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Results in Sizing and Simulation of PV Applications Based on Different Solar Cell Technologies

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Abstract

Modeling and simulation of photovoltaic (PV) systems represents an essential task for the integration of PV panels in current power applications. At the present time, there are sizing tools of photovoltaic systems available on the market, taking into account the proposed energy consumption, site localization and system cost. An advanced specialized program (PVSyst) was considered. The sizing and simulations of two PV important applications were developed using PV modules based on three different technologies: monocrystalline and polycrystalline silicon, as well as CIS. Our results showed how different types of solar cell technologies influenced the final power output and performances for a PV LED lighting, as well as for a PV water pumping system, in terms of overall yield, efficiency and system availability.

Keywords

Photovoltaic, Simulations, Monocrystalline, Polycrystalline, Copper Indium Selenide, Solar Cells, Photovoltaic Lighting, Photovoltaic Water Pumping System

1. Introduction

Photovoltaic systems have a wide range of applicability and also include public or privately owned solar-powered lighting systems or solar powered water pumps [1]. Solar pumps offer a clean and simple alternative to fuel-burning engines and generators for domestic water, livestock and irrigation [2]. They are most effective during dry and sunny seasons. They require no fuel deliveries, and very little maintenance. Solar-powered lighting is an effective way to implement illumination solutions in terms of technology and consumption [3]. Global pressures were made to protect the environment, which has become a priority. In meeting these types of problems, various systems have been developed to replace traditional lighting with energy efficient lighting. The most common method is the LED (Light Emitting Diode) technology.

Various system simulations and dimensioning were developed for specific regions and applications, but using only one type of PV technology. In the paper "Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India", V. Sharma and S. S. Chandel have used polycrystalline modules to assess the performance of a power plant installed in India [4].

In the paper called "Simulation and performance analysis of 110 kWp grid-connected photovoltaic system for residential building in India: A comparative analysis of various PV technology", a similar approach is considered for a system to be implemented in a residential building in India. Four types of PV technologies were simulated to determine performance ratios and energy yield [5].

The purpose of the present paper is to identify the best solar cell technology that offers the highest system performances in a specific location. In order to define the most efficient solution that could be implemented in a given location, simulations were developed using monocrystalline, polycrystalline and CIS photovoltaic modules [6].

2. Real-Life Usage

Solar-powered lighting is an effective way to implement illumination solutions in terms of technology and consumption. Global pressures were made to protect the environment, which has become a priority. In meeting these types of problems, various systems have been developed to replace traditional lighting with energy efficient lighting. The most common method is the LED technology (Light Emitting Diode).

The design and simulation also provides general information and guidelines on planning and designing of small solar powered water pump system for use in irrigation and livestock feeding operations. One benefit of using solar energy to power water pump systems is that increased water requirements tend to coincide with the seasonal increase of incoming solar energy. When properly designed, these systems can also result in significant long-term cost savings. Aside irrigation and livestock feeding operations, these systems can and are being used for potable water supply in underdeveloped countries. As more and more groundwater sources become unsafe for drinking purposes, potable water often needs to be drawn from depths that require pumping. A Solar-Powered Water Pumping System uses solar energy to power a pump to supply a village with potable water. Solar pumping systems are also commonly being used where it is too far to walk to a well or where the well only provides seasonally usable water.

3. About PVSyst Simulation Software

The PVSyst software used in our study is one of the most comprehensive programs used for sizing and simulations of various PV systems. The software manages various types of photovoltaic system analysis like stand-alone PV systems, grid connected of hybrid systems. PVSyst uses meteorological data from international databases as well as detailed information about the component technical specifications [7].

4. Sizing and Simulations for PV LED Lighting System

We have chosen the PVSyst software application for comparing various solar cell technologies that could power a photovoltaic lighting system. In order to obtain conclusive results, we varied only the solar cell technologies, but the other components of the system remained unchanged. The sizing for this type of system will be as a stand-alone type, meaning that connection to the local energy grid is not required. Most of this type of systems require means for energy storage, therefore our system will use a solar battery. The PV application must be dimensioned to fully charge the batteries when exposed to maximum intensity for the given application. To avoid the possibility of damaging the system because of solar radiation fluctuations or battery overload, the system will be equipped with a charge controller.

One of the main components of the system is the lighting fixture (**Figure 1**). This is an ELMA 80-12 component provided by Electromagnetica SA, a company that specialized in manufacturing LED system components for lighting fixtures, and provides the following advantages: easy configuration and install, ecologic product, very high energy efficiency, low heat emissions, high reliability coefficient, low maintenance costs. The main technical parameters provided by Electromagnetica SA in the product technical sheet for the lighting fixture are presented in **Table 1**, as follows [8].

