Potential areas for the development of renewable energy system in Kepulauan Seribu Regency: case study for tourism sector in Putri Island and Ayer Island

N Kamilah¹, T Nurlambang¹ and M H Susilowati¹

¹ Department of Geography, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok 16424, Indonesia

e-mail: naurah.kamilah@ui.ac.id

Abstract. Kepulauan Seribu Regency is one of the priorities of tourism development areas in Indonesia which triggers an increase in electricity demand as one of the primary needs of tourism activities. The existing condition of energy fulfillment for resort islands is diesel power plants (standalone). Meanwhile, renewable energy sources can be used as energy source in Kepulauan Seribu Regency. The purpose of this study is to find out the potential of energy that can be produced by renewable energy system based on the area suitability of communal photovoltaic and offshore wind turbine using Spatial Multi Criteria Analysis method. The results indicate that based on the mapping of the suitability area, the renewable energy system that has the potential to be developed on Putri Island and Ayer Island is a communal photovoltaic system, while the wind turbine system is not suitable for both islands. The study concluded that the potential energy that can be generated by Photovoltaic system is found greater in Putri Island which is located in the North Kepulauan Seribu if it is compared to Ayer Island which is located in the South Kepulauan Seribu.

1. Introduction

Kepulauan Seribu Regency is a group of small islands off the north coast of Jakarta, the capital of Republic of Indonesia. As one of the focus goals in Kepulauan Seribu Regency is the development of areas concentrates in maximizing the tourism sector. Kepulauan Seribu is targeted to be one of ten priorities of Kawasan Strategis Pariwisata Nasional (KSPN) or Strategic Area for Tourism since 2011 and is included in the Republic of Indonesia Regulation No. 50 Year 2011 which functions to organize the National Tourism Development Plan. Tourist destination in the Kepulauan Seribu Regency consists of island residents and island resort [1]. Two of the resort islands that become the top-visited islands and serve to provide the most growing secondary tourism facilities are Ayer Island and Putri Island. The demand in the sector of tourism facilities due to increased tourism activities can be indicated to an increase in electricity needs [2]. The supply of energy for resort islands has depended on innate energy sources which came from diesel power through the use of standalone PLTD. Meanwhile, islands have the potential of solar and wind energies which can be used as the power plants to fulfil the needs of energy [3] as the use of renewable energy.

The renewable energy system has determinants for the system’s placement in particular areas in order to produce the optimal energy. These determinants are divided into physical area and inhibiting variables [4]. The determination of potential areas for system implementation can be discovered by mapping the available resources and selecting suitable areas for the placement of power plants.
using spatial analysis through Spatial Multi Criteria Analysis (SMCA) method. The combination of GIS-MCDM methods (Geography Information System and Multi Criteria Decision Making) have been used in various city planning studies, urban infrastructure, and the recent energy-related applications [5]. The combination of GIS and MCDM can be an appropriate method in determining areas of suitability for the utilization of renewable energy systems [4]. This study purposes in examining the suitability of the development of renewable energy systems, specifically the photovoltaic (PV) and offshore wind turbine systems in Ayer Island and Putri Island. This study will seek on the scale of potential energy that can fulfill the electricity needs on these islands.

2. Materials and Methods

2.1 Study Area
The representations of resort islands that became the top-visited islands and serve to provide the most growing secondary tourism facilities are Ayer Island and Putri Island. Ayer Island is located in the North Kepulauan Seribu, while Putri Island is located in the South Kepulauan Seribu. Figure 1 shows the exact areas of the two islands.

![Figure 1. The location of Ayer Island and Putri Island which represents the study areas of this research Source: Badan Informasi Geospasial (Geospatial Information Agency of Indonesia), 2020](image)

2.2 Methods
Spatial Multicriteria Analysis (SMCA) is used as the method of this study, and the method used is based upon the mapping of factor and constraint variables. SMCA is one of the methods in the decision-making process at regional planning which uses the simulation model concerning to several criteria and factors. Weighted overlays are a technique used in measuring the scale of values of several different criteria. Weighted overlays combine GIS and MCA analyzes [6]. Every factor does not always have the same weight, the urgency of each factor depends on the purpose of its use. The weighting of variables used in this study is the result from analytical hierarchy process method with experts.

