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Evaluating the Rooftop Solar Photovoltaic Potential in Hau Giang Province

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Abstract

Renewable energy is a remarkable developing potential in Vietnam, in which solar photovoltaic (PV) energy is rapidly invested by investors in and out of the country in recent years. Specially, the solar radiation in Southern area is more tremendous comparing with other parts in Vietnam. Developing the PV energy is very essential and results in national economic, social and technical benefits. However, the state of uncontrollable developing rooftop PV in residential households and entrepreneurs affects national power system in the area. In this study, the potentials of rooftop PV energy in Hau Giang province – being located in Southern part and occupying about 0.5% of total area in Vietnam (1,608 km^2) - is evaluated by statistical methods, analysist methods and online map-based applications. As a results, total rooftop suitable area and the average peak capacity PV power potential in Hau Giang province are approximately 15.79 km^2 and 1,882.3 MW/year, respectively. Besides, power system steady state stability is analysed via commercial software ETAP when connecting rooftop PV power station in Hau Giang province and a study case is proposed to verify economic and social effects Hau Giang provinece.

Keywords: Rooftop solar PV power, theoretical rooftop solar PV potential, technical rooftop solar PV potential, rooftop solar PV economic and social effects, impacts of the rooftop solar PV on the power distributed system.

1. Introduction

Solar energy is an abundant renewable power source in Vietnam resulting to various potential benefits for economic, social development. In [1], authors presented the assessment for the importance of solar energy in Vietnam including: contributing to reducing greenhouse effects and burden of importing fossil fuel; reducing costs for traditional power generation; releasing loads for national power system; increasing electric cost competition; satisfying high demand in using power energy; being easy installation and connection to rural or isolated residential households. Besides, authors also represented tremendous potentials of solar energy in Vietnam with an average solar irradiation level of about 4-5 kWh/m^2/day, in which solar energy potential in Southern part is quite high comparing with others (even reaching to around 5.5 kWh/m^2/day in some area). The rooftop solar PV potentials of approximately 2-5 Gigawatt is for residential and commercial investors and more than 20 GW is for ground-mounted PV power plants. Realizing the enormous benefits of the energy, there are a lot of researchers taking parting in assessment and analysis of the PV potentials [2-5]. In 2018, the Effigis Geo-Solutions (Effigis) with their local partner reported the assessment of technical solar rooftop PV potential in Vietnam such as identification and characterization of rooftop, suitable rooftop surface area for installing PV system, technical rooftop solar PV assessment for 2 big cities in Vietnam (Ho Chi Minh and Da Nang) [6]. The results showed that Ho Chi Minh has potential of 18,000 GWh, which 6,6% of the demand of the City would supply by rooftop solar. In Da Nang city has potential of 2,300 GWh, which 6,9% of the city's needs would be met by using 5% of the rooftops solar in the city.

In 2020, technical potential of rooftop solar power in Ha Noi is evaluated to get the efficiency and payback for a study

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case without assessing and analysing for power system stability under connection of rooftop PV system which is a limit for this study [7].

Besides, the evaluation of rooftop PV system is performed via various methods and applications by researchers in the world. Rooftop solar PV technical potential is assessed in some specific countries such as the United State [8], the Europe Union [9], Saudi Arabia [10]. In 2008, technical potential of rooftop-PV system is estimated basing on data of land uses, population, building densities and GIS maps of urban area and author showed technical limit for roof-integrated PV system [11]. In 2012, Ha T. Nguyen provided a methodology for application of Light Detection and Ranging (LiDAR) to extract the most useful information for assessing rooftop solar PV potential in a Municipal district unit [12]. In 2013, Choongwan Koo proposed a framework of total 5,418 elementary school facilities in South Korea to analysis rooftop PV system for the net-zero energy buildings [13]. After some years, authors gave the evaluation of rooftop solar PV system by using Hill shade module to compute shadow area (shaded area) on rooftops [14, 15].

In recent years, with the development of computer science, some authors applied machine learning to estimate potential of rooftop solar PV system such as support vector machine (SVMs) [16], random forests [17]. Moreover, authors gave and analysed the effects of rooftop solar PV system to power system stability by observing voltage quality, power losses [18] and applying short circuit faults on specific system [19, 20].

In 2021, beside techno-economic analysis of PVSS feasibility, Zhalgas Smagulov also showed financial benefits from PV system under performance degradation related to weather aging [21]. To help to get largest economic benefits from rooftop solar PV system, the optimal investment strategies was proposed to study and apply in The Philippines [22].

In this study, the statistic and analysist methods are proposed to select data and evaluate rooftop solar PV potential in Hau Giang province through using online map-based applications such as Global solar, Solar GIS, 3D Sun-Path. Moreover, due to uncontrollable fast development of the renewable energy, effects of the rooftop solar PV system are also analysed to evaluate power flow and voltage quality of local power system stability and its effects on economic, because they are the important data for investor and related agencies to give future plan for developing this sustainable renewable energy.

2. Methods for selecting data and analysing rooftop PV potentials

In this study, statistic method is used to select and collect data about power plants and networking, solar PV power in Hau Giang province. Moreover, online map-based applications such as Global solar, Solar GIS, 3D Sun-Path are used to evaluate rooftop solar PV power potentials for each local area before rooftop suitable area is determined for installing PV system. To effectively judge effects of the rooftop solar PV on not only power flow and voltage quality of local power system stability but also economic social issues, the commercial software such as ETAP, which is an analytical engineering solution company specializing in the simulation, design, monitoring, control, operator training, optimizing, and automating power systems [23], and RETScreen, which is a Clean Energy Management Software system for energy efficiency, renewable energy and cogeneration project feasibility analysis as well as ongoing energy performance analysis [24], are applied on a study case. The process for selecting data and analysing rooftop PV potentials is showed in figure 1.

