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Original Article

Research Method for Assessing the Potential of Solar Energy Source: Case Study in Thanh Hoa Province

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Abstract: This research uses the GHI (Global Horizontal Irradiation Index) raster data source of solar radiation potential map developed by The World Bank Group and the land use map data, infrastructure in 2019 of Thanh Hoa province to calculate the solar radiation technical potential in Thanh Hoa province. In addition, GIS techniques are also applied to overlay thematic maps to determine the available solar energy development area according to the method of the Institute of Energy. The results show that the available solar energy development area is 54,621.15 ha, accounting for 5% of the province's natural area, the technical potential is 21,848.46 MWp. The well-developed regions are concentrated in the lowland and midland districts due to favorable conditions of land scale and infrastructure, less affected by natural disasters such as storms, floods and landslides. Regarding the method of determining technical potential, it is required to be more specific to identify available and exclusion areas with some types of land such as water surface, forest and paddy rice land.

Keywords: Solar energy, Recycled energy, Solar potential, Irradiation, Thanh Hoa province.

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1. Introduction

Currently, fossil energy sources such as coal, oil, and gas have been a major source of energy for electricity generation in many countries around the world as well as in Vietnam. Meanwhile, the use of fossil energy is one of the main causes of climate change and affecting air environment pollution. Fossil energy sources are also being exhausted, while Vietnam is facing major challenges because conventional energy sources to meet power generation needs have been and are exceeding the supply capacity. Therefore, with the demand growth of 10-15% per year in the period of 2011-2018 and the forecast of 7-8% per year in the period of 2021-2030 [1], the issue of promoting research and use of renewable energy sources, especially wind and solar energy, are very important for Vietnam.

There have been many methods of evaluating solar potentials, such as studies using GIS spatial analysis tools to assess the potential of solar roofs in Spain and Brazil [2, 3]. The World Bank Group has built Atlas global solar energy potential, detailed to the territory of countries based on solar radiation model, air temperature, solar energy potential model, and application of GIS technology [4].

Studies in Vietnam have applied methods to evaluate and forecast for different territories. In the energy development strategy to 2020, with a vision to 2030, the Institute of Energy used the potential source of solar radiation GHI (Global Horizontal Irradiation Index) of The World Band Group and applied GIS technology to determine technical potential for the territory of Vietnam [5]. From data on solar potential of The World Band Group and data on current land use map, Luu Ngoc An, et al [6] have applied GIS and methods to identify exclusion areas of the Institute Energy to determine availability and technical potential for Quang Ngai province. In Thanh Hoa province, in 2015, the Provincial People's Committee implemented the development of renewable energy planning in the province to 2020, with a vision to 2025 [7]. Based on the approved plan, the list of priority renewable energy projects calling for investment, in which the solar energy sector has four factories. Currently, there is no project to evaluate the potential of solar energy in the province.

This research uses the GHI raster data source of solar radiation potential map developed by The World Bank Group for the whole territory of Vietnam [4] and the land use map data, infrastructure in 2019 of Thanh Hoa province to calculate the solar radiation technical potential. Using the method of building a map to identify the available areas and determine the solar energy potential of the Institute of Energy [5] to evaluate the distribution of theoretical potential, available area and technical potential of solar energy in the province. The evaluation results are the basis for the planning and orientation for developing this energy source in the province.

2. Materials and Methods

2.1. Research Area and Data

2.1.1. Introduction of the Research Area

Thanh Hoa is the northernmost province in the North Central Coast, 153 km North of Hanoi capital, 138 km south of Vinh City, Nghe An province, 1,560 km from Ho Chi Minh City. Thanh Hoa is located at the positions from 19.18^0 to 20.40^0 Northern latitude and 104.22^0 to 106.40^0 Eastern longitude. The administrative boundaries of the province are as follows, the North border 3 provinces, which are (Ninh Binh, Hoa Binh, and Son La), the South borders - Nghe An province, the West border - Hua Phan province - Lao PDR and the East border - the Vietnam East Sea.

