Optimization of PV Self-Consumption Systems without Storage Based on Net Present Cost Using LabVIEW

José Francisco Deras Pérez[1,a*], Alicia María Reyes-Duke[1,b]
and Héctor Fernando Villatoro[1,c]

[1]Universidad Tecnológica Centroamericana, Honduras

[a]franciscoderas@unitec.edu, [b]aliciareyes@unitec.edu, [c]hector.villatoro@unitec.edu

Keywords: net present cost; DC capacity optimization; self-consumption; self-sufficiency; net metering; residential photovoltaic systems

Abstract. Proper sizing of a photovoltaic (PV) system is essential to reduce lifecycle costs. This research presents a LabVIEW-based tool developed to optimize the DC nominal capacity of a self-consumption PV system without storage, connected to the electrical grid. The tool minimizes the system's net present cost (NPC) using two main inputs: an annual hourly load profile and solar irradiance data. It plots NPC as a function of DC capacity and selects the capacity corresponding to the curve's minimum value. To demonstrate its functionality, the tool was applied using data from San Pedro Sula, Honduras. Three scenarios were evaluated: (1) surplus PV energy injected into the grid was discarded; (2) a net billing scheme was implemented; and (3) a net metering scheme was considered. The latter two aimed to improve economic performance by compensating excess generation. Results show that reducing the NPC leads to an increase in the optimal DC capacity. Therefore, the tool effectively optimizes system sizing based on financial criteria. Additionally, self-consumption and self-sufficiency indexes were calculated for each scenario. The self-consumption index decreases as PV capacity increases, since more energy is generated than used. In contrast, the self-sufficiency index increases with PV capacity, up to a point where additional generation no longer matches consumption without energy storage. The proposed tool provides an accessible and effective approach for the techno-economic design of residential PV systems in regions lacking clear regulatory frameworks for managing surplus energy.

Introduction

For a grid-connected PV system to be financially attractive, its net present cost (NPC) needs to be minimized. One of the ways to achieve this is by reducing the costs of purchasing electricity from the distribution network, by maximizing the consumption of photovoltaic energy by the load (also known as self-consumption), as shown in Fig. 1.
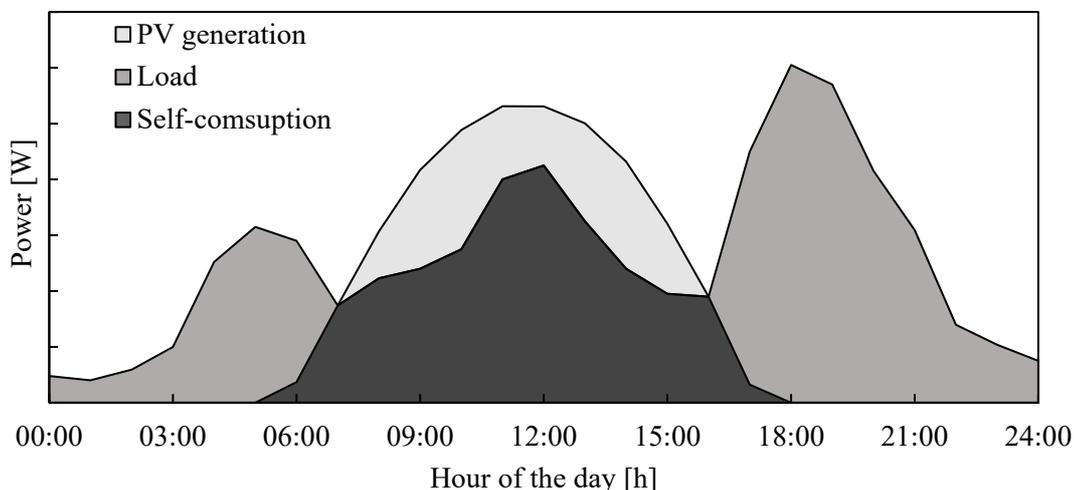
Fig. 1 Self-consumption of photovoltaic energy

This is because, in general, the tariffs paid for surplus energy injected into the grid by self-consumers are lower than the electricity tariffs charged by the distribution network. In other words, it is more cost-effective for the load to consume one kilowatt-hour produced by the PV system than to export it to the grid.

