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Land Suitability for Wind Farm Development in Pandeglang Regency, Banten Province, Indonesia

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ABSTRACT
The use of wind as the main energy in power plants cannot be separated from the ability of windmills to produce energy to meet needs. Based on a literature study, the Ministry of Energy and Mineral Resources 2018 released data related to the total potential of wind power in Banten Province of 300 MW spread across two areas, namely Lebak Regency and Pandeglang Regency with the potential in each area of 150 MW, thus it is necessary to conduct a spatial study related to the appropriate location for the construction of a new wind farm. Topographic factors (elevation, viewshed, slope, aspect direction, and area), technical (wind speed and power grid proximity), environmental (distance from lakes, rivers, reservoirs, dams, and land cover), and socioeconomic (settlement and transportation) are parameters that determine the success and potential of placing windmills as environmentally friendly renewable energy. This study aimed to determine the potential for wind farm development areas in Pandeglang Regency, Banten Province. The method used to analyze these parameters is the Multi-Weighted Criteria Modeler, by giving weight to each parameter in raster format and classified using the deterministic logic method and selecting areas with a large area coverage (≥ 10,000 m^2) using boolean. The results of this study indicate that there is an area of 350.71 km² that is suitable for the construction of a new wind farm in Pandeglang Regency. The final suitability map can be used as a guide for more detailed wind farm location exploration. This study concludes that Indonesia has great potential for the development of Wind Power Plants, especially in Pandeglang Regency. However, a wider research area coverage is needed to find out which areas have the potential for the development of Wind Power Plants in Indonesia.

Keywords: Renewable Energy, Wind Farm, Wind Power Plant.

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Introduction

When conditions are limited in energy resources, at the same time the need for world energy also increases, as well as demands to be able to maintain and protect the earth from global warming events and environmental pollution. So humans are required to be able to realize the latest technology for renewable energy sources. Fossil energy sources have contributed 87.7% of all the world's total energy needs which are expected to decrease due to reduced availability of reserve energy sources [1].

Wind Power Plant is a series of generating systems that utilize wind as a source that will be converted into electrical energy, wind power is an alternative energy source that has great potential to be utilized and clean energy that does not damage the environment [2]. The use of wind as an energy source can be carried out in areas with any landscape with high wind energy potential, but it needs to be identified so that it is more optimal [3]. Wind Power Plants are the main choice as an energy source for areas with good wind potential [4].

The use of wind as an energy source has been used by the Netherlands first and is referred to as the country of wind turbines. Starting in the 1970s

the use of fossil energy has begun to be reduced because of the impact it has on the environment. then it is replaced by energy sources that are friendlier to the environment and are abundantly available. Entering the 21st century the use of wind energy is increasingly being followed by developing countries with increasing capacities [5].

Wind is air that moves due to high pressure to low pressure or from low temperature to high temperature caused by radiation from the sun. The conditions of the earth's regions that are not the same cause differences in pressure and temperature in each region and cause an air flow [6].

As an archipelago that has a long coastline, Indonesia is also a country that has great wind energy potential. Based on the analysis of wind energy potential and mapping of wind energy potential that has been carried out, areas with considerable potential include Sukabumi with 170 MW, Garut with 150 MW, Lebak with 150 MW, Pandeglang with 150 MW and Lombok with 100 MW. The development and utilization of new renewable energy including wind energy as the backbone of national energy will continue to be pursued by the government in order to achieve the national energy mix target of 23% derived from renewable energy in 2025 [7].

Currently, Indonesia already has several Wind Power Plants, including those on the island of South Sulawesi, namely the Sidrap Wind Power Plants and the Jeneponto Wind Power Plants. According to the Ministry of Energy and Mineral Resources, apart from the Sidrap 1 Wind Power Plants, which will soon be put into operation, the Sidrap Phase 2 Wind Power Plants will soon be operational, then the Jeneponto Wind Power Plant in Jeneponto Regency, South Sulawesi Province and the Tanah Laut Wind Power Plants which is located in Tanah Laut Regency, South Kalimantan Province [7].

Based on the data above, there are 4 Wind Power Plants that are already operating and which will operate in Indonesia in stages. This is also a serious step for Indonesia in transitioning the use of fossil energy to renewable energy, especially in the utilization of wind potential which is quite potential in Indonesia [7].

Wind power generation is a renewable energy that is more environmentally friendly and has good work efficiency [8]. Wind energy offers several advantages such as providing continuous electrical energy from morning to night, does not produce greenhouse gas emissions, this energy system can be used in remote areas, and is not covered by the State Electricity Company's electricity grid [9].

