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The Status and Potential Assessment of Solar Power Energy Development in Vietnam

Khanh Huyen Nguyen, Ngoc Huong Giang Vu, Xuan Truong Nguyen*

Department of Energy, University of Science and Technology of Hanoi, Hanoi, Vietnam

Email address:
nguyen-xuan.truong@usth.edu.vn (X. T. Nguyen)
*Corresponding author

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Abstract: Vietnam has been regarded as a country with immense opportunities for renewable energy in general and for the development of solar and wind power in particular. Existing policy targets and mechanisms have been taken into practice with an aim to encourage this promising field and increase the proportion of electricity generated from these two power sources. However, the potential of these technologies has yet to be fully utilized, with approximately seven percentage of the nation's energy mix coming from renewable energy sources, according to Vietnam Electricity annual report. Conventional energy sources (coal, natural gas, and hydropower) still play a significant role in Vietnam's total primary energy supply. In this research, evaluation of the potential of renewable energy sources, emphasizing on solar power energy with its opportunities and challenges in Vietnam's power energy sector will be discussed. The main idea of this paper is to provide an overview of methodologies used for assessing photovoltaic potential and estimation of energy production from a given photovoltaic installation site. This can be a recommendation information of input indicators for investors, planners, and developers to strategize further decisions for the expansion of renewable power energy sources, especially photovoltaic systems in the chosen region.

Keywords: Renewable Energy, Conventional Energy, Energy Potential, Photovoltaic System, Rooftop PV, LCOE

1. Introduction

Vietnam has been recognized as one of the region's fastest growth rates in terms of economic growth, as reported by the World Bank [1]. In line with this development, the power domain, as well as the demand for electricity have experienced rapid growth over the last decade. In the annual report issued by Electricity of Vietnam (EVN), Vietnam relied predominantly on hydropower and thermal generation from fossil fuels, namely coal, oil, and natural gas, to fulfill its power demand [2]. In the upcoming period, coal will play a leading role in energy resources, followed by oil in the long term [3]. This can put national energy security under risks due to the dependence on international energy import. Besides, Vietnam's energy sector accounted for 60% of the total greenhouse gas (GHG) emissions recorded in 2014. In addition to the environmental impacts of GHG, the combustion of fossil fuels, which releases particles of SO_2, NOx and PM2.5, is one of the main reasons for local air pollution and health-related problems such as premature death. Such adverse impacts can create an economic burden and its associated issues.

In such a context, it urges that the energy resources must be diversified to reduce energy dependence and ensure national energy security. As a result, renewable energy (RE) is expected to encourage the process of supplying electricity at a reasonable cost, solve the problems related to environment and human health, and contribute to sustainable socio-economic development.

The paper is structured as follows: the first one provides a brief overview of solar energy in Vietnam, in which the current status of photovoltaic (PV) power, several policies for supporting solar electricity growth, some favorable conditions, and difficulties of solar energy in Vietnam will be discussed. The second part will focus on the estimation of photovoltaic power production for some area in Vietnam, which includes data assessment and estimation methods. Several factors affecting the procedure and specific case studies will also be analyzed accordingly with the proposed method.

2. Overview of Solar Energy in Vietnam

2.1. Current Status of Solar Photovoltaic Power

In recent years, there has witnessed a significant growth of RE in Vietnam, especially in the development of solar photovoltaic electricity. The enormous potential in expanding solar power projects has been recognized thanks to the promising solar irradiation, principally in the Southern, Highlands, and South-central coast regions. However, the share of solar power in the total primary energy supply is still limited compared to other energy resources. Before 2018, the amount of solar capacity in operation is insignificant but soon increased rapidly in the following year with approximately 4.5 GWp at the end of March 2020, thanks to measurements and initiatives taken by the Vietnamese government. According to EVN, as of 30 June 2019, 82 solar power plants with a total installed capacity of 4,464 MWp have successfully integrated into the transmission line systems, of which only 04 solar power plants have a capacity of smaller than 150 MWp in the whole solar power system. Up to that time, solar energy accounts for 8.28% of the total capacity of Vietnam's power sharing system [4]. As of 20 May 2020, the installed capacity of cumulative developed rooftop solar power systems in Vietnam is approximately 652 MWp with 31,506 photovoltaic rooftop systems. 56% of this capacity is used for industrial purposes, while residential photovoltaic rooftop system accounts for 28%, followed by commercial with 11% and administrative with 5%. The Southern region takes the lead of the solar market in both terms of installed capacity and the numbers of photovoltaic rooftop systems [5].

Besides, floating solar power systems have taken their first step for further development in Vietnam. Specifically, the first large-scale floating solar farm 47.5 MWp is now under construction on the human-made reservoir of its existing 175 MWp Da-Mi Hydropower plant under the financial aid of the Asian Development Bank [6]. This project is expected to support RE's installed capacity, especially solar power field, and simultaneously better utilize the transmission line of the existing hydropower plant.

2.2. Policies for Development of Solar Energy in Vietnam

Several policies have been taken to reinforce the potential of RE, particularly solar energy in Vietnam. Decision 2068/QĐ-TTg dated 25 November 2005 had been issued to approve Vietnam's RE development strategy up to 2030 with an outlook toward 2050 [7]. In this decision, RE development is expected to align with the economic, social, and environmental reality, as well as the expansion of the RE industry. It was indicated that supporting policies and incentives should be synergized with the market mechanism for addressing primary energy shortage and sustainable generation of RE sources [8]. In March 2016, the National Power Development Plan VII revised was approved to place a stronger emphasis on the development of RE (i.e. wind energy, solar energy, bio energy) and power market liberalization for the period of 2011-2020 with a vision toward 2050 [9]. One of the objectives is to "prioritize the development of RE sources for electricity production; increase the proportion of electricity generated from RE sources up to around 7% in 2020 and above 10% in 2030", see Figure 1.

