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Research Article

Potential sections for the development of solar energy using remote sensing data and GIS in Dak Nong Province, Viet Nam

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Abstract: For promoting the development of renewable energy in Vietnam, in 2015 the Government approved the "Strategy for the development of renewable energy in Vietnam to 2030, with a vision to 2050" intending to gradually increase the proportion of renewable energy in national energy production and reduce dependence on fossil energy sources, contribute to ensuring energy security, mitigating climate change, and sustainable socio–economic development. In recent decades, remote sensing and Geography information of system (GIS) have been able to build thematic maps with high accuracy for managing and monitoring natural resources and the environment, including the solar radiation potential. Establishing solar potential maps from satellite data combined with natural conditions, topography, and land cover will effectively assist in planning solar energy development while helping to identify the appropriate technology and lowest cost. Therefore, this paper presents the zonalization of the solar energy potential based on its calculations from Himawari–8 satellite and elevation from The Shuttle Radar Topography Mission data applied for Dak Nong province. The results show that only about 18% of land in Dak Nong province is suitable for solar energy development. The appropiate sites for the development of solar energy are distributed in different regions of the Dak Nong province.

Keywords: Surface solar irradiation; Himawari–8 Satellite; K–mean cluster, zonalization.

1. Introduction

Vietnam has a vast potential for solar resources that could be tapped for solar energy development using solar photovoltaic (PV) and solar thermal (ST) applications for the hot water, commercial heat and industrial generation. Current scientific estimates of total solar resources in Vietnam give an average of 4–5 kWh/m^2/day in most parts of southern, central and even partly northern Vietnam (total 1,460–1,825 kWh/m^2/year) and an average maximum irradiance of up to 5.5 kWh/m^2/day in some southern regions (total up to 2,000 kWh/m^2/year [1–2]. The rapid growth in electricity demand is challenging Vietnam's energy sector and green growth strategy. In response to this, the Government of Viet Nam has prioritized a development of the renewable energy in the National Power Development Plan VII with a share about 6% of the total energy production by 2030. In detail, the solar power was expected to reach 850 MW (0.5%) by 2020, about 4,000 MW (1.6%) in 2025 and about 12,000 MW (3.3%) by 2030 [3]. A report implemented by Vietnam Electricity (EVN) shows a rapid development of the renewable energy in Viet Nam (Figure 1).

In order to enhance this rapid development of the renewable energy, it is urgent to study, evaluate, and regionalize its potential for every energy source, including the irrandicance energy. However, the barriers to solar energy development are production costs, policies, database information for planning and policy; technology, and ancillary services [4]. Which, there are three difficulties related to planning issues: 1) Lack of reliable assessments of potential renewable energy sources; 2) lack of terrestrial data series with appropriate distribution for trend and reliability studies; 3) limited understanding of the variability and relationships of renewable energy potential with other variables such as climate, topography, and human impact on the environment [5].