The potential for the development of renewable energy sources depends on the geographical position and existing infrastructure [10]. Knowledge of the right location for optimal utilization of energy sources is very important. But in fact, determining the location to generate wind power is not easy. This determination requires in-depth research to get the right location [11].

Optimization of the development of wind power energy in Indonesia is still relatively low. Academics and the government are expected to be able to make a major contribution in supporting this renewable energy as a source in the development of electrical energy. Until 2004, the utilization of wind energy only reached 0.5 MW installed from the total existing potential [12].

Wind turbines as a source of electrical energy are expected to be able to work and operate continuously so that the wind supply can always be available. In order to obtain sufficient wind energy, research activities are needed to monitor wind availability. The monitoring process requires effort and data analysis. [13]. Monitoring and mapping of potential wind energy areas is carried out so that energy utilization can occur optimally. The selection of suitable locations for wind power plants is a complex problem and requires careful analysis of many criteria. Making a land suitability map is useful in order to show the exact location and description of the area where the Wind Power Plant will be established [14].

Experimental part

This type of research is quantitative research. Source of data used in the form of secondary data obtained from agencies, libraries, archives, and individuals. The secondary data used are elevation, viewshed, slope, aspect direction, wind speed, shapefiles of lakes, rivers, reservoirs or dams, land cover, settlements, and transportation. The methods used in this research are Multi - Weighted Criteria Method Modeler and Boolean logic.

Multi - Weighted Criteria Method Modeler is a tool used for decision-making with various spatial parameters to be combined [15]. The analysis will be carried out using the Multi - Weighted Criteria method the modeler uses several scripts. Decision making is carried out using Boolean logic which will be applied to the factors used in the analysis of wind power development based on the research of Idrizi. B, et.al in 2018 which will be explained further in the research results.

Boolean logic is a form of algebra whose variable values are true and false values, usually denoted by the numbers 1 and 0 for each parameter, simplifying the parameters of the boolean being able to search in other functions with fewer operations or terms [16]. The Boolean method is used in this study to select areas in Pandeglang Regency for the suitability of PLTB land with a large area coverage (> 100.000 m^2) as well as other factors as determinants in wind farm development. In its application to the Multi-Weighted Criteria method, areas with factors and criteria that are met will be denoted by the number 1, and areas that are not met will be denoted by the number 0.

Geographic Area Pandeglang Regency is geographically located between $6^0$21'-$7^0$10' South Latitude and $104^0$48' - $106^0$11' East Longitude with a total outer area of around 2.746,89 km^2 or 28.43% of the total area of Banten Province. In the northern part of this area is bordered by Serang Regency and in the east by Lebak Regency. Astronomically, the Pandeglang region is a district located in Banten Province. This regency is bordered on the north by Serang Regency, on the east by Lebak Regency and by the Indian Ocean on the west and south [17].

Pandeglang Regency consists of 35 sub-districts and 339 sub-districts/villages with additional villages, namely Bojenwetan, Ganggaeng, Simpang Tiga and Ramaya. The topography of the central and southern parts of Pandeglang Regency is dominated by highlands with hills that are not too high, namely around 320 - 480 meters. The area of the hills comprises around 85% of the total area of Pandeglang [17].

The Geology and Geomorphology Area of the research was conducted in the administrative area of Pandeglang Regency. In the northern part of this area is bordered by Serang Regency and in the east by Lebak Regency. Geologically Pandeglang Regency is included in the Bogor area zone which consists of hilly paths. Most of this area forms lowlands in the center to the south.

Stratigraphically, in the highlands of the eastern part of the Pandeglang region, there are holocene volcanoes which are the result of volcanic deposits, these deposits consist of alternations of lava, breccias, tuffs and lava deposits. There are also volcanic rocks of Pleistocene age which are composed of basalt-andesite originating from old volcanoes. In the western part of the coast of the Pandeglang area, alluvium (Qa) is found, coastal terrace deposits in the form of coral limestone (Qc), Cimapag formations (Tmc) and Bojongmanik formations (Tmb1) in the form of alternating sandstone and flaky claystone interspersed with claystone, conglomerate, tuff and agglomerates [18].

Identification of potential areas to become wind farms uses the Multi-Weighted Criteria Modeler method. The Multi-Weighted Criteria Modeler method is a tool used to decide from a variety of special parameters to be combined [15]. This method uses weighting for each parameter in the form of elevation data, viewshed, slope, aspect direction, wind speed, shapefiles of lakes, rivers, reservoirs or dams, land cover, settlements and transportation. In detail the description and geology of the Pandeglang area can be seen in Figure 1.

Then classified by statistical methods by selecting areas with an area of ≥10,000 m2 in boolean. Boolean logic is a form of algebra whose variable values are true and false. Usually denoted by the numbers 1 and 0 for each parameter. Boolean is able to find other functions with fewer operations or terms [16].