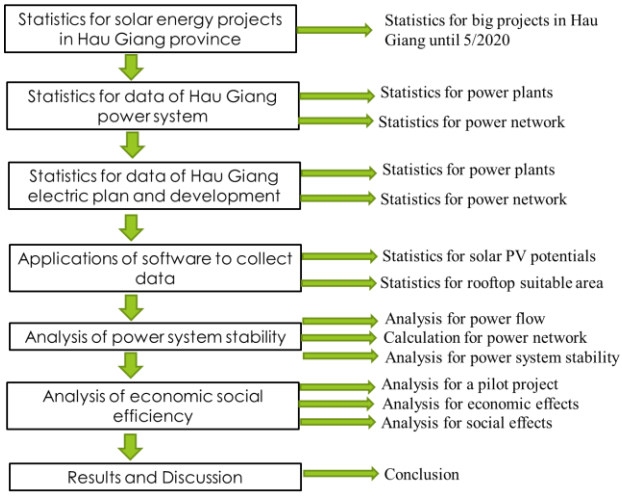


Figure 1. Flowchart for selecting data and analysing rooftop PV potentials

3. Policy for the rooftop solar in Vietnam

In Vietnam, the Prime Minister has issued Decision 11/2017/QD-TTg on a mechanism to encourage the development of rooftop solar power projects.

According to regulations, rooftop solar power projects can implement the mechanism of electricity purchase and sale according to the intersection and receiving direction separately of two-way metering electricity meters. The parties are responsible for implementing the applicable provisions of the laws on taxes and fees.

According to Decree No. 218/2013/ND-CP, where rooftop solar power projects belong to the industry "producing renewable energy, clean energy" should be subject to special investment incentives. Therefore, in order to create conditions and encourage businesses to invest in business in this field, at the same time, based on legal documents, the Ministry of Finance clearly guides import and export tax incentives.

In which, in terms of import and export tax incentives, rooftop solar power projects implement the preferential import tax exemption policy for imported goods to create fixed assets for the project. In addition, the rooftop solar

power project implements an import tax exemption policy within 5 years from the commencement of production for imported raw materials, supplies and components that cannot be produced domestically for project production.

Referring to incentives, Circular No. 78/2004/TT-BTC, corporate income from the project Solar rooftop solar power investment is only 4-year tax exemption, 50% tax reduction for the next 9 years, 10% preferential tax rate for a period of 15 years.

In case an enterprise produces electricity from rooftop solar power projects in a form of occupation that produces energy from sunlight and satisfies the criteria, sizes and standards of the energy producer. The amount of renewable energy from solar energy, the enterprise is entitled to a preferential corporate income tax rate of 10% for the income from socialization activities.

Pursuant to the Prime Minister's Decision No. 13/2020/QD-TTg dated May 22, 2020 and regarding the mechanism to encourage the development of solar power in Vietnam, the electricity selling price for rooftop grid connected systems to the national electricity system before December 31, 2020 is 8.38 UScents/kWh applied for 20 years.

4. Current status rooftop solar in Hau giang province

Hau Giang is a place with favourable conditions with a lot of sunshine and a lot of sunshine hours, suitable for expanding solar power projects. With the goal of becoming a pioneer in the field of environmental technology in Vietnam, many companies in industrial zones in the province have installed rooftop solar power, including large projects such as Joint Stock Company Aquaone Hau Giang 01 MWp, Lac Ty II Company with a capacity of 6.9 MWp, Number One Company Limited with a capacity of 8 MWp, Mekong Logistics Joint Stock Company with a capacity of 04 MWp and an Agricultural Export Market Company Limited capacity of 01 MWp [25].

This is a clean energy model applied by companies in production, greatly contributing to reducing greenhouse gas emissions and protecting the environment. On average, each MWp occupies about 7,000 m^2 of factory roof area. According to calculations, each year, the expected output of solar energy is about 1.3 million kWh/MWp, supplied to the power system in the industrial park, contributing to reducing the overload on the lines, at the same time, the system also helps reduce emissions of 663 tons CO_2/year for each MWp, equivalent to the efficiency of absorbing greenhouse gases during the life cycle of 44,320 crops, raising people's awareness of using clean energy protecting the planet [25].

According to statistics [25], customers have installed rooftop solar PV from EVN. As of January 31, 2019, the total output of solar power generated to the grid in 21 Southern provinces/cities was about 1,685,288 kWh. In which, Hau Giang province has the highest power output to the grid with an output of about 594,700 kWh showed in figure 2. Thus, it shows that Hau Giang is a province with great potential for solar power.

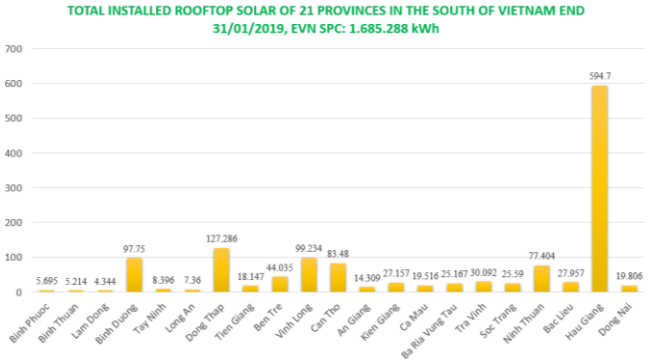


Figure 2. Solar power generation to grid in 21 southern provinces/cities until 31/01/2019.