In fact, in some countries—such as Honduras—there is still no well-established legal or regulatory framework that defines how surplus PV energy injected into the grid should be managed [1, 2]. Recent studies emphasize that the lack of clear policies reduces the profitability of self-consumption systems [3, 4].

Self-consumption of photovoltaic energy can also be increased through the use of energy storage systems, such as batteries. Instead of exporting surplus energy when it is not immediately needed, the energy is stored and made available later when demand arises. However, this solution increases the project's capital cost due to the high price of batteries and associated components, and therefore may counteract the goal of making the PV system financially attractive.

Context

Increasing economies of scale and technological advancements are expected to continue reducing the installed cost of solar photovoltaic (PV) systems. The Levelized Cost of Electricity (LCOE) for solar PV is already competitive with all fossil fuel-based generation sources and is projected to decline further as installation costs decrease and system performance improves [5]. Global analyses confirm this trend, especially in high-irradiation regions like Central America [6].

In many countries, residential PV systems have become a competitive alternative for electricity generation [4]. Between 2016 and 2021, the installed PV capacity increased rapidly in several regions—for example, in Poland [7]. However, sizing optimization remains a key challenge to maximize economic returns [8].

However, in most cases, battery storage is considered to supply electricity during nighttime hours when the PV generator is not available.

Furthermore, the anticipated rise in electricity supply costs from the local grid, combined with the continued decline in PV technology costs, is likely to encourage monetary incentives for increasing PV self-consumption in both the residential [9] and commercial sectors [10]. Additionally, the installation of PV generators helps reduce the thermal load on buildings [11], which is another relevant benefit to consider.

Methodology

A. Optimization Model

A mathematical optimization model consists of an objective function and a set of constraints in the form of a system of equations or inequalities. Optimization models are used in areas like engineering design and financial portfolios [12]. Recent work demonstrates that NPC-based models are critical for evaluating storage-free PV systems [13].

The proposed methodology solves an optimization problem whose objective function minimizes the net present cost of a self-consumption photovoltaic system, as shown in Eq. 1.

$$inNPC = I_0 + \sum_{t=1}^{N} \frac{O\&M_t + S_t + R_t}{(1+i)^t} + \left(\sum_{t=1}^{N} \frac{\rho_{Red_t} \cdot E_{Red_t}}{(1+i)^t} \right) \cdot (1 + r\rho_{Red})^t - \left(\sum_{t=1}^{N} \frac{\rho_{Exc_t} \cdot E_{Exc_t}}{(1+i)^t} \right) \cdot (1 + r\rho_{Exc})^t \tag{1}$$

Subject to the following conditions:

$$O\&M_t, S_t, R_t, \rho_{Red_t}, \rho_{Exc_t}, E_{Red_t}, E_{Exc_t} \geq 0; \; t = 1,2,\ldots,N$$

$$I_0, r\rho_{Red}, r\rho_{Exc\,FV}, i \geq 0$$

$$N = 25$$

Where:

I_0: *Capital Cost of PV System* [$]

$O\&M_t$: *Annual operating and maintenance costs* [$]

S_t: *Annual insurance costs* [$]

R_t: *Annual replacement costs* [$]

ρ_{Red_t}: *LCOE* $[\dfrac{\$}{kWh}]$

ρ_{Exc_t}: *Price of surplus energy injected into the grid* $[\dfrac{\$}{kWh}]$

E_{Red_t}: *Annual energy supplied by the distribution network* [kWh/year]

E_{Exc_t}: *Surplus energy injected into the distribution network* [kWh/year]

$r\rho_{Red}$: *Annual rate of increase in the price of electricity* [%]

$r\rho_{Exc\ FV}$: *Annual rate of increase in the price of surplus energy injected into the distribution network* [%]

i: *Annual real discount rate* [%]

N: *Project life* [years]

B. Application developed with LabVIEW

To calculate the net present cost of a self-consumption photovoltaic system based on its DC nominal capacity, an application was developed using LabVIEW. The NPC of a PV system is calculated by summing the total discounted cash flows over each year of the project's useful life [14].

