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Research Article

Comparison of the Models for Solar Photovoltaic System Performance Calculations for Ankara (Middle Anatolia)

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Abstract

In a techno-economic analysis, to reach truthful feasibilities, accurate performance calculation of PV systems is a must. There are many models/calculation schemes to estimate PV module performances. In this study, we compare the estimation of three software (PV*Sol, PVsyst, HelioScope) using a whole year field data obtained in Ankara, for five-module types. The reason for these choices of the software is their common utilization by designers, financing bodies and investors. The results of the preliminary analysis showed that the calculation methods for the PV systems performances should be carefully evaluated and used as they contain quite many located dependent empirical parameters, and distinctions in the fabricated modules. Therefore, the present article focuses on the systems that use the module types of Mono-Si, Poly-Si, µc-Si/a-Si, CIS, and HIT. The comparisons showed that the estimation accuracies of the software are reasonable, yet the software Helioscope performs better than the others for the weather conditions of Ankara, Middle Anatolia.

Keywords: Solar energy, photovoltaics, performance estimation, outdoor testing, PV*Sol, PVSyst, HelioScope.

Fotovoltaik Sistemlerde Performans Hesaplama Modellerinin Ankara (Orta Anadolu) için Karşılaştırılması

Öz

Tekno-ekonomik analizlerde doğru fizibilite sonuçlarına erişebilmek için FV sistemlerin performansı gerçeğe yakın hesaplanmak zorundadır. FV sistem performansını tahminlemek için birçok model/hesaplama yöntemi vardır. Bu çalışmada, tüm yıl boyunca beş modül için Ankara'da ölçülmüş açık alan test verileri ile üç yazılımın (PV*Sol, PVsyst, HelioScope) aynı yer için tahmin sonuçları karşılaştırılmıştır. Bu yazılımların seçilme nedeni tasarımcılar, finansal uzmanlar ve yatırımcılar tarafından yaygın olarak kullanılmalarıdır. Sonuçların ilk analizleri, FV sistemler için performans hesaplama metodları çok sayıda bağımlı ampirik parametre ve üretilen modüllerdeki farklılıkları içerdiklerinden dikkatli bir şekilde değerlendirilmesi ve kullanılması gerektiğini gösterdi. Bu sebepten ötürü bu makale Mono-Si, Poly-Si, µc-Si/a-Si, CIS, ve HIT modül tiplerini kullanan sistemlere odaklanmaktır. Karşılaştırma sonuçları yazılımların tahminleme doğruluklarının makul seviyede olduğunu ortaya çıkarmıştır ancak Heiloscope Ankara'nın (Orta Anadolu) iklim koşulları için diğerlerinden daha iyi performans göstermiştir.

Anahtar Kelimeler: Güneş enerjisi, fotovoltaikler, performans tahmini, açık alan testi, PV*Sol, PVsyst, HelioScope.

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1. Introduction

Solar photovoltaics (PV) has gained the utmost importance due to the decrease in the cost together with efficiency increase owing to technological developments (EIA, 2017; IRENA, 2018; Mayer, Philipps, Hussein, Schlegl, & Senkpiel, 2015; NREL, 2019; Solar Power Europe, 2017, 2018). Moreover, PV systems with all sub-technologies are also crucial for the achievement of sustainable development goals (i.e., SDG 7 – affordable and clean energy) and climate change mitigation (SDG 13 – Climate action) (Labouret & Villoz, 2010; United Nations, 2019).

The main component of PV power systems is the PV modules that convert Sun's energy directly into electricity. However, the Sun's energy is intermittent and variable over time. Consequently, how efficiently solar irradiation falling on the PV modules can be converted into electricity should be estimated in an appropriate manner (Abdullah Bugrahan Karaveli & Akinoglu, 2018). These estimations can be made by some software programs whose algorithms use satellite data or surface solar irradiation measurement and some assumptions and performance calculation algorithms. Software that uses artificial intelligence also exists in the calculation algorithms of PV performance estimations (Mellit, Kalogirou, Hontoria, & Shaari, 2009).

In a recent technical paper published by NREL, Guittet and Freeman reported that various software performs better than others deviating for different PV applications. They use measured data, and they mainly compare HelioScope with others and conclude its predictions are comparable with those of other tools. The annual normalized error range that they obtain is -7.0% to 4.3% with an hourly normalized RMSE range of 2.9% to 6.6% (Guittet & Freeman, 2018).