The PV system is intended to provide two days autonomy, in order to compensate for days with high cloudiness. This feature will result in a slightly oversized PV generator and battery. The types of PV technologies used in the simulations are monocrystalline silicon, polycrystalline silicon and CIS solar cells. In order to choose the most suited solar battery for the system, important factors are considered, like daily energy consumption (27 W), number of days for system autonomy (2 days), battery voltage (12 V) and discharge coefficient (0.4). To obtain the battery capacity, the following equation was used [9]:

$$\begin{aligned} C_{battery} &= \frac{\text{Daily Energy Use} \times \text{Number of Autonomy Days}}{\text{Battery Voltage} \times \text{Discharge Coefficient}} \\ &= \frac{27\ \text{W} \times 8\ \text{h} \times 2\ \text{days}}{12\ \text{V} \times 0.4} = 90\ \text{Ah} \end{aligned} \quad (1)$$

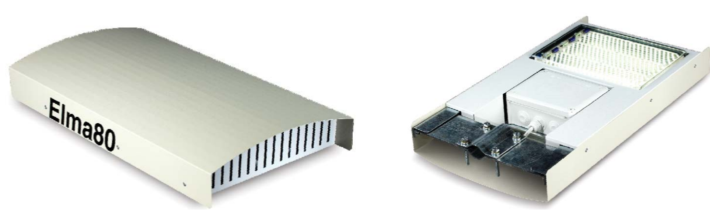

Figure 1. ELBI lighting fixtures.

Table 1. Main technical characteristics of ELMA LED.

Technical characteristics	Code RS81143A ELMA 80-12
Usage	Outdoor perimeter and street lighting
Nominal Voltage	12 Vdc
Nominal Power	27 W
Luminous Flux	2060 lm
Temperature color	4800 - 650 K
Working temperatures	−40˚C + 50˚C
Protection	IP65
Sizes	582 × 360 × 103 mm
Weight	6 Kg
Mounting height	5 - 10 meters

Taking this result in consideration, for all the different types of PV technologies used in the simulations, we have considered a Deka battery of 12 V/90 Ah. The solar radiation data for the photovoltaic generators were required from Meteonorm database for Bucharest site and is presented in Table 2 [10], as monthly daily values [kWh/m^2/day].

Table 3 represents the numerical simulation results for the LED system using monocrystalline silicon modules, while Figure 2 shows the normalized energy and the performance ratio of the system.

The simulation results of the photovoltaic system using monocrystalline silicon shows that for January, November and December months, the system fails to provide 3068 kWh of energy needed. A quantity of 75.68 kWh is lost due to the battery capacity. This problem could be adjusted by lowering the power of the PV modules.

In Table 4, the numerical simulation results for the LED PV system using polycrystalline silicon are presented, while Figure 3 shows the normalized energy and the performance ratio of the PV system.

Results using polycrystalline silicon, as well as the monocrystalline silicon indicate that in January, November and December, the system cannot fulfill the total system energy needs, by a quantity of 2546 kWh. Battery losses are also present in the quantity of 80.19 kWh. This could also be adjusted by using smaller PV modules but, it is important to take into consideration the solar resources in the months that with low solar radiation.

In Table 5, numerical simulation results for the PV LED system using CIS (Copper, Indium and Selenium) cells are presented, while Figure 4 shows the normalized energy and the performance ratio of the system.

Simulation results for CIS technology shows that a total of 2717 kWh is missing in order for the system to operate at maximum capacity. A total of 80.06 kWh are lost due to full battery.

Table 2. Mean daily values for Bucharest location.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hor. Global	1.40	2.49	3.55	4.75	5.86	6.53	6.58	5.75	4.17	2.74	1.53	1.12
Hor. diffuse	0.76	1.04	1.50	2.32	2.49	2.64	2.67	2.37	1.84	1.24	0.96	0.65
Clrn. index	0.39	0.48	0.5	0.51	0.53	0.56	0.58	0.57	0.52	0.47	0.38	0.36
Amb. Temp.	−1	1.5	6.7	11.8	17.9	21.1	23.7	23.4	17.1	11.9	6.4	0.4

Table 3. Monthly numerical simulation results for PV LED system using monocrystalline silicon modules.