2.1.2. Data used in the Research

- Solar radiation data

The theoretical potential of the study area is taken from the source of Global Horizontal Irradiation Index (GHI) for the whole of Vietnam provided by the World Bank Group [4]. This is a raster data of 276.86 m resolution calculated based on solar radiation model and air temperature model. This data is corrected to subdivide raster cells into raster data with cell

size 30x30m to match resolution of Digital Elevation Model (DEM).

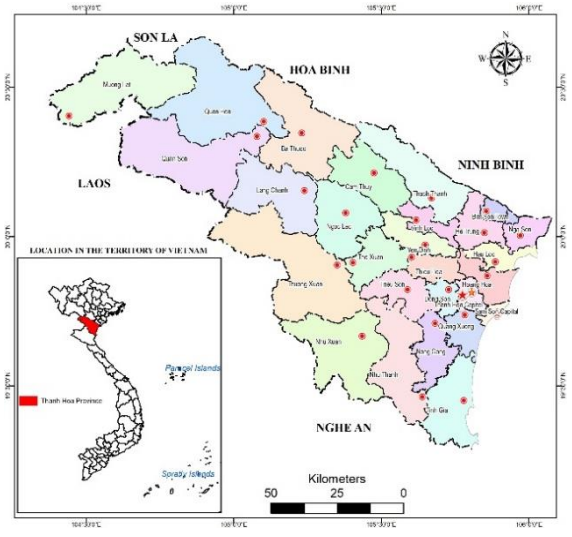

Figure 1. Geographical location of the study area.

- Digital Elevation Model (DEM) data

The Digital Elevation Model (DEM) satellite images 30m resolution provided by the U.S. Geological Survey (USGS) [8] was used to determine elevation and slope for the study area. DEM satellite image of Thanh Hoa province area consists of 6 pieces (Table 1).

Table 1. Information on DEM satellite image fragments of the study area [8]

Order	Title	Publication date	Resolution
1	SRTM1N19E106V3	2014/09/23	1-ARC (30 m)
2	SRTM1N20E106V3	2014/09/23	1-ARC (30 m)
3	SRTM1N19E105V3	2014/09/23	1-ARC (30 m)
4	SRTM1N20E105V3	2014/09/23	1-ARC (30 m)
5	SRTM1N19E104V3	2014/09/23	1-ARC (30 m)
6	SRTM1N20E104V3	2014/09/23	1-ARC (30 m)

- The current status of land use, infrastructure data

Land use data is used from the land use status map of Thanh Hoa province in 2019, scale 1/100,000 [9]; Infrastructure data (roads and power lines) are taken from the Socio-Economic Situation Map of Thanh Hoa Province in 2015 [10] and updated from the land use status map of Thanh Hoa province in 2019.

- Other data

Data on the number of sunshine hours in the last 20 years (1998 - 2017) in 5 climatic stations in Thanh Hoa province (Thanh Hoa, Tinh Gia, Nong Cong, Hoi Xuan, Nhu Xuan) [11].

2.2. Methods

2.2.1. Building Thematic Maps

Using ArcGIS 10.4 software with the Editor Toolbar to edit and build thematic maps: i) Urban land; ii) Rural land; iii) Forest land, protected areas, paddy rice fields, archaeological area and shoreline; iii) Water surface (system of main rivers and streams); v) Transportation system, electricity lines; and vi) Military land and airports. Using the Data Management Tool and 3D Analyst Tool to combine images, cut DEM satellite images according to the study area boundaries, calculate the slope and build a map of elevation and slope of the study area.

Use Data management tool with Raster processing function in ArcGIS 10.4 to resample raster with cell size 276.86 m into raster data with cell size 30 m to match resolution of DEM.

2.2.2. Method of Overlaying Thematic Maps and Calculating Technical Potential

Table 2. Criteria and indicators of excluded areas [5]

Criteria	Indicators
Slope Elevation	$> 15^0$ > 2000 m
Minimum distance from Urban areas	2000 m
Minimum distance from Rural areas	500 m
Minimum distance from reserve areas, forest, paddy rice field, archaeological area and shoreline	200 m
Minimum distance to the shore of the water	100 m
Minimum distance to roads, railways, power lines	50 m
Minimum distance to airports and military land	2000 m

Use the Analyst Tool to create exclusion buffer zone by distance to the objects to build the exclusion areas of thematic maps according to the criteria and indicators in Table 2. Then overlap the thematic maps to build available areas and exclusion areas map (Figure 2). After overlaying, the available areas with the area <900 m^2 will be excluded due to the smaller pixel value of the smallest map layer which is the slope and elevation maps with 30 m resolution.

