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Article

Feasibility Study for Investment in VSPP Solar Power Plant in Thailand Using GIS and Financial Modelling

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Abstract

The study aims to evaluate the financial feasibility and land suitability for investment in VSPP solar plant in Thailand using Geographic Information System (GIS) and financial modeling techniques. The study analyze key parameters, including photovoltaic power output (PVOUT), land price, and distance from existing infrastructure. The methodology comprises GIS-based spatial analysis and financial performance assessment using indicators consisting of the Net Present Value (NPV), the Project Internal Rate of Return (PIRR), the Equity Internal Rate of Return (EIRR), and the simple payback period (SPB) to identify area and location for investment in VSPP solar power plant. The study areas were categorized into three groups based on the values of PVOUT - the 10% lowest PVOUT (Group 1), middle range PVOUT (45%-55%) (Group 2), and 10% highest PVOUT (Group 3). The results indicated that locations with the highest 10% PVOUT (Group 3) demonstrated the best financial performance, with an NPV of approximately 15 million THB, PIRR of 9.75%, EIRR of 11.50%, and a SPB of 9.25 years. Conversely, locations with the lowest 10% PVOUT (Group 1) were financially infeasible.

Keywords: Solar Farm, Project Feasibility, Site Selection, Renewable Energy, GIS, Project Financial Modelling

1. Introduction

In the current global trend, various countries are transitioning from fossil fuel-based energy to renewable energy to ensure energy sustainability and reduce emissions, particularly in the electricity generation sector. During the COP27 conference which focused on global warming, Thailand announced its goal to achieve carbon neutrality by 2050 and net-zero carbon emissions by 2065. This transition necessitates a shift away from fuel-based electricity generation such as natural gas, oil, and coal towards renewable energy sources such as solar, wind, and hydropower.

As of 2022, Thailand's total installed electricity generation capacity is 57.22 GW, producing 182,000 GWh annually, with the total installed solar PV capacity is only 3.06 GW, approximately 5% of the total installed capacity. Solar PV generates only 5,000 GWh annually, equivalent to 2% of the total electricity production [1]. According to the Power Development Plan (PDP) of Thailand for the years 2018-2037 revision 1, the country aims to increase solar PV capacity to 8,740 MW by 2037. This plan outlines the targets and strategies for electricity generation and development over the specified period [2]. To achieve the PDP goals, an estimated area of 84 km^2 is required for solar PV power plant establishment, raising concern regarding the encroachment on agricultural land and potential impacts on local communities. Additionally, various land areas face technical challenges such as low solar radiation, far from main road, and regulation challenges including protected areas, forest areas, and city planning restrictions.

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The success of development is a complex problem. Key factors that influence site selection include solar radiation, land cost and closest to main road and transmission lines. Various tools including GIS and financial modeling are employed in site assessments to evaluate location suitability and ensure financial feasibility. Data for these analysis is sourced from various source including the solar radiation data from SolarGIS database, land cost information from the Treasury Department of Thailand, and roads locations form the Department of Highways of Thailand.

Solar radiation is a general term for the electromagnetic radiation emitted by the sun. Solar radiation data for electric systems are often represented as kilowatt-hours per square meter (kWh/m2/year) [3]. However, the data is derived from various databases employing collection methodologies. The Department of Alternative Energy Development and Efficiency (DEDE) calculates the monthly average daily solar radiation covering Thailand using ground-based and satellite data. The solar radiation map of Thailand is presented in Figure 1. Solar radiation databases is essential for performance assessments of solar PV power plant, with the annual average Global Horizontal Radiation (GHI) in Thailand estimated at 1,775.52 kWh/m2/year.

The SolarGIS is also provides a GHI map and summary of the estimated solar energy available, as presented in Figure 2 [4]. Luehong [5] analyzed the economic feasibility of the VSPP solar PV power plant utilizing the DEDE's solar radiation map. Ali [6] employed long-term daily average GHI data from the SolarGIS database with a spatial resolution of 1x1 km, covering the period from 2007 to 2015 in GeoTIFF raster (gridded) data format to identify the feasible sites. Jed [7] compared meteorological data from NASA's satellite and ground-based data considering 4 locations in Algeria and Mauritania, Six statistical parameters were applied, including MABE, RMSE, R^2, RRMSE, RPE, and MAPE. The results show that without measured data, NASA's estimated data can be used in solar energy projects to estimate solar potential in Algeria and Mauritania. Bawonda [8] conducted a similar comparison in Nigeria, evaluating ground-based data against satellite data.