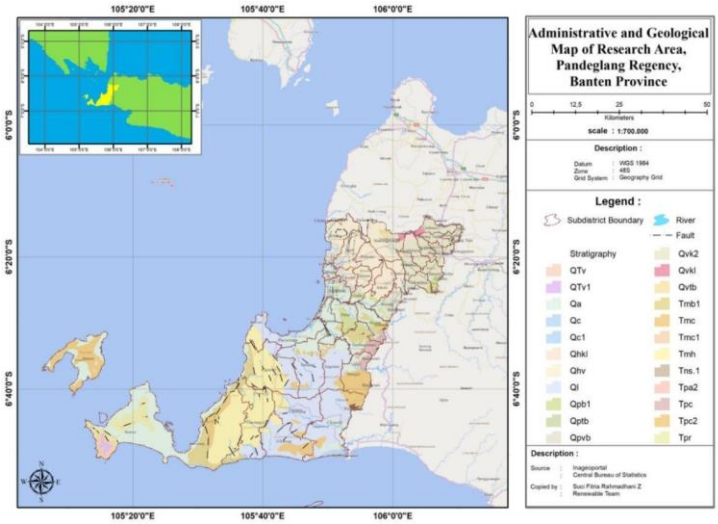

Figure 1 - Administrative Map of Pandeglang Regency, Banten Province

This type of research is quantitative research. Source of data used in the form of secondary data obtained from agencies, libraries, archives and individuals. The secondary data used are elevation, viewshed, slope, aspect direction, wind speed, shapefiles of lakes, rivers, reservoirs or dams, land cover, settlements and transportation.

Results and Discussion

The spatial analysis that has been carried out from the dataset of factors for the suitability of Wind Power Plant areas in Pandeglang Regency includes topographical factors, technical, environmental and socio-economic criteria.

Topographic factors include elevation on the height factor, slope, aspects of the slope direction and area with each criterion. Areas that are too high are generally not suitable for placing wind turbines, steep slopes are also considered unsuitable for placing wind turbines because they can pose a danger to wind turbines and the area around where wind turbines are placed. The details of the criteria for topographic factors can be seen in Table 1.

Height was obtained that the Pandeglang Regency area was dominated by areas with an altitude of less than 1500 meters above sea level. So that almost the entire area of Pandeglang Regency is included in the "appropriate" category. The suitability map for all topographical factor parameters can be seen in Figure 2.

Table 1 - Topographic Factors and Criteria

Factor	Criteria
Height	<1.500 m
Slope	<15%
Aspect of Slope	315<value>360
Direction	> 1.000 m^2
Area	>100.000 m^2

Source: Idrizi, 2018

Slopes that have a role as a determining factor in carrying out spatial planning to assess whether the observation area is suitable can be used as a Wind Power Plant. The Pandeglang Regency area has a slope that is included in the "appropriate" category because it has an area with a slope of less than 15°. The suitability map for all topographical factor parameters can be seen in Figure 3.

The direction of the slope of the slopes in the Pandeglang Regency area is dominated by Northwest to Southeastern directions, which is also influenced by factors from the direction of the Monsoon winds in the Banten region. The suitability map for all topographical factor parameters can be seen in Figure 4.

Technical factors only observe one parameter, namely the wind speed in the Pandeglang Regency area. In determining the area to be used as a wind farm, namely the success of a wind turbine turbine can produce energy obtained from the wind which will rotate the turbine. Suitable and unsuitable wind speed can be seen in Figure 5.