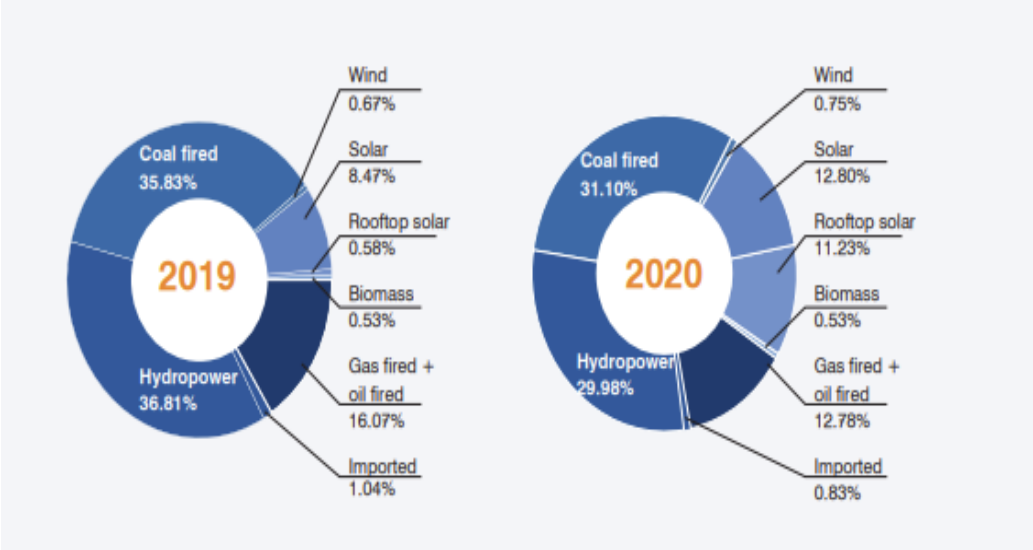

Figure 1. Renewable Energy Productivity Growth 2019–2020 by Vietnam Electricity [25].

Solar energy estimation using satellite data has been studied and applied very early in countries such as the USA, EURO, Brazil, China, Iran, India, and Vietnam [5–8]. With outstanding advantages in terms of coverage, spatial resolution, and monitoring frequency, satellite data has become a useful alternative for large–scale extraction of surface radiant energy parameters, especially for areas without hourly frequency measurement stations [9]. The satellites commonly used for irradiance calculations are Geostationary Satellites like MGS (Meteosat Second Generation) – SEVIRI, GOES-USA, INSAT-India, FY-2-China, and MTSAT/ Himawari-8 (Japan). Vietnam is in the best coverage of satellites GMS/Himawari-8 (Japan), Elecktro–Russia, and FY-2 (China). However, from 1997 until now, Vietnam's Ministry of Natural Resources and Environment has only collected Himawari–8 data for weather forecasting. Therefore, this study also used this data to estimate the value of solar energy in Vietnam

The concept of zoning is quite broad, including natural geographic zoning, landscape geography, ecological zoning, climatic zoning, economic zoning, and cultural zoning. However, the principle of zoning is to divide the territory into regions with similar and homogenous characteristics. From there, serving the planning for each object or the overall development [10–15]. The objective of radiation zoning is a combination of radiation characteristics and many other factors such as topography, land use, etc. to study zoning for the development of solar energy [16]. For example, the study [17] presented the development zoning for solar power plants with a capacity of 1MWe or more over Vietnam. The research [7] has also performed solar energy potential zoning for the solar power plant using terrestrial PV technology with a capacity of more than 1MWe. However, there has been no research on solar zoning at the provincial level. Therefore, this study implements zoning of the solar potential for Dak Nong province, contributing to the formulation of a solar energy development strategy in the Dak Nong province.

2. Data and Methodology

2.1. Data

Solar radiation data: The Himawari 8 satellite was launched in 2014 and became commissioned by the Japan Meteorological Agency (JMA) in July 2015. The Himawari–8 features the new 16–band Advanced Himawari Imange (AHI), covering visible, shortware–IR and thermal–IR spectra. A high–speed algorithm to estimate solar radiation using HIMAWARI–8/AHI data was developed by the Oceanic and Atmospheric Research Institute (AORI) of Japan. The goal of satellite–based irradiance estimation models is to use information about irradiance at the top of the atmosphere and albedo to calculate total Global horizontal irradiance (GHI) and Direct Normal Irradiation (DNI). In this study, we used the GHI data as detaily described in our previous publications [18–19] for radiation potential zoning in Dak Nong province, and the average GHI value is calculated from data of three years from 2016 to 2019.

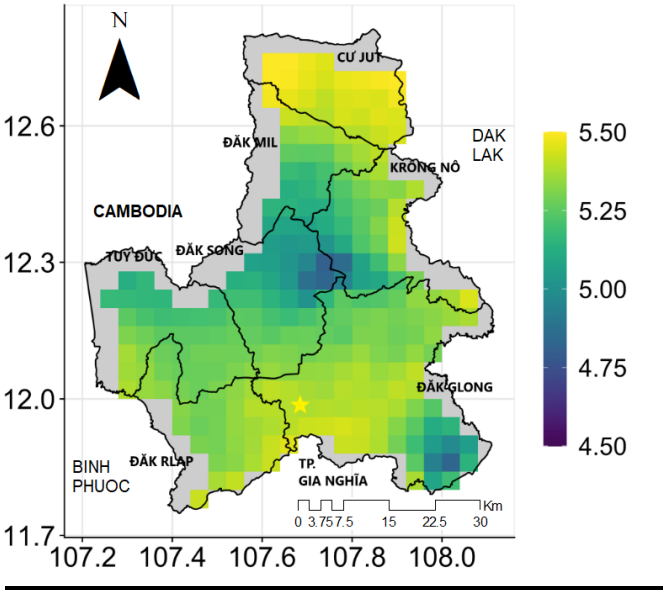

Figure 2. Average surface radiation in the period 2016–2018 in Dak Nong province (kWh/m^2/day).

