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Developing spatial analysis approach to determine potential site for solar power application

Tran Thi Van*, Le Nguyen Thanh Tra, Ha Duong Xuan Bao

Ho Chi Minh City University of Technology, Vietnam National University Ho Chi Minh City, 268 Ly Thuong Kiet Street, District 10, Ho Chi Minh City, Vietnam;

Abstract

The use of fossil fuels have been proven to cause many implications for global climate change today. Therefore, renewable energy sources, using green energy is being put more attention from the community. Renewable energy technologies are not only as a means to help reduce greenhouse gases and adapt to climate change, but it also brings many benefits directly and indirectly to the economy due to the reduction our dependence on fossil fuels and imported fuels, improves local air quality, environmental security, accesses to energy security, helps promote economic and social development in sustainable way. The paper presents the approach of space technology from the combination method of remote sensing, GIS and multi-criteria analysis to select the location of potential development for solar power application on the territory. This study based on spectral band characteristics of the Landsat image to extract related indices as the basis for the steps on GIS spatial analysis. The results is the steps of integrated approach finished. This is will be for future realization of the project

Keywords: climate change, optimal location, renewable energy, solar power, spatial analysis

1. Introduction

Using locally available renewable resources avoids potential disruptions in the fuel delivery chain and environmental risks during transportation (Laura, 2015). Renewable energy technologies not only help in reducing carbon emissions to mitigate climate change, it also brings many directly and indirectly benefits to the economy by minimizing our dependence on fossil fuels and imported fuels, improving local air quality to ensure environmental sustainability, enhancing energy supply security, and actively promoting structural change in the economy, such that softening job losses in declining manufacturing sectors by opening new employment opportunities for addressing these multiple environmental related to renewable energy (Edenhofer et al., 2015).

Viet Nam has potential solar energy for sustainable development. The year-round high solar radiation of 5 kWh/m^2/day in most of the middle and the southern provinces, and about 4 kW/h/m2/day in the northern provinces, which is not only plentiful but also steady for most part of the year, and reducing about 20 percent from dry season to rainy season in the South of Viet Nam (Trinh, 2009). Solar PV technology in Vietnamare has been applied for remote areas such as islands, high mountainous areas where the electricity network can not reach. Although the exploitation of solar PV technology is still in low level, small scales and dispersed, Vietnam has increasingly created more opportunities in developing this kind of renewable energy source.

* Corresponding author. Tel.: 84-091-918-8485

E-mail address: vanbaokt@yahoo.com.

Today, the advances in materials science and engineering make up breakthroughs to increase energy conversion efficiency of photovoltaic cells, directly contributing to rationalize the cost of solar energy, and promising significant investments in the future. Beside, selecting a suitable site is a crucial component of developing a viable solar PV project. In general, a suitable site requires high global tilted irradiation (GTI), the total solar energy received on a unit area of a horizontal surface, considering constraints in geographic, environment, engineering and finance (John et al., 2015). To determine potential locations for investments on grid-connected centralised PV applications, this paper describes a general integrated framework to evaluate land suitability for the optimal placement of photovoltaic solar power plants, which is based on a combination of a Geographic Information System (GIS), remote sensing techniques and analytic hierarchy process (AHP). In this process, the applications of satelite images capability provide a lot of useful information quickly and repeatedly on a large range, positive supporting for tracking changes on the surface, as well as formulating geographical potential criteria. Those could not be examined by the remote sensing technique, GIS tools in combination with multi-criteria methods consist an excellent analysis tool that creates an extensive database of spatial and non-spatial data that will be used to simplify problems, to solve and visually display the importance or relative limits of each criterion. The results of multi-criteria analysis is maps of the most suitable areas for developing solar solar power applications.

This paper outlines steps in combination of remote sensing technique, GIS tools and multi-criteria analysis to locate potential sites for solar power applications. The purpose of developing this method is able to apply to different regions, support to decision-making in selection suitable sites for infrastructure planning to exploit solar energy potential, and attend to planning stage and sustainable development of green energy sources in the current context for climate change adaption.

2. Methodology

2.1. Site selection methodology for potential grid-connected Solar PV plants

The key steps for developing a solar PV project are well established, and yet there is no definitive detailed “road map” to follow (John et al., 2015). According to the experience of previous projects, an appropriate location should have high amount of incident solar radiation, availability of vacant land for its present as well as for its future development, accessibility to site from highways as it affects the transportation cost and thus the initial cost, distance from transmission lines to minimize the losses, low mineral content water as it is preferred for cleaning PV modules. The characteristics of a PV module are determined at standard temperature conditions of 25˚C; for every degree rise in celsius temperature above this standard, crystalline silicon modules reduce in efciency, generally by around 0.5 percent (John et al., 2015). The degradation of cells happens due to high wind velocity, extreme temperatures, shadow on modules and dusting on arrays, thus variation of local climate, environmental, human and wildlife factors are significant criteria for this work. The criteria should also include dust particles from traffic, building activity, agricultural activity or dust storms and module soiling from bird excreta as efficiency of plant could be reduced significantly if modules are soiled. Moreover, geotechnical issues like consideration of groundwater resistivity, load bearing properties, soil pH levels and seismic risk are recommended prior to final selection to ensure that the mounting structures of PV panels will have adequately designed foundations (John et al., 2015). By considering topography of site, flat or slightly south facing slopes are preferable for projects in the northern hemisphere (Khan and Rathi, 2014). Geotechnical political issues such as site near to sensitive military zones and historical places should be avoided.

