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Climate-based technology screening and temperature-derating assessment of commercial PV modules under hot-arid conditions in Najaf, Iraq, using NREL SAM

Hiba Qasim Mohammed

Department of Mechanical Technologies, Kufa Institute, Al-Furat Al-Awsat Technical University, Al-Najaf, IRAQ
**Corresponding Author: e-mail: hiba.mohammd@atu.edu.iq*
ORCID ID :http:/orcid.org/ 0009-0007-5193-710X

Abstract

High ambient temperature is a major constraint on photovoltaic (PV) performance in hot desert regions, where modules are still often screened primarily by rated efficiency or total annual energy. The aim of study to describe the use of these resources for resource assessment and performance modeling is quite common, as with NSRDB-type data and a comparison between different commercial PV module technologies was conducted for the city of Najaf, Iraq, based on climate parameters and by employing the PV module simulation tool (NREL SAM) with MATLAB post-processing. All cases used the same weather file to remove the variability introduced by the climatic input to compare module technology and the temperature derating that happens to each one of them. This study presents a climate-based comparison of four commercial PV module technologies for Najaf, Iraq, using the National Renewable Energy Laboratory System Advisor Model (NREL SAM) with MATLAB post-processing. A fixed-tilt, grid-connected rooftop PV system of about 10 kWp was modeled under identical location, orientation, inverter, loss, and grid assumptions. The cases comprised SunPower SPR-E19-310-COM and Jinko JKM400M-72L-V monocrystalline silicon modules, a Panasonic EVP370PK high-efficiency monocrystalline silicon module, and a First Solar FS-7550A-FT1 CdTe thin-film module. Annual AC energy, specific yield, DC capacity factor, performance ratio, the Pmax temperature coefficient, and deviation from standard test conditions (STC) were compared. SunPower and Jinko delivered the highest annual AC energy (18,731 and 18,720 kWh/year), largely because their installed DC capacities were slightly higher. After normalization by installed capacity, however, the CdTe module performed best, reaching a specific yield of 1,782 kWh/kWp/year, a performance ratio of 0.80, a Pmax temperature coefficient of −0.295 %/°C, and an STC deviation of −6.914 %. The results show that total annual energy is an inadequate sole criterion for module selection in this climate and that normalized yield, performance ratio, and temperature-related derating should also be considered. The conclusions apply to the four modules and system assumptions examined.

Keywords: CdTe module, solar, Panasonic EVP370PK, photovoltaic system; technology screening; temperature derating; hot-arid climate; NREL SAM; specific yield; performance ratio; module selection

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1. Introduction

Modular, scalable, and perfectly suited for both centrally generated and decentralized generation, PV technology is one of the most widely used renewable-energy options (Aalaska et al 2017). Rooftop and small grid-connected systems can help to de-couple reliance on traditional electricity supply and contribute to more sustainable provision of electricity in regions with sufficient solar resources (Kannan and Vakeesan, 2016). However, high irradiance is not sufficient to ensure high energy yield; operating temperature, soiling, irradiance distribution, wind speed, inverter behavior and module electrical characteristics, etc. (Skoplaki and Palyvos, 2009) also (Dubey et al 2013) all influence field performance.

One of the primary limitations for PV operation in a hot desert environment is in terms of power loss due to temperature. The rating is at standard test conditions (STC) (25 °C and 1000 W/m²) although the temperature in the field is often significantly higher than STC, especially in summer months with high irradiance. The maximum power decreases then, as a function of the temperature coefficient (Mani and Pillai, 2010) for most technologies. If the two modules have different temperature coefficients and thermal responses, they can yield quite different annual yields in the same climate with the same rated power (Sarver T, 2013).

Such an effect is particularly significant in Iraq where high ambient temperatures occur during the period of high irradiation for most of the year. A single criterion of nominal efficiency or rated power should therefore not be used to choose the PV technology. The effectiveness of each technology in converting the available resource into usable AC electricity under field conditions in metrics that account for capacity and operating losses (specific yield, performance ratio, capacity factor, and performance derating under operating conditions) (Maghami et al. 2016). PV technologies are not equally sensitive to high temperature. Although the dominant technology is crystalline silicon, its production is typically hurt by a relatively large negative temperature coefficient. The temperature coefficient can be smaller for CdTe thin film modules (Ilse et al. 2008), so that there may be a performance advantage in hot climates, and depending on the design of the module, the high efficiency monocrystalline silicon modules can also limit the magnitude of the temperature coefficient compared to conventional silicon modules (Darwish. et al, 2015). In order to make a meaningful selection, the candidate modules should be evaluated under the same local climate and system configuration (Chanchangi et al, 2020).

