

Review

# A Critical Appraisal of PV-Systems' Performance

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**Abstract:** Climate change and global warming have triggered a global increase in the use of renewable energy for various purposes. In recent years, the photovoltaic (PV)-system has become one of the most popular renewable energy technologies that captures solar energy for different applications. Despite its popularity, its adoption is still facing enormous challenges, especially in developing countries. Experience from research and practice has revealed that installed PV-systems significantly underperform. This has been one of the major barriers to PV-system adoption, yet it has received very little attention. The poor performance of installed PV-systems means they do not generate the required electric energy output they have been designed to produce. Performance assessment parameters such as performance yields and performance ratio (PR) help to provide mathematical accounts of the expected energy output of PV-systems. Many reasons have been advanced for the disparity in the performance of PV-systems. This study aims to analyze the factors that affect the performance of installed PV-systems, such as geographical location, solar irradiance, dust, and shading. Other factors such as multiplicity of PV-system components in the market and the complexity of the permutations of these components, their types, efficiencies, and their different performance indicators are poorly understood, thus making it difficult to optimize the efficiency of the system as a whole. Furthermore, mathematical computations are presented to prove that the different design methods often used for the design of PV-systems lead to results with significant differences due to different assumptions often made early on. The methods for the design of PV-systems are critically appraised. There is a paucity of literature about the different methods of designing PV-systems, their disparities, and the outcomes of each method. The rationale behind this review is to analyze the variations in designs and offer far-reaching recommendations for future studies so that researchers can come up with more standardized design approaches.

**Keywords:** buildings; photovoltaic (PV)-system; PV-systems' design; PV-systems' performance; solar energy; renewable energy

## 1. Background

Photovoltaic (PV) system technology has largely become popular as a sustainable source of electrical energy. Researchers and industrialists have generated tremendous interest in PV-systems and their design. They are widely recognized for numerous reasons. Primarily, most habitual places worldwide have enough solar radiation; therefore, solar energy is an easy choice for individuals who wish to use sustainable energy sources. Likewise, depending on clients' demands, PV-systems can be designed from a few watts to thousands of kilowatts, making them suitable for both domestic (powering household appliances) and large-scale purposes [1]. They are highly durable. According to the latest renewable energy market forecast by the International Energy Agency Affairs (IEA), the world's renewable electric power capacity will rise by 1200 gigawatts by 2024 due to reductions in cost [2].

PV-systems account for 60% of this increase [2]. Another survey shows that PV-systems can provide sufficient energy capacity worldwide and exceed all other sources of energy by the next decade [3]. Likewise, they are modular and can be easily expanded if power demand increases in the future. Nonetheless, they have caused a high reduction in greenhouse gases. A study by the World Energy Council shows that 1kW of electricity installed in a home reduces its carbon footprint by over 3000 pounds annually [4].

Despite this positive level of adoption of PV-systems, much still needs to be done to ensure they become a mainstream technology. The adoption of PV-systems has been hampered by the high cost of installation [5]. However, the high cost has gradually reduced in recent years. Researchers have reviewed the vital trends that have caused the prices of PV-systems technology to fall. Firstly, the installation of PV-systems has been largely supported by some governments—e.g., the Indian government—and Non-Governmental Organizations (NGOs) such as the Honnold Foundation, who give huge subsidies and incentives. Secondly, there is a recorded improvement in the production of more efficient solar cells [6]. These two reasons have led to a massive surge in the production and installation of PV-systems, which has forced the cost to gradually reduce. Therefore, PV-systems are benefitting from an economy of scale. The higher the demand of the technology, the cheaper it gets. Evidently, the price per watt ( $\$/W_p$ ) of PV-systems modules will continue to drop even without subsidies [7]. In many places of the world, PV-systems have reached grid parity [1].

An imminent concern faced by individuals who install PV-systems is poor performance [8]. The rationales for the disparity in the performance of PV-systems are many. Firstly, a PV-system consists of so many components (e.g., cables, inverters, batteries, PV-modules, etc.), with each of these components having different characteristics, including different performance indicators. Thus, evaluating the performance of PV technology as a system requires a detailed understanding of the performance of the constituent components. Secondly, the different permutations in the combination of components can influence the performance of PV-systems. In practice, stand-alone and grid-connected PV-systems are examples that can perform differently because of the combination of different components and how they are integrated. Thirdly, the effect of alterable environmental factors such as poor solar irradiance, the presence of dust, and shading on components compel thorough evaluation. Lastly, different methods for the design of PV-systems require different assumptions, leading to a variation in the accuracies of the design of the different components and the system. Recent studies have revealed that one of the reasons installed PV-systems fail is due to poor design methods. A study that was conducted [9] compared the use of ambient temperature against module temperature to determine solar irradiance, and a large difference in the performance of the PV-systems was indicated because of the different design parameters/methods used. In [10], an installed PV-system generated a small amount of electric energy due to the poor design methods used to determine the angle of inclination. This poor performance was due to the fact that the modules were installed at different angles. This design method is unusual from the conventional approach of installing modules at a uniform angle towards the sun's radiation. [11] describes the impact that module inter-row spacing design methods have on the electric energy output and performance of a PV-system when different depths of shading are applied. Similarly, errors in inverter selection and sizing strains the entire PV-system and drastically reduces its performance [12]. In a paper by [13], different design models were analyzed to estimate the solar irradiance for a PV-system resulting in dissimilar values for energy yield. This difference in energy yields presented proves that different design methods result in the different performances of PV-systems where the required electric energy output is not generated due to errors in the design stage.

A previous study [14] published a performance analysis of 100,000 installed PV-systems and found that problems relating to PV-system performance are caused by performance quantification methods, ineffective grid data collection, poor weather conditions, hardware failure, installation, and quality assurance. Building/roof renovations during which the installed PV-system may be switched off or temporary removed (for renovation purposes) are also common causes of poor PV-system performance.

In this review [14], an average energy production loss of 20% was recorded, with a continuous increase in the subsequent years. From the occurrence and maintenance reports gathered by the authors, performance loss rates were apparent and clearly visible, although they could be recoverable with time. Another study [15] performed a performance assessment of PV-systems by observing different module types and provided a report of their energy outputs after 2.5 years of use. A similar study [16] appraised the factors that influence the efficiency of PV-systems; however, this review only considered material types, Maximum Power Point Tracking (MPPT) techniques, and converters. Most available studies in the literature address single factors. For instance, the effect of dust on the performance of PV-systems [17], energy loss due to the soiling of PV-systems [18], and the performance assessment of PV modules [19]. These studies focused on single factors affecting the PV-system performance. This study aims to introduce and investigate the numerous causes of poor performance in installed PV-systems altogether and provide a comprehensive review to inform future study.