Electricity output from solar PV systems, designated as PVOUT, is determined through simulation that requires a variety of data inputs. including GHI, tilted angle of PV modules, losses in equipment such as PV modules, inverters and cables, DC/AC transformer losses, and plant availability [4]. The PVOUT was used for investigating project feasibility during the planning phase and for selecting solar PV location [9].

The cost of land, which is influenced by factors such as the type of land ownership, directly impacts the Capital Expenditure (CapEx) of a solar PV project. In Thailand, the type of land ownership includes the Freehold Title Deed, the Nor Sor 3 Kor (NS3K), and other forms of documentation. Luehong [5] found that the suitable area has high solar energy potential and land costs would not exceed 480,293.25 THB per Rai, demonstrating the impact of land price on the overall project cost.

The distance from main road and existing transmission line impacts CapEx [6]. Janjai [10] recommended that project site should be located no more than 10-km from roads, existing electricity transmission line and substation. Selection of project locations which far away these infrastructures increases CapEx, particularly the costs of constructing transmission lines. Therefore, selection of project location can help to reduce these expenses.

2. Material and Method

2.1. Data collection

This study used secondary data from various sources, including PVOUT, land price, distance from main road, CapEx, OpEx, electricity price, and financial costs. Using the GIS technique for data with coordinates including PVOUT, land price and distance from main road were analyzed as spatial data in raster format (gridded). Data without coordinates, including CapEx, OpEx, electricity price, and financial costs, were used in the financial model constructed in Microsoft Excel. The proposed methodology is presented in Fig. 1.

2.1.1. Global horizontal radiation

The GHI data were obtained from SolarGIS for spatial data covering Thailand and DEDE for 38 stations including Bangkok, Kanchanaburi (Thong Pha Phum), Kanchanaburi (TMD), Lopburi, Lampang, Nakhonsawan, Phetchabun, Phitsanulok,

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Tak, Phrae, Nan, Prachuap Khiri Khan, Prachuap Khiri Khan (Hua Hin), Chiang Mai, Chiang Mai (Doi Inthanon), Mae Hong Son, Mae Hong Son (Mae Sariang District), Chiang Rai, Nakhon Ratchasima, Surin, Khon Kaen, Roi Et, Nong Khai, Nakhon Phanom, Loei, Prachin Buri, Trat, Chon Buri, Chumphon, Ranong, Surat Thani (Phunphin), Surat Thani (Samui), Phuket, Trang, Songkhla, Narathiwat, Sakaeo, and Ubon Ratchathani. This study will compare GHI from both sources to define the differences and errors between both databases using statistical performance indicators such as MBE, RMBE, RMSE, and RRMSE.