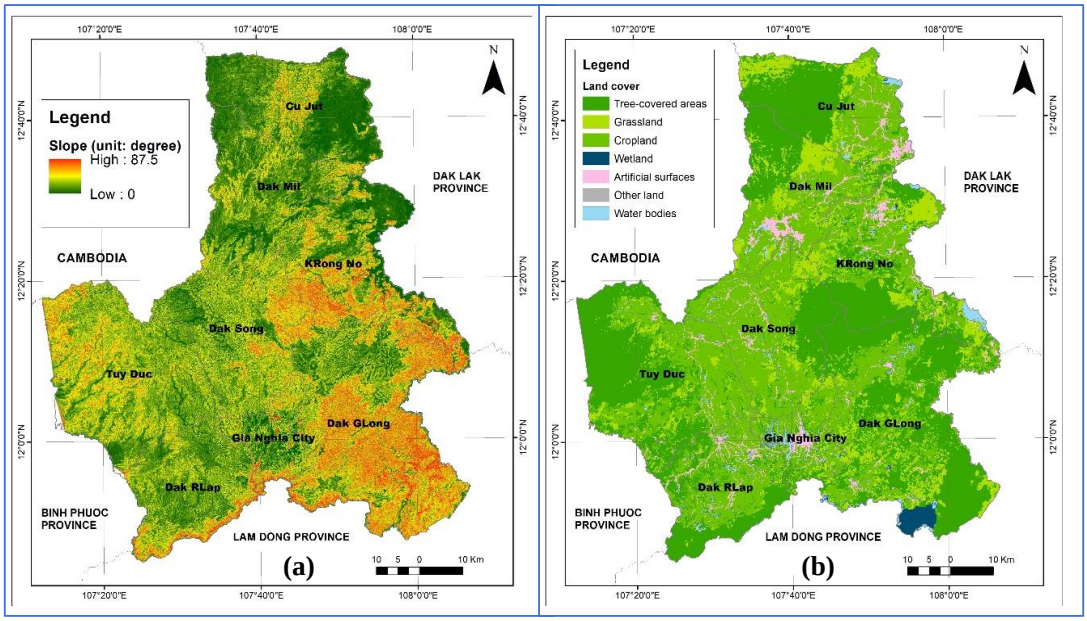

Figure 3. The slope map of Dak Nong province is built from DEM–SRTM30M; Land cover map in Dak Nong province.

Digital elevation model and slope: DEM–Digital Elevation Model of Dak Nong province is the 30meter resolution SRTM (The Shuttle Radar Topography Mission). This data is avaiable on the USGS Earth Explore and from the site: https://gisgeography.com/free-global-dem-data-sources/ (Figure 3a).

Land–use and land cover data: Land use data for 2014 of Dak Nong province (Figure 3b) was collected from the Department of Natural Resources and Environment of Dak Nong province. This study uses Sentinel–2 satellite data in 2019 to update the landcover in Dak Nong.

2.2. Methodology

The GIS technology has been widely used to integrate spatial data analysis and mapping to assess solar energy potential in the world. We also applied the GIS technique for solar energy potential zoning in this study for Dak Nong province and the process consists of 6 following steps:

Step 1: Data collection.

Step 2: Estimation of GHI using

Step 3: Updating and classifying land use 2019.

Step 4: Classification of slope criteria, suitable land use for PV power development

Step 5: Theoretical Potential Mapping: Partition of GHI data using K–means algorithm.

This method has also been presented in our previous studies [18, 23]. The K–means clustering algorithm belongs to the class of unsupervised learning methods (Machine Learning) that groups the unlabeled data set into different clusters. Firstly, it determines the best value for K centers or centroids through an iterative process.