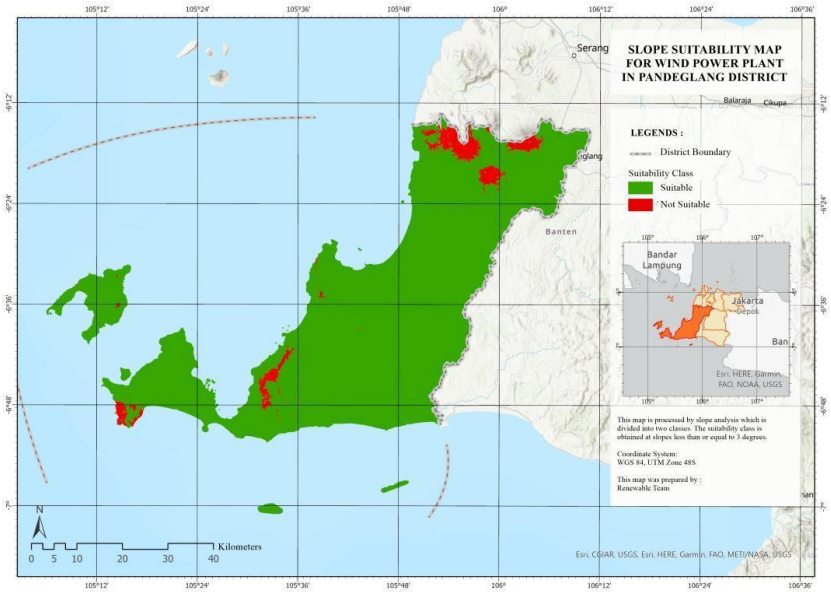

Figure 2 - Altitude Parameters on Topographic Factors

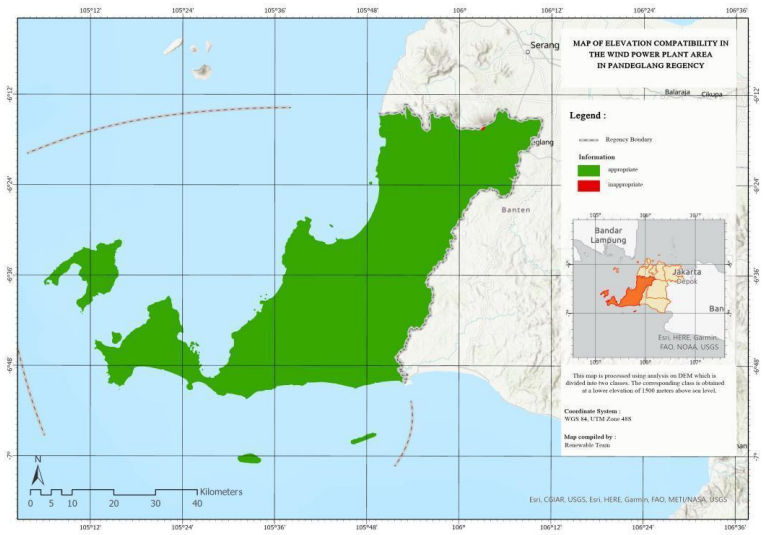

Figure 3 - Slope Height Parameters on Topographic Factors

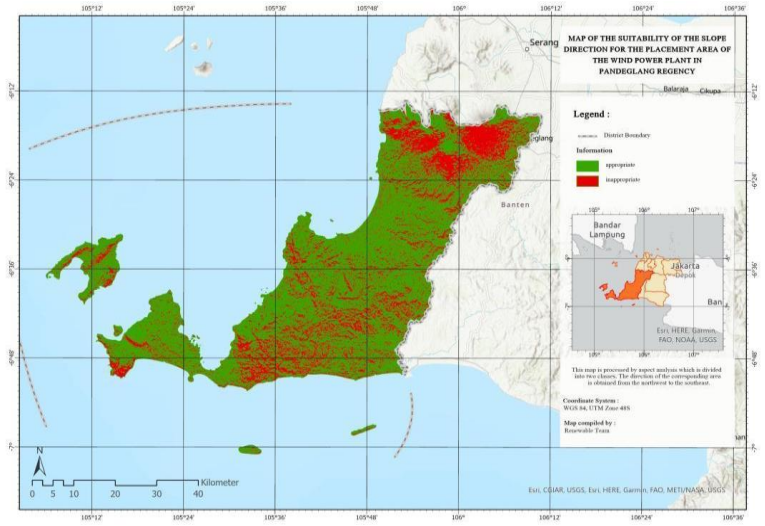

Figure 4 - Slope Direction Aspect Parameters on Topographic Factors

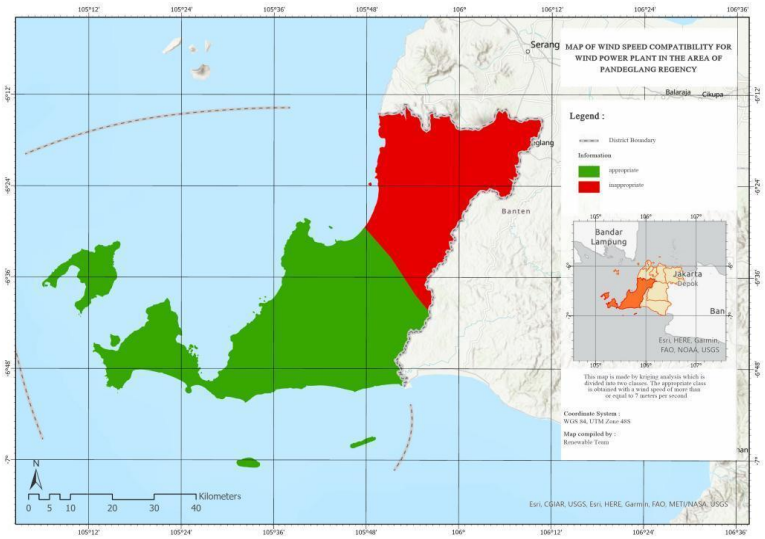

Figure 5 - Parameters on Technical Factors namely Wind Speed

Wind speed is a technical factor as well as a key holder in connecting renewable energy sources and producing as much energy as possible into the national energy network. This is a very important factor and must be considered. The details of technical factors can be seen in Table 2.