2.2.1 Variable for suitability area of photovoltaic system
Based on previous reviews of suitability area for PV technology, researchers used factor variable and constraint variable [4,5,7,8]. Factor variable consisting of the annual average GHI, the average annual wind speed, altitude, slope, aspect, distance from water bodies, distance from cities, distance from settlements, distance from transmission network. Constraint variable consisting of the built areas, areas of tourist destination, national park, mangrove cultivation, protected areas, and catchment areas.

a. Global Horizontal Irradiance. GHI is the total amount of radiation received by horizontal surfaces on the ground [9]. In general, the efficiency of Photovoltaic (PV) is high in sunny areas and has minimum radiation of 3.5 kWh/m²/year [4]. The Global Horizontal Irradiance (GHI) data obtained is the raster data from Global Solar Atlas. Each island has different GHI value. The GHI data was confirmed by measurement in the field. GHI is one of the factor variables which calculated to find out the potential area for a PV system.

b. Distance from tourism secondary facilities. The factor of distance towards the object of secondary facilities needs to be concerned for the purpose of photovoltaic system efficiency. The closer it is to the secondary facilities, the greater the value of area suitability. This study has conducted validation and observation of field survey to determine the location of secondary facilities which exists on Ayer Island and Putri Island. The plotting result is then delineated into the area of secondary facilities on each island. The Euclidian range is calculated from the outermost delineation line.

c. Distance from coastline. The Euclidian range is calculated from the outermost island based upon the coastline data. The range processes are performed through ArcGIS feature, including multiple ring buffer which goes into the mainland island from the coastline. The class of range used is classified according to the criteria of variable in the suitability matrix.

d. Constraint area. Constraint area is an area that does not allow the construction of photovoltaic devices due to certain land uses or functions. The data of the land use is used to discover the built areas, areas of tourist destination, national park, mangrove cultivation, protected areas, and catchment areas on an island to which the suitability areas will be established. The constraint area is the result of data overlay from the built areas, conservation areas, and catchment areas.

2.2.2 Suitability area of wind turbine system
The data process in obtaining the potential area of wind turbines went through the use of Spatial Multi Criteria Analysis (SMCA) with the Analytical Hierarchy Process method. The limit range in determining the area of suitability is 2 kilometres from the coastline of the island in order to minimize the cost factor for turbine construction. The suitability area of wind potential is affected by variables of the wind speed’s average annual climate, location (the depth of the sea and the distance from the island), and constraint variable, including conservation area.

a. Wind speed. Wind speed is the most significant factor in determining the proper location for wind turbine utilization. In determining the suitable location for wind power plants, the wind speed is regularly monitored for at least one year or more [10]. The areas which possess 4.4 m/s wind speed are considered as good areas for the development of wind power [11]. The average wind speed data which are also categorized as raster data are obtained from Indonesian wind prospecting. The average value of wind speed can be classified into three classes that match the criterion class variable on the following suitability matrix on Table 4.
b. **Distance from the island.** The distance from the settlement needs to be concerned in determining the proper location of the wind turbine in regard to the consideration of noise and safety in a certain area [12]. The further the distance from the settlement, the better it is to be the suitable location of the wind turbine installation. The Euclidian range is calculated from the outermost island based upon the coastline data. The class of range used is classified according to the criteria of variable on the following suitability matrix.

c. **Depth of the sea.** Bathymetry is a measurement of the sea depth for both elevation as well as the seabed depression in which it provides topographic information regarding the seabed and the structure of the sea depth [13]. It will be getting worse if the bathymetry increases because the maximum bathymetry depth is 60 m for installing wind turbine technology [12]. Moreover, data of ocean depth was obtained from the General Bathymetric Chart of the Oceans. The bathymetric data was then divided into three classes according to the variable of criterion class on the following suitability matrix on Table 4.

d. **Constraint area.** In this study, the constraint area in determining the suitability area of offshore wind turbine consists of conservation areas and built areas. The conservation areas are discovered based on the map data of conservation area from Directorate for Conservation of Areas and Fish Species, Ministry of Marine Affairs and Fisheries in the form of the zoning data in Kepulauan Seribu National Park and coral reef areas.

