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Assessment of PV potential in mountain areas using four Muti-Criteria Decision Methods

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ABSTRACT

In this study, Yongren County, Yunnan Province was selected as the study case, and a photovoltaic (PV) power potential assessment system based on Geographic Information System (GIS) and Multi-Criteria Decision Making (MCDM) method was used to calculate the PV power potential in mountainous areas and to estimate the levelized cost of electricity for PV power generation in mountainous areas. The results show that the ordinal priority approach (OPA)-MCDM is the best among the four different multi-criteria decision methods, and the selected optimal PV construction area fits well with the existing PV facilities, which demonstrates the effectiveness of the proposed method. The PV power generation potential is about 7861.953 million kwh, and the levelized cost of electricity is 0.3963 RMB/kWh. The estimated annual power generation capacity can meet the social power demand of Chuxiong Prefecture.

Keywords: Mountainous areas, PV, Multi-Criteria Decision Making, Generation potential, Levelized cost of electricity.

NONMENCLATURE

Abbreviations	
PV	Photovoltaic
GIS	Geographic Information System
OPA	ordinal priority approach
AHP	analytic hierarchy process
FGAHP	Fuzzy Group decision making AHP
CRITIC	CRiteria Importance Through Intercriteria Correlation
Symbols	
km^2	Square kilometre

1. INTRODUCTION

According to the Global Carbon Atlas, China's carbon emissions to reach 9.839 billion tons in 2017, accounting for about 27.2% of global carbon emissions, China has become the world's largest carbon emitter[1]. Solar energy, as an inexhaustible and renewable energy source, occupies an important position in the long-term energy strategy[2]. With the development of solar PV, the shortage of land use has become one of the main factors limiting the development of PV construction. A large amount of unused land exists in mountainous areas with abundant solar thermal resources. Therefore, it is important to build PV facilities in mountainous areas to reduce carbon emissions and promote the development of PV industry.

In order to solve the problem of less available land for PV industry development, studies have been conducted to explore the possibility of using existing infrastructure such as railroads, roads, and airports for PV power generation [3]. Meanwhile, the use of deserts, Gobi and mountainous areas for PV construction is also attracting attention [4].

In the past, many researchers have used different methods to evaluate the potential of photovoltaic power generation in different regions, but few studies have been conducted to evaluate the suitability of PV sites in mountainous areas [5–8]. The undulating terrain in mountainous areas poses great problems for the installation of PV mounts, so it is important to choose the right terrain and elevation to build PV facilities in mountainous areas. Another point is the need to consider the stability of the land. Mountainous areas are prone to landslides after heavy rains, so PV facilities

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should be built in places with low surface deformation rates.

Multi-Criteria Decision Methods can make optimal choices from multiple criteria to find out high potential development areas, and have been widely used in decision making in many fields. In this study, four Multi-Criteria Decision Methods are used for the first time to calculate the weights of each criterion and select the optimal method from them for PV power potential assessment, which provides an accurate finding of the best location for PV power generation in mountainous areas.

2. DATA AND METHODOLOGY

The main steps of the method are as follows:1) ground deformation estimation in mountainous areas using MT-InSAR method; 2) the weights of the seven evaluation criteria were calculated using analytic hierarchy process (AHP), interval type-2 fuzzy analytic hierarchy process, OPA-based MCDM approach and combinative weighting method based on Fuzzy Group decision making AHP (FGAHP) and CRiteria Importance Through Intercriteria Correlation (CRITIC), and the optimal method was selected for land suitability evaluation through comprehensive comparison; 3) evaluate PV potential and estimate levelized cost of electricity for the optimal site selection area. Fig. 1 shows the main workflow of the evaluation system.

