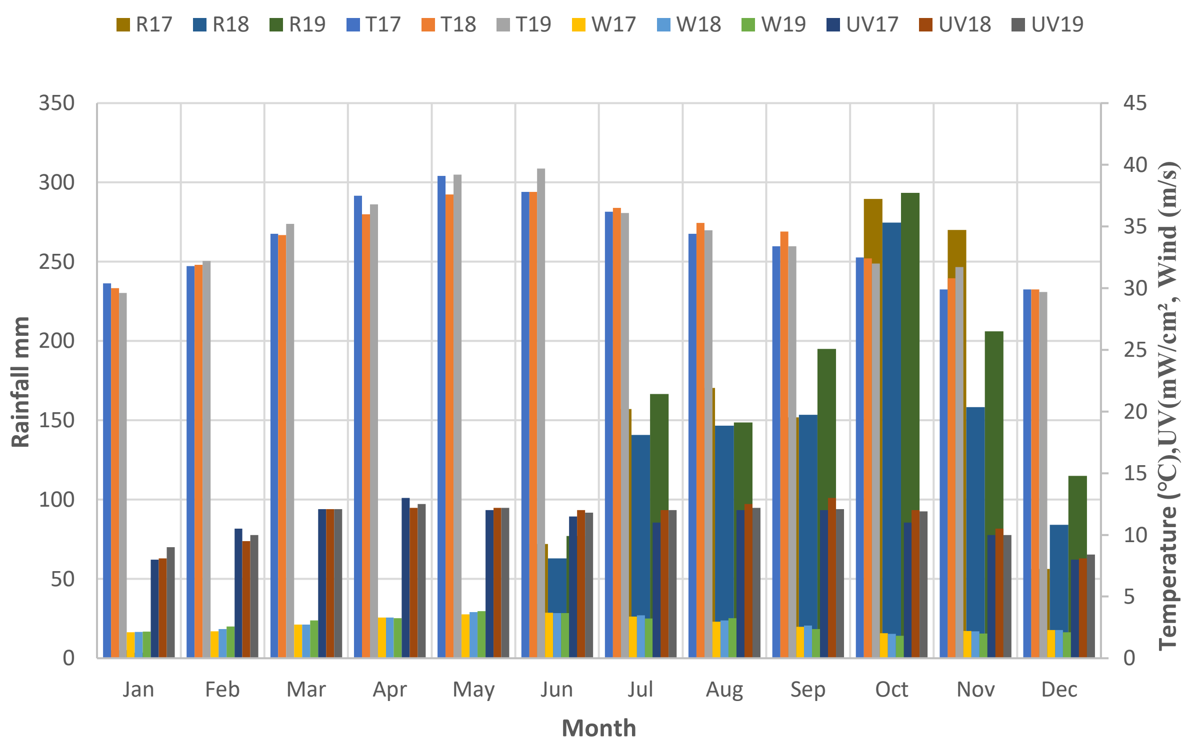


Figure 48 Climate conditions for all seasons.

Graph definition of terms.

- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019

- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019 W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

6.3.3 Weather conditions effect on PV system energy generation.

The purpose of this section is to compare the weather conditions pattern over three years and analysis the energy generation performance of the PV system. Analysis of energy generation performance in relation to the weather conditions is shown in Figure 49.

Performance decreased as temperature increased, and at the same time wind speed increased, resulting in a decrease in UV and system performance. The performance under rainfall shown in figure 50 shows that the energy generation performance of the system decreases with increasing rainfall. There is also a correlation between rainfall and UV, temperature, and wind speed. An increase in rainfall resulted in a decrease in wind speed, temperature, and UV radiation.

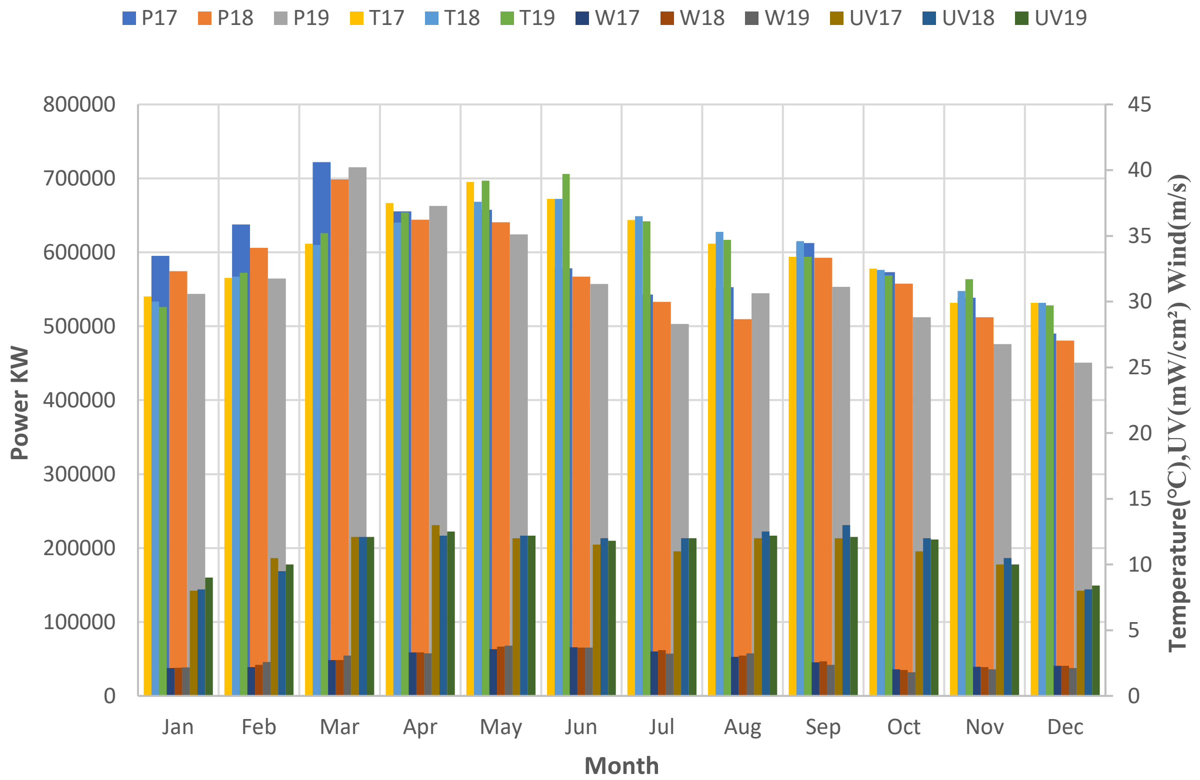


Figure 49 Performance against temperature, ultraviolet radiation, and wind speed.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.

- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

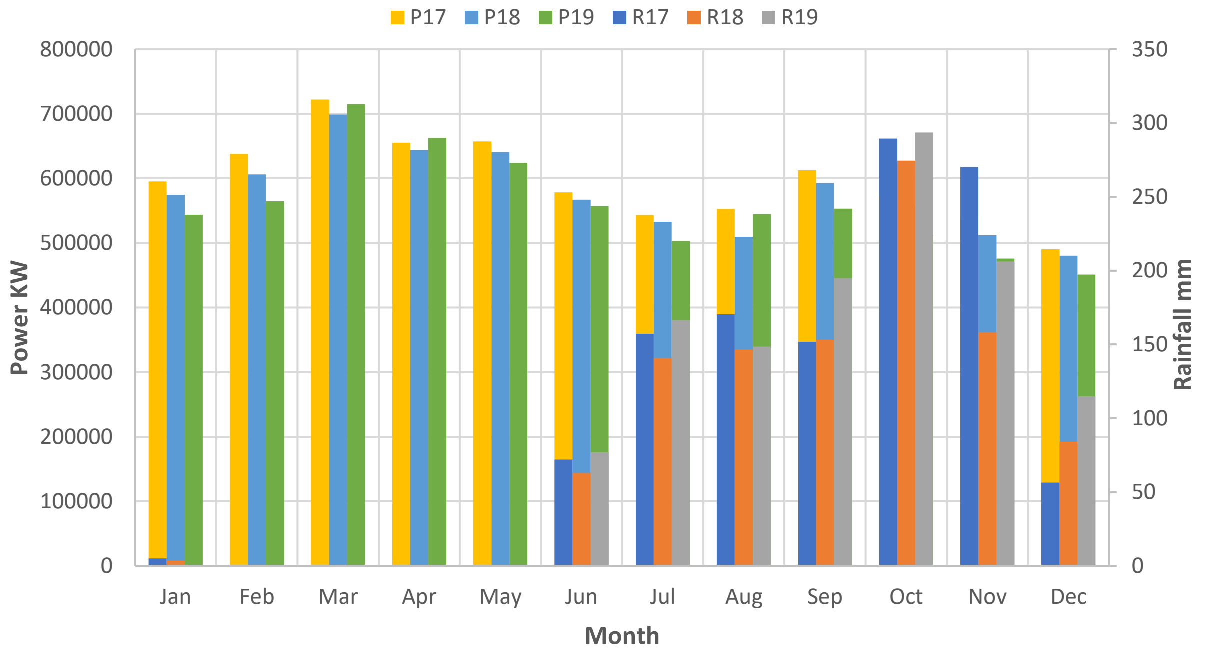


Figure 50 Performance under rainfall

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019.

6.3.4 Seasons breakdown of PV system energy generation performance.

From the available data collected, three seasons to be considered when investigating PV system performance for this location. The performance of the PV system will be study against the weather conditions during winter, summer, and monsoon.

(i) Winter season

The winter season starts from November to February. This time of the year there is a natural cold wind coming from north India during the winter months. The winter in Chennai features cold waves with temperatures ranging from 20°C to 25°C (IndianTimes, 2021).

A minimum temperature of 26.7°C is recorded in Chennai during the winter season from 2017-2019, similar to the temperatures that are recorded in other countries during the summer season. When the temperature increases during this period, ultraviolet radiation increases so does the amount of energy generated by the system. As can be seen in figure 51, the amount of energy generated by the plants during the season increases as ultraviolet radiation increases. There is also a slight increase in wind speed during the peak performance. During this period, rainfall decreased resulting in a drop in temperature as shown in figure 52, however performance increased as rainfall decreased. During the three years of the project (2017-2019), there have been a bit of dry and wet periods to evaluate the performance of the PV energy generation system.

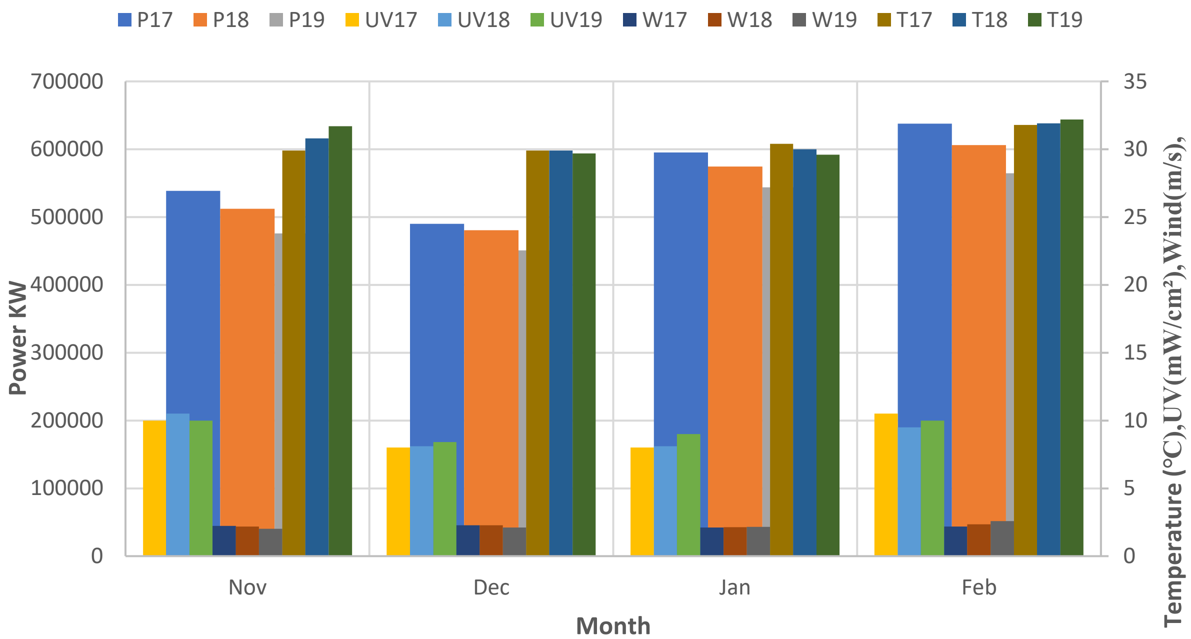


Figure 51 Performance under temperature, UV, and wind during the Winter season.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

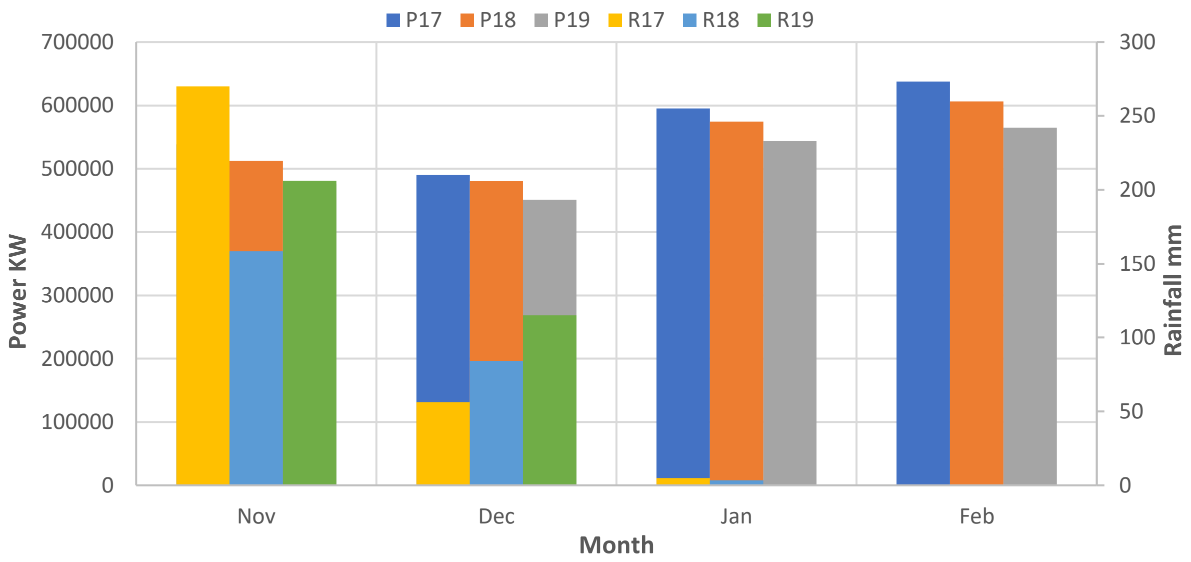


Figure 52 Performance and rainfall for the winter season.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019.

(ii) Summer season

The summer season starts from March to June. Chennai's summer climate is hot and humid with temperatures reaching 40°C in the height of the season. In Chennai, summer is naturally the hottest season. A plot of the PV system's energy generation under all the conditions under investigation is shown in figure 49.

This shows that the minimum temperature during generation for the winter is above 35℃. Increasing temperature causes an increase in ultraviolet radiation, while increasing wind speed causes the radiation to stay flat until rainfall begins. As the temperature increases and ultraviolet radiation changes, performance decreases, generally before rain begins. Monsoon season began with rainfall close to the end of the summer season.

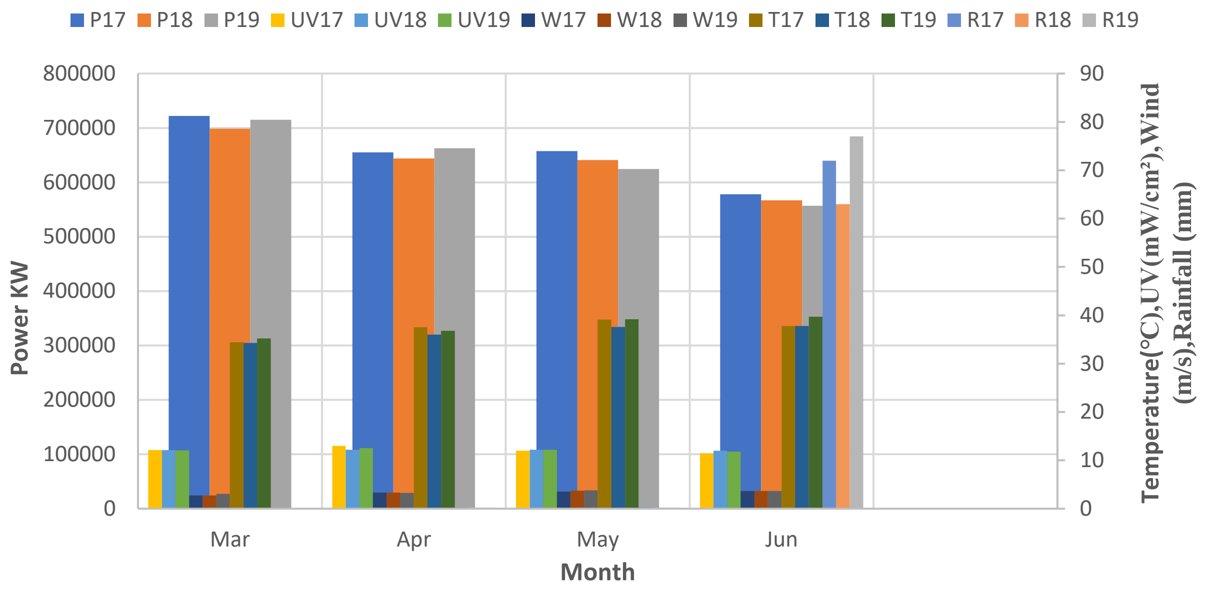


Figure 53 Performance under rainfall, temperature, UV, and wind during the summer season

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

(iii) Monsoon season

The monsoon season in Chennai starts from July to September. A heavy rainy season and strong wings are associated with monsoon season since the PV system location is closer to the sea (IndianTimes, 2021).

Figure 54 shows performance of the PV system under ultraviolet, temperature and wind conditions over the three years. The temperature during this season ranges from 32℃ to 36.1℃, and wind speed decreases with a decrease in temperature. The ultraviolet radiation experienced a slight rise when rainfall was stagnant at about 120mm but decreased slightly with an increase in rainfall from 150mm to 300mm, as shown in figure 54 and figure 55. The monsoon season is the peak of rainfall compared to the summer and winter. A decrease in temperature and a slight decrease in radiation result in decrease in performance, however a slight increase of (1.2 Wm/cm²) in ultraviolet radiation increased the performance. Figure 55 is a good example of correlation of conditions as the system performance continues to increase despite low rainfall (150mm) during the monsoon season as the system performance peaks. However, performance began to decline in September and October as rainfall increased.

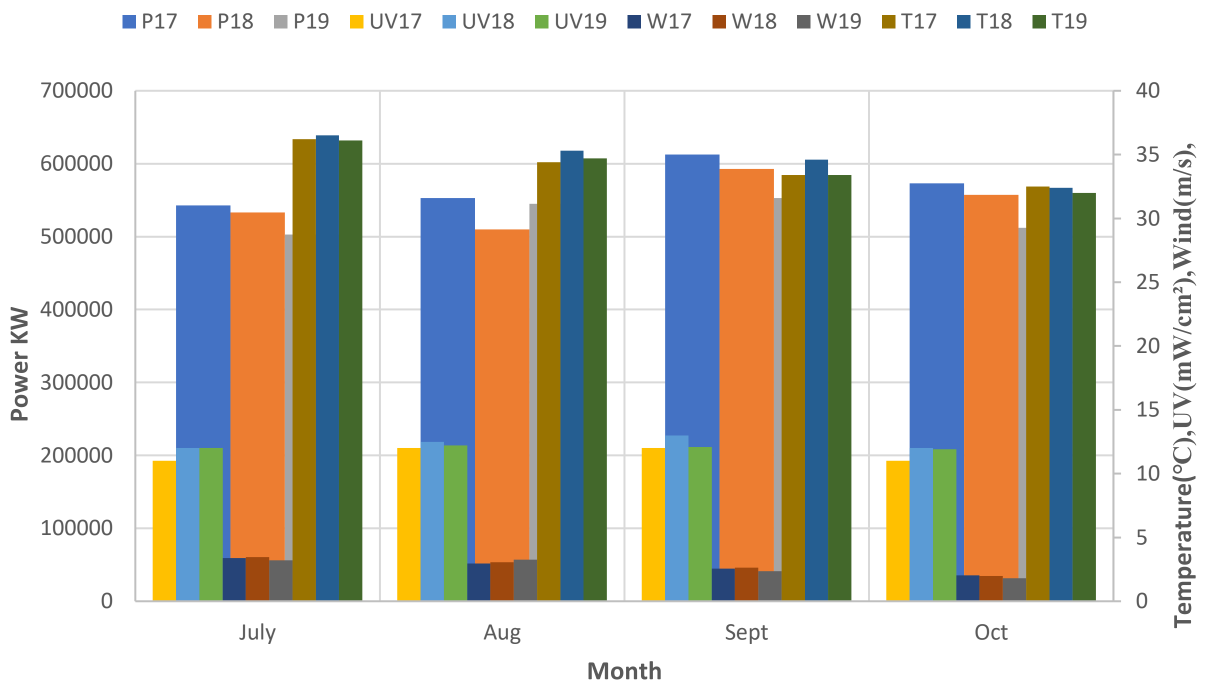


Figure 54 Performance under temperature, UV, and wind during the Monsoon season.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

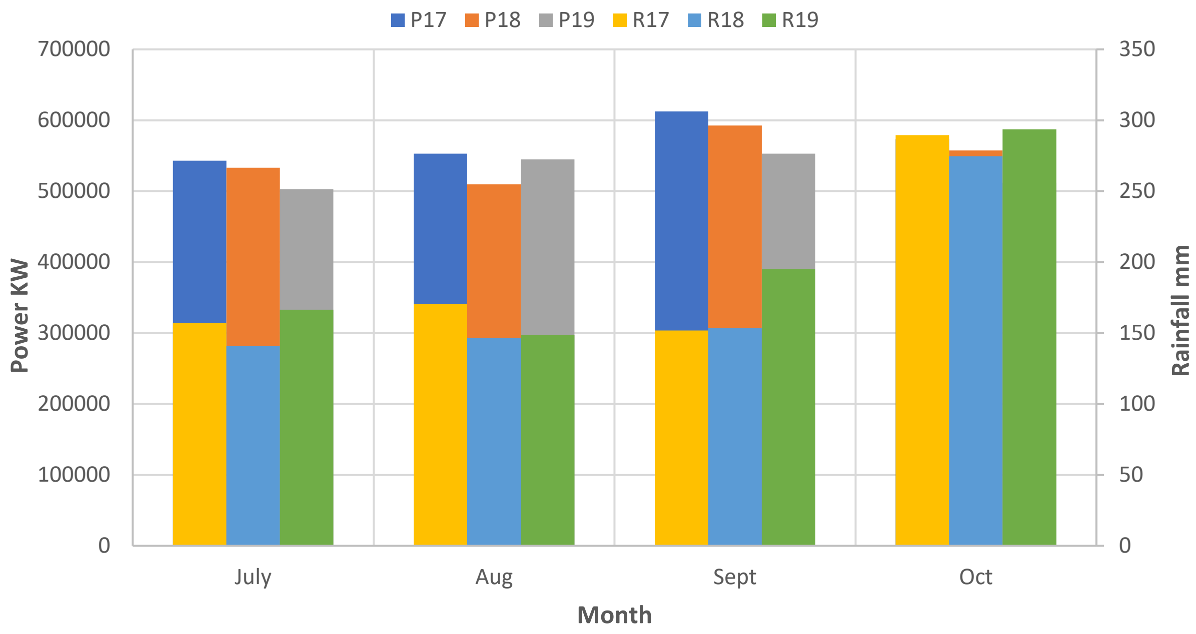


Figure 55 Performance and rainfall for monsoon season.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019.

6.3.5 Discussion of Results.

Three seasons are associated with the climate conditions in Chennai, and each season has distinct levels of conditions that overlap each other. Chennai has particularly good solar potential levels ranging from 4.0 kWh/kwp to 4.4kwh/kwp daily and 1461kwh/kwp to 1607kwh/kwp per year. As a result, PV systems in this climate is expected to perform better when they are operating under the right conditions.