Diagram of the process of identifying exclusion areas, overlapping with Intersect Tool in ArcGIS 10.4 for making the available area map in this study is shown in Figure 2.

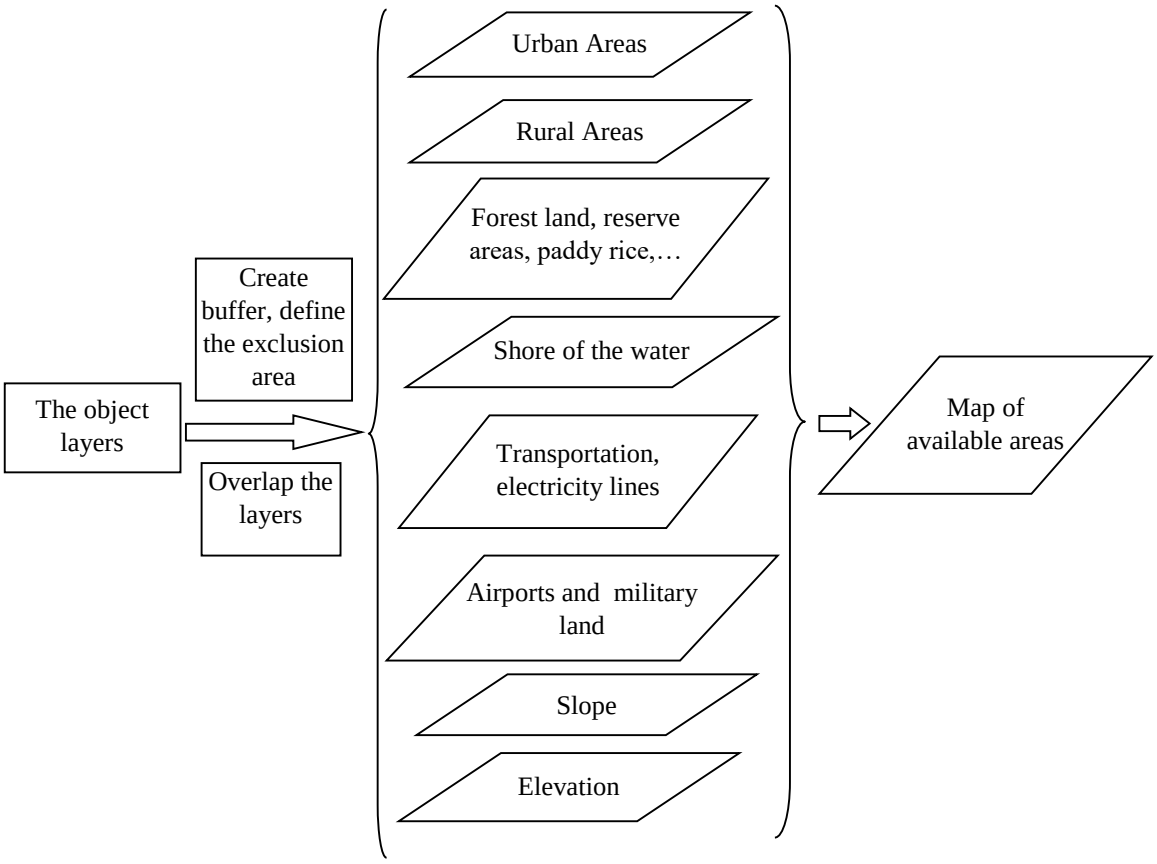

Figure 2. Overlapping method to construct a solar energy potential map.

After determining the available area map, calculate the available area and calculate the solar technical potential according to the following formula:

Technical potential (MWp) = Total available area (ha) x Land consumption rate for solar power project (MWp/ha) (1)

In which: Land consumption rate for solar power projects is 0.4 MWp/ha [6].

2.2.3. Spatial Statistics Method

Using the Calculate Areas tool in the Spatial Statistics tool of ArcGIS 10.4 software to calculate the area of available areas, export area data by administrative units (district, city, town). Then calculate the technical potential in administrative units according to the formula (1) mentioned above.

