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Research Article

The Impact of Electrical Energy Consumption on the Payback Period of a Rooftop Grid-Connected Photovoltaic System: A case Study from Vietnam

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Abstract. Recently, the use of small-scale grid-connected photovoltaic (GCPV) systems for households has been growing in Vietnam. The installation of a rooftop GCPV system provides many benefits to households, such as lowering monthly electricity bills, reducing absorbed heat of the building, and creating additional income by penetrating electric power to the grid. However, the technical issues of the payback period is complicated and requires a lot of considerations. The main goal of this study is to develop a computational model and investigate the effect of electrical energy consumption on the payback period of rooftop GCPV systems. A case study is used in this study to create a model of a rooftop GCPV system for households in north-central Vietnam under feed-in tariff (FiT) schemes. The results show that the investment rate and electrical energy consumption of the installed household have a strong influence on the payback period of the GCPV system. In the case of the lowest investment rate of 666.4 USD/kWp, the fastest payback period is 43 months for households consuming all of the generating energy of the GCPV system, and the longest payback period is 131 months for households that do not use electricity, implying that all of the generating energy of the GCPV system is connected and sold to the distribution grid. The research findings will actively assist in calculating the installed capacity suitable for households in order to have the most suitable payback period while also assisting policymakers in the future in setting a reasonable rate of feed-in tariff for rooftop GCPV systems.

Keywords: Payback period, grid-connected, photovoltaic, energy consumption, FiT.

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1. Introduction

Renewable energy is becoming increasingly important in economic development. Investing in renewable energy sources, such as solar power, not only benefits the economy but also contributes to environmental protection (Phap, Huong, Hanh, Van Duy, & Van Binh, 2020). In Vietnam, over 101,029 rooftop PV projects with a total installed capacity of nearly 9,296 MWp have been connected to the power system as of December 31, 2020 (Ky, Hieu, & Hieu, 2021; Ngo, Nguyen, & Do, 2022; Huu & Ngoc, 2021)

Solar power systems are classified into three types: grid-connected photovoltaic (GCPV) systems without storage (Ali Khan, Liu, Yang, & Yuan, 2018; Cuong, Hong, Tuan, & Nhu Y, 2021), GCPV systems with storage (Bloch, Holweger, Ballif, & Wyrsch, 2019; Thanh, Minh, Duong Trung, & Anh, 2021), and stand-alone photovoltaic (PV) systems (Kumar, Saha, & Dey, 2019; Bukar & Tan, 2019). This study investigates GCPV systems without storage because they limit the storage components with high costs and maintenance, help save money on electricity, and truly bring efficiency in investment (Ngo *et al.*, 2020).

Investors in investment projects must analyze economic problems, particularly the payback period (Ha & Nguyen, 2019). Payback period for GCPV system is also an estimation of how long it will take for the benefits of GCPV system to outweigh the costs when the initial investment costs are deposited in the bank.

The Ibrik study (Ibrik, 2020) analyzed the results obtained from the continuous data monitoring of a 41 kWp GCPV system. The GCPV installed on the rooftop of the medical faculty building at An-Najah National University, Nablus, Palestine. It is shown that, the final yield was 1684 kWh/kWp and the reference yield was 2046.5 kWh/kWp, with the capacity utilization factor was found to be 18.5% and average annual performance ratio 0.84. The annual benefit from PV system was simply calculated by the generated energy with the unit price of electricity sold to the grid, resulting in a simple average payback period of 4.33 years. This means that the full cost of the project will be recouped in the first 5 years of its life. And for the remaining 15 years it will be profitable, which means the project is also viable.

To study the financial efficiency of investment in the rooftop GCPV system with storage compared to other forms of investment, the simplest way is to deposit money in a bank using a dual interest rate. In one study (Nguyen,

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Le, Ninh, & Tran, 2020), the benefits from the GCPV system is only calculated from the generated electrical energy to the grid, in this case, the payback period was calculated to be 98 months.

A research on the GCPV systems in the Central Highlands of Vietnam showed that the retail price of electricity affects the payback period (Lan, et al., 2020). The article assumed that the capacity of a rooftop system for households has different power usage levels. With the installation costs of a solar energy on the roof at 1,200 USD/kWp, 1 kWp of solar power will generate a monthly energy output of 166 kWh. Calculation results have shown that the shortest time is 4 years for the GCPV system with a capacity of 3.33 kWp, which is installed on the household using the highest level of electricity (over 400 kWh). The longest time was 11 years for a 0.3 kWp system, which installed on a household using electricity of first level (Lan, et al., 2020).

In Malaysia, many researchers have studied on the payback time of rooftop GCPV systems. A study on a GCPV system with self-consumption in Monash city has been conducted. The results have shown that the estimated simple payback period was about 8 years for this GCPV system, which is only one-quarter of the life of the system (Saleheen, Salema, Islam, Sarimuthu, & Hasan, 2021). A study of the economics of a 7.8 kWp GCPV system at a residential house in Kuala Terengganu according to the feed-in tariff scheme for two years 2018–2019 showed that the simple payback period, the shortest time for economic savings to accumulate equal to the total initial investment, is in the range of 5-7 years (Anang, Azman, Muda, Dagang, & Daud, 2021).

A simulation study and economic analysis of a grid-connected rooftop solar power project with a capacity of 8.36 kWp for a household in Thu Dau Mot City, Vietnam were presented in the paper (Nguyen & Van, 2021). This study used Pvsyst software to simulate the system with a given household load, with a total capacity of 7 kW and a daily energy consumption of about 27 kWh. The PV system's revenue is calculated based on the assumption that the consumption yield in the day was completely used energy yield from the PV system, this is not yet representative of the system's cases of solar power systems. Therefore, it was given that the payback period was 11%, the payback period is 6.7 and 12 years, respectively (Nguyen & Van, 2021).