Related studies [20–22] have investigated poor PV-system performance based on specific causes, such as considering the array sizing, inverter selection, or shading. However, there are not enough comprehensive studies with details on how different design methods result in different PV-system sizes. Incorrectly sized systems often face performance concerns. This study elaborates on PV-systems design methods and the different component selection processes that exist. To facilitate understanding, calculations were provided as an example. The logical beginning of this study will be to examine the different constituent elements of a PV-system. This will be followed by an examination of the performance parameters of PV-systems in Section 3. In Section 4, the factors that affect the performance of PV-systems will be examined. The methods for the design of a PV-system will be considered in Section 5. The study is summarized in Section 6.

## 2. Overview of Photovoltaic Systems

### 2.1. Photovoltaic Systems as a Type of Solar Energy

Solar energy is simply energy from the sun converted into electrical energy using solar cells. A PV-system uses solar energy absorbed from the sun together with the mechanical energy stored within the PV-technology to generate electric energy for use. This technology relies solely on the photoelectric effect that exists within its solar cells [23]. The most common solar cell material is silicon [24]. Like every other physical matter, these solar cells are made up of atoms. When photons radiate from the sun, solar energy is transferred to the electrons within the silicon atom. The electrons move the absorbed energy to one another and begin to flow in one direction, thereby creating an electric imbalance within the cell. Similarly, this unilateral flow of energy is made possible due to the nature of the atoms within silicon: n-type (possess spare electrons) and p-type atoms (have missing electrons/holes) [25]. When the n-types and p-types are arranged together within a solar cell, the spare electrons in the n-types move to fill up the empty holes in the p-types. Therefore, n-type and p-type silicon become negatively and positively charged, respectively. This creates an electric field throughout the cell. This field traverses in a systematic manner and thereby produces an electric current that is used in powering our household appliances [23].

However, occasionally, when the light-generated electrons encounter a hole (also known as a charge carrier), they may recombine and emit a photon, thereby cancelling out their input to the electric current [26]. This reversal process does not convert the electron's energy into electric energy but releases it as heat. A further recombination process may occur when charge-carriers encounter a defect in the crystal structure of the solar cell. This charge-carrier recombination is one of the basic drawbacks of solar cells. Recombination, together with ambient temperature, solar radiation wavelength, and the reflection of radiation off the solar cells, are the factors that affect solar cells' conversion efficiency [26,27]. Improving this conversion efficiency is one of the fundamental targets of most solar cell manufacturing companies [27] because solar cells with higher efficiencies produce more electric energy than less efficient solar cells [24].

While most solar cells are made of silicon, other materials are also used to develop solar cells. Organic solar cells use conductive organic polymers to absorb solar radiation and produce electricity [24]. A most recent solar cell technology is perovskite solar cells. They operate in a similar manner to silicon solar cells; they absorb photons and initiate a flow of electrons to produce electricity. However, perovskite solar cells have a unique crystallographic structure known as calcium titanium oxide ( $\text{CaTiO}_3$ ) that makes them achieve high conversion efficiencies [24]. In fact, researchers believe that this will exceed the efficiencies of silicon solar cells once it becomes fully developed [24,28]. Oxford PV (<https://www.oxfordpv.com/>) built perovskite solar cells on top of silicon solar cells to create tandem solar cells. These cells set a world record for perovskite-silicon solar cells with a 28% conversion efficiency [29].

## 2.2. Components of PV-Systems

PV-systems generate electrical energy through an arrangement of a set of components. They start with photovoltaic solar cells that capture solar energy and convert it to electric energy [4]. These cells are assembled to form solar modules in standard sizes such as 36-cell, 60-cell, and 72-cell modules [30–32]. PV-system modules can be found in different forms of materials, sizes, efficiencies, and costs. Each comes with its unique watt rating (given by the manufacturer of the module). Despite their difference, they all perform the same task of converting solar energy to direct current (DC) electrical energy. A grouping of these modules builds a solar array of a desired electric output. Figure 1 presents a typical PV-array field showing the standard terms of some of the components.

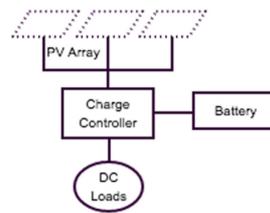


**Figure 1.** A Photovoltaic Array Field.

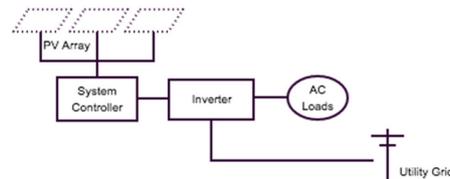
Most PV-systems installed in residential buildings need an inverter to convert the DC electricity generated by solar modules into alternating (AC) current for use by the building [1]. Additionally, most residential PV-systems require batteries to store backup or excess electric energy. Typically, batteries should hold an adequate amount of electric energy for use during non-sunny hours and at night. Batteries also require charge controllers to regulate the electrical current and voltage that goes through to the system. Additionally, they prevent batteries from excessive charging and discharging. Generators are used to connect the PV-system to other energy sources when required. Finally, cables and wires ensure that all elements of the system are connected, thus providing paths for electricity flow throughout the PV-system. These components are designed to operate together and achieve their task of generating electrical energy. The subsequent sections review how these components are combined to form different PV-systems.

## 2.3. Different Types of PV-Systems

A PV-system can be a stand-alone, grid-connected, or hybrid system. Stand-alone systems are often used to power buildings in isolated areas far from grid electricity [1]. They operate independently of the grid and require a battery to store their excess electricity. On the contrary, grid-connected PV-systems do not require the use of batteries. They are connected to the grid through an inverter. If the PV-system generates more electricity than the building requires, the excess electricity can be sold to the grid. This is a huge return on investment. Governments have conditions that must be met in order for one to be eligible to sell their extra electricity to the grid. For instance, the United Kingdom government contains detailed technical guidelines, guarantees, and legal demands that regulate transmission of solar electricity to the grid. Figures 2 and 3 shows the typical connections for stand-alone and grid-connected PV.



**Figure 2.** Stand-alone Photovoltaic System connection.



**Figure 3.** Grid-connected Photovoltaic System.

PV hybrid systems combine a photovoltaic generator with other power sources—typically a diesel generator, but occasionally another renewable supply such as a wind turbine [33]. The PV-system generator would usually be sized to meet the base load demand. This type of connection is the most prevalent in countries (e.g., Nigeria) where the grid electricity is insufficient.

