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Suitability Analysis for Solar Energy System Development using GIS and AHP in Cagayan Province, Philippines

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Abstract

Renewable energy system development includes necessary and precise planning for identifying the energy potentials involving the selection of sufficient factors, criteria, methods and techniques. Establishing a solar energy system in Cagayan Valley Region is very suggestive; however, scientific reports and literature about it are lacking. This study aimed to determine a suitable location for solar energy system development and potential energy generation in Cagayan province, Philippines. It employed and demonstrated the application and combination of the geographic information system (GIS) and multi-criteria decision-making (MCDM) technique, particularly the analytical hierarchy process (AHP). Three criteria were considered, namely technical aspect (solar insolation), environmental aspect (land use-land cover and protection buffers) and economic aspect (slope, elevation and road proximity). Results showed that only 18.47% (1716.9 km^2) of the total land area was suitable for solar photovoltaic system development. With the total suitable area, a solar electricity generation potential of 139.9 TWh/year can be attained even considering the least module efficiency of 10%. This solar energy generation potential is generally higher than that of the household electricity consumption of the Cagayan Valley Region, which could be a great avenue for energy sustainability for the province and the region. With sufficient factors and criteria, the combination of GIS and AHP tool is a great technique in identifying renewable energy projects' suitability in a certain location.

***Keywords**:* analytical hierarchy process, Cagayan, geographic information system, renewable energy, solar energy suitability

1. Introduction

Renewable energy is becoming more important in the overall energy mix. This is due to the unsustainable options presented by non-renewable energy sources such as fossil fuels, which present an undesirable impact on the environment (Hernández-Callejo *et al*., 2019). Renewable energy generation is regarded as environmentally friendly, clean and safe compared with non-renewable energy sources. As mentioned by Sen (2004) and Hernandez *et al*. (2015), a shift from carbon-intensive fuels to renewable energy sources would address problems on energy both in environmental and economic terms.

The Philippines has various options on which type of renewable energy to utilize; however, there is a high regard for solar energy. The country's strong solar energy potential is attributed to its geographical location between two tropical zones. Selecting solar energy as an energy resource is very suggestive in the country. Nevertheless, the selection for a possible location for the establishment of solar energy generating system is quite challenging as site suitability selection of renewable energy systems is complex (Hernandez *et al*., 2015). The selection also requires evaluating natural physical, socio-economic and environmental conditions (Duc, 2006). This is evident as social, economic and environmental factors are interdependent; failure in one can lead to the fizzle in the entire project. This suggests adequate knowledge and information on the several energy site selection aspects in the light of technology, energy policies and economic factors.

The selection of criteria (factors and constraints) is the most critical phase since it has the most significant impact on the evaluation process. The criteria may depend on several available information, which can be obtained from literature reviews and expert consultation (Van Dael *et al*., 2012). Many studies have been conducted about site selection and investigation of solar energy availability in specific areas and locations. Charabi and Gastli (2011) used a geographic information system (GIS)-based spatial multi-criteria evaluation approach in terms of the fuzzy logic ordered weight averaging (FLOWA) to assess solar energy resources in Oman. A combination of GIS and the analytical hierarchy process (AHP) was employed by Merrouni *et al*. (2016) to assess the capacity of Eastern Morocco to host large-scale photovoltaic (PV) farms. Noorollahi *et al*. (2016) utilized fuzzy AHP (FAHP) and GIS overlaying techniques in developing a prioritization map of different regions of Iran for exploiting solar PV plants. Wang *et al*. (2016) made use of overlaying technique of remotely sensed data in the GIS environment for solar energy assessment in Tibet. A GIS-multi-criteria decision-making (MCDM) technique and AHP were employed by Asakereh *et al*. (2017) to prioritize the land of Khuzestan province in Iran for solar PV farms.