Rooftop solar PV power unit in Hau Giang province has been installed 2-way meter with 180 units installed completely by customers. In which installation in living accounts for 160 customers.

In recent years, the solar power market, especially rooftop solar PV power, has grown at a dizzying speed. According to Viet Nam Energy Partnership Group: Roofing Solar Power Development in September 2020, the total system as well as the installed capacity of rooftop solar PV has increased by nearly 5 times in 12 months, since September 2019. By the end of September 2020, there are 56,139 rooftop solar power systems with a total installed capacity of 1,543.2 MWp (end of August 2020: 48,631 systems with a total capacity of 1,168.2 MWp). In addition, according to EVN, there are 4,850 rooftop solar PV power projects (capacity of 2,860 MWp) registered for implementation in 2020 showed in figure 3.

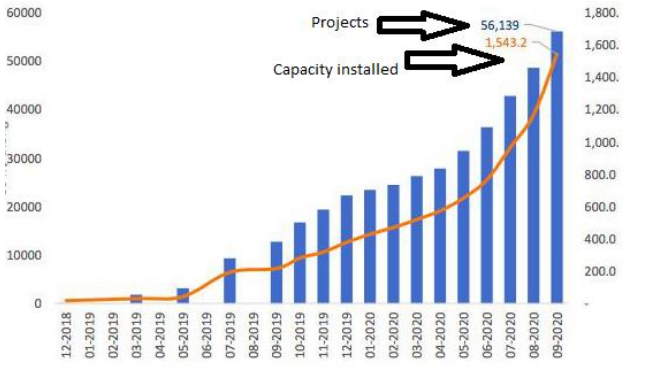


Figure 3. Number of projects of rooftop PV power

5. Theoretical and technical potential for installing rooftop solar PV system

There are 3 main areas for installing rooftop solar PV system including rooftops of residential households, industrial company and headquarter administrative units. Hau Giang is located in the Mekong Delta region in Southern area of Vietnam with total area of 1,608 km^2, population of

776,663,126 people in 2018 increasing 2,035 people (0.26%) comparing with that in 2017. Table 1 presents total area, population and population density in each district of Hau Giang province.

According to enterprises, Hau Giang has an industrial zone of 902 hectares with total large number of companies about manufacturing and processing industry (1,679 companies) showed in table 2. Besides, there are a lot of building rooftops for state agencies consisting of 57 buildings for education and training agencies; 388 buildings for health and social supporting agencies; 129 buildings for finance, banking and insurance and 627 buildings for administration and support services.

Table 1. Total area, population and population density in each district of Hau Giang province

		Area (km^2)	Average population (Thousand persons)	Population density (Person/km^2)
No.	Total	1,621.7	776,663	479.92
1	Vi Thanh	118.86	76,321	642.11
2	Nga Bay	78.07	61,209	784.03
3	Chau Thanh A	160.63	104,982	653.56
4	Chau Thanh	140.90	82,135	582.93
5	Phung Hiep	484.51	195,355	403.2
6	Vi Thuy	229.37	99,440	433.54
7	Long My	260.07	84,662	325.54
8	Long My town	149.29	72,559	486.03

Basing on solar energy Solar Gis map in Hau Giang province [26], data about solar potential in Hau Giang province is collected. The specific photovoltaic power out (PVOUT), which is defined as the amount of generated power per unit of the installed PV capacity over the long term in unit of kilo watthours per installed kilowatt-peak of system capacity (kWh/kWp) reaches to 1,366 kWh/kWp/year while the average global horizontal irradiance (GHI) representing the total amount of shortwave radiation received from above by a surface horizontal to the ground gets 1,717 kWh/m^2/year. Moreover, direction normal irradiance (DNI) are a basic index to calculate and determine installed PV capacity gaining about 1,102 kWh/m^2. All parameters are showed in figure 4.

Table 2. Statistics for the number of industrial companies in Hau Giang province

	Years	2014	2015	2016	2017	2018
No.	Total	1,239	1,347	1,552	1,582	1,679
1	Vi Thanh	263	253	251	278	285
2	Nga Bay	141	140	164	147	156
3	Ch.Thanh A	234	269	311	282	309
4	Chau Thanh	176	206	250	247	263
5	Phung Hiep	154	160	189	198	210
6	Vi Thuy	102	144	191	232	246
7	Long My	37	38	49	57	60
8	Lo My town	132	137	147	141	150

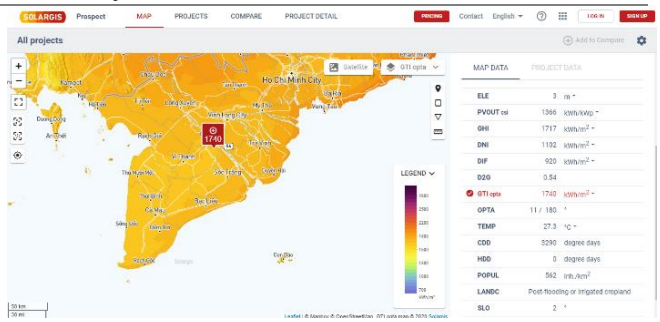


Figure 4. Solar irradiance data of Solar Gis in Hau Giang province

According to data source of Effigis [28], total sunshine duration in Hau Giang province summarized in table 3. The average sunshine time is around 2,521.7 hours in 2018. The lowest average sunshine time is in October with about 176.1 hours while the highest one is in March with around 276.1 hours. Likewise, the information about sunshine duration is also identified at any positions on website 3D Sun-Path, the aim of 3D Sun-Path is to demonstrate the relationship between geographic location and solar position throughout the year [27], showed in figure 5. For example, total annual day length in Chau Thanh district can be estimated as approximately 4,438.5 hours/year (equally to 12.11 hours/day).