Table 2 - Technical Factors and Criteria

Factor	Criteria
Wind velocity	>5 meters/second

Source: Idrizi, 2018

Environmental factors include the area's proximity to rivers, lakes, dams and land cover. This is as a precaution so that the foundation of the wind turbine avoids flooding, because it will cause damage to the wind turbine. Land cover in the form of forest must also be considered in making wind farms and placing wind turbines, because vegetation in the forest can interfere and hinder the performance of wind turbines. The details on the environmental factors for placing wind turbines can be seen in Table 3.

Table 3 - Environmental Factors and Criteria

Factor	Criteria
River *Proximities*	>300 m
Proximity Lake	>300 m
Land Cover Soil Surface	>300 m
Dam *Proximity*	>500 m
River *Proximities*	>300 m

Source: Idrizi, 2018

Proximity Analysis or proximity factor analysis is an analysis of geospatial information systems that are usually used in determining land for strategic purposes. Buffering is another form of proximity analysis from a proximity analysis which is carried out by identifying the relationship between a point or area with other areas around it [[19], [20]].

The western and eastern parts of the Pandeglang Regency are dominated by jungle, only a few swamp areas, namely around the coast of Ujung Kulon National Park. Throughout Pandeglang Regency there are many rivers flowing, such as the Cipunten Agung, Caringin and Ciliman rivers. In this area there are also lakes such as Tegal Paku Lake, Gonggong Lake and Cikendal Lake. The proximity of rivers, lakes, forests and swamps can be seen in Figure 6.

The appropriate area in Figure 6 is an area that is not too close to rivers, lakes, forests and swamps. The Wind Power Plant area must have a distance of more than 300 meters from rivers, lakes, forests and swamps. The distance between the Wind Power Plant area and rivers and lakes is to prevent flooding. The Wind Power Plant area should not be too close to the swamp because the strength of the soil in the swamp area is very low to support the windmill. Meanwhile, the Wind Power Plant area must be far from the forest to avoid equipment accidents that can have a negative impact on the forest.

The distance from the dam to the Wind Power Plant construction site is an environmental factor that should be taken into account because the existence of a dam increases the risk of hydrometeorological disasters, especially floods and flash floods, so that a considerable distance from the dam is needed to build a Wind Power Plant. The proximity of the dam can be seen in Figure 7.