### 3. Performance Parameters of PV-Systems

Experts in the domain of PV-systems admit that performance evaluations are a benchmark for an effective deployment of PV-systems [34]. Performance models encapsulate mathematical accounts of PV-systems' electrical output with respect to the system components, the design, and the climatological condition of the location of installation. Hukseflux [35] states that performance modelling should include a detailed analysis of different PV-system component configurations, a comparison of different PV-system installations at different geolocations, an assessment of the difference between the design expectations and the actual performance, and an analysis of all the performance trends and potential failures of a given PV-system. The international standard for PV monitoring systems International Electrotechnical Commission (IEC) 61724 has specified different performance parameters of PV-systems [35]. The ensuing section discusses the different types of performance parameters: the performance yields (array  $Y_A$ , reference  $Y_R$ , and final  $Y_f$ ) and performance ratio (PR).

#### 3.1. Different Types of PV-System Performance

##### 3.1.1. Performance Yields

Hukseflux [35] explains that PV-system performance yields (kWh/kW) are ratios of the PV array's actual operational output (in kWh) to its rated capacity (in kW). Experts and researchers in the PV-system domain compute yield ratios in three ways: the array energy yield  $Y_A$  [36], the final PV-system yield  $Y_F$  [37], and the reference yield  $Y_R$  [38]. As stated in the PV-system performance standards IEC 61724 [35], performance yields are defined as:

$$Y_A = B_{DC}/P_O, \quad (1)$$

$$Y_F = E_{AC}/P_O, \quad (2)$$

$$Y_R = H_t/G_O, \quad (3)$$

where:

- $B_{DC}$  is total energy generated by PV-system rows over a given period;
- $P_O$  is the DC rated power of the PV-array;
- $E_{AC}$  is the total energy produced by the PV-system;
- $H_t$  is the total amount of solar radiation received at the surface of PV panels;
- $G_O$  is the reference radiation quantity [36];
- The standard conditions for PV installation are 1000 W/m<sup>2</sup> solar irradiation, 25 °C ambient temperature, and a reference spectrum air mass of 1.5-G [36];
- $Y_A$ ,  $Y_F$ , and  $Y_R$  are interrelated in determining energy losses, such that the array loss  $L_A$  is computed as  $L_A = Y_R - Y_A$  and the system loss as  $L_S = Y_A - Y_F$  [34].

All three yield ratios are significant performance parameters; therefore, they are used in all performance modelling. Detailed computations and applications of the performance yields have been elaborated in detail in case studies in [34,36–42]. Ascencio-Vasquez et al. [39] present a worldwide mapping of the final energy yield using standard figures for a typical PV module.

### 3.1.2. Performance Ratio (PR)

PR is a PV-system performance measure based on environmental parameters such as solar irradiance, power dissipation, shading, ambient temperature, and all other climatic conditions that affect the output of a PV-system. Performance experts compute it as a ratio of the actual energy output to the theoretical energy output of the PV-system plant over a period [37]. As stated in the PV-system performance standards IEC 61724 [35,43], the performance ratio is defined as:

$$PR_{AC} = Y_{fAC}/Y_r, \quad (4)$$

where  $Y_{fAC}$  is the final system yield and  $Y_r$  is a ratio of the plane-of-array insolation (kWh/m<sup>2</sup>) to the reference irradiance (1000 Wm<sup>-2</sup>) [35,36]. Detailed studies conducted on PR can be found in [38–40,44–46]. Experts who have conducted performance ratio studies have acknowledged that it informs the user of exactly how energy efficient and consistent their PV-system plant is [34]. Similarly, it is proven that PR is highly dependent on ambient temperature changes. Its values are lower during warm parts of the year and higher during the colder seasons. Ascencio-Vasquez et al. [39] present a worldwide mapping of performance ratio using standard figures for a typical PV module.

## 4. Factors Affecting the Performance of PV-System

It has been established that PV-systems have reached grid parity in many markets, and this has led to a global increase in installation [47]. Therefore, it is surprising to know that PV-systems are widely used ineffectively. In most recent cases, a few months after perfectly installing a PV-system, the technology fails to generate the intended output of electrical energy, leaving the homeowners dissatisfied and confused. The question is, why do the PV-systems not meet their requirements? Several studies have identified alterable and unalterable factors that affect the performance of PV-systems. The following sections discuss each factor.

### 4.1. Location on Earth

Frequently, the PV-system components that work best for one location may not necessarily be well optimized in another. Every location on earth has unique coordinates (longitude and latitude) and weather features such as temperature, humidity, wind velocity, and so on. Hussin et al. [12] studied the relationship between PV-system components and the temperature of the environment and concluded that modules ought to suit the ambient temperature of the location to be able to perform well. Modules that work best in Europe may not work properly in Africa. For example, monocrystalline modules are less affected by high temperatures; thus, they are suitable for locations around the equator,

while polycrystalline modules are sensitive to high temperatures and may not generate the desired electrical energy output. In a case study conducted, modules designed to be used in the USA were adopted for use in Fortaleza Brazil and a performance error (a criteria used by the researchers to measure array loss ( $L_A$ )) higher than 20% was observed [48]. Unexpected climatological effects such as lightning strikes, hurricanes, tornadoes, visible hail, and large snowstorms can all have terrible effects on the installed PV system [14]. There is a need for academics and specialists in this domain to use location-specific values to avoid location-related performance problems.

#### 4.2. Dust

One of the most important weather-dependent factors that affect PV-systems' performance is dust [12,49]. Dust is made of tiny solid particles that accumulate on surfaces, often caused by different environmental and weather conditions. It is a common phenomenon that is prevalent everywhere in the world. Numerous performance analysis conducted have attributed PV-system power loss to dust deposition on the panels [50,51]. Studies on the effect of dust on the performance of PV-systems showed that dust with a density as small as  $1\text{g/m}^2$  may cause a significant loss in energy output by large amounts of  $\text{V/kW}_p$  annually [52]. Another study has indicated that an increase in dust density from 0 to  $22\text{g/m}^2$  caused a significant reduction in output efficiency from 0% to 26% [53]. The amount or level of the performance loss is, however, determined by the nature of the dust, climate condition, wind velocity, PV-system angle of inclination, and array surface conditions.

Dust particles are scattered in the atmosphere and are easily carried by the wind. For that, researchers claim that the nature of dust is site-specific and is influenced by the environment [54]. In an earlier study on the effect of the performance of a PV-system, it is observed that the dust elements generated from industrial environments have caused an 80% drop in the electric output of PV-systems [55]. Another experiment was conducted on the effect of airborne dust on PV-systems' performance and observed a decrease in efficiency of up to 65.8% [56]. Others have revealed that areas of high humidity also have high tendency to have accumulated dust on panels [49].