In the winter season, temperatures ranged from 29.6°C-32.2°C, which does not seem to be typical winter conditions in other parts of the world where temperatures can drop below 1°C. The first month of the winter season is often associated with rainfall with a minimum temperature (29.6°C). The correlation between rainfall, performance, and ultraviolet radiation is strong. From figure 50 and figure 49 rainfall period resulted in a decrease in temperature from 31.7°C to 26.6°C and ultraviolet radiation from 10mW/cm² to 8.4mW/cm². After the rain stopped, performance improved by 15.7%, with ultraviolet levels increasing with the temperature increasing. The peak performance occurred at the maximum ultraviolet radiation levels at 10.1mW/cm² when the wind speed increased by 0.10m/s.

The beginning of the summer overlap with some conditions from the Monsoon. The summer is the hottest with the temperature ranging from 35.2℃ to 39.7℃. The rainfall began in the last month of the summer to enter the monsoon season. From figure 49, the peak performance occurred at higher ultraviolet radiation levels at 12.09mW/cm² and a wind speed of 3.06m/s. Since the temperatures continue to rise, the performance dropped by up to 18.8%. Due to a 0.61m/s increase in wind speed and a 0.60mW/cm² drop in UV radiation. A minimum performance of 0.42% is achieved during the summer compared to the peak performance during the winter.

In the first month of the monsoon season, rainfall averaged 140mm levels, but rose to 300mm in the last month. At the beginning of this period, the temperature ranged from 36.1°C to 32°C, with 32°C being the highest. At a minimum rainfall of 150mm, the peak performance occurred during UV radiation peak at 12.10mW/cm². There is a stronger correlation between ultraviolet radiation and performance. There was a decrease in ultraviolet radiation and wind speed as a result of a rise in rainfall to 300mm in the last weeks of the season, which resulted in an 11.3% decrease in performance.

In figure 49, decline in performance is observed from the first-generation year (2017) to all subsequent years. The performance from 2017 to 2019 in the summer was 13,9% and 15.4% better than the monsoon and winter seasons, respectively. There is a range of influences on performance that are observed in all three seasons, which are caused by a mixture of different conditions. The percentage drop from 2017 performance up to 2019 for summer is 189kW, winter is 274kW and monsoon is 256Kw. This shows that PV modules are more susceptible to Chennai winter conditions and therefore more likely to deteriorate faster follow by the monsoon and the summer.

During the winter season, there was half rain and half dry weather, with rainfall of up to 250mm in the first month and 100mm in the second month. In contrast, in the last half of the day it becomes dry, resulting in higher wind speeds from 2.01m/s to 2.58m/s and ultraviolet radiation from 8.4mW/cm² to 10.5mW/cm². In the winter season, the temperature ranges from 29.7°C to 32.2°C, which is excessively high for the time of year. In summary generation performance suffered in the first half of the winter season due to low ultraviolet radiation levels and wind speeds, but performance improved in the dry half of the winter season due to higher UV levels.

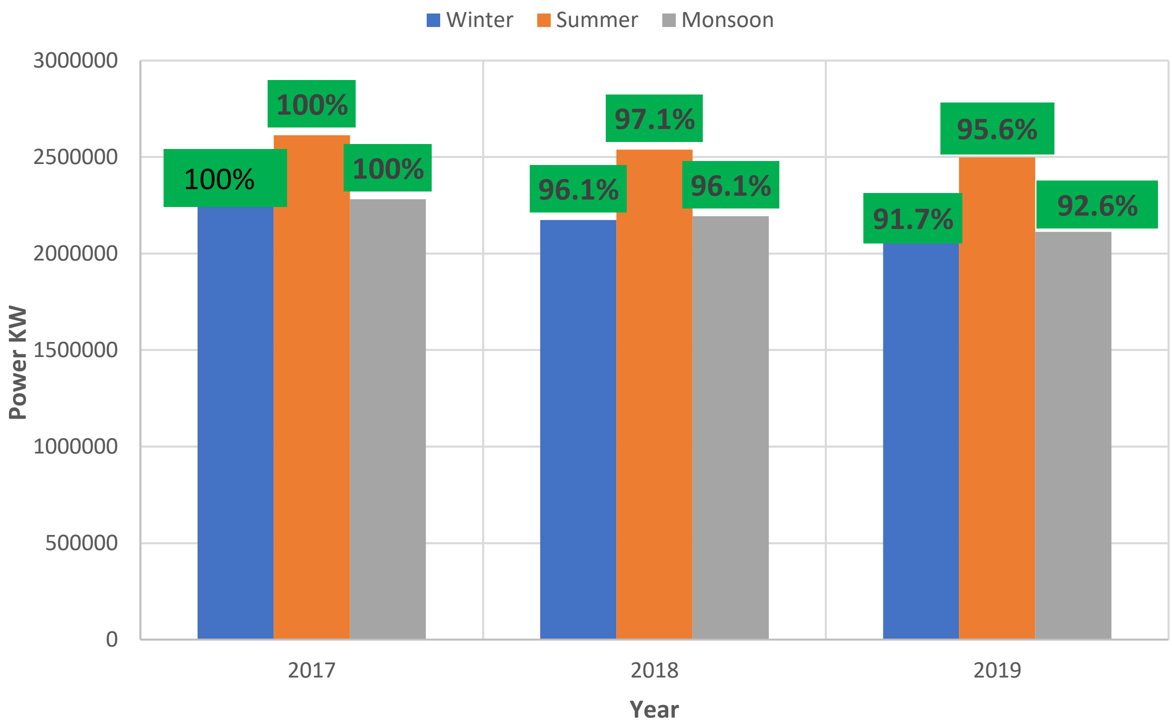


Figure 56 All-season performance drops in percentage.

As a result of the scorching summer temperature levels, 35.2°C to 39.3°C were recorded during this season. The performance decreases with the continuous rise of temperature and ultraviolet radiations up to 12.09mW/cm². Peak performance occurred when the wind speed was at its maximum (3,67m/s) and the temperature was at its lowest (35.2°C).

The monsoon season experienced uniform rainfall, but rainfall increased in the last quarter. The rainfall resulted in a continuous decline in temperature from 35.3℃ to 32℃ and UV levels from 12.03mW/cm² to 11.9mW/cm². Performance improving with a continuous decline of temperature and minimal decrease of 0.9m/s wind speed. There was an increase in rainfall from 150mm to 300mm in the last quarter of the season, which lead to a decrease in temperature and ultraviolet values. As a result, performance drops with increasing rainfall.

6.3.6 Future Projection.

There has been a remarkable amount of interest in the performance readings that have been drawn from the three seasons of data. Figure 57 provides a projection for future PV system performance based on the three-year performance trend. Using 2019 levels as a benchmark, we estimate that summer performance will drop 44%, monsoon performance will drop 74%, and winter performance will drop 83% by 2039. From 2019 levels, summer generation would have been down 16%, monsoon generation would be down 23%, and winter generation would be down

31%. As a result, PV system performance would be down by 70% from 2019 generation performance.

It has been shown in other studies that an increase in temperature accelerates degradation and reduces performance (Kim, et al., 2016). The question is why the summer would only lose 16% of its performance compared to the monsoon and winter? There was a higher wind speed during the summer period compared to the other seasons. The wind speed at the summer was 3.06m/s-3.81m/s compared to winter wind speed from 2.17m/s-2.58m/s and monsoon wind speed of 1.8m/s-3.22m/s. The wind speed increase help to manage the temperature conditions during this period and actively expected to help prolong the lifespan of the module.

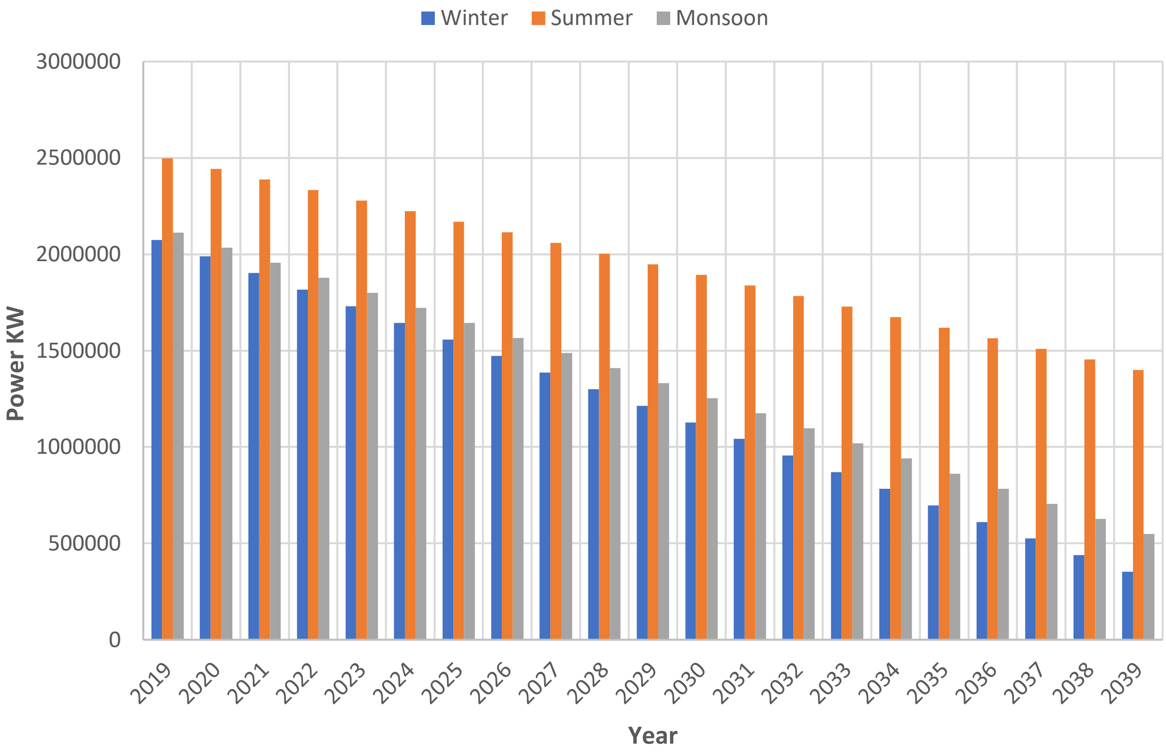


Figure 57 Performance projection of the PV system.

6.4 Machynlleth-Wales.

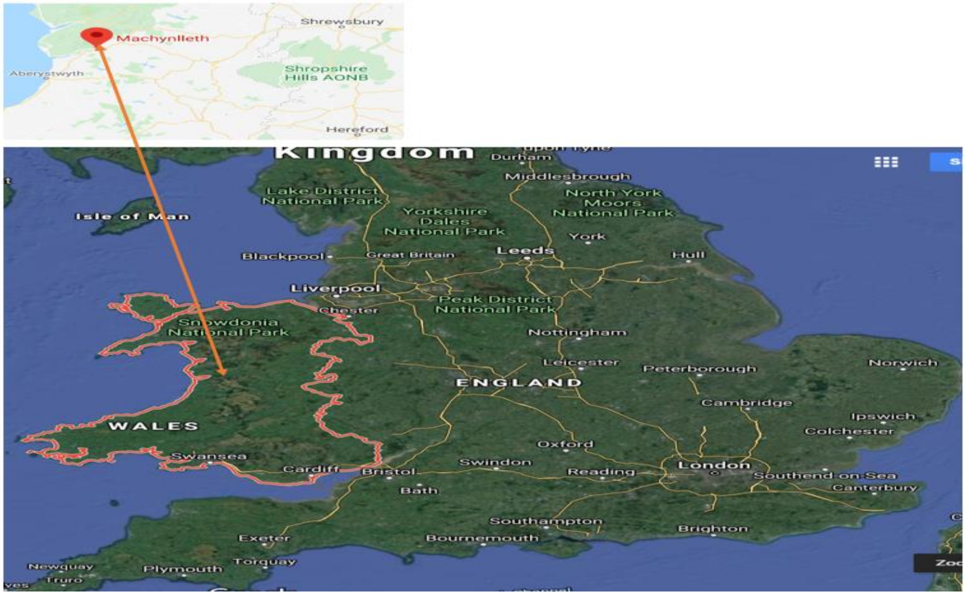


Figure 58 Machynlleth in mid-Wales (MWT, 2020)

Machynlleth is a historic town in mid-Wales which sits at the mouth of the Dyfi estuary in the heart of the UNESCO Dyfi Biosphere which has been made one of only two UNESCO Biosphere Reserve sites in the UK (MWT, 2020). Machynlleth is located at 52.60° N 3.85° W and 46 m above sea level (MetOffice, 2020).

This PV system is a home-based microgeneration system installed on his rooftop. In order to make use of the excess energy generated in the system, the system is connected to the grid. The rooftop PV system rated at 3.87kWp is made up of 18 Kyocera KD15 modules with a 3.6kW inverter and 7kWh Tesla Powerwall on the direct current (DC) side of the system. The PV system was installed on the roof of a private house in January 2017 and monitoring system was installed to provide day-to-day data on the performance of the system. Due to its maximum ventilation capabilities, this type is the most cost-effective and provides the best performance from the system.

Figure 59 Roof-mounted system (EnergyCC, 2020)

6.4.1 Solar potential for Machynlleth.

Machynlleth-Wales is in the United Kingdom closer to the St Georges Channel and Irish sea, therefore, experienced regular chilly wind from the channel. Solar potential for Machynlleth in mid-Wales is presented as part of the United Kingdom solar potential map in figure 37. From the solar potential map, Machynlleth is in the zone with a slightly solar potential compared to the High Wycombe in the United Kingdom. The solar potential levels for the village in Wales range from 2.4kwp/kWh to 2.8 kwp/kWh daily equal to 876kwp/kWh-1022kwh/kwp per year levels solar PV potential.

6.4.2 Climate seasons of the location.

Machynlleth is a popular market town situated in the beautiful Dyfi estuary in Mid Wales with a population of around 2,000 (Net, 2013). Machynlleth which is in Wales and part of the United Kingdom has numerous historic buildings, including the medieval townhouse known as The Parliament House on Maengwyn Street. Wales goes through four similar climate seasons to England which are summer, autumn, spring, and winter.

A first-hand view of the actual weather conditions during PV energy production can be seen in figure 60. The first peak rainfall of the year occurred during December-January, which resulted in the lowest temperature and most ultraviolet radiation of the year. During March to May, rainfall was at its lowest, but temperatures and ultraviolet radiation were at their highest. After June, rain picks up again until October, which is the second peak period of the year.

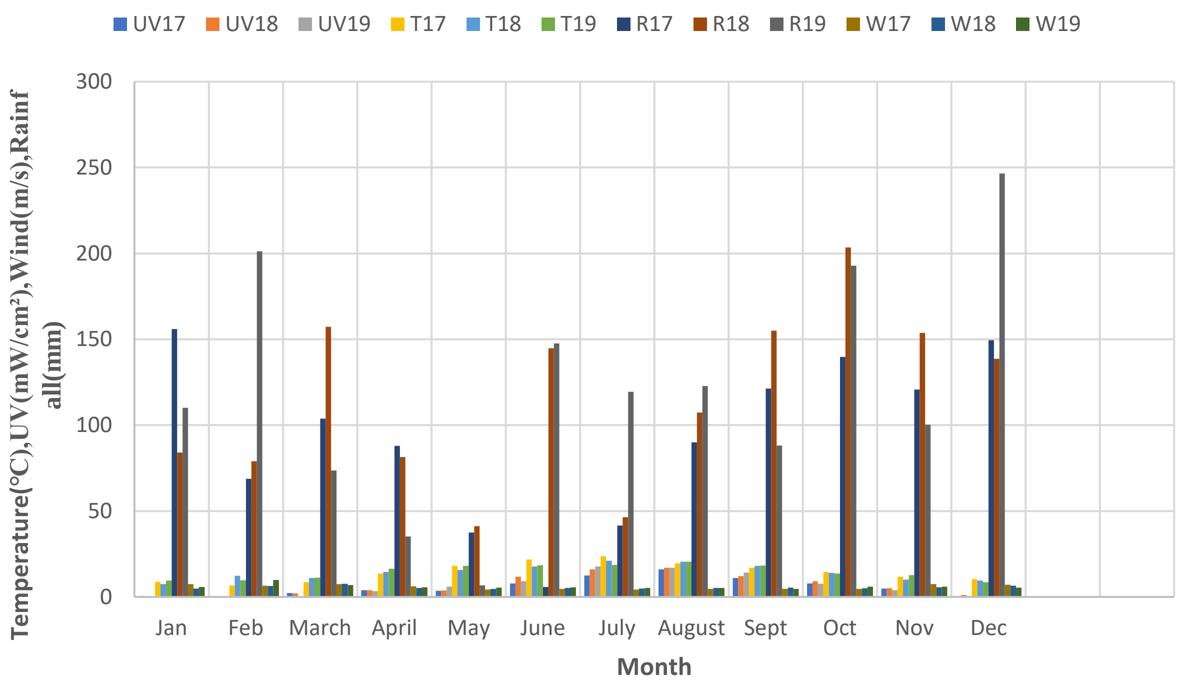


Figure 60 Climate condition for all seasons.

Graph definition of terms.

- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- R17= Rainfall 2017, R18=Rainfall 2018, R19= Rainfall 2019
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

6.4.3 Weather conditions effect on PV system energy generation.

Figure 61 shows the performance of the system in terms of energy generation over the past three years. The peak performance is from April to July when rainfall activity begins to drop in April. There was significant rainfall activity during the peak generation period between 41.2mm and 150mm as well as the highest temperature levels (16.43°C-18.58°C) for the years through the same period. The maximum ultraviolet radiations level between 9.1mW/cm² to 17.8mW/cm² occurred between April to July which is the period of peak performance during the minimum wind speed of the year ranging between 5.16m/s to 5.40m/s. Over the period of weak performance, there was a continuous increase in rainfall resulting in a decrease in temperature and UV levels, while wind speed was consistently high.

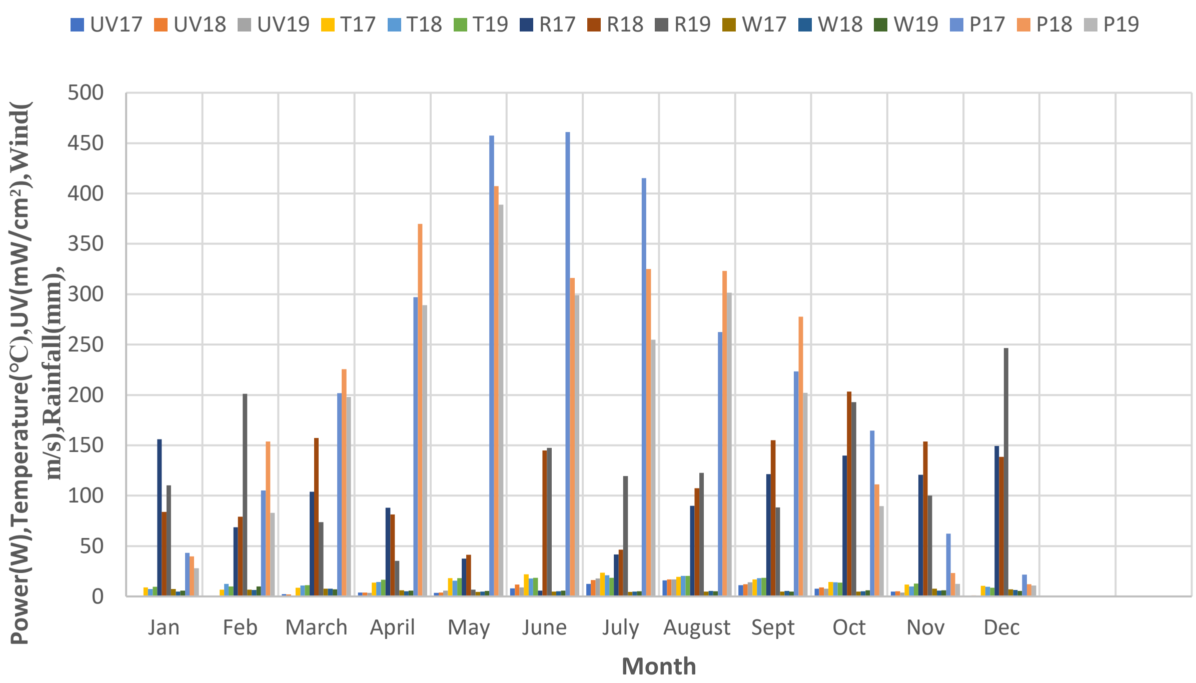


Figure 61 Performance against temperature, UV, rainfall, and wind speed.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- R17= Rainfall 2017, R18=Rainfall 2018, R19= Rainfall 2019
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

6.4.4 Seasons breakdown of PV system energy generation performance.

(i) Spring season

The northern hemisphere's atmospheric circulation peaks in spring because of temperature differences between the northern and southern hemispheres. It is when the earth's atmosphere and earth begin to warm that thunderous showers can occur as air turbulence is created in the atmosphere. There is an average temperature of 5°C-16°C, although it can be even hotter.

In figure 62, we can see the actual conditions under which PV system performance was achieved during spring. From the graph, PV system performance gradually increases from the beginning of the season to the end of May, then declines. As the season began, rainfall reached 81.4mm but fell to a minimum of 41.2mm, and UV radiation increased from 0.3mW/cm² to peak at 5.9mW/cm². As a result of the high temperatures over this time period from 11.15°C to 18.09°C in comparison to what was predicted or usual, the actual temperatures were higher.

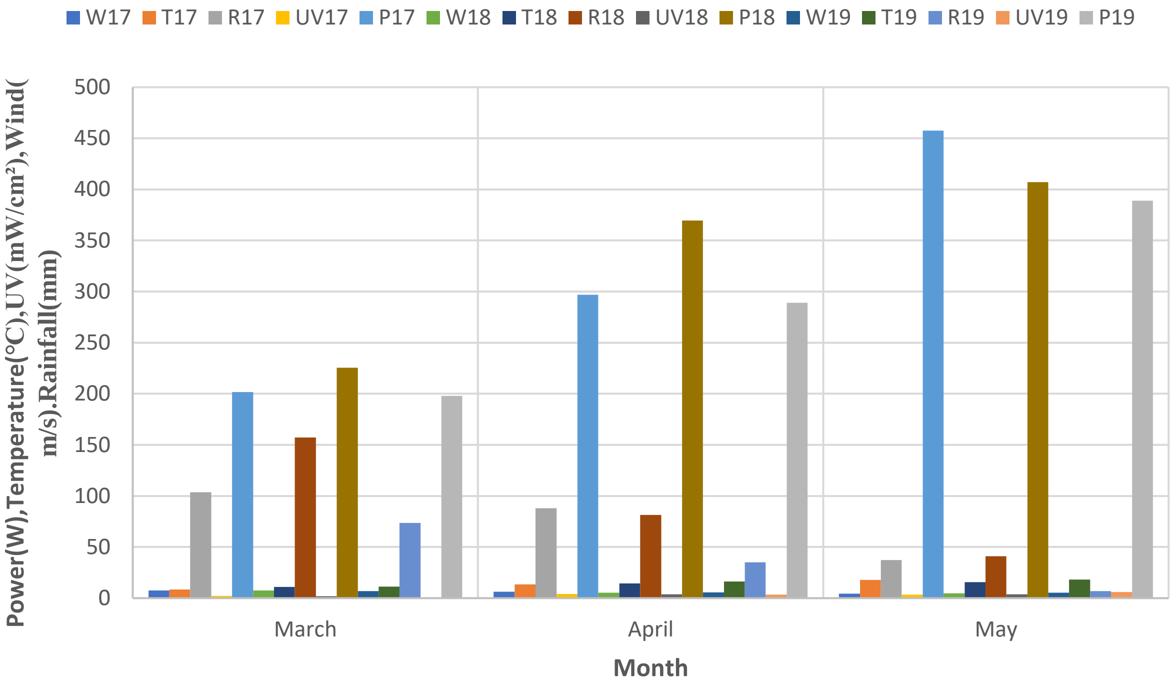


Figure 62 Performance against temperature, UV, rainfall, and wind speed during the spring season.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- R17= Rainfall 2017, R18=Rainfall 2018, R19= Rainfall 2019
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.
-

(ii) Summer season.

The summer (June-August) is the warmest season and long days' average temperature in the region of 10℃ to 28℃. A high temperature period usually occurs in the middle of August, with a showery period beginning in July and an anticyclone condition for a short period of time.

It is common for the summer in Wales to be the hottest month of the year. Figure 63 shows the performance level of the PV system during the summer months. At the beginning of the season, rainfall levels were 150mm, but decreased to 90mm and increased to 100mm by the end. The UV radiations during this period continue to rise from 9.1mW/cm² to 17.8mW/cm² with a consistent wind speed average of 5.1m/s. A temperature reading of 19.55°C to 23°C was recorded during this time period. The peak performance occurred at the minimum rainfall and the peak ultraviolet radiation of 17.85mW/cm² before performance begin to drop with an increase in rainfall at the end of the season.