Then, it assigns each data points its nearest k center data points close to the respective center k form a cluster. Therefore, each cluster has data points with some similarities and is separate from the othe clusters. Figure 4 explains how the K-mean clustering algorithm works:

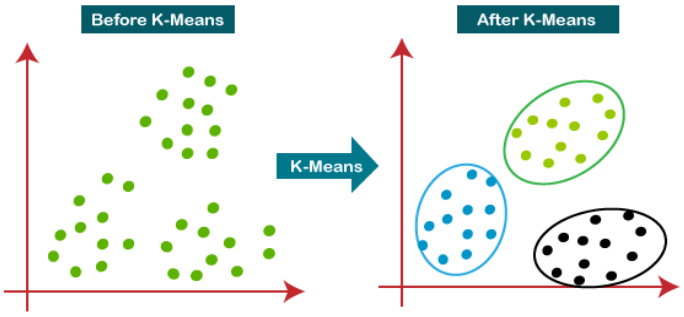

Figure 4. The diagram of the K–mean clustering algorithm.

A diagram of the K–means algorithm used in the study is presented in Figure 5.

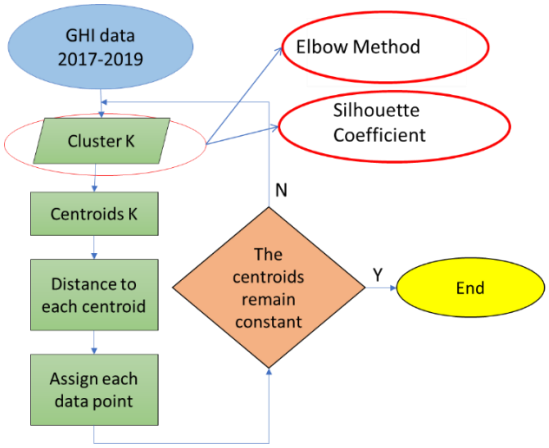

Figure 5. The Diagram of the K–means algorithm for GHI data.

Step 6: Mapping geographic potential using multi–criteria spatial analysis method by combining zoning results with groups of geographical criteria (land use, topography) that promote or limit the development of solar energy.

3. Results and Discussion

The results obtained from the GHI solar irradiance zoning by the K–means method show that for the GHI surface radiation annual process in Dak Nong area, the division into 4 clusters is reasonable. This is shown by the similarity in the results of both Elbow method and Silhouette coefficient. Therefore, in this study, the number of "optimal" clusters selected is 4. Figure 6 below shows the results of GHI zoning in Dak Nong province and Table 1 shows the solar radiation characteristics by months and years of the clusters.

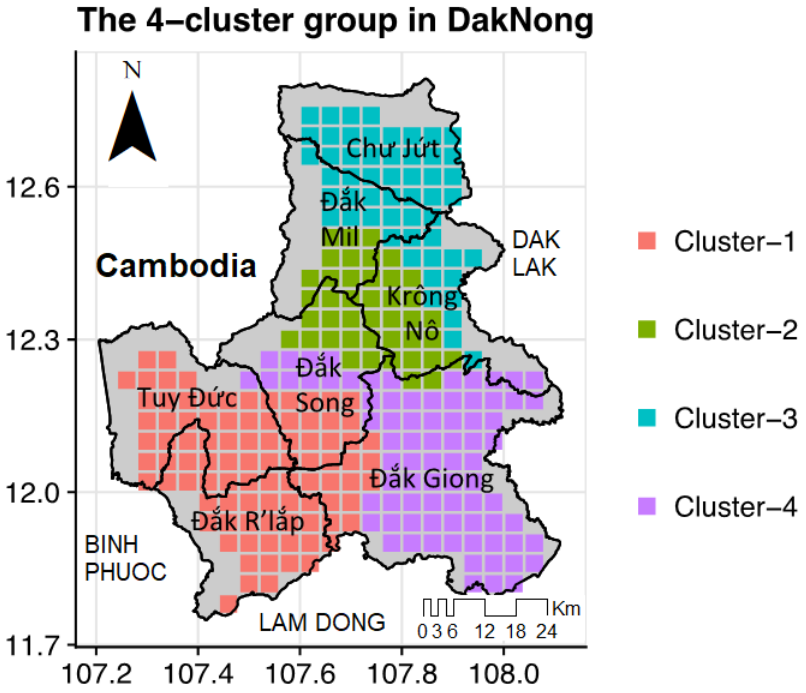

Figure 6. Radiation zoning in Dak Nong province.