To visualize the data graphically on the front panel of the LabVIEW application, a waveform graph was added, allowing multiple curves to be plotted on a single graph. Self-consumption and self-sufficiency indices are calculated for each evaluated value of the DC nominal capacity in each simulation performed by the tool [15].

C. Simulations

A series of simulations were carried out using the developed program tool to illustrate its proper operation. Three scenarios were considered:

- Scenario 1: Surplus energy injected into the distribution network is not remunerated; that is, there is no established legal or regulatory framework governing the management of such surpluses.
- Scenario 2: Surplus energy injected into the distribution network is compensated by the grid operator based on wholesale market prices (net billing).
- Scenario 3: Surplus energy injected into the distribution network is recognized by the grid operator as energy credits in favor of the self-producing user (net balance). These credits remain available until they are fully offset against the user's consumption.

Each scenario was evaluated using electricity consumption data from two homes located in San Pedro Sula, Honduras.

The first house is occupied by a family of four, with an average daily consumption of 37.14 kWh. Consumption occurs mostly at night, as shown in its load or demand curve in Fig. 2.
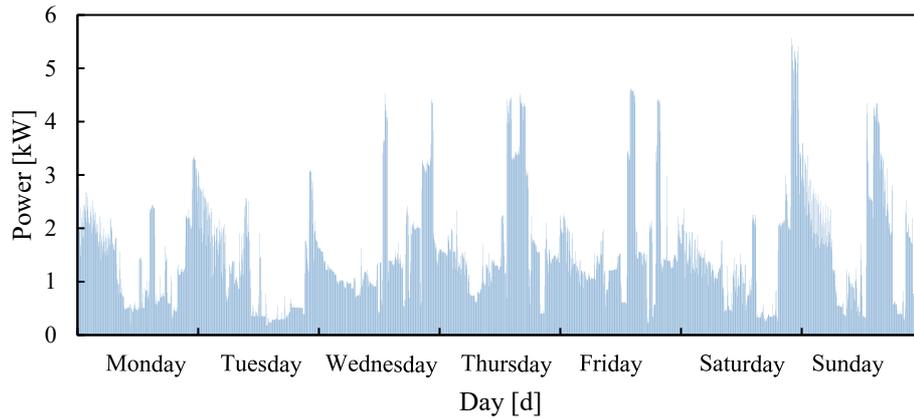
Fig. 2 Weekly load profile of House 1

The second house is occupied by a family of six, with an average daily consumption of 52.4 kWh. From Monday to Friday, the demand curve shown in Fig. 3 indicates very similar consumption patterns. This is because the house includes an office that operates during regular working hours.
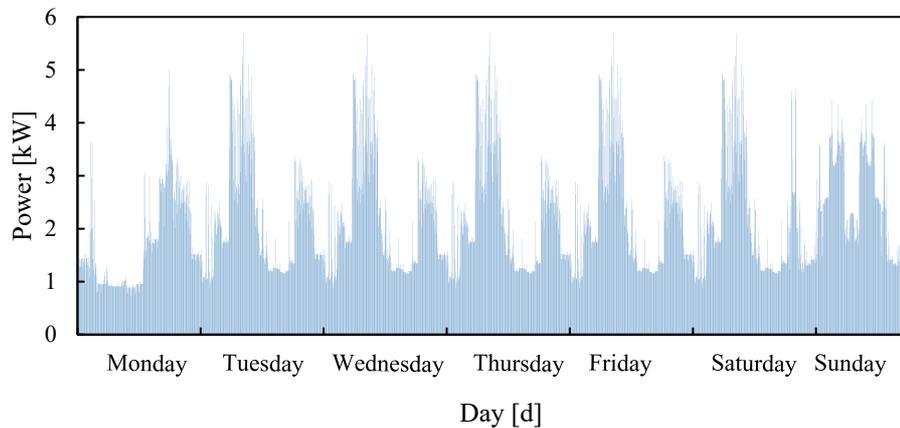
Fig. 3 Weekly load profile of House 2

Electricity consumption was measured at 5-minute intervals over a full week. However, since the solar irradiance data are recorded hourly, the demand values were adjusted to hourly averages.