In general, the process of site selection must consider the constraints and the impact they will have on the cost of the electricity generated. The main constraints that need to be assessed include: solar resource, local climate, available area, land use, topography, geotechnical issues, geopolitical issues, accessibility, grid connection, module soiling, water availability, financial incentives. (Miller et al., 2012).

Analyzing and evaluating the impact of the above criteria help us determine the actual potential of solar energy in regions and minimize the fact that theoretical potential assessment is too high from reality. In addition to examining the relationship between suitable areas for investment, the use of technology factors also greatly affect the factual potential. Therefore, calculations of geographical potential and technical potential will help us specify the practical areas which are suitable for developed planning of solar PV plants

(1) *Theoretical Potential:* The highest level of (resource) potential is the theoretical potential. This potential only takes into account restrictions with respect to natural and climatic parameters. (Farooq and Kumar, 2012).

(2) *Geographical Potential:* The geographical potential is the theoretical potential limited by the resources at geographical locations that are suitable for installation of specific technology. Consequently, the geographical potential is presented in order to consider the geographical impaction refers to the available and suitable production of renewable energy for given regions. For the geographical potential of solar energy, the following expression is used (Farooq and Kumar, 2012; Wang et al., 2009):

$$GPi = Ii * Rai \tag{1}$$

Where, i - observation year; Ii - the time-averaged irradiance (kWh / m2); Rai - the available area (km2); GPi - geographical potential (MWh).

(3) *Technical Potential:* The technical potential is the geographical potential by the losses of conversion efficiencies of the primary energy to secondary energy sources which is varied when using different technically feasible technologies. The technical potential can be as follows:

$$TPi = GPi * \eta i * pri \tag{2}$$

Where, i - observation year; TPi - technical potential (MWh); GPi - geographical potential (MWh); ηi - the conversion efficiency of the technology (%), which has close relation with both the PV cells and the module temperature. A bulk of literatures discussing the parameter ηi can be found in, or among others (Yamaguchi, 2000; Martin et al., 2015); pri - the performance ratio of the system (fraction), which is defined as the ratio between the actual performance of the system and the performance under standard test conditions. Availability factor refers to number of days/hours per year the technology can be used for electricity generation. The value is lowest for solar technologies (0.33) due to their dependency on sunshine. (Farooq and Kumar, 2012; Wang et al., 2009).

2.2. Remote sensing and GIS analysed foundation

(1) Extraction of Land Surface Temperature (LST) from LANDSAT 7 ETM+ image

LST are extracted from Landsat 7 ETM+ image, which was processed at level 1G (L1G) (band 61 or 6L in corresponding to high gain state, and band 62 or 6H in corresponding to low gain state). Digital number values (DN) of image had to be converted to spectral radiance values (Lλ) using published post-launch gains, then continuing to be converted to brightness temperature (TB) at satellite sensor (the temperature is referenced to a black body). (USGS, Landsat 7 userguide).

Converting DN to Lλ: Lλ values are calculated from DN values following the equation:

$$L\lambda = (LMAX - LMIN)/255 * DN + LMIN \tag{1}$$

Where, Lλ - spectral radiance W/(m2.str.µm); DN - digital number; LMAX, LMIN - are derived depend on gain status.

Converting Lλ to TB: In next step, the spectral radiance is converted to brightness temperature using the following equation:

$$T = K2/\ln \quad (K1/L\lambda+1) \tag{4}$$

Where, T - brightness temperature at satellite sensor (K); Correction factor K1 and K2 are provided on header file of each scence, K1 = 666.09 (W/(m2.sTr.µm)); Correction factor K2 = 1282.71 (K)

Emissivity correction: Because the temperature values above are referenced to a black body with an invariable emissivity and the specified emissivity values. The derived temperature values above is required make a correction to types of land cover as the below equation:

$$Ts = T/(1+ \lambda T/a \ \ln \ \varepsilon) \tag{5}$$

Where, λ - wavelength (µm); a = h*c/K = 1.438 x 10-2 m.K; Planck's constant h = 6.26 x 10 -34 (J.sec); velocity of light c = 2.998 x 108 (m/sec); Boltzmann's constant K = 1.38 x 10-23 (J/K); ε - emissivity constant of each type of land cover.