In general, the radiation shows the maximum in March and the minimum in December. For cluster 1, cluster 3, and cluster 4, the annual radiation process has 2 peaks with the maximum being in March and the sub–max in September and 2 times being the minimum. Particularly for cluster 2, during the period from June to September, the average monthly radiation volume is almost unchanged. Compared with the average annual radiation value of the whole province, the months with significantly lower average radiation amounts are July–August in cluster 1 and cluster 4; November–December in all 4 clusters, and January in clusters 2 and 3. Months with significantly higher mean radiation values are from February to May (in clusters 1, 3, and 4), and from March to May (in clusters 2). The period with a large amount of radiation usually falls in the dry period before the rainy season begins in the Central Highlands.

Table 1. Average radiation value by month ($kW/m^{-2}day^{-1}$).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Cluster–1	5.18	6.20	6.58	6.31	5.67	5.05	4.62	4.63	5.15	5.07	4.83	4.36	5.30
Cluster–2	4.22	5.31	6.78	6.32	5.57	5.15	5.11	5.14	5.29	4.86	3.97	3.21	5.09
Cluster–3	4.64	5.67	6.96	6.57	6.08	5.37	5.43	5.44	5.59	5.07	4.29	3.60	5.39
Cluster–4	5.04	6.08	6.83	6.33	5.72	5.05	4.64	4.69	5.25	5.00	4.57	4.04	5.27

The geographic potential is a combination of geographical criteria such as land use and topography. The criteria of land use and topography are only to exclude areas that are not allowed or cannot develop Solar Energy according to the following criteria:

Topographic standard: Considering the slope criteria suitable for solar PV development as studied [17, 24] are below 15^o. For terrain elevation, the solar development standard is lower than 2000 m. Therefore, this study uses an area that encourages solar development with an altitude below 2000 m and a slope lower than 15^o (Figure 7a). The optimal slope direction for solar PV development is the South direction and is flat, so the aspect for solar PV development in Dak Nong is where the aspect is < 1^o and from 112.5^o (southeast) to 292.5^o (west) (Figure 7b).

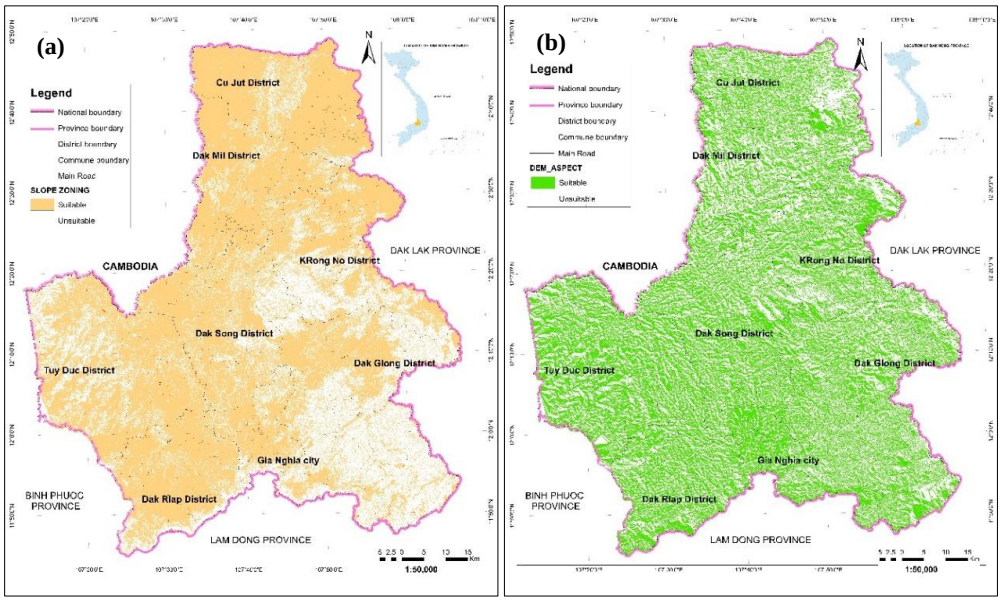

Figure 7. (a) Elevation and slope zoning (Orange is the promotion zone and white is the unsuitable zone for Solar PV Development); (b) The Aspect zoning (Green is the promotion zone and white is the unsuitable zone for Solar PV Development.