	GlobHor kWh/m²	GlobEff kWh/m²	EAvail kWh	EUnused kWh	EMiss kWh	EUser kWh	E Load kWh	SolFrac
Jan	43.3	68.2	7.66	0.46	0.556	6.884	7.440	0.925
Feb	69.6	103.4	11.82	3.89	0.0	6.720	6.720	1.000
Mar	109.9	137.9	15.22	7.03	0.0	7.440	7.440	1.000
Apr	142.5	153.2	16.62	8.46	0.0	7.200	7.200	1.000
May	181.7	178.6	18.64	10.38	0.0	7.440	7.440	1.000
Jun	195.8	184	18.87	10.80	0.0	7.200	7.200	1.000
Jul	203.9	196.7	20	11.75	0.0	7.440	7.440	1.000
Aug	178.3	187.6	19.19	10.91	0.0	7.440	7.440	1.000
Sep	125	147.2	15.46	7.51	0.0	7.200	7.200	1.000
Oct	85	114.7	12.28	4.12	0.0	7.440	7.440	1.000
Nov	45.9	64.9	6.99	0.37	0.268	6.932	7.200	0.963
Dec	34.7	55.9	6.07	0.00	2.244	5.196	7.440	0.698
Annual	1415.6	1592.5	168.81	75.68	3.068	84.532	87.600	0.965

where: -GlobHor represents Horizontal global irradiation; -GlobEff represents Effective global irradiation corrected for IAM and shadings, where IAM is the Incidence Angle Modifier; -EAvail represents the produced solar energy; -EUnused represents losses due to unused energy; -EMiss represents the missing energy in order for the system to function; -EUser represents the energy supplied to the user; -ELoad represents the energy needed of the user; -SolFrac represents the Solar Fraction, which is calculated as EUser/ELoad [11].

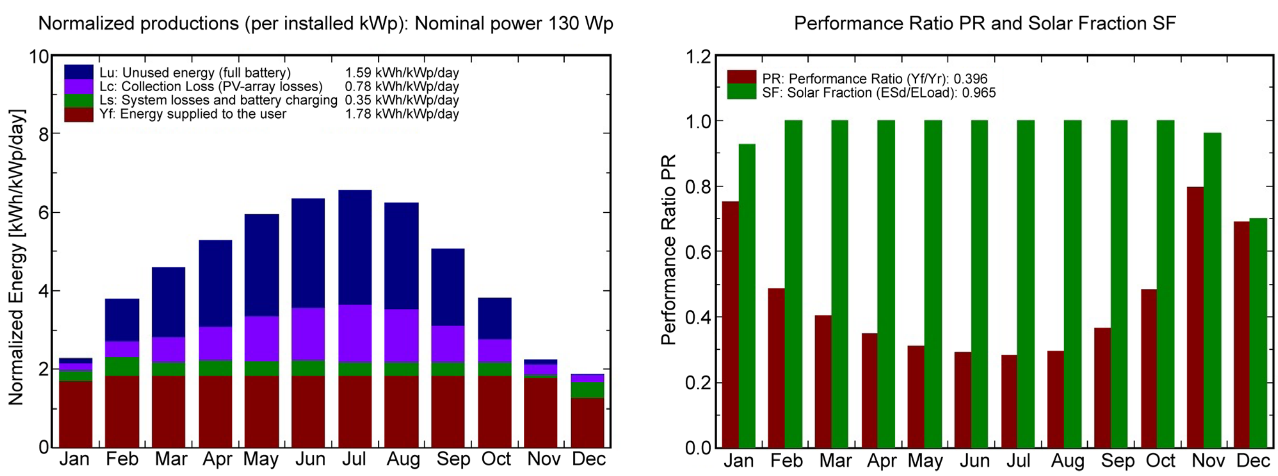

Figure 2. Normalized energy productions, system performance ratio and solar fraction for monocrystalline silicon modules.

Table 4. Monthly numerical simulation results for PV LED system using polycrystalline silicon modules.

	GlobHor kWh/m²	GlobEff kWh/m²	EAvail kWh	EUnused kWh	EMiss kWh	EUser kWh	ELoad kWh	SolFrac
Jan	43.3	68.2	7.94	0.63	0.501	6.939	7.440	0.933
Feb	69.6	103.4	12.21	4.24	0.0	6.720	6.720	1.000
Mar	109.9	137.9	15.70	7.55	0.0	7.440	7.440	1.000
Apr	142.5	153.2	17.13	8.96	0.0	7.200	7.200	1.000
May	181.7	178.6	19.17	10.92	0.0	7.440	7.440	1.000
Jun	195.8	184	19.38	11.31	0.0	7.200	7.200	1.000
Jul	203.9	196.7	20.53	12.29	0.0	7.440	7.440	1.000
Aug	178.3	187.6	19.70	11.42	0.0	7.440	7.440	1.000
Sep	125	147.2	15.91	7.95	0.0	7.200	7.200	1.000
Oct	85	114.7	12.67	4.50	0.0	7.440	7.440	1.000
Nov	45.9	64.9	7.23	0.42	0.118	7.082	7.200	0.984
Dec	34.7	55.9	6.30	0.00	1.927	5.513	7.440	0.741
Annual	1415.6	1592.5	173.87	80.19	2.546	85.054	87.600	0.971