2.2.3 Data

There are two types of data used in this study, secondary data and primary data. Secondary data is data obtained from the relevant agency or service that owns the data. While primary data is data from findings in the field. The following Table 1 consists of the primary and secondary data of this study.

**Table 1.** Research variable data of potential areas of PV systems and offshore wind turbines

| Data Type       | Data                                | Data Source                                                                 | Information |
|-----------------|-------------------------------------|----------------------------------------------------------------------------|-------------|
| Physical condition | Coastline map                      | DCKTRP - Jakarta’s Office of Public Works - Human Settlements and Spatial Planning (2016) | 1: 25,000   |
|                  | Landuse map                         | DCKTRP - Jakarta’s Office of Public Works - Human Settlements and Spatial Planning (2016) | 1: 25,000   |
|                  | Administrative map                  | BIG - Geospatial Information Agency of Indonesia (2017)                    | 1:25,000    |
|                  | Bathymetry map                      | British Oceanographic Data Center, General Bathymetric Chart of the Oceans (GEBCO) (2019) (https://www.bodc.ac.uk/) | 1Km x 1Km   |

| Climate condition | Annual average solar radiation (GHI) data | Global Solar Atlas https://globalsolaratlas.info/downloads/indonesia tahun 2018 | 90 X 90 m   |
|                  | Map of the annual average wind speed    | Wind Energy Resources of Indonesia http://indonesia.windprospecting.com/ tahun 2018 | 1Km x 1Km   |

| Data Primer       | Validation of location tourism secondary facilities | Field survey | GPS |

2.3 **Analytical Hierarchy Process (AHP) Expert Judgement**

The suitability matrix in this study was made by modifying the similar previous studies in terms of the similar research and regional character. The weighting of each variable of suitability area is discovered based on Analytical Hierarchy Process (AHP) result in which this study has conducted interviews from the experts to obtain the weighting for each variable of suitability area. The interviewees of this study are experts in the field of renewable energy.
The weighting of variable of the suitability area is based upon the interview results with five experts in the field of renewable energy, geography and energy education, electricity, photovoltaic and wind turbine systems, as well as energy-related policy makers. They are from several institution which are PPSDM KEBTKE (Center for Electricity, New Energy, Renewable and Energy Conservation Human Resources Development), Faculty of Engineering University of Indonesia, and Kookmin University. The following list includes the expertise of interviewees regarding this study to find out the weighting of factor variable in renewable energy system:

1. Renewable energy educator from PPSDM KEBTKE (will be defined as experts no. 1)
2. Renewable energy expert from PPSDM KEBTKE (will be defined as experts no. 2)
3. Profesor from Faculty of engineering, Universitas Indonesia (will be defined as experts no. 3)
4. Doctoral Researcher of Sustainable Energy, Kookmin University (will be defined as experts no.4)
5. Doctoral Student of Sustainable Energy, Kookmin University (will be defined as experts no.5).

2.4 SMCA
An assessment on suitability area of the optimal renewable energy development in fulfilling the energy for the tourism sector in Kepulauan Seribu is carried out through an overlay analysis or Spatial Multi Criteria Analysis (SMCA) alongside with the quality of variable that has been gained by the method of AHP. The analysis on the suitability of potential areas deploys the weighted overlay method for the suitability areas of the energy use in which it is carried from PV system and wind turbine.