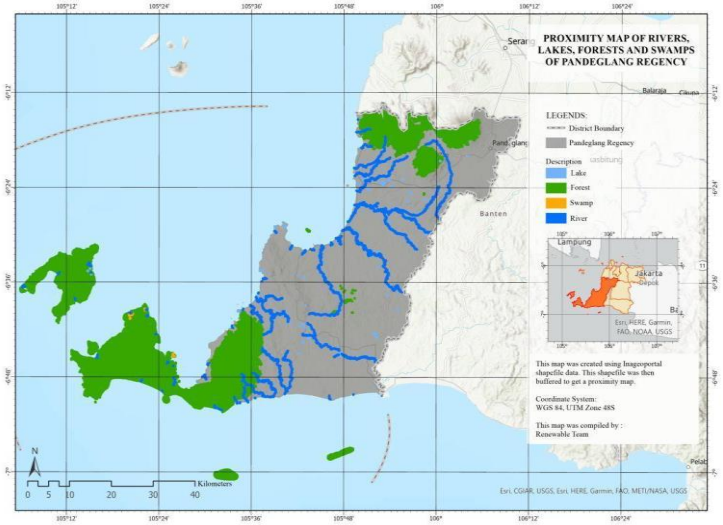

Figure 6 - Proximity to Rivers, Lakes, Forests and Swamps

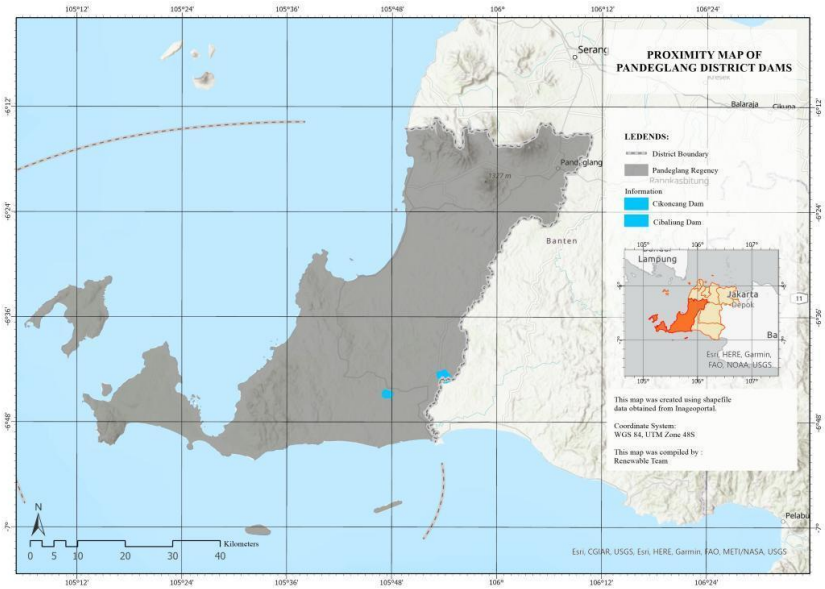

Figure 7 - Proximity to Dams

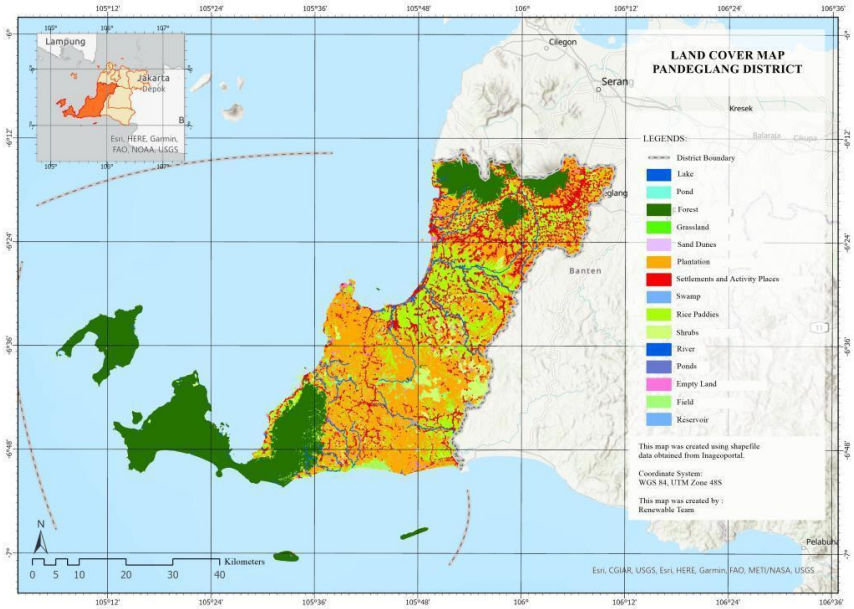

Figure 8 - Land Cover in Pandeglang Regency

The potential distance for establishing a PLTB is >500 meters from the dam. Pandeglang Regency itself has 2 dams, namely the Cikoncang Dam and the Cibaliung Dam. However, in terms of the reach of the dam, it does not really dominate the Pandeglang Regency area, so there are still many potential locations for establishing PLTB in Pandeglang Regency.

Data and information related to land cover in Pandeglang Regency was obtained based on Sentinel-2 image processing. Sentinel image results monitor land cover in the form of lakes, ponds, jungle, grasslands, sand dunes, plantations, settlements, swamps, rice fields, shrubs, rivers, ponds, vacant land, fields, and reservoirs. Based on the processing results, the land cover of Pandeglang Regency was obtained as can be seen in Figure 8.

The area of Pandeglang Regency is dominated by land cover in the form of plantations covering an area of 1,188 km², jungle forest covering an area of 770 km², rice fields covering an area of 570 km², settlements covering an area of 110 km², shrubs covering an area of 55 km² and fields covering an area of 53 km².

The rest of this area is filled with land cover in the form of lakes, ponds, swamps, rivers, ponds and reservoirs. The Wind Power Plant development area in Pandeglang Regency is covered in scrub land and

vacant land. This is because the Wind Power Plant construction is unlikely to disturb the land cover that has been used by the community, such as settlements, plantations, rice fields, and others.

Socio-Economic Factors are only influenced by the proximity of the road, because this is useful for the safety and comfort of road users caused by wind turbines at Wind Power Plant.

The ideal distance criterion between the Wind Power Plant area and the main road is around >250 meters. The proximity of roads in the Pandeglang Regency area can be seen in Figure 9 and the details on the socio-economic factors for placing wind turbines can be seen in Table 4.