3. Results and Discussion

3.1. Theoretical Potential

The results of the theoretical potential of solar energy map based on the GHI index for the study area in Figure 3 show that the GHI value of Thanh Hoa province is distributed from 1,097 - 1,499.35 kWh/m^2/year. In terms of distribution, most of the coastal areas and western mountains have the highest GHI value, in the range of 1,300 - 1,400 kWh/m^2/year.

Compared to the average GHI value throughout the territory of Vietnam (distributed in the range of 1,168 – 2,045 kWh/m2/year [4]) the GHI value of Thanh Hoa province is located in the North Central region, which is assessed at a good level. The GHI value is higher than Northern mountainous provinces (except Lai Chau, Dien Bien, Son La), quite similar to other provinces in the Red River Delta, but lower than the South-Central Coast, Central Highlands, Southeast and Mekong Delta [4, 12].

Detailed statistics of GHI radiation intensity and distribution range in Thanh Hoa province are shown in Table 3. GHI values in the range of 1,300-1,400 kWh/m²/year account for the largest proportion, accounting for 81.55% natural area of the province, followed by GHI value of about 1400 - 1500 kWh/m²/year, accounting for 16.32% of the province's natural area. The remaining GHI value ranges from 1,907 - 1,300 kWh/m²/year accounting for a very small proportion with 2.14% of the province's natural area.

Table 3. Global horizontal radiation intensity (GHI) distribution in Thanh Hoa province.

Order	GHI value (kWh/m²/year)	Area (ha)	%
1	1,097-1,200	289.75	0.03
2	1,200-1,300	23,399.20	2.11
3	1,300-1,400	906,373.00	81.55
4	1,400-1,500	181,403.05	16.32
Total		1,111,465.00	100.00

Regarding solar radiation distribution over time of year, using the average data of hours of sunshine in 20 years (1998-2017) at 5 meteorological stations in the province to assess. The results show that the distribution of radiation is concentrated from April to November, the most concentrated from May to August. The months with low radiation are from December to March next year (Figure 4).

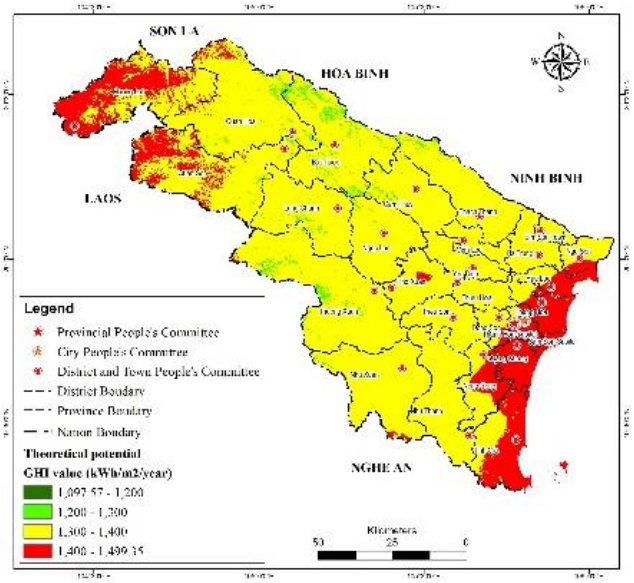

Figure 3. Map of theoretical solar potential according to GHI value.

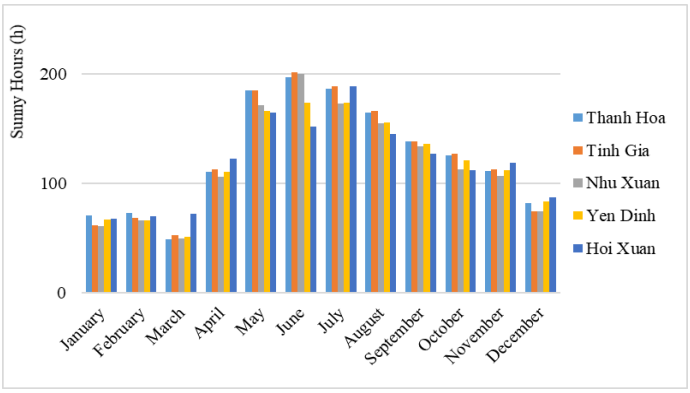

Figure 4. Number of solar energy hours per month in stations in Thanh Hoa province.