The other significant loss mechanism in dry areas is soiling. Transmittance of the front glass is reduced by the deposition of dust on the surface, and the amount of dust which can be removed from the glass, its type and size, surface properties, humidity, wind velocity, inclination, and cleaning frequency (Faiman, 2008) influence how much light actually reaches the cells. In harsh environments, degradation and reliability should also be considered as long term degradation is technology specific. (Schwingshackl, et al 2013., Makrides. et al, 2009).

Where long-term field data are scarce, simulation is commonly used to estimate PV performance before installation. The System Advisor Model (SAM), developed by the National Renewable Energy Laboratory (NREL), can represent module, inverter, weather, array, and loss effects in a consistent framework (Marion et al, 2005, Reich et al, 2012). Given representative meteorological inputs, it returns annual and monthly generation together with standard performance indicators. In this study, SAM was used to compare four commercial module technologies in one grid-connected rooftop configuration at Najaf, Iraq, while MATLAB was used for post-processing, plotting, and comparative analysis (Huld et al 2010).

Although many feasibility and simulation studies for hot regions report annual energy or overall resource potential, fewer studies screen module choice through specific yield, performance ratio, temperature coefficient, and operating-condition derating considered together. Yet modules with different installed capacities and thermal characteristics can behave quite differently in service, so nominal efficiency or total annual energy provides a weak basis for selection. To address this screening gap, four commercial modules were compared under Najaf conditions: SunPower monocrystalline silicon, Jinko high-power monocrystalline silicon, First Solar CdTe thin-film, and Panasonic high-efficiency monocrystalline silicon. Annual AC energy, specific yield, capacity factor, performance ratio, and operating-condition derating were then interpreted together to support climate-based screening for the modules and assumptions considered, rather than to propose a universal ranking of PV technologies (Cañete et al, 2014).

2. Literature Review

2.1 PV Performance Modeling and Assessment Indicators

PV performance modeling relies on weather data, module electrical parameters, inverter characteristics, array layout, and system-level loss assumptions. Several established models have been developed to estimate array output under field conditions. The De Soto model improved prediction by representing irradiance- and temperature-dependent changes in module parameters ; detailed system models have been proposed for coupled module–inverter behavior (Sharma et al, 2013); and the Sandia array performance model remains a standard reference for PV prediction and parameterization . For grid-connected systems, annual AC energy is informative but does not support a fair comparison when installed DC capacities differ. Capacity-based indicators — especially specific yield, capacity factor, and performance ratio — are therefore widely used, because they place systems of different size, technology, and climate on a comparable basis. The same indicators were adopted here to compare module technologies under identical location, configuration, and loss assumptions (Carr et al 2004).

2.2 Temperature Effect on PV Module Performance

PV output is directly influenced by cell temperatures; the higher the temperature above the STC, the lower the PV module voltage and, therefore, the lower the maximum power. There has been a thorough review of operating-temperature correlations and of the dependence of power on temperature). A practical approach for the estimation of module temperature in the outdoors has been suggested by Faiman and the influence of wind speed on the thermal behavior of modules has been discussed and (Aste et al 2014). Dubey et al. discussed the effect of temperature on PV efficiency and its implications for the energy production. Makrides et al. also demonstrated that the thermal response and yield is influenced by technology and local climate . Heat loss and thermal-management techniques have also been examined as possible approaches to reducing temperature losses in hot environments. The Pmax temperature coefficient was used in this work as an important technology-dependent parameter due to the high ambient temperature and strong irradiance of the site considered for the installation of Najaf.

2.3 Outdoor Performance of Different PV Technologies

Field performance depends not only on rated power and efficiency but also on how technology behaves under real operating conditions. Huld et al. mapped the performance of different module types and showed that both technology and data averaging influence yield estimation . Comparative outdoor studies have likewise shown that technology choice can alter energy yield, performance ratio, and temperature-related loss under otherwise similar conditions (Fezzani et al 2022).