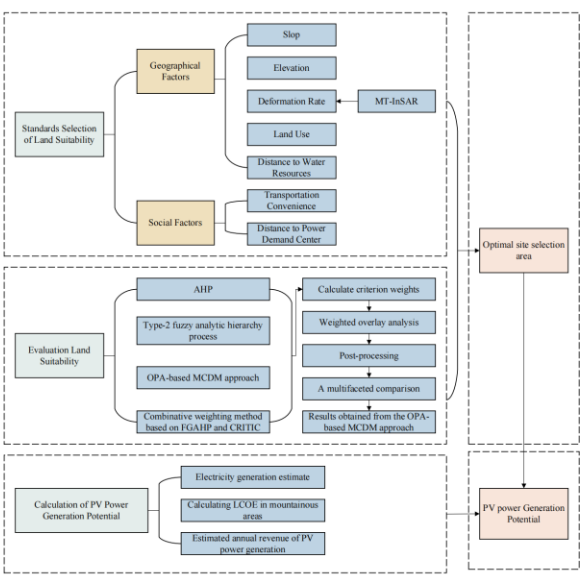

Fig. 1. Overview of research method

2.1 Determination of the weight of criterion

In order to determine the suitable area for PV power generation, suitable assessment guidelines are selected for land suitability evaluation.

2.1.1 Slop

Topographic slope affects the optimal conditions for PV module orientation and inclination, and influences the power generation efficiency of PV power plants.

2.1.2 Elevation

Elevation affects the construction cost.

2.1.3 Deformation rate

Ground deformation rate can evaluate the stability of the ground and is related to the stability of PV power generation facilities, which has an important impact on power generation efficiency and later equipment maintenance. The ground deformation from interferometric synthetic aperture radar (InSAR) were used to provide the stabilities of the mountain region.

2.1.4 Land cover

Land cover types that are not suitable for PV power generation should be excluded.

2.1.5 Transportation convenience

Transportation affects the transportation cost of PV facilities.

2.1.6 Distance to power demand center

The construction cost of transmission lines between PV facilities and power demand centers is high, and the closer the PV facilities are to the power demand centers, the more cost savings can be achieved.

2.1.7 Distance to water resources

Water can cool PV modules, thus achieving high power generation efficiency.

Based on the above considerations, this study finally determined seven criteria: terrain slope, elevation, surface deformation rate, land cover, accessibility, distance to the power demand center, and distance to water resources.

2.2 Postprocess of the land suitability results

Four methods, analytic hierarchy process (AHP), interval type-2 fuzzy analytic hierarchical process, OPA-based MCDM approach, and combined weighting method based on FGAHP and CRITIC, were used to determine the weights of these seven criteria, and the weights of each evaluation index were weighted and superimposed to obtain the final evaluation results of the suitability of PV land in the study area[7]. The spatial resolution of the obtained land suitability results is 30m, and the small and isolated area is not suitable for PV power generation construction, so a window of 300m×300m is selected, and the window with a suitability area ratio greater than 60% is identified as a suitable aggregation area for PV facility construction, which is the best site for PV power generation facility construction.

2.3 Levelized cost of electricity model(LCOE)

The LCOE model is a full life-cycle analysis method that converts expected future costs into present value[9]. Assuming that the full life-cycle LCOE of a PV facility is a constant, it can be calculated using equation (1)[10]:

$$LCOE = \frac{I_0 + \sum_{t=0}^{N} \frac{C_t}{(1+d)^t} - \frac{v_R}{(1+d)^N}}{\sum_{t=0}^{N} \frac{E_t}{(1+d)^t}} \quad (1)$$

where I_0 is the initial investment,C_t is the total cost in year t,E_t is the generation capacity in year t, N is the project lifetime, d is the discount rate, and V_R is the residual value.

2.4 Estimated power generation potential

$$3 \quad E_t = H \times IC \times \eta \times (1-r)^t \quad (2)$$

where H is the annual utilization hours of the PV system, IC is the total installed capacity, η is the generation efficiency, and r is the annual decay rate. In this study, H is taken as 1300h, the generation efficiency η is 78%, the annual decay rate r is 0.8%, and the discount rate d is 5%.