In another recent article, Ceylan and Tasdelen compare various software using the measured data of a power plant located in Isparta/Turkey. Their results showed that the software HelioScope gives the best performance giving the least error statistics. The authors argue that all software, in general, can provide performance prediction within acceptable accuracy. They listed the other software they compared in terms of their performance accuracy as PVGIS, Polysun Online, and PV*Sol (Ceylan & Tasdelen, 2018).

This study compares the results gathered from software tools by considering different PV sub-technologies. The algorithm/software programs used for performance estimation purposes for PV modules are PV*Sol, PVsyst, HelioScope, etc. The most appropriate way to define the most accurate estimations is to compare the results that were determined through the software mentioned above programs with on-site measurements. If the calculations are made through software tools and the comparison is made via statistical comparison models such as mean bias error (MBE), mean absolute error (MAE), root-mean-square error (RMSE), then the performance of the software tools can be evaluated.

The next section is the methodology followed in the present study. Section three gives our research results and discuss the main findings. The last section is on the conclusion and our future research plan.

2. Material and Methodology

We used the value of the power at maximum point (P_{MPP}), which is simply the product of current at maximum power point (I_{MPP}) and the potential at maximum power point (V_{MPP}) at every instant of measurement of the tested modules for comparisons in the present study. Thus, the energy yield is obtained using measured data of the above parameters during the used testing period of one year. We compared these measured data with the estimated values obtained by the software mentioned above.

The standard parameters measured at standard test conditions (STC: Irradiance: 1000 W/m^2, Module temperature: 25 °C, Air mass: 1.5 (AM 1.5) spectrum) tabulated in Table 1 are the datasheet values that are essentially supplied by the manufacturers through the datasheets. Mainly, these parameters are used in the yield estimations of the software. They are explained in the followings: Current and voltage to produce maximum power that can be extracted STC, I_{MAX}, and V_{MAX}; the maximum power that can be extracted at STC, $P_{MAX} = I_{MAX} \times V_{MAX}$; Open circuit voltage at STC, V_{OC}; Short circuit at STC, I_{SC}; Efficiency calculated with per unit area values of input and yield at STC, η.

2.1. On-Site Measurements System

There is an on-site measurement system owned by The Center for Solar Energy Research and Applications (GÜNAM) within the campus of the Middle East Technical University (METU) (A B Karaveli, Ozden, & Akinoglu, 2018; Ogulgonen, Ozden, Yardim, Turan, & Kincal, 2015). This on-site measurement system is located in Ankara province in the Central Anatolia with a latitude of 39.895º. The measurement system consists of many different sub-technologies of PV modules such as Monocrystalline Silicon (Mono-Si), Polycrystalline Silicon (Poly-Si), Micro-Crystalline based Amorphous Silicon (μc-Si/a-Si), Cupper Indium Selenide (CIS) and Heterojunction with Intrinsic Thin layer (HIT) that have been in operation for about seven years.

GÜNAM outdoor module test platform is computer-controlled with 16 testbeds where PV modules are tilted at 32 degrees. Figure 1 gives the outdoor test platform together with a schematic representation of the test facility. The facility is located in Ankara where the climate is cold and semi-arid (Climate Change & Infectious Diseases Group, 2019; Ǩoppen, 1884; Rubel, Brugger, Haslinger, & Auer, 2017). The measured data is recorded in 10 minutes time interval. The parameters that have been measured within this facility are I-V characteristics, electrical properties, module temperatures, weather parameters. Thus, there are various short and long term accumulated data for different kinds of PV module sub-technologies.

