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Solar Resource Potentials of a Very Large Scale PV System in Sahara Desert

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Abstract: A desert has abundant irradiation and plenty of land. Especially, a gravel desert is suitable for a PV system installation, because it is consisted of flat hard soil. To find suitable places such as the flat gravel desert for the Very Large Scale PV (VLS-PV) system, the authors have been developed remote sensing method with satellite images. Land condition is evaluated by using three analyses: ground cover classification, which is statistical calculation; undulating hills classification, which is extraction of edges of satellite images; and vegetation index. Then, we applied the method to Sahara desert, and found that 373 TW VLS-PV systems are possible to be installed, and it can generate 626 PWh/year. This is four times as world energy demand in 2010.

Keywords: Desert, Remote sensing, Satellite image, VLS-PV

1. Introduction

The Very Large Scale Photovoltaic power generation (VLS-PV) system has been studied in order to resolve the world energy and environmental issues in the Task8 in the Photovoltaic Power Systems Programme (PVPS) in the International Energy Agency (IEA). The objective is to examine and evaluate the feasibility of the VLS-PV System, which have a capacity ranging from over multi Megawatt to Gigawatt, and develop practical project proposals for demonstrative research toward realization of the VLS-PV Systems in the future. The desert has very large energy resource, because the desert has abundant solar irradiation and plenty of land. However, the VLS-PV system can be installed in not all area in desert. For example, sand dune is difficult for installation, and trees should not be damaged. The gravel desert is suitable, because it consists of small locks and is flat land area.

The authors have been developed a method which extracts suitable areas for the VLS-PV by using remote sensing with satellite images. The result of the method shows not only suitable area but also potentials of PV power generations in the desert. This method has been updated from last method (Sakakibara *et al*., 2005) to give improved accuracy.

2. Satellite images and the method

In this paper, we use two types of satellite images for the method. One is LANDSAT-7/ETM+ images which are available at a web site of the Global Land Cover Facility (GLCF) in University of Maryland[A)]. It provides satellite images for free, however, there is some limitation. Another is NOAA/ AVHRR images to obtain Normalized Difference Vegetation Index (NDVI). This NDVI dataset are possible to download at web site of the Center for Environmental Remote Sensing (CEReS) in Chiba University[B)]. The yearly maximum NDVI (NDVIymax) was calculated from the NDVI dataset. For smoothing yearly climate variability, average of five-year

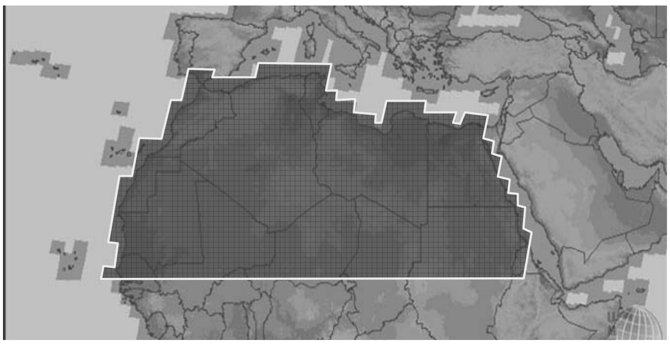
Fig. 1. Analysis area of Sahara desert in this study.

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NDVIymax is utilised, since the amount of precipitation of desert differs widely each year. An analysis area in this study is the Sahara desert in North Africa as shown in **Figure 1**. The analysis area covers 12.5 million km^2 which is approximately 8 percent of whole land area on the Earth.

To find suitable area for the VLS-PV system, three analysis methods were developed as shown in **Figure 2**. We used vegetation index developed by using NOAA. Landsat satellite images are also investigated for estimations of ground cover classification and undulating hills classification. At first, the Landsat satellite images were converted by using reflection ratio. The ground cover classification was done by maximum likelihood procedure. And the rolling ground classification was done by Laplacian filter. The result of three analyses were weighted and integrated, and we obtained suitable areas for the VLS-PV systems. In addition, we did ground truth to evaluate the method.

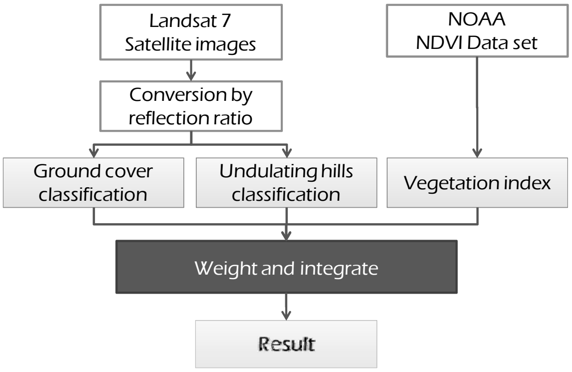

Fig. 2. Scheme of the analysis method.


Fig. 3. Undulating hills extraction.