3. EXPERIMENTAL RESULTS

3.1 Study area

Yongren County is in the northern part of Yunnan Province and is extremely rich in solar energy resources. With an average annual sunshine time of 2836.4 hours, an average annual temperature of 18.8°, and a total annual average solar radiation of 6571 MJ/m2, Yongren County is second only to Lhasa in Tibet in terms of light resources and is known as the "Sunshine City of China", which belongs to the first-class area for solar energy development. Therefore, Yongren County was selected as the study area. The study area is shown in Fig. 2.

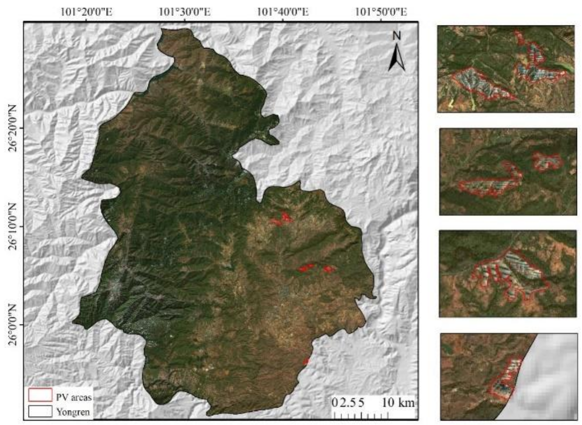

Fig. 2. Study Area Overview

3.2 Results and analysis

The weights were determined by analytic hierarchy process (AHP), interval type-2 fuzzy analytic hierarchical process, OPA-based MCDM approach and combined weighting method based on FGAHP and CRITIC, and the weights of each evaluation index were weighted and superimposed to obtain the final evaluation results of PV land suitability in the study area. The evaluation results were post-processed, and the results are shown in Fig. 3.

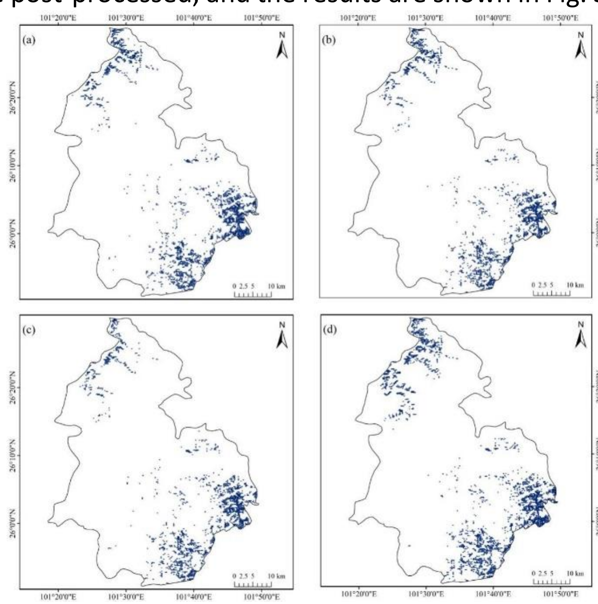

Fig. 3. The optimal site selection results for PV power generation in mountainous areas. (a), (b), (c) and (d) are the best site selection results obtained by analytic hierarchy process, interval type-2 fuzzy analytic hierarchy process, OPA-based MCDM approach and combinative weighting method based on FGAHP and CRITIC, respectively.

The best areas of PV power generation in Yongren County obtained under three different weight determination methods were 120.90km^2, 107.89km^2, 102.26km^2, 141.02km^2, and the areas falling within the actual PV construction area after cluster analysis of the weighted results of the three methods were

2.2 km^2 ,1.94 km^2 ,2.12 km^2 ,2.23 km^2 , accounting for 1.8%,1.8%, 2.08%, and 1.58% of all the best areas suitable for PV power generation, respectively. Finally the OPA-based MCDM is chosen to determine the weights of each criterion.