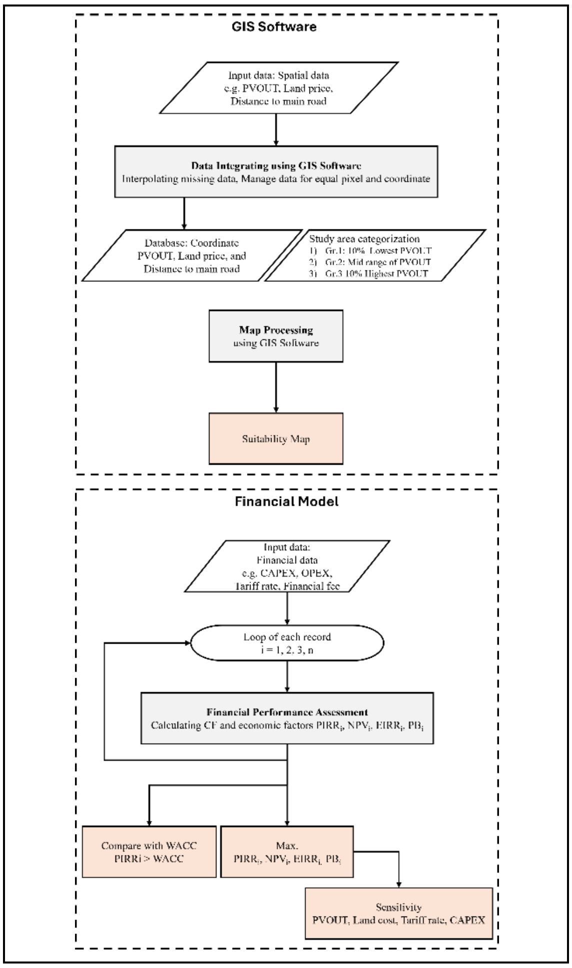

Fig. 1. Flowchart of the proposed methodology

2.1.2. Photovoltaic power output

PVOUT data had a spatial resolution of 1x1 km in raster format (gridded) and were measured in kWh/kWp/year. PVOUT was simulated using numerical models developed and implemented from the SolarGIS database. In this study, the term PVOUT was used for simplification rather than using the term GHI. The PVOUT data for the entire nation is presented in **Error! Reference source not found.**.

2.1.3. Land price

Data of land price were collected from the Treasury Department of Thailand. However, there were still several records that were either incomplete or unclear for the NS3K data set. Therefore, in this study, only the land prices for parcels whose ownership was “title deed” were used. The raw data did not specify coordinates, but we could locate the location using the identification number in the 1:4000 map sheets which could be related to the GIS system. The average land prices from the 1:4000 map sheet are shown in Fig. 3. Additionally, this study excluded the restricted areas.

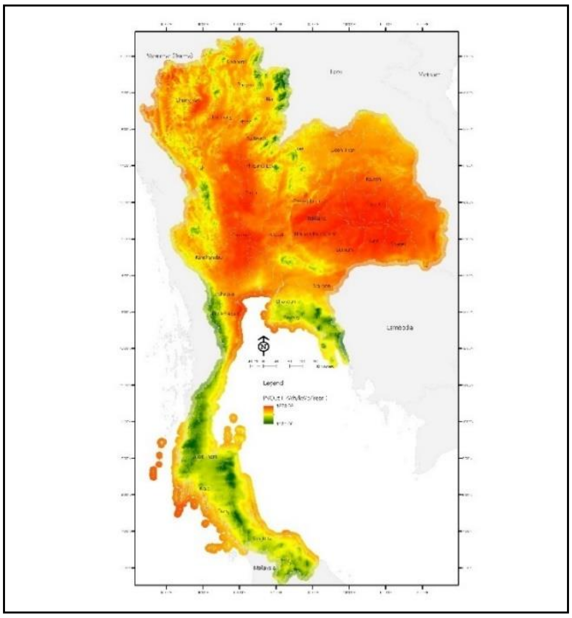

Fig. 2. PVOUT in Thailand from SolarGIS

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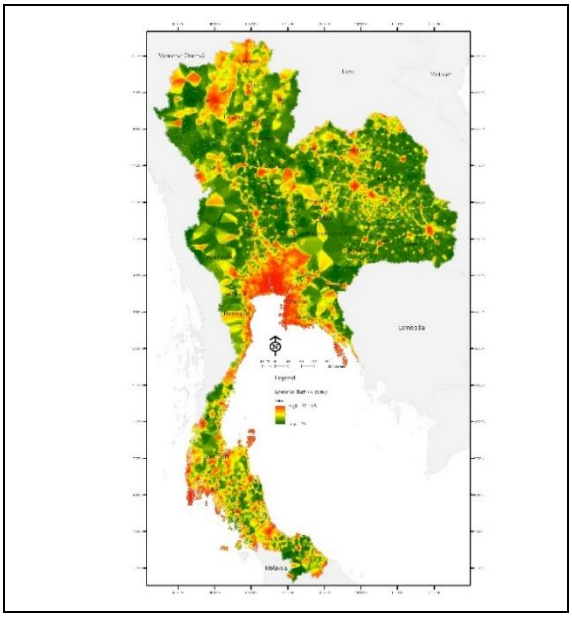

Fig. 3. Land price in Thailand

2.1.4. Distance from main road

Data of distance from main road were collected from the Department of Highways of Thailand using the distance from roads in raster format with the same resolution as the other data sets. The center of each pixel was used as a reference point and all units were measured in kilometers. The data are presented in Fig. 4.