Different combinations of techniques show the advantage of its own; however, among the technique combinations used in prioritizing and analyzing areas for solar energy system assessment and development, the combination of the GIS-MCDM technique and AHP tool was mostly and widely used (Guptha *et al*., 2015; Duc, 2006; Al Garni and Awasthi, 2017). This is linked to the ability of the GIS-MCDM technique to combine distinct data with the views of energy stakeholders, public perceptions and experts' opinions in accomplishing defined objectives like solar resource assessments. Also, it can resolve complex problems mainly when multiple factors affect a single objective.

According to several authors, anchoring the decisions on comprehensive and extensive information using GIS offers several significant advantages including improved project performance, reduced power loss and minimized environmental impacts (Guptha *et al*., 2015; Al Garni and Awasthi, 2017). On the other hand, according to Taha and Daim (2013), AHP is the most applied technique compared with several approaches due to its simple structure, which allows the user to manipulate the results until the consistency is reached. Furthermore, the GIS-MCDM technique in combination with the AHP tool provides an opportunity to blend the opinions of experts and decision-makers in pairwise comparisons of numerous factors, which can be used in a GIS environment to achieve specific goals.

The possibility of solar energy system development and establishment in the Cagayan Valley Region, Philippines is very high. However, scientific reports and literature on the suitability analysis and estimation of the quantifiable solar energy potential are scant. Hence, this study was carried out to identify the suitable areas in Cagayan province for solar energy system development. The result of this study could be used as a basis for area selection and prioritization for the future establishment of a solar energy generation system.

2. Methodology

2.1 Study Area

Cagayan province is situated in the Cagayan Valley Region occupying the northeastern section of Luzon, Philippines (Figure 1). It has a total land area of 9,295.75 sq. km (PhilAtlas, n.d.). There are two types of climates within the province. The northwestern part of Cagayan including Santa Praxedes and Claveria and the eastern section along with the Sierra Madre Mountain range fall under Type II climate while the rest of the province fall under Type III (Philippine Atmospheric, Geophysical and Astronomical Services Administration [PAGASA], n.d.). On the other hand, the temperature within the province typically varies from 26 to 32°C and is rarely below 24 °C or above 33 °C (Weather Spark, n.d.). The province experiences an average solar irradiance of 1794 W/m^2/yr (National Renewable Energy Laboratory [NREL], 2014).