Table 3. Total sunshine duration in Hau Giang province. Unit: hours

	2014	2015	2016	2017	2018
Total	2,689	2,956	2,597	2,467	2,521
January	229.3	227.8	281.8	208.8	215.4
February	259.6	251.8	261.6	231.1	232.7
March	300.6	306.0	305.9	275.9	276.1
April	249.6	292.8	301.7	261.6	268.6
May	250.9	276.3	219.5	166.4	180.3
June	150.0	202.0	194.2	193.2	195.8
July	202.5	229.6	219.3	179.4	180.1
August	217.0	258.5	191.8	203.0	203.5
September	199.2	206.2	176.1	208.4	208.9
October	204.0	222.5	115.9	178.1	176.1
November	226.4	244.1	201.1	174.8	195.3
December	200.8	238.8	128.6	186.7	188.9

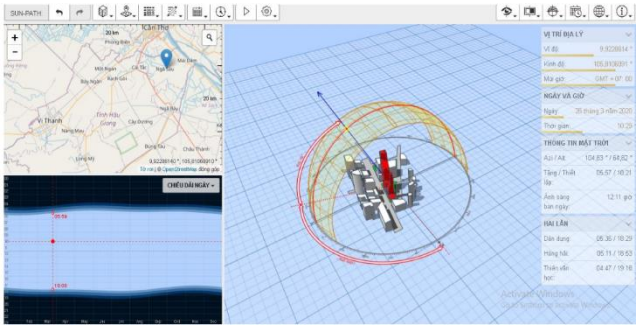


Figure 5. Data sunshine duration on website 3D Sun-Path.

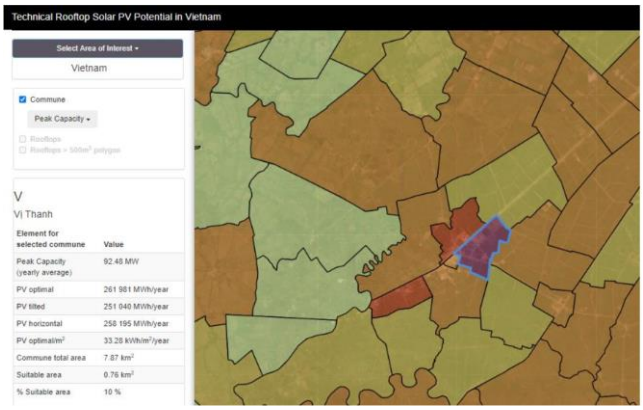


Figure 6. The suitable rooftop area Effigis program

After evaluating the solar potential for implementation of rooftop solar PV system, the suitable rooftop area is identified by the program of Effigis [28] in figure 6. Total suitable rooftop area in Hau Giang province is extracted in table 4.

Table 4. Total suitable rooftop area in Hau Giang province

No.	Administrative units	Area (km^2)	Suitable rooftop area (km^2)	Capacity (MW)
1	Long My district	540.2	2.67	326.66
2	Vi Thanh city	118.7	2.86	349.3
3	Vi Thuy district	230.2	2.29	284.56
4	Chau Thanh A district	156.6	2.18	269.62
5	Phung Hiep district	485.5	3.59	382
6	Nga Bay city	79	1.2	147.52
7	Chau Thanh district	134.5	1.0	122.64
	Total	1,744.7	15.79	1,882.3

Table 5. The suitable area for rooftop solar power by using Effigis and Google Earth program

No.	Administrative units	Area (km^2)	EFFIGIS (km^2)	GOOGLE EARTH (km^2)
1	Phu Huu A	17.33	0.16	0.33
2	Ward V, Vi Thanh City	7.87	0.76	0.86
Total	Hau Giang Province	1608	15.79	17.92

To verify the accuracy of Effigis program, Google earth is also used to get the suitable rooftop area in figure 7. As can be seen, the difference of the two programs is about 13.5% with 15.79 km^2 for Effigis and 17.92 km^2 for Google Earth. The detail is summarized in table 5.

Figure 7. The suitable rooftop area google earth

6. The Hau Giang electric power system

Hau Giang power system is connected from southern power system consisting of 5 transformer substation 110kV with total capacity of 290 MVA. Table 6 summarize parameters of transformer substations parameters of Transformer substations and transmission networking in the power system.

It can be seen that the transmission lines in Hau Giang province are under load with highest load percentages (50.66%) of the 110kV transmission line connecting from Hung Phu and Chau Thanh substation. The detail Hau Giang power networking are showed in figure 8.