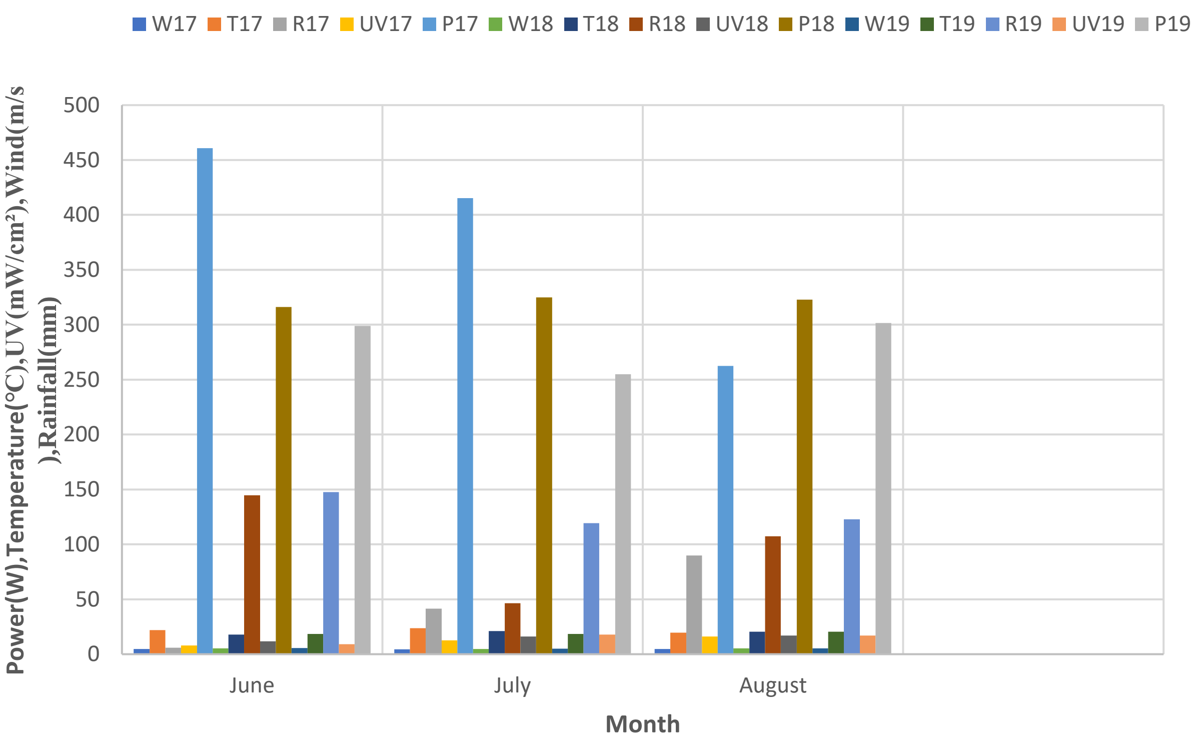


Figure 63 Performance against temperature, UV, rainfall, and wind speed during the summer season.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- R17= Rainfall 2017, R18=Rainfall 2018, R19= Rainfall 2019
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

(iii) Autumn season.

In Wales, September is a fruit picking month; however, the month of October can be very rainy with night frog development in November. Although November weather can be dull and wet, it depends on the summer and autumn that the country had during the month of November.

The Autumn season begins with some similar conditions to the summer season. The PV system's performance between September and November is shown in figure 64. The season began with a higher temperature of 18.32°C and continue to fall to 10°C. The season started with a rainfall level of 155mm, this continues to increase above 200mm before dropping back to below 50mm.

The peak performance occurred in the first month (September) when ultraviolet radiation for the season was at a maximum (14.1mW/cm²) at a minimum wind speed of 4.67m/s. When wind speed increased, performance started to dip, and UV continued to fall to the end of the season.

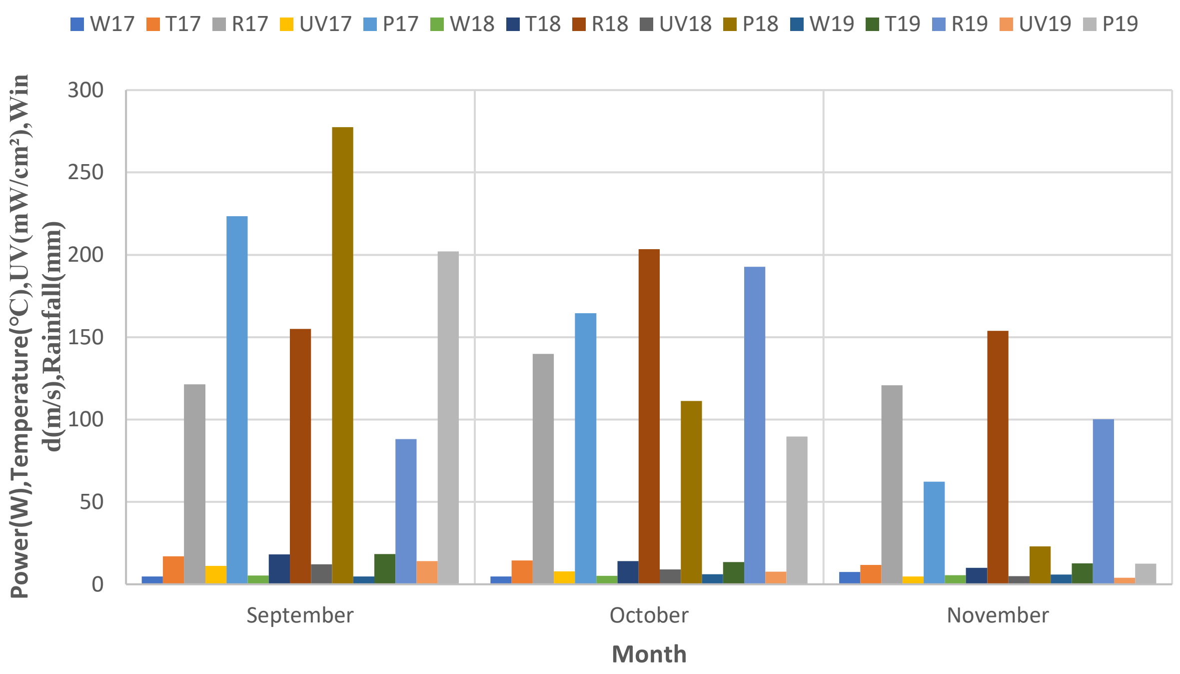


Figure 64 Performance against temperature, UV, rainfall, and wind speed during the autumn season.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- R17= Rainfall 2017, R18=Rainfall 2018, R19= Rainfall 2019
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

(IV)Winter season

Winter is the coldest month of the year, with short days and temperatures ranging from 0°C to 8°C. Winter brings some of the worst gales in December with January being the coldest month and snowdrops and crocuses appearing in the winter.

Figure 65 shows that rainfall figures from 150mm to 250mm was at its highest at the beginning of the winter season but dropped to a minimum of 68mm by the end of the season. The performance of the PV system continues to improve slowly as the rainfall continues to fall until the end of January. The temperature for the season started from 8.5℃ and continue to rise to 9.1℃ as wind speed experienced intermittent rise and fall from 5.5 m/s to 9.9 m/s and back down to 6.2m/s. It should be noted that ultraviolet radiation levels continue to increase with performance levels from 0.1mW/cm² to 0.5mW/cm².

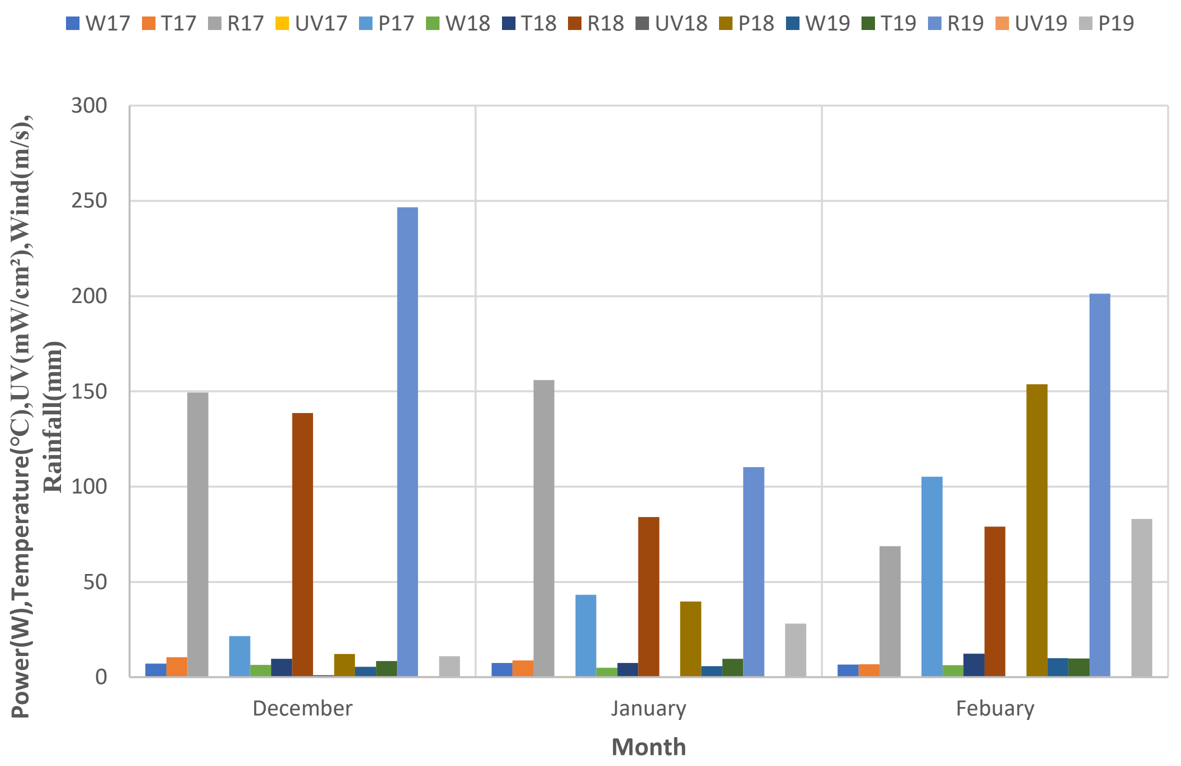


Figure 65 Performance against temperature, UV, rainfall, and wind speed during the winter season.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- R17= Rainfall 2017, R18=Rainfall 2018, R19= Rainfall 2019
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

6.4.5 Discussion of results.

The solar potential for Machynlleth town in Wales which is part of the United Kingdom is between 2.8 kWh/kwp to 3.0 kWh/kwp daily and 1022kwh/kwp to 1095kwp/kWh yearly. As compared to countries like Ghana and India, which are among the areas for this research, the solar capabilities in these countries are considered fair.

Figure 66 represent the performance drop of the PV system in seasons over the three years. From the spring performance, it appears that 2018 performance was better than 2017. The 4.8% performance increase was caused by various levels of weather conditions between 2017 and 2018. Rainfall during the spring season peaked in 2017 at 103mm to 37mm, significantly lower than 157mm to 41mm in 2018. The power generation of the system is, however, increased as ultraviolet radiation increases and wind speed decreases. The 2018 has 2mW/cm²- 3.81mW/cm² UV levels and 4.77m/s -5.2m/s of wind speed at an average temperature range of 10℃-15.63℃, which was much better compared to 2.3mW/cm²-3.5mW/cm² UV levels with a higher wind speed of 4.39m/s-7.55m/s at low-temperature range from 7.55℃- 18.02℃. During the spring season, performance dropped by 3.2% on average from 2017 to 2019.

This is because of the favourable conditions during the summer season, and the performance was better than during the rest of the year. The higher temperature levels were recorded in the summer ranging from 17.75℃ to 21. 83℃.It is important to note that even though temperatures are higher, in 2018 and 2019 the summer had higher rainfall levels from 119.4mm to 144.8mm, which contributed to a significant drop from the 2017 performance levels. While there was much rainfall unlike summer, ultraviolet radiation was higher from 7.9mW/cm² to 16.9mW/cm² with low-level wind speed (4.37m/s-5.18m/s) compared to other seasons. There has been an average drop of 7.9% in performance during this timeframe.

A higher level of rain was recorded during the autumn months, ranging from 88.2mm to 203.4mm. At the beginning of the season, there was a minimum rainfall of 88mm, which rose to 200mm by the end of the season and maintained a minimum temperature (10°C) and UV radiation level (0.9mW/cm²). The energy generation continues to drop with the continued increase of rainfall up to 203mm. As the season went on, the PV system's performance continued to drop even though the rain fell to minimum (62.75mm). There is an average drop of 7.5% in the performance each autumn.

The winter is naturally the coldest month of the year. There was a peak in rainfall activity from 138.6mm to 246.6mm at the beginning of the season. The winter also recorded the lowest UV radiation levels from 0.3 mW/cm² to 1.1 mW/cm². As rainfall levels decrease, UV levels increase from 0.1 mW/cm2 to 1.1 mW/cm², resulting in an increase in performance. The average performance drops over the winter season around 7%.

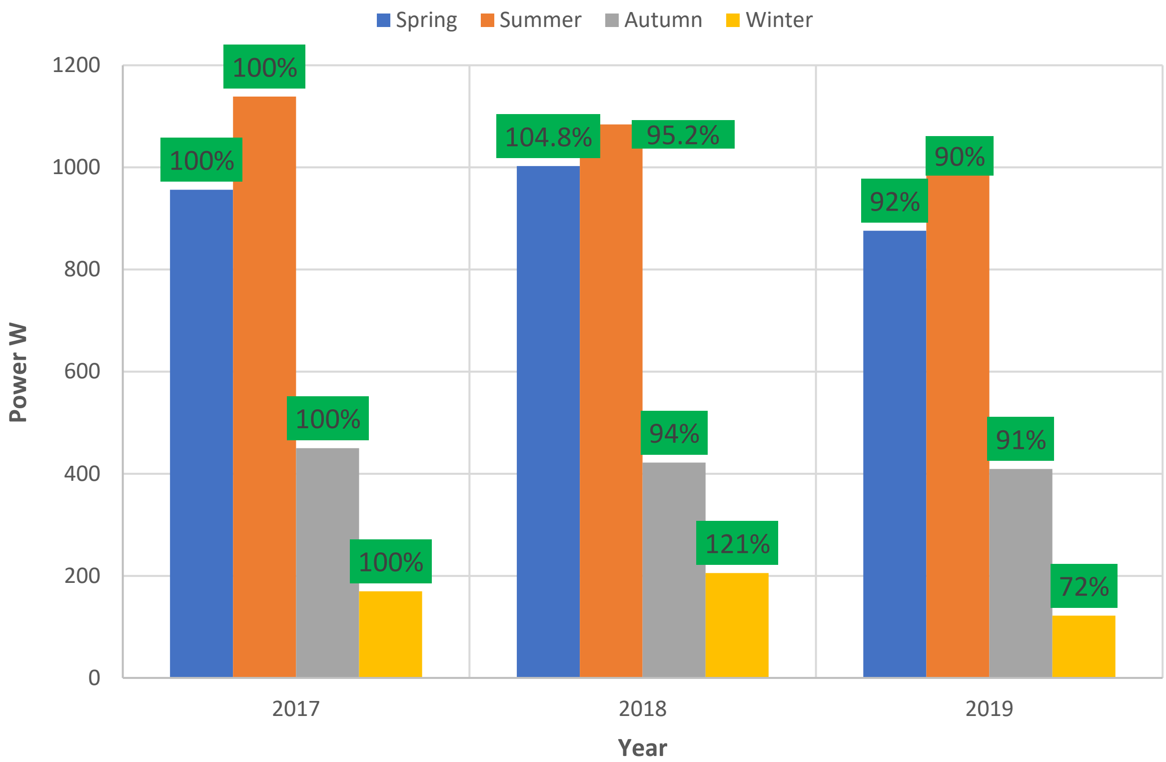


Figure 66 All-seasons performance drops in percentage.

6.4.6 Future projection.

In order to project future PV performance, the performance of the PV system is studied and examined over a three-year period and a percentage drop in performance is calculated. Based on the last recorded readings [2019], the future projection provided different but authentic readings for each season.

In accordance with the projections shown in figure 67, PV system performance for the winter season will decline by 10%, autumn by 10%, and summer by 5.2% by 2031. The spring season will still perform at 62%, which is better than the winter, summer, and autumn seasons. As a result, the PV system will be operating at 28% efficiency by the year 2031, compared to 2019 performance levels.

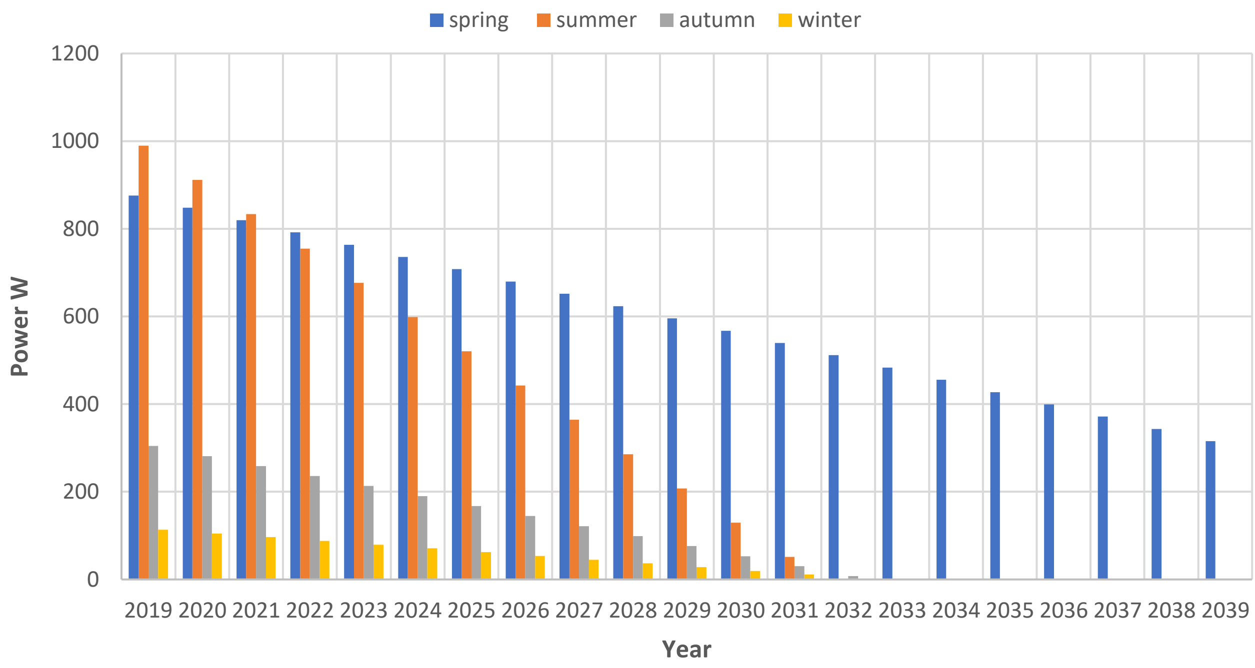


Figure 67 Performance projection of the PV system

6.5 Seattle -Washington- USA.

Washington is located on the northern shore of the Potomac River at the point where it crosses the river and is the district of Columbia the capital of the United States (Fogle, 2021).

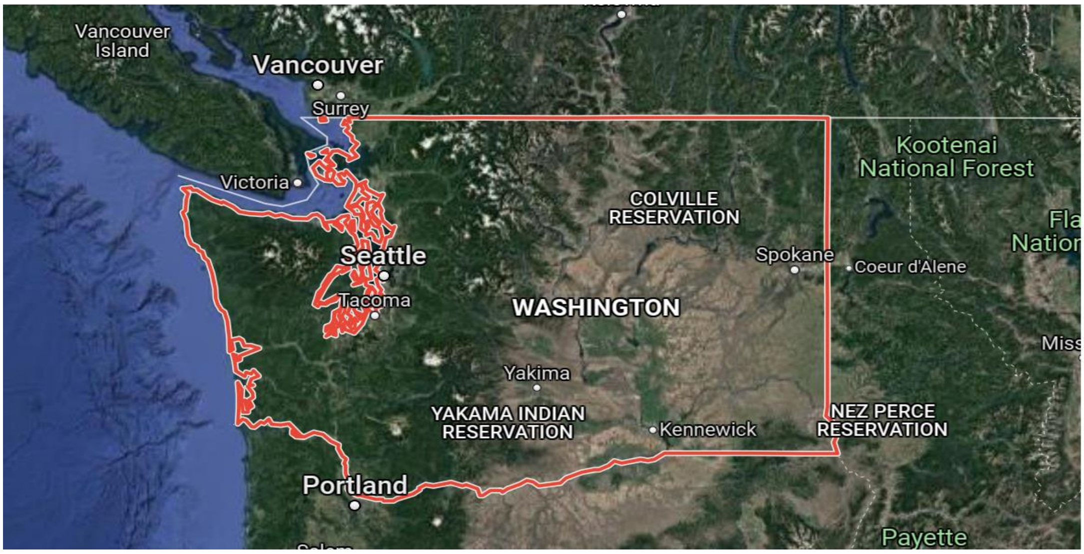


Figure 68 Google map showing the PV system location (Google-Map, 2021)

Washington has a latitude of 47.7511° N and a longitude of 120.7401° W which spans a diverse range of landscape at the midway point in the coordinates of 120°16.1' W and 47°20' N (WPR, 2021). There are four usual climates in Washington, with summer temperatures reaching 26°C in the summer and winter temperatures sometimes dropping below 8°C (WPR, 2021). In Seattle, which is in the west of Washington, there is frequent fog and drizzle, while the cascade slopes receive up to 200 inches of snow and 16 inches of rainfall per year (WTG, 2021). The PV system data collected for this study is rooftop in a residential area of seattle.

Figure 69 Roof mount residential system (Sayre, 2020)

This is a rooftop-mounted PV system with a rating of 50kw/h has been installed in a residential facility. In total, 49 panels of solar modules from Marysville-based Silicon Energy are used to construct the array. When solar panels are mounted at a 30-degree tilt angle towards the south, the most optimal orientation will be true south.

6.5.1 Solar potential for Washington.

The solar potential for this part of United States is good to have a decent PV system performance, however all depends on the actual weather conditions of the day. In comparison with other states in the country, Washington has a very good solar potential. From the solar potential map shown in figure 70, the solar potential for a day is around 4.019kWh/kWp which gives an expected annual total of around 1467.0kWh/kWp. Seattle, which is on the western side, is enriched with a solar potential of around 1200kWh/kWp-1600kWh/kWp annually.

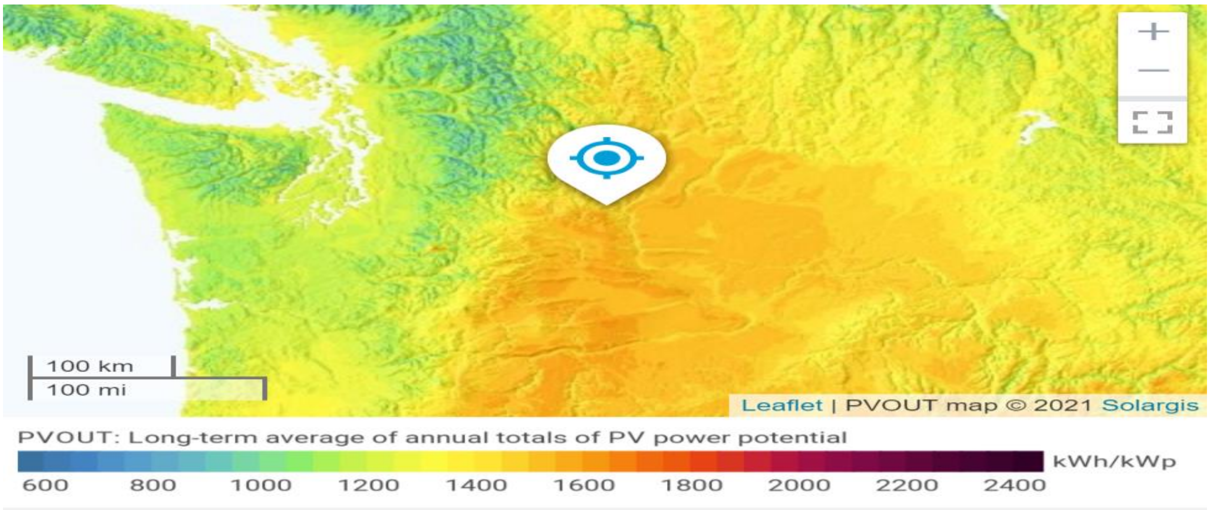


Figure 70 Solar potential map for Washington (Solargis, 2021)

6.5.2 Climate seasons of the location.

The city of Seattle is the largest city in Washington DC and is located on the mainland. The city is situated nearby lake Washington a major seaport of the north-western USA. The city is known for indie rock, and hip-hop music and is the fourth-largest port in the North of the US. Throughout the year, Seattle experiences four seasons: spring, summer, fall, and winter.