Cañete et al. proposed that comparing module technologies should be done on normalized basis and not on nominal basis . Sharma et al., Carr and Pryor, and Aste et al. all reported differences in outdoor performance that were related to the technology . In more recent years, (Fezzani et al 2022). evaluated multi-technology modules in the field in Ghardaïa, Algeria, a hot and dry location similar to the present climate situation (Adeeb J, et al 2019). There have also been other studies involving cell technologies and their characteristics in the Middle Eastern and other regional climate conditions (Balaska A, et al 2017). The temperature-coefficient magnitudes of CdTe thin-film modules are generally smaller than those of conventional silicon modules, and CdTe is often used in high-temperature applications. However, total annual energy is also dependent on installed DC capacity, the module area, sizing and inverter matching. There should be, therefore, a fair comparison of total output and capacity indicators such as specific yield and performance ratio. (Barion et al 2014).

2.4 Soiling, Degradation, and Hot- Climate Challenges

PV systems are operated under hot and dry conditions, where both high temperatures and dust loss challenges are present. Dust particles on the glassdecrease the transmittance and the irradiance at the cell. Soiling has been identified as a significant loss mechanism by (Mani and Pillai, 2014) and the mechanisms, measurement and mitigation of soiling losses have been reviewed by (Sarver et al. 2005) and by (Maghami et al. 2019).

The soiling is affected by the type of dust, particle-size distribution, surface properties, humidity, wind speed, tilt and cleaning frequency. The basics of the process were explained by Ilse et al., and Darwish et al. investigated the impact of the type of dust pollutant on PV performance .Results from other dusty areas also confirm the importance of soiling to assess PV systems in dry climates. The AM was therefore assumed as a monthly soiling-loss input in the SAM runs to take into account dust losses at Najaf.

Long term output is also influenced by degradation and reliability, which varies with module type, such as crystalline silicon, CdTe, CIGS, dye-sensitized, organic and perovskite modules. Jordan and Kurtz discussed degradation rates, and subsequent compilations presented degradation rates for technologies and field conditions ; reliability studies have followed trends of module performance parameters over time (Alaa 2025). Literature was consulted with regard to long-term degradation, although not central to the present study, this literature was useful in interpreting the present findings and future-work recommendations.

3. Materials and Methods

3.1 Study Location and Weather Data

The city of Najaf has been chosen as it is situated in a hot and dry region with high solar radiation during summer. The simulations are based on a fixed rooftop installation at about 32.01° N., 44.30° E. Climatic data provided by A typical meteorological year (TMY) file of Najaf was used as input to SAM such as solar radiance, ambient temperature and wind speed.

Where long-term ground measurements are limited, satellite- and model-derived datasets are commonly used in PV studies (Al-Ghezi et al 2022). This type of data is supplied by NASA POWER and the use of these resources for resource assessment and performance modeling is quite common, as with NSRDB-type data (Velmurugan 2026). All cases used the same weather file to remove the variability introduced by the climatic input in order to compare module technology and the temperature derating that happens to each one of them.

3.2 Simulation Tool and Modeling Framework

The simulations were performed in NREL SAM, version 2025.4.16, which estimates system performance from weather data, module electrical parameters, inverter specifications, array configuration, and loss assumptions. The underlying PV-performance approach is based on established models reported in the literature. The choice of the grid-connected PV model was made without considering financial analysis as it was not an aim of the study. The CEC databases were used for the retrieval of modules and inverter. All cases shared the same location, weather, module orientation, grid assumptions, inverter, and loss settings with the differences observed related primarily to electrical and thermal properties of the module (Kettle et al 2022).

3.3 PV System Configuration

The modeled system was a fixed-tilt, grid-connected rooftop array of about 10 kWp, representing a small distributed installation relevant to residential, educational, and small commercial buildings in Najaf. No storage or tracking was included. Tilt was set to 30° and azimuth to 180° (due south), which is appropriate for a fixed array in Iraq. Every case utilized an inverter by Tigo Energy with a capacity of approximately 10.08 kW AC, which means that the performance differences in the cases were attributable more to the module than to the inverter. The electrical and loss parameters were not changed among the various cases, the limitation for grid export was turned off, and the external shading was not considered.

3.4 PV Module Cases

Four commercial modules were examined to represent a range of technologies and temperature-coefficient behavior. Case 1 used a SunPower SPR-E19-310-COM monocrystalline silicon module as the silicon baseline; Case 2 used a Jinko JKM400M-72L-V high-power monocrystalline silicon module; Case 3 used a First Solar FS-7550A-FT1 CdTe thin-film module; and Case 4 used a Panasonic EVP370PK high-efficiency monocrystalline silicon module.