On 6 April 2020, decision 13/2020/QD-TTg [10] was officially approved by the Prime Minister on the mechanism of promoting the development of solar energy in Vietnam, which takes place from 22 May 2020 to replace the expired Decision 11/2017/QD-TTg. Comparing to Decision N° 11, the new feed-in-tariff is more specific for different solar power technologies, see Table 1 [10]. This can be considered as an encouragement for investors and the community to pursue solar power utilization. The government's firm and timely act by setting targets, ensuring the purchase price of electricity produced by photovoltaic power systems, conducting practical incentives, and permitting mechanisms and technical standards to facilitate grid interconnection has become the driving force for investors and energy-based organizations to put their effort RE development. From the aforementioned actions taken by both the Vietnamese government and organizations, the potential for RE is relatively promising.

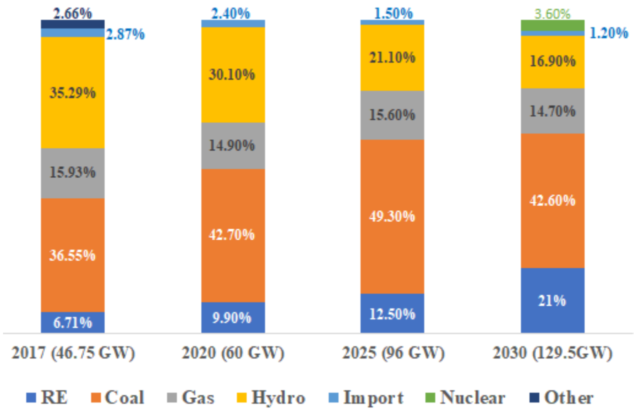

Figure 1. *Installed capacity target, according to [9].*

Table 1. *Feed-in-tariff for solar power in Vietnam [10].*

Solar power technology	Equivalent to USCent/ kWh
Floating solar power project	7.69
Ground-mounted solar power project	7.09
Rooftop solar power project	8.38

2.3. Opportunities and Challenges of Solar Power Energy Deployment in Vietnam

2.3.1. Opportunities for the Development of Solar Energy

With a suitable geographical location and a tropical monsoon climate, Vietnam is considered one of the most promising countries in Southeast Asia with abundant sunshine hours. According to the global solar atlas published by the World Bank Group, the value of daily global horizontal irradiance (GHI) in Vietnam lies within the range of 3.16 to

5.52 kWh/m^2 with the average value of 4.25 kWh/m^2. Considering the weather conditions with a cloudy sky, this value in the Northern regions is estimated at around 3 and 4 kWh/m^2. Meanwhile, with a stable high-temperature range and a number of 2,000 to 2,500 hours of sunshine annually, the Southern, Highlands, and South-central regions appear to be the best areas to enlarge the application of solar energy. These regions possess a value of daily GHI between 4 and 5.5 kWh/m^2, which can be compared with developed solar markets in Asia [11]. Table 2 shows each region's potential in the growth of solar energy, especially for the utility-scale solar photovoltaic systems. It can be noticed that the Southern Central Coast, the Central Highlands, and the North East account for approximately 70% solar potential across the country, presenting the highest chance for expanding large-scale solar projects [12]. The theoretical potential according to the technology selected and the solar resource estimated across the country is placed in the range of 60-100 GWh/ year for Concentrated Solar Power systems, and 0.8-1.2 GWh/ year in the case of Photovoltaic systems [13].

Table 2. *Potentiality for utility-scale solar systems within 10 km of existing power lines.*

Region	Solar Area (km^2)	Solar Potential (GW)
Central Highlands	361.8	9.05
Mekong Delta	4.2	0.10
North Central Coast	4.8	0.12
North East	331.8	8.30
North West	184.7	4.62
Red River Delta	317.8	7.95
South Central Coast	594.5	14.86
South East	122.5	3.06
Total	1922.3	48.06

2.3.2. Difficulties in Scaling-up Solar Power in Vietnam

Although RE, especially solar photovoltaic system, has been flourishing in Vietnam recently, it cannot be denied that the proportion of renewable in the total amount of electricity generated annually is still negligible due to some barriers related to technical and management issues. Even though plenty of researches on solar potential have been conducted, further investigation needs to be done to provide a sufficiently reliable database. Lack of those data resources can lead to the problems in estimating and planning for the upcoming solar projects. In the current context, a fully developed study at national level on related factors is essential for the promotion of sustainable investment.

Furthermore, the concerns in planning and managing solar resources set an issue to the development of photovoltaic power in Vietnam. Currently, the country has only been focusing on promoting the growth of photovoltaic centralized projects mainly in the south region. Over investment in provinces with high density such as Ninh-Thuan and Binh-Thuan has led to the national electricity grid's congestion problems because the investment in the transmission grid project has not kept pace with the construction progress of solar power projects. Specifically, it takes usually 6 months to implement a solar power project while completing a 220 kV or 500 kV transmission project takes about 3 to 5 years [14].

Besides, the estimated levelized cost of energy (LCOE) of ground-mounted solar "grade-1" is 8.84 UScent/ kWh while LCOE of rooftop PV "grade-1" reaches 10.56 UScent/ kWh in 2017 [15]. Those values decrease to 8.07 UScent/ kWh for ground-mounted solar and 9.8 UScent/ kWh for rooftop systems in 2020, see Figure 2. The second-highest cost belongs to rooftop PV systems, making it one of the least cost-effective energy resources across the country. Although it has witnessed a downward trend over the last years, LCOE of solar PV systems for both types in Vietnam is still relatively high, nearly double those of other countries such as China, Australia, and the UAE, specifically 5 UScent/ kWh for large-scale PV systems. This makes PV less competitive than other energy resources not only at the national level but also at the international level.