7. Power flow analysis

ETAP software is applied to analyse power system steady state stability when connecting rooftop solar PV system. ETAP proposed 04 methods for calculating power flow including Newton-Raphson, Adaptive Newton-Raphson; Fast-Decoupled and Gauss-Seidel methods. In this study, Newton-Raphson method is utilized due to common use and fast convergence in calculating non-linear equation of power flow. Figure 8 and 9 show power distribution of Hau Giang province before and after rooftop solar PV system is connected.

The summarization for comparison of power distribution and voltage at substations before and after connecting the PV system are shown in table 7 and 8.

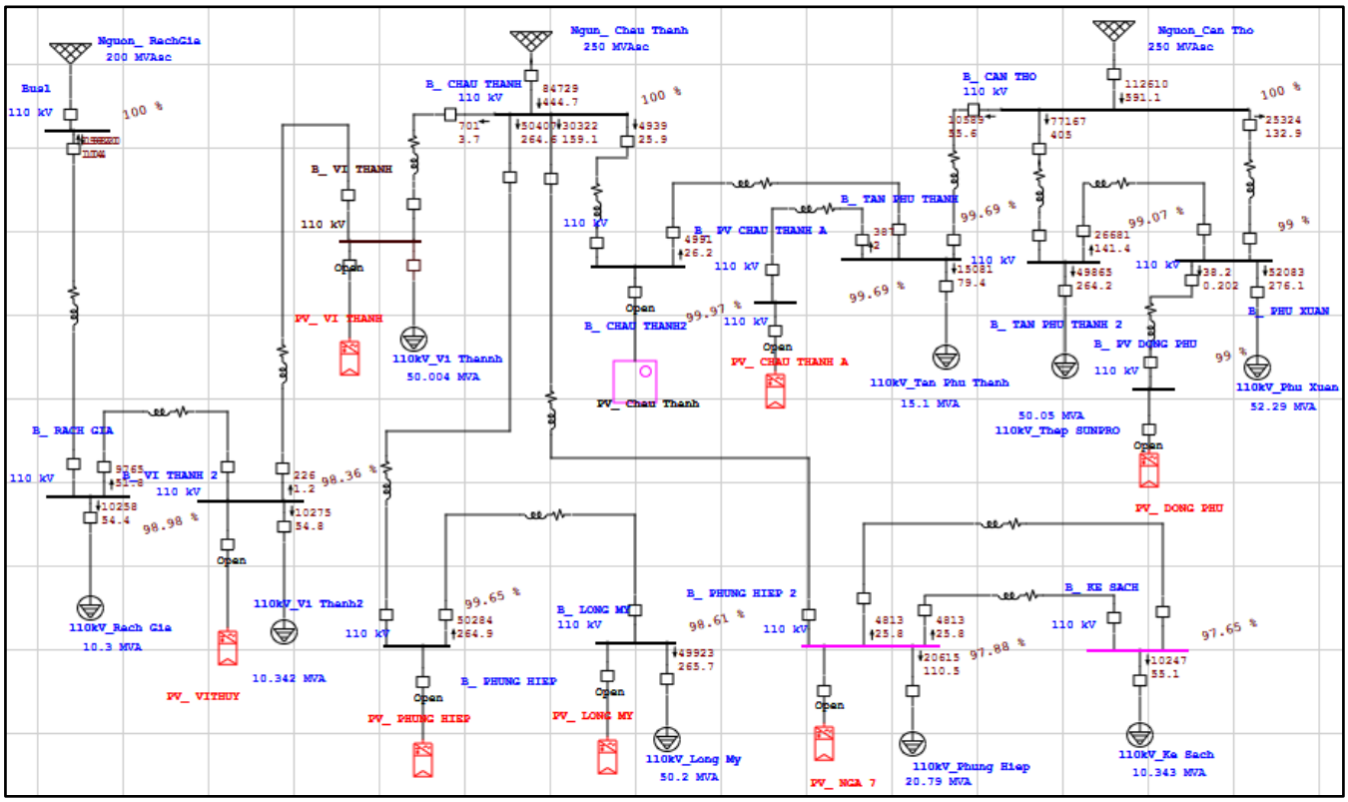


Figure 8. Power flow before connecting the rooftop solar PV system

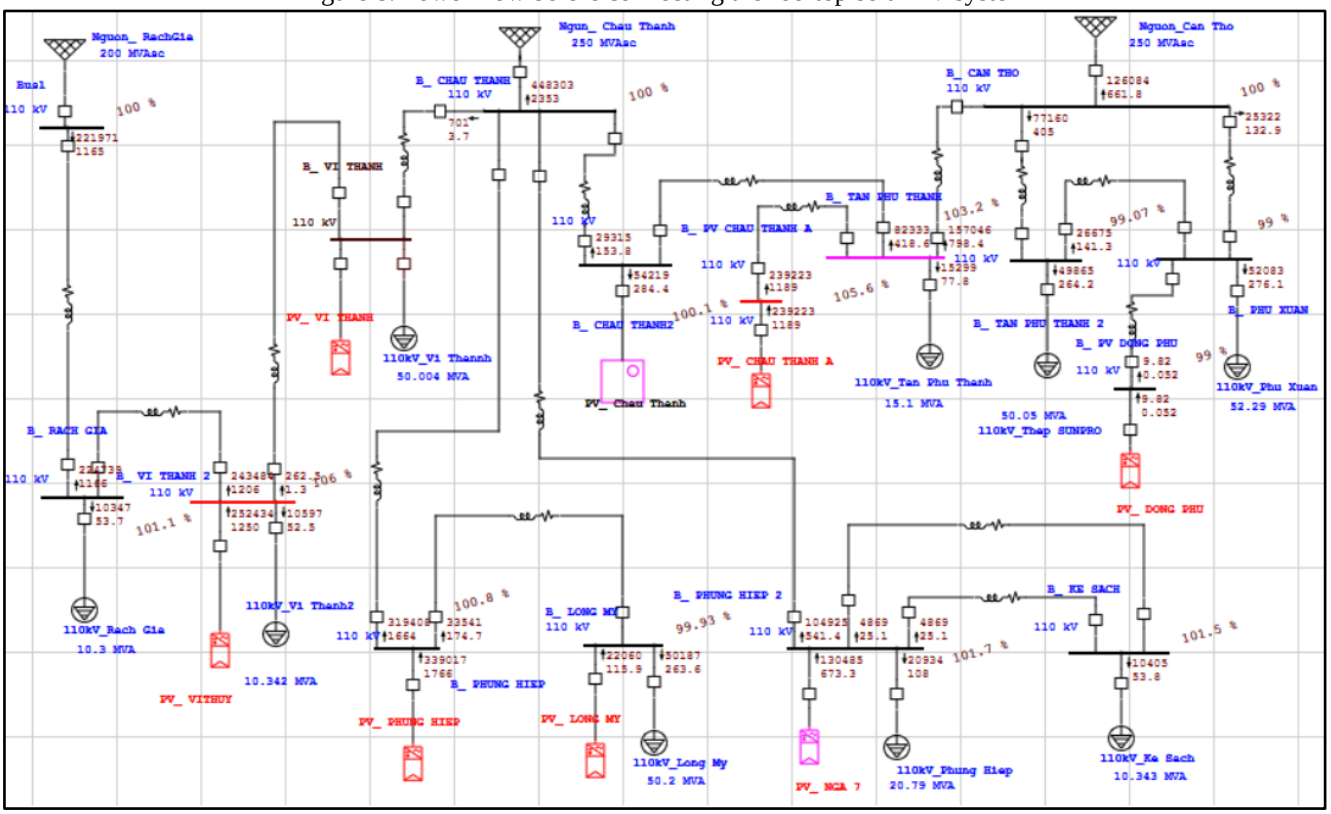


Figure 9. Power flow after connecting the rooftop solar PV system

Table 6. The parameters of transmission lines in the Hau Giang power system

No.	Transmission line 110kV	Conductor	L (km)	P_{max} (MW)	I_{max} (A)	Load (%)
1	Hung Phu – Chau Thanh	ACSR-240/32	29.26	39.7	306.5	50.66
2	Chau Thanh –Phung Hiep	ACSR-240/32	32.63	30.6	157.6	16.04
3	Phung Hiep – Soc Trang	ACSR-240/32	28.42	29.4	151.0	25.05
4	Giong Rieng- Vi Thanh	ACSR-185/29	31.2	46.1	239.0	46.86
5	Vi Thanh- Long My	ACSR-185/29	17.24	18.2	95.7	18.76
6	Long My- Hong Dan	ACSR-185/29	33.97	18	94.1	18.45
7	Can Tho Substation 220kV- Phu Xuan Substation	ACSR-240/32	15.2	21	106	17.52