In order to evaluate the possibility of improving the payback period of the GCPV projects, six types of GCPV systems with the same capacity of 20 kWp with different types and installation orientations in Jordan were studied in the article (Abdallah & Salameh, 2020). Research results have shown that the most generated electricity output is in the following order: concentrated PV type with two-axis tracker; south-facing monocrystal PV; south-facing polycrystal PV; east-west monocrystalline; south-facing thin-film; east-west polycrystalline. With a 7-level living electricity price and a project life of 25 years at the study site, the payback period is 3 years for concentrated PV types with two-axis trackers, south-facing thin-film, south-facing monocrystal PV, and south-facing polycrystal PV systems, and a payback period of 4 year for east-west polycrystalline and east-west monocrystalline systems (Abdallah & Salameh, 2020).

According to the findings of the aforementioned works, the rooftop GCPV system without storage is the system most commonly used under feed-in tariff (FiT) schemes. This is a system that works in combination with solar power and the electrical distribution grid. When the GCPV system generates electricity, it will power the equipment, and any excess will be pushed to the distribution grid. The payback period for rooftop GCPV systems will vary significantly depending not only on the performance of the system, but also on the impact of FiT schemes and the installed building's electrical energy consumption. As a result, calculating the benefits generated by a GCPV system is more complicated than calculating the benefits generated by other solar power systems. Furthermore, the difference in household electrical energy consumption affects the system's payback period, which is the main contribution of this paper. The rest parts of this paper will describe a case study and concentrate on developing models that use data appropriate to the study site to calculate the solar power output used and connected to the grid in different load cases, calculate the benefits for each case, and introduce a payback period for rooftop GCPV systems dependent on electrical energy consumption.

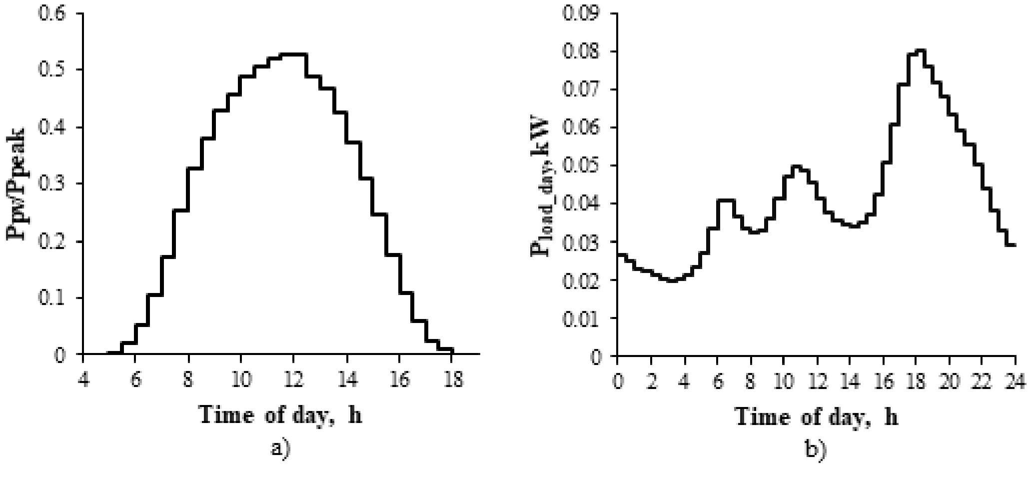

Fig. **1**. a) Typical daily power curve of GCPV system; b) Typical household daily load curve with an average electrical energy consumption of 1 kWh.

2. Methods and Case Description

2.1 Case description

The case study in this paper uses a household model in the tropical monsoon climate of Thua Thien Hue province in central Vietnam. With the following initial assumptions, households used average monthly electrical energy consumption E_L kWh corresponds to $C_{consumption}$ USD and electrical energy consumption remains constant, and installed a rooftop GCPV system with peak power of P_{peak} kWp and with an investment rate of A USD/kWp (including warranty, maintenance and system cleaning costs twice a year). The performance degradation of the GCPV system is assumed to be constant during operation. Develop a model to calculate the payback period for that project based on the household's electrical energy consumption.

2.2 Typical daily power curves of GCPV system

The generating power output of the GCPV system depends on weather factors, solar radiation, temperature, shading, and dirt (Cuong, Hong, Tuan, & Nhu Y, 2021). Therefore, to achieve a good GCPV generating power output, the GCPV system needs to be cleaned regularly (Syafiq, Pandey, Adzman, & Abd Rahim, 2018), as well as use inverter technology with multiple MPPT inputs (Eltawil & Zhao, 2010), or use a solar tracking system (Vinh Thang, Myo Naing, Xuan Cuong, Dinh Hieu, & Anatolii, 2021). This can affect investment as well as operating costs, but the long-term effect will likely increase. To assess grid-connected and used power output, this research has built a typical daily power curve of a GCPV system based on measurement results from the proposed rooftop GCPV system with a power of 1.32 kWp and an installation investment rate of 666.4 USD/kWp, which consists of four commercial polycrystalline photovoltaic panels SUN330-72P (performance warranty of 25 years) and a HY-1200-Pro grid-connected microinverter with four MPPT inputs (25-year warranty). Due to the long warranty period of the system's equipment, operating and maintenance costs are not considered in this research. This study analyzed the electricity output of the proposed GCPV system from January 2021 to the end of December 2021. Figure 1(a) presents a typical daily power curve of a GCPV system with an installed power of 1kWp, which is calculated on the installed peak power (P_{peak}). Based on this typical daily power curve, it is possible to build a graph of the generating power of GCPV systems with different peak powers.