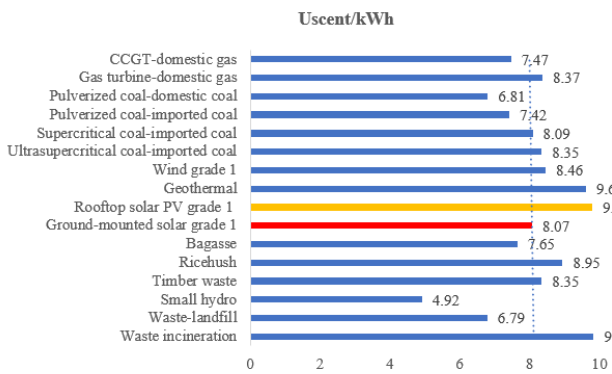

Figure 2. *LCOE of different energy invested in 2020.*

3. Assessment of solar Power Production in VIETNAM

3.1. Data Assessment

In 2017, Solargis had released the Global Solar Atlas based on their solar resource database under the funding of the World Bank Group [16]. Solargis uses a semi-empirical solar radiation model for its database. Solargis uses the satellite-to-irradiance model to retrieve the solar radiation. The data collected from different geostationary satellites is processed using a 15- or 30-minutes time step depending on the satellite platform. The resolution reaches 250 m x 250 m for solar radiation, 1 km x 1 km for air temperature, and approximately 25 to 35 km for other meteorological data, making the data more precise. Besides being easily accessible, it is also able to calculate the theoretical solar power generation capacity and the potential of different types of PV systems such as small residential, medium-size commercial and ground-mounted large-scale systems with the scale of the data processing up to each district in Vietnam. For the calculation, Global Solar Atlas permits users to use the default parameters or enter the optional data of azimuth angle, tilt angle, and system size. In this research, the data of solar irradiation and other related factors is collected from this resource.

3.2. Estimation Method

3.2.1. Considered Factors for Estimation of Solar Power Production

a. Global Horizontal Irradiance (GHI)

Global Horizontal Irradiance (GHI) is the total amount of short-wave radiation from the sun to a surface on Earth. This type of solar irradiance includes Direct Normal Irradiance (DNI) after accounting for the solar zenith angle z, Diffuse Horizontal Irradiance (DHI), and the reflected irradiance Albedo.

$$GHI = DNI \times cos(z) + DHI + Albedo \qquad (1)$$

According to GSA, GHI in Vietnam is within the range of 3.16 to 5.52 kWh/m^2 per day, which is equivalent to 1153.4 to 2014.8 kWh/m^2 each year. The average value of GHI is 4.25 kWh/m^2 each day or the yearly total equals 1551.25 kWh/m^2, see Figure 3.

When it comes to the distribution of daily GHI around Vietnam, according to GSA, there is around 31% of the area where the GHI is more than 4.8kWh/m^2 and around 43% of the area where this figure is from less than 3.4 to 4kWh/m^2, see Figure 4. The percentage of the GHI value between 4.0 and 4.8 kWh/m^2 is quite small due to the noticeable difference between GHI in the northern and southern regions, as illustrated in Figure 3.

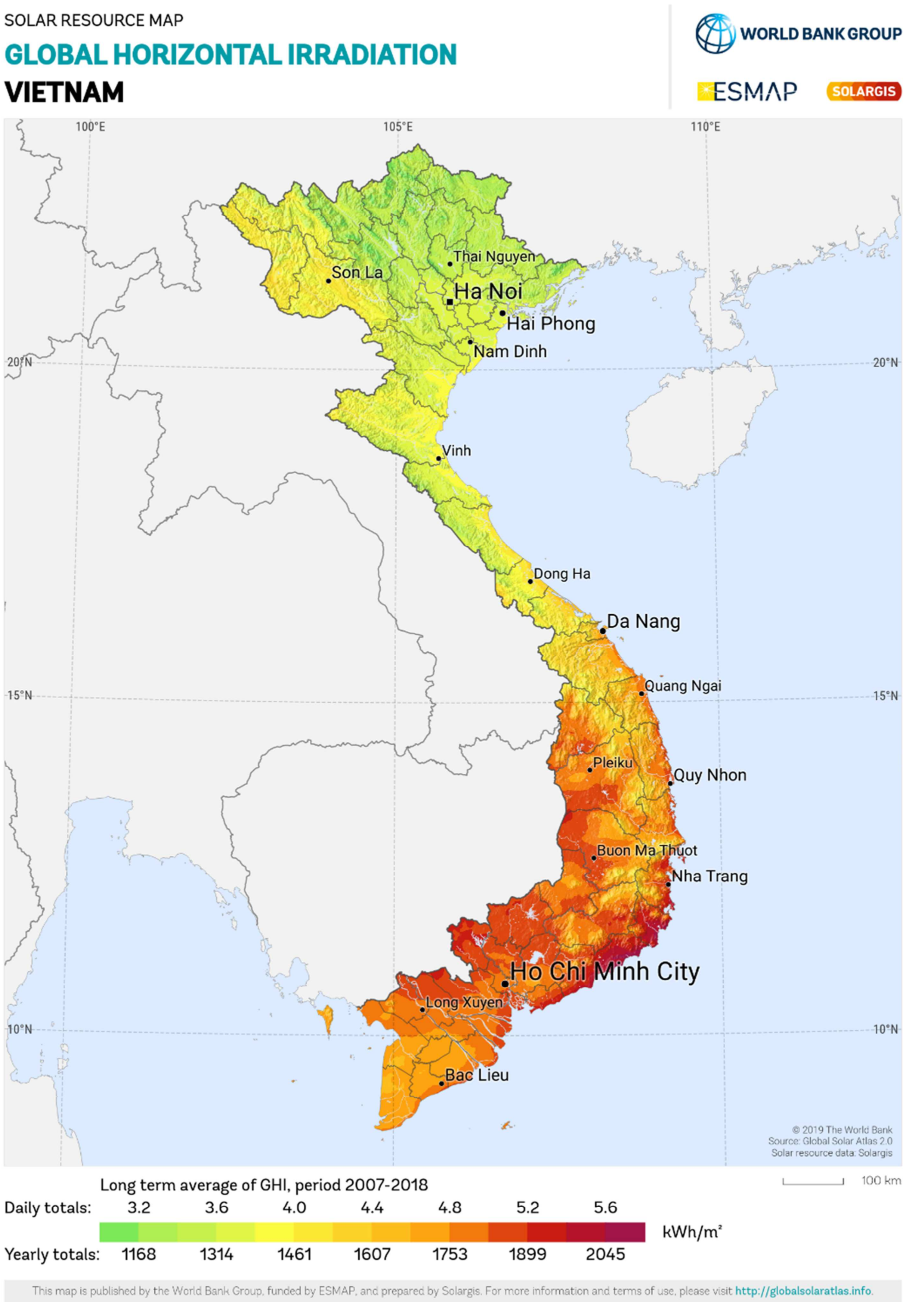

Figure 3. *Global Horizontal Irradiation in Vietnam - Note that Vietnam's administrative map includes both the Paracel and Spratly Islands (Source: solargis.com [16]).*

