Potential areas for the development of renewable energy system in Kepulauan Seribu: a case study for households in Pari Island, Tidung Island, and Pramuka Island

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Abstract. Kepulauan Seribu is a group of islands in the Java Sea where electricity source uses submarine cables that that can be damaged of damage the marine ecosystem. Whereas the government decides the Kepulauan Seribu region to be a Special Economic Zone that requires a strong electricity condition and sufficient electricity supply. Households as economic drivers have very high electricity consumption compared to other sectors in Kepulauan Seribu. The aim of this study was to analyze the potential areas for developing renewable energy systems that are appropriate for regions with high levels of electricity consumption. The method used in this study is Multi-Criteria Decision Making (MCDM) with an Analytical Hierarchy Processess (AHP) weighting technique. The result shows that renewable energy that potentially developed in Kepulauan Seribu is Solar Energy whereas wind energy offshore has a low potential. The findings show that solar energy has high potential to be developed in the Kepulauan Seribu region. Meanwhile offshore wind energy has low potential to be developed in Kepulauan Seribu.

The energy that can be generated by the PV system on Tidung Island is 108,505 kWh/m²/day, Pari Island is 66,976 kWh/m²/day, and Pramuka Island is 18,845 kWh/m²/day/day.

1. Introduction

Kepulauan Seribu is a group of islands in Jakarta Bay which has 110 islands, 11 of which are of resident function [1]. Electricity has become a basic need that can encourage development in various sectors in a country [2]. Electrical energy needs are inseparable from space, time and change which are embedded in various practices of activities carried out by the community to form patterns, variations, and dynamics of energy consumption [3]. Yang et al. [4] states that electricity consumption can be used as one of the development parameters in a country. The main driving factor of growth in electricity demand is population growth accompanied by increasing activity in various economic sectors and development in certain regions [5].

A household is a group of people who live together in one house and manage the same kitchen [1]. Households are a sector that dominates and experiences an increase in electricity demand every year [6]. Household electricity needs are based on living behavior in using electrical equipment that is classified as advanced, cooking (microwave, rice cooker, oven, refrigerator), hygiene (washing machine, iron, hairdryer, dust cleaning machine), entertainment (TV, radio, CD player), cooling (AC, fan), lighting, and information (telephone, computer, laptop, printer) [7].

Geographical conditions with the character of the archipelago make the distribution of fuel a challenge that can inhibit the growth of household electrification in Indonesia [8]. At present, the
fulfillment of electricity in Kepulauan Seribu uses submarine cables and diesel for several islands, and the government plans to develop renewable energy in the Kepulauan Seribus region [9]. Despite its benefit, underwater cable installation has a negative impact that can cause damage to coral reefs, electromagnetic field emissions, reduced fish populations, thermal radiation, chemical pollution, and underwater noise [10].

Kepulauan Seribu government plan to enter the Special Economic Zone which will reduce the availability of superior electricity [11]. Development of renewable energy is one way to meet electricity needs, minimize negative impacts on the environment, and avoid price dependencies and availability of fossil fuels [12]. Renewable energy is energy sourced from natural processes without involving fossil resources [13]. Renewable energy development in Indonesia is still low due to high investment costs and prices that cannot compete with fossil fuels, while based on national development targets, it requires exploration of local resources as access to electricity for remote areas [14].

Indonesia, located on the equator, has abundant solar radiation potential with a daily average of around 4 kWh/m² and an average annual wind speed of 2-6 m/s [13]. This research uses solar energy utilization technology with Photovoltaics (PV) which uses solar cells to convert solar energy into a direct electric current (DC) using a photovoltaic effect [15]. Utilization of wind energy using wind turbine technology is very dependent on the average speed of the wind [16]. Mapping the area of potential renewable energy development is important for analyze the amount of energy production and the location of power plants based on the factors that influence [17].