Power output of GCPV systems degrades over time. In this research, the annual degradation factor has been considered to be 0.6% (Branker, Pathak, & Pearce, 2011), equivalent to 0.05% per month. So GCPV power output at the time of the month is calculated by Eq. (1):

$$P_{PV} = P_{PV\_T} \cdot P_{peak} \cdot (1+D)^j \qquad (1)$$

where, P_{PV_T} – typical GCPV power output; P_{peak} - installed peak power; D – monthly degradation factor, %; j - month of calculation.

2.3 Typical household daily load curve

In terms of geographical location, Thua Thien Hue is the southernmost province on the north-central coast, located in the tropical monsoon climate. Every year, there are two distinct rainy and sunny seasons, and the daily-life loads have completely similar electricity usage characteristics on all days. The peak usage times are in the evening (from about 17h00 to 21h00) and noon (from about 11h00 to 13h00), which means low load during the working hours of the day (Nguyen, 2019). A typical household daily load curve with an average electrical energy consumption of 1 kWh is shown in Figure 1(b). Based on this, it is possible to construct a typical household daily load curve with a given electrical energy consumption. The average daily electrical energy consumption is calculated by Eq. (2):

$$E_{Load\_day} = \frac{E_L}{N_d} \qquad (2)$$

where, E_L - average monthly electrical energy consumption, kWh; N_d - number of days in the month, the average is 30.

2.4. Initial investment capital

On the basis of a given assumption, the initial investment capital of the system is calculated by Eq. (3):

$$C_{investment} = P_{peak} . A \qquad (3)$$

where, $C_{investment}$ - the initial investment capital, USD; P_{peak} - peak power of the installed GCPV system, kWp; A – investment rate, USD/kWp.

According to the installed system and survey data from documents (Vuphong, 2021), the investment rate of a GCPV system is between 666.4 and 1110.6 USD/kWp. The study uses three investment levels as a basis for research, which are 1110.6, 888.5, and 666.4 USD/kWp.

2.5. Payback period calculation method

2.5.1. Retail domestic electricity price

In Viet Nam, the electricity selling price is probably regulated by the Ministry of Industry and Trade under the proposal of the Vietnam Electricity Group. Accordingly, the electricity selling price can be divided into: industry, administrative, business, and households, depending on the operating voltage level and operating hours, the tariff will different.

Table 1
Retail domestic electricity price (exclusive of 10% VAT)

i	Level i	Usage norms in level, N (kWh/month)	Retail electricity price (USD/kWh)*
0	Level 0: 0	$N_0 = 0$	$REP_0 = 0$
1	Level 1: 0–50 kWh	$N_1 = 50$	$REP_1 = 0.0745$
2	Level 2: 51–100 kWh	$N_2 = 50$	$REP_2 = 0.0770$
3	Level 3: 101–200 kWh	$N_3 = 100$	$REP_3 = 0.0895$
4	Level 4: 201–300 kWh	$N_4 = 100$	$REP_4 = 0.1127$
5	Level 5: 301–400 kWh	$N_5 = 100$	$REP_5 = 0.1259$
6	Level 6: 401 kWh or more	$N_6 = \infty$	$REP_6 = 0.1300$

**VND/USD exchange rate = 22,510 [Vietcombank exchange rates, 10/2/2022]*

Table 2
Electricity bill is calculated according to the level of 6 steps.

Electrical energy consumption, kWh	500	1000	2000	3000	4000	8000
Electricity bill, USD	58.7	130.2	273.3	416.3	559.3	1131.5

Table 3
FiT purchase price of installed GCPV system in 2020 year.

Number	Solar power technology	Purchase price, USD/kWh*
1	Floating solar power project	0.0792
2	Ground solar power project	0.0730
3	Rooftop GCPV system	0.0863

**VND/USD exchange rate = 22,510 [Vietcombank exchange rates, 10/2/2022]*

This study only deals with domestic electricity users, so the retail price in Table 1 is suitable for households applied from 2020 to present (Lan, *et al*., 2020).

Households using total monthly electrical energy of E_L kWh, their electricity bill will be calculated by Eq. (4):

$$C_L = \sum_{i=1}^{6} E_{iL}.REP_i \tag{4}$$

where, REP_i - Retail domestic electricity price of i^th level, USD; E_{iL} - electrical energy consumption in i^th level, kWh, and it is calculated using Eq. (5):

$$E_{iL} = \begin{cases} 0 & if\ E_L < \sum_{k=0}^{i-1} N_k \\ N_i & if\ E_L \geq \sum_{k=0}^{i} N_k \\ E_L - \sum_{k=0}^{i-1} N_k & other \end{cases} \tag{5}$$

where, N_k - Usage norms in k^th level, kWh/months.

According to the above formula, it is possible to calculate the monthly electricity bill corresponding to the consumed power as shown in Table 2. According to the summary from the article (Vnexpress, 2021), Vietnam Electricity (EVN) has 12 times increased electricity prices since 2007-2019 from 0.0382 to 0.0828 USD/kWh with an increase coefficient of 8.98%/year or equivalent to K_{REP}=0.81%/month. This factor will be added to the retail electricity price when calculating the payback period with Eq. (6):

$$REP_{ij} = REP_{i0}.(1 + j.K_{REP}) \tag{6}$$

where, REP_{i0} - electricity price of i^th level in first month; REP_{ij} - electricity price of i^th level in j^th month; j - month of calculation; K_{REP} - electricity price increase coefficient by month, %/month.