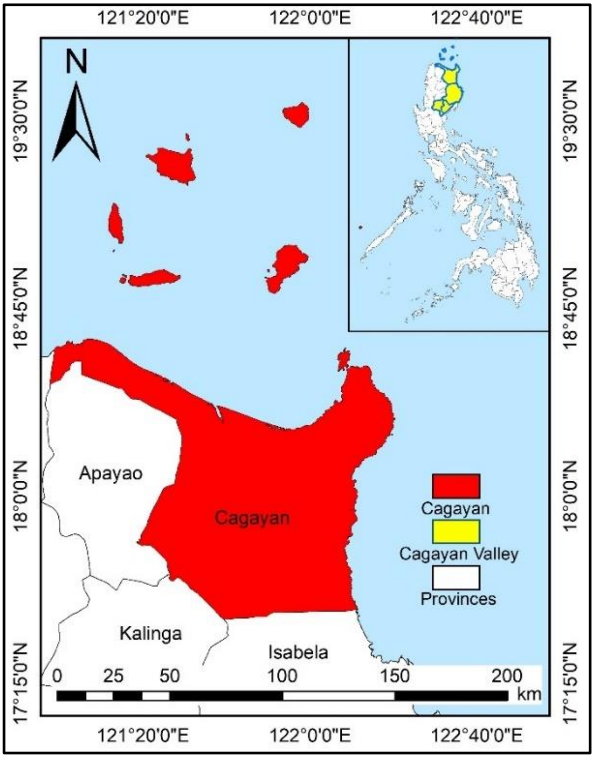

Figure 1. Location of the Cagayan province

2.2 Criteria Selection

The selection process for suitable sites for the PV system is affected by several factors and criteria, which are generally categorized as technical, economic and environmental (Charabi and Gastli, 2011). In this study, three layers were created in a GIS environment: the technical (solar insolation), economic (road proximity, elevation and slope) and environmental (land use-land cover and protection buffers) aspect layers. Each layer was given a value score from 0 and 9. Zero took the value for unsuitable sites or areas with full restrictions, while 1 to 9 got the value for suitable sites for the solar PV system. Thereafter, AHP was used to weigh and combine the three layers to create a unique layer. Finally, the land suitability layer for the solar PV system for Cagayan province was obtained (Taha and Daim, 2013; Guptha *et al*., 2015; Duc, 2006; Merrouni *et al*., 2016; Al Garni and Awasthi, 2017; Asakereh *et al*., 2017).

2.3 Technical Aspect (Solar Insolation)

Solar insolation refers to the amount of solar radiation reaching the earth's surface or any area under consideration. It is generally expressed in kWh/m^2/day. The considerable value of solar irradiation, as well as solar insolation, plays a significant role in the generation of electrical power in each location. It is considered the top criterion in the PV system site selection (Al Garni and Awasthi, 2017). A higher amount of solar insolation gives a higher potential for electricity generation (Arnette and Zobel, 2011).

In this study, the solar insolation data used was taken from Geospatial Toolkit (GST) for the Philippines of the NREL of the United States (NREL, 2014). The layer exported from the GST was imported to a GIS application. The centroids of this polygon data were determined and exported as point data. The point data were then processed using the spatial interpolation technique (Kriging interpolation) to obtain the solar interpolation data for the province.

2.4 Economic Aspect

2.4.1 Road Proximity (Distance from Major Roads)

Proximity to major roads on the possible location for a renewable energy system is an indispensable factor that determines the easiness and difficulty of carrying renewable energy (RE) utilities (Asakereh *et al*., 2017). Also, distance to road links directly affects construction costs – that is, the less accessible location tends to have higher transportation costs and construction cost in totality. Different studies have considered various maximum acceptable distances. Baban and Parry (2001) used 10 km, while Asakereh *et al*. (2014) and NREL (2008) utilized 40 km. In this study, 10 km proximity was used making areas more than 10 km away from the road unsuitable. Also, a 150-m buffer zone from major roads was employed as suggested and used by Dunsford *et al*. (2003).

2.4.2 Slope and Elevation

Slope and elevation are two of the basics of topography. Land with a steep slope and high elevation is not recommended for solar projects by almost all studies – land with a mild slope and low elevation helps to avert the high construction cost. Locations of high slopes and elevations were not considered in the study. This was due to the restrictions on the construction and transport of equipment and RE facilities. According to Sánchez-Lozano *et al.* (2014), a slope between 0 and 30% is the best, while more than 50% is the worst. Bravo *et al.* (2007) used a slope greater than 10% as unsuitable. Mondino *et al.* (2014) utilized 15% as restrictions. In contrast, Sun *et al.* (2013) and Aydin *et al.* (2013) employed a slope of 7% as the suitability limit. The present study considered slope less than or equal to 15% and an elevation not greater than 500 m as the restriction for the suitability.

2.5 Environmental Aspect

2.5.1 Land Use-Land Cover Aspect

The existing use of a portion of land determines its feasibility on the establishment of other infrastructure. The land use-land cover aspect was considered in the selection to eliminate areas that were preserved as a natural habitat and those areas that are dedicated to industrial/commercial or agricultural purposes (Sun *et al.*, 2013). Other areas that were eliminated as potential sites are those that are reserved for perennial crops, marine and natural reserves and protected areas or areas of wildlife designations (Bravo *et al.*, 2007; Sun *et al.*, 2013; Mondino *et al.*, 2014).

2.5.2 Protection Buffers

The establishment of solar farms nearby residential or built-up areas can harm rural and urban growth and population (Uyan, 2013). As recommended by several studies, a protection buffer for residential must be employed. In the study conducted by Baban and Parry (2001) and Aydin *et al*. (2013), a protection buffer of up to 500 m was used.