Zaihidee [49] investigated dust accumulation in relation to wind velocity and observed that slow wind patterns support dust collection while, in contrast, fast wind would clean up the dust amassed on panels. Similarly, a horizontal PV-system installation is more likely to collect dust than an installation made inclined at an angle. Additionally, a sticky panel will be more likely to accumulate dust than a less sticky surface. Simple maintenance procedures such as the cleaning of the panels are routinely required to reduce the effect of dust on performance [8].

#### 4.3. Solar Irradiance and Angle of Inclination

In a study of performance evaluation of PV-systems, it is argued that poor solar irradiance has led to the poor performance of PV-systems [8,57]. The poor radiation received by solar panels is often due to wrong angles of inclination. If the tilt and orientation have been calculated wrongly during the design stage, then the optimal position of the PV-system in relation to the direction of solar radiation cannot be obtained. Performance parameters such as the reference yield,  $Y_r$ , will give incorrect values if there are errors in the irradiance values. In [10], an installed PV-system generated a small amount of electric energy due to the poor design methods used for computing the correct angle of inclination. In another study, scholars concluded that, for an optimal performance, the angle of inclination should be very close to the angle of latitude of that location [51]. Other researchers have stated that poor PV-system performance often results from the incorrect selection of the solar irradiance measurement parameters to use [55]. These parameters are discussed in Section 5.1. Once there is a poor absorption of solar irradiance, the poor performance of the PV-system will be inevitable.

#### 4.4. Shading

Shading is one of the most damaging factors in the poor performance of PV-systems. The shading of PV panels causes non-uniform solar radiation due to the temporary obstruction of solar rays by trees, neighboring buildings, utility poles, clouds, or other obstacles [8,58]. Studies undertaken have proved that once a part of the PV-array receives less irradiance due to shading, its temperature becomes lower than the unshaded part of the array. The thermal distribution across the array becomes non-uniform, and thus the PV-system performance decreases [59]. Shading conditions also cause hot spots on modules, and these damages the cells in the short run [8]. In a study by [60], it was established that the shading of arrays causes inconsistent panel voltage and shifts in power transmissions. These severely affect the performance of the converter and subsequently the total output of the PV-system.

#### 4.5. Multiplicity of PV-System Components in the Market and Insufficient Knowledge about Them

There is a multiplicity of PV-system components. It is evident that tens of thousands of PV-system components are manufactured globally in Africa, Europe, America, and Asia, with distinctive features and capacities [37]. These components are easily available. Users face challenges in selecting a suitable PV-system to procure and install. Individuals who wish to purchase and install PV-systems often have very little knowledge of the difference(s) between the components; their types, sizes, and outputs; and the effect they have on the overall design of the PV-system. Trade-off decisions that involve an increase or decrease in the surface area, efficiency, and cost of components must be understood. Vital knowledge about all the factors affecting PV-systems' performance, especially those discussed above (the effect of shading, angle of inclination, dust accumulation, and ambient temperature), must be comprehended. Several researchers have attempted to identify the challenges associated with managing information related to the selection of PV-system technology products. In a case study in Nigeria, the researchers indicated that the main cause of the terrible performance of installed PV-systems is the lack of sufficient knowledge about the technology [6]. Others emphasized that poor installation procedures were used by personnel who were inexperienced and did not have adequate technical knowledge of the process. They further argued that a lack of profound knowledge on setting up charge controllers also affected the performance negatively [57]. These issues can be solved by excellent methods of sizing PV-systems and the application of appropriate selection procedures.

#### 4.6. Design Methods

The electrical energy output projected in the design stage is always different from the output received after a PV-system is installed. This great difference between the projected energy output and the actual output obtained after installation shows there is a problem in the methodologies used in selecting and designing PV-systems. Since it has been established that a PV-system output varies with different component characteristics (sizes, efficiencies, and performance indicators), design methods must include a detailed understanding of the selection and performance of each component. Furthermore, different permutations for the combination of components must be analyzed because different permutations could result in dissimilar performance estimates. For example, since the connections for stand-alone and grid-connected PV-systems are different, methodologies to obtain compatible configurations are desirable. The synchronization and optimization of the different components would ensure that the PV-system provides the required and intended energy output. Finally, different design methods require different assumptions, leading to different accuracies in the design of the different components and system. The ensuing section discusses the different methods known so far that offer solutions to this problem.

## 5. Methods of PV-System Design

Designing a PV-system is quite complex. Several conditions and compositions must be analyzed. The first step in PV-system design is to investigate the meteorological conditions of the intended location, followed by the determination of the energy load of the building. The size of the modules and PV-array are then determined based on the energy output needed. The other components are sized based on this energy output and the panel size. Once all the components are selected and sized, the design is examined to ensure that the negative conditions that affect performance are eliminated.

### 5.1. Geolocation and Solar Irradiance

For an effective design of a PV-system, the first factor to consider is the location of the proposed building where the PV-system would be installed. This is because the performance of PV-system components depends on the solar irradiance and temperature. Every geographical location has unique values for longitude and attitude. Furthermore, the irradiation for each location comes in three (3) unique parameters [61]. These are global horizontal irradiance (GHI), diffuse horizontal irradiance (DHI), and direct normal irradiance (DNI). Table 1 presents the descriptions of each of these parameters. These components, together with the plane of array (POA) and the ambient temperature of any given location, are vital to solar energy conversion technologies. POA is a combination of direct solar radiation, diffused radiation, and radiation reflected by the ground [62].

$$\text{In mathematical terms, } \text{GHI} = \text{DNI} \times \cos(\theta) + \text{DHI}, \quad (5)$$

$$\text{POA} = I \cos \theta, \quad (6)$$

where  $I$  = direct normal irradiance;

$\theta$  = angle of inclination [64].

**Table 1.** Difference between Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI), and Global Horizontal Irradiance (GHI).

Names	Description	Instrument
Direct Normal Irradiance (DNI)	This gives the value of solar radiation coming directly from the sun.	Pyrheliometer [63]
Diffuse Horizontal Irradiance (DHI)	This is the amount of solar radiation reflected by the ground (scattered in the sky) very close to the horizontal surface of absorption.	Shaded pyranometer [62]
Global Horizontal Irradiance (GHI)	This is the geometric total amount of the solar radiation received in each dimension on the ground.	Shaded pyranometer [62]

Most PV-system performance models use either GHI or POA irradiance and ambient temperatures as input factors. However, these parameters are rarely used in the design of small-scale PV-systems because their measurement instruments are expensive [61]. Therefore, the accuracy of irradiance values for small-scale PV-systems rely on general calculations made for POA and ambient temperature in any given location. Mathematical models are available in the literature for POA [64,65]. While the ambient temperature is the normal temperature around the PV-system modules at the time of solar radiation, for a standard operating condition (SOC):

$$T_A = T_C - (\text{NOCT} - 20 \text{ } ^\circ\text{C}), \quad (7)$$

where  $T_A$  is ambient temperature,  $T_C$  is the module temperature, and NOCT is the nominal operating cell temperature given by the PV module manufacturer [66].