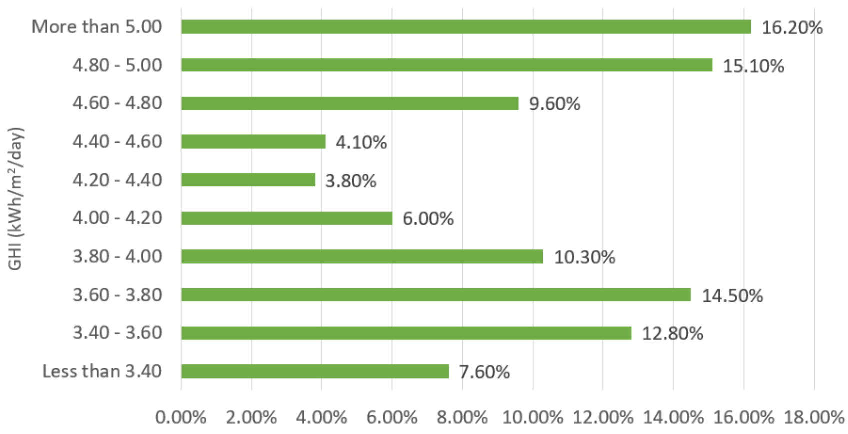

Figure 4. *Distribution of daily GHI in Vietnam (Source: Global Solar Atlas [16]).*

b. Ambient temperature

Solar cells are semiconductor devices that are sensitive to change in temperature. In practical cases, when the PV cell operates at a higher temperature than the standard test condition, the solar cell open-circuit voltage (V_{OC}), the maximum voltage that the cell can deliver when there is no current, decreases, and thus leads to the output voltage also decreases. Another factor that needs taking into consideration is during the photovoltaic process, photons with excessive energy than the required threshold bandgap energy will lose their energy due to the deexcitation process and produces heat, which also influences the performance of the PV cell. The operating temperature plays a central role in the photovoltaic conversion process. Both the electrical efficiency and, hence, the power output of a PV module depend linearly on the operating temperature decreasing. It has been reported that PV module power output decreases by 0.4 – 0.5% for 1°C increase in temperature above the standard operating temperature, depending on the temperature coefficient of the power of the module [17].

c. Sun-path effect and Sun position

The irradiation on a tilted surface depends mostly on the Sun's position; therefore, studying sun-path gives out information about the length of daytime and the amount of daylight received throughout the year, which are valuable insights for evaluating the performance of the solar system. The sun-path during winter months is lower than summer months, so it can be considered December as the worst scenario when the solar system produces the least amount of energy.

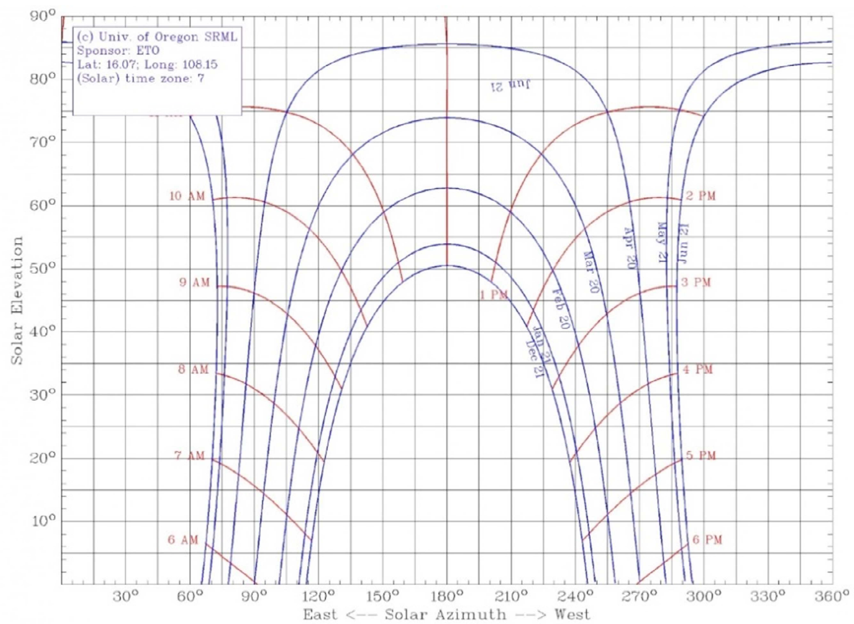

Figure 5. *The horizon and sun-path in Danang, Vietnam (Source: University of Oregon - Solar Radiation Monitoring Laboratory [18]).*

There are three input parameters for calculating the module row spacing to estimate the production in PV ground-mounted systems from Figure 5.

1) The zenith angle (θ_z): the angle between the line to the sun and the vertical line

2) The solar elevation angle (α_s): is the angle between the horizontal and the line to the sun. It is the complement of the zenith angle θ_z

3) The solar azimuth angle (γ_s): is the angular displacement from south of the projection of beam radiation on the horizontal plane; displacements east of south are negative and west of south are positive.

d. Determination of the optimal orientation and tilt angle for PV systems

Vietnam is situated in the northern hemisphere, so as a general rule, the most suitable orientation of the PV array is considered to be the geographic south, which is the direction toward the Southern Pole, because the solar panels can receive most of the direct sunlight throughout the day at this orientation [11]. For average optimum tilt angle, it is recommended that solar systems should be placed with a tilt angle equal to the latitude of the placing area and face the south. Furthermore, depending on the seasons, the tilt angle can be adjusted by adding 15° during the winter months and subtracting 15° during the summer to capture the most amount of solar energy. Many studies have been conducted to calculate the optimal angle for PV systems based on practical observation and characteristics of the installed site [19, 20]. There also exists optimum tilt angles of solar collectors, which are based on the theoretical model [21].