An environmental protection buffer for airports was also employed in this study. According to the Federal Aviation Administration (2018), the surface of a solar PV is generally reflective. The development of solar farms may have undesirable impacts both when airplanes are taking off and landing. It also causes a distraction to air and the air traffic control system.

Moreover, the distance of threats to protected areas has been underscored by several works in realizing conservation goals (Bravo *et al*., 2007; Arnette and Zobel, 2011; Sun *et al*., 2013; Mondino *et al*., 2014). The establishment of any structure adjacent to any conservation or protected areas may inhibit land cover change, and habitat loss and fragmentation (Hernandez *et al*., 2015). For the protection of natural reserves and environmental designation, a 1000-m buffer zone was recommended by several studies (Arnette and Zobel, 2011; Asakereh *et al*., 2014; Watson and Hudson, 2015).

In this study, a residential buffer distance of 500 m was taken; areas inside the 500-m buffer zone were considered not suitable. Furthermore, a 1,000-m protection buffer was utilized both for airport facilities and protected areas.

2.6 Analytical Hierarchy Process (AHP)

The analytical hierarchy process is one of the commonly used MCDM techniques developed by Saaty in the 1970s for resolving unstructured problems (Saaty, 1980). It can handle decision-making problems requiring a high degree of flexibility, reliability and acceptability (Asakereh *et al*., 2017). In the AHP spatial analyst tool, a pairwise comparison was undertaken. As recommended by Saaty (1980), the consistency ratio (CR) must not be greater than 0.10. Accordingly, with AHP undertaken in a GIS environment, the suitability map will be produced displaying the distribution of both suitable and not suitable areas with their corresponding value scores across the study area. A site is not suitable if the value score is 0 and suitable if the value score is between 1 and 9. This output map was further reclassified using the suitability index shown in Table 1.

Table 1. Suitability index

Suitability	Value score
Highly suitable (HS)	6-9
Moderately suitable (MS)	1-5
Not suitable (NS)	0

2.7 Solar Energy Conversion

The potential electricity generation of a particular site using solar energy can be determined by considering several factors including average annual solar radiation intensity, area of the site and the efficiency of the solar energy conversion system (Charabi and Gastli, 2011; Asakereh *et al.*, 2017). To calculate the potential solar electricity generation, Equation 1 was used.

$$GP = SR \times CA \times AF \times \eta_{Tot} \tag{1}$$

where:

GP = solar electricity generation potential per year (kWh/year)
SR = solar radiation intensity per year (kWh/m^2/year)
CA = area of the site selected (m^2)
AF = area factor
η_{Tot} = solar energy conversion efficiency

The efficiency of the solar energy conversion was determined using Equation 2 as used by Asakereh *et al*. (2017) and Bergamasco and Asinari (2011).

$$\eta_{Tot} = \eta_{Mod} \times \eta_T \times \eta_{AZ} \times \eta_{inst} \tag{2}$$

where:

η_{Mod} = module efficiency
η_T = temperature variations
η_{AZ} = module installation angle efficiency
η_{inst} = installation efficiency

The values used in the estimation of annual solar energy generation for Cagayan province are presented in Table 2. The values of SR and CA were based on the average solar radiation intensity on suitable sites and the area of the suitable sites, respectively. As highlighted by a number of literature, three different module efficiencies representing three different scenarios were employed in this study (e.g., 10, 15 and 20%) (Bergamasco and Asinari; 2011; Charabi and Gastli, 2011; Asakereh *et al.*, 2017). The total efficiency corresponding to these three scenarios is presented in Table 3.