Hamhaber [18] argues that energy geography analyzes the use of energy by society as one of the fundamental resources and its relationship to space, the development of energy geography can help spatially analyze related fossil energy availability, renewable energy potential, energy technology, and energy consumption. Geographic Information Systems can be a tool for visualizing and analyzing potential energy resources, infrastructure projects, and policymaking considerations by adjusting information and planning [19]. Multi-Criteria Decision Making (MCDM) model can help determine potential areas for renewable energy development [20]. The variable weighting system in this study uses the Analytical Hierarchy Processes (AHP) technique to compare several variables by assigning a weighting of importance relative to each of the factor variables considered [21].

2. Materials and methods

2.1 Study Area

![Figure 1. Study area in Kepulauan Seribu](image-url)
Kepulauan Seribu, as shown in the map of Figure 1, is a low-lying area formed by a group of coral reef islands with main livelihoods as fishermen, tourism accommodation providers, and other services [1]. Based on the results of the field survey, it was found that Pari Island, Tidung Island, and Pramuka Island were islands that tourists most visited island and had high electricity consumption. Tidung Island has an area of 50.13 Ha with a population of 96 people/Ha, Pari Island has an area of 41.1 Ha with a population density of 29 people /Ha, and Pramuka Island has an area of 16 Ha with a population density of 118 people/Ha [6].

2.2 Data
The data used in this study consisted of physical condition data consisting of water body map data, land use maps, bathymetry maps, and administrative maps, as depicted in Table 1. While climate condition data consists of data on average annual solar radiation and average annual wind speed.

| 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 | GEBCO - British Oceanographic Data Center, General Bathymetric Chart of the Oceans (2019) | 1 × 1 km |

| Climate condition | Data | Data Source | Information |
|------------------|------|-------------|-------------|
| Annual average solar radiation (GHI) data | Global Solar Atlas | 90 × 90 m |
| Map of the annual average wind speed | Wind Energy Resources of Indonesia | 1 × 1 km |

2.3 Analytical Hierarchy Processes (AHP)
This study uses AHP technique to determine the variables to be used in the study and determine the weights for each variable. AHP technique has advantages among other techniques because, it is widely used for research or energy project policies, has a logic that is understood, the most popular method and it is often combined with other methods, consistency can be measured, applies to quantitative and qualitative criteria, and can handle complex decision problems [22].

Based on the results of previous reviews the potential PV technology area researchers used a 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, and barrier variables [21,23,24,25]. Based on previous studies, the variables used to build offshore wind turbines consist of average wind speed, distance from coastline, distance from settlements, bathymetry, and barrier variables consisting of conservation areas and mining areas [26,27]. Variables in this study was determined by conducting interviews with experts related to the variables to be used that have similarities to Kepulauan Seribu.

This research conducted interviews with 5 people who are experts in the field of renewable energy, geography and energy education, electricity, photovoltaic systems, and wind Turbines. The interviewees are:

1. Expert and teacher in renewable energy from PPSDM KEBTKE-Center for Electricity, New Energy, Renewable and Energy Conservation Human Resources Development (expert number 1).
2. Renewable Energy Expert from PPSDM KEBTKE-Center for Electricity, New Energy, Renewable and Energy Conservation Human Resources Development (expert number 2).
3. Professor from Faculty of Engineering, University of Indonesia (expert number 3).
4. Doctoral Researcher of Sustainable Energy, Kookmin University (expert number 4).
5. Doctoral Student of Sustainable Energy, Kookmin University (expert number 5).

2.4 Variable

2.4.1 Annual average solar radiation
Annual average solar radiation used in this study is based on Global Horizontal Irradiance (GHI) which is the total incoming solar radiation from either the scattered component or Diffuse Horizontal Irradiance (DHI) and components that are directly accepted by the earth or Direct Normal Irradiance (DNI) [20]. In general, the efficiency of PV is high in sunny areas and has minimum radiation of 3.5 kWh/m²/year [23].