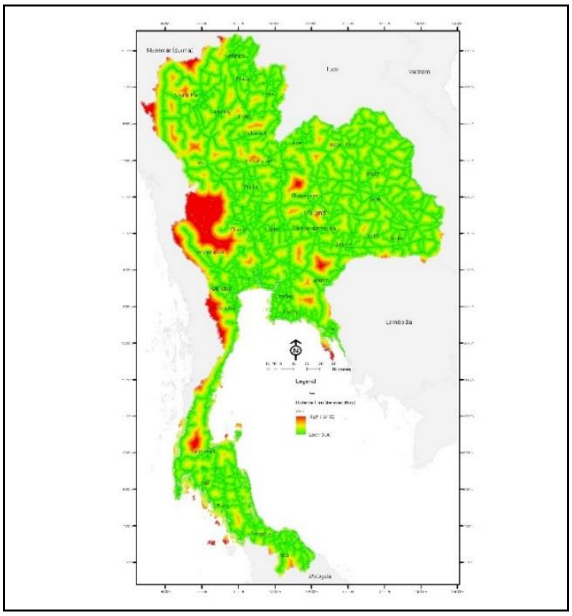

Fig. 4. Distance from main road network in Thailand

2.1.5. Capital expenditure

The CapEx for VSPP solar PV power plant includes turnkey PV systems price for VSPP solar PV power plant costs, turnkey transmission line costs for connecting the plant to the grid, Environmental Impact Assessment (EIA) and permitting costs, project development costs to address environmental concerns and regulatory approvals, and contingency costs. For simplicity, main CapEX referred to the turnkey PV systems price from DEDE as presented in Table 1.

2.1.6. Operational cost

The OpEx is considered to exclude the salary of employees since the employees working on solar projects can be shared services within the same company.

Table 1. Turnkey PV system price in Thailand

Type	Prices (THB/MW)
Average the turnkey PV systems price for VSPP solar power plant	22,594,200.00

2.2. Land suitability analysis using GIS

Data type and resolution of PVOUT, land price and distance from main road as presented in Table 2 are shown. QGIS was chosen as the GIS software for this study. The initial data input for the analysis was in raster data format (gridded). Some data might be errored and missing. The Inverse Distance Weight technique was used to interpolate any missing data to minimize data gaps. Also, due to the mismatched pixel formats, sizes, and positions of each data set, the three data sets were converted into vector format (polygon) with multi-valued attributes in a single dataset. Then, the centroid of each polygon was determined to map with each other.

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2.3. Financial performance assessment using financial modeling

A financial model was developed using Microsoft Excel VBA Programming. The key financial parameters were the NPV, the PIRR, the EIRR and the SPB. The estimations of model parameters were based on 2 type of assumptions regarding PVOUT, land cost, distance from main road as presented in Table 3, and unit cost of CapEx, OpEx, electricity price, financial costs, and annual escalation are summarized presented in Table 4.

2.3.1. Capital expenditure

The total CapEx for the VSPP solar PV power plant project could be accurately calculated as presented in Table 5, providing a solid foundation for further financial analysis.

Table 2. Summary of key data for GIS tools utilized in the feasibility study and land suitability analysis for investment in VSPP solar PV power plants

Data	Format/ Resolution	Source
PVOUT	Raster 1 x 1 km	SolarGIS
Land price	Raster 2 x 2 km	Treasury Department
Distance from road	Raster 2 x 2 km	Department of highway

Table 3. Dataset Structure

Dataset Structure	Unit
Latitude	Coordinate
Longitude	Coordinate
PVOUT	kWh/kWp/year
Land price	THB/Rai
Distance from road	km