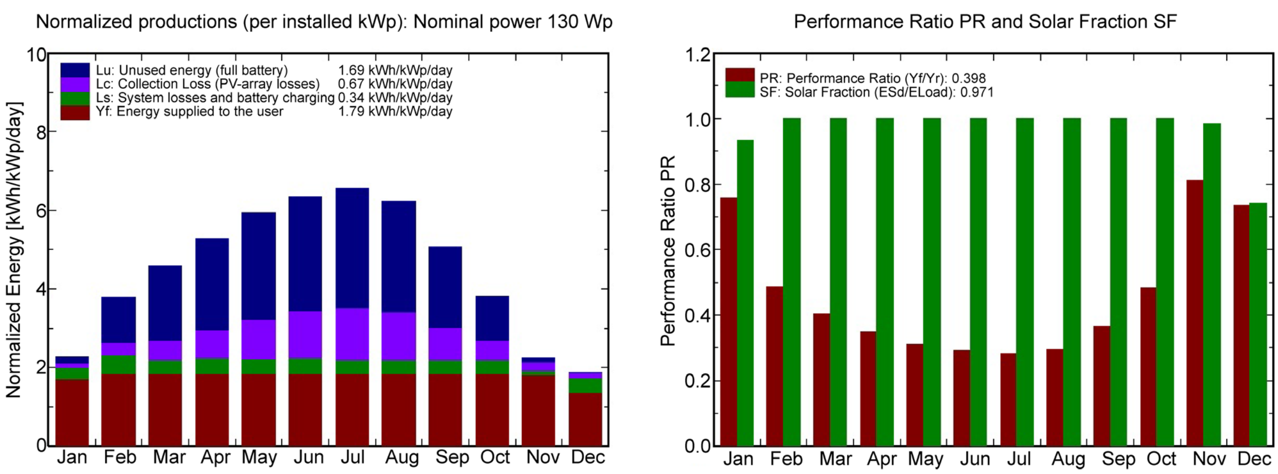

Figure 3. Normalized energy productions, system performance ratio and solar fraction for PV LED system using polycrystalline silicon modules.

Taking into account the obtained results, in this study the polycrystalline silicon offers the best yield. This is highlighted by the annual solar fraction between the energy supplied and the energy needed of the system. However, the overall energy loss caused by the full battery situations is 80.19 kWh, which is the highest of the analyzed situations. During the simulations, the modules used are almost identical in means of power and voltage, the main differences are the type of cells used. The simulation program estimates the module losses reported to the power tolerance, namely to a value of half of the inferior tolerance. This value is given by the manufacturers. During simulations, because of different manufacturers and power tolerance values, it could explain the fact that the polycrystalline silicon is more efficient than monocrystallinne silicon.

Table 5. Monthly numerical simulation results for PV LED system using modules with CIS cells.

	GlobHor kWh/m²	GlobEff kWh/m²	EAvail kWh	EUnused kWh	EMiss kWh	EUser kWh	ELoad kWh	SolFrac
Jan	43.3	68.2	7.91	0.62	0.523	6.917	7.440	0.930
Feb	69.6	103.4	12.21	4.24	0.0	6.720	6.720	1.000
Mar	109.9	137.9	15.67	7.50	0.0	7.440	7.440	1.000
Apr	142.5	153.2	17.09	8.92	0.0	7.200	7.200	1.000
May	181.7	178.6	19.15	10.90	0.0	7.440	7.440	1.000
Jun	195.8	184	19.38	11.30	0.0	7.200	7.200	1.000
Jul	203.9	196.7	20.56	12.32	0.0	7.440	7.440	1.000
Aug	178.3	187.6	19.73	11.45	0.0	7.440	7.440	1.000
Sep	125	147.2	15.89	7.94	0.0	7.200	7.200	1.000
Oct	85	114.7	12.62	4.47	0.0	7.440	7.440	1.000
Nov	45.9	64.9	7.17	0.41	0.301	6.899	7.200	0.958
Dec	34.7	55.9	6.25	0.0	1.892	5.548	7.440	0.746
Annual	1415.6	1592.5	173.61	80.06	2.717	84.883	87.600	0.969