(2) The normalized difference vegetation index NDVI

NDVI is a vegetation index to monitor the condition of vegetation or vegetation health. NDVI is the most commonly used vegetation index for monitoring vegetation globally. NDVI provides methods to estimate plant production of different plant communities, to identify ecological zones, to monitor seasonal changes of vegetation, length of harvest and drought cycles. NDVI values indicate the presence of vegetation cover in pixels. Higher NDVI values show thriving status of vegetation. NDVI is defined as follows:

$$NDVI = (NIR-RED)/(NIR+RED) \tag{6}$$

Where, NIR - reflectance values at the near-infrared wavelengths; RED - reflectance values at the red wavelengths.

(3) Modification of Normalized Difference Water Index MNDWI

MNDWI is derived from the NDWI by the use of middle infrared instead of near-infrared. Water bodies are better delineated by a more efficient discrimination between open surface water and dry surfaces. The MNDWI is more suitable for enhancement of water with many built-up land areas in the background than the NDWI because it can efficiently reduce and even remove built-up land noise. (Xu, 2006).

$$MNDWI = (Green-MIR)/(Green+MIR) \tag{7}$$

Where, Green - reflectance values at the green wavelengths; MIR - reflectance values at the middle infrared wavelengths. The computation of the MNDWI will produce three results: water will have greater positive values than in the NDWI as it absorbs more MIR light than NIR light; built-up land will have negative values as mentioned above; and soil and vegetation will still have negative values as soil reflects MIR light more than NIR light, and the vegetation reflects MIR light still more than green light. The MNDWI was originally developed for use with Landsat TM bands 2 and 5. However, it will work with any multispectral sensor with a green band between 0.5-0.6 µm and a MIR band between 1.55-1.75 µm.

(4) The normalized difference built-up index NDBI

This index highlights urban areas where there is typically a higher reflectance in the shortwave-infrared (SWIR) region, compared to the near-infrared (NIR) region. Applications include watershed runoff predictions and land-use planning. (Zha et al., 2013).

$$NDBI = (MIR-NIR)/(MIR+NIR) \tag{8}$$

Where, MIR - reflectance values at at the middle infrared wavelengths; NIR - reflectance values at the near-infrared wavelengths. The NDBI was originally developed for use with Landsat TM bands 5 and 4. However, it will work with any multispectral sensor with a MIR band between 1.55-1.75 µm and a NIR band between 0.76-0.9 µm.

(5) Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is one such multicriteria decision-making method and can be used to analyze and support decisions which have multiple and even competing objectives and also unstructured problems (Uyan, 2013). It helps to capture both qualitative and quantitative aspects of a decision problem and provides a powerful yet simple way of weighting the decision criteria, thus reducing bias in decision-making (Saaty, 1987; Georgiou et al., 2012). The AHP is based on pair-wise comparisons and used to derive normalized absolute scales of number whose elements are then used as priorities. By comparing pairs of criteria one at a time and using integer numbers from the 1 to 9 scale of the AHP, decision-makers can quantify their judgment about the relative importance of criteria (Uyan, 2013). .

Table 1. AHP evaluation scale

Relative Importance	Value	Definition
Equal importance	1	Two criteria have equal contribution / Equal importance of i and j
Equal importance to Slightly importance	2	Experience and decision slightly inclined to one criterion / slightly
Slight importance	3	importance of i over j
Slight importance to Moderately importance	4	Experience and decision moderately inclined to one criterion /
Moderate importance	5	Moderate importance of i over j
Moderate importance to Very importance	6	Strong importance criterion / Strong importance of i over j
Strong importance	7	Top priority criterion / Extreme importance of I over j
Strong importance to extremely importance	8	
Extreme importance	9	

Source (Van and Son, 2014)

For example, if element A is more important than element B, then A is rated at 9 and B is less important than A so it has a value of 1/9. Mathematical nature of AHP is structuring a matrix represent interconnections in the set of element values. Matrix supports closely for computations. For each primary element, we set up a comparison matrix of its secondary elements.