Six existing PV facilities in Yongren County were identified by optical images and used to verify the estimation results. Fig. 4 shows the details of the estimated PV generation area and the existing PV facilities, and all six existing PV facilities match with the optimal sites we evaluated for PV facility construction indicating the validity of the method in this paper.

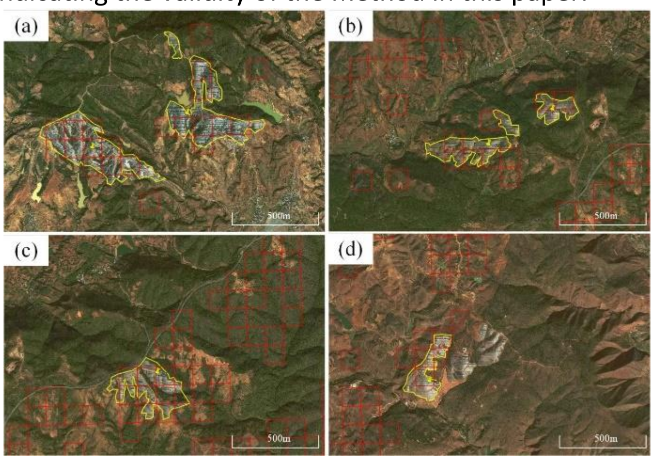

Fig. 4. Existing PV facilities and site selection results. The red rectangle is the best site selection area. The yellow polygon represents the existing PV facility area.

The potential of PV power generation is 7861.953 million kWh calculated by equation (2), and the levelized cost of electricity is 0.3963 RMB/kWh calculated by equation (1). Fig. 5 shows the social electricity consumption of Chuxiong Prefecture from 2017 to 2021, the potential of the best site for PV facilities in Yongren County can meet the social electricity consumption of Chuxiong Prefecture for one year. The power generation potential of the best site for PV facilities in Yongren County can meet the entire social electricity demand of Chuxiong Prefecture for one year.

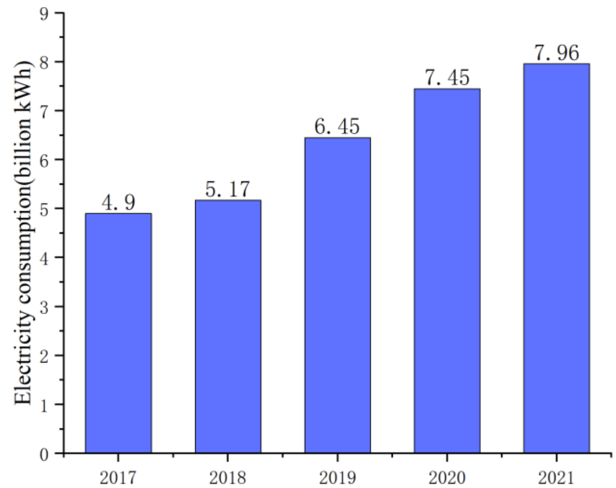

Fig. 5. 2017-2021 Chuxiong State, the whole society electricity consumption

4. CONCLUSIONS

In this study, the optimal areas of PV power generation in Yongren County obtained under three different weighting determination methods were 120.90 km^2,107.89 km^2, 102.26 km^2, and 141.02 km^2, respectively, and the areas that fell within the actual PV construction areas after cluster analysis of the weighting results of the three methods were2.2 km^2 ,1.94 km^2 , 2.12 km^2, and 2.23 km^2, respectively, which accounted for all the optimal areas suitable for PV power generation of 1.8%,1.8%, 2.08%, and 1.58%, respectively. The optimal results of the OPA-based MCDM method are the best, and the selected optimal PV construction area matches well with the existing PV facilities, which shows the effectiveness of the proposed method. The power generation potential is 7861.953 million kWh, and the levelized cost of electricity is estimated to be 0.3963 RMB/kWh, and the annual power generation can meet approximately the whole society's electricity demand in Chuxiong Prefecture.

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