Each array was sized to remain close to 10 kWp while satisfying the inverter voltage and stringing limits. The SunPower case used 7 modules per string and 5 strings; Jinko used 9 modules per string and 3 strings; the First Solar CdTe case used 2 modules per string and 9 strings; and Panasonic used 9 modules per string and 3 strings. All remaining settings were fixed.

3.5 Loss Assumptions

There were no differences in the loss settings among cases. The monthly soiling loss was to be 5 % and external shading and snow loss were to be ignored. The losses at the DC side were 2 % losses due to module mismatch, 0.5 % losses due to diode and connection losses, and 2% losses due to DC wiring losses. SAM calculated inverter and conversion losses using the selected inverter model. The inclusion of soiling was due to the fact that, in dry climates, the loss mechanism of dust accumulation plays a critical role. It is shown here as a constant monthly deposition; further field studies will clarify the seasonal deposition, cleaning frequency, rainfall and site-specific particulate properties (Jordan et al 2013).

3.6 Performance Indicators

The indicators considered were annual AC energy, monthly AC energy, specific yield, DC capacity factor, performance ratio, and module deviation from STC — all standard measures for evaluating and comparing grid-connected PV systems across climates and technologies (Jordan et al 2016).

Annual AC energy is the useful electricity delivered after inverter conversion and system losses. Specific yield, which normalizes annual energy by installed DC capacity, was computed as

$$Y_f = \frac{E_{AC,annual}}{P_{DC,installed}} \tag{1}$$

where Y_f is the specific yield (kWh/kWp/year), E_AC,annual is the annual AC energy (kWh/year), and P_DC,installed is the installed DC capacity (kWp).

The DC capacity factor, expressing annual utilization relative to installed DC capacity, was computed as

$$CF_{DC}(\%) = \left[\frac{E_{AC,annual}}{P_{DC,installed} \times 8760}\right] \times 100 \tag{2}$$

where 8760 is the number of hours in one year.

The performance ratio was adopted as a capacity-normalized measure of overall system performance relative to the available plane-of-array irradiation:

$$PR = \frac{E_{AC,annual}}{[P_{DC,installed} \times (\frac{H_{POA,annual}}{G_{STC}})]} \tag{3}$$

Where H_{POA},annual is the annual plane-of-array irradiation (kWh/m²) and G_{STC} is the reference irradiance under STC (1 kW/m²). Because G_{STC} equals 1 kW/m², the ratio $H_{POA,annual}$ / G_{STC} represents the equivalent annual peak-sun-hours. The module deviation from STC reported by SAM was used as an indicator of operating-condition derating, reflecting the output reduction caused by real conditions, chiefly elevated cell temperature and irradiance departures from STC.

3.7 MATLAB Post-Processing and Statistical Analysis

Data was processed, plotted, and compared using MATLAB. The monthly and annual outputs exported from SAM were post-processed to provide comparative figures and indicators, especially annual AC energy, comparison in monthly trends, specific yield, capacity factor, performance ratio and STC deviation. A correlation also was calculated between the Pmax temperature coefficient and the deviation from STC of the module. This result was used to draw a comparative conclusion within the sample as it was only four modules that were investigated, and not as an absolute statistical conclusion.

4. Results and Discussion

4.1 Annual Energy Performance

The annual results distinguish total AC energy from capacity-normalized yield. The SunPower monocrystalline silicon case produced the highest annual AC energy, 18,731 kWh/year, narrowly ahead of the Jinko high-power monocrystalline silicon case at 18,720 kWh/year. The CdTe thin-film and Panasonic high-efficiency monocrystalline silicon cases produced 17,649 and 17,580 kWh/year, respectively. The lower totals of the CdTe and Panasonic cases were partly attributable to their smaller installed DC capacities relative to SunPower and Jinko. Specific yield and performance ratio therefore provide a fairer basis for comparison, because the effect of system size must be removed before technologies can be judged on performance (Meyer et al 2004). Table 1 summarizes the annual indicators for the four cases.

Table 1. Annual performance indicators of the simulated PV module cases.