Table 1 summarizes the common parameter values for the three scenarios, while Table 2 presents the parameters specific to each scenario.

**Table 1.** Common parameter values across the three scenarios

Parameter	*Value*	*Unit*
Nominal power of the photovoltaic module	1	W
Performance ratio (PR)	0.75	-
DC/AC ratio	1.2	-
Annual degradation rate of the photovoltaic module	0.5	%
Annual increase rate of consumed energy	0.6	%
Electricity price	0.2111	$/kWh
Specific capital cost of the photovoltaic module	0.35	$/W
Specific capital cost of the inverter	0.3	$/W
Specific capital cost of balance of system (BOS)	1.05	$/W
Annual O&M costs	12	$/kW
Annual insurance costs (% of capital cost)	0.6	%
Nominal discount rate	10	%
Annual inflation rate	2.3	%
Annual increase in electricity price	6	%

Table 2. Scenario-specific parameter values

Parameter	1	2	3
Price of surplus energy injected into the grid [$/kWh]	0	0.0056	0.211
Annual real discount rate [%]	0	0	6

Results

The program was developed using NI LabVIEW software and takes two text files as main inputs: a load profile and global irradiance data of the site, both provided at one-hour intervals over a full year. Each text file must contain a single column with 8,760 values, expressed in kilowatts and kilowatts per square meter, respectively. Fig. 4 shows the flow diagram of the algorithm.
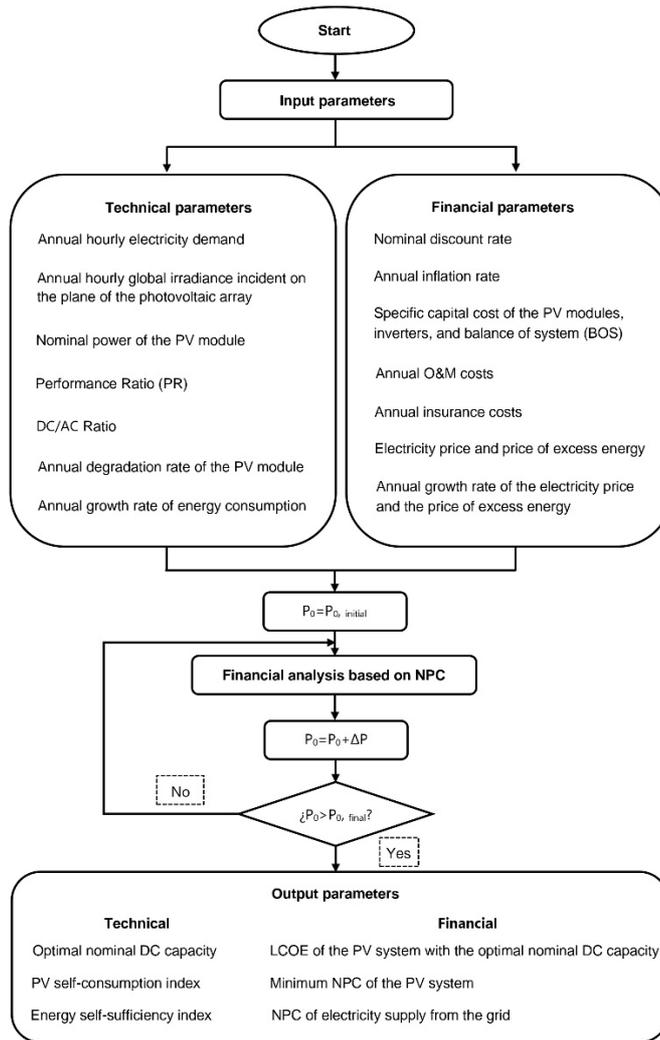

Fig. 4. Flow diagram of the program algorithm developed with LabVIEW

The number of iterations performed by the program in each simulation depends on the PV module power rating entered by the user.