From the table 7, national power system must generate real and reactive power (186,839 MW and 110,563 MVar) to Hau Giang power system. It means Hau Giang power system cannot adapt enough power for the demand of relatively high local loads. Therefore, the Hau Giang power system become a burden for national power system. However, the problem is solved when solar PV system is installed. The burden of national power system is shared by the solar PV system with total generated power of 983,229 MW. Consequently, national power system received real power (704,416 MW) with high power factor increasing to 86.6% lagging to 94.24% leading from the solar PV system to supply for other local power systems but the reactive power also increasing from 110,563 MVar to 250,099 MVar

Table 8. Load low report

		Before connecting PV system		After connecting PV system	
		Voltage			
Bus ID	kV	% Magnitude	% Angle	% Magnitude	% Angle
CAN THO	110	100	0.0	100	0.0
CHAU THANH	110	100	0.0	100	0.0
LONG MY	110	98.6	-0.6	99.9	1.4
PHU XUAN	110	99.0	-0.4	99.0	-0.4
PHUNG HIEP	110	99.6	-0.2	100	1.5
TAN PHU THANH	110	99.6	0.0	103	1.8

due to absorbing reactive power from solar PV system. Likewise, most of voltage amplitude percentage at the buses increase slightly to 100% while voltage angles at the buses (B_Long My, B_Phung Hiep and B_Tan Phu Thanh) also increase insignificantly to around 1.5% showed in table 8. The results match the evaluation in [29].