Comprehensive mathematical models for ambient temperature can be found in [9,66,67] and are adopted by satellite-derived values. In a paper by [13], different design models were analyzed to estimate the solar irradiance for a PV-system resulting in dissimilar values for the energy yield.

Researchers have argued that irradiance estimation errors are caused by the parameters available for solar irradiance measurements [48]. The choice of the measurement parameter used can make a difference of a few percent [62]. Further studies of the difference between the two methods of irradiance calculations, including the benefits and drawbacks of each, can be found in [1,61,63,67]. The predetermined solar irradiance values of any location in the world can be found with NASA metrological [68], Meteonorm [69], solcast [70], Total Solar Irradiance (TSI) Composite Database [71], Sorce [72], Photovoltaic Geographical Information System (PVGIS) [73], etc.

### 5.2. Determining Energy Load of the Building

The size of a PV-system is primarily dependent on the energy requirement of the user. This energy load can be acquired in different forms. The primary form of obtaining the energy load of a building is by reading the electricity bill provided by the electricity supplier in kilowatt-hours (kWh) [74]. Occasionally, a building may be charged a standing (fixed) amount per day regardless of how much energy is consumed. However, the most common method is to be charged per unit rate depending on the amount of energy consumed. Individuals who may not comprehend the information provided in electricity bills may only note the amount due to be paid. In such situations, one could use the unit rate that is charged by the electricity provider to calculate the energy consumption of the building. For example, in the United Kingdom, although the price per unit rate may vary depending on the region and the type of energy plan subscribed to, the average unit rate of electricity is 14.37 p/kWh (pence/kilowatt-hour) [75]. Where this average unit rate applies and a monthly electricity bill of £70 is charged, the energy load of the building could be obtained through a simple equation where  $\text{electricityBillAmount} = \text{unitRate} \times \text{energyLoad}$ . The result is 487.3 kWh of electricity consumed.

Another method is to obtain a cumulative sum of the energy consumed by all the electrical appliances used in the building [76]. Electrical ratings, such as wattage, current, voltage, frequency, etc., are normally clearly written on labels on all appliances. However, if the wattage is not provided, it can be easily calculated using the formula given in Equation (8), while Equation (9) obtains the energy consumed by that appliance. Once the energy consumed by each appliance is obtained, a summation of all the values gives the electrical energy load of the building.

$$\text{Active or Real Power (W)} = \text{Current (I)} \times \text{Voltage (V)}, \quad (8)$$

$$\text{Electrical Energy} = \text{Active or Real Power (W)} \times \text{Total time the appliance is in use (hours)}. \quad (9)$$

Other approaches for determining the energy load of the building are available in the literature. [77] created two (2) models for estimating energy consumption through sampling of monitored data and a “bottom-up” approach that predicts energy demand. Results from validation of both models gave similar values with metered data. Researchers proved that it is an improved approach when compared to common practices discussed above; however, their models are only suitable for appliances with small wattage or power ratings. In [74], average system loss of components is estimated to be 30%; therefore, 130% of the calculated building load is used in that study for the system design. In another study [78], the researchers developed a model that generates heating and cooling profiles for a building using real-life values obtained from monitoring mean temperatures outside versus the corresponding electricity consumption inside the building. The model was applied on case studies and proved accurate in determining energy loads of the buildings. However, it is imperative to note there can be variable energy demand (peak, average, and minimum energy load) depending on the time of day or the seasons. During the design process, when the peak load is adopted, this means that the PV-system will be large and expensive. Likewise, the energy generated will be wasted during the average and minimum periods. On the contrary, if the minimum load is adopted, then user may require alternative sources of energy to power appliances during the average and maximum periods.

### 5.3. Methods for Sizing of PV Components

In PV-system design, each component is modelled and sized. Subsequently, they are evaluated in respect to one another to generate the required energy output. Similarly, when the components' sizing is well-optimized performance issues can be potentially avoided.

#### 5.3.1. Selection and Sizing of Modules

There are different types of module materials. The most common are monocrystalline, polycrystalline, and thin film. The next accepted module type is amorphous module. Amorphous cells are a type of thin-film cells [79]. Most small appliances that use PV-cells such as calculators are powered by thin film made of amorphous cells. Other types of thin-film module types are composed of cadmium telluride (CdTe) and copper indium diselenide (CIS) [80]. However, these technologies have high toxin substances that require cautious handling during manufacturing and disposal [37]. Other types of PV-system modules include gallium arsenide and multi-junction cells [3], which are less common due to high cost. Additional module materials include Perovskite cells, organic solar cells, dye-sensitized solar cells, and quantum dots; however, they are new and not fully explored [3]. Three (3) important factors that make each module type suitable for different electric energy outputs are efficiency of cells, surface area, and costs. Table 2 provides the difference between the dominant module types.

An important point to make is that a module of higher efficiency generates more electrical energy output than a similarly sized module of a lower efficiency. Comparably, modules of higher efficiency require lower amounts of mounting surface area than modules of lower efficiency. However, the higher the efficiency, the more expensive the technology. The important question to ask in selecting modules is what matters most to the user. A PV-system owner with a large mounting space may select a less efficient module type to cut down price, while another person may prefer the most efficient module type if they have a small mounting space. Price, space, and efficiency trade-offs are unavoidable when selecting modules.