March to May is the beginning of the spring season, June to August is the beginning of the summer season, September to November is the beginning of the fall season, and December to February is the beginning of the winter season. Figure 71 shows all conditions during the PV system energy generation. It is observed that during the summer the temperatures and UV peaks occurred, and during the summer when the windspeeds and rainfall were at their lowest.

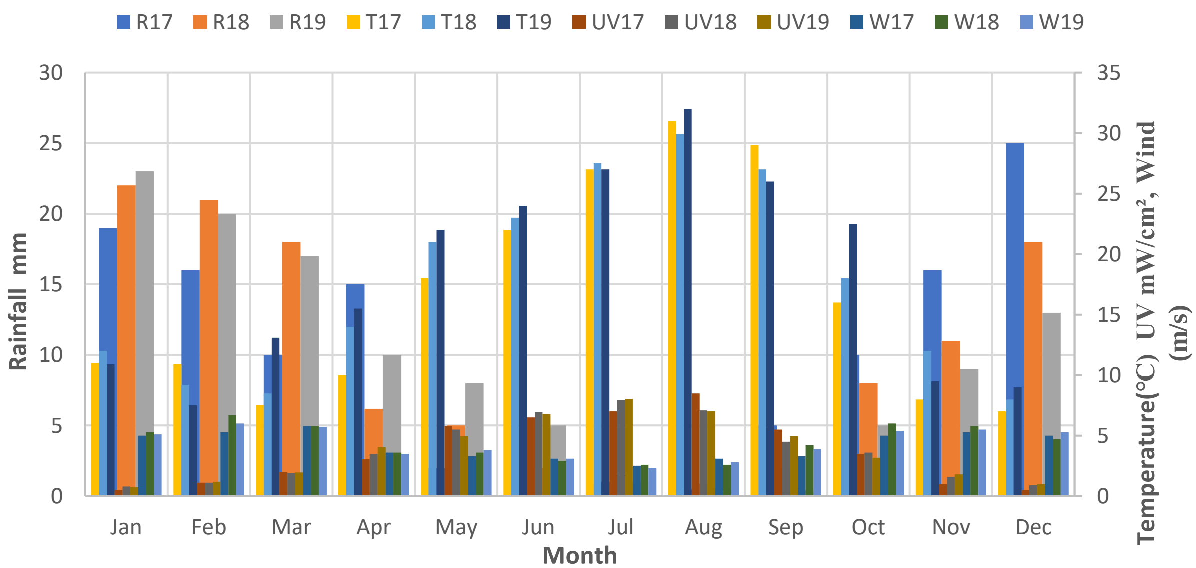


Figure 71 Climate conditions for all seasons.

Graph definition of terms.

- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019

W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

6.5.3 Weather conditions effect on PV system energy generation.

A three-year analysis of the PV system energy generation can be seen in Figure 72 below. Peak performance was achieved in August during peak ultraviolet radiation levels between 7.5 and 8.5 mw/cm². The PV system performance increases in February, peaks in August, and then drops until after the freezing conditions begin in the winter.

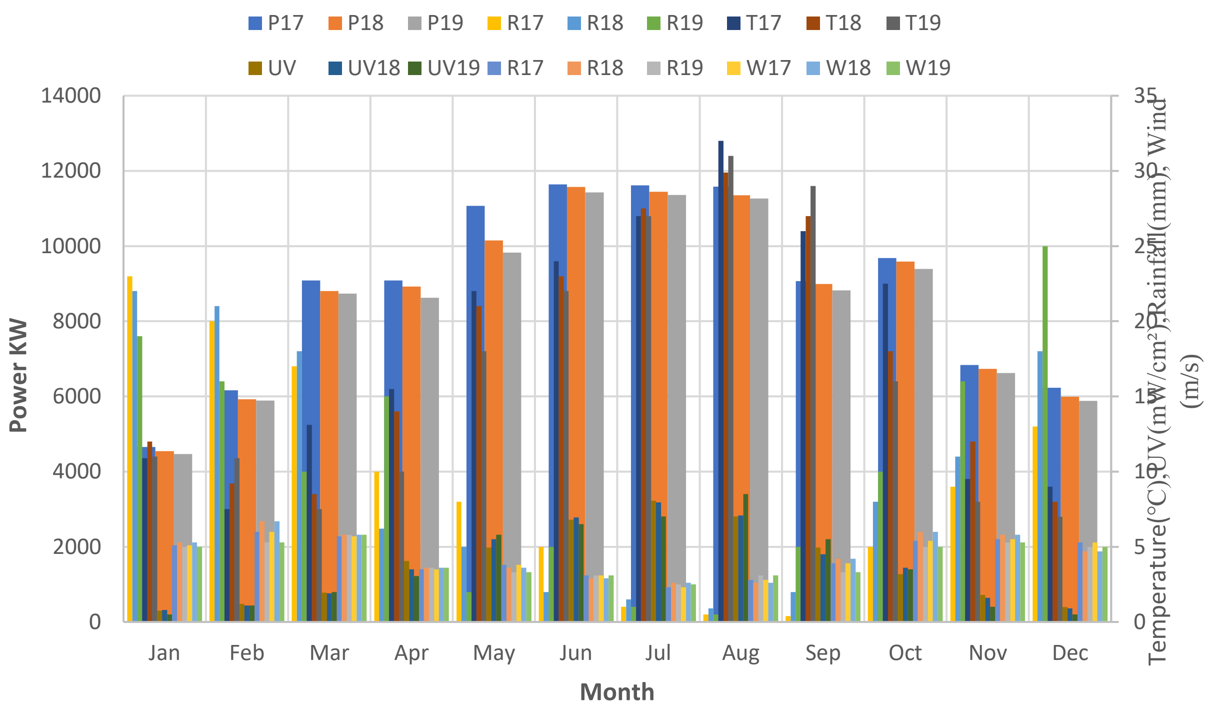


Figure 72 Performance against temperature, UV, rainfall, and wind speed.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- R17= Rainfall 2017, R18=Rainfall 2018, R19= Rainfall 2019
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

6.5.4 Seasons breakdown of PV system energy generation performance.

A PV system performance will be assessed under the four natural seasons (Spring, summer, fall and winter) in Seattle USA during the energy generation period from 2017 – 2019. In order to make a projection based on the results, we will also examine how each season weather conditions affects the PV system energy generation performance.

(i) Spring season

There is a lot of rain and cold weather in Seattle during spring season, which means layers of clothing are essential. Overcast days of cooler weather alternate with sunshine on warmer days to indicate the arrival of spring. As the spring season approaches, the daylight hours are increasing, and the sun is shining more frequently. Locals flock to Seattle's shorelines and parks on sunny days in the spring after the coldest seasons to enjoy the weather. In Seattle, the average climate temperature for the spring months is 11.1°C for March, 14.4°C for April, and 17.8°C for May. The temperature continues to elevate from the first month to the last month of the spring into the summer season.

The actual weather conditions recorded during the spring generation are shown in figure 73. This season started with a minimum UV of 1.95mW/cm^2 and continues to increase steadily to the peak of 5.5mW/cm^2. At the beginning of the season, there was a maximum rainfall of 18mm, and the level dropped further to 8mm near the end. Since there was less rain, UV levels increased, resulting in improved performance toward the end of the season.

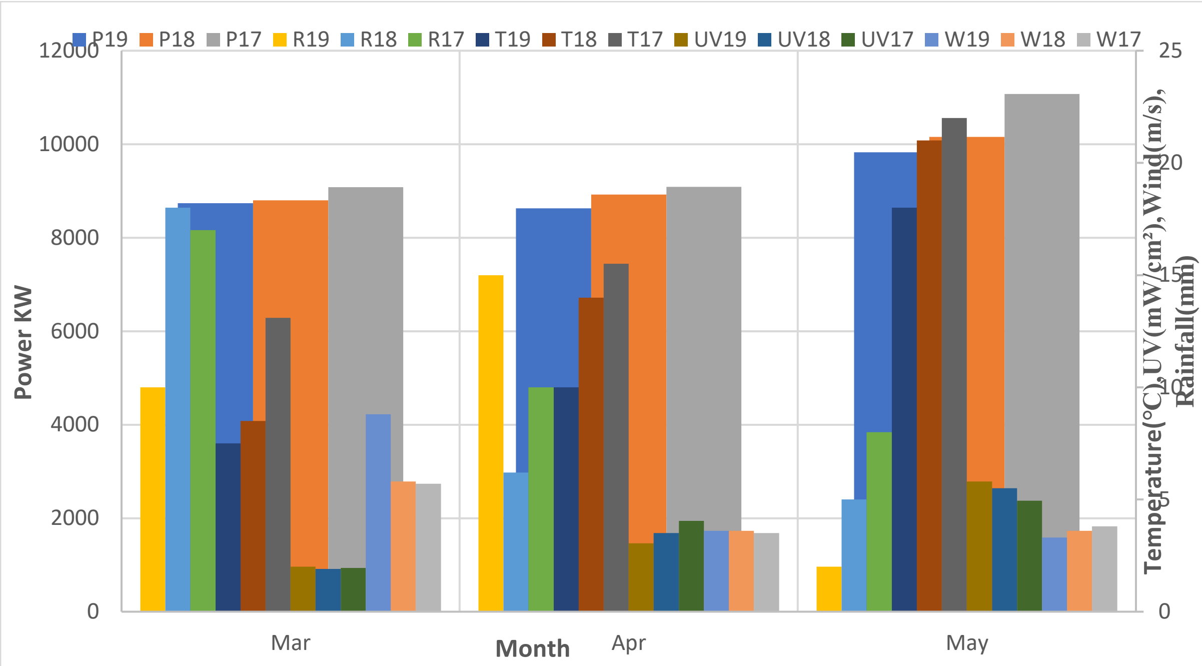


Figure 73 Performance against temperature, UV, rainfall, and wind speed during the spring season.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

(ii) Summer season

Summer in Seattle brings about perfect conditions for outdoor activities. In the summer, the sun rises early in the morning and sets late at night, giving locals a chance to enjoy hiking and other outdoor activities. The average temperature in the summer months is 20.5℃ for June, 22.2℃ for July and 22.8℃ for August. However, the summer month can be warm and dry with temperatures rarely peaking above 32.2℃ (Atlas, 2022).

Figure 74 shows the actual conditions for the PV system energy generation during the summer season. The amount of rainfall during the season was between 6mm to 0.5mm over the calendar year. At the beginning of the summer season, the minimum temperature was 23℃, increasing to 32℃ by the end. According to the correlation between high-temperatures and UV radiation levels, the peak ultraviolet radiation levels during the summer season are around 11.05mW/cm².

Performance at the beginning of the season continued to decline as temperatures increased and wind speeds dropped from 3.2m/s to 2.6m/s.

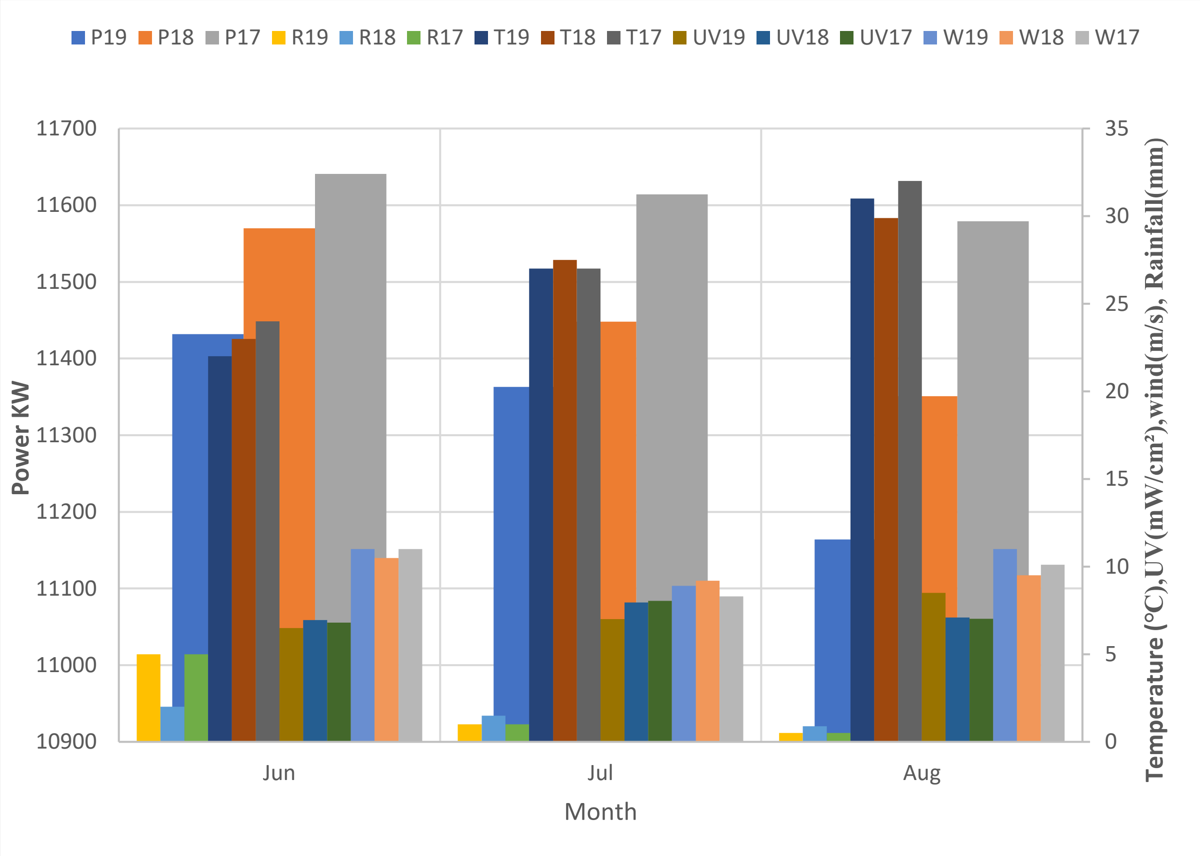


Figure 74 Performance against temperature, UV, rainfall, and wind speed during the summer season.

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

(iii) Fall season.

In Seattle, the fall season can be quiet and bring plenty of warm, sunny days, but this varies from year to year. Some years can bring cool, rainy conditions and others not quite so. The temperature during this season begins to fall from the summer levels with the average temperature for September being 19.4℃, October being 15℃ and November being around 10.6℃. As winter conditions begin to take hold during the first half of November, some days are going to be very windy with wind speeds of 40-50 mph (Atlas, 2022).

Figure 75 shows the PV system performance during the fall season in Seattle. Fall marks the beginning of rainy season after the hot season, when rain amounts increased from 0.5mm to 12mm the maximum at the end of the season. The temperature experienced a very sharp drop from 29℃ to 11℃ and a drop in UV radiations levels from 4.95mW/cm² to 1.8mW/cm². At the same time, the wind speed of the season began to increase from 3.9m/s to 5.5m/s levels. After reaching its peak at midseason, the fall season's performance decreased with decreasing UV levels and increasing wind speed.

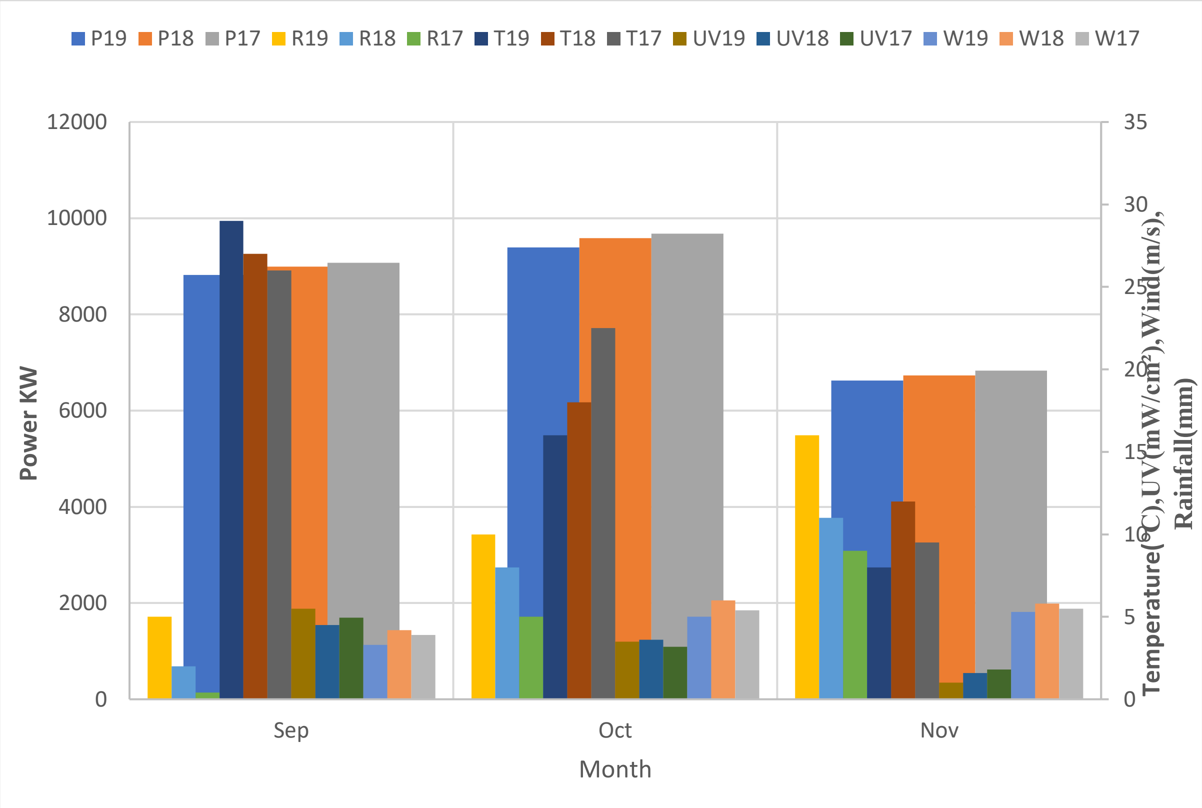


Figure 75 Performance against temperature, UV, rainfall, and wind speed during the fall season

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.

- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

(iv) Winter season.

The winter season in Seattle brings about freezing conditions and consistent rains. There is a temperate climate in the city, which ranges from cold winters to extremely hot summers. The winter can sometimes bring about cold waves, sometimes even in November, with freezing conditions down to -10 °C or even below (Atlas, 2022).

The temperatures in Seattle are rarely extreme levels, the temperature for the winter months is for December is 8.3℃, January 7.2℃ and February around 8.9℃. During this period the Seattle's average temperature is between -1.1℃ and 32 ℃ throughout the year.

PV system performance during the winter season is shown in figure 76. The winter season began with steady increases in rainfall from 18mm to 23mm and UV levels of 0.98 mW/cm². Increasing the temperature from 9°C to 12°C caused the performance to noticeably decrease. Nevertheless, performance improved from mid-season to end when UV radiation levels increased from 0.98 mW/cm² to 1.2 mW/cm² and temperature dropped from 12℃ to 9.2℃.

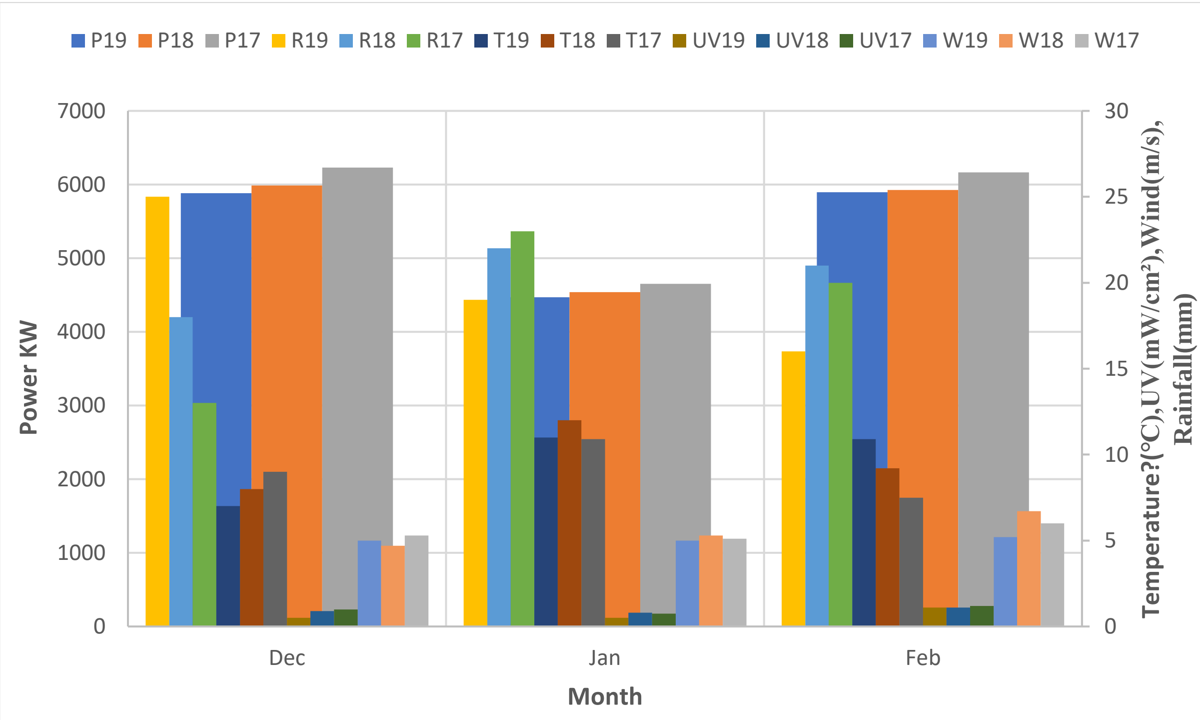


Figure 76 Performance against temperature, UV, rainfall, and wind speed during the winter season

Graph definition of terms.

- P17 = Power output 2017, P18 = Power output 2018, P19 = Power output 2019.
- UV17 = Ultraviolet radiations 2017, UV18 = Ultraviolet radiations 2018 UV19= Ultraviolet radiations 2019.
- R17 = Rainfall 2017, R18 = Rainfall 2018, R19 = Rainfall 2019.
- T17= Temperature for 2017, T18 = Temperature for 2018, T19 = Temperature for 2019.
- W17= Wind speed for 2017, W18= Wind speed for 2018, W19= Wind speed for 2019.

6.5.5 Discussion of results.

The solar potential for Seattle, in Washington of the United States of America, has a very decent with the daily potential of 4.019 kWh/kwp with the annual expected potential of 1200kWh/kWp-1600kWh/kWp. It is reasonable to expect that this PV system will perform better in this area since it will have a reasonable solar potential. The extreme different weather conditions can counter the expected potential of PV systems in this area.

In figure 77, we can see the drop in performance of each of the three seasons. Due to changes in weather conditions, and performance in spring decreased year over year. The UV radiation which is correlated with temperature, rainfall, wind speed and performance increased steadily from 1.95mW/cm² to 5.5mW/cm² which gives rise to improved performance. At the same stage wind speed steadily drop from 5.8m/s to 3.8 m/s as the rainfall decreases from 17mm levels to under 5mm.

Compared to the rest of the seasons, summer's performance was better due to pleasant weather conditions. The summer was the hottest period of the year with temperatures reaching up to 32℃ and higher UV levels of the year (6.8mW/cm² to 8.5mW/cm²) depends on the temperature levels. The summer season experienced the minimum rainfall levels of 5mm to 0.9 mm which contributed to the elevated levels of UV radiation. According to figure 74, the performance made steady progress from 3.1 m/s to 2.8 m/s as the wind speed steadily decreased.

During the fall season, performance increased steadily until midseason before decreasing over the last half and end of the season. The fall is naturally the beginning of rain activities and figure 75 shows that rainfall began to increase from 2mm to 13mm keeping temperature levels falling from 26℃ to 9℃. The performance increases with increasing UV radiations levels, in parallel with the decrease in ultraviolet radiation from 5.5mW/cm² to 1.8mW/cm², the system's ability to generate energy also declined during the period.

In Seattle, the winter is typically the coldest month of the year, but there is still a variety of weather conditions in the winter as well. Despite the peak performance in the beginning of the winter, different combinations of weather resulted in a sharp decline by midseason and then increased in this half to the end of the season. The UV radiations steadily increased from 0.75mW/cm² to 1.2mW/cm² which happened to be the lowest levels of the year. An increase in rainfall from 16mm to 22mm contributed to the sharp drop in temperature from 10.9°C to 7.5°C to further demonstrate the correlation with the two.