Table 7. The summarization for comparison of power distribution and power factor (a) before and (b) after connecting the PV system

a)

SUMMARY OF TOTAL GENERATION, LOADING & DEMAND

	MW	Mvar	MVA	% PF
Source (Swing Buses):	186.839	110.563	217.102	86.06 Lagging
Source (Non-Swing Buses):	0.000	0.000	0.000	
Total Demand:	186.839	110.563	217.102	86.06 Lagging
Total Motor Load:	149.202	92.467	175.532	85.00 Lagging
Total Static Load:	36.393	22.554	42.815	85.00 Lagging
Total Constant I Load:	0.000	0.000	0.000	
Total Generic Load:	0.000	0.000	0.000	
Apparent Losses:	1.244	-4.458		
System Mismatch:	0.000	0.000		

Number of Iterations: 3

b)

SUMMARY OF TOTAL GENERATION, LOADING & DEMAND

	MW	Mvar	MVA	% PF
Source (Swing Buses):	-704.416	250.099	747.496	94.24 Leading
Source (Non-Swing Buses):	983.229	0.000	983.229	100.00 Lagging
Total Demand:	278.813	250.099	374.548	74.44 Lagging
Total Motor Load:	184.271	114.201	216.789	85.00 Lagging
Total Static Load:	45.037	27.912	52.985	85.00 Lagging
Total Constant I Load:	0.000	0.000	0.000	
Total Generic Load:	0.000	0.000	0.000	
Apparent Losses:	49.506	107.987		
System Mismatch:	0.000	0.000		

Number of Iterations: 4

8. A study case for evaluating the economic and social effects of rooftop solar PV system

8.1 Introduction to a study case

The study assumes that, the total installed capacity is about 1,882 MW with the large number of solar panels (7,845,000 panels). The system used an inverter SMA to connect to transmission line 110 kV. The basic information is in table 9.

Table 9. Information rooftop solar PV system on study case

Project name	Rooftop solar energy
Position	Hau Giang province
Capacity	1,882 MW
Connecting method	Connecting directly to transmission line 220V
Solar batery technology	Photovoltaic battery technology-SPV
Inverter technology	Integrated inverter SMA
Number of solar panels	7,845,000

To evaluate the economic and social effects of rooftop solar PV system, RETScreen Expert software is applied. RETScreen Expert links to global open data about weather condition from 6,700 earth station systems and NASA's satellite weather data. The software helps users to not only identify, evaluate and optimize comprehensive financial and technical potential projects about renewable energy but also measure and determine the actual efficiency in production and energy savings.

8.2 Project analysis to a study case

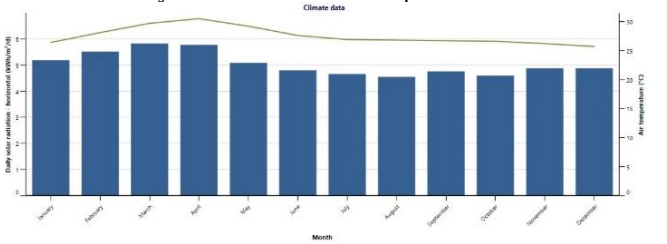
RETScreen software is utilized to estimate costs and revenue, cumulative cash flow, payback time and Greenhouse gas emission reduction of the project as followings:

Selecting the planned position: RETScreen shows the parameters about geographical location of projects, average height and weather data. From table 10 and 11, the weather condition and monthly solar radiation remain stable and high level at planned location.

Table 10. The weather data at the planned location

Month	Air temperature °C	Relative humidity %	Precipitation mm	Daily solar radiation - horizontal kWh/m²/d	Atmospheric pressure kPa	Wind speed m/s	Earth temperature °C	Heating degree-days 18 °C °C-d	Cooling degree-days 10 °C °C-d
January	26.4	68.1%	10.54	5.19	101.1	3.4	27.3	0	508
February	28.1	60.2%	7.84	5.52	101.1	4.0	29.6	0	597
March	29.7	57.4%	16.74	5.83	101.0	4.3	31.7	0	611
April	30.5	60.3%	48.90	5.78	100.8	3.8	32.3	0	615
May	29.2	73.0%	132.68	5.09	100.8	3.4	30.1	0	595
June	27.6	82.7%	191.70	4.80	100.7	3.8	27.9	0	528
July	26.9	85.4%	196.09	4.66	100.8	3.9	27.1	0	524
August	26.8	86.3%	201.81	4.55	100.8	4.2	26.9	0	521
September	26.7	86.8%	193.80	4.76	100.8	3.6	26.8	0	501
October	26.6	86.3%	204.29	4.60	100.9	2.8	26.8	0	515
November	26.2	83.7%	97.80	4.88	101.0	3.0	26.5	0	486
December	25.7	77.4%	28.21	4.88	101.1	3.2	26.1	0	487
Annual	27.5	75.7%	1,332.40	5.04	100.9	3.6	28.2	0	6,397
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at						m 10	0		

Table 11. Daily solar radiation at the planned location



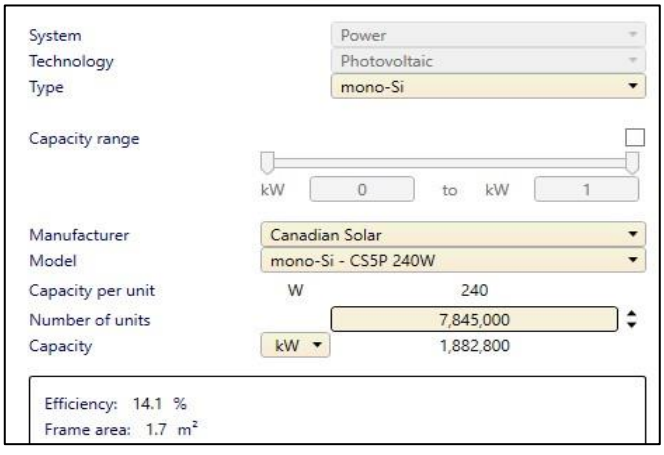


Figure 10. The parameters of Canadian Solar panels

Selecting type of the solar panels and method to install the panels: SC5P-240W-MaxPower from Canadian Solar panels with the capacity of 240 Wp per each are chosen in figure 10. Total of area to install rooftop solar PV system is about 16.85 km^2.