Table 4 - Socioeconomic Factors and Criteria

Factor	Criteria
Distance to Highway	>250 m

Source: Idrizi, 2018

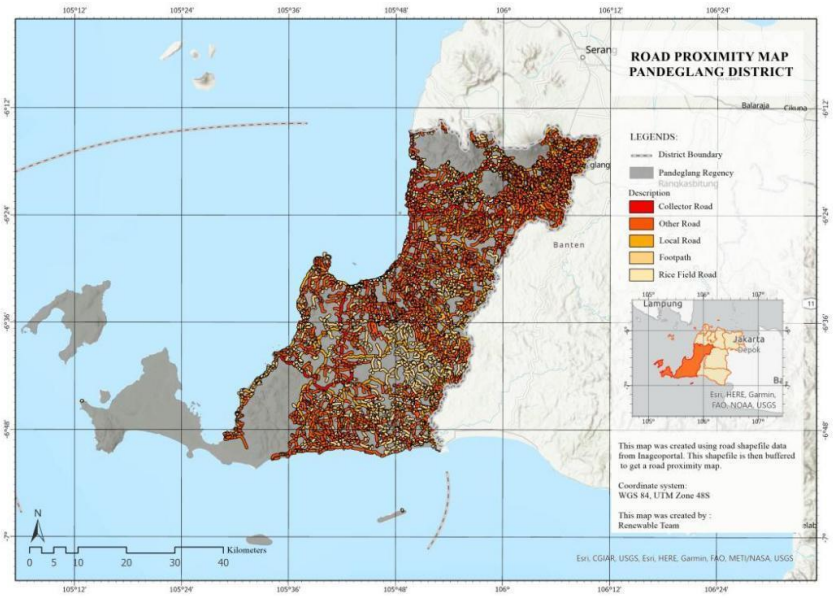

Figure 9 - Proximity to the Road

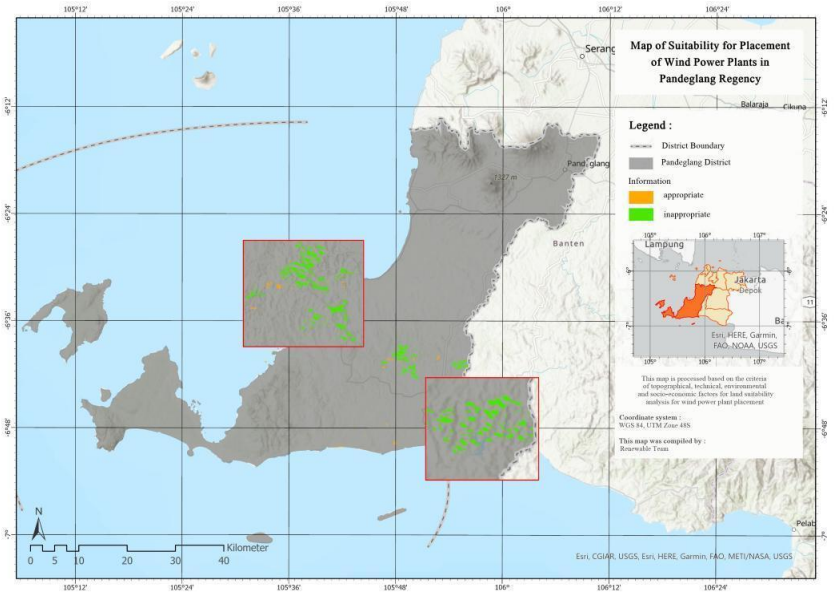

Figure 10 - Wind Power Plant Area Suitability Map

Potential Wind Farm Areas. The suitability of the area obtained for Wind Power Plant placement is based on factors and parameters consisting of categories, suitable and not suitable.

The areas suitable for Wind Power Plant are Sobang Sub-District, Leuwibalang Sub-District, Kadubadak Sub-District, Cihanjuang Sub-District, Cikadongdong Sub-District, and Pancaran Sub-District. As for the less suitable areas, there are Sindangkerta Village and Tanjungan Village. From the total area of Pandeglang Regency of approximately 2,746.89 km^2, the area suitable for wind farms is 350.71 km^2 and the area less suitable for wind farms is 30.49 km^2 but can still be considered for utilization. As for the appropriate and less suitable areas can be seen in Figure 10.

Conclusions

The construction of the Wind Power Plant in Pandeglang Regency can be carried out in the Leuwimalang, Kadubadak, Cihanjuang, Cikadongdong and Pancaran Sub-Districts. The total area suitable for the construction of a Wind Power Plant is 350.71 km². Areas suitable for the construction of Wind Power Plants are obtained from the Multi - Weighted Criteria analysis Modeler and Boolean with factors namely: topography, technical, environmental, and socio-economic.