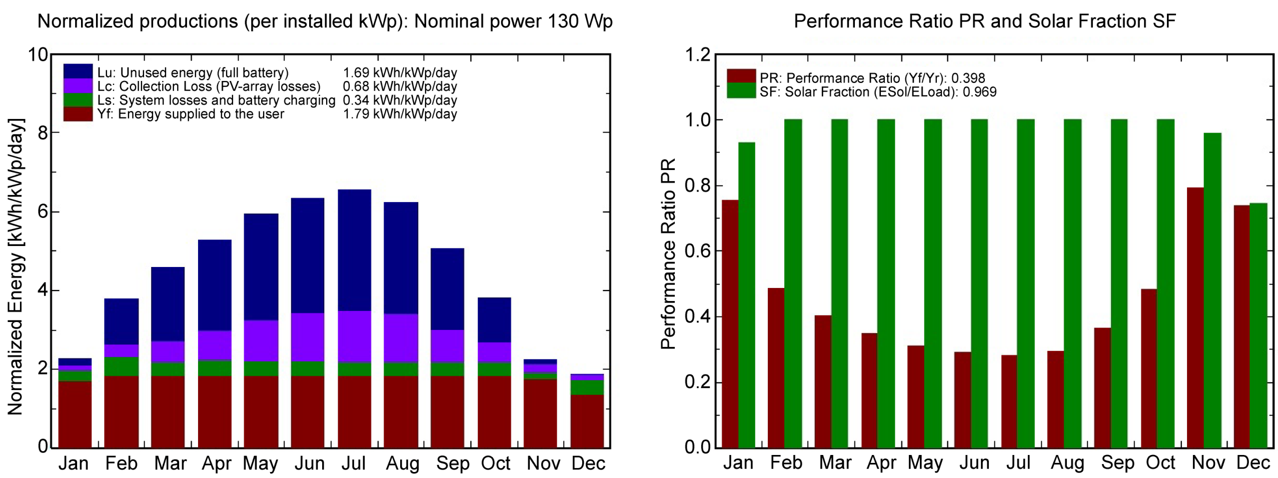

Figure 4. Normalized energy productions, system performance ratio and solar fraction for PV LED system using modules with CIS solar cells.

5. Sizing and Simulations for PV Water Pumping System

The PV pumping systems are able to deliver water both for irrigation and local water supply. These pumps are usually using direct current for operation that means that the power could be delivered straight from the PV modules. The pumps that use alternative current are also used but have some disadvantages, for example the system components are more complex and the yield drops when the type of current is changed by inverter.

In order to simulate a PV pumping system properly, we have used specific steps for choosing the right components of the system [12]. These steps are:

1-identification of the water needs,

2-identification of the water supply,

3-identification all necessary components and their location,

4-designing a water storage component,

5-solar availability,

6-identification of needed water flow,

7-identification of total dynamic head pump,

8-pump selection and nominal power,

9-PV system design.

The project simulates the need of water in a farm in Romania. The water need for the project is calculated for 100 cattle. The farm area is contained in 16 hectares of land. We need that the system will be able to supply water in the period of May-September from a water well, when the animals are grazing. A storage tank will also be used, to store the water in order for the system to function in periods with clouds or poor solar availability [13]. A comparison between the different types of PV cells is made and the results are presented in the following tables and figures.

Figure 5 represents the simulation of the PV water pumping system using polycrystalline cell technology.

Table 6 represents the numerical simulation results for polycrystalline cell technology on an average monthly basis.

The results show that from the annual needed water amount of 1460 m^3, the system provided an amount of 1331 m^3. Energy in the amount of 46 kWh was lost due to the system oversize and annual, the amount of 8.9 % of water was not provided. Months in which the system is unable to provide water are January, February and December. This is due to the low solar radiation availability needed to power the system.

Table 7 represents the numerical simulation results for the PV pumping system using CIS (Copper, Indium and Selenium) cells, while Figure 6 shows the normalized energy and the performance ratio of the system.