e. Correction factor

To estimate the solar irradiation without considering meteorological factors (temperature data, sunshine hour data, etc.), a correction factor (CF) is introduced. CF only depends on the longitude and the altitude of a location, which is crucial for accessing areas where the facilities for measuring meteorological data are inadequate [22, 23].

f. Transposition factor

Another factor which should be taken into account when evaluating the production of solar energy is transposition factor (TF) - the proportion of annual incident solar energy received on a horizontal plane with that of different orientation and tilt angles. TF indicates the gain and loss when adjusting the collector PV plane at different angles. This factor varies in different locations and regions, and it can be recorded hourly, daily, monthly, or yearly. So far, the TF in Vietnam has not been accessed, thus for better demonstration, the TF in Europe is shown as an example, see Table 3 [24].

Table 3. *Transposition factor in Europe.*

Orientation	Inclinations			
	0°	30°	60°	90°
West	0.87	0.82	0.69	0.48
South-west	0.87	0.95	0.86	0.62
South	0.87	1.00	0.93	0.67
South-east	0.87	0.95	0.86	0.62
East	0.87	0.82	0.69	0.48

g. Shading factor

In operating time, shading in the PV system can occur due to shadows of neighboring buildings, near-by trees, or even the panels themselves [25]. Therefore, it should be seriously taken into consideration during the early planning stage of PV systems and should be avoided as much as possible. Only partial shading can cause significantly decreased PV cell performance. In some partial shading cases, the shaded areas act as “hot-sinks” and heat the modules up to 100°C causing decreased efficiency and PV cell damage. The shading factor (SF) indicates the shaded fraction of the PV field with respect to the full surface area for a given sun orientation. The assumption for SF for estimation method mentioned in this paper is shown in Table 4:

Table 4. *Shading factors for three cases.*

Shading type	Shading factor
Non-shaded	0
Fully shaded	1
Partially shaded	0.8

h. Structural coefficients

The structural coefficient is determined by the types of panels and their ventilation [26]. An example of structural coefficients from different PV technologies is shown in Table 5. The more ventilated the PV module, the higher the structural coefficient is. It can also be deducted from the table that monocrystalline – the PV module with the highest efficiency, has the highest structural coefficients than its counterparts.

Table 5. *Structural coefficients of different PV modules with different ventilation (typical).*

PV technology	Module efficiency	Module: *unventilated*	Module: *ventilated*	Module: *very ventilated*
Monocrystalline	17.5%	0.0875	0.09375	0.1
Polycrystalline	15.5%	0.0805	0.08625	0.092
Amorphous	7%	0.035	0.0375	0.040

3.2.2. Theoretical Estimation Method of Solar Power Production

The inter-row spacing needs to be considered to ensure that the PV system can produce maximum energy, see Figure 6.

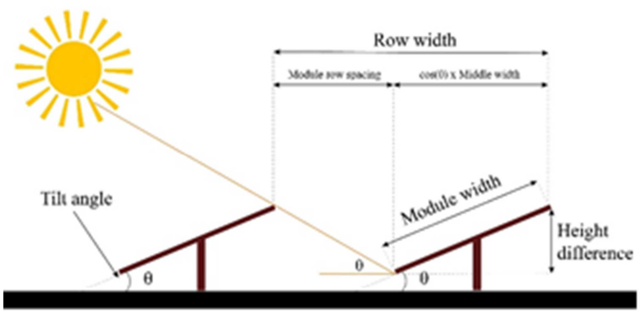

Figure 6. *Calculate module row spacing.*

The height difference is calculated by the following formula:

$$H = W_{module} \times \sin(\theta) \quad (2)$$

where H is the height difference, W_{module} is the module width and θ is the tilt angle of the module.

As previously stated, the University of Oregon has released the sun path depend on the geographical location to help to calculate the solar elevation angle and azimuth correction angle, see Figure 5. Assuming the sun hours from 9am to 3pm in December when the system receives the least sunlight, the solar elevation angle has a value of 32° while the solar azimuth correction angle equals to 50°.

To avoid the effect of shading, each row of solar panels has to be placed following the minimum row spacing which is calculated by the equation

$$MRS_{min} = \frac{H}{\tan(\alpha_s)} \times \cos(\gamma_s) \quad (3)$$

where MRS_{min} is the minimum module row spacing, α_s is the solar elevation angle and γ_s is the solar azimuth correction angle.

The annual production of this system can be calculated by using two methods. The two methods will yield two different results due to the errors in the database. The first method will utilize the incident energy, and the overall efficiency of the PV system while the second method will work with the correction factor (CF) and the potential PV power generation (PVout).

The first method is conducted as follows:

The incident energy (G) is the product of annual GHI and the transposition factor (TF)

$$G = G_{ref(yearly)} \times TF \quad (4)$$

The overall efficiency of the PV system (η) includes the structural coefficient (CS) and the shading factor (SF)

$$\eta_{global} = SF \times CS \quad (5)$$

The annual production (E_{PV}) is the product of the incident energy (G), the overall efficiency of the system (η), and the total surface area of the solar panels (S_{PV})

$$E_{PV} = G \times S_{PV} \times \eta_{global} \quad (6)$$

Due to the second method, the annual production (E_{PV}) of the system is the product of the potential PV power generation (PVout), the correction factor (CF) and the total peak PV power of the solar panels

$$E_{PV} = PVout \times CF \times \text{Total peak PV power} \quad (7)$$

4. Result and Discussion

a. Estimated PV farm system at Hoa-Khanh Bac, Lien Chieu, Danang

The typical area for the estimated solar farm Hoa-Khanh Bac, Lien Chieu, Danang, is located at 16°04'12" North and 108°09'00" West has a total commune area of 9.93km^2. The GHI measured in this area has a value of 1700 kWh/m^2/year [16].

In this solar power system, the type of solar panel chosen is Monocrystalline silicon (mc-Si), with efficiency equal to 19.4%. The panel has a nominal output of 400 Wp.