Table 4. Key Financial Data for the Financial Model

Description	Amount	Ref.
Installed Capacity	8.00 MW	[11]
Contract PPA	25 Years	[12]
Electricity price	2.17 THB/kWh	[12]
Required area	48.00 Rai	-
CapEx		
Turnkey PV system price	22.594 THB/MW	[13]
Turnkey transmission line	4,700 THB/m	-
Project development cost	3.00%	[14]
Contingency	0.5%	[14]
OpEx		
O&M cost	449,000 THB/MW	[15]
Escalation	1.54%	[16]
Financial cost		
Tenor	12 Year	[14]
Debt	70.00%	[15]
Equity	30.00%	[15]
Interest rate as of 07/06/24	7.67%	[17]
Tax rate	20.00%	[18]
BOI - without corporate tax	8 Year	[19]
Depreciation	25 Year	-

Table 5. Estimate project cost excludes land and transmission cost

Description	Amount
Turnkey PV system price	162,354,240 THB
Project Development Cost	5,449,661 THB
Contingency	5,589,740 THB
VAT	13,488,634 THB
Total CapEx	186,882,275 THB

2.3.2. Free cash flow

The Free Cash Flow to the Firm (FCFF) and Free Cash Flow to Equity (FCFE) are presented as the net cash generated and accounting for cash inflows and outflows. The key components included CapEx, annual revenue, OpEx, depreciation, debt interest, and debt repayment taxes.

$$FCFF = EBIT \times (1 - Tax\ rate) + NWC + Depraciation - CapEx$$

2.3.3. Net present value

The NPV is presented as the value of all cash inflow and all outflow over a period.

$$NPV = \sum_{t=0}^{T} \frac{FCFF_t}{(1 + WACC)^t} - FCFF_0$$

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2.3.4. Internal rate of return

The IRR is another term for the discount rate. It can make NPV of project equal to zero.

$$0 = \sum_{t=0}^{T} \frac{FCFF_t}{(1+r)^t}$$

2.3.5. Simple Payback period

The SPB is the time period required for profitability of the project.

$$SPB = \frac{Investment}{Net\ annual\ cash\ flow}$$

2.3.6. Weighted average of capital

The weighted average cost of capital (WACC) represents a firm's average after-tax cost of capital from all sources. The estimated parameters are presented in Table 6.

$$WACC = W_d \times K_d \times (1 - Tax\ rate) + W_d \times K_e$$

where, Wd are the percentage of capital that is debt
We are the percentage of capital that is equity, using the Capital Asset Pricing Model
Kd are the debt interest, which is equal to 7.67% (data as of 30 May 2024)
Ke are the tcost of equity

2.3.7. Sensitivity analysis

The sensitivity analysis was based on assumptions such as PVOUT, land cost, electricity price, and construction cost which would be calculated to assess the impact of the assumption.

Table 6. Weighted Average Cost of Capital

Description	Value
Beta	1.41
Tax rate	20%
Debt ratio	70%
Equity ratio	30%
Ke	14.67%
Kd	7.67%
WACC	8.70%

2.3.8. Limitation.

The limitations of this study were the availability and accuracy of secondary data sources such as solar irradiance data. Additionally, assumptions made in the financial model may only partially capture future uncertainty. The study did not include the consideration of secondary road areas, elevation, land slope, canals, railway tracks, reserved forests, and land-use restrictions according to Thai law.

3. Results and Discussion

3.1. Data validation

This study investigated solar radiation using data from the SolarGIS database. It was found that the average GHI was in the range between 1,432.87 – 1,940.48 kWh/m²/year. The average GHI over the country from the satellite database was 1,798.25 kWh/m²/year. The SolarGIS database was validated with ground station data from DEDE of Thailand, as presented in Table 7. It was found that the distribution of monthly average GHI is in the range of 1,585.57 – 1,920.47 kWh/m²/year and averaged GHI over the whole area of the country, the average value is found to be 1,775.52 kWh/m²/year.

Table 7. Comparison of yearly average GHI database

Description	Energy per Area (kWh/m²/year)	%
MBE	117.62	6.64%
RSME	156.20	0.45%

The comparison results show that the average MBE is calculated to be 6.64% and the average RMSE is calculated to be 0.45%. therefore, SolarGIS database is sufficiently accurate for this study. This study used PVOUT for simplification and substituted GHI data. the SolarGIS database was utilized to estimate the PVOUT as presented in Table 8.