After conducting the weighted overlay based on the existing quality of variable, the suitable areas for solar photovoltaic utilization and the suitable areas for wind turbine installation can be obtained. Furthermore, these will be classified based on class criteria with the categorization of suitable, less suitable, and not suitable. The availability of energy produced from solar photovoltaic and wind turbine technology can be estimated based on the suitable areas which exist on the maps of these areas for potential use of Solar Photovoltaic and wind turbine. Yue and Yang [14] estimate the energy that can be produced from wind energy potential in an area can be calculated using equation (1).

\[
\hat{P} = P_{\text{rated}} \times CF \\
\hat{P} = P_{\text{rated}} \times \left(0.087VA - \frac{P_{\text{rated}}}{D^2}\right)
\] (1)

\(\hat{P}\) is the wind energy Output (kW), \(index\) is the power produced by the wind turbine (kW), \(CF\) is the Capacity Factor (considered as 1), \(VA\) is the average wind speed (m/s), and \(D\) is the diameter of the turbine (m). While Doorga et al., [4] estimate the energy that can be generated from the potential of solar energy in an area of the potential area can be calculated using equation (2).

\[
GP = SR \times CA \times AF \times \eta \times CF \times 365
\] (2)

\(GP\) is the potential for electricity generation per year (kWh/m²/year), \(SR\) is the annual average solar radiation for a suitable region (kWh/m²/day), \(CA\) is a calculated Area of the appropriate region (m²), \(AF\) is a fraction of the total area that can be covered by PV panels (0.70), \(\eta\) represents solar panel efficiency (30%), and \(CF\) is a conversion factor (0.28).

3. Results and Discussions
3.1 AHP Result
Table 2 shows the calculation of AHP to determine the weight of each variable. Based on the results of AHP with the involvement of experts, The AHP data results for offshore wind turbine system revealed that the variable which had very high effects was the wind speed at 61%, bathymetry at 9%, and the distance from the settlement at 30%. The AHP data results for PV system revealed that the variable which had very high effects was GH1 at 60%, Distance from secondary facility at 9%, and the distance from coastline at 30%. The result of calculation will be the basis of the suitability matrix which can be seen on Tables 3 and 4.

The factor variable is overlaid using a weighted overlay based on the weight of each variable. Then, the results will be overlaid with the constraint region. Spatial multi criteria analysis is performed using
a the suitability matrix with variable weights obtained based on the results of AHP Expert judgment. This following Table 3 and Table 4 is the suitability matrix for assessing the suitability of PV and Wind Turbine system placement.

### Table 2. Results of priority weighting based on expert judgment (AHP Method)

| Criteria                  | Technology             | Expert Number | Mean |
|---------------------------|------------------------|---------------|------|
| Annual average wind speed | Wind turbine           | 0.76 0.21 0.70 0.71 0.66 0.61 |
| Bathymetry                | offshore system        | 0.14 0.08 0.10 0.06 0.07 0.09 |
| Distance from secondary facility |              | 0.10 0.71 0.20 0.23 0.28 0.30 |
| Total                     |                        | 1 1 1 1 1 1.00 |
| GHI                       | PV system              | 0.74 0.62 0.68 0.22 0.76 0.60 |
| Distance from secondary facility (m) | Wind turbine          | 0.19 0.31 0.21 0.70 0.15 0.32 |
| Distance from coastline   |                        | 0.07 0.07 0.11 0.08 0.09 0.08 |
| Total                     |                        | 1 1 1 1 1 1 |

### Table 3. Potential areas’ matrix of the PV system with AHP

| Criteria                  | Weight (%) | GHI (kWh/m²/day) | Value         |
|---------------------------|------------|-----------------|---------------|
|                           |            | 60              | No potential | Less potential | Very potential |
|                           |            | <3.5            | 4             | >4             |
| Distance from coastline (m) | 8          | 50              | 100           | >100           |
| Distance from secondary facility (m) | 32        | 50              | 100           | >100           |
| Constraint area            | -          | Conservation Areas, forests, mangroves, settlements | Empty land, Shrub, settlements | Empty land, Shrub, settlements |

### Table 4. Potential areas’ matrix of the Wind Turbine system with AHP

| Criteria                  | Weight (%) | Value         |
|---------------------------|------------|---------------|
|                           |            | No potential | Less potential | Very potential |
| Annual average wind speed (m/s) | 61         | <3.8          | 3.8 – 4.5      | >4.5           |
| Bathymetry (m)            | 9          | >20           | <10            | 10-20          |
| Distance from secondary facility (m) | 30       | <50           | 50-100         | >100           |
| Constraint area            | -          | Conservation Area | Non-Conservation Areas | Non-Conservation Areas |

3.2 Suitable Area for Photovoltaic System
The variable of the distance from secondary facilities is calculated from the outermost secondary facilities’ area in each island. The area of secondary facilities is the result from delineating the locations which are being the area of secondary facilities. The data of secondary facility location were obtained
from the result of plotting field survey and the map of land use. The following Figure 2 and Figure 3 are locations of secondary facilities in Ayer Island and Putri Island.