Accordingly, the j^th month's domestic electricity bill will be calculated by Eq. (7):

$$C_{Lj} = \sum_{i=1}^{6} E_{iL}.REP_{ij} = \sum_{i=1}^{6} E_{iL}.REP_{i0}(1 + j.K_{REP}) = (1 + j.K_{REP})C_{L0} \tag{7}$$

where, C_{L0} - domestic electricity bill in first month (start installing GCPV system); j - month of calculation; K_{REP} - electricity price increase coefficient by month, %/month.

2.5.2. Electricity price for GCPV system

The solar power system in Vietnam developed strongly in early 2017 under the feed-in tariff mechanism (Riva Sanseverino, et al., 2020). Currently, according to government regulations, solar GCPV systems in Vietnam are divided into three main types: Floating solar power project, ground solar power project; Rooftop GCPV system (Do, Burke, Baldwin, & Nguyen, 2020). Depending on the type of terrain, GCPV systems have a different rate of feed-in tariff as shown in Table 3 (EVN, 2021). Rooftop GCPV systems are normally installed on residential houses or factories, are equipped with 2-way metering systems, and can sell electricity to the Power Company at the above price.

Thus, with a rooftop GCPV system, a benefit from the grid-connected electrical energy of the GCPV system in j^th month will be obtained by Eq. (8):

$$B_{PV\_GCj} = E_{PV\_GCj}.P_{fit} \tag{8}$$

where, E_{PV_GCj} –grid-connected electrical energy of GCPV system in j^th month, kWh; P_{fit} – FiT purchase price (0.0863), USD/kWh.

2.5.3. Benefits from the bank

In the case of depositing the initial investment capital for the GCPV system in a bank with an interest rate of x %/month, benefits from the bank after m month according to Eq. (9):

$$B_{bank} = C_{investment}(1 + x)^m \tag{9}$$

where, m – number of months from the time of installation; $C_{investment}$ - initial investment capital of the system, USD; x - an interest rate, %/month.

To make a typical example, the bank deposit interest rate for individual customers with a term of more than 12 months is selected at 5.60%/year (Vietinbank, 2021), corresponding to the monthly interest rate x = 0.4667%/month.

2.5.4. Benefits from GCPV system

The electrical energy generated by the GCPV system is used by the load in part and fed to the grid in part, so the benefit from the GCPV system consists of the two parts listed above.

At the same time, with the load power consumption P_L, GCPV power output P_{PV}, then GCPV power output used by the load is calculated by Eq. (10):

$$P_{PV\_L} = \begin{cases} P_{PV} & if\ P_{PV} < P_L \\ P_L & if\ P_{PV} \geq P_L \end{cases} \tag{10}$$

Grid-connected power output from the GCPV system is calculated by Eq. (11):

$$P_{PV\_GC} = P_{PV} - P_{PV\_L} \quad (11)$$

Load power consumption from the distribution grid is calculated by Eq. (12):

$$P_{L\_evn} = P_L - P_{PV\_L} \quad (12)$$

Electrical energy is calculated by the area bounded by the power curve and coordinate systems, so electrical energy output from GCPV system E_{PV}, electrical energy consumption of the load E_L, electrical energy output from GCPV system used by the load E_{PV_L}, electrical energy consumption of the load from the distribution grid after using the GCPV system E_{L_evn}, grid-connected electrical energy of GCPV system E_{PV_GC} in a month is calculated by Eq. (13):

$$\begin{aligned} E_{PV} &= N_D \sum_1^n P_{i\,PV} t_i \\ E_L &= N_D \sum_1^n P_{i\,L} t_i \\ E_{PV\_L} &= N_D \sum_1^n P_{i\,PV\_L} t_i \\ E_{L\_evn} &= E_L - E_{PV\_L} \\ E_{PV\_GC} &= E_{PV} - E_{PV\_L} \end{aligned} \quad (13)$$

where, P_i – power during the i[th] survey period, kW; t_i – sampling times, h; n- sampling number per day; N_D - number of days in a month.

Benefits from the GCPV system for the j[th] month will be calculated as the benefit from grid-connected electrical energy of the GCPV system, which is calculated according to formula (8), and the difference in electricity bill before and after using the GCPV system, calculated by formula (7), and this benefit is calculated using Eq. (14):

$$B_j = B_{PV\_GC\,j} + (C_{L\,j} - C_{L\_evn\,j}) = E_{PV\_GC\,j} \cdot P_{fit} + \\ + (\sum_{i=1}^{6} E_{i\,L} \cdot P_i - \sum_{i=1}^{6} E_{i\,L\_evn} \cdot P_i)(1 + j \cdot K_{REP}) \quad (14)$$

where, $B_{PV\_GV\,j}$ - Benefit from the grid-connected electrical energy of the GCPV system, USD; $C_{L\,j}$ - monthly electricity bill before using GCPV system, USD; $C_{L\_evn\,j}$ - monthly electricity bill after using GCPV system, USD.