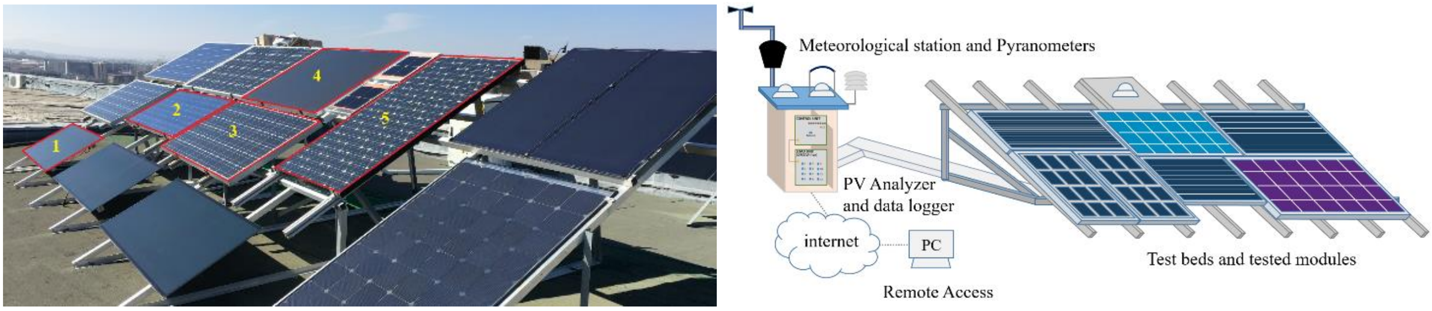


Figure 1. METU-GUNAM Outdoor Test Facilities and the modules evaluated in this study
(1: CIS, 2: Poly-Si, 3: Mono-Si, 4: µc-Si / a-Si, 5: HIT)

To make estimations for electricity production of PV modules and evaluate PV performance, solar irradiation that incident on the PV module should be known accurately (Abdullah Bugrahan Karaveli, Soytas, & Akinoglu, 2015). Then, using the module features (Table 1) and reference efficiency, efficiency variation with module temperature (temperature coefficient), and the ambient temperature, the electricity production of the system can be estimated (A B Karaveli et al., 2018).

Table 1. Properties of PV module on site measurement

Module Type	**P_{MAX} [W]**	**η [%]**	**V_{OC} [V]**	**I_{SC} [A]**	**V_{MAX} [V]**	**I_{MAX} [A]**	**Area [m²]**	**Testing Period Started**	**Testing Period Ended**
µc-Si / a-Si	128	9,14	59,8	3,45	45,4	2,82	1,4	Apr, 2012	Continue
CIS	130	12,38	59,5	3,28	44,9	2,90	1,05	Oct, 2014	Continue
Mono-Si	160	12,50	43,7	5,06	35,3	4,58	1,28	Aug, 2012	Continue
Poly-Si	130	12,75	21,7	8,18	17,8	7,30	1,02	May, 2012	Continue
HIT	230	16,55	42,3	7,22	34,3	6,71	1,39	Apr, 2012	Continue

2.2. Software Programs and Methodology

PV performance evaluations are carried out using the software mentioned above, namely PVsyst, PV*Sol, and HelioScope whose calculation methodology and procedures are given in Table 2.

Table 2. The used software programs and their performance and yield calculation methodologies

Procedure	**PVsyst**	**PV*SOL**	**HelioScope**
Modeling timestep	Hourly	Hourly	Hourly
Decomposition of global horizontal irradiance (GHI)*	Erbs	Reindl	N/A
Transposition to-plane-of-array*	Perez	Hay-Davies	Perez
Module Model	Shockley's single diode model	Enhances single diode	Shockley's single diode model
Thermal Model	Thermal balance equation	Thermal balance equation	Sandia National Laboratory
Albedo	0.2	0.2	0.2

* The correlations used are given in detail in Duffie and Beckman (Duffie & Beckman, 2013).

Within this study, the nameplate specifications of 5 different module types tested in the outdoor test facility are given in Table 1. The identical modules included within the library of the software mentioned above are chosen to evaluate the performances for comparisons. Installation of around 2 kWp is designed using PV modules within the software. The systems are hypothetically installed to the roof of the Department of Physics building where GÜNAM's outdoors test facility is located as free-standing. Then, the DC yield and performance data of the installations gathered from three software are reduced to per unit area outcomes. Similarly, we reduced also the DC yields of tested modules (Table 1 and Fig. 1) to per unit area. Thus, using the estimated values by the software and measured data, the comparisons are carried out with statistical error measures of Mean Biased Error (MBE), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE).

These statistical errors are calculated on a monthly based using the deviation between the measured and estimated values, $E_{error} = E_{measured} - E_{estimated}$, as follows:

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(E_{error,i}\right) \quad (1)$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|E_{error,i}\right| \quad (2)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(E_{error,i}\right)^2}. \quad (3)$$

MBE is a measure of over- or under-estimations of the measured values by the used methodology of the software. The other two, MAE and RMSE gives information on the overall accuracy of the estimations. While MAE gives an absolute accuracy, RMSE results in a large number if any one of the deviations gets an extreme value rather.