![Figure 2. The location of secondary facilities in Ayer Island](image1)

![Figure 3. The location of secondary facilities in Putri Island](image2)

After discovering the location of secondary facilities, there exists the area of suitability based on the variables. Figures 4 and 5 are the maps of suitable areas of a photovoltaic system in each island.
The result of weighted overlay the variable above based on the matrix in Table 5 generates the photovoltaic system's area of suitability as it can be seen on the following Figures 6 and 7. From the the map above, the area of suitability in Ayer Island takes 39.9% of the suitable area, 13.9% is included as less suitable area, and the rest of 46.1% is not a suitable area for photovoltaic system installation. In Putri Island, there is found that the area of suitability is 49.15%.

Results revealed that Putri Island has more energy potential which is emanated from photovoltaic system because the scale of suitable area in Putri Island is found larger than the scale of suitable area in Ayer Island. These facts are exhibited in Figures 6 and 7.

| Island Name | Suitable area (m²) | SR (kWh/m²/day) | Energy produced (kWh/year) |
|-------------|--------------------|-----------------|----------------------------|
| Ayer        | 25,951.26          | 5.07            | 28,238,177.3               |
| Putri       | 40,751.55          | 4.87            | 4,259,349.6                |
3.3 Suitable Area for Wind Turbine

Mapping the suitable area of wind turbine technology in Ayer Island is carried out by overlaying the map of suitable area. The limit range in determining the area of suitability is 2 kilometers from the coastline of the island in order to minimize the cost factor for the turbine installation. Figure 8 is the map of offshore wind turbine suitability variable in Ayer Island. The overlay result of each variable in Figure 8 can be found in Figure 9.

Figure 9 shows that the area in Ayer Island is not considered as the suitable area for the installation of wind turbine technology. The rationale indicated that the result is caused by the wind speed in Ayer Island in which the wind speed is not categorized suitable. The wind speed blows between 4.24 m/s to 4.30 m/s, so this does not fit into the standardization of a suitable area. The areas which are not suitable for the wind turbine installation are on coral reefs areas, on shallow sea depths, as well as the distance that is less than 50 meters from the coastline.

The average wind speed in Kepulauan Seribu gradually increases and becomes higher in the north area of Kepulauan Seribu. Putri Island is located in the North Kepulauan Seribu in which Putri Island has greater wind speed compared to Ayer Island. The wind speed range of 4.52 to 4.76 m/s is classified as the most fit wind speed. The existence of conservation zone of Kepulauan Seribu National Park which is included as the constraint area causes this area not suitable for the wind turbine technology installation.
Figure 8. Offshore wind turbine system’s area of suitability variable in Ayer Island

Figure 9. Offshore wind turbine system’s area of suitability variable in Ayer Island

Figure 10. Constraint area for offshore wind turbine technology installation in Putri Island and Harapan Island

Figure 10 shows wind speed of 4.52 – 4.76 m/s in Putri Island in comparison with Ayer Island, and the wind speed is categorized into the appropriate wind speed. Figure 10 also portrays that Harapan Island is located within Kepulauan Seribu National Park Zone (TNKS), while Putri Island is located...
within the TNKS zone and is close to Kepulauan Seribu National Park core zone. The existence of TNKS zone made the location as the constraint area which causes Putri Island as the area that is not suitable for the offshore wind turbine installation. This indicates that Putri Island did not have suitable areas left for offshore wind turbine technology.