2.4.2 Annual average wind speed
Wind comes from the movement of air due to changes in air temperature and heating from solar radiation [28]. Wind speed is very important in determining the potential area, an area that has a wind speed at least 4.4 m/s is a good area for developing energy [29]. Manwell [30], defines the amount of wind energy produced in an area proportional to the wind speed produced, by equation (1).

\[ P = \frac{\rho \cdot A \cdot v^3}{2} \]  

(1)

2.4.3 Distance from roads, settlements, and water bodies
Distance from roads, settlements, and water bodies is an important criterion related to cost savings that will come out when building a power plant. The power plan should be as close as possible to roads and settlements because electricity access is close to the source of the load, which is a settlement. Distance from the body of water is used to consider that the character of the island region that allows the tides and tides of seawater, so that areas that have greater potential are at a distance that is not too close to the coastline.

2.4.4 Bathymetry
Bathymetry is a measure of sea depth, both elevation and regarding seabed depression that can provide topographic information on seabed and sea depth structures [31]. The deeper the bathymetry, the worse the potential for solar energy. The maximum depth of bathymetry is 60 m [32].

2.4.5 Constraint variable
Variables in this study consisted of land use and conservation areas. Inappropriate land uses for building communal PV systems are mangroves, water bodies, and settlements. Meanwhile, for offshore wind turbine systems, improper land uses are mangroves, coral reefs, and island land. Another barrier variable is the conservation area which is an area that has a function as a protection for the survival of existing biota. Thus, not appropriate if it is used as an area for the development of renewable energy systems [32].

2.5 Multi Criteria Decision Making (MCDM)
This study uses MCDM model to determine decision making from existing criteria. Data processing using the MCDM model for determining suitability of the potential region of the PV system and weighting techniques using Analytical Hierarchy Processes (AHP). Variables are classified based on the suitability of potential regions. The results of variable data processing are overlaid using a weighted overlay on ArcGIS. The suitability matrix of the PV system and the offshore wind turbine system are in Tables 2 and 3.
### Table 2. Potential areas of PV system with AHP

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

### Table 3. Potential areas of wind turbin offshore 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 settlements (m)     | 30         | <50            | 50-100       | >100           |
| Constrain area                    | -          | Conservation Area | Non-Conservation Areas | Non-Conservation Areas |

### 2.6 Analysis of the Potential Area for Renewable Energy Development

The energy that can be produced from a region of potential sun and wind can be done by calculating the conversion formula from the potential area into the amount of power that can be generated by renewable energy systems. Yue and Yang [27] estimate the energy that can be produced from wind energy potential in an area by using equation (2).

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

\(\hat{P}\) is the wind energy Output (kW), \(P_{\text{rated}}\) is the power produced by the wind turbine (kW), \(CF\) is the Capacity Factor (1), \(VA\) is the average wind speed (m/s), and \(D\) is the diameter of the turbine (m). While Doorga et al., [23] estimate the energy that can be generated from the potential of solar energy in an area of the potential by using equation (3).

\[
GP = SR \times CA \times AF \times \frac{\eta}{100} \times CF \times Y \tag{3}
\]

\(GP\) is the potential for electricity generation per year (kWh/m²/year), \(SR\) is the annual average annual 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), \(\frac{\eta}{100}\) represents solar panel efficiency (30%), \(CF\) is a conversion factor (0.28).

### 3. Results and Discussions

#### 3.1 AHP Results

Three criteria are used in determining the area of development of PV technology systems and offshore wind turbines. Table 4 is the result of experts’ calculations regarding the area weighting potential for the development of renewable energy systems.
The average result of AHP calculation for PV systems is that 4 experts consisting of 1, 2, 3 and 5 experts believe that solar radiation has a very high influence on the potential area. The 4th expert believes that the distance from the settlement is more important than solar radiation, with the consideration that if the radiation value is large but far from the settlement it will require higher costs in terms of construction. The distance from the coastline has a very small weight compared to other variables, this is because the development of design and technology makes it easier to find a safe location without considering the line from the coast.