Since Vietnam lies in the Northern hemisphere, the free-standing solar panels will be installed facing the south. Consider that the area for PV installation is 20 ha, with the length of the farm is 1000 m, and the width is 200 m. Due to the lack of a precise database of the factors related to the process of estimation, all of the factors will be assumed, see Table 6.

Table 6. *Assumed factors of the simulated PV farm.*

Tilt angle	Correction factor	Transposition factor	Shading factor	Structural coefficient
16°	1	1.1	1	0.09375 (ventilated)

The simulated solar PV farm has a total number of 63,973 solar panels with 481 panels per row 133 rows having a total installed peak PV power of 25,589.2 kWp. The solar panels distribution map is shown in the Figure 7. The total surface area of the solar panels (S_{PV}) is 131,872m^2.

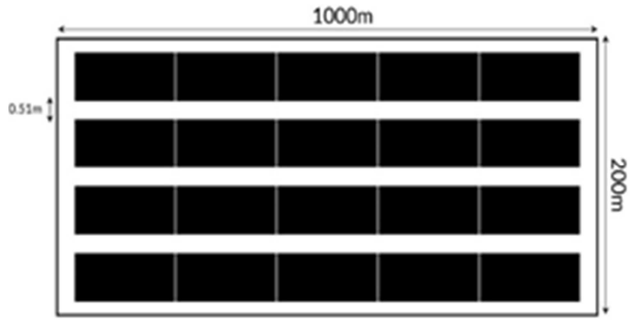

Figure 7. *Solar panels arrangement for the estimated farm.*

According to the method mentioned in part 3.2.2, the amount of power generated in a year of the PV farm has a value of 23,118 MWh in the first case, while the second case yields 35,722 MWh per year.

b. Rooftop PV system at 41/317 La Thanh Street, Hanoi

To achieve nearly zero-energy or carbon-neutral housing, the project team proposed that 75% of the power consumption of a house could be locally produced with rooftop PV, and the remaining 25% could be obtained carbon neutral from the grid, since it is the share of hydropower in the power generation in Vietnam for 2020, according to the PDP VII revised, is 25%.

It can be affected by the feasibility study of using RE for self-consumption in the houses. For the demonstration, the project team selected a household with a high average income level (i.e., middle-class families in Hanoi urban area) and an average electrical consumption over 700 kWh/month. The address is N. 41/371 La Thanh Street, Hanoi. The chosen area for installing the rooftop PV system is a household of available area 50m^2, located at 21.021° South and 105.821° East.

A PV system at this house was designed with concrete technical specifications to ensure the installation of the PV system will work well and can be monitored. The project team modelled three options with different nameplate peak power capacity:

1) 6 kWp (area for PV installation of 40 – 48 m^2) can cover up to 75% of household power consumption.
2) 4 kWp (area for PV installation of 28 – 32 m^2) with the

optimized electricity use.

3) 3 kWp (area for PV installation of 20 – 24 m^2) with a limited budget.

The project team concluded the design phase by deciding to implement a 3kWp PV system on the house's rooftop. The location for PV array installation is due to the south. The rooftop inclines 15° to the front and the back of the house, constituting approximately 24m^2 of the total rooftop area. The rooftop system has installed ten solar panels of the type VMC-SP-310M-72 monocrystalline with efficiency equal to 18.56%, a nominal output of 310 Wp, and a dimension of 1956 x 992 x 40mm, see Figure 8.

Figure 8. *Rooftop PV system at N. 41/371 La Thanh Street, Hanoi (source: SEU-HANOI project, 2017 [27]).*

Table 7. *Assumed factors of the rooftop PV system.*

Tilt angle	Correction factor	Transposition factor	Shading factor	Structural coefficient
15°	0.97	1.1	1	0.0875 (not ventilated)

In this section, to evaluate the performance of the typical rooftop solar power system in Hanoi, the case study will be analyzed and compared based on three approaches. Firstly, during the assessment stage, some parameters are assumed in the evaluation method based on the installed area's location to evaluate the power generated from this solar power system.

The system has a total area (S_{pv}) of 19.40 m^2, and daily GHI measured in this area, as stated in GSA, equals 3.568 kWh/m^2/day. As in the first case study, all of the factors will be assumed to evaluate the rooftop PV system's theoretical power production, see Table 7.

The theoretical daily rooftop PV output is estimated the same as the PV farm's preceding calculation. The estimated value of the daily output of the system obtained is 6.66 kWh while the monthly value reaches 199.8 kWh for the month of 30 days and 206.46 kWh for the month of 31 days.

A simulation software PVsyst is utilized for the second approach, taking into account several factors such as shading albedo and temperature losses [28]. The results were obtained from the simulated 3 kWp Si-mono photovoltaic system modeled in the PVsyst V6.85 as per the project specifications and constraints. In this simulation, mainly produced energy, specific production, performance ratio, system output power distribution, and arrow losses were obtained. Acquired results, see Table 8, were analyzed to assess the performance of the Si-mono photovoltaic system compared with the real-recorded data from the system during a two-early month operating system. The first indicator is the total amount of energy produced from the PV system on an annual basis, which is referred to as produced energy, i.e., 3452.7 kWh/year. The second parameter is the specific production on an annual basis per installed kWp is 1114 kWh/kWp/year. The third parameter is the annual average performance ratio (PR) is 79.80%.

The main results shown in Table 8 include GHI, ambient average temperature, in which soiling losses and shading losses are taken into account, and energy injected into the grid (i.e., energy consumed by the load) where the losses in electrical components, a photovoltaic array, and system efficiency are considered. The values of each variable mentioned in Table 8 were obtained in terms of monthly and yearly values. Yearly values of the variables are possible as averages for temperature, efficiency, and summation for solar irradiance and energy. The annual GHI is 1374.6 kWh/m^2, and the global incident energy on an annual basis on the collector without optical corrections and effective global irradiance after optical losses are 1396.0 kWh/m^2 and 1347.1 kWh/m^2, respectively. With this effective irradiance, annual DC energy produced from the PV array and annual AC energy injected to the building grid are 3642.1 kWh and 3452.7 kWh, respectively. The PV array's annual average efficiency is 13.45%, while the system's annual average efficiency is observed to be 12.69%. The energy produced by the PV array cannot be the same as energy injected into the grid. To feed the grid, energy from the PV array has to be converted from DC to AC. During this, some amount of energy is lost in terms of AC wiring and Inverter efficiency losses. The PV system generated and injected more energy into the grid in August, specifically 375.2 kWh. The lowest amount of AC energy that is injected into the grid is 183.6 kWh in February.