3. Results and Comparison

The overall software results for the per unit area yield of the modules are tabulated in Table 3. HIT module performance is much better than the others as expected. The yield reaches 30.5 kWh/m^2 for July for HIT while the lowest yield is around 14 kWp/m^2 for μc-Si / a-Si. A clear distinction in the yields can be observed between thin-film μc-Si / a-Si modules and crystalline modules Mono-Si, Poly-Si, and HIT. However, interestingly CIS module yield seems similar to that of Mono- and Poly-Si, which is unexpected and this can be attributed to rather newer technology used in producing CIS modules. It can also be observed in outdoor measurement results given in the last row of Table 3.

Table 3. The monthly yields of the modules estimated using three software and measured in the field (in kWh/m^2).

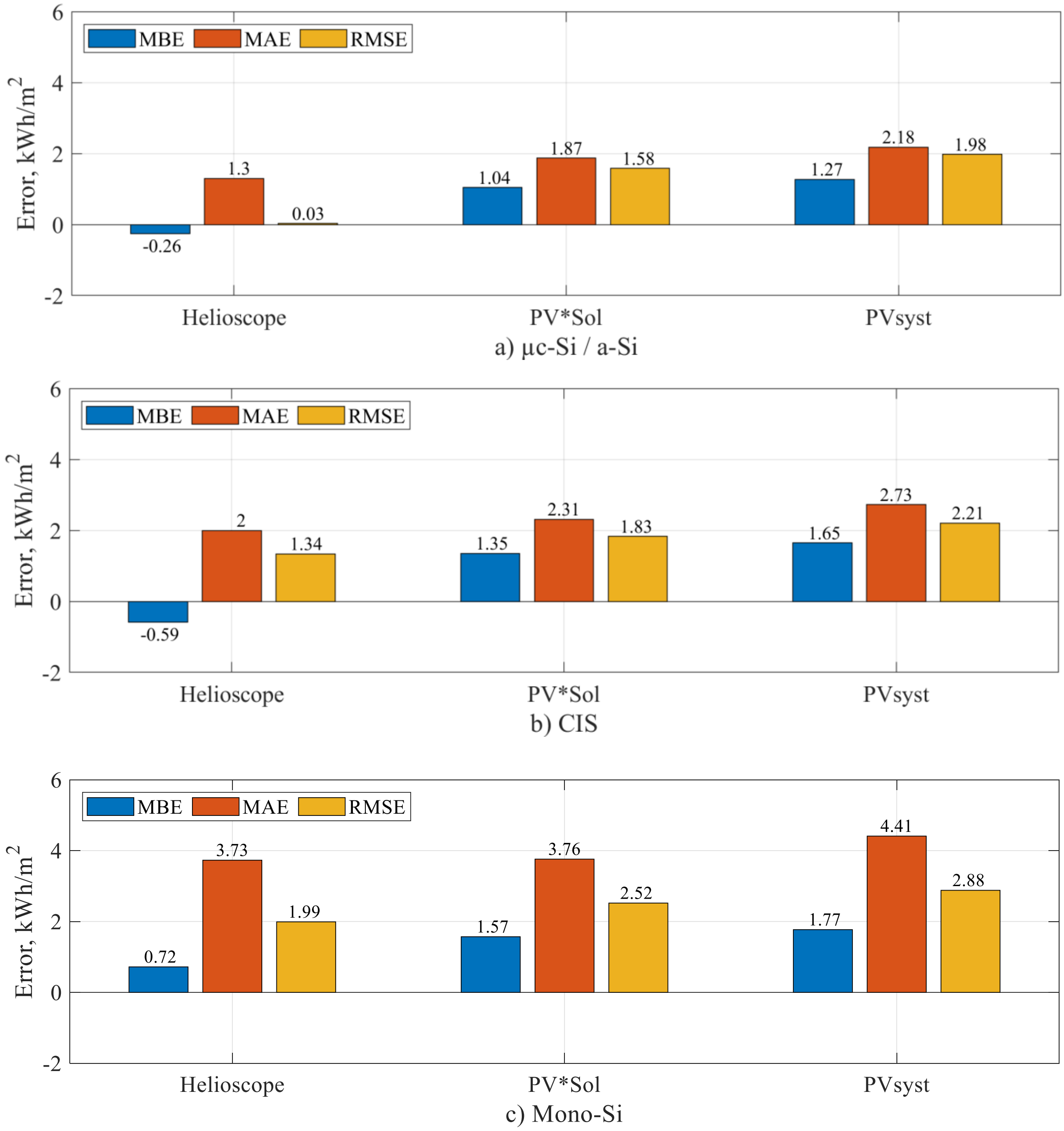
	Months*	January	February	March	April	May	June	July	August	September	October	November	December
μc-Si / a-Si	PVsyst	9,4	7,9	10,0	12,8	13,6	14,7	15,0	15,0	11,8	10,0	8,2	7,6
	PV*Sol	6,5	7,3	8,9	11,3	11,8	13,2	14,0	13,5	10,6	9,0	7,7	7,3
	Helioscope	6,8	8,1	10,1	12,8	13,6	15,3	16,6	16,0	13,1	10,6	8,8	8,2
	Measured	5,1	8,5	9,6	10,4	12,9	15,9	17,1	15,7	15,0	11,8	8,4	6,2
CIS	PVsyst	9,1	10,7	13,2	16,7	17,6	19,0	19,2	19,4	15,4	13,3	11,2	10,6
	PV*Sol	9,3	10,3	12,5	15,7	16,3	18,0	18,9	18,1	14,5	12,4	10,8	10,5
	Helioscope	9,6	11,5	14,3	18,2	19,4	21,7	23,6	22,7	18,6	15,0	12,4	11,7
	Measured	9,4	13,0	14,1	14,7	17,7	21,2	22,4	20,2	19,8	16,5	12,8	9,7
Mono-Si	PVsyst	9,4	11,0	13,4	16,9	17,9	19,4	19,7	19,9	15,8	13,7	11,5	11,0
	PV*Sol	8,6	9,7	11,8	15,0	15,4	17,1	18,0	17,3	13,8	11,7	10,2	9,9
	Helioscope	9,4	11,3	14,0	17,8	19,0	21,3	23,1	22,3	18,2	14,8	12,2	11,4
	Measured	8,6	13,9	15,0	15,8	19,3	23,1	24,2	21,7	20,9	17,6	13,5	9,7
Poly-Si	PVsyst	9,3	10,9	13,2	16,6	17,6	19,0	19,2	19,3	15,5	13,4	11,4	10,9
	PV*Sol	9,4	10,0	12,1	14,9	15,3	16,8	17,6	16,8	13,8	11,8	10,7	10,6
	Helioscope	9,6	11,4	14,3	18,1	19,3	21,6	23,5	22,6	18,5	15,0	12,4	11,6
	Measured	7,8	13,0	14,0	14,7	18,0	21,1	21,7	19,5	19,0	16,3	12,6	9,3