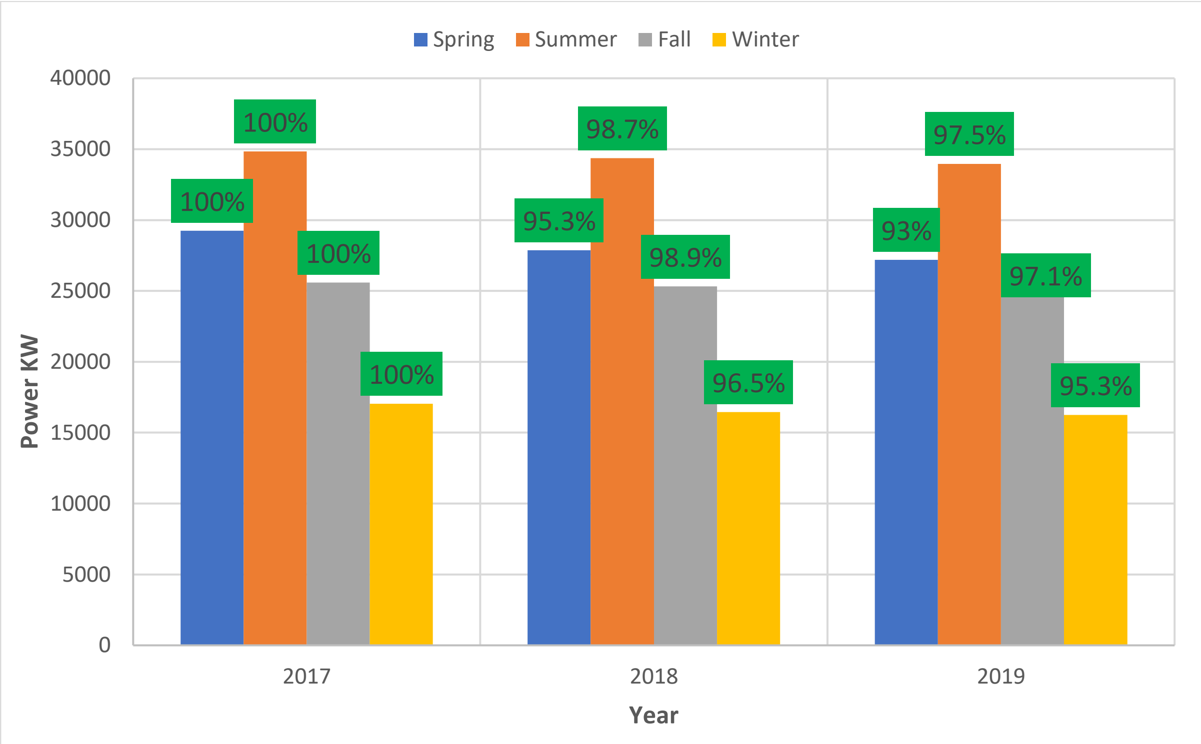


Figure 77 All-seasons performance drops in percentage.

6.5.6 Future projection.

On the basis of the performance data from 2017 to 2019, figure 78 represents the percentage prediction for future performance of the PV system. Using the first three years' data of the system performance trend, a projection of future generation patterns in Seattle is generated showing PV performance drops throughout the year.

To show performance degradation over the seasons, the 2019 data is used as a baseline measurement. A future projection indicates that by 2035, the PV system performance will be 47% of what it was in 2019. In terms of the season, performance would be 6.4% for the spring representing a 93.6% drop in performance, 69.6 % for the summer representing a 30.4% drop in performance, 68% for fall representing a 32% drop in performance and 96% for winter showing 4% drop in performance.

The performance drop is expected to be worse in the spring than in the other three seasons, why? Considering the geographical location of the system in Seattle and the weather conditions data during generation. There was an extraordinarily high wind speed of 3.8 to 5.7 m/s during spring, and the maximum temperature was 22°C, which is below the temperature of the standard test for solar cells. The wind speed is an effective and passive cooling method for PV panels, which can enhance their efficiency. Hence, wind accessibility on solar PV panels is important only during high-temperature conditions (25°C) (Xingcai & Kun, 2018). In contrast, higher wind speeds at lower temperatures can affect system performance by cooling when it is not needy.

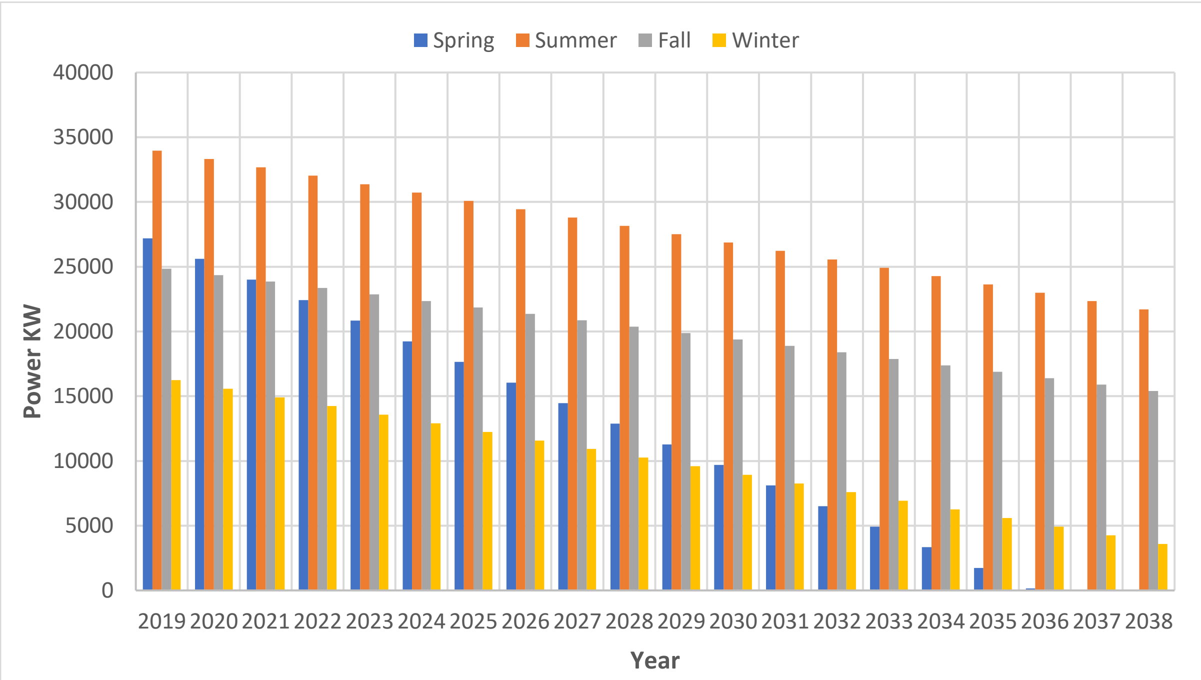


Figure 78 Performance projection of the PV system

7.0 Rainfall, dust, and angle of inclination impact on UV and temperature on PV system.

A PV system's performance can be adversely affected by weather conditions, dust, and angle of tilt since these factors affect UV radiation and the solar panels' temperature during operation.

A PV system's performance can be positively impacted by rainfall, since it removes dust and other debris from the solar panels' surface, improving their efficiency. A PV system's energy output, however, can be decreased by rainfall during lower temperatures as observed in England

and Wales. Rainfall can reduce UV radiation reaching the surface of the solar panels, resulting in decreased power output, this is because water droplets can scatter and absorb some UV radiation, which prevents it from reaching the solar cells. A rainfall can also be beneficial to cleaning the surface of solar panels, removing dust and debris that may have accumulated on them. This allows more sunlight to reach the solar cells, which can increase the efficiency of the PV system. In addition, rain helps reduce the temperature of the PV system by providing cooling to minimise the impact of overheating of modules.

A PV system's performance can be significantly impacted by dust, which reduces UV radiation reaching the solar panels. Dust can accumulate on the panels' surfaces, reducing the amount of light that can penetrate through to the solar cells which can result in a decrease in power output and efficiency. Additionally, dust can increase the temperature of a PV system by decreasing the ability of the panels to dissipate heat, which in turn reduces the amount of UV radiation reaching the panels. The degradation of solar cells is accelerated by high temperatures, which leads to reduced power output and efficiency.

A PV system's performance can be significantly affected by the angle at which sunlight shines the panels surface. To maximize the amount of UV radiation reaching the solar cells, solar panels should be positioned so that they receive direct sunlight perpendicular to their surfaces. However, if the angle of incidence is too steep, some of the UV radiation will be reflected rather than absorbed, resulting in a decrease in power output. Additionally, the angle at which sunlight strikes the solar panels can impact the temperature of the PV system. If the panels are angled towards the sun, they will absorb more UV radiation and become hotter. This can lead to a decrease in efficiency, as high temperatures can cause solar cells to degrade more quickly.

7.1 Microsoft excel 3D surface plot of performance using weather conditions.

In the research data analysis of all locations, it was found that PV modules were susceptible to UV levels above 8.5 MW/cm², equivalent to 26°C-27°C, regardless of a PV module's location. On the basis of the results of the study, Table 1 shows the pattern of performance as measured in percentages of PV systems generated. Manually calculating the performance degradation in all conditions is based on the correlations between parameters, along with their effects on one another. All the locations used for this study exhibit the same pattern even though there is different weather conditions. The table 1 shows how the modules degradation is correlated with two inputs: wind and UV radiation.

PV modules degradation is influenced by UV and wind effects on the rate of degradation shown in the table 1. This is manually generated using the function (UV) = f(T) and (Degradation (%)) = f(w).

Table 1 3D simulated data of degradation of PV system performance record.

Wind/UV	15	14	13	12	11	10	9	8
0.5	64	64.8	65.1	65.9	66.2	66.8	67.1	67.9
1.0	68.1	68.9	69.2	69.8	70.1	70.9	71.2	71.8
1.5	72.2	72.8	73.3	73.8	74.2	74.7	75.3	75.9
2.0	76.1	76.9	76.1	76.6	77.1	77.7	78.3	78.9
2.5	79.5	79.8	80.0	80.9	81.2	81.8	82.1	82.5
3.0	83	83.2	83.9	84.1	84.8	85.3	85.6	85.9
3.5	86.1	86.7	86.9	87	87.2	87.5	87.9	88.1
4.0	88.4	88.7	89	89.3	89.7	89.9	90.2	90.6
4.5	90.9	91.0	91.4	91.9	92.2	92.6	92.8	93.0
5.0	93.3	93.7	93.9	94.1	94.6	94.9	95.2	95.7
5.5	95.89	96.2	96.5	96.9	97.2	97.5	97.9	98.1

Figure 79 shows the 3D surfing plot of PV performance about the wind and UV radiation. A 3D plot shows that sunlight must be present for a PV system to convert solar energy into electricity. As the temperature rises, UV radiations are produced, which are correlated with the performance of the system. Even though these reactions are common to all locations, the extent of these reactions differs from one location to another.

According to empirical data findings, the performance of PV systems also dependent on the availability of wind at the installation site. A 3D simulation of the first and second simulations shows that PV system degradation rate increases rapidly with increasing UV radiation levels, but wind increases can slow down the degradation rate to prolong the PV system's performance and lifespan.

As seen in figure 79, the system's performance trend is plotted on three dimensions when wind, UV, and other inputs are present as the main sources of energy. In the primary axis, UV radiation levels and performance are represented, while in the secondary axis, the wind is represented. In the 3D plot, the slope on top represents the performance and degradation of the generation of output of the PV system.

At a higher wind speed, the block shape has a higher percentage, whereas at a lower wind speed, it has a lower percentage as an example, when wind speed is 0.5 m/s, performance is below 64%. However, when wind speed is 3.5 m/s, performance is slightly above 87%. This implies that at higher UV levels wind speed is necessary to improve performance. The trend is an indication of the correlation between wind speed, UV, and degradation of the PV system. This represents the general trend in Seattle in the USA, Navrongo in Ghana, Chennai in India, High Wycombe in England, and Machynlleth in Wales.

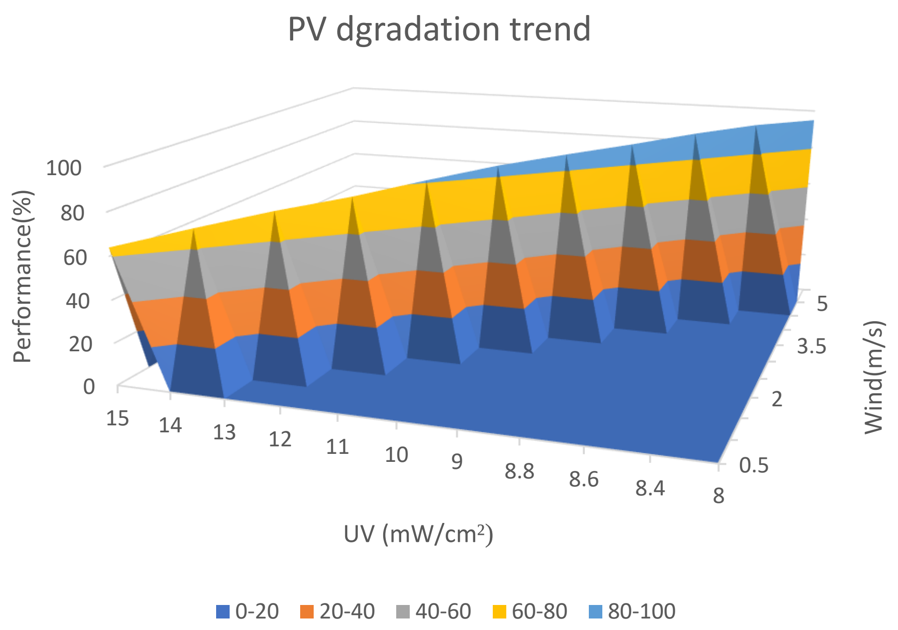


Figure 79 3D surface plot of performance degradation of PV systems.

MATLAB software plot for the same result of the Microsoft excel 3D surface is shown in Figure 80. Using the same wind, UV radiations, and performance inputs, it provides a similar to 3D surface plot using Excel, but it is different in terms of extraction of information patterns. From the plot, the solar cells do not perform better when viewed from the far right of the secondary axis. When the wind speed is lower at UV levels above 8mW/cm², which is temperature equivalent of 26°C or higher, the PV system performs is low. However, at a higher wind speed of UV levels around 8mW/cm² or above the system performance is significantly improved because the higher winds provided cooling resulting in an improved performance. In my opinion, this underpins the trend of 26°C temperature of equivalent UV light, PV system cooling as being crucial to improving the efficiency of energy generation.

Taking all this information into account, we can come up with a pattern of PV system performance with temperatures above 25°C. For solar cell performance to be enhanced in high temperatures conditions, temperature management is necessary to provide cooling for all PV panels modules to function as expected.

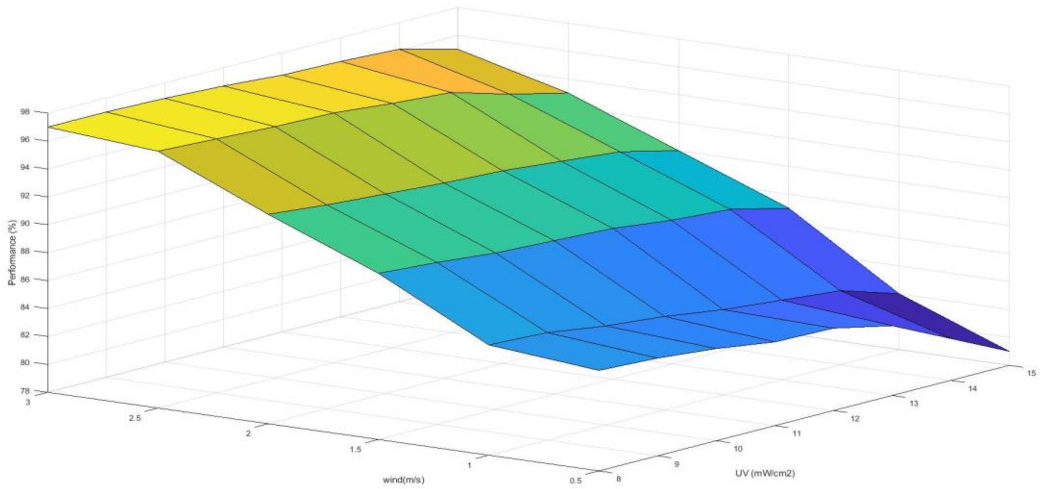


Figure 80 MATLAB simulation for degradation of performance.

The table 2 below shows the combination of findings into data of wind effect on performance at lower UV radiation levels to plot 3D surfacing plotting to show the trend.

Table 2 Wind effect on performance at below 8mW/cm²

Wind/UV	5.5	5	4.5	4	3	2	1
0.5	67.9	67.4	66.1	65.7	65.2	64.8	64.3
1.0	71.8	71.0	70.6	69.8	69.3	69.0	68.8
1.5	75.8	75.3	74.7	74.2	73.7	73.5	73.01
2.0	78.7	78.25	77.68	77.2	77.0	76.7	76.3
2.5	82.6	82.0	81.7	81.01	80.8	80.5	79.9
3.0	85.8	85.2	84.9	84.1	83.4	83.1	82.6
3.5	88.1	87.7	87.0	86.6	86.3	86.0	85.6
4.0	90.4	90.0	89.6	89.1	88.7	88.28	87.2
4.5	93.6	93.0	92.4	92.0	91.8	91.3	91
5.0	95.6	95.0	94.9	94.3	93.8	93.20	92.2
5.5	96.5	96.2	96.0	95.3	95.01	94.7	94.3

Using the equivalent temperature levels of the location and the wind speed trends at low ultraviolet radiation levels, figure 81 illustrates how wind speed trend affects solar PV performance at low UV radiation levels. From the findings it has been proven that PV system performance increases with increasing UV radiations levels. Furthermore, PV system materials are susceptible to degradation at 8mW/cm² UV levels and above, requiring temperature management to improve performance and system lifespan. The period of higher UV levels requires wind accessibility around the system, allowing the temperature levels to be controlled.

The wind can also cause the PV system to underperform when UV levels are low, and the temperature also low. In conditions where UV levels are below 5mW/cm² and the temperature is below 16°C, wind speed slightly impacts performance. Observations were made in England, Wales, and Chennai, which have low temperatures in some seasons. Figure 81 also shows the wind effect on performance at low UV levels. The secondary axis represents UV levels, and the x-axis represents wind speed. According to the y-axis, performance decreases with increasing wind speed.

Based on the analysis of data from this research study, it was found that as wind speed increases at lower UV levels, performance level drops slightly, but to varying degrees at different levels. In summary whenever the wind speed is high at lower UV levels, the PV system's performance is reduced.

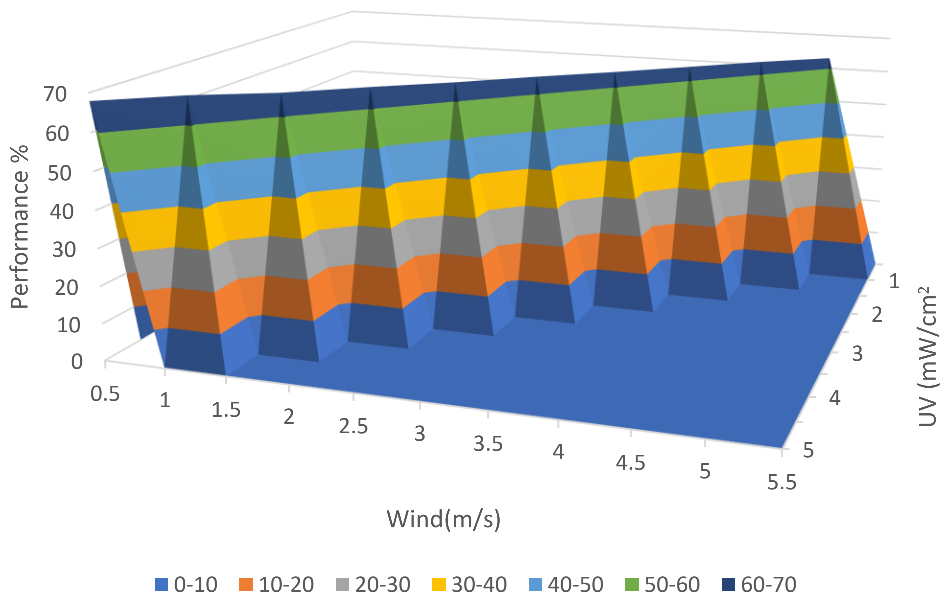


Figure 81 wind effect pattern on performance below 5mW/com² UV levels.

7.2 Using neural Network Intelligence programming for the results of analysis.

A neural network is a type of intelligent learning approach that is inspired by the way neurons communicate in the brain. The use of neural networks is especially suitable for modeling nonlinear relationships in speech, vision, and control systems to perform pattern recognition and classify objects or signals.

The purpose of this section is to provide software programming based on the findings of the research study of the empirical data of the PV system energy generation. For example, using neural network intelligence to write a program based on the findings of the research to predict future performance. To represent the inputs used in the analysis of PV performance, empirical data from all PV systems are used. As can be seen from the data analysis of all locations, UV, temperature, wind, and rainfall are related, but to a varying extent depending on the intensity of each. Regardless of location or country, the pattern of effects of all inputs extrapolated from individual system performance in each system location is the same.

Additionally, neural networks are excellent tools for addressing complex problems with handling huge data to give a single output such as this research. Modeling nonlinear and complex relationships can be achieved using neural networks; which can offer generalizations, can reveal hidden relationships, patterns, and predictions; and they can make predictions based on highly volatile data and variances. The neural network ability to identify anomalies provides the opportunity to obtain single results from multiple inputs to give near-accurate predictions. The ability of neural networks to predict PV system performance can assist with the decision-making process of installing a PV system in a particular location, which can help improve scientific and business decisions. Predicting the system performance is based on the analysis of the data and the findings made from the research results or findings from using rainfall, temperature, wind, and ultraviolet radiation as inputs to predict the performance of the PV system.

With the neural network programming, the four inputs from different locations were combined to provide a generic single output for all the locations. The neural network intelligence concept is used to predict an output closest to exact when you have several inputs. The concept is now used to give an output performance by calculation based on the intelligence prediction of input data fed into the programing comparison. This can be applied to solar systems in any location to provide performance forecast with the following input conditions, temperature, wind, rainfall, and ultraviolet radiation if all the data are available. The information can now be used in the program to predict how PV system will perform before the installation of a solar PV system either by an individual or investors.

7.3 The programing.

In this section I will be showing how I managed to approximate a 4-variable function with neural network regression methods which is somehow a simple task to do. With the use of MLP (Multi-layer Perceptron), one of the simplest neural network modules, the code is written in Python using only NumPy and Pandas libraries. The TensorFlow library can also be used for much simpler code, but we decided to do the coding ourselves since this is not a complex problem.

1. **Reading data**

For the analysis, 4 independent variables were used, with one dependent variable. To use the data for the network, we convert it to a matrix with four rows and one column by using pandas and NumPy.

2. **Normalizing data**

Considering we will multiply the input matrix and weight matrix many times, it's not unlikely that the values get too large over time and take a long time to process. To avoid this, we can basically fit all our data to the range of [0, 1] or in some cases [-1, 1] etc.

This process is called normalizing and we use it before feeding data into the network and as a result, the network only gets small numbers to work with.