Land–use standard: Figure 8 and Table 2 lists the types of land use suitable for solar power development in Dak Nong province. Including 31 types of land use suitable for solar energy development with a total area of 158,528.21 ha, equivalent to 22.9% of the province's area.

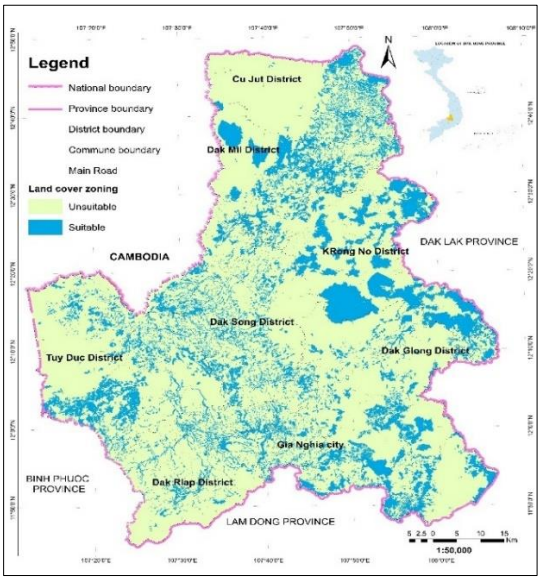

Figure 8. Land cover zoning (blue is the promotion zone and green is the unsuitable zone for Solar PV Development.

Table 2. Lists of types of Land use suitable for solar power in Dak Nong province.

Code	Land use type	Area (ha)
BCS	Unused flat land	51.05
CAN	Security land	1,213.09
CDG	Specialized land	779.88
CQP	Defense land	2.885.65
DBV	Land for post and telecommunications works	6.82
DCH	Market land	33.36
DCK	Land for other public works	1.55
DCS	Unused hilly land	18,065.93
DDT	Land with historical and cultural relics	17.56
DGD	Land for construction of educational and training institutions	412.92
DNL	Land for energy works	8,344.65
DRA	Land for landfill, waste treatment	45.40
DSH	Land for community activities	49.31
DTS	Land for construction of headquarters of non–business organizations	31.86
DTT	Land for construction of sports facilities	83.13
DVH	Land for construction of cultural facilities	32.39
DXH	Land for construction of social service establishments	7.39
DYT	Land for construction of medical facilities	70.64
NHK	Upland land for planting other annual crops	104,671.34
NKH	Other agricultural land	108.38
ODT	Land in urban areas	2,115.60
ODT+CLN	Land in urban areas + Land for perennial crops	553.30
ONT	Land in countryside	15,730.46
ONT+CLN	Land in countryside + Land for perennial crops	2,240.67
ONT+NHK	Land in countryside + Upland land for planting other annual crops	57.19
PNK	Other non–agricultural land	235.96
SKC	Land for non–agricultural production facilities	6.71
SKS	Land used for mineral activities	385.49
TIN	Land of faith	0.87
TMD	Commercial and service land	15.65
TON	Land for religious facilities	130.51
TSC	Land to build office headquarters	197.50

The zoning result is an integration of the criteria of solar irradiance and geographical criteria (slope and land use) using GIS tools. Thus, the zoning results show that Dak Nong province is divided into four potential solar energy zones, with average radiation values ranging from 5.09 to 5.39 kW/m^2/day. The selection of numerical partition value ranges is to help users use solar radiation data in choosing solar power technologies suitable for use purposes (Figure 9). The detailed results of the area suitable for solar energy development in Dak Nong province are presented in Table 3 and Figure 10.

Table 3. The area suitable for solar power by districts in Dak Nong province.