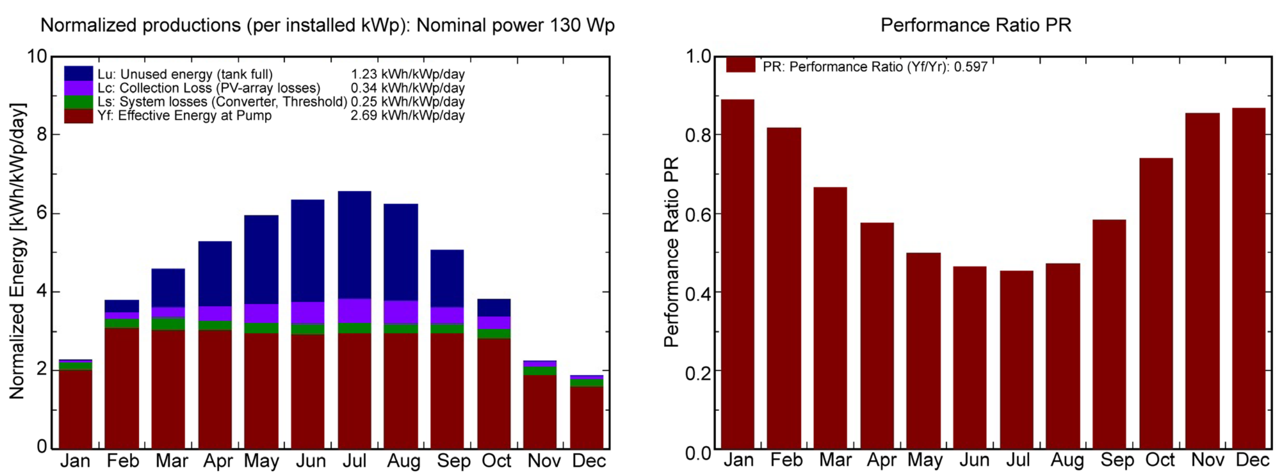

Figure 5. Normalized energy productions, system performance ratio and solar fraction for PV pumping system using polycrystalline silicon modules.

Table 6. Monthly numerical simulation results for PV pumping system using polycrystalline silicon modules.

	GlobEff kWh/m^2	EArrMPP kWh/m^2	EPmpOp kWh	ETkFull kWh	HPump meterW	WPumped m^3	WUsed m^3	WMiss m^3
Jan	68.2	8.94	8.13	0	7.936	84.8	92.8	31.19
Feb	103.4	13.16	11.27	0.965	8.378	117.6	110.7	1.33
Mar	137.9	16.89	12.29	3.165	8.252	128.2	124	0
Apr	153.2	18.35	11.83	5.195	8.222	123.5	120	0
May	178.6	20.57	11.92	7.119	8.109	124.4	124	0
Jun	184	20.73	11.44	7.749	8.084	119.4	120	0
Jul	196.7	21.91	11.94	8.398	8.164	124.6	124	0
Aug	187.6	20.98	11.88	7.643	8.243	124	124	0
Sep	147.2	17.14	11.49	4.411	8.134	119.8	120	0
Oct	114.7	13.83	11.36	1.410	8.107	118.6	124	0
Nov	64.9	8.22	7.46	0	7.815	77.8	85.3	34.71
Dec	55.9	7.26	6.52	0	7.767	68	66.7	57.35
Annual	1592.5	187.98	127.54	46.055	8.111	1330.6	1335.4	124.58

where: -GlobEff represents Effective Global radiation correlated for IAM shadings; -EArrMpp represents Array virtual energy at MPP; -EPmpOp Pump represents the operating energy; -ETkFullis the unused energy (when the water tank is full); -WPumped represents the amount of water pumped; -WUsed represents the water drawn by the user; -WMiss represents the missing water [14].

Table 7. Monthly numerical simulation results of PV pumping system using modules with CIS cells.

	GlobEff kWh/m^2	EArrMPP kWh/m^2	EPmpOp kWh	ETkFull kWh	HPump meterW	WPumped m^3	WUsed m^3	WMiss m^3
Jan	68.2	8.91	7.90	0	7.922	82.4	90.4	33.56
Feb	103.4	13.18	11.19	0.409	8.327	116.7	110.7	1.33
Mar	137.9	16.89	12.33	1.757	8.155	128.7	124	0
Apr	153.2	18.35	11.88	2.844	8.089	123.9	120	0
May	178.6	20.57	11.67	3.380	7.934	121.7	124	0
Jun	184	20.75	11.57	2.703	7.913	120.7	120	0
Jul	196.7	21.95	12.07	2.500	7.915	125.9	124	0
Aug	187.6	21.02	11.88	2.301	7.934	123.9	124	0
Sep	147.2	17.13	11.49	1.305	7.997	119.9	120	0
Oct	114.7	13.80	10.32	0.721	7.953	107.6	120	3.98
Nov	64.9	8.17	6.94	0	7.767	72.4	73.1	46.91
Dec	55.9	7.21	6.25	0	7.567	65.2	64	59.99
Annual	1592.5	187.93	125.48	17.920	7.967	1309.2	1314.2	145.77