Case	Module	Technology	DC capacity (kW_{dc})	Annual AC energy (kWh/year)	Capacity factor (%)	Specific yield (kWh/kWp/year)	Performance ratio
Case 1	SunPower SPR-E19-310-COM	Mono-c-Si	10.855	18,731	19.7	1,725	0.78
Case 2	Jinko JKM400M-72L-V	High-power Mono-c-Si	10.809	18,720	19.8	1,732	0.78
Case 3	First Solar FS-7550A-FT1	CdTe thin-film	9.905	17,649	20.3	1,782	0.80
Case 4	Panasonic EVP370PK	High-efficiency Mono-c-Si	10.006	17,580	20.1	1,757	0.79

Figure 1 compares the annual AC energy of the four cases. SunPower and Jinko ranked highest, at 18.73 and 18.72 MWh/year, while First Solar CdTe and Panasonic followed at 17.65 and 17.58 MWh/year. This ordering should be interpreted alongside the installed DC capacities, because the CdTe and Panasonic systems were slightly smaller.

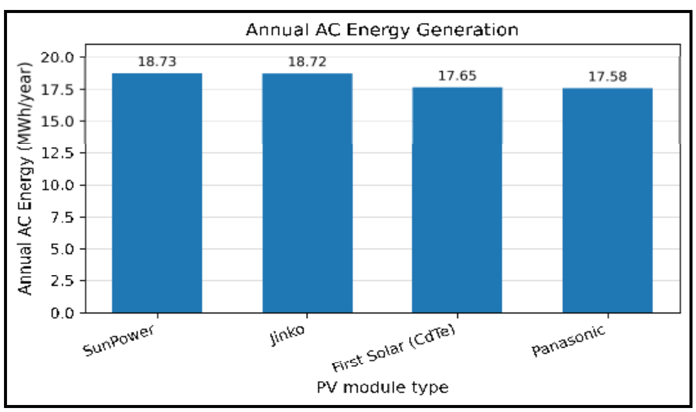

Figure 1. Annual AC energy generation of the four simulated PV module cases under Najaf climatic conditions.

Because the installed DC capacities differed, specific yield was used for a capacity-normalized comparison (Figure 2). The First Solar CdTe module achieved the highest specific yield, 1,782 kWh/kWp/year, followed by Panasonic at 1,757 kWh/kWp/year, while the Jinko and SunPower monocrystalline silicon modules yielded 1,732 and 1,725 kWh/kWp/year. The CdTe module therefore produced the most energy per installed kilowatt-peak, consistent with its more favorable high-temperature behavior.

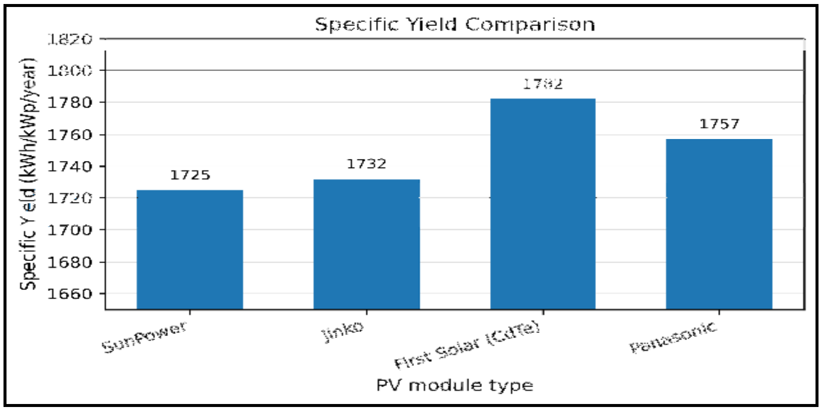

Figure 2. Specific yield of the investigated PV module cases under Najaf climatic conditions.

4.2 Monthly Energy Generation

Monthly AC energy followed the same seasonal pattern in every case, rising from winter to summer and peaking in June, July, and August. This pattern reflects the stronger summer irradiance at Najaf, although part of the seasonal gain is offset by higher module temperatures, which depress conversion efficiency (Ndiaye et al 2013).

In the SunPower case, the maximum AC energy utilized was 1827.74 kWh monthly in July, and the minimum was 1162.55 kWh monthly in November. Jinko did the same, with July's total of 1,822.79 kWh and November's of 1,164.77 kWh. Also, July saw the highest level for the CdTe case, with a score of 1,743.02 kWh, and for Panasonic, it was 1,723.13 kWh. These profiles show that availability of resources is the determinant for the seasonal trend, while the differences between the technologies are explained by the temperature response of the modules. Table 2 shows the monthly results of all cases.

Table 2. Monthly AC energy generation for the simulated PV module cases (kWh).