3. **Creating feed forward**

A feed forward model is one where inputs and weights are multiplied and then biases are added. Then passing it through an activation function. In summary, matrices are used to do multiplications because they are easier to use with many multiplications. The input to layer 2 will be output of layer1 and the input to layer 3 is the output of layer 2 etc. The network consists of 6 hidden layers and 2 input and output layer. Each hidden layer has 32 neurons and the total number of neurons in the network is 192.

$$laver1\ out = \begin{bmatrix} w11 & w21 & w31 & w41 \\ w21 & w22 & w32 & w42 \\ w31 & w32 & w33 & w43 \\ w41 & w42 & w43 & w44 \\ w51 & w52 & w53 & w54 \\ w61 & w62 & w63 & w64 \end{bmatrix} \begin{bmatrix} i1 \\ i2 \\ i3 \\ i4 \end{bmatrix} + biases \xrightarrow{acrivation\ Function} inpu\ of\ layer\ 3$$

4. **Activation function**

Using the ReLU (Rectified Linear Unit) activation function which is a routine approach for simple regression problems like this. This simple method is surprisingly effective because it requires little training time and requires no complicated calculations.

$$f(x) = \begin{cases} 0, & x < 0 \\ x, & x \geq 0 \end{cases}$$

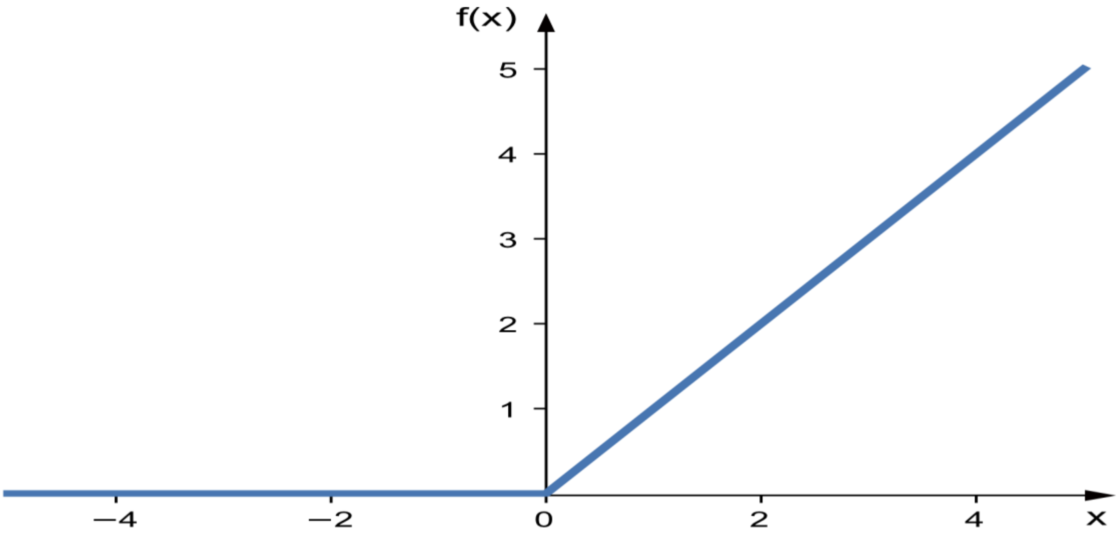


Figure 82 Rectified Linear unit approach graph.

5. **Calculating loss:**

By comparing the predicted value against the real output, we can determine the error of the model. The next step will involve adjusting the weights and biases and determining whether the error decreases. Loss means the error of the network. There are different formulas for calculating loss but turns out that MSE (Mean Squared Error) is one of the most bests for regression problems.

$$\text{MSE} = \frac{1}{n} \sum_{i=1}^{n} (y_i - \tilde{y}_i)^2$$

6. **Optimizer:**

Our optimizer is going to be required to adjust all those parameters in every training period. In spite of the fact that you may think we can adjust parameters randomly to produce a good result. Gradient descent methods and derivatives are used by the Optimizer to minimize the number of epochs necessary to adjust the parameters as efficiently as possible. An epoch means training the whole network for one cycle. They are different optimizers like SGD, RMS Prop and etc. We have decided to use Adam optimizer which gave us the best results.

7. **Saving the parameters:**

In order to get the best result, we save the new parameters that we used after reaching the target loss. Otherwise, we will have to train the network every time we want to use the program. As training the network takes some time while using a lot of processing power, saving the parameters is the most efficient way.

8. **Drawing the real performance vs Predicted performance graph:**

The program draws a plot after the training is finished. X axis shows the real performance value which is in our dataset and the Y axis shows the Network output.

The more the real and predicted performance match with together, the closer the slope gets to 45 degrees. It can be seen on the graph that the slope is very close to 45 degrees, so the network is doing a good job and the error is low.

9. **Final results:**

In order to determine performance with an ignorable error, we simply load the save data and run the program. Figure 83 illustrates how an example neural network can be implemented with rainfall, wind, temperature, and UV inputs in order to predict the location's performance with a percentage error. Also illustrated in figure 83 is the flow chart of the development of a neural network that can predict future PV system performance based on the following inputs: wind, temperature, rainfall, and ultraviolet radiation.

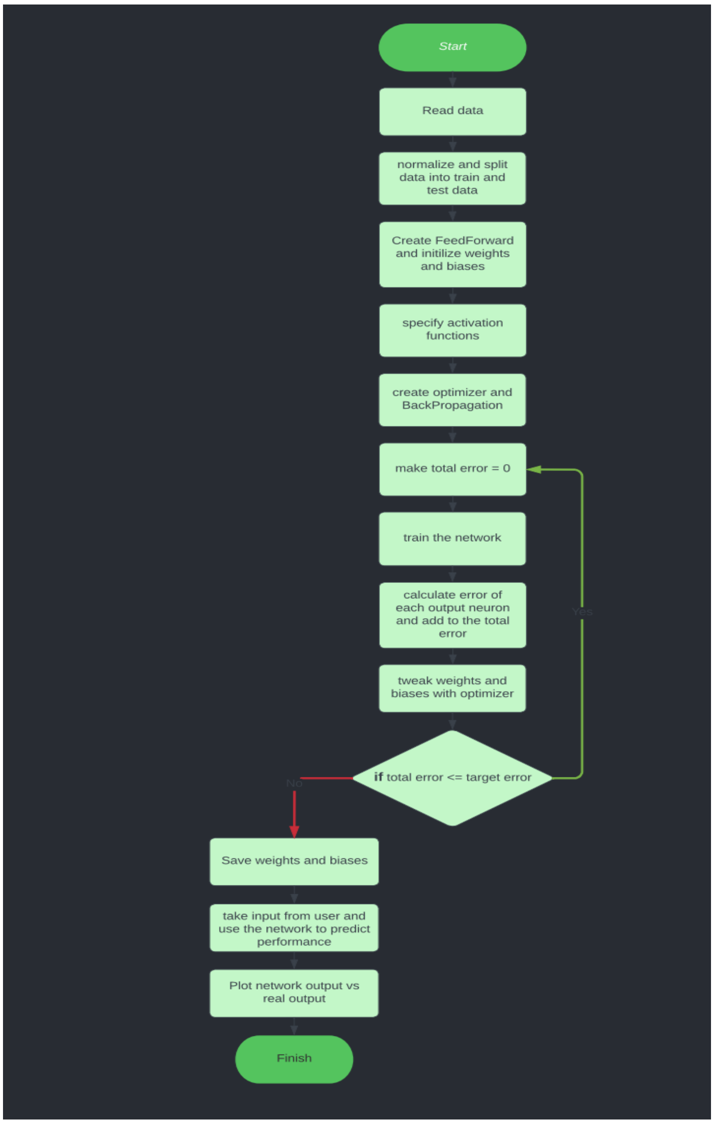


Figure 83 Neural network programming flow chart

In Figure 84, you will see an example of a PV system performance prediction based on your location's wind speed, temperature, rainfall, and UV radiation.

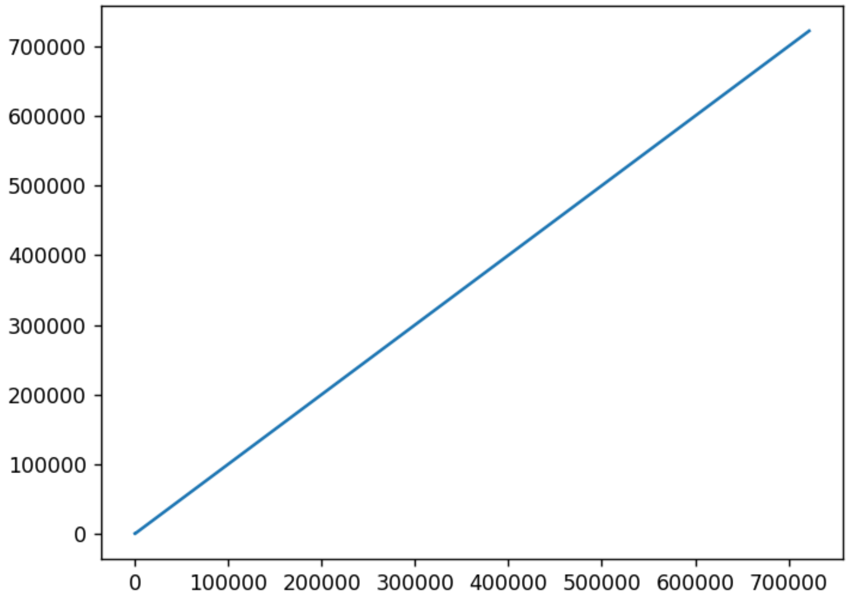


Figure 84 neural network results of inputs of wind, temperature, rainfall, and UV.

By utilizing neural network programming developed, the output performance of a typical domestic installation in Wales can be verified based on the input parameters. A neural network simulation can be used to demonstrate PV system efficiency during the different seasons for 2018. The four seasons of Spring, Summer, Autumn, and Winter can be used to calculate each season's performance. Using the average input parameter over the seasons, this data is generated.

Table 3 Performance comparison of PV system data and neural network prediction.

Seasons	PV system Power (KW)	Perf %	Wind (m/s)	Rainfall (mm)	Tempt (°C)	UV (mW/cm²))	N. Network estimated Power (KW)	N. Network Perf [%]
Winter	68.5	7.9	3	100.5	9.8	0.5	66	6.9
Summer	321.4	37.3	2.6	99.5	19.8	15	298	31.2
Autumn	137.3	15.9	2.8	170.7	14.1	8.7	268	28.1
Spring	334.1	38.8	3.03	93.3	13.7	3.4	320	33.6
Total	**861.3**						**952**	

Perf= performance   N. Network = Neural network

According to the neural networking program, the winter estimate is 6.9% with 0.04 error percentage as shown in figure 85, which is close to what the actual data of 7.9% shows.

As can be seen from the results, power generation increases with increasing UV, suggesting a doubt in the UV data recorded by the residential instrument, which cannot be verified. The calibration from neural network programming gives clear and accurate expected performance for normal winter conditions.

```
 enter the values in the given order: Tempreture , wind, UV, Rain
 *Note*: you have to press enter after you type each value

9.8
3
0.5
100.5
error_percent: [[0.0444503]]

selected data for calibiration: [  8.57   3.9    2.3  103.8 ]
Network prediction: [[65.02179944]]
Final prediction: [[65.56899812]]
```

The neural network estimate for summer performance is 31.2% with 0.006 percentage error after calibration as shown in figure 86. The actual PV system performance for summer is 37.3%. By comparing both data, the neural networking program gives a clear indication of expected performance with average summer conditions.

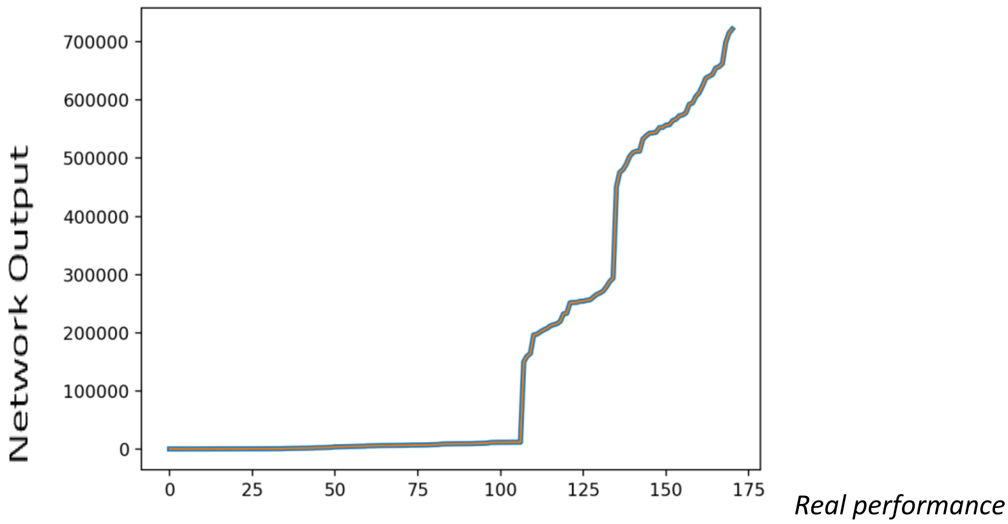
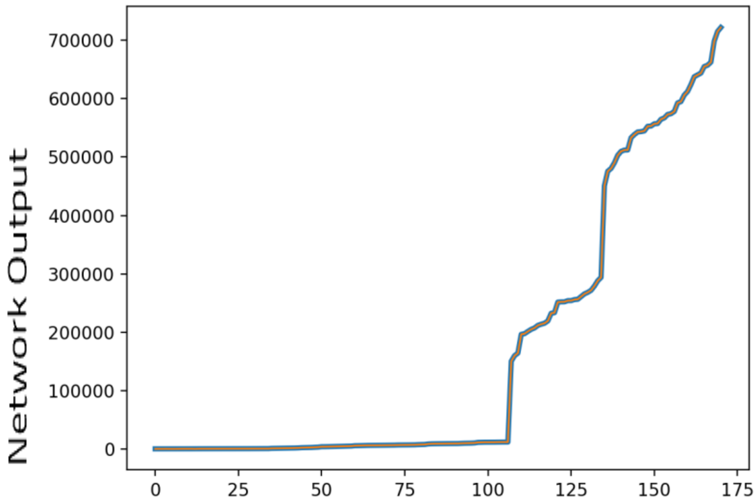


Figure 85 Winter neural network estimate

```
 enter the values in the given order: Tempreture , wind, UV, Rain
 *Note*: you have to press enter after you type each value

19.8
2.6
15
99.5
error_percent: [[0.00607718]]

selected data for calibration: [19.55  2.4  16.   90.  ]
Network prediction: [[298.92306752]]
Final prediction: [[297.34169594]]
```



Real performance

Figure 86 Summer neural network estimate

In summary, using neural network programming will provide a clear baseline estimated performance for PV systems at all locations assuming the same input parameters are used in all locations. The result is an accurate prediction of expected performance at any location with the lowest error percentage possible.

7.4 Payback comparison of PV system actual performance and the neural network prediction.

PV system payback is the amount of time it takes for a solar power system to generate enough energy savings to recoup its initial investment cost. The payback period for a PV system varies depending on several factors, including the cost of the system, the amount of electricity it generates and feed-in tariff.

The latest Feed-in Tariff for 2023 by Ofgem is 0.12p for domestic installation up to 4KWh (Ofgem, 2023). The average cost for domestic solar up to 2KWh is £2,600 (E.ON, 2023)

Table 4 Payback calculation of energy generation and Neural network prediction.

Performance	PV system (KW)	Neural network Prediction (KW)
Yearly total	Annual generation = 861 Annual energy cost savings = 861kWh x 0.12/kWh = £103.32 Cost of installation = £2,600 (£2,600/103.32) Payback period =25 years	Annual generation = 952 Annual energy cost savings = 952kWh x 0.12/kWh = £114.24 Cost of installation = £2,600 (£2,600/114.24) Payback period = 22.8 years

According to the above calculation of the payback duration for residential solar PV installations in real time, the process will take 25 years. When neural networks are programmed on the same system, the payback duration is 23 years.

8.0 Conclusion and recommendation.

Research results identified some unique and generalised trends between weather conditions and solar PV system performance. The findings of some of the studies were actually in agreement with those of other research studies. As a major factor that determines the performance of a PV system, the UV also play an important role in the performance of other environmental factors such as rainfall, wind, and temperature.

8.1 Ultraviolet radiation influence on PV system performance.

Throughout all locations, UV levels are correlated with performance, temperature, rainfall, and wind speed. The amount of UV radiation increases with an increase in temperature and decreases with an increase in rainfall and wind speed.

In all locations, UV radiation levels increased PV system energy generation performance levels, but they also contributed to performance reduction the same way. For example, there were remarkably similar UV levels observed in Ghana during both wet and dry seasons, measuring 12 $mWcm^2$-$13mWcm^2$. In the dry season, however, fewer rainfall activities occurred at the system location, resulting in longer exposure to UV radiation.

Because UV radiation increases with increasing temperature, but decreases with increasing rainfall, the rain during the wet season provided some relief from UV exposure. This led to less impact on performance than during the dry season, when PV panels were exposed for prolonged periods of time. A key point of degradation in PV modules has been proven to be prolonged exposure to ultraviolet radiation (Dunn, et al., 2013). According to the results of the prolonged UV degradation of modules, higher UV exposure causes more severe chemical degradation, which can affect module performance by affecting solar cell condition (Liu, et al., 2014).

There is no doubt that constant UV radiation exposure had a significant impact on the performance of PV panels during the dry season. According to the future projection using the first three years, during the dry season, the modules will perform 94% lower due to sustained and prolonged exposure to elevated UV levels. The UV is then a critical factor in determining the rate at which PV performance will degrade during the lifetime of the PV system. Providing decent UV radiation can improve performance, but prolonged and continuous exposure can be a problem and affect the lifespan of PV systems.

8.2 Temperature influence on PV system performance.

The results of data analysis indicate that UV levels increase with increasing temperature in all of the studied locations. When temperatures reached 32°C, the performance of Navrongo and Seattle PV systems was adversely affected. In terms of projected degradation, what are the likely differences between the two systems? In 15 years', time, Seattle's PV system performance would have decreased by 30.4% and Ghana's PV system performance would have decreased by 94%.

There was a range of wind speeds from 2.8 m/s to 3.1 m/s and a range of temperatures between 24 °C and 32 °C for the Seattle system. It was estimated that moderated UV levels, which depend on the temperature, ranged between 6.8 mW/cm² and 8.5 mW/cm². However, Navrongo had wind speeds ranging from 1.5m/s to 2.05m/s, temperatures between 28.6°C and 32.2°C, and UV radiation levels ranging from 8.5mW/cm² to 12.8mW/cm².

Several research studies have shown that when the temperature increases, the performance of solar cells decreases, affecting the amount of energy produced (Kant, et al., 2016). Temperature and UV radiation content that is transmitted through the EVA encapsulant are two major external parameters that can influence PV panel materials (Oliveira, et al., 2018) to affect its performance. The degradation of solar panels contributes to their reduced performance; therefore, it is essential to introduce cooling methods to slow down the degradation of panels and to improve performance in the system as a whole. (Siecker, et al., 2017). Accordingly, the Seattle system, which enjoyed a cooling wind from the sea, was able to minimise the performance degradation compared to the Navrongo system, which experienced very little wind speed, making it difficult to provide enough cooling to reduce degradation. In Seattle - USA, wind speed levels acted as passive cooling for the PV panels during hot temperature levels, which is particularly important to prolong the lifespan of the PV system compared to the PV system in Navrongo - Ghana. There is enough evidence I n this study, cooling methods provide a highly effective way to improve PV performance through temperature control.

8.3 Wind speed influence on PV system performance.

There has been a great deal of research done on the importance of temperature management in PV systems during hot weather**.** A key factor in managing temperature during energy generation is wind accessibility around the PV system. According to the studies, wind availability around PV system locations is equally important to prolonging the lifespan of PV systems. As a result of continuous exposure to higher levels of UV radiation and temperature, wind availability helps slow down the rate at which PV modules degradation. There was evidence of this in Seattle, Washington, Chennai, India, and Navrongo, Ghana.

Chennai experiencing summer temperatures of 33°C-36°C while Seattle experienced temperatures of 24°C-32°Cm, which are similar to Ghana's temperatures of 28.6°C to 32.2°C. It was found, however, that the rate of degradation in Navrongo was higher than in Chennai and Seattle, due to a faster rate of degradation. The difference is the availability of wind in Seattle and Chennai, as these two locations naturally receive more wind from the seaside, compared to Navrongo in Ghana, which has a dry environment with little wind, which is an opposite to what occurred in Seattle.

However, at lower temperature levels which are equivalent to below 6mW/cm² UV levels especially in Wales and England the PV performance of the system is slightly affected by too much cooling by increasing in wind speed. According to future projections, Seattle and Chennai will experience a slower degradation and longer lifespan since wind helps to manage temperature effects, thus prolonging the PV module's lifespan.

8.4 Summary

A data analysis of PV system energy generation data collected from four different continents across the globe reveals the effects of weather conditions on PV system performance. A neural network model developed from data study can, however, accurately predict future PV performance if average weather conditions of wind, rainfall, temperature, and UV levels are known. As a result, solar power investors and individuals interested in getting into solar power will make more informed decisions about where to install a PV system.

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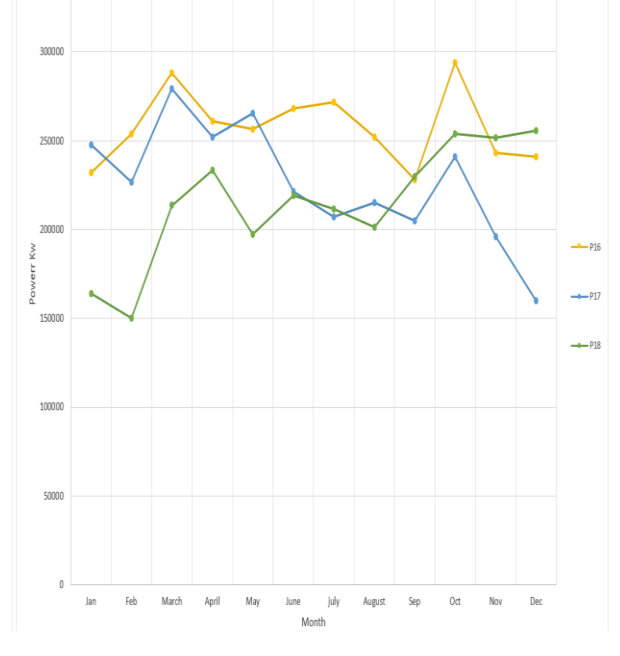
Appendix A- Nadvrongo-Ghana.

The appendix shows the empirical PV system and weather conditions data.