HIT	PVsyst	11,9	14,0	17,3	22,0	23,3	25,4	25,9	26,1	20,5	17,6	14,7	13,9
	PV*Sol	12,0	13,3	16,3	20,4	21,3	23,6	24,9	23,9	19,1	16,2	14,0	13,6
	Helioscope	12,5	14,9	18,6	23,6	25,1	28,1	30,5	29,4	24,1	19,5	16,1	15,1
	Measured	11,2	18,0	19,6	20,6	24,9	30,2	32,0	29,0	28,2	23,4	18,1	12,8

*The comparisons are carried out using the data of the same year of 2017, for all the modules.

Estimation of the three-software compared to the measured values seem acceptable within some accuracy. However, Helioscope and PVsyst seem better than the other as can be observed in Table 3. In some of the months, the difference between estimations and measured values is rather high, which can be attributed to the uncommon weather condition of the specific months in the year of measurement.

For a detailed comparison Fig. 2 is presented on statistical errors. It can be observed that the software Helioscope performs better than the other two. The RMSE value reached to quite a high value of 5.14 kWh/m^2 for HIT with PV*Sol. Considering that the average value of the monthly yield of a 1 m^2 module to be around 20 kWh/m^2, the value of 5.14 kWh/m^2 for RMSE is large. It is due to the uncommon weather condition of some specific months as mentioned before. Another interesting result is that the two of the software PV*Sol and PVsyst underestimate, as can be observed from MBE values in Fig. 2.