The total benefit from the GCPV system after m months will be calculated by Eq. (15):

$$B_{PV} = \sum_{j=1}^{m} B_j \quad (15)$$

2.5.5. Payback period

A Payback period (PBP) is the period during which the benefit generated by a project is equal to the investment capital. A project with a longer PBP usually comes with a higher risk for the investor. Compare the benefits from the GCPV system after m months with benefits from the bank, and the PBP is calculated by Eq. (16) and rounded up by the month:

$$B_{PV} \geq B_{bank} \quad (16)$$

3. Results and Discussion

In this study, common rooftop GCPV systems with peak power ranging from 1 kWp to 20 kWp are installed for households with varying average monthly electrical energy consumption. This study chose a 10 kWp GCPV system for a general analysis of the grid-connected power output of GCPV systems. Figure 2 depicts a typical household daily load curve (P_Load), a typical daily power curve of a GCPV system (P_PV), and the generated GCPV power output used by the load (P_PV_L) for households with average monthly electrical energy consumption of 2000 and 4000 kWh, respectively. Figure 2(a) clearly shows that when the load power is low, a portion of the GCPV power output is connected to the grid, whereas Figure 2(b) shows that when the load power is high, no GCPV power output is connected to the grid.

Figure 3 depicts the annual power output of a 10 kWp GCPV system with an average monthly electrical energy consumption of 2000 kWh. Obviously, the energy output from the GCPV system is equal to the sum of the energy output from the GCPV system used by the load (EPV_L) and the GCPV system's grid-connected electrical energy (EPV_GC). Within the last 20 years, analysis results have revealed that as a result of attenuation, energy outputs decrease over time.

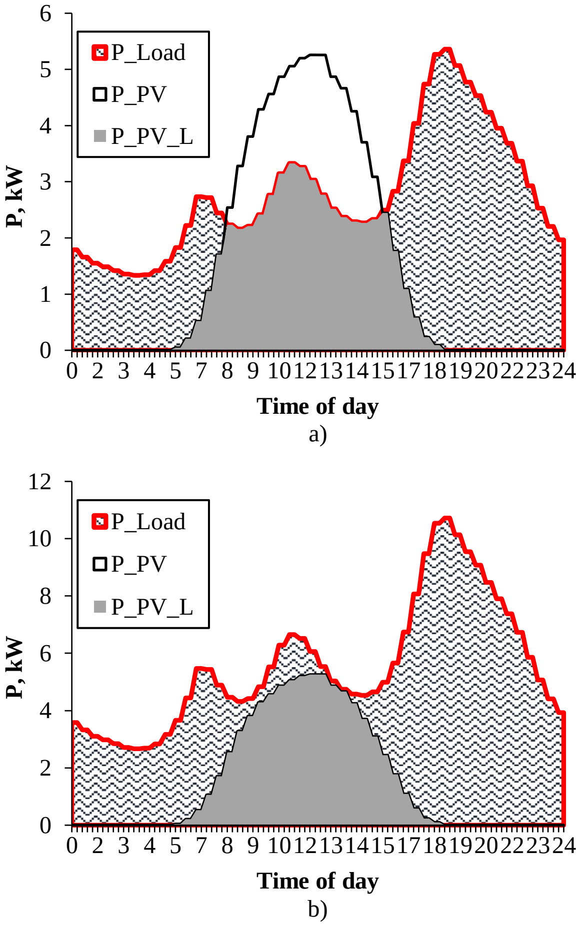

Fig. 2. Typical daily power curves of load, of GCPV system, and GCPV power output used by the load with average monthly electrical energy consumption of 2000 kWh (a), and 4000 kWh (b).

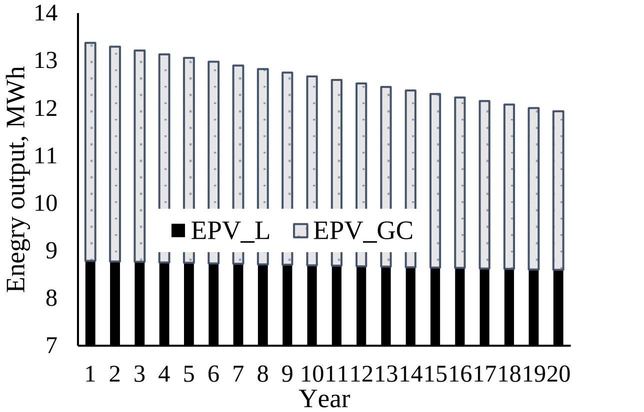

Fig. 3. Annual power output of a 10 kWp GCPV system with average monthly electrical energy consumption of 2000 kWh.

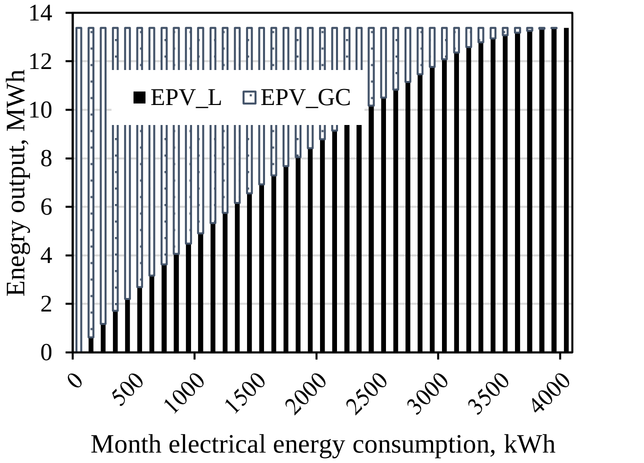

Fig. 4. Dependence of first year power output of a 10 kWp GCPV system on average monthly electrical energy consumption.

When a household's average monthly electrical energy consumption rises, the grid-connected electrical energy of the GCPV system (EPV_GC) falls to zero. Figure 4 depicts this. The grid-connected electrical energy of a 10 kWp GCPV system does not exist when the average monthly electrical energy consumption is around 4000 kWh.