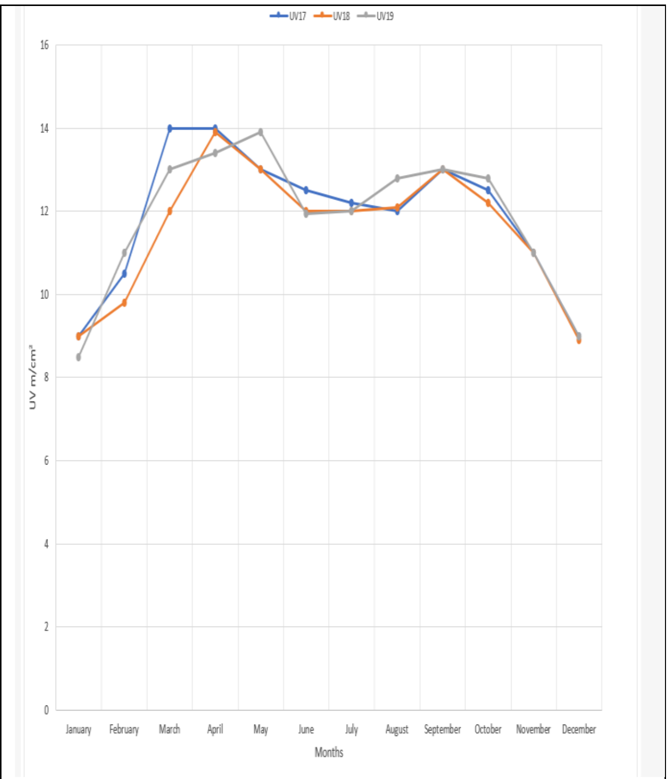
PV data Kw

	2017	2018	2019
January	232273.5	247545.5	164068.4
February	253992.2	226826.6	150099.3
March	288082.1	279046.4	213591.1
April	260915.4	251897.7	233362.6
May	256350.8	265572.1	197409
June	268192.3	221445.4	219214.7
July	271694.7	207199.6	211571.6
August	251972	215260.5	201237.6
September	227921.9	204777.1	229796.7
October	293830.4	240877.5	254047.9
November	243036.3	196201.5	251443.4
December	240899.5	159719.6	255798.9

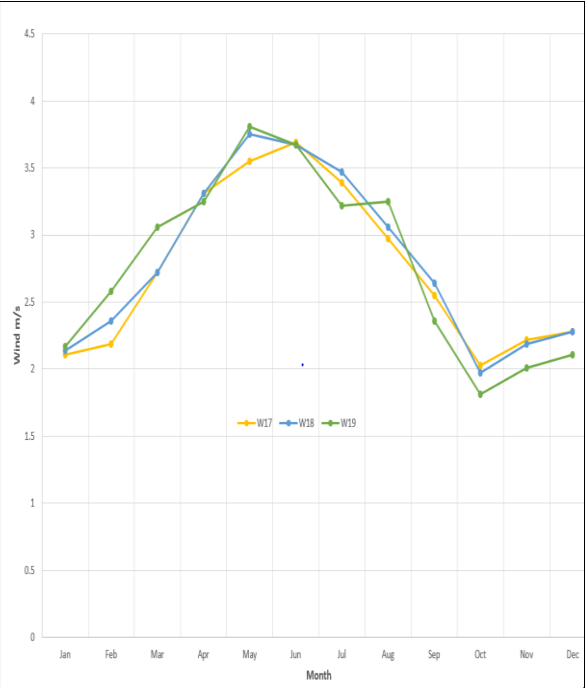


UV

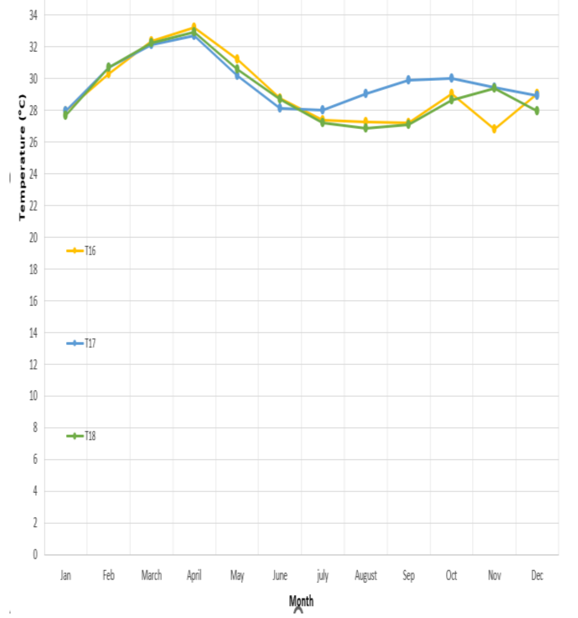
	2017	2018	2019
Jan	9	9	8.5
Feb	10.5	9.8	11
March	14	12	13
April	14	13.9	13.4
May	13	13	13.9
June	12.5	12	11.95
july	12.2	12	12
August	12	12.1	12.8
Sep	13	13	13
Oct	12.5	12.2	12.8
Nov	11	11	11
Dec	9	8.9	9



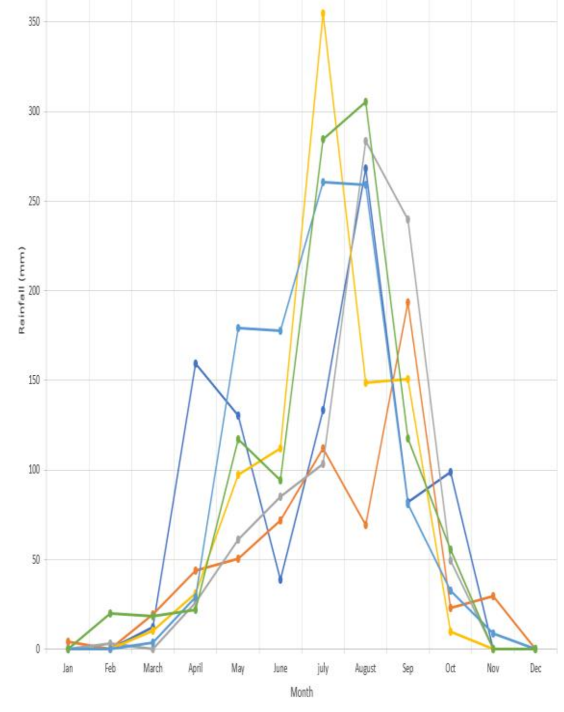
wind speed m/s	2017	2018	2019
Jan	2.05777	2.05777	2.05777
Feb	1.54333	1.54333	1.54333
March	1.02888	1.02888	1.54333
April	1.54333	1.54333	1.54333
May	1.54333	1.54333	1.54333
June	1.54333	1.54333	1.54333
july	1.54333	1.54333	1.54333
August	1.54333	1.54333	1.54333
Sep	1.54333	1.54333	1.54333
Oct	1.54333	1.54333	1.02888
Nov	1.54333	1.02888	1.02888
Dec	1.88333	1.99333	1.94333



tempt(°C)	2017	2018	2019
Jan	27.95	27.95	27.65
Feb	30.3	30.7	30.7
March	32.35	32.1	32.2
April	33.2	32.7	32.9
May	31.2	30.15	30.55
June	28.75	28.1	28.65
july	27.35	28	27.2
August	27.25	29	26.85
Sep	27.2	29.9	27.1
Oct	29	30	28.6
Nov	26.8	29.4	29.35
Dec	29	28.9	27.95



rainfall (mm)			
	2017	2018	2019
Jan	0	0	0
Feb	0	0	19.8
March	10.5	3.6	18.5
April	30.9	29.1	21.8
May	97.1	179.1	117.1
June	112.2	177.8	94.2
july	354.9	260.6	284.5
August	148.9	259	305.6
Sep	150.5	81.2	117.5
Oct	10	32.6	55.8
Nov	0	8.9	0
Dec	0	0	0

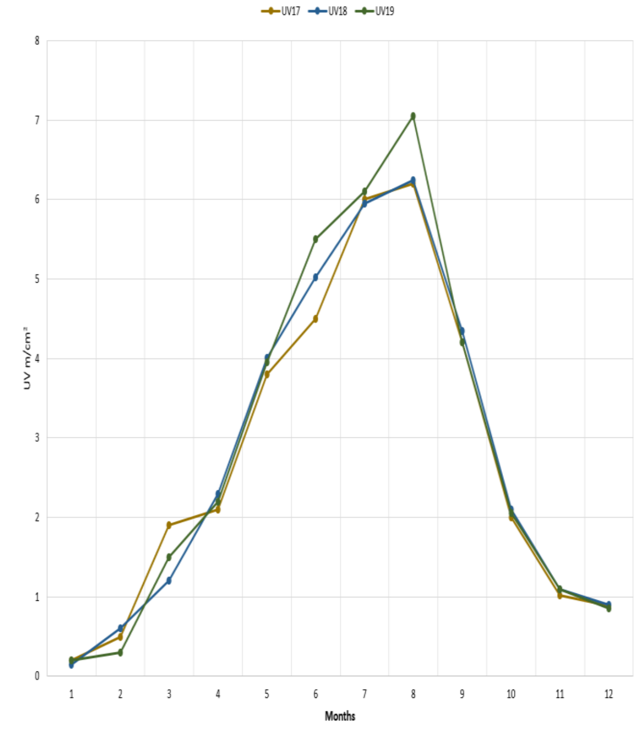


Appendix B-High Wycombe -England.

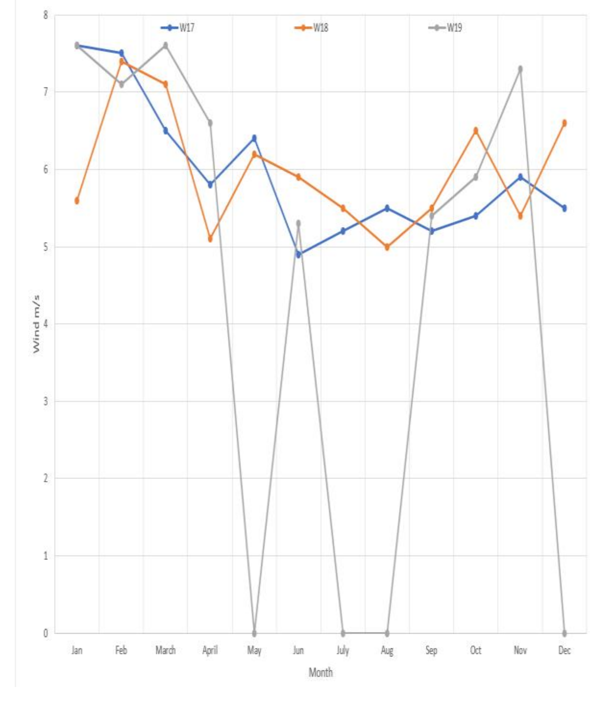
PV system energy generation data

PV data			
	2017	2018	2019
Jan	974	1011	836
Feb	2120	1477	2388
March	4130	3667	2724
April	5634	5450	4410
May	7245	6239	7536
June	5387	6771	7414
july	6709	6034	8306
August	6644	6405	5934
Sep	3904	3843	4803
Oct	2952	2292	3691
Nov	1675	2013	1406
Dec	1266	1132	912

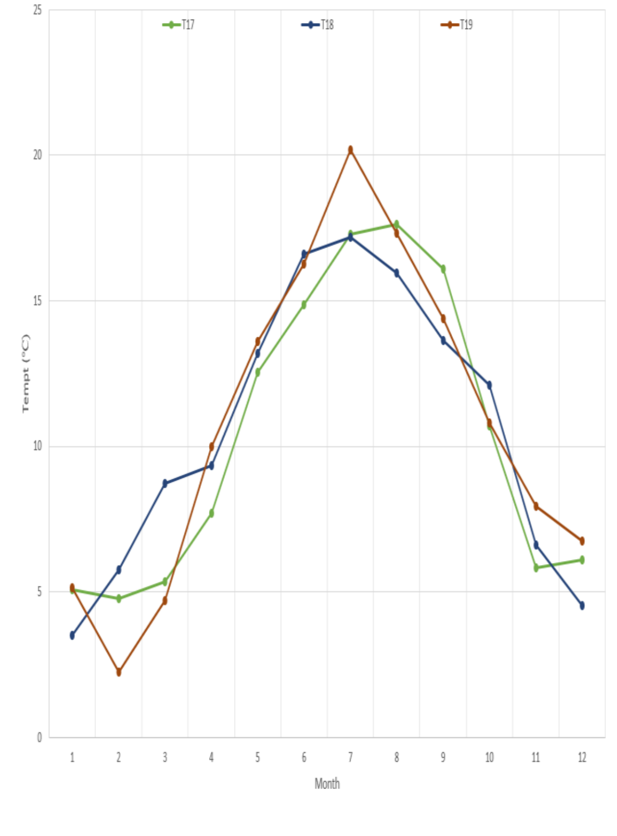
	UV index		
	2017	2018	2019
Jan	0.2	0.15	0.2
Feb	0.5	0.6	0.3
March	1.9	1.2	1.5
April	2.1	2.3	2.2
May	3.8	4.01	3.95
June	4.5	5.02	5.5
july	6.01	5.95	6.1
August	6.2	6.25	7.05
Sep	4.2	4.35	4.2
Oct	2	2.1	2.05
Nov	1.02	1.1	1.09
Dec	0.89	0.9	0.85



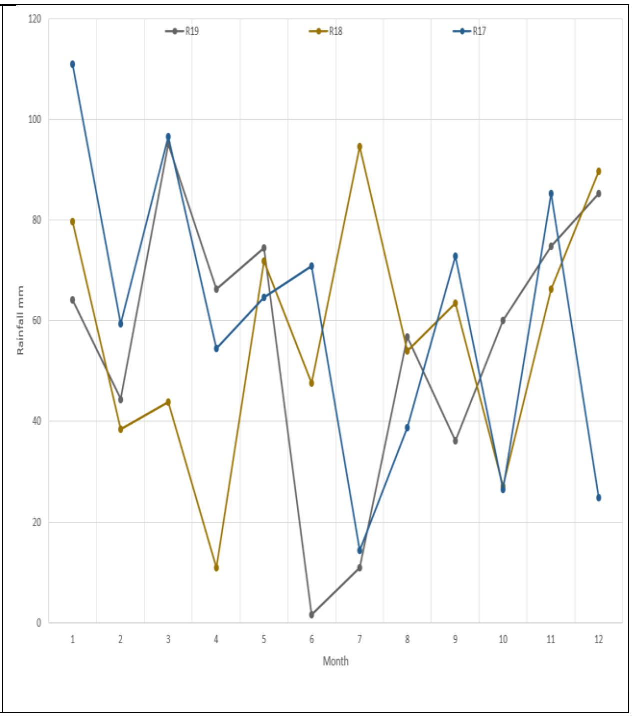
	Wind m/s		
	2017	2018	2019
Jan	7.6	5.6	7.6
Feb	7.5	7.4	7.1
March	6.5	7.1	7.6
April	5.8	5.1	6.6
May	6.4	6.2	0
June	4.9	5.9	5.3
july	5.2	5.5	0
August	5.5	5	0
Sep	5.2	5.5	5.4
Oct	5.4	6.5	5.9
Nov	5.9	5.4	7.3
Dec	5.5	6.6	4



Tempt (℃)			
	2017	2018	2019
Jan	5.07	3.5	5.15
Feb	4.78	5.77	2.24
March	5.34	8.71	4.7
April	7.69	9.34	9.97
May	12.53	13.2	13.61
June	14.87	16.59	16.27
july	17.29	17.18	20.19
August	17.62	15.96	17.32
Sep	16.1	13.64	14.37
Oct	10.71	12.11	10.81
Nov	5.82	6.61	7.94
Dec	6.08	4.51	6.75



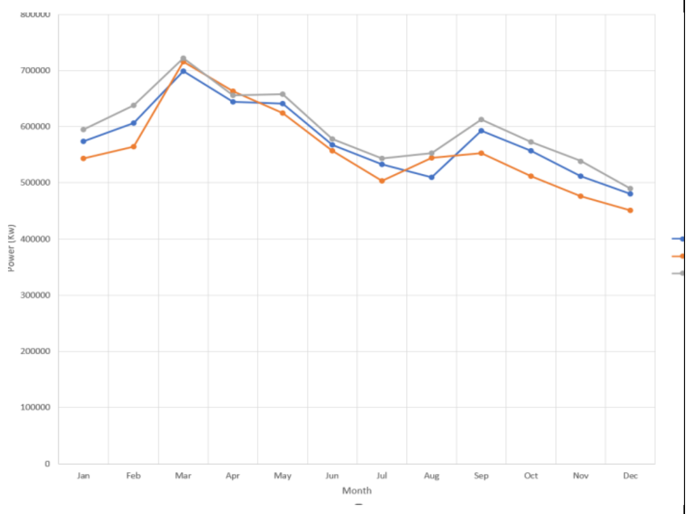
Rainfall mm			
	2017	2018	2019
Jan	111	79.6	64.2
Feb	59.4	38.4	44.4
March	96.6	43.8	95
April	54.4	11	66.2
May	64.6	71.8	74.4
June	70.8	47.6	1.6
july	14.4	94.6	11
August	38.8	54	56.8
Sep	72.8	63.4	36.2
Oct	26.4	27.2	60
Nov	85.2	66.2	74.8
Dec	24.8	89.6	85.2



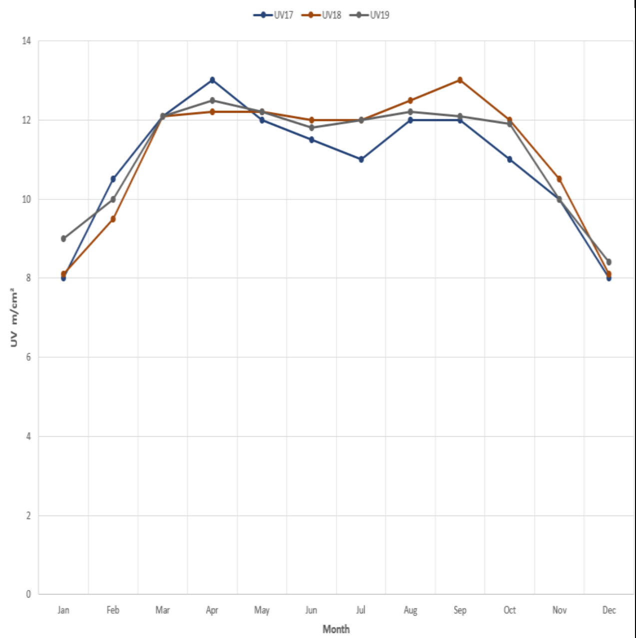
Appendix C- Chennai- Gummidipoondi- India

PV system energy generation data

PV KW	2017	2018	2019
Jan	595040	574320	543600
Feb	637760	606240	564720
Mar	722080	698640	715200
Apr	655200	643920	662640
May	657360	640800	624240
Jun	578200	567120	557040
Jul	543040	533040	503040
Aug	552720	509760	544800
Sep	612480	592800	553120
Oct	573040	557520	512000
Nov	538640	512160	475680
Dec	490086	480480	450874

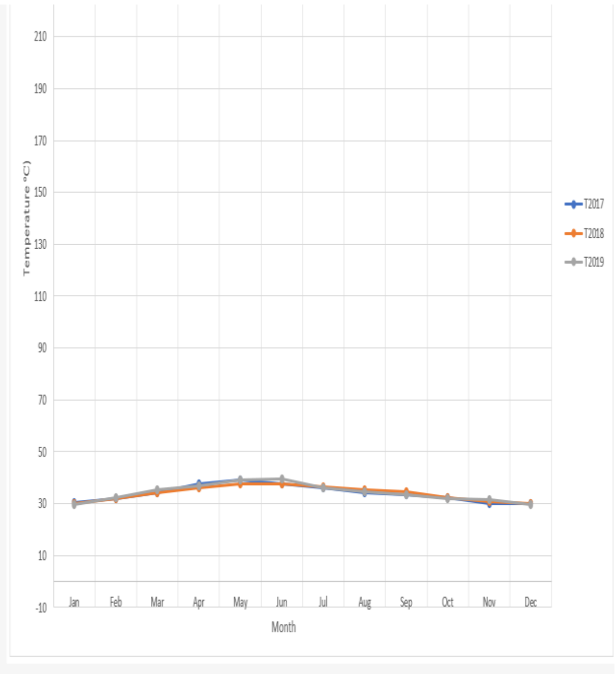


UVmWcm2	2017	2018	2019
Jan	8	8.1	9
Feb	10.5	9.5	10
Mar	12.1	12.1	12.09
Apr	13	12.2	12.5
May	12	12.2	12.2
Jun	11.5	12	11.8
Jul	11	12	12
Aug	12	12.5	12.2
Sep	12	13	12.09
Oct	11	12	11.9
Nov	10	10.5	10
Dec	8	8.1	8.4

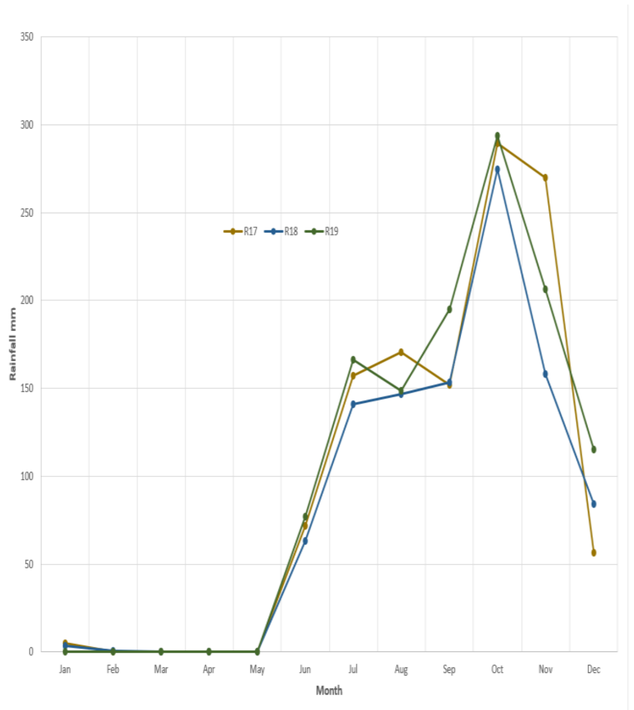


	Wind (m/s)		
	2017	2018	2019
Jan	2.11	2.14	2.17
Feb	2.19	2.36	2.58
Mar	2.72	2.72	3.06
Apr	3.31	3.31	3.25
May	3.55	3.75	3.81
Jun	3.69	3.67	3.67
Jul	3.39	3.47	3.22
Aug	2.97	3.06	3.25
Sep	2.55	2.64	2.36
Oct	2.03	1.97	1.81
Nov	2.22	2.19	2.01
Dec	2.28	2.28	2.11

	Tempt	(°c)	
	2017	2018	2019
Jan	30.4	30	29.6
Feb	31.8	31.9	32.2
Mar	34.4	34.3	35.2
Apr	37.5	36	36.8
May	39.1	37.6	39.2
Jun	37.8	37.8	39.7
Jul	36.2	36.5	36.1
Aug	34.4	35.3	34.7
Sep	33.4	34.6	33.4
Oct	32.5	32.4	32
Nov	29.9	30.8	31.7
Dec	29.9	29.9	29.7

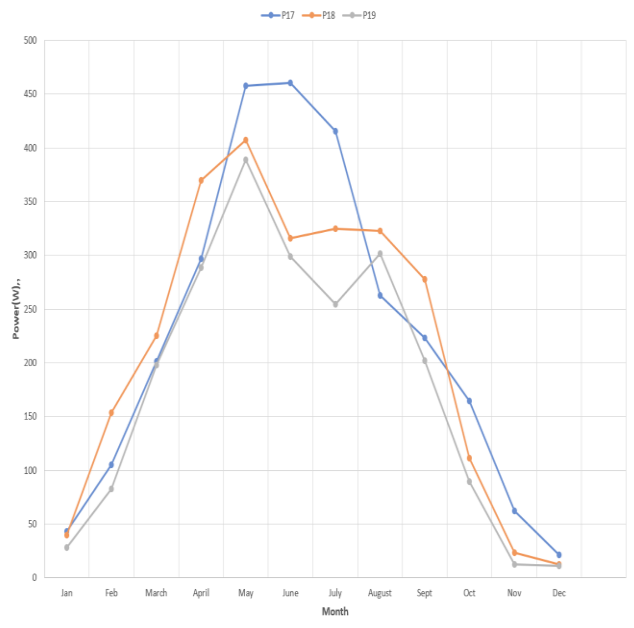


Rainfall(mm)			
	2017	2018	2019
Jan	5	3.5	0
Feb	0.3	0.5	0
Mar	0	0	0
Apr	0.2	0.2	0.2
May	0.3	0.25	0.21
Jun	72	63	77
Jul	157.2	140.8	166.5
Aug	170.5	146.7	148.6
Sep	151.9	153.4	195
Oct	289.5	274.6	293.5
Nov	270.1	158.4	206.2
Dec	56.4	84.2	115

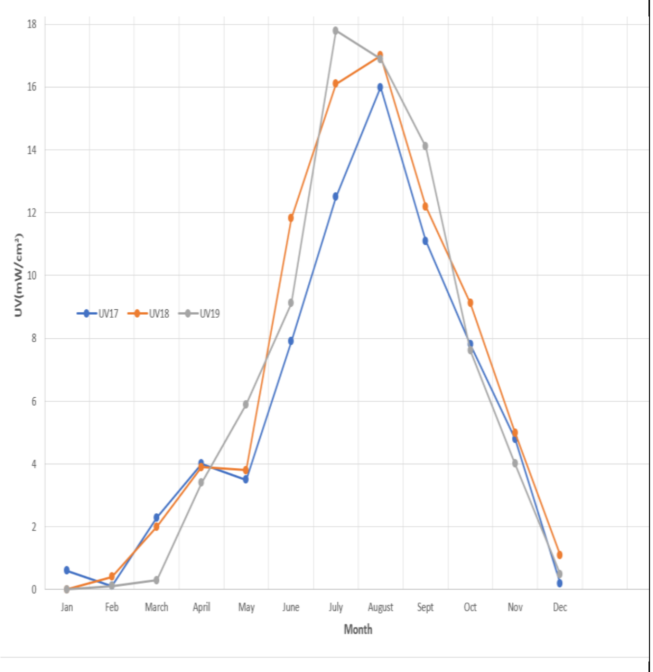


Appendix D Machynlleth-Wales

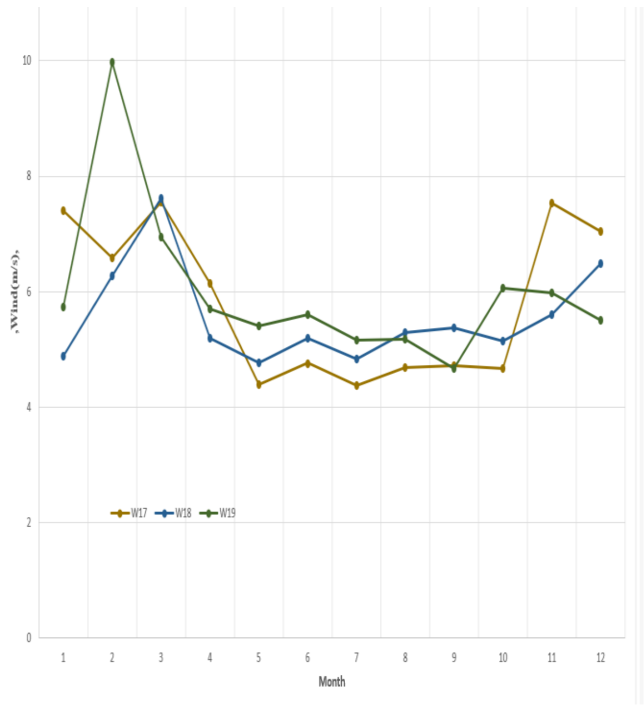
PV(W)			
	2017	2018	2019
Jan	43.25	39.73	28.1
Feb	105.19	153.73	83.04
March	201.68	225.49	198
April	297.01	369.66	289.02
May	457.56	407.2	388.9
June	460.83	316.11	299.05
July	415.26	324.97	254.9
August	262.46	322.99	301.6
Sept	223.48	277.58	202.1
Oct	164.59	111.19	89.7
Nov	62.35	23.11	12.57
Dec	21.53	12.2	10.98