Table 8. Relationship between GHI and PVOUT of SolarGIS

Database	Value
GHI	1,432.87 – 1940.48 kWh/m²/year
PVOUT	1,184.87 - 1,576.05 kWh/kWp/year

3.2. Data integration using GIS software

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The studied areas were selected based on the PVOUT and land cost as presented in Fig. 5. and Table 9. Three groups have been selected to investigate the feasibility of investing in a VSPP solar PV power plant. Group 1 (lowest 10% of energy production area) represented the challenges of low energy areas. Group 2 (middle range of energy production areas) represented typical performance and average land cost scenarios. Group 3 (highest 10% of energy production area) represented high efficiency and high economy. This study constructed a financial analysis of each group.

3.3. Financial performance assessment and comparison

The three groups were chosen as case studies to determine the feasibility of investing in VSPP solar PV power plant. Key driven parameters include PVOUT, land price and distance from main road of each location. This study focused on the financial performance assessment by using financial indicators including PIRR, EIRR, PNPV, SPB, and as presented in Table 10 and Table 11. It was found that Group 1 could not achieve the expected return even in the maximum financial performance location. The maximum PIRR was 8.12% and NPV was negative (WACC = 8.70%). Therefore, projects with low energy output, low land price, and no cost of transmission line were not feasible to invest. Group 2 could achieve the expected return in the maximum financial performance location. The maximum PIRR was 8.98% and NPV was positive. Therefore, projects with moderate energy output could purchase the land with the maximum price at 10,148 THB per Rai, but the project should not have the cost of transmission lines. Additionally, Group 2 projects can purchase land up to 235,216.00 THB per Rai, maintaining a PIRR equal to WACC. Group 3 could achieve the expected return in the maximum financial performance location. The maximum PIRR was 9.75% and NPV was positive. Therefore, projects with high energy output can purchase land with maximum price of 73,988 THB per Rai. Similarly, the project should not have cost of transmission lines. Group 3 projects can purchase land up to 356,800.00 THB per Rai, maintaining a PIRR equal to WACC.

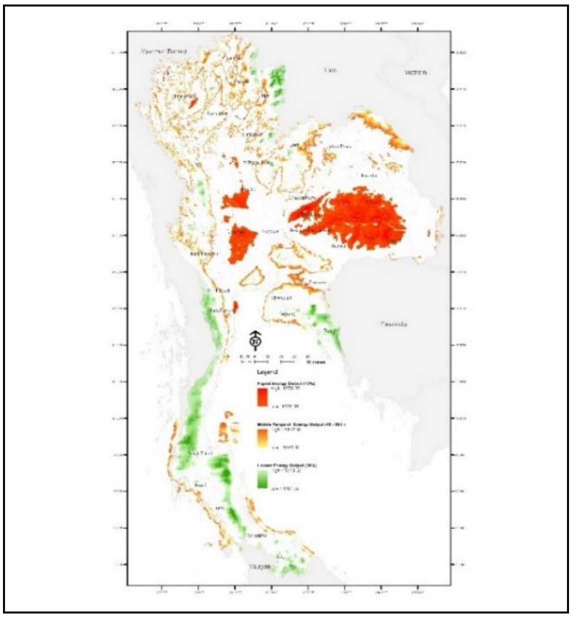

Fig. 5. Study area classified by PVOUT

Table 9. PVOUT and land price of study area

Range of PVOUT (kWh/kWp)	Range of Land Price (THB/rai)	Study area (km²)
Group 1 (10% lowest energy output)		
1,184 -1,393	27,468 - 4,382,524	62,383
Group 2 (Middle range of energy output)		
1,458- 1,472	10,016 - 13,989,732	49,804
Group 3 (10% highest energy output)		
1,537- 1,576	32,848 - 6,383,984	41,087

Table 10. Best financial performance

Indicator	Value
Group 1 (10% lowest energy output)	
PIRR	8.12%
EIRR	8.46%
NPV	- 8,377,378.77 THB
SPB (Year)	10.67
Land price (THB/Rai)	34,720.00
Group 2 (Middle range of energy output)	
PIRR (%)	8.98%
EIRR (%)	10.04%
NPV (THB)	4,295,948.49
SPB (Year)	9.88
Land price (THB/Rai)	10,148.00
Group 3 (10% highest energy output)	