Table 2. Values used in the estimation of annual solar electricity generation

Quantity (Unit)	Value	Source
SR ($kWh/m^2/year$)		NREL (2014)
CA (m^2)		Suitable Area
AF (%)	70	Asakereh *et al*. (2017) Charabi and Gastli (2011)
η_{Mod} (%)	10 15 20	Asakereh *et al*. (2017)
η_T (%)	90	Asakereh *et al*. (2017) Bergamasco and Asinari (2011)
η_{AZ} (%)	90	Asakereh *et al*. (2017) Bergamasco and Asnari (2011)
η_{inst} (%)	80	Asakereh *et al*. (2017)

Table 3. Total efficiency on three scenarios

Quantity	Scenario A	Scenario B	Scenario C
η_{Mod} (%)	10	15	20
η_T (%)	90	90	90
η_{AZ} (%)	90	90	90
η_{inst} (%)	80	80	80
η_{Tot} (%)	6.48	9.72	12.96

3. Results and Discussion

3.1 Technical Aspect (Solar Insolation) and Solar Energy Potential

The intensity of solar insolation in Cagayan province is shown in Figure 2. The average minimum monthly solar insolation was 3.94 $kWh/m^2/day$ that usually occurs during December months while the average maximum monthly solar insolation was 5.93 $kWh/m^2/day$, which occur in April months.

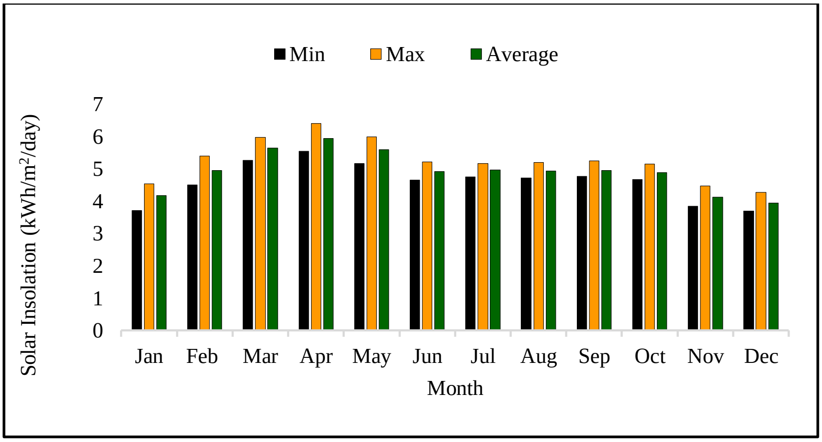

Figure 2. Minimum, maximum and average solar insolation for each month of the year

The average annual solar insolation was 4.92 kWh/m^2/day. According to NREL (2008), this value belongs to the good class (4-5 kWh/m^2/day) for solar PV system development (Asakereh *et al*., 2017). This suggests that the whole Cagayan province is suitable for solar PV system development. However, the potential of the province on solar energy generation does not only depend on solar insolation or solar radiation intensity but is also based on other factors including environmental and economic factors.

The potential annual solar energy generation potential of the province could be in the range of 757.2 TWh/year to 1,514.4 TWh/year when constraints considered were overlooked. On the other hand, the solar radiation intensity distribution over the province is shown in Figure 3 revealing that solar radiation intensity increased from east to west direction.

3.2 Economic Aspect (Road Proximity, Slope and Elevation)

The economic aspect of a certain project is of great consideration as it states the feasibility of a project in financial terms. It also gives a rough estimation of the cost and the benefits of the project.

As observed, most of the areas in the province have a slope less than or equal to 15% and an elevation of not greater than 500 m (Figure 4). The areas were equivalent to 85.1% (7,910.7 km^2), while areas with good accessibility to road links were 68% (6,321 km^2) (Figure 5). Although most of the areas (considering these two constraints) gave large suitable areas, the combination of which reduced the suitable area since some suitable areas in each aspect did not overlap.