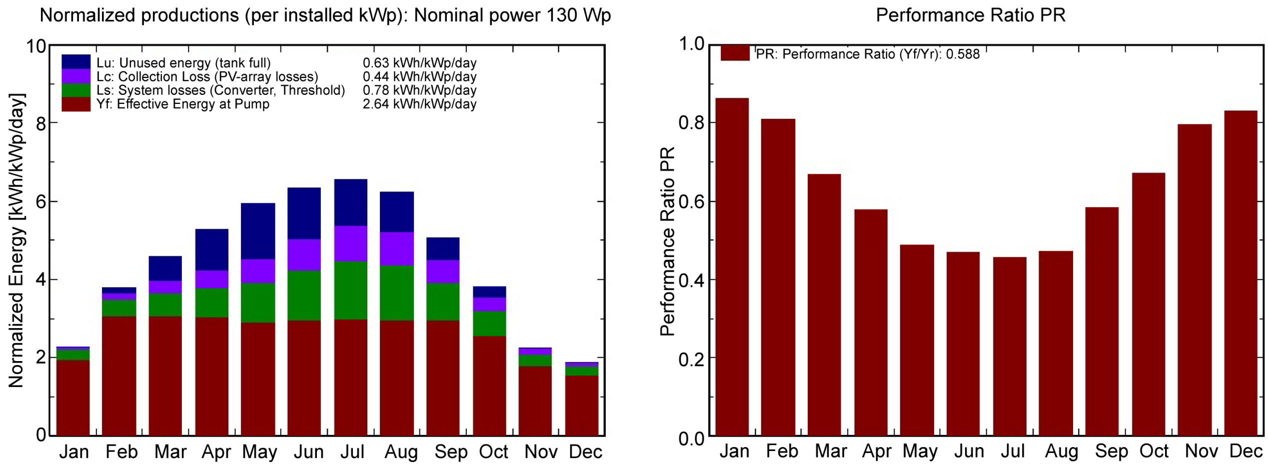

Figure 6. Normalized energy productions, system performance ratio and solar fraction for PV pumping system using modules with CIS solar cells.

The simulation results conclude that from an annual quantity of 1460 m^3 of water, the system provided a quantity of 1309 m^3. An overall energy of 18 kWh was lost due to oversizing the system. The annual missing water quantity is 10.3%.

Table 8 represents the numerical simulation results for the PV pumping system using modules with monocrystalline cells, while **Figure 7** shows the normalized energy and the performance ratio of the system.

The results show that the system delivered 739 m^3 of water. There were no energy losses due to oversizing the system and the overall missing water quantity is of 49.4%. The reason this simulation has a very low yield is due to the fact that the voltage of the PV module (16 V) resides below the converter working voltage (19 - 38 V). Another converter more suited for this system could be installed to obtain better results, however in the PVSyst database, such converter doesn't exist.

6. Conclusions

Sizing and simulations of a photovoltaic system before installation are a very important step. Critical information could result in finding unknown errors in the system or, why not, enhancing the system overall yield.

This paper shows the results of systems using various solar cell technologies but with almost identical BOS components [15]. For the analyzed systems, our simulations show that polycrystalline solar cell technology offers the best results in terms of overall yield. However, we have to take into consideration that these results are dependent by a series of factors like emplacement, solar resources availability, type of application, operating period, etc., and could differ from other PV application projects in various regions.

Further studies could also take into consideration grid-connected photovoltaic systems, however, in order to improve results, data regarding implementation and simulations of additional system components like inverters and regulators

Table 8. Monthly numerical simulation results for PV pumping system using modules with monocrystalline silicon cells.

	GlobEff kWh/m²	EArrMPP kWh/m²	EPmpOp kWh	ETkFull kWh	HPump meterW	WPumped m³	WUsed m³	WMiss m³
Jan	68.2	8.64	7	0	7.934	73.1	79.1	44.9
Feb	103.4	12.79	9.99	0	8.140	104.2	103	9
Mar	137.9	16.46	10.29	0	7.890	107.4	108.6	15.4
Apr	153.2	17.86	9.17	0	7.683	95.7	93.2	26.8
May	178.6	20.03	4.89	0	7.378	51.1	53.5	70.5
Jun	184	20.19	3.19	0	7.308	33.3	33.3	86.7
Jul	196.7	21.33	1.99	0	7.241	20.7	20.7	103.3
Aug	187.6	20.42	1.90	0	7.233	19.8	19.8	104.2
Sep	147.2	16.65	5.05	0	7.426	52.7	52	68
Oct	114.7	13.40	6.63	0	7.599	69.1	68.6	55.2
Nov	64.9	7.91	5.43	0	7.649	56.7	56.3	63.7
Dec	55.9	6.99	5.29	0	7.770	55.2	54.5	69.5
Annual	1592.5	182.66	70.82	0	7.633	739	742.9	717.1