Month	SunPower Mono-c-Si (kWh)	Jinko Mono-c-Si (kWh)	First Solar CdTe (kWh)	Panasonic Mono-c-Si (kWh)
Jan	1,291.09	1,294.65	1,197.31	1,200.57
Feb	1,373.71	1,375.95	1,273.99	1,278.22
Mar	1,681.18	1,682.01	1,568.49	1,570.12
Apr	1,642.45	1,642.20	1,542.17	1,538.68
May	1,766.02	1,763.27	1,673.44	1,662.97
Jun	1,778.43	1,774.64	1,688.19	1,674.62
Jul	1,827.74	1,822.79	1,743.02	1,723.13
Aug	1,769.29	1,767.57	1,691.56	1,675.59
Sep	1,700.36	1,696.00	1,615.16	1,604.62
Oct	1,501.63	1,500.30	1,422.40	1,414.58
Nov	1,162.55	1,164.77	1,087.70	1,085.89
Dec	1,236.12	1,239.50	1,150.59	1,151.39

The seasonal behavior is discussed in Figure 3. Production was higher in the early parts of the growing season (winter) and then peaked in July, followed by June and August before dying down towards the year-end, minimum in November and December. While all four cases had a seasonally similar output shape, the SunPower and Jinko modules had slightly higher output in most months.

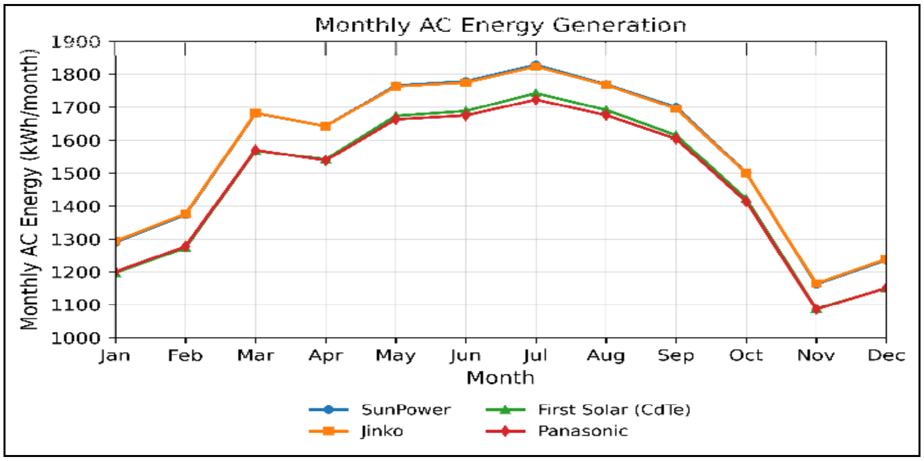

Figure 3. Monthly AC energy generation of the investigated PV module cases under Najaf climatic conditions.

4.3 Temperature-Derating Behavior

The Pmax temperature coefficient was broadly consistent with the operating-condition derating estimated by SAM. Jinko had the largest coefficient magnitude (−0.402 %/°C), followed by SunPower (−0.380 %/°C); Panasonic was lower (−0.339 %/°C), and CdTe was the smallest (−0.295 %/°C).

The results obtained in the table below yielded good values, as shown in the figure below, indicating the efficiency of the method used, which produced statistically significant results. The STC deviations broadly followed the same order. The SunPower and Jinko monocrystalline silicon cases deviated by −9.850 % and −9.495 %, the Panasonic high-efficiency module by −8.000 %, and the CdTe module by the smallest amount, −6.914 %, indicating the greatest resistance to operating-condition derating in this climate. Table 3 lists the coefficients and decreasing values.

Table 3. P_{max} temperature coefficient and operating-condition derating of the simulated PV module cases.

Case	Module	Technology	P_{max} temperature coefficient (%/°C)	Module deviation from STC (%)
Case 1	SunPower SPR-E19-310-COM	Mono-c-Si	−0.380	−9.850
Case 2	Jinko JKM400M-72L-V	High-power Mono-c-Si	−0.402	−9.495
Case 3	First Solar FS-7550A-FT1	CdTe thin-film	−0.295	−6.914
Case 4	Panasonic EVP370PK	High-efficiency Mono-c-Si	−0.339	−8.000

Thus, the smallest coefficient of magnitude had the lowest derating in the module. However, when the total annual energy was normalized by the installed DC capacity, the CdTe module had higher efficiency, even though its total annual energy was much lower, which is important in hot climates where high ambient temperature can cause significant efficiency loss (Gilman et al 2018). STC deviation should be viewed as the result of the combined effects of cell temperature, irradiance level, and spectral sensitivity, and not just the magnitude of the temperature coefficient; the difference in deviation between STC and SunPower is slightly less than that for Jinko, even though it has a higher coefficient magnitude.