For the ground cover classification, we applied a maximum likelihood estimation method. Band 2, 3 and 4 were utilised, and classified as sand dune, gravel, Steppe, trees, and water area. Training data from the test site were prepared in advance. Average and variance were used for the calculation. And by using the majority filtering, noises in the results were reduced.

The algorithm of extracting undulating hills was done by filtering which emphasize edges, reduce noises, and cut and emphasize specific frequency. We did the filtering to band 3, because it is data of the near-infrared and it is suitable for making out geological structures. We used the Laplacian filter for the algorithm because it can extract not only vertical and horizontal edge but also slanting edge. After that, we used dilation and erosion. An example of the result is shown in **Figure 3**.

The Landsat 7 has high resolution, and is good for evaluate geographic condition. However, if we use the free images, it is difficult to get its images in same season, and image size is small. Therefore, we have to use satellite images of dry and rainy season at same area's evaluation. We made a collection method of seasonal differences, but it is not very good. On the other hand, NOAA AVHRR is low resolution, but one image cover large area. In addition, CEReS, Center for Environmental Remote Sensing, in Chiba University is distributing a NDVI database which consists of 36 data which are 12 months data and three 10-days data in a month. And the data is from 1980 to 2000. **Figure 4** shows an annual maximum NDVI. Dark gray shows lower vegetations, and white shows higher vegetation.

We referred to a paper (Ma and

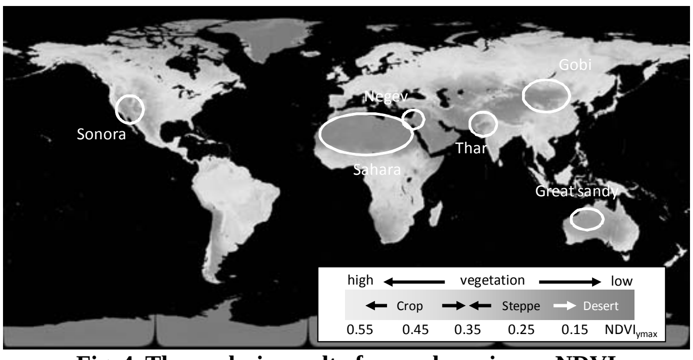

Fig. 4. The analysis result of annual maximum NDVI.

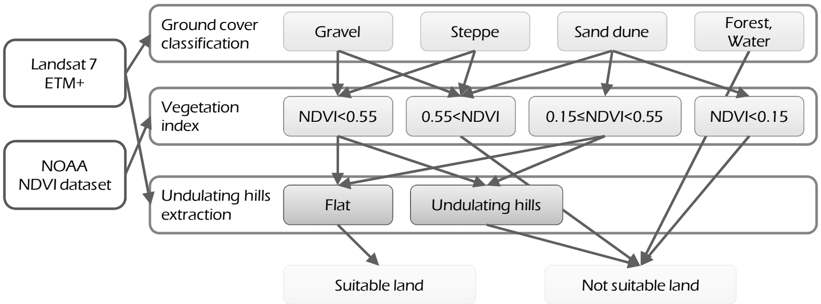

Fig. 5. The integration of three classification analyses.

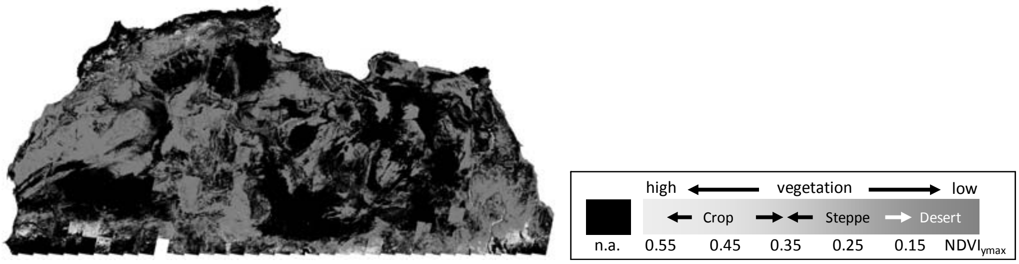

Fig. 6. Result of the evaluation of the Sahara area.

Veroustraete, 2006), we define three vegetation levels. Desert level (NDVIymax < 0.15): Very little vegetations. It may seem that almost areas are available for the VLS-PV. However, this very small NDVIymax is made by mobile sand. Therefore these areas are not gravel areas but sand dune areas. Steppe level (0.15 ≤ NDVIymax < 0.35): Vegetations can grow in rainy season. The condition is not harder than desert level. Therefore, there are some villages in these areas. Crop level (0.35 ≤ NDVIymax < 0.55): This level is crop or grass area. The vegetation level gets higher in rainy season. But it reduces to steppe level in dry season.