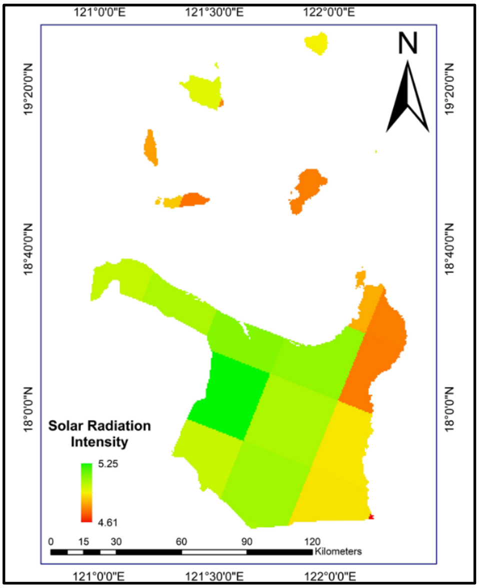

Figure 3. Solar radiation intensity in Cagayan province

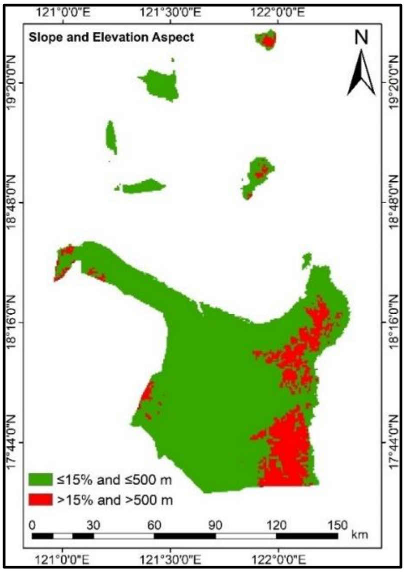

Figure 4. Reclassified slope and elevation aspect

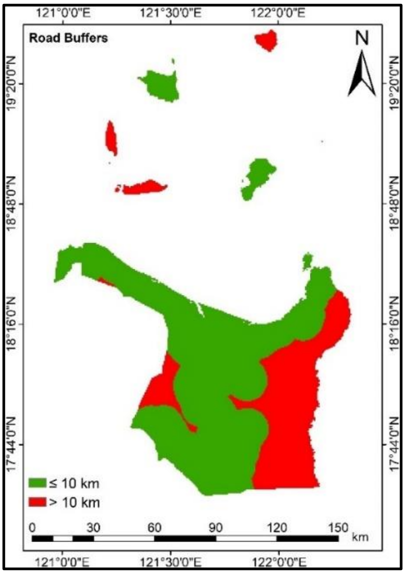

Figure 5. Reclassified road proximity

The overall areas considered as economically viable for solar PV system development (Figure 6) in the province were equivalent to 65.7% (6107.3 km^2). Considering these constraints and restrictions, the solar energy potential of the province reduced by 34.3% giving a solar energy generation potential of 497.5 to 995.0 TWh/year.

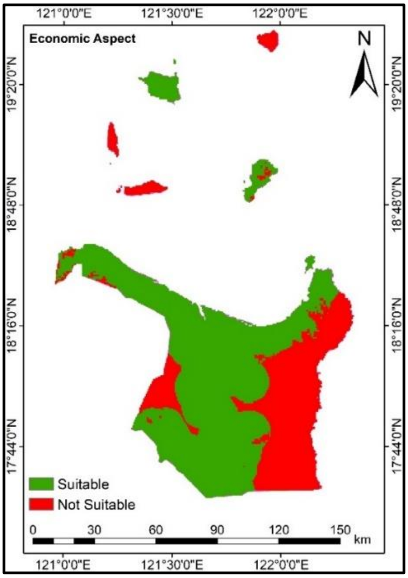

Figure 6. Solar energy suitability considering economic aspect

3.3 Environmental Aspect (Land Use-Land Cover and Protection Buffers)

Figures 7 and 8 show the layers for land use-land cover aspect and buffer protection constraints, respectively. As observed, the two restrictions were overlapping, which reduced the possible area for solar PV system development. These restrictions included agricultural lands, water bodies, protected areas, forest areas/reserves, and built-up and residential areas. It also comprised the protection buffers employed for residential and built-up areas, protected areas and airport facilities.