The data obtained from the simulations for each scenario are presented below, along with an interpretation of the results. The self-consumption (φ_{SC}), self-sufficiency (φ_{SS}) and net present cost (NPC) curves were plotted as a function of the nominal DC capacity for each scenario. Each graph shows a single minimum value of the net present cost (NPCmin), which corresponds to the optimal DC rated capacity.

A. Scenario 1: Waste of surplus PV
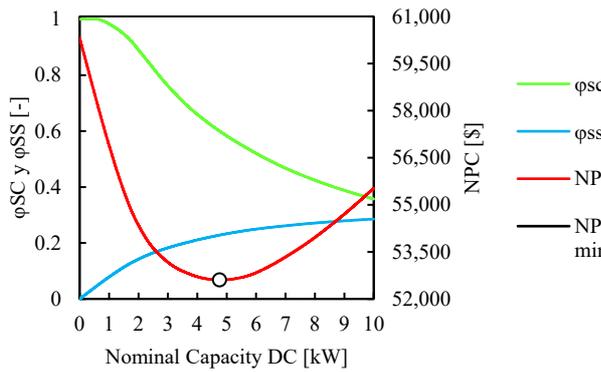Figs. 5 and 6 show the results obtained in Scenario 1.
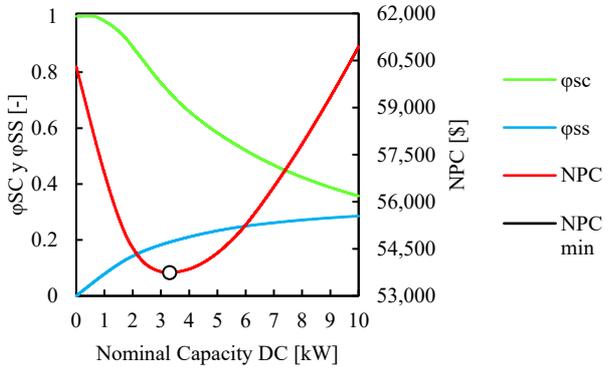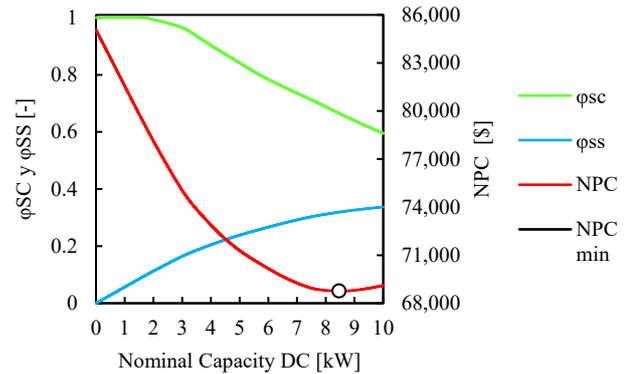

Fig. 5 Scenario 1 – House 1
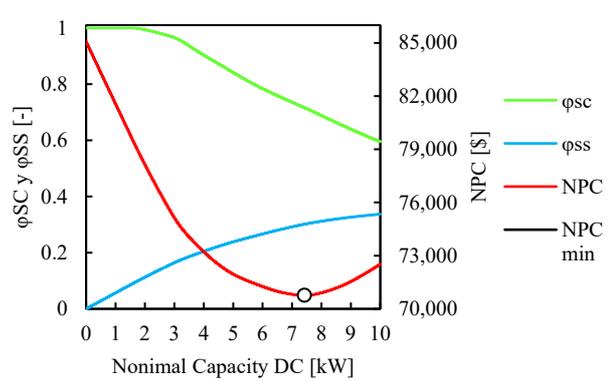
Fig. 6 Scenario 1 – House 2