Identifying costs for installation, operation and maintenance: on this project, total installation cost is 1,167,336,000 USD and total costs for operation and maintenance are 5,648,400 USD/year showed in table 12. As a results, with the installed capacity of 1,882 MW, total commercial generated solar power is 2,325,559 MWh/year for total economic operation time of 25 years.

Table 12. The initial costs and revenue of the study case

Costs | Savings | Revenue			
Initial costs			
Initial cost	100%	$	1,167,336,000
Total initial costs	**100%**	**$**	**1,167,336,000**
Yearly cash flows - Year 1			
Annual costs and debt payments			
O&M costs (savings)		$	5,648,400
Debt payments		$	0
Total annual costs		**$**	**5,648,400**
Annual savings and revenue			
User-defined		$	196,509,756
Electricity export revenue		$	0
GHG reduction revenue		$	0
Other revenue (cost)		$	0
CE production revenue		$	0
Total annual savings and revenue		**$**	**196,509,756**
Net yearly cash flow - Year 1		**$**	**190,861,356**

Table 13. Emission analysis for GHG reduction in the study case

Calculating the reduced amount of Greenhouse gas emission when project is under operation showed in table 13. Specifically, a conventional fossil fuel power plants with the rated capacity of 2,325,559 MWh/year will emit 1,071,741.2 t.CO_2 while the rooftop solar PV system with the same capacity only enter 75,021.9 t.CO_2. It means that the project will reduce Greenhouse gas emission of 996,719.3 tCO_2 reaching to 93% of GHG reduction.

Calculating costs and cash flow showed in table 14: In economic area, with total initial investment cost of 1,165,336,000 USD and annual saving and revenue of 196,509,756 USD, the net annual cash flow is 190,861,356 USD.

Calculating the amount of payback time of 6.1 years in this project: The project helps to solve social issues such as promoting investment and development for industrial companies and creating chances for citizens; decreasing the burden for power industry under fast demand of electrical usage and helping national power system actively operate under different load levels, resolving lack of electricity annually especially in drying season as showed in table 14.

Table 14. The financial analysis on the study case

Financial viability		
Pre-tax IRR - equity	%	16%
Pre-tax MIRR - equity	%	5.8%
Pre-tax IRR - assets	%	16%
Pre-tax MIRR - assets	%	5.8%
Simple payback	yr	6.1
Equity payback	yr	6.1
Net Present Value (NPV)	$	3,604,197,911
Annual life cycle savings	$/yr	144,167,916
Benefit-Cost (B-C) ratio		4.1
Debt service coverage		No debt
GHG reduction cost	$/tCO$_2$	-145
Energy production cost	$/kWh	1,000,000,000,000

9. Results and discussion

Hau Giang province possess the abundant area for developing the rooftop solar PV energy such as total area of 1,608 km^2 occupying about 0.5% of total area in Vietnam, population of 776,663,126 people in 2018, an industrial zone of 902 hectares with total large number of companies about manufacturing and processing industry (about 1,679 companies) and over 1,201 buildings for state agencies. Moreover, the solar radiation index in Hau Giang province is extremely impressive and high: The specific photovoltaic power out reaching to 1,400 kWh/kWp/year, total average sunshine time is around 2,521.7 hours. By using statistical methods, analysist methods and online map-based applications like Global solar, Solar GIS, 3D Sun-Path, total rooftop suitable area and the average generated PV power in Hau Giang province are estimated with approximately 15.79 km^2 and 1,882.3 MW, respectively. This power help to not only release the burden but also supply real power 704,416 MW and increase power factor for national power system.

To evaluate the feasibility and the economic and social effects, a study case is evaluated. The solar PV system with the rated capacity 1,882 MW is installed on total suitable area of about 16.85 km^2. As a results, total commercial generated solar power is calculated with 2,325,559 MWh/year for total economic operation time of 25 years. The project also reduces Greenhouse gas emission of 996,719.3 tCO$_2$ reaching to 93% of GHG reduction comparing with a conventional fossil fuel power plants in the same rated capacity. In economic area, although total initial investment cost for the project is approximately 1,165,336,000 USD, total economic operation time of 25 years and the amount of payback time of 6.1 years can be acceptable due to annual saving and revenue of 196,509,756 USD and the net annual cash flow of 190,861,356 USD. From above analysed results, it can be confirmed that the project can be definitely effective and feasible about the technical, economic and social area.

10. Conclusions

The study evaluated rooftop solar PV potentials in Hau Giang province with the solar irradiance ranging from 4.68 to 4.72 kWh/m^2/day and total sunshine time of 2,521.7 hours. As a result, total estimated suitable rooftop PV power potential and the average peak capacity are approximately 15.79 km^2 and 1,882.3 MW, respectively. Besides, ETAP software is used to analyse the Hau Giang power system power flow before and after the rooftop solar PV system is connected.

A project is proposed to evaluate the feasibility and the economic and social effects. As a result, with total initial investment cost of 1,167,336,00 USD, the rooftop solar PV system built and operated in 25 years will generate 2,325,559 MWh/year and contribute to 93% reduction GHG (about 996,719.3 t.CO$_2$) comparing with conventional fossil fuel power plants. The payback time is only 6.1 years.

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