**Table 2.** Different types of PV-system modules.

Module Type	Description	Efficiency	Advantages	Disadvantages
Monocrystalline	<ul style="list-style-type: none"> <li>They are made from a single, uniform, pure, thin silicon crystal [81].</li> <li>Module has a distinctive hexagonal shape and a dark crystal look [3].</li> </ul>	20–25%	<ul style="list-style-type: none"> <li>High efficiency rate.</li> <li>High power output.</li> <li>Highly suitable for commercial uses.</li> <li>Less affected by high temperatures.</li> <li>Space efficient.</li> <li>High lifespan.</li> </ul>	<ul style="list-style-type: none"> <li>Expensive.</li> <li>Manufacturing process is slow.</li> <li>It is labor intensive.</li> </ul>
Polycrystalline	<ul style="list-style-type: none"> <li>They are made from multiple grains of silicon crystals [81].</li> <li>They have a bright blue look, with distinct squares.</li> <li>Polycrystalline modules are the most dominant PV modules in the market. They make up 70% of the world's PV modules.</li> </ul>	15–20%	<ul style="list-style-type: none"> <li>Less expensive.</li> </ul>	<ul style="list-style-type: none"> <li>Less efficient.</li> <li>Sensitive to high temperatures.</li> <li>Shorter lifespan.</li> <li>Not space efficient.</li> </ul>
Thin Film	<ul style="list-style-type: none"> <li>These modules are produced by layering thin layers of PV material on a substrate such as glass, plastic, or metal [3].</li> <li>The final product is very flexible and contains less than 1% of the silicon used in making crystalline modules [12].</li> </ul>	7–10%	<ul style="list-style-type: none"> <li>Flexible.</li> <li>Easy to produce.</li> <li>Much lower price due to economy of scale.</li> <li>Less affected by high temperatures.</li> </ul>	<ul style="list-style-type: none"> <li>Much less efficient.</li> <li>They take up a lot of space.</li> <li>These cells experience about a 20% drop in efficiency in the first few months of installation.</li> <li>Much shorter lifespan.</li> </ul>
Concentrated PV cells	<ul style="list-style-type: none"> <li>They use curved lenses to focus solar energy on their cells.</li> <li>They use solar trackers to increase efficiency.</li> <li>They use direct normal irradiance (DNI).</li> </ul>	Up to 40%	<ul style="list-style-type: none"> <li>High efficiency under DNI.</li> <li>Small array size.</li> <li>Low cost of manufacturing.</li> <li>Less affected by high temperatures.</li> </ul>	<ul style="list-style-type: none"> <li>Far less common than the conventional cell types; they are not standardized.</li> <li>Power output could be affected by shifts in radiation.</li> </ul>

Once a module type has been selected, the total number of the modules needed to collectively generate the required capacity of electric output gives the array size. Conversely, surface area constraint is mandatory, such that  $\text{mountingSurfaceArea} \geq \text{arraySurfaceArea}$ . In Usman et al. [74], a mathematical computation was applied to calculate the array size as a ratio of total watt or power rating required, to the rated power of the module type selected. In this study, the total power required is increased by 30% due to energy losses in the system. Furthermore, a varying factor known as the Panel Generation Factor (PGF) is considered. PGF helps to determine the energy output after losses due to the temperature, dirt, poor irradiance, and ageing of panels. A similar calculation is available in [1]. In [82], models were developed to calculate module efficiency and maximum power, where:

$$\eta_{pv} = \eta_{ref} \{1 - a[(G_B)/18] + T_A - 20\}, \quad (10)$$

where  $\eta_{pv}$  is the module efficiency,  $\eta_{ref}$  is the reference efficiency,  $a (=0.0042)$  is the power correction factor determined by the study,  $G_B$  is the solar irradiance, and  $T_A$  is the ambient temperature. Similarly, the maximum PV power is determined by:

$$W_p = \eta_{pv} G_B A, \quad (11)$$

where  $\eta_{pv}$  is the module efficiency,  $G_B$  is the solar irradiance, and  $A$  is the PV module surface area [82]. A comprehensive guide for array sizing can be found in [83].

### 5.3.2. Selection and Sizing of Inverters

Inverters are selected and sized based on the total energy output expected from the PV-system. They are often selected based on their operational power and size. A suitable PV-system inverter should be sizeable enough to hold the total energy load of the building at any point in time. Some researchers state that the size of the inverter should only be 80–90% of the power rating required to save costs, since the PV-systems hardly generates its maximum required energy [84]. However, other scholars disagree and argue that the size of the inverter should be 25–30% bigger than the required energy output [11]. Others agree and state that at high temperature, an undersized inverter becomes strained and regularly reduces the performance of the PV-system [12]. However, it is important to note that the bigger the inverter, the more expensive it is. The configuration and reliability of inverters must be considered at design stage of the system. In [14], problems related to poor inverter selection was reportedly the most common reason for poor performance of the installed PV-systems. System interruptions caused by inverters led to poor energy production for weeks. A detailed study on the performance of PV-system inverters can be found in [85]. Likewise, a design margin in terms of inverter reliability is recommended [86].

### 5.3.3. Selection and Sizing of Batteries, Charge Controllers and Wires

Naturally, the nominal voltage of inverters and batteries should be the same. However, because batteries are used to store enough backup energy, it is recommended to design the PV-system with a battery capacity as high as the user can afford [74]. Factors considered in sizing of PV-system battery are its performance, durability, and depth of discharge. The best battery types are those that can withstand deep discharge. Battery types with short lifespan are normally the types that charge slowly and discharge rapidly. Detailed review of causes of poor battery performance can be found in [74,87]. Alternative energy [88] calculates battery as a ratio of the total watt-hours needed from PV modules to the system voltage. A comprehensive guide for battery sizing according to accepted methods can be found in [74,83]. Furthermore, a review of battery selections for use in PV-systems can be found in [89].

Battery charge controllers keep batteries within a suitable limit of charge. They help to prolong the lifespan of battery in a PV-system. Researchers advise to size the charge controller based on the energy and an increase percentage of 1.3 as a safety ratio [1]. Nonetheless, the bigger the charge controller, the more expensive it is. For long-lasting connections, single-conductor wires are used to connect

PV-system panels. Numerous types of wires can be used for PV-system connections, but they must meet the requirements of the “UL 4703 Standard for Photovoltaic Wire” [90]. Standard wires and cables are flexible. They also have moisture resistant coverings and insulation jackets to protect them during wet days or during harsh radiation periods. Experts in PV-system wiring often recommend the best wires to be used; however, it is important to note that human errors may occur, and this leads to the poor performance of installed systems. Likewise, it is also imperative to note that electricians who are familiar with indoor wiring do not necessarily have comprehensive knowledge of the exposed cables used in PV-system connections. The UL 4703 standard should be used to select the most suitable wires.

In a review by [14], installation improvements were required for most wires within the first few years of use. The need to replace PV-system components (which occur frequently) within the first year of installation, clearly indicate issues regarding installation standards and quality. While there is a 100% occurrence of at least a single hardware issue in a year, figures show fewer hardware concerns in PV-systems by installers who have installed hundreds to thousands of PV-systems than for those who have installed a few. Most often, the need to reduce installation costs leads to the acceptance of counterfeit products. Based on [14], most installation problems are caused by the use of undersized wires [14]. These affect PV-system energy productions and may lead to not only performance but also safety concerns.