4. Conclusions
Based on the results of spatial multi-criteria analysis in determining the suitable areas for photovoltaic and wind turbine system, the renewable energy systems that have the potential to be developed in Putri Island and Ayer Island is the photovoltaic system. The wind turbine system is not suitable to be developed in both Putri Island and Ayer Island. The areas for offshore wind turbine technology in Ayer Island are dominated with less suitable areas. Putri Island has more potential in the utilization of higher wind turbine, but the existence of constraint areas made this island becoming not suitable for the installation of offshore wind turbine.

The results of mapping the photovoltaic system’s area of suitability for Ayer Island and Putri Island revealed that each island has suitable characteristics for photovoltaic system. Putri Island has the potential to have more amount of energy coming from the photovoltaic system since it has larger scale of suitable areas rather than Ayer Island. This study is the application of previous studies in mapping the suitability of renewable energy technology that is specialized in the commercial sector on the remote island. The result of AHP and methods on this study can be considered as the basis for further research to examine the suitability of the utilization of PV and offshore wind turbines, especially in areas with commercial characteristics for tourism.

Acknowledgements
The authors acknowledge the financial support from Hibah PITTA B Universitas Indonesia 2019 No. NKB-0680/UN2.R3.1/HKP.05.00/2019.

References
[1] Central Government of the Republic of Indonesia (2011). Peraturan Pemerintah (PP) tentang Rencana Induk Pembangunan Kepariwisataan Nasional Tahun 2010 - 2025 Nomor 50.
[2] Muchlis, M. (2015). Analisis Kebutuhan Energi Sektor Komersial Provinsi Gorontalo.
[3] Watson, J.J.W. and Hudson, M. (2015). “Regional scale wind farm and solar farm suitability assessment using GIS-assisted multi-criteria evaluation”. Landscape and Urban Planning 138:20–31.
[4] Doorga, J.R., Rughooputh, S.D. and Boojhawon, R. (2019). “Multi-criteria GIS-based modelling technique for identifying potential solar farm sites: a case study in Mauritius”. Renewable Energy 133:1201-1219.
[5] Sánchez-Lozano J.M., Teruel-Solano, J., Soto-Elvira, P.L. and García-Cascales, M.S. (2013). “Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: case study in South-Eastern Spain”. Renewable and Sustainable Energy Reviews 24:544–56.
[6] Chaudhari, R. and Lal, D. (2018). “Weighted overlay analysis for delineation of ground water potential zone: a case study of pirangut river basin”. Int. J. of Remote Sensing 7:1–7.
[7] Suh, J. and Brownson, J.R.S. (2016). “Solar farm suitability using geographic information system fuzzy sets and analytic hierarchy processes: case study of Ulleung Island, Korea”. Energies 9(8):648.
[8] Uyan, M. (2013). “GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya / Turkey”. Renewable and Sustainable Energy Reviews 28:11–17.
[9] Al Garni, H.Z and Awasthi, A. (2017). “Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia”. Applied Energy 206:1225–1240.
[10] Wiranti, J. and Utomo, A. R. (2013). “Studi Pemilihan Turbin Berdasarkan Potensi Energi Angin Pada Kawasan Bandara Depati Amir”. Universitas Indonesia, Depok.

[11] Ayodele, T.R., Ogunjuyigbe, A.S.O., Odigie, O. and Munda, J.L. (2018). “A multi-criteria GIS based model for wind farm site selection using interval type-2 fuzzy analytic hierarchy process: the case study of Nigeria”. Applied Energy 228:1853–1869.

[12] Saleous, N., Issa, S. and Al Mazrouei, J. (2016). “GIS-based wind farm site selection model offshore Abu Dhabi Emirate, UAE”. Int. Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives 41:437–441.

[13] Arief, M., Hastuti, M., Asriningrum, W. and Parwati, E. (2013). “Pengembangan metode pendugaan kedalaman perairan dangkal menggunakan data satelit SPOT-4 studi kasus: Teluk Ratai, Kabupaten Pesawaran”. J. Penginderaan Jauh dan Pengolahan Data Citra Digital 100(1).

[14] Yue, C.D. and Yang, M.H. (2009). “Exploring the potential of wind energy for a coastal state”. Energy Policy 37(10):3925–3940.