AHP data calculation results for offshore wind turbine systems found that the variable that had a very high effect was wind speed with an average weighting of 61%, for bathymetry of 9%, and distance from settlements of 30%. For the speed variable there is a difference of opinion between the 2nd expert and the others, where the expert 2 view is that the distance from the settlement is far more important than the wind speed. This is because if the installation of the wind turbine is far from the settlement, it will throw away the construction costs, like a PV system. For the bathymetry variable, all experts think to believe that bathymetry does not have a large influence on the potential area of wind turbine system development.

### 3.2 Potential Areas Wind Turbine Offshore System

Kepulauan Seribu is an archipelago which some of the areas fall into the conservation Category. Due to having shallow waters, the islands surrounded by coral reefs. This causes the area categorized as suitable for development to be within the protected coral reef zone. Seleous [26] and Yue et al. [27] made the conservation area a constraint area to protect marine biota from being destroyed due to the development of renewable energy. The results of data processing, there is no area classified as the most suitable for the development of wind turbine offshore systems (Figures 2 and 3). This is because the wind speeds in Kepulauan Seribu region are not included in the very appropriate category. This is because the wind speeds in Kepulauan Seribu region are not included in the very appropriate category. The data states that Indonesia, located on the equator, has little wind potential, but not with areas with diverse topography or mountain slope areas. The character of the Kepulauan Seribu coastal area surrounded by other islands such that the wind speed is not higher with the island facing the ocean. Flat topography also causes the wind speed is not high because there is no significant difference in air pressure.

The development of offshore wind turbines in Kepulauan Seribu is not suitable. The results of research conducted by Saleous [26], the development of wind turbine systems in the Abu Dhabi Emirate region is not appropriate because most of its territory is largely due to the presence of restricted zones (conservation areas). Such as in Kepulauan Seribu, in the northern part of Kepulauan Seribu (Pramuka Island) is in included in protected territorial water. Kepulauan Seribu National Park. The zoning map of the park is shown in Figure 4, and the variables of PV system development in Tidung Island is presented in Figure 5.
3.3 Potential Areas PV System

Development of PV systems for regions with island character in Kepulauan Seribu has the potential to replace undersea cable systems that are not environmentally friendly. Mapping areas of suitability becomes an important issue for investment development that depends on terrain quality, proximity to roads and transmission lines, and environmental conservation issues [26]. Doorga [23] includes major settlements as a barrier in the development of PV systems to avoid the forced displacement of citizens for construction, indirectly population density determines the availability of land for the location of PV system development.

Tidung Island has ample land availability, evidenced by many potential land spreads that can be used as the location of PV system development. The location of the potential land distribution is located not
far from the settlement, so it is ideal to minimize the cost of cable withdrawals in distributing electricity to each resident's home. Pramuka Island has a dense population and has a high demand for electricity. Pari Island has a level of density that is not too high when compared to other islands. Pramuka Island and Pari Island are surrounded by the seated sea. Land use on Pramuka Island is dominated by settlements, while Pari Island has a large land area and has the potential to become a location for PV system development. A map of the research criteria is shown in Figure 6 and Figure 7.

The distribution of areas that have high potential in Pramuka Island is spread on the coast of the island, this is because the middle side of the island has the character of land use in the form of settlements which are constraint areas in this study. While the region with high potential for PV system development in Pari Island is in the northern part of the island, the southern part of the island is a residential area, while the eastern region has a bush characteristic but has remote access to the road, making it less appropriate to be the location for PV system development (Figure 8).

3.4 Fulfillment of Renewable Energy for the Household Sector
Electricity consumption in the household sector in Kepulauan Seribu is dominated for cooling lighting, (Air Conditioner and fan), and cooking (refrigerator and rice cooker). Pramuka, Pari, and Tidung are islands with a high level of electricity consumption in Kepulauan Seribu because it is a resident island which is a tourist destination. The right renewable energy system to be developed in Kepulauan Seribu region is a PV system because it has high potential compared to offshore wind turbine systems which have low potential. The energy that can be produced by the PV system is in Table 5.
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