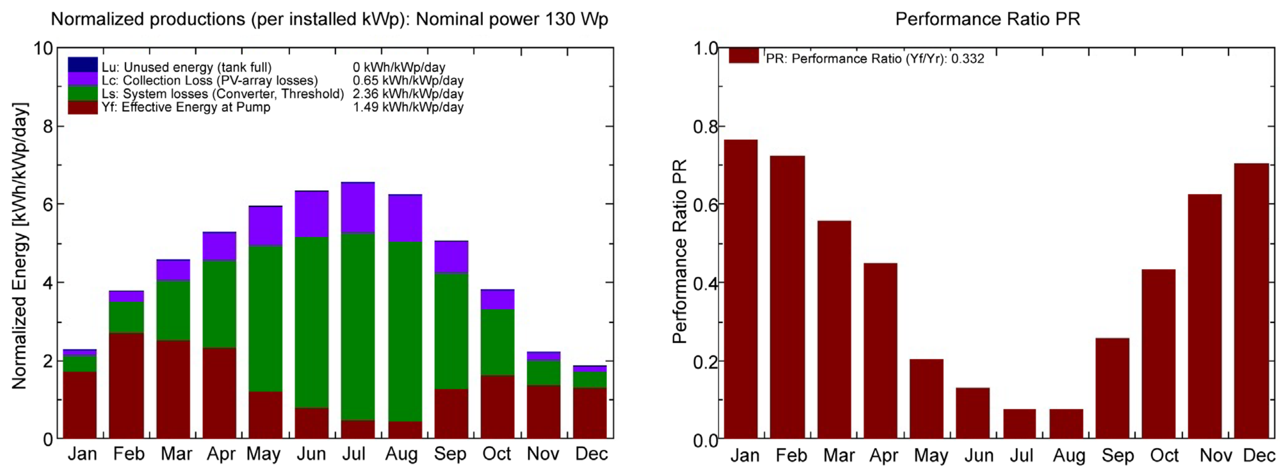

Figure 7. Normalized energy productions, system performance ratio and solar fraction for PV pumping system using monocrystalline silicon cells.

should be considered.

References

[1] Mohanty, P., Muneer, T. and KolheSolar, M. (2014) Solar Photovoltaic System Applications. In: Mohanty, P., Muneer, T. and Kolhe, M., Eds., *Green Energy and Technology*, Springer International Publishing, Switzerland, 49-83.

[2] Wikipedia Contributors (2016) Solar-Powered Pump. https://en.wikipedia.org/wiki/Solar-powered_pump

[3] Wikipedia Contributors (2016) Solar Street Light. https://en.wikipedia.org/wiki/Solar_street_light

[4] Sharma, V. and Chandel, S.S. (2013) Performance Analysis of a 190 kWp Grid Interactive Solar Photovoltaic Power Plant in India. *Energy*, **55**, 476-485.

[5] Shukla, A.K., Sudhakar, K. and Baredar, P. (2016) Simulation and Performance Analysis of 110 kWp Grid-Connected Photovoltaic System for Residential Building in India: A Comparative Analysis of Various PV Technology. *Energy Reports*, **2**, 82-88.

[6] Mohammad, B.A., Mahmoud, M.A.V. and Mohsen, M. (2015) Types of Solar Cells and Application. *American Journal of Optics and Photonics*, **3**, 94-113. https://doi.org/10.11648/j.ajop.20150305.17

[7] PVsyst SA (2016). http://www.pvsyst.com/en/about-us

[8] Electromagnetica SA (2016). http://www.elma-led.ro/lampa-stradala-perimetrala-elma-80-12-cu-led#tab-product-view2

[9] Li, J., Wei, W. and Xiang, J. (2012) A Simple Sizing Algorithm for Stand-Alone PV/Wind/Battery Hybrid Microgrids. *Energies*, **5**, 5307-5323.

[10] Meteotest (2016). http://www.meteonorm.com/en/downloads/horizonhttp://files.pvsyst.com/help/simulation_variables_standalone.htm

[11] United States Department of Agriculture (2010) Design of Small Photovoltaic (PV) Solar-Powered Water Pump Systems. Technical Note No. 28, Portland, Oregon. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_046471.pdf

[12] Diaconu, A., Moraru, A. and Fara, L. (2013) PV Pumping Systems. Case Study: Sheep Farm in South Romania. *Proceedings of the International Conference on Energy Efficiency and Agricultural Engineering*, Ruse, Bulgaria, 17-18 May 2013, 606-616.

[13] PVsyst SA (2016). http://files.pvsyst.com/help/index.html?simulation_variables_standalone.htm

[14] Fara, L., Bartok, B., Moraru, A., Oprea, C., Sterian, P., Diaconu, A. and Fara, S. (2013) New Results in Forecasting of Photovoltaic Systems Output Based on Solar Radiation Forecasting. *Journal of Renewable and Sustainable Energy*, **5**, Article Number: 041821. https://doi.org/10.1063/1.4819301

[15] Fara, L. and Yamaguchi, M. (2013) Advanced Solar Cell Materials, Technology. IGI Global, Hershey.