#### 5.4. Methods to Detect Shading of Modules

In a PV-system array of modules, there is usually a non-linear relationship between the current and voltage. However, there exists an operating point where maximum power is generated by the array. This is called maximum power point (MPP). Shading causes failures in functioning of Maximum Power Point Tracking (MPPT) [59]. It is often very challenging to obtain the MPP when a PV-system array is partially shaded [60]. Numerous studies have been conducted to derive algorithms for detecting MPP under partial shading conditions (PSC). As a result, several algorithms have been developed to improve the energy efficiency in PSC to find the MPP. Ma et al. [8] has complained that these algorithms use a sudden change in energy output as an input indicator for PSC and argued that this method is not efficient enough to distinguish between PSC and an abrupt change in the weather condition of the environment.

To avoid PSC from the design stage of the PV-system, it is imperative to apply machine learning techniques to detect possibility of shading [91]. Ma et al. [8], Spataru et al. [91], and Salem et al. [92] have applied machine-learning based methodologies to detect shading of PV modules. In Ma et al. [8], a sorting algorithm is used not only to predict shading but also to estimate the shading strength and voltage at MPP. It takes in the current, voltage, and cell temperatures of the PV-system array as input parameters. This method has been tested and validated on existing PV-systems. Although these algorithms successfully predict shading and can ascertain the MPP of the PV-system, its effect on the other components of PV (such as inverters) have not been fully explored [60]. A comprehensive review [63] offers a list of MPPT techniques that have been developed to maximize the output of PV-systems with a thorough appraisal of the advantages and limitations of each technique. The techniques increase the maximum power of the PV-system regardless of shading.

#### 5.5. Example Calculations

From the irradiance values of a given period in [61], the GHI, DHI, DNI, and ambient temperature for Oxford are 7.41, 4.3, 6.5, and 10.3, respectively. The estimated average building energy load is 8.5 kWh per day, while the solar irradiance value obtained from NASA metrological [68] for Oxford is 3.8 kW/m<sup>2</sup>. Similarly, we assume that a monocrystalline module of 300 W<sub>p</sub> with an efficiency of 18.4% and a surface area of 65 is selected.

The subsequent sections provide example calculations (shown on Tables 3–7) for solar irradiance, energy output, and array size, as well as sizes for modules, inverters, and batteries.

### 5.5.1. Solar Irradiance

From Section 5.1 above, solar irradiance values could be obtained either through the meteorological data given for the location or plane of array obtained using a formula  $GHI = DNI \cos(\theta) + DHI$ , from Equation (5) [35] above and  $POA = DNI \cos(\theta)$  from Equation (6).

The results from (13) show different solar radiation values compared to the meteorological irradiance value from [68]. Any subsequent calculations performed using these values will give different results.

### 5.5.2. Energy Output and Array Size

Two design methods are used here for calculating the array size twice. The first uses the solar irradiance value of  $3.8 \text{ kW/m}^2$ , while the second uses plane of array irradiance value of  $3.08 \text{ kW/m}^2$ . The first is the sizing method proposed in [74], and the second is a method in [82]. Using the mathematical formulae in [74], for the PV-system array size to be determined the watt-hours needed per day from the modules (WM) and the total watt-peak rating of the electric output ( $W_p$ ) that the modules are expected to generate must be determined.

**Table 3.** Solar irradiance calculations

Meteorological Data	Plane of Array
Solar irradiance data obtained for Oxford is $3.8 \text{ kW/m}^2$ .	Calculation for plane of array (POA):
	$GHI = DNI \cos(\theta) + DHI$ ,
	$\cos(\theta) = (GHI - DHI)/DNI$ ,
	$\theta = \cos^{-1} ((7.41 - 4.3)/6.5)$
	$\theta = \cos^{-1} (0.4743)$
	$\theta = 61.69^\circ$ (12)
	$POA = DNI \cos(\theta)$
	$POA = 6.5 (\cos (61.69))$
	$POA = 3.08 \text{ kW/m}^2$ (13)

**Table 4.** Calculations for Energy Output.

Method 1: Design method proposed in [74] and irradiance of $3.8 \text{ kW/m}^2$	Method 2: Design method proposed in [82] and irradiance of $3.8 \text{ kW/m}^2$
Watt-hours needed from PV modules (WM) = building energy load $\times$ 103 $\times$ 1.3 (where 1.3 is used to account for system losses) $WM = (8.5 \times 10 \times 1.3)$ $WM = 11,050 \text{ Wh}$	$W_p = \eta_{pv} G_B A$ from Equation (11) above, where $\eta_{pv}$ is module efficiency (18.4%) $G_B$ is solar irradiance (3.8) $A$ is the PV module surface area (56)
Total watt-peak rating ( $W_p$ ) = Watt-hours needed from PV modules (WM)/Panel Generation Factor (PGF)	
Panel Generating Factor (PGF) = Solar irradiance $\times$ (Losses due temperature, dirt, poor radiation and ageing)	
$PGF = (3.8 \times (0.90 \times 0.86 \times 0.90 \times 0.95))$ $PGF = 2.49$	$W_p = \eta_{pv} G_B A$ , $W_{p2} = 18.4 \times 3.8 \times 56$ $W_{p2} = 3915.52 \text{ W}$
Therefore, $W_p = WM \div PGF$ $W_{p1} = 11,050 \div 2.49$ $W_{p1} = 4437.75 \text{ W}$	
Array size1 = $W_{p1} \div 300 W_p$ Array size1 = $4437.75 \text{ W} \div 300 W_p$ Array size1 = 14.79, approximated to 15 modules.	Array size2 = $W_{p2} \div 300 W_p$ Array size2 = $3915.52 \text{ W} \div 300 W_p$ Array size2 = 13.05, approximated to 13 modules.
Therefore, this system will be powered by minimum 15 modules of $300 W_p$ .	Therefore, this system will be powered by minimum 13 modules of $300 W_p$ .

**Table 5.** Calculations for Array Size.

Method 3: Design method proposed in [74] and plane of array irradiance value of 3.08 kW/m <sup>2</sup>	Method 4: Design method proposed in [82] and plane of array irradiance value of 3.08 kW/m <sup>2</sup>
Watt – hours needed from PV modules (WM) = building energy load × 103 × 1.3 (where 1.3 is used to account for system losses) WM = (8.5 × 10 × 1.3) WM = 11,050 Wh	$W_p = \eta_{pv} G_B A$ from Equation (11) above, where $\eta_{pv}$ is module efficiency (18.4%) $G_B$ plane of array (3.08) A is the PV module surface area (56)
Total watt-peak rating ( $W_p$ ) = Watt - hours needed from PV modules (WM) ÷ Panel Generation Factor (PGF)	
Panel Generating Factor (PGF) = Solar irradiance × (Losses due temperature, dirt, poor radiation and ageing)	
PGF = (3.08 × (0.90 × 0.86 × 0.90 × 0.95)) PGF = 2.04	$W_p = \eta_{pv} G_B A$ , $W_{p4} = 18.4 \times 3.08 \times 56$ $W_{p4} = 3173.63$ W
Therefore, $W_p = WM \div PGF$ $W_{p3} = 11,050 \div 2.04$ $W_{p3} = 5416.67$ W	
Array size3 = $W_{p3} \div 300 W_p$ Array size3 = 5416.67 W ÷ 300 $W_p$ Array size3 = 18.06, approximated to 18 modules. Therefore, this system will be powered by minimum 18 modules of 300 $W_p$ .	Array size4 = $W_{p4} \div 300 W_p$ Array size4 = 3173.63 W ÷ 300 $W_p$ Array size4 = 10.57, approximated to 11 modules. Therefore, this system will be powered by minimum 11 modules of 300 $W_p$ .