The PBP was calculated using the above-mentioned formula. The PBP of a GCPV system with a peak power of 10 kWp is shown in Table 4. Figure 5 shows a benefit-over-time graph in which the benefit from the bank is B_bank_1, B_bank_2, and B_bank_3, with investment rates of 1110.6, 888.5, and 666.4 USD/kWp, respectively, and the benefit from GCPV system investment is B_PV for households using 4000, 2000, and 0 kWh. The PBP of the GCPV system corresponds to the point at which the bank benefit and the GCPV system benefit intersect; these values are depicted in Figure 6.

We saw that in the case of installing a GCPV system with an investment rate of 666.4 USD/kWp and grid-connection of all electrical energy output from the GCPV system, the PBP is 131 months, and if more, with an investment rate of 1110.6 and 888.5 USD/kWp, it can't return the investment. In the event that the load completely consumes the GCPV power output, the shortest PBP is 43 months when installing a GCPV system with an investment rate of 666.4 USD/kWp. The results of the study for GCPV systems in four climates of Nigeria also give simple payback periods ranging from 3.7 to 5.2 years under feed-in tariff schemes (Umar, Bora, Banerjee, & Anjum, 2021). In addition, in Thailand, a country with a climate and economy quite similar to Vietnam, a study of the economics of the GCPV system in many regions shows that the same discounted payback period is 6.1 years under the feed-in tariff scheme (Yoomak, Patcharoen, & Ngaopitakkul, 2019). It can be seen that a high investment rate means good system quality, but the payback time will be slow, and solar photovoltaic technology is economically viable and profitable in many regions of the world.

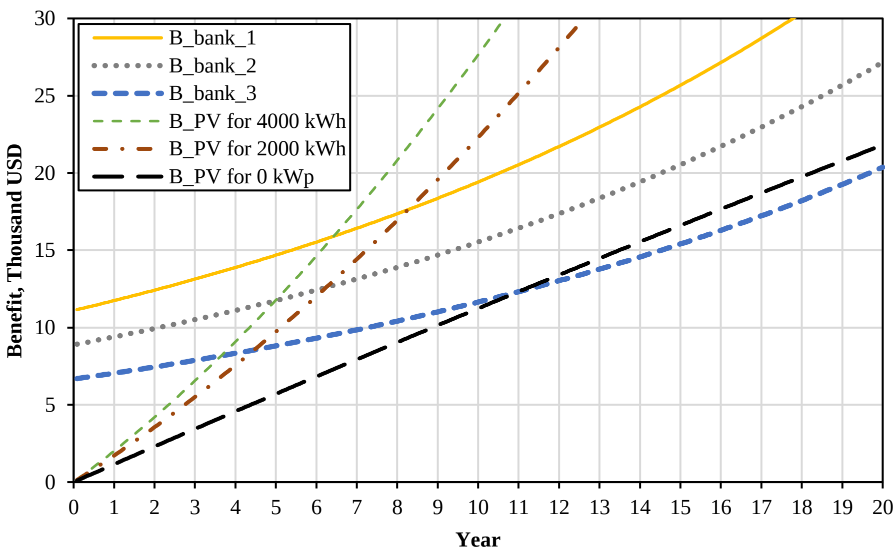

Fig. 5. Benefit over time.

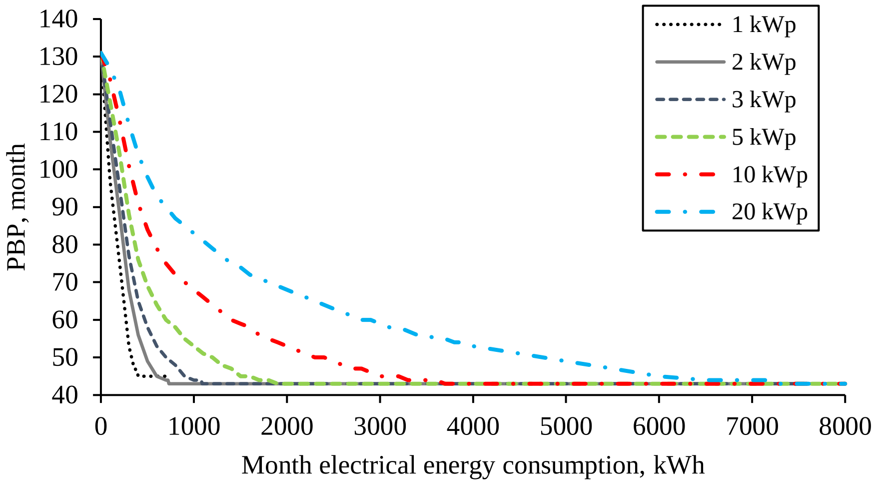

Fig. 6. Dependent PBP on the average monthly electrical energy consumption.

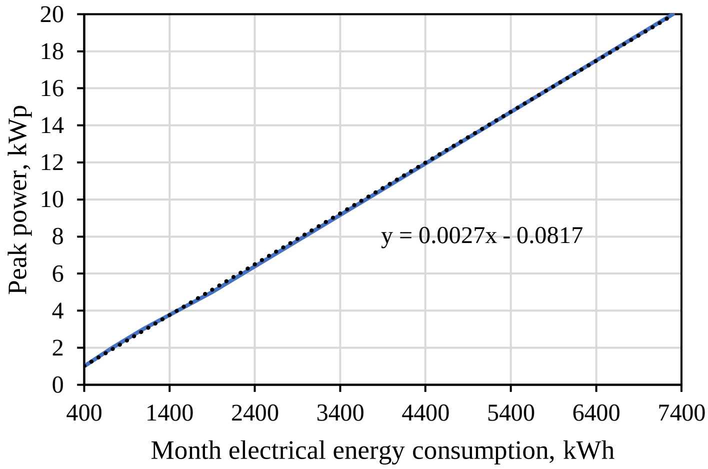

Fig. 7. Relationship between peak power of GCPV system and average monthly electrical energy consumption with shortest PBP.