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Indicator	Value
PIRR (%)	9.75%
EIRR (%)	11.50%
NPV (THB)	15,997,541.83
SPB (Year)	9.25
Land price (THB/Rai)	73,988.00

Table 11. Maximum land price able to purchase

Indicator	Value
Group 1 (10% lowest energy output)	
PIRR (%)	Not feasible
EIRR (%)	
NPV (THB)	
SPB (Year)	
Land price (THB/Rai)	
Group 2 (Middle range of energy output)	
PIRR (%)	8.70%
EIRR (%)	9.96%
NPV (THB)	110,430.00
SPB (Year)	10.12
Land price (THB/Rai)	235,216.00
Group 3 (10% highest energy output)	
PIRR (%)	8.70%
EIRR (%)	9.51%
NPV (THB)	130,710.20
SPB (Year)	10.13
Land price (THB/Rai)	356,800.00

3.4. Land suitability analysis

The land suitability for each group was assessed using GIS software. Key parameters considered were PVOUT area and financial indicators, including PIRR and WACC. The suitable area for the three groups are detailed in Fig. 6 and Table 12. The analysis reveals that the most suitable land for investment in VSPP solar PV power plants is located in areas with the highest PVOUT values (Group 3), with a total suitable area of 13,880 km² (33.78% of the group area). These areas offer the most promising financial returns, making them highly suitable for investment. Group 2 also presents potential opportunities, with a suitable area of 1,080 km² (2.17% of the group area). Conversely, Group 1 areas are deemed unsuitable for investment due to poor financial performance. The suitable area for Group 2 and 3 was presented in Fig. 6.

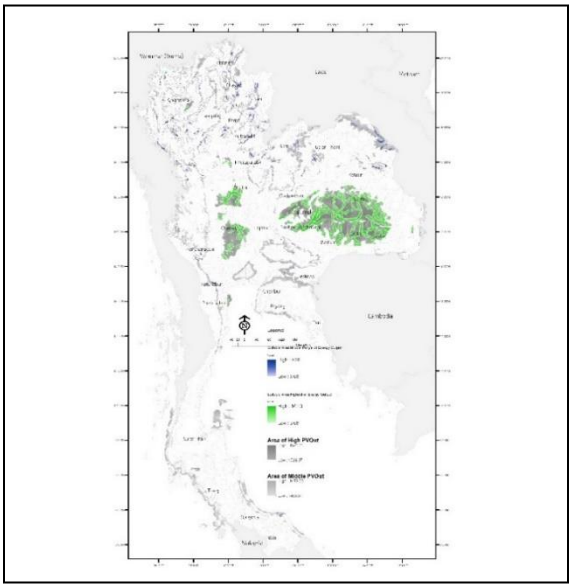

Fig. 6. Suitable map

Table 12. Suitable Area

Studied Area	Area (km²)	Suitable Area	Percentage of Suitable Area (%)
Group 1 (10% lowest energy output)			
	62,383	0	0.00%
Group 2 (Middle range of energy output			
	49,804	1,080	2.17%
Group 3 (10% highest energy output)			
	41,087	13,880	33.78%

3.5. Discussion

This study is set assumption of solar technology, financial cost and other incentive based on current and fixed tariff according to the purchase of electricity from renewable energy sources under a Feed-in-Tariff (FiT) scheme by Government, However, market conditions, policy changes, and solar technology may significantly impact financial performance over time.

4. Conclusions

The study assessed the financial feasibility and land suitability for investment in VSPP solar plant in Thailand using Geographic Information System (GIS) and financial modelling techniques. This methodology helps to identify area and location for investment in VSPP solar power plant while financial modelling shown the key financial

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indicators such as NPV, IRR and SPB which provide that feasibility of investment.

The results demonstrate that several areas in Thailand is high suitability for VSPP solar power plant investment and offer good financial performance which have 90,891 km² (Group 2 and 3) achieve WACC.

However, these results based solely on technical and financial assessment without a consideration of secondary road areas, elevation, land slope, canals, railway tracks, reserved forests, and land-use restrictions according to Thai law. Future research could enhance the framework by incorporating further data. as well as expanding the analysis to other renewable generation technology.

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