Figure 5 shows the summary of the integration algorithm. At first, the Landsat satellite images were divided to four categories; gravel, steppe, sand dune, and forest and water. Forest and water areas are evaluated at not suitable land. Second, we evaluate the areas classified as gravel, steppe and sand dune. The gravel and steppe areas are evaluated by NDVI. If it is lower than 0.55, they go to next step. If not, they are not suitable land. The sand dune areas are also evaluated. If the NDVI is between 0.15 and 0.55, they go to next step. Finally, the passed areas are evaluated by the undulating hills extraction. If they are classified as flat land, they are suitable land for VLS-PV. If not, they are not suitable land.

3. Results and Discussion

Figure 6 shows evaluation results by the three analyses. The image area is 12.5 million km^2. Suitable land area for the VLS-PV was: 4.5 thousand km^2 at desert level; 5.3 thousand km^2 at desert and steppe level; and 5.5 thousand km^2 at desert, steppe and crop level. They were about 36 %, 43 % and 44 % of analyzed area.

To evaluate the accuracy of the algorithm, we did the ground truth. It is comparison between actual land condition and the results of the evaluation. We went to the Sahara desert, and took photos with location data by GPS.

The ground truth in Sahara desert was investigated in September in 2007. Its root was from Djerba island to Tozeur through Ksar Ghilane, Douz, salt lake, and mountain area. A left figure of **Figure 7** is consists of 4 images which were taken on December, April, May and June. A right figure shows a result and a track line showing white line. We checked 135 points. The accuracy was 86 %. However, area ratio which is actual data divided by suitable area was 75 %. We suppose that there are areas of combined sand dune and gravel area which the algorithm evaluates as sand dune. And because salt lake is an easy place to evaluate, accuracy there is high.

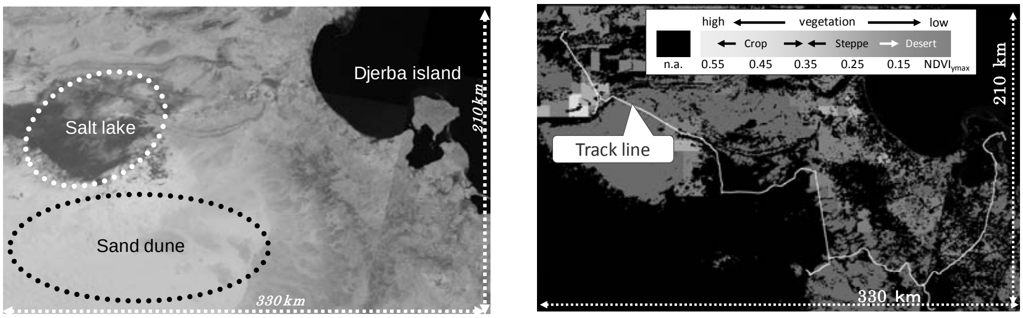

Fig. 7. The ground truth in Tunisia.

Table 1. Analysis result of PV potential.

Area	Analysis area [10^3 km^2]	Vegetation level	Area ratio [%]	PV capacity [TW]	Anural generation [10^3TWh]
Sahara	12,514	Desert	35.9	314.2	527.3
		Steppe and lower	42.6	373.1	626.0
		Crop and lower	43.9	384.9	645.0

4. Solar energy potential

The 14 % efficiency is the typical efficiency of a multi crystalline silicon PV module. Its output is 140 W at standard test conditions which are 1000 W, 25 centigrade, AM1.5. 50 % space factor was set for distance because of shadow of arrays. The performance ratio of 0.7 is also typical or lower than average considering desert conditions. Annual yield means the amount of irradiation, which can be calculated using an irradiation database. We used NASA's irradiation database which was prepared by the project SeaWiFS, Sea-viewing Wide Field-of-view Sensor[C)]. This data was evaluated by remote sensing. Resolution is 2.5° × 2.5°, 280 km × 280 km. Error is ±5W/ m^2. The data in 1990 was used. Our program calculates the irradiation and PV output of each pixel, and annual yield was calculated as 2684 h. **Table 1** shows analysis result of PV potential. For steppe vegetation level, 373 TW PV systems can be installed and it generates 626 PWh. It is 4 times as world energy demand in 2010.

5. Conclusions

The suitable area and resources for the VLS-PV systems in deserts have been estimated by the remote sensing approach. The algorithm has been improved by the integrated evaluation approach with three kinds of layers. The PV capacity is calculated with 373 TW in desert and steppe level, and the quantity of annual generation is 626 PWh. It is enormous and has a potential to mitigate the global warming and energy issues.

Acknowledgement

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Annotation

A) Global land Cover Facility web site, http://www.landcover.org/index.shtml
B) Center for Environmental Remote Sensing (CEReS) Chiba University: Twenty-year Global 4-minute AVHRR NDVI Dataset of Chiba University
C) Goddard Institute for Space Studies, New York, N.Y.: SeaWiFS Surface Solar Irradiance

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