3.2. Technical Potential

3.2.1. Building Exclusion Areas Map

3.2.1.1. Exclusion Area for Slope and Height Criteria

Based on DEM data, conduct elevation partitioning (above 2000 m and below 2000 m) and slope (above 15^0 and below 15^0) to build an exclusion area map due to elevation and slope criteria. The results of the construction of the exclusion area map are presented in Figure 5, because the study area does not have elevations greater than 2000 m, so only the slope-based exclusion area map. In general, the areas with a slope less than 15^0 are coastal plains, midlands and low hills and valleys along rivers and streams in the Western mountainous region of Thanh Hoa province (Figure 5).

3.2.1.2. Thematic Maps with Land use Criteria

Criteria related to the current land use status include the current land use status, the infrastructure is separated into each object layer and the thematic maps of exclusion areas, including: Urban areas, Rural areas, reserve areas, forest, paddy rice field, archaeological area, shoreline, shore of the water, roads, railways, power lines, airports and military land (Figure 6).

3.2.2. Building Available Areas Map and Calculate Technical Potential

Perform an overlay of night exclusion area maps to determine availability and exclusion areas. After identifying the available areas, overlap the theoretical potential map to make a map of areas available for solar energy development in Thanh Hoa province. Results of overlapping and statistics of available areas show that the availability of solar energy development in the province covers an area of 54,621.15 ha. In particular, the potential area of 1,300 - 1,400 kWh/m2/year accounts for most of the area that can develop solar energy in the province with 91.01%, followed by the area of 1,400 - 1,500 kWh/m2/year accounting for 8.40%; the remaining area has potential of 1,200 - 1,300 kWh/m2/year accounting for a very small proportion, only 0.54% (Figure 7a and Table 4).

Regarding the spatial distribution of available areas, the statistical results in Table 4 show that 25/27 administrative units have available areas to be able to produce solar energy (except Thanh Hoa City, Sam Son City, excluded due to the large urban land area). The districts with large available areas include Nhu Xuan with an area of 9,723.79 ha, accounting for 17.80% of the total available area of the province; Lang Chanh accounted for 15.94%, Nhu Thanh accounted for 9.3%, Tinh Gia accounted for 9.03%, Thuong Xuan 7.04%, Ba Thuoc 6.30%, Thach Thanh 5.89%, Cam Thuy 5.59% and other districts accounted for less than 5%.

Regions with high radiation intensity of GHI value from 1400-1500 kWh/m^2 are distributed

mainly in the coastal and western mountainous areas of the province, which can be classified into 2 groups: i) Plain and coastal districts the sea includes: Tinh Gia with an area of 2,301.92 ha; Hau Loc 382.49 ha; Hoang Hoa 346.95 ha; Quang Xuong 198.90 ha; Nong Cong 77.20 ha; Nga Son 16.55 ha; and ii) Western mountainous district including Quan Son an area of 475.84 ha; Muong Lat 464.84 ha; Nhu Xuan 295.02 ha; Quan Hoa 28.24 ha; Most of the available area has available radiation intensity in the range of 1300-1400 kWh/m^2 (accounting for 91% of the available area), distributed in most districts in the province. The districts with large area include Nhu Xuan (9,428.77 ha); Lang Chanh (8,655.72 ha); Nhu Thanh (5,071.73 ha).