Table 8. *Main results of 3 kWp Si-mono PV rooftop system in Hanoi.*

Month	GlobHor (kWh/m^2)	T Amb (°C)	E_Grid (kWh)	EffArr R (%)	EffSysR (%)
Jan	67.3	15.45	185.4	14.06	13.03
Feb	69.2	17.33	183.6	13.95	12.99
Mar	86.6	20.62	217.8	13.68	12.73
Apr	104.9	24.44	255.7	13.43	12.57
May	144.1	27.81	337.7	13.20	12.40
Jun	153.3	29.36	356.0	13.17	12.50
Jul	159.9	29.39	371.9	13.14	12.48
Aug	155.1	28.46	375.2	13.22	12.56
Sep	131.2	26.84	330.7	13.31	12.61
Oct	129.8	25.02	348.0	13.45	12.79
Nov	92.9	20.72	261.0	13.71	12.95
Dec	80.4	17.24	229.7	13.95	13.12
Year	1374.6	23.59	3452.7	13.45	12.69

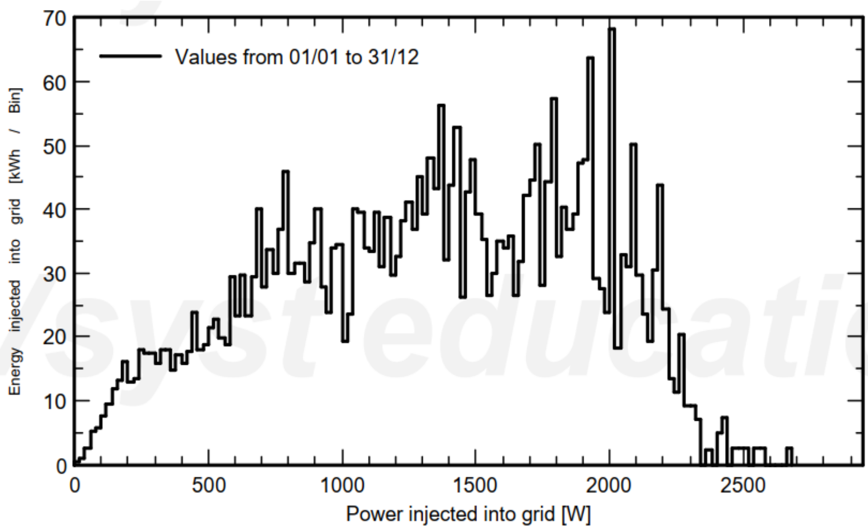

Figure 9. *System output power distribution.*

In Figure 9, it can be observed that the PV system's output power reaches a maximum of 2600W. However, the power distribution also indicates that the majority of the time the system operates at the output power level is achieved between 800W and 2000W. This can be recorded as the cause of the loss of the PV system. The system performance depends on the weather conditions at the installation site.

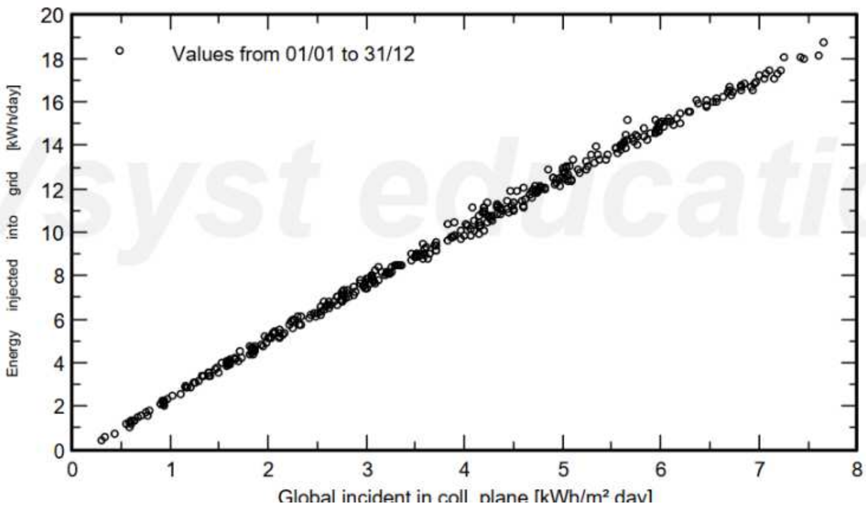

Figure 10. *Daily input/output diagram.*

The daily global irradiance on the collector plane (PV modules) without any optical corrections is in the range of 0.3 kWh/m^2 to 7.6 kWh/m^2, but the thickest distribution point is from 4 kWh/m^2/day to 5.5 kWh/m^2/day. The AC energy generated by the 3 kWp PV rooftop system in a day is distributed from 0.5 kWh to 19 kWh, see Figure 10.

The simulation by using PVsyst software is useful to evaluate the performance of a PV system during early-stage design in term of energy yield output. The simulation results help intuitively identifying the system's efficiency compared to the actual operating system in the first years. Within this paper's scope, the project team had put the PV rooftop system into operation since early August 2017. After two months, the system's energy in the operating conditions in which the solar radiation is best irradiance condition was collected and analyzed by comparing with the proposed methods of evaluating the solar energy potential. However, the accessed data were interrupted due to the fact that the monitoring system had to be re-configured after being in operation for the first two months.

The simulation of daily output energy of the 3 kWp PV system has been shown in Figure 11, which indicates the range from approximately 52 kWh/day to 17 kWh/day. The simulation also projects that the system output is above 7 kWh/day from the middle of August until the end of the month. However, the actual data is lower than the simulated. The total solar production in 8/2017 (from 8 Aug 2017 to 7 Sep 2017) is 227.1 kWh, with a daily average production output of 7.3±0.3 kWh/day. The highest peak of the PV system is 14.0 kWh/day, and it hit the lowest at 2.8 kWh/day, see Figure 12.