Table 4.
PBP for GCPV system with peak power of 10 kWp.

Average monthly electrical energy consumption, kWh	Investment rate *A*, USD/kWp		
	666.4	888.5	1110.6
0	131	x	x
500	84	138	x
1000	68	100	144
1500	59	84	115
2000	53	74	99
2500	49	68	88
3000	45	63	81
3500	44	60	78
4000	43	59	77

(x – PBP does not exist)

According to Table 4, the lower the investment rate, the shorter the PBP, which is true for all projects. On the other hand, the PBP of the GCPV system is determined by the electrical energy consumption or the average electricity bill payable in a month, as well as the peak capacity of the GCPV system. Figure 6 depicts the PBP for GCPV systems with peak power of 1, 2, 3, 5, 10, and 20 kWp and an investment rate of 666.4 USD/kWp based on monthly average electrical energy consumption. The shortest PBP is 43 months, and the average monthly electrical energy consumption of households is 400, 730, 1090, 1900, 3700, and 7300 kWh, respectively, with GCPV systems of 1, 2, 3, 5, 10, and 20 kWp. This result is similar to the results obtained in the paper (Lan *et al.*, 2020), with a payback period of 48 months when a 3.3 kWp GCPV system is installed in a household with full electricity use at 6th level. The difference between 40 and 48 months is due to the initial investment rate of the study (Lan, *et al.*, 2020), which is 1200 USD/kWp, and in this case it is 666.4 USD/kWp. It is also worth noting that in the article (Lan, *et al.*, 2020) the energy output of the GCPV system was assumed to come from hours of sunshine per month, whereas in this study, the typical output generated by the real, installed GCPV system in the study area is used.

Figure 7 depicts the relationship between the peak power of a GCPV system and the average monthly electrical energy consumption with the shortest PBP. This is a linear relationship. It is clear that in order to get the best return on investment, households must consider their average monthly power consumption when installing a GCPV system of appropriate capacity.

4. Conclusion

The article has presented the influence of electrical energy consumption on PBP of rooftop GCPV system, building a calculation model to PBP for rooftop GCPV system taking into account the electrical energy consumption of households and characteristics of GCPV system.

The study is presented for the GCPV system in central Viet Nam, the results have shown that the PBP is greatly affected by the investment rate and electricity consumption of the installed household. In case the lowest investment rate is 666.4 USD/kWp, the fastest PBP is 43 months for households consuming all the generating energy of the GCPV system, and 131 months for non-use electricity households, this means that all generating energy of GCPV system is connected and sold to the distribution grid. Through this calculation result, households can calculate the installed capacity suitable for them to have the earliest PBP, and the above results also partly help policymakers to come up with a reasonable rate of a feed-in tariff for rooftop GCPV systems in the future.

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References

Abdallah, S., & Salameh, D. (2020). Technical and Economic Viability Assessment of Different Photovoltaic Grid-Connected Systems in Jordan. *Proceedings of International Conference of Aerospace and Mechanical Engineering 2019* (pp. 291-303). Singapore: Springer.

Ali Khan, M., Liu, H., Yang, Z., & Yuan, X. (2018). A comprehensive review on inverter topologies and control strategies for grid connected photovoltaic system. *Renewable and Sustainable Energy Reviews, 94*, 1120-1141.

Anang, N., Azman, S. S., Muda, W. M., Dagang, A. N., & Daud, M. Z. (2021). Performance analysis of a grid-connected rooftop solar PV system in Kuala Terengganu, Malaysia. *Energy and Buildings*, 111182.

Bloch, L., Holweger, J., Ballif, C., & Wyrsch, N. (2019). Impact of advanced electricity tariff structures on the optimal design, operation and profitability of a grid-connected PV system with energy storage. *Energy Informatics, 2(1)*, 1-19.

Branker, K., Pathak, M., & Pearce, J. (2011). A review of solar photovoltaic levelized cost of electricity. *Renewable and Sustainable Energy Reviews, 15*(9), 4470-4482.

Bukar, A. L., & Tan, C. W. (2019). A review on stand-alone photovoltaic-wind energy system with fuel cell: System optimization and energy management strategy. *Journal of cleaner production, 221*, 73-88.

Cuong, N. X., Hong, N. T., Tuan, D. A., & Nhu Y, D. (2021). Performance Ratio Analysis Using Experimental Combining Historical Weather Data for Grid-Connected PV Systems. In K. U. Sattler, D. C. Nguyen, N. P. Vu, B. T. Long, & H. Puta, *Advances in Engineering Research and Application. ICERA 2020. Lecture Notes in Networks and Systems* (Vol. 178). Springer, Cham. doi:10.1007/978-3-030-64719-3_73

Do, T. N., Burke, P. J., Baldwin, K. G., & Nguyen, C. T. (2020). Underlying drivers and barriers for solar photovoltaics diffusion: The case of Vietnam. *Energy Policy, 144*, 111561.

Eltawil, M. A., & Zhao, Z. (2010). Grid-connected photovoltaic power systems: Technical and potential problems—A review. *Renewable and sustainable energy reviews, 14(1)*, 112-129.