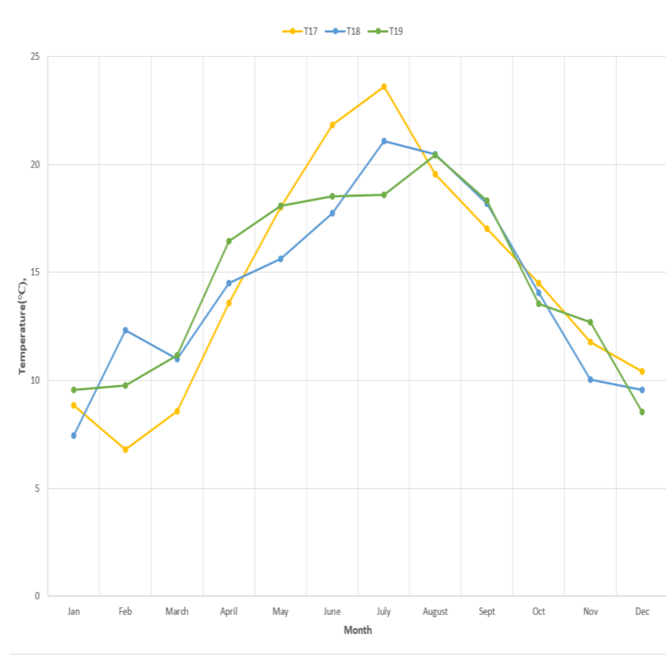
UVmWcm²	2017	2018	2019
Jan	0.6	0	0
Feb	0.1	0.4	0.1
March	2.3	2	0.3
April	4	3.9	3.4
May	3.5	3.8	5.9
June	7.9	11.8	9.1
July	12.5	16.1	17.8
August	16	17	16.9
Sept	11.1	12.2	14.1
Oct	7.8	9.1	7.6
Nov	4.8	5	4
Dec	0.2	1.1	0.5



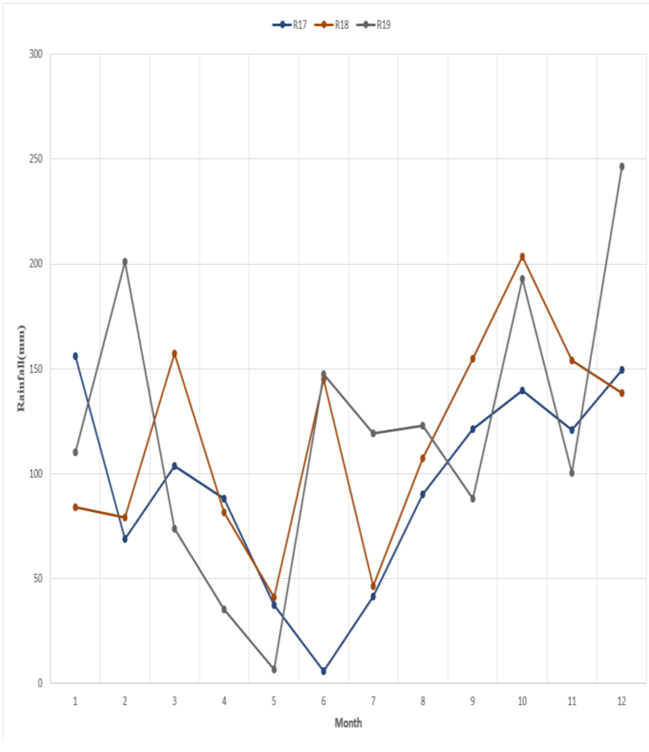
Wind m/s	2017	2018	2019
Jan	3.8	2.5	2.9
Feb	3.4	3.2	5.1
March	3.9	3.9	3.6
April	3.2	2.7	2.9
May	2.3	2.5	2.7
June	2.5	2.6	2.9
July	2.3	2.5	2.6
August	2.4	2.7	2.7
Sept	2.4	2.7	2.4
Oct	2.4	2.6	3.1
Nov	3.9	2.9	3.1
Dec	3.6	3.3	2.8



Tempt °C	2017	2018	2019
Jan	8.83	7.46	9.56
Feb	6.8	12.31	9.76
March	8.57	10.99	11.15
April	13.58	14.5	16.43
May	18.02	15.63	18.09
June	21.83	17.75	18.54
July	23.6	21.07	18.58
August	19.55	20.47	20.45
Sept	17.04	18.19	18.32
Oct	14.49	14.06	13.55
Nov	11.79	10.03	12.71
Dec	10.4	9.56	8.53



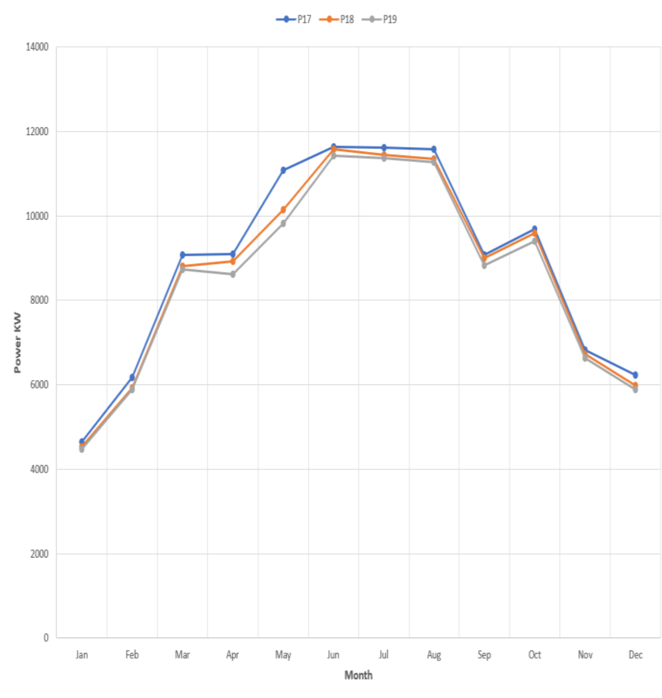
Rainfall mm	2017	2018	2019
Jan	156	84	110.2
Feb	68.8	79	201.2
March	103.8	157.2	73.6
April	88	81.4	35.2
May	37.4	41.2	6.8
June	5.8	144.8	147.6
July	41.6	46.4	119.4
August	90	107.4	122.8
Sept	121.4	155	88.2
Oct	139.8	203.4	192.8
Nov	120.8	153.8	100.2
Dec	149.4	138.6	246.6



Appendix E - Seattle Washington- USA

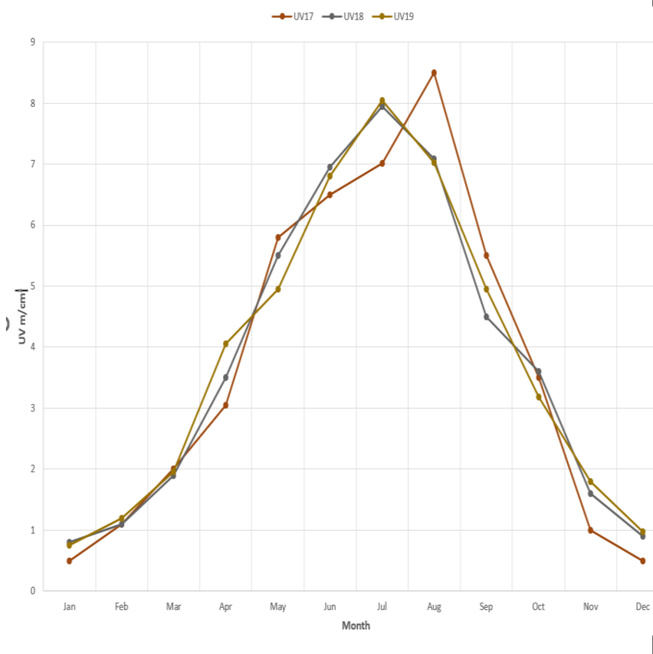
PV (KW)

	2019	2018	2017
Jan	4470	4541	4652
Feb	5894	5928	6167
Mar	8739	8802	9083
Apr	8627	8920	9089
May	9826	10154	11073
Jun	11432	11570	11641
Jul	11363	11448	11614
Aug	11264	11351	11579
Sep	8823	8991	9071
Oct	9396	9587	9679
Nov	6623	6731	6832
Dec	5883	5989	6231



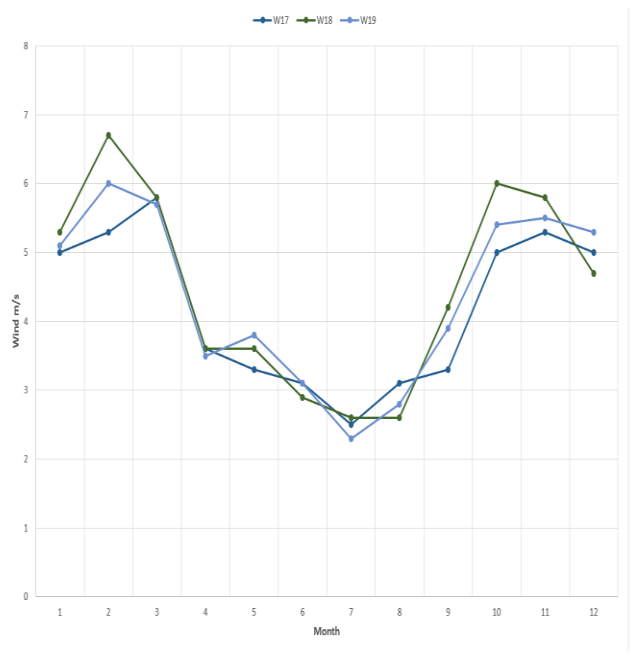
UVmWcm^2

	2017	2018	2019
Jan	0.5	0.8	0.75
Feb	1.1	1.1	1.2
Mar	2	1.9	1.95
Apr	3.05	3.5	4.05
May	5.8	5.5	4.95
Jun	6.5	6.95	6.8
Jul	7.01	7.95	8.05
Aug	8.5	7.09	7.02
Sep	5.5	4.5	4.95
Oct	3.5	3.6	3.18
Nov	1	1.6	1.8
Dec	0.5	0.9	0.98



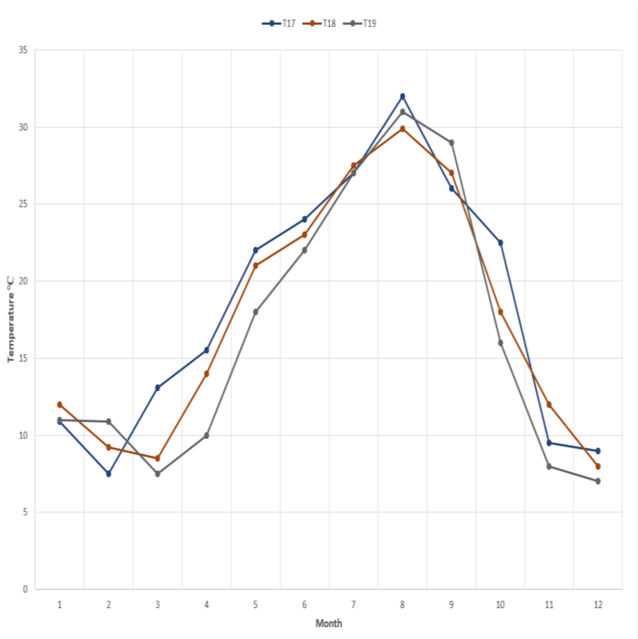
Wind m/s

	2017	2018	2019
Jan	5	5.3	5.1
Feb	5.3	6.7	6
Mar	5.8	5.8	5.7
Apr	3.6	3.6	3.5
May	3.3	3.6	3.8
Jun	3.1	2.9	3.1
Jul	2.5	2.6	2.3
Aug	3.1	2.6	2.8
Sep	3.3	4.2	3.9
Oct	5	6	5.4
Nov	5.3	5.8	5.5
Dec	5	4.7	5.3

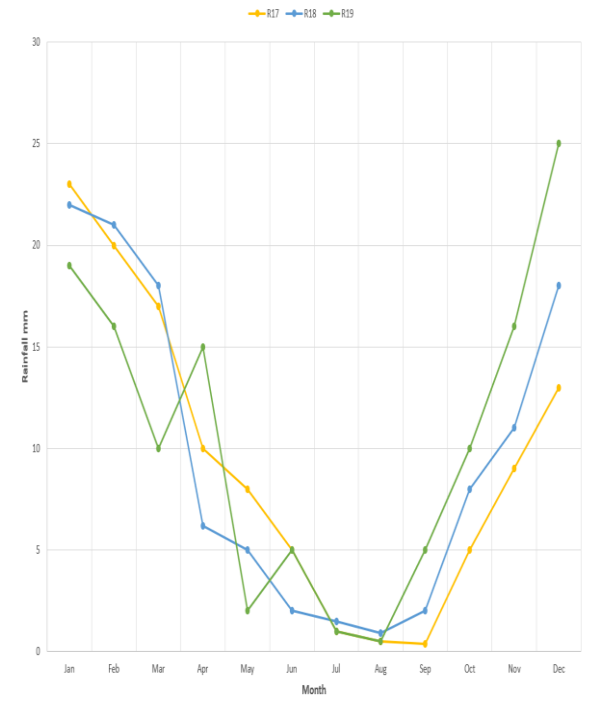


Tempt (℃)

	2017	2018	2019
Jan	11	12	10.9
Feb	10.9	9.2	7.5
Mar	7.5	8.5	13.1
Apr	10	14	15.5
May	18	21	22
Jun	22	23	24
Jul	27	27.5	27
Aug	31	29.9	32
Sep	29	27	26
Oct	16	18	22.5
Nov	8	12	9.5
Dec	7	8	9



	Rainfall(mm)		
	2017	2018	2019
Jan	19	22	23
Feb	16	21	20
Mar	10	18	17
Apr	15	6.2	10
May	2	5	8
Jun	5	2	5
Jul	1	1.5	1
Aug	0.5	0.9	0.5
Sep	5	2	0.4
Oct	10	8	5
Nov	16	11	9
Dec	25	18	13



Appendix F- Neural network programming file.

```
import numpy as np

import math

import pandas as pd

import matplotlib.pyplot as plt

import pickle

np.random.seed(100)

file = pd.read_csv("Data.csv")

X = np.array(file.iloc[108:,[0,1,2,3]])

y = np.array(file.iloc[108:,[4]])

class LayerDense:

def __init__(self, n_inputs,n_neurons,

 weight_regularizer_L1=0,

weight_regularizer_L2=0,

 bias_regularizer_L1=0,bias_regularizer_L2=0):

 self.weights = np.random.randn(n_inputs,n_neurons)

 self.biases = np.zeros((1,n_neurons))
```

```
 self.weight_regularizer_L1 = weight_regularizer_L1
 self.weight_regularizer_L2 = weight_regularizer_L2
 self.bias_regularizer_L1 = bias_regularizer_L1
 self.bias_regularizer_L2 = bias_regularizer_L2
def forward(self, inputs):
 self.inputs = inputs
 self.output = np.dot(inputs , self.weights) + self.biases
def backward(self,dvalues):
 self.dweights = np.dot(self.inputs.T, dvalues)
 self.dbiases = np.sum(dvalues, axis=0, keepdims = True)
 #L1 on weights
 if self.weight_regularizer_L1 > 0:
 dL1 = np.ones_like(self.weights)
 dL1[self.weights < 0] = -1
 self.dweights += 2 * self.weight_regularizer_L1 * dL1
 #L2 on weights
 if self.weight_regularizer_L2 > 0:
 self.dweights += 2 * self.weight_regularizer_L2 * \
 self.weights
 #L1 on biases
 if self.bias_regularizer_L1 > 0:
 dL1 = np.ones_like(self.biases)
 dL1[self.biases < 0] = -1
 self.dbiases += 2 * self.bias_regularizer_L1 * dL1
 #L2 on biases
 if self.bias_regularizer_L2 > 0:
 self.dbiases += 2 * self.bias_regularizer_L2 * \
 self.biases
 #gradiant on values
 self.dinputs = np.dot(dvalues, self.weights.T)
class LayerDropout:
```

```
def __init__(self, rate):
 self.rate = 1 - rate
def forward(self, inputs):
 self.inputs = inputs
 self.binary_mask =
np.random.binomial(1,sel.rate,size=inputs.shape)/self.rate
 self.output = inputs * self.binary_mask
def backward(self, dvalues):
 self.dinputs = dvalues * self.binary_mask
class ActivationReLU:
def forward(self, inputs):
 self.inputs = inputs
 self.output = np.maximum(0,inputs)
def backward(self,dvalues):
 self.dinputs = dvalues.copy()
 self.dinputs[self.inputs <= 0] = 0
class ActivationSoftmax:
def forward(self, inputs):
 self.inputs = inputs
 exponential_values = np.exp(inputs - np.max(inputs, axis = 1 ,
keepdims = True))
 probabilities = exponential_values / np.sum(exponential_values,
axis = 1 , keepdims = True)
 self.output = probabilities
def backward(self, dvalues):
 self.dinputs = np.empty_like(dvalues)
 #enumerate outputs and gradiants
 for index, (single_output, single_dvalues)in \
 enumerate(zip(self.output,dvalues)):
 single_output = single_output.reshape(-1,1)
 #jacobian of output
```

```
 jacobian_matrix = np.diagflat(single_output) - \
 np.dot(single_output,
single_output.T)
 self.dinputs[index] = np.dot(jacobian_matrix,
single_dvalues)
class ActivationSigmoid:
def forward(self, inputs):
 self.inputs = inputs
 self.output = 1/(1+ np.exp(-inputs))
def backward(self, dvalues):
 self.dinputs = dvalues * (1 - self.output) * self.output
class ActivationLinear:
def forward(self, inputs):
 self.inputs = inputs
 self.output = inputs
def backward(self, dvalues):
 self.dinputs = dvalues.copy()
class OptimizerAdam:
def __init__(self, learning_rate=0.01,
decay=0,epsilon=1e-7,beta_1=0.9,beta_2=0.999):
 self.learning_rate = learning_rate
 self.current_learning_rate = learning_rate
 self.decay = decay
 self.iterations = 0
 self.epsilon = epsilon
 self.beta_1 = beta_1
 self.beta_2 = beta_2
def pre_update_params(self):
 if self.decay:
 self.current_learning_rate = self.learning_rate * \
 (1./ (1. + self.decay * self.iterations))
```

```
def update_params(self,layer):
 if not hasattr(layer,'weight_cache'):
 layer.weight_momentums = np.zeros_like(layer.weights)
 layer.weight_cache = np.zeros_like(layer.weights)
 layer.bias_momentums = np.zeros_like(layer.biases)
 layer.bias_cache = np.zeros_like(layer.biases)
 #update momentum:
 layer.weight_momentums = self.beta_1 * \
 layer.weight_momentums+\
(1 - self.beta_1) * layer.dweights
 layer.bias_momentums = self.beta_1 * \
 layer.bias_momentums + \
(1 - self.beta_1) * layer.dbiases
 weight_momentums_corrected = layer.weight_momentums /\
 (1-self.beta_1 ** (self.iterations + 1))
 bias_momentums_corrected = layer.bias_momentums /\
 (1 - self.beta_1 ** (self.iterations + 1))
 layer.weight_cache = self.beta_2 * layer.weight_cache + \
 (1 - self.beta_2) * layer.dweights ** 2
 layer.bias_cache = self.beta_2 * layer.bias_cache + \
 (1 - self.beta_2) * layer.dbiases ** 2
 weight_cache_corrected = layer.weight_cache / \
 (1 - self.beta_2 ** (self.iterations + 1))
 bias_cache_corrected = layer.bias_cache / \
 (1 - self.beta_2 ** (self.iterations + 1))
 layer.weights += -self.current_learning_rate * \
 weight_momentums_corrected / \
(np.sqrt(weight_cache_corrected)+ self.epsilon)
 self.new_weights = layer.weights
 layer.biases += self.current_learning_rate * \
 bias_momentums_corrected / \
```

```
(np.sqrt(bias_cache_corrected) +
self.epsilon)
 self.new_biases = layer.biases
def post_update_params(self):
 self.iterations += 1
class Loss:
def regularization_loss(self, layer):
 regularization_loss = 0
 if layer.weight_regularizer_L1 > 0:
 regularization_loss += layer.weight_regularizer_L1 * \
 np.sum(np.abs(layer.weights))
 if layer.weight_regularizer_L2 > 0:
 regularization_loss += layer.weight_regularizer_L2 * \
 np.sum(layer.weights * \
 layer.weights)
 if layer.bias_regularizer_L1 > 0:
 regularization_loss += layer.bias_regularizer_L1 * \
 np.sum(np.abs(layer.biases))
 if layer.bias_regularizer_L2 > 0:
 regularization_loss += layer.bias_regularizer_L2 * \
 np.sum(layer.biases * \
 layer.biases)
 return regularization_loss
def calculate(self,output,y):
 sample_losses = self.forward(output, y)
 data_loss = np.mean(sample_losses)
 return data_loss
class LossCategoricalCrossentropy(Loss):
def forward(self,y_pred,y_true):
 #number of samples in a batch
 samples = len(y_pred)
```

```
 #clip data to prevent division by 0
 y_pred_clipped = np.clip(y_pred, 1e-7 , 1 - 1e-7)
 if len(y_true.shape) == 1:
 correct_confidences = y_pred_clipped[range(samples),
y_true]
 elif len(y_true.shape) == 2:
 correct_confidences = np.sum(y_pred_clipped * y_true,
axis = 1)

 negative_log_likelihoods = -np.log(correct_confidences)
 return negative_log_likelihoods
def backward(self, dvalues, y_true):
 samples = ln(dvalues)
 labels = len(dvalues[0])
 if len(y_true.shape) == 1:
 y_true = np.eye(labels)[y_true]
 self.dinputs = -y_true / dvalues
 self.dinputs = self.dinputs / samples
class ActivationSoftmaxLossCategoricalCrossentropy():
def __init__(self):
 self.activation = ActivationSoftmax()
 self.loss = LossCategoricalCrossentropy()
def forward(self, inputs, y_true):
 self.activation.forward(inputs)
 self.output = self.activation.output
 return self.loss.calculate(self.output, y_true)
def backward(self, dvalues, y_true):
 samples = len(dvalues)
 if len(y_true.shape) == 2:
 y_true = np.argmax(y_true, axis=1)
 self.dinputs = dvalues.copy()
```

```
 self.dinputs[range(samples), y_true] -= 1
 self.dinputs = self.dinputs / samples
class LossBinaryCrossentropy(Loss):
def forward(self, y_pred, y_true):
 y_pred_clipped = np.clip(y_pred, 1e-7, 1- 1e-7)
 sample_losses = -(y_true * np.log(y_pred_clipped) + (1- y_true)*
np.log(1 - y_pred_clipped))
 sample_losses = np.mean(sample_losses, axis = -1)
 return sample_losses
def backward(self,dvalues,y_true):
 samples = len(dvalues)
 outputs = len(dvalues[0])
 clipped_dvalues = np.clip(dvalues, 1e-7 , 1 - 1e-7)
 self.dinputs = -(y_true / clipped_dvalues - (1- y_true)/(1 -
clipped_dvalues))/outputs
 self.dinputs = self.dinputs / samples
class LossMeanSquaredError(Loss):
def forward(self, y_pred, y_true):
 sample_losses = np.mean((y_true - y_pred)**2, axis = -1)
 return sample_losses
def backward(self, dvalues, y_true):
 samples = len(dvalues)
 outputs = len(dvalues[0])
 self.dinputs = -2 * (y_true - dvalues) / outputs
 self.dinputs = self.dinputs / samples
class LossMeanAbsoluteError(Loss):
def forward(self, y_pred, y_true):
 sample_losses = np.mean(np.abs(y_true - y_pred), axis = -1)
 return sample_losses
def backward(self, dvalues, y_true):
 samples = len(dvalues)
```

```
 outputs = len(dvalues[0])
 self.dinputs = np.sign(y_true - dvalues) / outputs
 self.dinputs = self.dinputs / samples
class OptimizerSGD:
def __init__(self, learning_rate = 0.1):
 self.learning_rate = learning_rate
def update_params(self,layer):
 layer.weights += -self.learning_rate * layer.dweights
 layer.biases += -self.learning_rate * layer.dbiases
```