As an agricultural and forest province, the environmental constraints constituted the most significant percentage of the reduction of suitable areas. The restriction areas corresponded to 56.2% of the total land area or equivalent to 5,224.2 km^2. About 64% (3,343.5 km^2), 31% (1,619.5 km^2), and 3% (156.7

km^2) of the unsuitable areas were protected areas and forest reserves, agricultural land and water bodies, respectively.

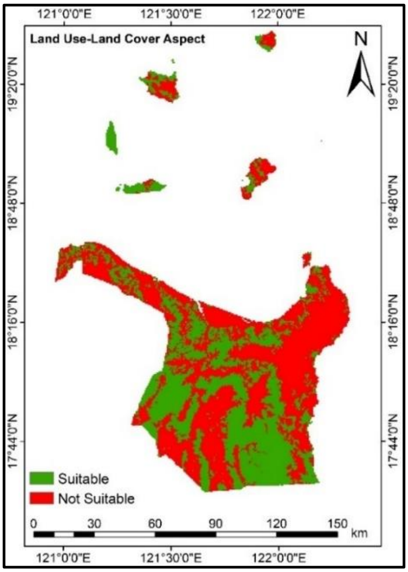

Figure 7. Solar energy suitability considering land use-land cover aspect

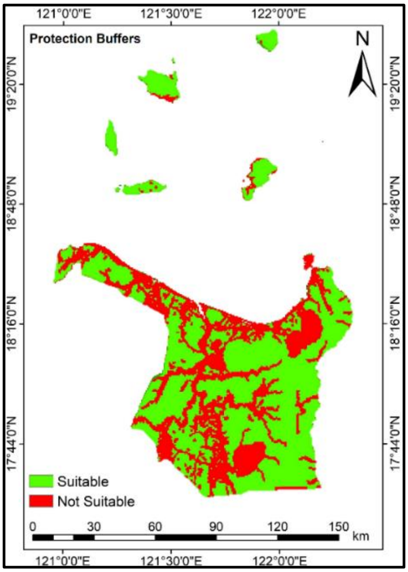

Figure 8. Solar energy suitability considering Protection buffers

In total, 43.8% (4,071.5 km^2) of the total land area of the province is exploitable for solar PV system development (Figure 9) considering environmental constraints and protection buffer aspects. With these constraints and restrictions, the overall solar energy potential of the province reduced by 56.2%, which resulted in a solar energy generation potential of 331.7 to 663.3 TWh/year.

3.4 Solar PV Land Suitability

The solar PV land suitability was determined by combining and comparing the three main criteria, namely technical (solar insolation), environmental (land use-land cover and protection buffers) and economic (slope, elevation, and road proximity) aspects. The determination process involved a pairwise comparison with criteria weight estimation following the guidelines of the AHP technique. The weights and pairwise comparison results are shown in Table 4. The technical aspect (solar insolation) had the highest weight (76.41%) followed by the environmental aspect (land use-land cover and protection buffers) (12.10%) and the economic aspect (slope, elevation and road proximity) (11.49%). The output map of the AHP tool was further reclassified into three following the suitability index presented in Table 1.

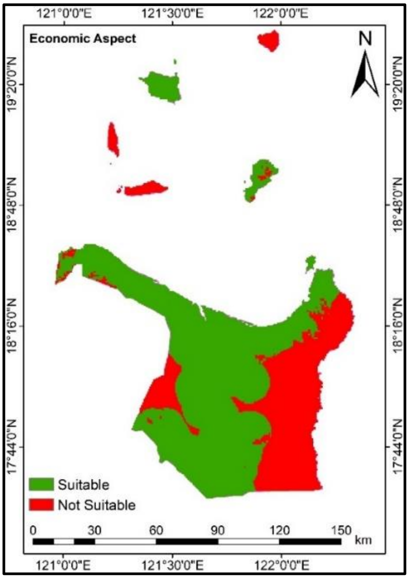

Figure 9. Solar energy suitability considering environmental aspect

Table 4. Pairwise comparison matrix

Objective	Technical aspect	Environmental aspect	Economic aspect	Weight
Technical aspect	1	6	7	0.7641
Environmental aspect	0.167	1	1	0.1210
Economic aspect	0.143	1	1	0.1149