B. Scenario 2: Net Turnover
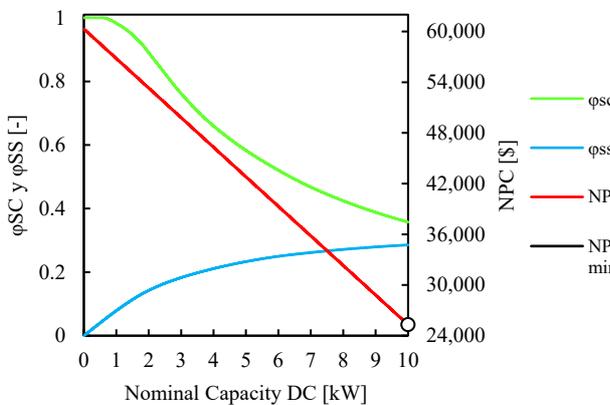Figs. 7 and 8 show the results obtained in Scenario 2.

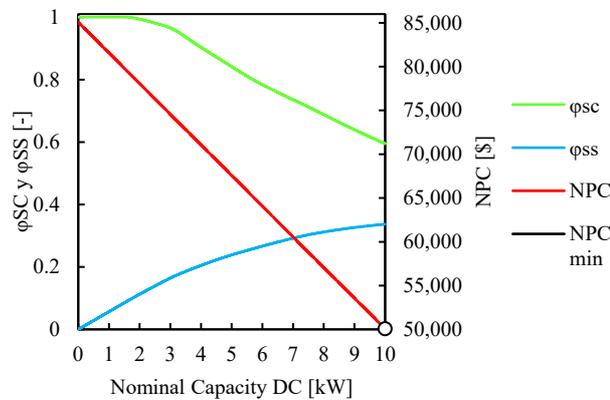**Fig. 7** Scenario 2 – House 1

Fig. 8 Scenario 2 – House 2

C. Scenario 3: Net Balance
Figs. 9 and 10 show the results obtained in Scenario 3.

Fig. 9 Scenario 3 – House 1

Fig. 10 Scenario 3 – House 2

Table 3 was prepared to present the simulation results in an organized manner, summarizing the most important findings discussed in this section.

Table 3 Scenario-specific parameter values

Parameter	Housing 1			Housing 2		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Nom. Cap. DC [W]	3,312	4,763	10,000	7,420	8,469	10,000
NPC min PV [$]	53,735	52,604	25,302	70,760	68,760	50,060
NPC local grid [$]	60,310	60,310	30,310	85,068	85,068	85,068
φ_{SC} [-]	0.7267	0.5996	0.3572	0.7164	0.665	0.5949
φ_{SS} [-]	0.2195	0.2604	0.3258	0.3437	0.3641	0.3846

As shown in Table 3, when surplus energy injected into the electricity grid is remunerated, the optimal DC nominal capacity of the PV system increases. This is because higher DC capacities generate more photovoltaic power and, consequently, greater energy surpluses. As a result, the income from selling electricity to the distribution network increases, leading to a reduction in the net present cost of the PV system.

Regarding the self-consumption and self-sufficiency curves, the former decreases as the nominal DC capacity increases, while the latter increases under the same condition.

Conclusion

This research successfully developed a software tool that optimizes the nominal DC capacity of a grid-connected, self-consumption photovoltaic (PV) system without storage, based on minimizing its net present cost (NPC).

The results show that a decrease in the NPC leads to an increase in the optimal DC capacity calculated by the tool. Therefore, it can be concluded that the program effectively optimizes the DC rated capacity of a PV system according to economic performance criteria.

Future Work

The present project was developed using monthly average values of hourly global irradiance incident on the solar array at the optimal tilt angle. In other words, hourly averages were used for each month of the year to construct an annual profile containing 8,760 data points.

As a next step, the integration of a solar radiation model into the program is proposed. This model would allow the calculation of global irradiance on an optimally tilted surface based on global horizontal irradiance data. Incorporating such a model would improve the accuracy of the photovoltaic energy production and consumption estimates.