**Table 6.** Inverter sizing calculations.

Using design method in [90], inverter size is recommended to be only 80–90% of the energy load since PV-systems hardly generate the maximum required energy load. Therefore, inverter size = (8.5 × (80%)) = 8.5 × 0.8 = 6.8 kVA.	Following the inverter design recommendations in [11,12] inverters should be 25–30% more than the energy load. Therefore, inverter size = (8.5 × (125%)) = 8.5 × 1.25 = 10.63 kVA
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**Table 7.** Battery sizing calculations.

Selection method proposed in [74]	Selection methods proposed in [82]
Given a standard nominal voltage of 12 V, and days of autonomy to be 2;	From battery calculation method in [82],
Battery capacity = (building energy load × days of autonomy) ÷ (nominal voltage × depth of discharge × 0.85),	Battery capacity = total watt-hours from modules WM ÷ system voltage.
Battery capacity = (8.5 × 10 <sup>3</sup> × 0.85 × 0.7) Battery capacity = 842.92 Ah	Battery capacity = 11,050 ÷ 12 = 920.83 Ah
Therefore, a battery with minimum capacity of 843 Ah should be used.	Using this method, a battery with minimum capacity of 920 Ah should be used.

### 5.5.3. Inverter Sizing

From this review, the size of the inverter is equal to the energy load, then the inverter size = 8.5 kVA. Two example calculations are given below:

### 5.5.4. Battery Sizing

To size a battery, a 70% depth of discharge is expected. Likewise, an 85% performance is expected due to the battery losses in the system.

In most PV-system models, solar irradiance is either obtained from meteorological databases or a calculation for the plane of array irradiance is conducted. Several studies [13,48,61] have attempted to use both irradiance values in designing PV-systems and observed that different results were obtained. Based on the example calculations given above, it is clear that these solar irradiance parameters differ, and subsequent calculations performed using any of the values give different results. For the purpose of this research, it is imperative to note that predetermined solar irradiance data is more reliable. Parameters for the calculations of the plane of array are likely to have errors due to the azimuth error.

Similarly, two example calculations were given for array size. The method proposed in [82] requires the module type and size to be known before the total peak power rating required is calculated. The design method proposed in [74] is more elaborate. It considers the hours of electricity required and also considers system losses. It gives a comprehensive design calculation that can be used to know exactly the size of the array before a module type is selected; this way, the user has an idea of which module type and size would best fit the requirements. Similarly, an approach that accounts for system losses should be used, since system losses are inevitable.

Similarly, different methods for selecting inverters result in different inverter sizes. It is important to note that an undersized inverter may help cut costs; however, the inverter will be strained and will regularly reduce the performance of the PV-system. Therefore, it is highly recommended to select an inverter that has the capacity to handle 125% of the energy load. In battery sizing, the difference between the method proposed in [74,82] is that the first considers the days of autonomy and the performance drop due to battery system losses. It is therefore a preferable method, as uncertainties should be measured. These examples show that different design methods lead to different system outputs.

## 6. Conclusions

This paper provided a review of PV-systems, their components, and their different types. It has been established that, despite the growing interest in the adoption of PV-systems, many existing systems are affected by poor performance. Although the performance assessment parameters discussed in this study help to derive the expected yields, PV-systems most often do not generate the electric output they are designed to produce. The main finding of this research is that it is apparent that PV-system design and component sizing is challenging. Furthermore, incorrect sizing and other different factors are responsible for the disparity in the performance of PV-systems. The most common factors discussed are the lack of adequate knowledge of the different component types and their characteristics [12,37], as well as the effect of the geographical location, solar irradiance [8,57], wrong angle of inclination, dust [12,49], shading [59,60], and different design methods on PV-systems [8].

Existing studies [8,57] have also attempted to analyze poor PV-system performance based on specific causes, such as considering array sizing, inverter selection, or shading separately. As observed in this study, there are huge multiplicities in the design of the PV-system. Different methods for calculating building load; incorrect assessments of solar irradiance parameters; undermining thorough the collection of meteorological values of the location; poor calculation for the optimum array angle of inclination; and trade-off decisions that involve an increase or decrease in the surface area, efficiency, and cost of modules must be understood. Other issues include the under-sizing of inverters, wrong battery choices, and so on. It has been observed through example calculations that different design methods result in different values. These miscalculations subsequently result in the poor performance of PV-systems once installed. It is recommended to use design methods that use predetermined meteorological values rather than methods where the inputted variables could lead to errors. Similarly, the component selection processes that account for system losses should be used to minimize losses. Furthermore, it is highly recommended to adopt a methodology that is capable of calculating the complete PV-system size (electric output required and array size) regardless of what module type is used. The module type, size, and efficiency should be selected based on the estimated system size.

Furthermore, long-term performance decline, due to undetected, unrecoverable, or delayed hardware concerns, have great negative effects on the PV-system. It is important to note that preventive maintenance events should be performed more often than active repairs approaches. A proactive approach will have a lower impact on the energy loss than an active repair approach which may require some PV-system components to be repaired or replaced. The effect of energy loss will be felt immediately. The systems interruptions caused by inverters often take weeks to resolve. Wires frequently take a longer time to resolve due to the difficulty of detection; therefore, a proactive maintenance approach is highly recommended.

Due to an increase in performance concerns, for a technology that is capital-intensive it is imperative to look towards automating the processes involved in the design of PV-systems. It is recommended for researchers and experts in the domain to come up with standard design methods. The component configurations for respective locations should also be standardized. During the design stage, the energy output should be projected based on known environmental input data rather than estimates. On-site monitoring and results from already installed PV-system plants should be used to validate projections for new PV-systems. It is highly recommended to use system analysis and optimization methods to guarantee that the performances of PV-systems installed will be enhanced. However, the factors affecting the performance are confounding and complicated. Further studies should investigate the causes of poor performance collectively.

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