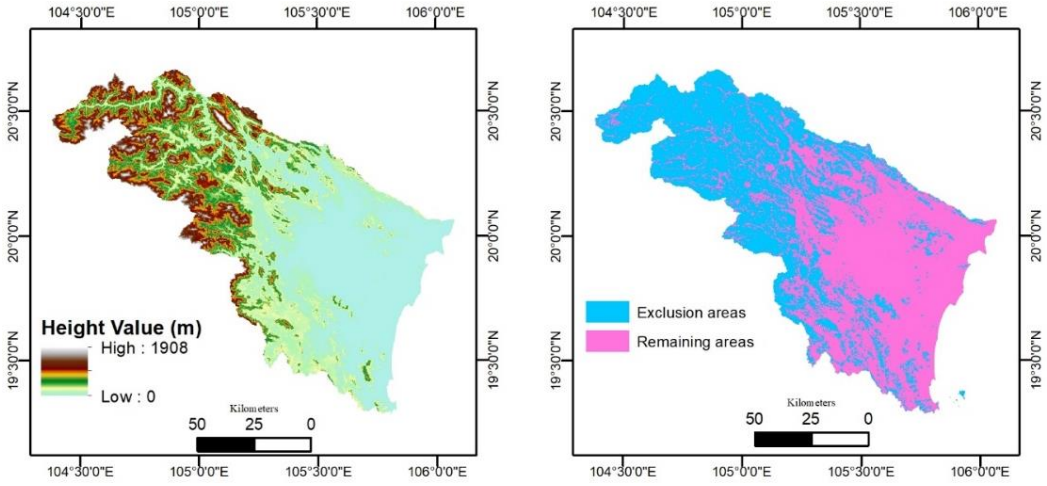

Figure 5. Digital Elevation Model (left) and exclusion area due to slope factor (right).

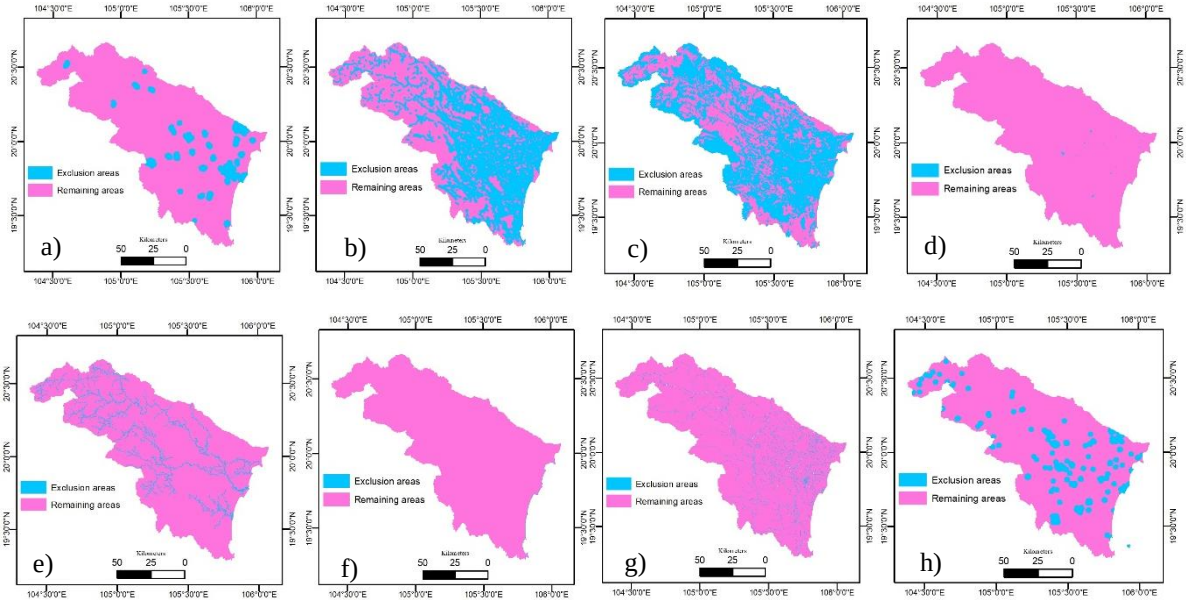

Figure 6. Map of exclusion areas for objects: Urban areas (a); Rural areas (b); reserve areas, forest, paddy rice field (c), archaeological area (d); shore of the water (e), shoreline (f); roads, railways, power lines (g), airports and military land (h).

The total value of technical potential in Thanh Hoa province is 21,848.46 MWp. The distribution of technical potential to district and town levels in Thanh Hoa province is shown in Figure 7b and in Table 4.

The results in Figure 7b show the technical potential according to the total area available for solar power development and the land use consumption for the solar power project. The technical potential is positively correlated with the usable area, the greater the usable area the greater the technical potential and vice versa. Districts and towns with large available solar energy development have great technical potential (Table 4).