The Geographic Information system-based method in this study provides a quantitative evaluation and assessment of factors and constraints that must be considered in determining land suitability for the wind power plant area in Pandeglang Regency. The final suitability map can be used as a guide towards a detailed search of the Wind Power Plant site. Additional surveys and measurements should be carried out before making a final decision for wind development. In addition, the final results of the final map must be additionally validated by wind speed measurements as well as by observing other important ecological variables in each specific area for the placement of a potential Wind Power Plant.

This study concludes that Indonesia has the potential to develop Wind Power Plant, which can meet Indonesia's target in the transition from fossil fuel use to the use of renewable energy in total, in addition to solar, water and micro-hydro power. However, an analysis with a wider coverage area is needed to find out other areas that have a high level of suitability for the development of Wind Power Plant. Based on these findings, it is expected to be a basis for the government and related institutions in the development of renewable energy, especially in the development of wind power in the construction of power plants.

Conflicts of interest. On behalf of all authors, the corresponding author states that there is no conflict of interest.

CRediT author statement: **F.Suci**: Conceptualization, Methodology, Writing draft preparation, Editing, Investigation; **I. Muhamad**: Data curation, Writing draft preparation, Software, Visualization, Investigation, Editing.

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Қабылданды: *18 ақпан 2025*

ТҮЙІНДЕМЕ
Қарастырылып отырған зерттеу Индонезияның Бантен провинциясы Пандегланг-Реджансидегі жел электр станциясын дамытудың әлеуетін ашады және мұндай нысандарды орналастыру орнын таңдауға әсер ететін әртүрлі факторларды жан-жақты талдаудың маңыздылығын көрсетеді. Қарастырылған параметрлер топографиялықтан әлеуметтік-экономикалықға дейін жел диірменін орнату және энергия өндіру жобасының сәтті болуына әсер етеді. Зерттеуде қолданылатын «Көп салмақты критерийлерді модельдеу» әдісі аумақтың әртүрлі сипаттамаларын тиімді бағалауға және құрылыс үшін ең қолайлы жерлерді таңдауға мүмкіндік береді. Бұл тәсіл сандық және сапалық деректерді біріктіреді, нәтижесінде дәлірек және дұрыс нәтижелер алынады. Зерттеу нәтижелері Пандегланг округінде жаңа жел электр станциясын құру критерийлеріне сәйкес келетін 350,71 км² аумақ бар екенін көрсетеді. Бұл ақпарат аймақтағы жаңартылатын энергия жобаларын одан әрі зерттеуге және егжей-тегжейлі әзірлеуге негіз бола алады. Осылайша, зерттеу нәтижелері Индонезияның жел энергетикасын дамыту үшін үлкен әлеуеті бар екенін көрсетеді және қосымша қолайлы аймақтарды анықтау үшін елдің басқа аймақтарын зерттеуді жалғастырудың маңыздылығын көрсетеді. Осылайша, Индонезиядағы жел энергетикасы әлеуетінің зор екендігіне қарамастан, елдегі жел энергиясын тиімді пайдаланудың барлық ықтимал бағыттарын анықтау үшін зерттеулер кеңірек болуы керек.

Түйін сөздер: жаңартылатын энергия, жел электр станциясы, жел диірмені.

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Оценка пригодности земель для строительства ветряной электростанции в районе Пандегланг, провинция Бантен, Индонезия

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АННОТАЦИЯ
Исследование, о котором идет речь, раскрывает потенциал развития ветряных электростанций в округе Пандегланг провинции Бантен, Индонезия, и подчеркивает важность комплексного анализа различных факторов, влияющих на выбор местоположения для таких объектов. Рассмотренные параметры — от топографических до социально-экономических — оказывают влияние на успех реализации проекта по установке ветряных мельниц и производству энергии. Метод Multi-Weighted Criteria Modeler, использованный в исследовании, позволяет эффективно оценить различные характеристики территории и выбрать наиболее подходящие участки для строительства. Этот подход сочетает количественные и качественные данные, что обеспечивает более точные и обоснованные результаты. Выводы исследования говорят о наличии области площадью 350,71 км², которая соответствует критериям для создания новой ветряной электростанции в округе Пандегланг. Эта информация может стать основой для дальнейших исследований и детальной разработки проектов в области возобновляемой энергетики в регионе. Таким образом, результаты исследования свидетельствуют о большом потенциале Индонезии для развития ветряных электростанций, и подчеркивается важность продолжения исследования других регионов страны для выявления дополнительных подходящих территорий. Таким образом, несмотря на потенциал ветряной энергии в Индонезии, исследования должны быть более широкими, чтобы выявить все возможные районы для эффективного использования ветряной энергии в стране.

Ключевые слова: возобновляемая энергия, ветряная электростанция, ветряная мельница.

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