The final solar PV land suitability map (Figure 10) shows that only a small portion of the total land area of the province has excellent potential for the development of solar PV. An area of about 18.47% (1,716.9 km^2) was suitable, and 81.53% (7,578.8 km^2) was not suitable. The suitable areas were further reclassified into two: moderately (14.56% or 249.9 km^2) and highly (85.44% or 1,466.9 km^2) suitable.

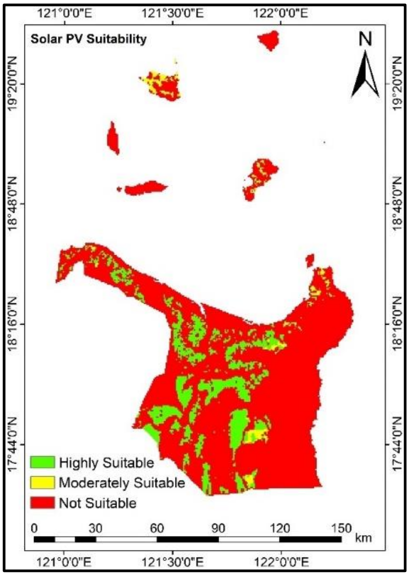

Figure 10. Land suitability for the solar PV system

The small potential areas, however, could still be sufficient for generating large amounts of solar electricity. Table 5 presents the solar energy generation potential using a solar PV system.

Table 5. Solar energy potentials

Class name		Not suitable	Moderately suitable	Highly suitable
Area (%)		81.53	2.69	15.78
Energy generation potential (TWh/year)	A[a]	617.4	20.4	119.5
	B[b]	926.0	30.6	179.2
	C[c]	1229.0	40.7	239.0

[a]Total energy conversion efficiency is 6.48%; [b]total energy conversion efficiency is 9.72%; [c]total energy conversion efficiency is 12.96%.

Using Equations 1 and 2, the solar energy potentials for suitable areas (total of moderately suitable and highly suitable) for scenarios A, B and C were 139.9, 209.8 and 279.7 TWh/year, respectively. In any of the three scenarios, the amount of annual solar energy generation potential was unarguably higher than that of the household electricity consumption in the Cagayan Valley Region for 2011 (79.19 GWh) (Department of Energy, 2011). With this value, it is evident that electricity generation through solar PV systems could be a great avenue towards energy sustainability in Cagayan province and the Cagayan Valley Region.

4. Conclusion

The study found that Cagayan province is generally good for solar PV system development with an average annual solar insolation of 4.92 kWh/m^2/day. Solar energy suitability decreased by 56.2% when environmental constraints and protection buffers were considered and decreased by 34.3% when economic aspects were taken into account. About 85.1% (7,910.7 km^2) of the total land area of the province has an elevation of 500 m and below and a slope of 15% and below; 68% (6,321 km^2) has good accessibility to road links (road networks). Protected areas and forest reserves, agricultural land and water bodies constituted 56% (5,224.2 km^2). With the three criteria considered, 18.47% (1,716.9 km^2) was found suitable for solar PV system development in the province, while 81.53% (7,578.8 km^2) was not suitable. The province has great potential for generating solar electricity through photovoltaic arrays which could reach up to 139.8 TWh/year. This solar energy generation potential could be attained even at the least conversion efficiency (scenario A) of 6.48% considered in this study. This generation potential is more than enough to supply the household electricity needs of the Cagayan Valley Region. This could be a great opportunity for energy sustainability for the province. With sufficient factors and criteria, the method combining the GIS and the AHP tool is a good technique in identifying renewable energy projects' suitability in a certain location.

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