The magnitude of the Pmax temperature coefficient is plotted against the STC deviation in Figure 4. The correlation is mostly positive with a higher derating being associated with a higher negative correlation. The smallest coefficient magnitude and smallest deviation were recorded with the First Solar CdTe module, while the monocrystalline silicon modules deteriorate more strongly, which is in accordance with the significance of the thermal effects on the selection of technologies for hot climates (Soto et al 2006). The trend is an indication only for this sample, as only four modules were compared (Tian et al 2012).

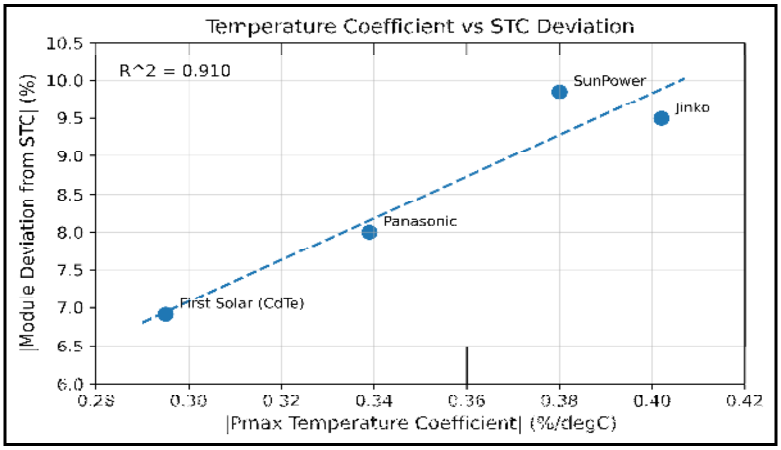

Figure 4. Relationship between the magnitude of the P_{max} temperature coefficient and the module deviation from STC for the investigated PV module cases.

These derating results are consistent with the Najaf climate, where high operating temperature reduces module output, most strongly for modules with larger negative Pmax coefficients. CdTe performed better on normalized terms because of its lower absolute coefficient and smaller STC deviation, whereas the crystalline-silicon modules, despite their higher total energy, were more temperature-sensitive after normalization. The temperature coefficient is not the sole determinant of yield, however: irradiance distribution, module electrical characteristics, inverter matching, and SAM model assumptions also affect the final result.

4.4 Comparative Technology Assessment

The results indicate that energy alone (total annual AC) is not a good indicator for the most appropriate technology for this climate. The DC capacity of SunPower and Jinko were slightly bigger, but once normalized by capacity, the CdTe module had the highest specific yield and performance ratio. The Panasonic module was in between. It had a smaller coefficient in magnitude than SunPower and Jinko, and resulted in a higher specific yield of 1,757 kWh/kWp/year and a performance ratio of 0.79, even if lower than CdTe, which had the smallest coefficient in magnitude along with the smallest STC deviation (Mondol et al 2006).

In general, the selection of modules for Najaf and similar climates should take rated power, efficiency, temperature coefficient and normalized yield into account. You can achieve high rated power without necessarily achieving the greatest yield per kWp in a hot climate application, as modules with more favourable thermal characteristics may have greater yield per kWp installed per kWp, which can become more significant over the lifetime of a hot climate installation. This is in line with previous outdoor comparisons and research highlighting the temperature dependency of the module's behaviour. (Jehan et al 2024).

4.5 Climate-Based PV Technology Ranking

To translate the simulated indicators into a screening outcome, the four cases were ranked on both absolute and capacity-relevant measures rather than on annual AC energy alone. Annual AC energy represents total output, specific yield removes the effect of installed capacity, performance ratio reflects conversion quality under field conditions, and the Pmax coefficient together with STC deviation helps explain why some technologies maintain performance better at high temperature (Ayompe et al 2011). Because the cases carried slightly different DC capacities, the largest annual energy does not by itself identify the most suitable technology. Table 4 presents the resulting suitability matrix (Kymakis et al 2009).