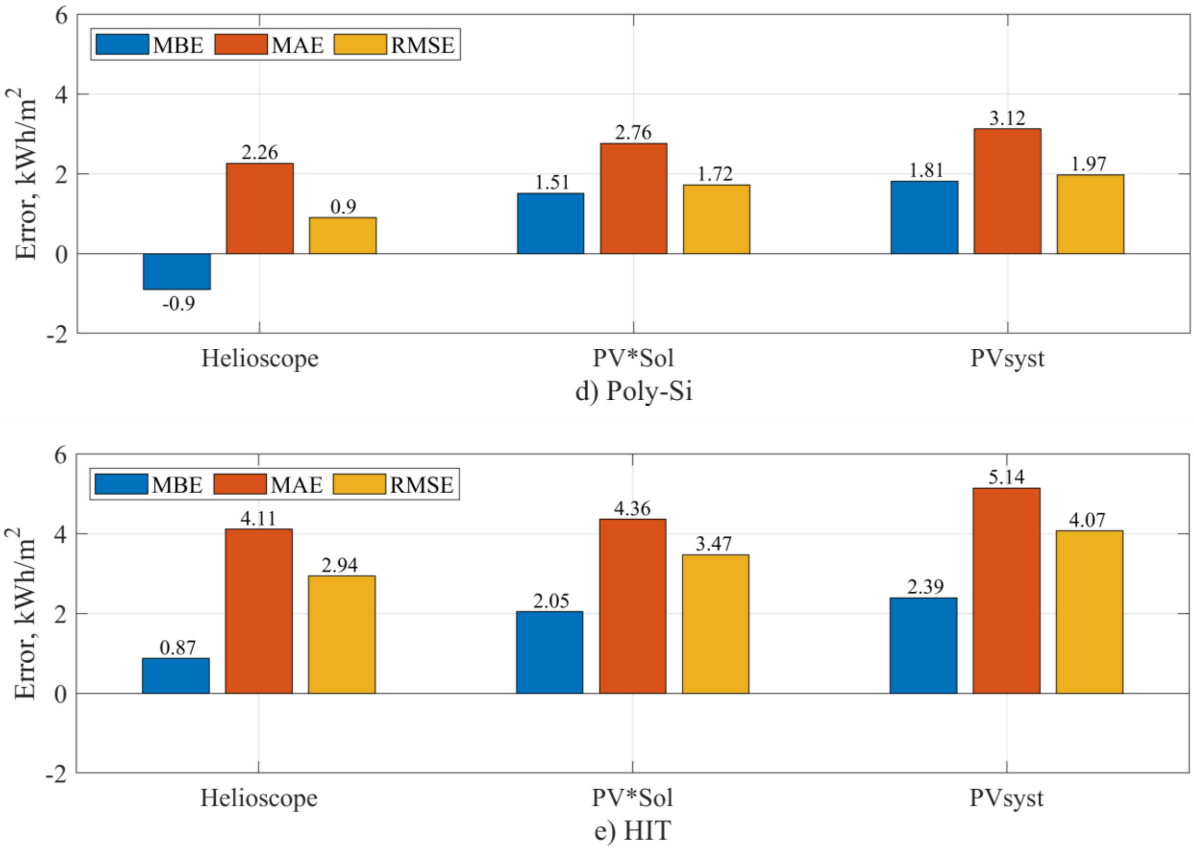


Figure 2. Results of statistical comparisons (in kWh/m^2)

Conclusion

The installation of energy systems such as PV should be based on techno-economic feasibility analysis. To reach truthful feasibilities, the performance calculations of PV systems should be conducted with methodologies validated using field data. Consequently, the calculation schemes of the performance of PV modules should be carefully evaluated while the module types should be determined carefully.

In the present study, comparisons of performance predictions of PV modules are carried out using different software. They have quite differing performances. Predictions of the software depend mainly on estimating the input accurately. Although the performances are acceptable, they can further be modified. The best performing software is Helioscope, and the next is PVsyst.

Our further research plan is to extend these calculations to different types of modules commercially available. Besides, different climatic regions of the country will be considered for the techno-economic feasibility analyses that we carry out. Another future research of interest is to compare the results of software with a techno-economic feasibility algorithm that we recently developed (Abdullah Bugrahan Karaveli, 2018).

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