Name of Districts	Unsuitable	Under 5.09 kM/m^2/day	5.09–5.27 kM/m^{2}2/day	5.27–5.30 kM/m^2/day	5.30 –5.39 kM/m^2/day
Cu Jut Dist.	59905.67	0.00	0.00	**11659.70**	0.00
Dak Mil Dist.	55824.77	0.00	3781.53	**7610.32**	0.00
Krong No Dist.	67295.40	0.00	5357.16	**7027.33**	1780.47
Dak Song Dist.	74102.14	2111.35	1685.93	0.00	2741.61
Gia Nghia City	24217.52	3750.01	0.00	0.00	252.10
Dak Rlap Dist.	57400.41	6018.93	0.00	0.00	0.00
Tuy Duc Dist.	98839.62	**11454.87**	0.00	0.00	393.91
Dak Glong Dist	133661.17	299.37	47.27	0.00	**10541.00**
Total Area	**571246.70**	**23634.53**	**10871.89**	**26297.36**	**15709.09**

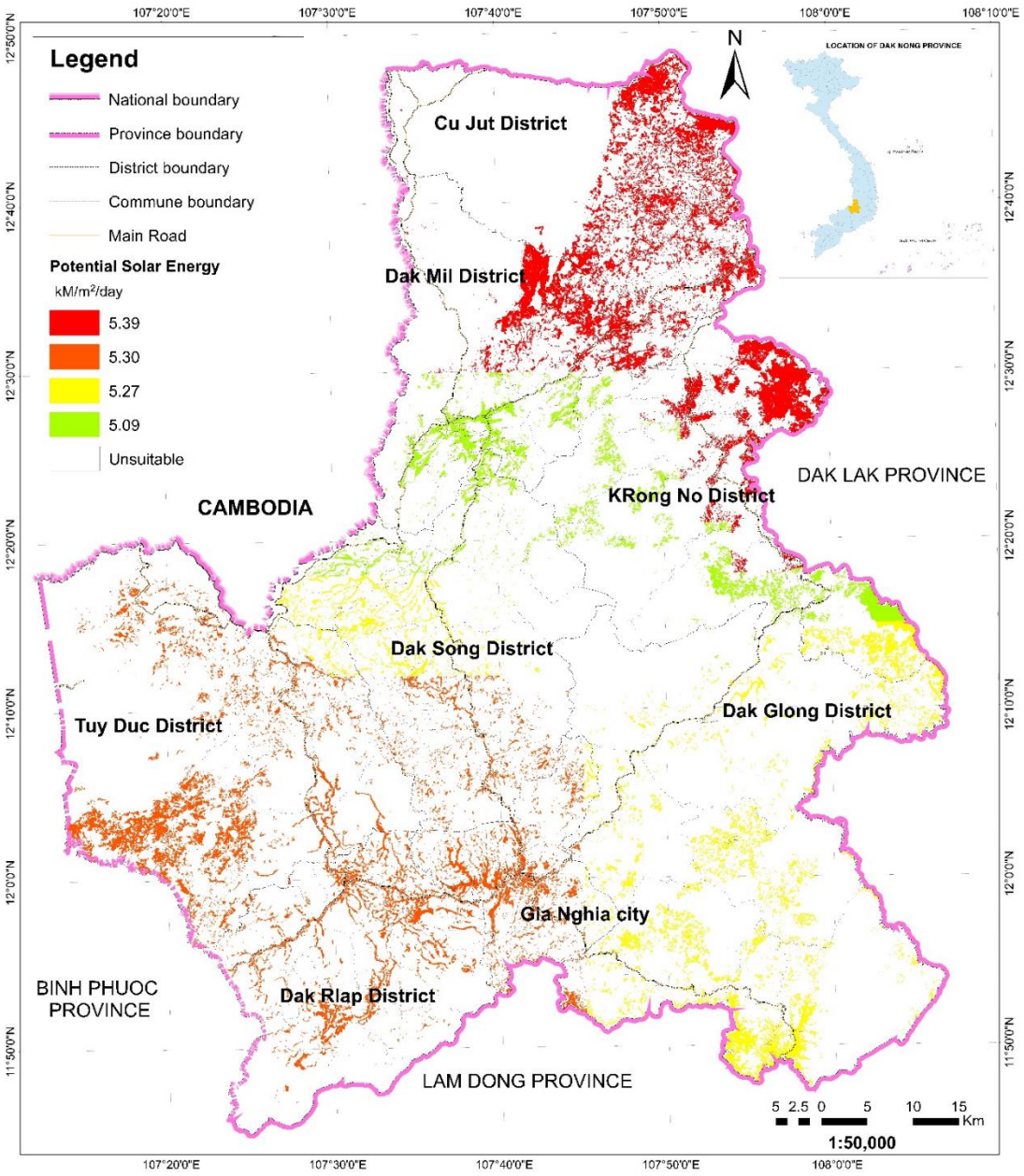

Figure 9. Map of potential zoning for solar energy development.

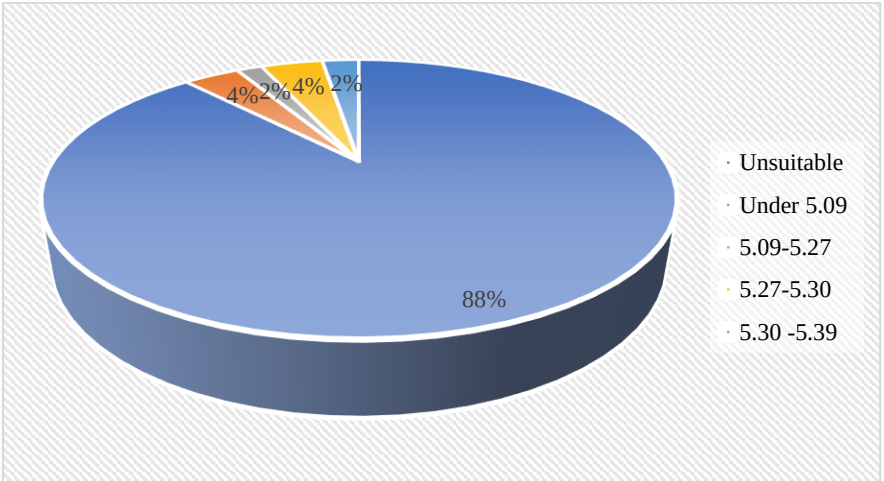

Figure 10. The ratio of the area suitable for developing solar energy (Unit: kM/m^2/day).

The results show that only about 18 percent of the entire area of Dak Nong province is suitable for solar power development. Distributed in different areas of the province. Solar energy development potential is highest in the northeast of Dak Nong province in Cu Jut district (total suitable area is 11.659 ha), then in some southwestern areas of the province in Tuy Duc district is 11.454 ha, and Dak GLong district is 10.541 ha.

4. Conclusions

This study has provided a scientific basis for potential zoning for solar energy development planning in Vietnam, applied as a pilot for Dak Nong province. The theoretical potential is partitioned by the k-means clustering method, then the geographic potential is the combination of zoning results with criteria to exclude areas that are not suitable for solar PV development. The standard land use thresholds and slope criteria are used as the basis for excluding areas that are not permitted or unsuiable for solar PV development.

Remote sensing data and and GIS are useful for site assessment in zoning mapping for the solar energy development in Dak Nong province, determining specific thresholds for each criterion. We used the 3-year average of solar radiance from the Himawari-8 estimation and the K-means method for clustering. The results of clustering solar radiation in Dak Nong province are divided into 4 clusters. The land use map in 2014 year in Dak Nong province has been updated with satellite images from 2014 to 2020. The types of land use that are considered unsuitable for development solar energy are rice, land for growing perennial trees and forest. The total area suitable for the development of solar energy potential in Dak Nong province is 76.512 ha, which accounts for 18% of the total area of the province.

In this study, disaster risk and future climate factors, and the opinions of users such as planners, politicians and engineers have not been clarified. Nevertheless, the constructed map of solar energy potential zonalization is likely a useful information for development planning of solar power and similar maps are possibly developed for other provinces to assisst solar potential zoning in the future.

Author contribution statement: Conceived and designed the study: P.T.T.N.; Selection of research methods: P.T.T.N., N.T.C.; Analyzed and interpreted the data; analysis tools and mapping: P.T.T.N., N.T.C., D.T.T.; wrote the manuscript: P.T.T.N., D.T.T.

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