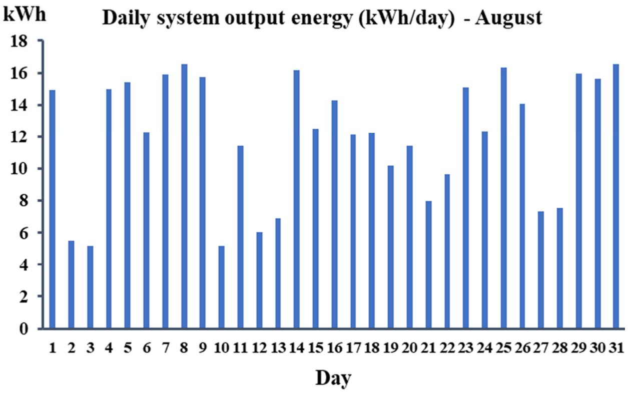

Figure 11. *Simulated daily 3 kWp PV system output energy in August.*

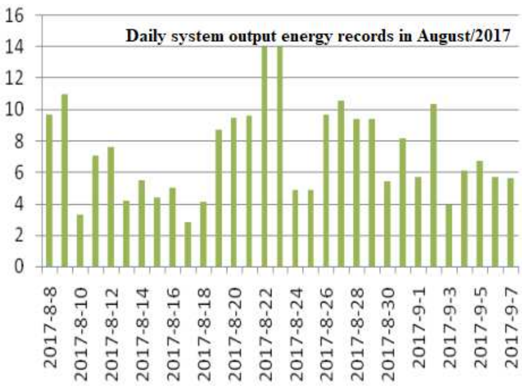

Figure 12. *Recorded daily 3 kWp PV system output energy from 8 August to 7 September 2017.*

It can be clearly seen that the estimated value of total solar energy output had reached 109%/day and 114%/month compared to the real recorded values. Such deviation between theoretical and practice results mainly attributed to the imperfection in meteorological data. During the operating time, the number of rainy and cloudy days increased significantly. Moreover, it can be concluded that the deviation also attributes to air pollution in urban areas in Hanoi, where the dust layer in the atmosphere can influence the solar irradiance reaching the PV system.

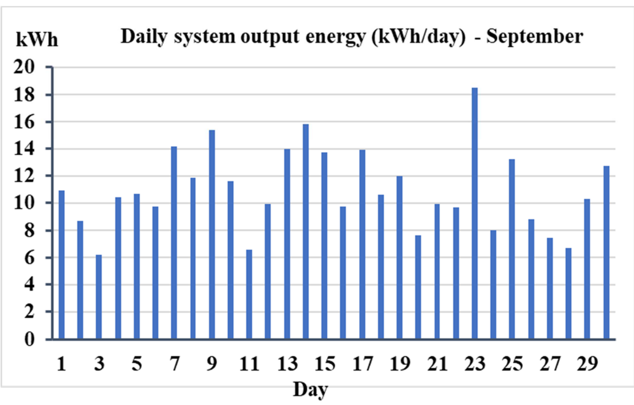

Figure 13. *Simulated daily 3 kWp PV system output energy in September.*

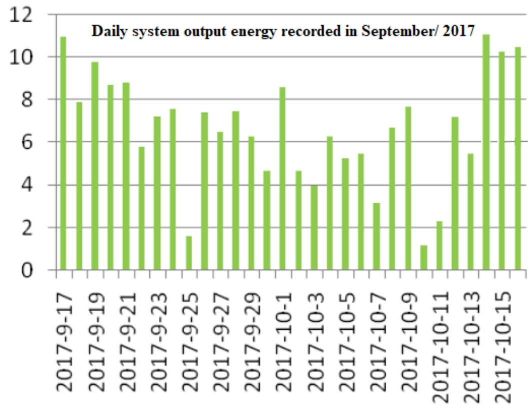

Figure 14. *Recorded daily 3 kWp PV system output energy in September 2017.*

With the same manner, the simulated output energy in September 2017 ranged from around 6.2 kWh/day to 18.2 kWh/day, yet the actual results were much lower. The total solar production in September 2017 (from 17 September 2017 to 16 October 2017) reached 200.5 kWh, with the average daily output of 6.7±2.6 kWh/day. During this month, the highest efficiency of the PV system was 11.4 kWh/day (14 October 2017), and the lowest was 1.2 kWh/day (10 October 2017), see Figure 14.

In this case, the theoretical estimation accounts for approximately 99.65%/month and 99.4% of the real practical results. It can be seen that in the case of September 2017, the estimation for the monthly production output is more reliable.

From this purposed method, although deviation between projected and actual data exists, the simulation provides an overview of daily output energy, and can become an input for the household PV rooftop to better utilize this power source.

5. Conclusion

Green energy transition, the urge to reinforce independence from conventional energy sources to solve environmental issues are the main driving forces for the development of RE in Vietnam. Geographical advantages, coupled with supportive mechanisms approved by policymakers and initiatives taken by organizations, have laid the foundation for the prosperity of RE in Vietnam. However, data-reliability, financial accessibility, managing, and planning are the main bottlenecks that need resolving. This can be done by strengthening cooperation between government, organizations, and consumers, upgrading the required infrastructure for accessing essential data for evaluating the potential of the installed PV system in a given area more precisely, applying the latest technologies to maximize the output, and improve the efficiency of the solar system.

The methodology for estimating solar energy production in different technologies discussed in the paper can be an input for investors, planners, and developers to execute the next steps before installing a Photovoltaic system in a particular area. Case studies with assumed factors that can influence the energy output are taken into account and compared with actual results for evaluating the reliability of the estimation and simulation method. Deviation has been found between theoretical, simulated and practical results due to insufficient meteorological data and lack of measuring devices, yet these problems can be addressed by investing in facilitating the infrastructures and equipment for measuring and recording data.

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