Table 4. Distribution of the availability areas and technical potential of solar energy in Thanh Hoa province

Scale / Administrative Units	Area according to the GHI values (ha)			Total (ha)	%	Technical potential (MWp)
	1200-1300 (kWh/m^2)	1300-1400 (kWh/m^2)	1400-1500 (kWh/m^2)			
Nhu Xuan		9,428.77	295.02	9,723.79	17.80	3,889.52
Lang Chanh	52.36	8,655.72		8,708.08	15.94	3,483.23
Nhu Thanh	6.82	5,071.73		5,078.55	9.30	2,031.42
Tinh Gia		2,631.35	2,301.92	4,933.27	9.03	1,973.31
Thuong Xuan	9.11	3,837.42		3,846.53	7.04	1,538.61
Ba Thuoc	89.60	3,354.18		3,443.78	6.30	1,377.51
Thach Thanh	32.18	3,183.90		3,216.08	5.89	1,286.43
Cam Thuy	28.91	3,026.72		3,055.64	5.59	1,222.25
Ngoc Lac	57.76	2,092.10		2,149.86	3.94	859.94
Quan Son		1,394.06	475.84	1,869.90	3.42	747.96
Quan Hoa	18.74	1,646.49	28.24	1,693.47	3.10	677.39
Trieu Son		1,607.27		1,607.27	2.94	642.91
Ha Trung		899.24		899.24	1.65	359.70
Vinh Loc		804.89		804.89	1.47	321.96
Muong Lat		339.87	464.84	804.72	1.47	321.89
Tho Xuan		760.88		760.88	1.39	304.35
Hau Loc		5.39	382.49	387.87	0.71	155.15
Hoang Hoa		1.95	346.95	348.90	0.64	139.56
Nga Son		325.11	16.55	341.66	0.63	136.66
Yen Dinh		312.95		312.95	0.57	125.18
Quang Xuong			198.90	198.90	0.36	79.56
Nong Cong		98.62	77.20	175.81	0.32	70.32
Thieu Hoa		166.98		166.98	0.31	66.79
Bim Son		68.15		68.15	0.12	27.26
Dong Son		23.98		23.98	0.04	9.59
Total (ha)	295.49	49,737.71	4,587.94	54,621.15	100.00	21,848.46
%	0.54	91.06	8.40	100.00		

3.3. Discussion

The technical potential of solar energy for Thanh Hoa province was built based on the GHI value map throughout the territory of Vietnam developed by the WB Group and the exclusion criteria proposed by the Institute of Energy (Vietnam). The results show that in the whole

territory of Thanh Hoa province, there are 54,621.15 ha of land suitable for developing solar power plants, accounting for nearly 5% of the natural area of Thanh Hoa province, while this value of the whole territory of Vietnam is 14% [5].

The socio-economic development process of urban areas, rural residential areas and other constructions will expand, so the scale of the solar technical potential area will be reduced due to the exclusion criteria, so in the planning in the long term, the electricity and renewable energy industries need to forecast the demand for solar energy development to arrange land banks in areas with appropriate radiation intensity.

The intensity of radiation according to the GHI value in the whole territory of Thanh Hoa is quite good compared to other regions in Vietnam, the intensity of radiation is concentrated in April to November with the number of sunny hours at 5 stations in the province are higher than 147 hours/month, equivalent to more than 4.9 hours/day. Assessing theoretical potential, available areas and technical potentials shows that Thanh Hoa is a province capable of developing solar power production well. The well-developed regions are concentrated in lowland and midland districts with GHI values of about 1,300-1,400 kWh/m^2. In these areas, the scale of land and infrastructure are favorable and less affected by natural disasters such as storms and landslides. The coastal areas and the Western mountains have a higher theoretical potential but are often affected by natural disasters such as storms, flash floods and landslides every year. Besides, the coastal areas are oriented for industrial development, seaports, tourism, densely populated areas and paddy rice cultivation. In the West, due to the mountainous terrain, transportation and infrastructure are the most difficult in the rainy season affected by landslides and floods.