2.3. Integrated approach of AHP and GIS

This approach is used to assess the importance of criteria as well as combine them together by using GIS tool to obtain the map of potential location for solar PV applications. Based on this result, the potential areas are calculated to establish geographical potential map and technical potential map. The process applying this method can be divided into the following stages:

- *Identification and Description of Criteria:* Select criteria that should be in study, hierarchize priority and eliminate less important criteria. These criteria represent appropriate data layers that needed for the analysis in order to set up digital geo-database.
- *Evaluating:* Select and compare pairs of criteria base on experience and the importance of each criterion to the whole system, in order to assess how they affect the research. Evaluate the relative importance between pairwise criteria and give them values in Table 1.
- *Weighting:* Calculate weights of criteria and sub-criteria according to AHP algorithm. These weights based on subjective criteria can be changed according to the needs of researchers. If the numbers of criteria increase, the importance level of each criteria will be reduced. The total weight of all criteria must be 100% or equal to 1. Setting up weights base on the importance and influences of each criterion to the research.
- *Making decision:* After calculating EBQ Ranking Vector or weight of each criterion, conducting to compare consistency ratio to standards. If AHP may not yield meaningful results, than remove, reselect an evaluate criteria affecting research that best suits the requirements set forth until the consistency ratio meet the standard.
- *Mapping:* Criteria maps will be prepared with weight values obtained from AHP by using ArcGIS tools. These maps are put in overlay analyzing and combine with land cover classification result from satellite images to produce suitability land map for developing solar PV plant.

3. Conclusion

The general integrated framework above are outlined theories as the platform for technical application of spatial analyzing techniques, including remote sensing and GIS, integrating with multi-criteria analysis AHP to choose potential locations for solar power applications. These evaluated steps propose technical capabilities of spatial analysis supporting to optimize potential site selection for solar PV plant in any territory level. In the context of fossil fuel sources increasingly scarce, solar energy is an infinite replacing option. Besides, there is an increasing frequency occurs of extreme weathers, the replacement of green energy sources such as solar energy is a inevitable process, in order to protect humanity.

References

Edenhofer, O. et al., 2012. Renewable Energy Sources and Climate Change Mitigation, Special Report of the Intergovernmental Panel on Climate Change, New York: Cambridge University Press. Available: <http://www.ipcc.ch/pdf/special-reports/srren/SRREN_Full_Report.pdf>.

Farooq, M. K. and Kumar, S., 2012. An assessment of renewable energy potential for electricity generation in Pakistan". *Renewable and Sustainable Energy Reviews*, 20 (2013), 240–254.

Georgiou, A., Polatidis, H. and Haralambopoulos D., 2012. Wind energy resource assessment and development: Decision analysis for site evaluation and application, *Energy Sources*, Part A: Recovery, Utilization, and Environmental Effects, 34(19), 1759 – 1767

John, K. et al., 2015. Utility-Scale Solar Photovoltaic Power Plants, A project Developer's Guide. International Finance Corporation, A Member of World Bank Group. Viewed Argust 16, 2016. Available at: <http://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/ifc+sustainability/learning+and+adapting/knowledge+products/publications/publications_utility-scale+solar+photovoltaic+power+plants>.

Khan, G. and Rathi, S., 2014. Optimal Site Selection for Solar PV Power Plant in an Indian State Using Geographical Information System (GIS). *International Journal of Emerging Engineering Research and Technology*, Volume 2, Issue 7, ISSN 2349-4395, 260-266.

Laura, E.W., 2015. Feature: Using renewables for climate change adaptation, *REN21*, SAIREC, 122-125.

Martin, A. G. et al., 2015. Solar cell efficiency tables (version 47). *Progress In Photovoltaics: Research and Applications*,24(2016), 3–11.

Miller, A. et al., 2012. Utility Scale Solar Power Plants, A Guide For developers And investor (online). *InternatIonal Finance CorporatIon*, A Member of World Bank Group, Viewed 02 June 2016. Available: <http://documents.worldbank.org/curated/en/2011/12/15796991/utility-scale-solar-power-plants-guide-developers-investors>.

Saaty, W.R., 1987. The Analytic Hierarchy Process – What it is and how it is used. *Math Modelling* 9(3-5), 161 – 176, 1987.

Trinh, Q. D., 2009. Photovoltaic technology and solar energy development in Viet Nam, Viewed 24 April 2016. Available <http://media.nmm.de/56/5e-dangdinhthong-solarenergyinvn-enerexpo2012s_26188956.pdf>

USGS, Landsat 7 userguide. *Landsat Science Data Users Handbook*. NASA.

Van, C. T. and Son, N. T., 2014. Xây dựng phương pháp tính trọng số để xác định chỉ số dễ bị tổn thương lũ lụt lưu vực sông Vu Gia - Thu Bồn. *Tạp chí Khoa học ĐHQGHN: Khoa học Tự nhiên và Công nghệ*, Tập 31, Số 1S (2015), 93-102.

Wang, S. et al., 2009. A new thinking for renewable energy model Remote sensing-based Renewable energy model. *International Journal Of Energy Research*, 33, 778–786.

Yamaguchi, M., 2000. Present status and prospects of photovoltaic technologies in Japan. *Renewable and Sustainable Energy Reviews*, 5 (2001), 113–135.

Zha, Y. et al., 2003. Use of Normalized Difference Built-Up Index in Automatically Mapping Urban Areas from TM Imagery. International *Journal of Remote Sensing* 24, No. 3, 583-594.