The CdTe module achieved the highest values for the screening modules in the modules studied, namely the highest specific yield of 1,782 kWh/kWp/year, the highest performance ratio of 0.80, the smallest coefficient magnitude of −0.295 %/°C, and the smallest difference with the STC of −6.914 %. The Panasonic high-efficiency monocrystalline silicon module was second to CdTe, but it performed better in terms of thermal behavior than did the other silicon modules and was less on a normalized basis (Padmavathi et al 2013). It is observed that the slightly higher installed DC capacities of Jinko and SunPower resulted in a higher total annual energy, but once the capacity was removed, it was observed that they had a larger negative coefficient and also had a higher STC deviation, which resulted in them dropping to third and fourth places (Biva et al 2015) This ranking is a comparative screening result for the modules analyzed and does not include all PV technologies (Milosavljevic et al 2015).

Practical implications. Modules should be rated by normalized yield for deployment in Najaf and similar hot regions, by performance ratio instead of annual energy, and by thermal derating instead of nominal efficiency, and should be judged for suitability on the basis of the local climate. If a module's temperature coefficient is very negative, then it may have a low energy per kilowatt-peak, despite having a high rated power or high annual energy (Bahaidarah et al 2013). This is more significant over the years of operation at high ambient temperature.

Table 4. Technology-suitability matrix for the investigated PV module cases under Najaf hot-arid conditions.

Module	Annual AC (kWh/yr)	Specific yield (kWh/kWp/yr)	PR	Pmax temp. coeff. (%/°C)	STC dev. (%)	Strength	Weakness	Rank
First Solar FS-7550A-FT1 (CdTe)	17,649	1,782	0.80	−0.295	−6.914	Top normalized yield	Lower total AC	1
Panasonic EVP370PK (high-eff. Mono-c-Si)	17,580	1,757	0.79	−0.339	−8.000	Good thermal behavior	Below CdTe yield	2
Jinko JKM400M-72L-V (Mono-c-Si)	18,720	1,732	0.78	−0.402	−9.495	High annual AC; high CF	Largest |temp coeff.|	3
SunPower SPR-E19-310-COM (Mono-c-Si)	18,731	1,725	0.78	−0.380	−9.850	Highest total AC	Lowest specific yield	4

5. Conclusions

In this study, a comparison between different commercial PV module technologies was conducted for the city of Najaf, Iraq, based on climate parameters and by employing the PV module simulation tool (NREL SAM) with MATLAB post-processing. All cases were tested with the same orientation, inverter, weather, grid, and loss assumptions, and included modules from a variety of types, including monocrystalline silicon, high-power monocrystalline silicon, high-efficiency monocrystalline silicon, and CdTe thin-film. The SunPower and Jinko monocrystalline silicon cases produced the most for the total annual AC energy, at 18,731 and 18,720 kWh/year, primarily as a result of the slightly larger DC capacities installed. With the capacity-normalized specific yields (kWh/kWp/year) being the highest at 1,782 kWh/kWp/year and the highest performance ratio of 0.80, respectively, First Solar CdTe module performed best and followed Panasonic with 1,757 kWh/kWp/year and 0.79, respectively. The derating analysis results indicated that the CdTe module has the smallest Pmax coefficient and STC deviation, which means that the module has high thermal suitability under high-temperature operation. This MATLAB correlation was consistent and showed a relationship between the size of the coefficient and the derating due to the operating condition for the modules studied, but the number of modules was small.

In general, the findings suggest that rated power and total annual energy should not be the sole basis used for choosing a module in hot climates; additional factors such as specific yield, performance ratio, and temperature derating should also be considered when making module selection choices. In terms of normalized performance, CdTe was the best option for Najaf and similar regions, and high-efficiency silicon was competitive in systems with higher capacity and availability, and under specific project requirements. By combining annual energy with normalized and derating indicators, the study provides practical climate-based screening support for module selection in Najaf and comparable dry, hot regions. It also shows that the highest total annual energy and the best normalized performance can belong to different technologies. These conclusions apply only to the modules and assumptions examined and should not be interpreted as a universal ranking.

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Biographical notes

Hiba Qasim Mohammed received her B.Sc. and M.Sc. degrees in Mechanical Engineering (Thermal Engineering). She has published one paper in a Scopus-indexed journal and Two papers in international journal. Her research interests include renewable energy, solar energy, photovoltaic/thermal (PV/T) systems, solar desalination, and thermal engineering.