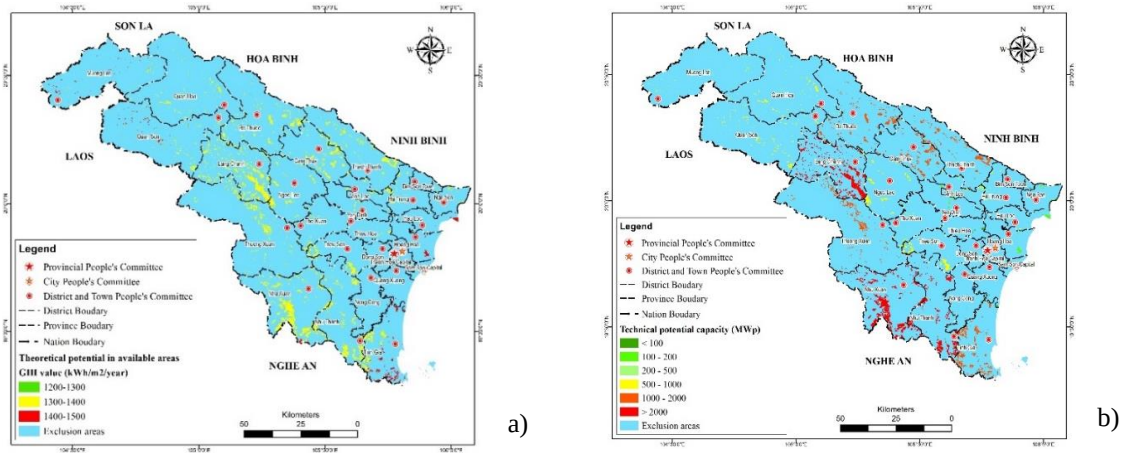

Figure 7. Available areas and theoretical potentials in Thanh Hoa province (a); Map of potential technical distribution of solar energy in the study area (b).

Regarding the method of determining technical potential, it is required to be more specific to identify areas of availability and exclusion with some types of land such as water surface, forest and paddy rice land. For water surface in the excluded areas, it is necessary to clearly identify that rivers, streams, irrigation systems, hydropower systems need to ensure safety corridors,... because some solar energy projects in the area where the panels can be installed can be placed on the water surface. For example, Yen Dinh Solar Power Plant has been operating in Thanh Hoa province, which was built on the water surface which was formerly an aquaculture lake. This has also been reflected in Decision No. 13/2020/QD-TTg about incentives

for development of solar energy in Vietnam, under which solar energy technology is divided into 3 groups: i) The floating solar power project (on the surface water); ii) The ground solar power projects; and iii) The rooftop solar power system [13]. Finally, for forest land and rice land, it is necessary to determine more details for the excluded areas which are special-use forest land, protective forest land, natural production forest land, land used for two or more paddy rice crops. Due to the norms of special-use forest land, protection forests and land of two or more paddy rice crops in the land use plan allocated by the national level to the provincial level to ensure food security and forest coverage.

4. Conclusions

i) The results of the assessment of solar energy potential of Thanh Hoa province show that the province's available solar energy development area is 54,621.15 ha, accounting for 5% of the province's natural area. In particular, the area of horizontal radiation intensity (GHI) is 1,300 - 1,400 kWh/m^2/year accounting for most of the available area of the province with 91.01%, followed by the area of 1,400 - 1,500 kWh/m^2/year accounting for 8.40%; the remaining areas have potentials of 1,200 - 1,300 kWh/m^2/year accounting for a very small proportion, only 0.54%

ii) The technical potential in Thanh Hoa province is 21,848.46 MWp, which is assessed as being capable of developing good solar power production. The well-developed regions are concentrated in the lowland and midland districts due to favorable conditions of land scale and infrastructure, less affected by natural disasters such as storms, floods, landslides.

iii) Regarding the method of determining technical potential, it is required to be more specific to identify areas of availability and exclusion with some types of land such as water surface, forest and paddy rice land. For water surface in the excluded areas, it is necessary to clearly identify that rivers, streams, irrigation systems and hydropower systems need to ensure safety corridors. Also for forest land and rice land, it is necessary to determine more details for the excluded areas which are special-use forest land, protective forest land, natural production forest land, land used for two or more paddy rice crops. Due to the norms of land use types in the land use plan allocated by the national level to the provincial level to ensure food security and forest coverage.

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