EVN. (2021). *Decision No. 13/2020/QD-TTg of the Prime Minister officially takes effect from 22 May 2020, rooftop solar power is expected to thrive*. Retrieved July 10, 2021, from https://en.evn.com.vn/d6/news /Decision-No-132020QD-TTg-of-the-Prime-Minister-officially-takes-effect-from-22-May-2020-rooftop-solar-power-is-expected-to-thrive-66-142-1853.aspx

Ha, D. T., & Nguyen, H. V. (2019). Potential industrial sectors promising for commercialization of solar pv rooftop applications in Danang city. *2019 International Conference on System Science and Engineering (ICSSE)* (pp. 224-228). IEEE.

Huu, D., & Ngoc, V. (2021). A Two-Level Desired Load Profile Tracking Algorithm for Electric Two-Wheeler Charging Stations. *Engineering, Technology & Applied Science Research, 11(6)*, 7814-7823.

Ibrik, I. H. (2020). Techno-economic assessment of on-grid solar PV system in Palestine. *Cogent Engineering, 7(1)*, 1727131.

Kumar, N., Saha, T. K., & Dey, J. (2019). Multilevel inverter (MLI)-based stand-alone photovoltaic system: modeling, analysis, and control. *IEEE Systems Journal, 14(1)*, 909-915.

Ky, H. V., Hieu, T. T., & Hieu, N. H. (2021). Potential and Barriers to the Evolution of Rooftop Solar in Central VietNam. *2021 IEEE Madrid PowerTech (pp. 1-6)* (pp. 1-6). IEEE.

Lan, T. T., Jirakiattikul, S., Chowdhury, M. S., Ali, D., Niem, L. D., & Techato, K. (2020). The effect of retail electricity price levels on the FI values of smart-grid rooftop solar power systems: a case study in the central highlands of Vietnam. *Sustainability, 12(21)*, 9209.

Ngo, X. C., Nguyen, T. H., Do, N. Y., Nguyen, D. M., Vo, D.-V. N., Lam, S. S., . . . Le, Q. V. (2020). Grid-Connected Photovoltaic Systems with Single-Axis Sun Tracker: Case Study for Central Vietnam. *Energies, 13*, 1457. doi:10.3390/en13061457

Ngo, X., Nguyen, T., & Do, N. (2022). A Comprehensive Assessment of a Rooftop Grid-Connected Photovoltaic System: A Case Study for Central Vietnam. *International Energy Journal, 22(1)*, 13-24.

Nguyen, D. T., Le, V. L., Ninh, V. N., & Tran, T. S. (2020). Comparing profits of investing in grid-connected rooftop pv system and deposit money in bank using dual interest rate. *Journal of Science and Technology, Hanoi University of Industry, 56(2)*, 27-32.

Nguyen, T. B., & Van, P. H. (2021). Design, Simulation and Economic Analysis of A Rooftop Solar PV System in Vietnam. *EAI Endorsed Transactions on Energy Web*, e19.

Nguyen, T. M. (2019). *Research on building typical load graph, application at Thua Thien Hue power company*. Abstract of master's dissertation, University of Science and Technology - University of Danang.

Phap, V. M., Huong, N. T., Hanh, P. T., Van Duy, P., & Van Binh, D. (2020). Assessment of rooftop solar power technical potential in Hanoi city, Vietnam. *Journal of Building Engineering, 32*, 101528.

Riva Sanseverino, E., Le Thi Thuy, H., Pham, M. H., Di Silvestre, M. L., Nguyen Quang, N., & Favuzza, S. (2020). Review of potential and actual penetration of solar power in Vietnam. *Energies, 13(10)*, 2529.

Saleheen, M. Z., Salema, A. A., Islam, S. M., Sarimuthu, C. R., & Hasan, M. Z. (2021). A target-oriented performance assessment and model development of a grid-connected solar PV (GCPV) system for a commercial building in Malaysia. *Renewable Energy, 171*, 371-382.

Syafiq, A., Pandey, A. K., Adzman, N. N., & Abd Rahim, N. (2018). Advances in approaches and methods for self-cleaning of solar photovoltaic panels. *Solar Energy, 162*, 597-619.

Thanh, T., Minh, P., Duong Trung, K., & Anh, T. (2021). Study on Performance of Rooftop Solar Power Generation Combined with Battery Storage at Office Building in Northeast Region, Vietnam. *Sustainability, 13*, 11093. doi:https://doi.org/10.3390/su131911093

Umar, N. H., Bora, B., Banerjee, C. G., & Anjum, N. (2021). Performance and economic viability of the PV system in different climatic zones of Nigeria. *Sustainable Energy Technologies and Assessments, 43*, 100987.

Vietinbank. (2021). *Interest rate*. Retrieved July 10, 2021, from https://www.vietinbank.vn/web/home/en/doc/saving

Vinh Thang, L., Myo Naing, Z., Xuan Cuong, N., Dinh Hieu, L., & Anatolii, S. (2021). Research of Solar Tracking Controller for PV Panel Based on Fuzzy Logic Control. *2021 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (ElConRus)* (pp. 2696-2699). IEEE.

Vnexpress. (2021). *Rise in Vietnam electricity prices over the last 10 years*. Retrieved July 10, 2021, from https://e.vnexpress.net/infographics/economy/rise-in-vietnam-electricity-prices-over-the-last-10-years-3891750.html

Vuphong. (2021). *Dien mat troi.* Retrieved July 10, 2021, from https://vuphong.vn/dien-mat-troi/

Yoomak, S., Patcharoen, T., & Ngaopitakkul, A. (2019). Performance and economic evaluation of solar rooftop systems in different regions of Thailand. *Sustainability, 11(23)*, 6647.