References

[1] J.L.O. Fernandez, J.L.O. Avila, R.A. Ordoñez, Potential effect on the energetic matrix of Honduras with the installation of residential photovoltaic generators for self-consumption, 2019 IEEE 39th Central America and Panama Convention (CONCAPAN XXXIX), Guatemala City, Guatemala, (2019) 1–6. https://doi.org/10.1109/CONCAPANXXXIX47272.2019.8976994

[2] A.M. Reyes Duke, E.S. Osorio Hernández, Implementación de un sistema híbrido solar fotovoltaico - diésel en la municipalidad de Puerto Lempira, Gracias a Dios, Honduras, Innovare: Rev. Cienc. Tecnol. 7(2) (2018) 14–30. https://doi.org/10.5377/innovare.v7i2.8080

[3] R. Luthander, J. Widén, D. Nilsson, J. Palm, Photovoltaic self-consumption in buildings: A review, Appl. Energy 142 (2015) 80–94. https://doi.org/10.1016/j.apenergy.2014.12.028

[4] International Energy Agency (IEA), Trends in Photovoltaic Applications 2022, IEA PVPS, Paris, (2022). https://iea-pvps.org/trends-reports/

[5] IRENA, Future of Solar Photovoltaic: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation: paper), International Renewable Energy Agency, Abu Dhabi, (2019).

[6]   Fraunhofer ISE, Levelized Cost of Electricity Renewable Energy Technologies, Fraunhofer Institute, Freiburg, (2021). https://www.ise.fraunhofer.de/en/publications/studies/lcoe-renewable-energy.html

[7]   K.J. Cieślak, Multivariant analysis of photovoltaic performance with consideration of self-consumption, Energies 15 (2022) 6732. https://doi.org/10.3390/en15186732

[8]   C.D. Rodríguez-Gallegos, H. Liu, O. Gandhi, J.P. Singh, A deeper analysis into the economic viability of grid-connected PV systems with self-consumption, Energy 193 (2020) 116727.

[9]   G. Jiménez-Castillo, F. Muñoz-Rodriguez, C. Rus-Casas, D. Talavera, A new approach based on economic profitability to sizing the photovoltaic generator in self-consumption systems without storage, Renew. Energy (2019).

[10] C. Lara Monge, L. Vásquez Márquez, A.M. Reyes Duke, Case study: Optimization of grid-connected photovoltaic self-consumption systems for the commercial sector in Honduras, IOP Conf. Ser.: Earth Environ. Sci. 801 (2021) 012025. https://doi.org/10.1088/1755-1315/801/1/012025

[11] I. Ochoa, M. Ávila, H. Villatoro, Efectos de módulos fotovoltaicos en la carga térmica de un edificio industrial, Innovare: Rev. Cienc. Tecnol. 9(2) (2020) 63–70. https://doi.org/10.5377/innovare.v9i2.10207

[12] G. Merei, J. Moshövel, D. Magnor, D.U. Sauer, Optimization of self-consumption and techno-economic analysis of PV-battery systems in commercial applications, Appl. Energy 168 (2016) 171–178.

[13] J. Hoppmann, J. Volland, T.S. Schmidt, V.H. Hoffmann, The economic viability of battery storage for residential solar photovoltaic systems, Energy Policy 65 (2014) 609–620.

[14] F.J. Ramos-Webb, L.M. Fernández-Ramírez, C.R. Sánchez-Sánchez, Techno-economic analysis of photovoltaic self-consumption systems: A review of modeling approaches and operational strategies, Renew. Sustain. Energy Rev. 145 (2021) 111496. https://doi.org/10.1016/j.rser.2021.111496

[15] P.L. Cruz, M.J. Ortega, G.M. Pérez-Díaz, Self-consumption and self-sufficiency indices for photovoltaic systems: Standardization and case studies, Appl. Energy 278 (2020) 115872. https://doi.org/10.1016/j.apenergy.2020.115872