Evaluation of The Wind Energy Potential of Thailand considering its Environmental and Social Impacts using Geographic Information Systems

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Abstract- Some areas of Thailand do not allow the installation of wind turbines or require further investigation of the impacts before installation. These areas can be divided into 3 classes with 21 criteria, including residential communities. This article presents an analysis of Thailand’s wind energy potential and identifies suitable areas for wind turbine installation that minimize the environmental and social impacts on nearby communities during operation. In this study, we have evaluated the possibility of reducing the environmental and social impacts of wind energy development projects in 4 case studies using geographic information system analysis. We are used two different formulas to evaluate the wind power potential and create wind resource map for use as a guideline to select suitable areas for wind turbine installation that reduced the negative impacts of future projects on the community. This model has removed the risk from the most sensitive areas and included the moderately sensitive rural resident community area. This area is the most affected by the wind turbine project. The suitable areas provide sites for wind turbine installation located in the northeast, including the appropriate wind speed potential.

Keywords- Wind energy potential; GIS; renewable energy; Thailand

1. Introduction

Energy shortage is a major problem in Thailand and will have a more serious impact on the future development of the country. Reserves of fossil fuels used to generate electricity, such as oil, natural gas, and coal, are limited and are projected to be depleted in the future. In addition, Thailand has limited water resources that can be developed to produce electricity. There have been some attempts to create new energy resources; however, there are some cost and time constraints in building new renewable energy infrastructure or insufficient natural renewable energy resources. Thailand has a high growth rate of electricity consumption and the demand for electricity was projected to increase by an average of 2.67% per year or by 1,981.323 MW in 15 years (2014-2036) [1,2]. The country will need to increase the import of electricity and build more power plants to meet the growing demand for electricity. A study by [3] reported good wind power potential in Thailand was average in level 3, with a wind speed of 6.4 m/s at 50 m by a total capacity of 300 W/m^2. Towards this purpose, Thailand revised and announced the Alternative Energy Development Plan (AEDP) 2015 to promote energy production from available renewable raw materials in the country with full potential and develop the appropriate renewable energy technologies that would reduce the environmental and social impacts of energy production. The proportion of electricity from renewable energy in Thailand was 20% of the total electricity demand in AEDP 2015. Therefore, the wind energy target has been increased from 1,800 MW to 3,002 MW for the year 2036 [4].

The current supply of Thailand's electricity from wind power is very small compared to other energy sources. Wind turbines across the country provided 233.9 MW of energy in 2015 [5]. Wind energy is considered a minor resource supported by the Electricity Generating Authority of Thailand (EGAT) to reduce energy imports and improve energy security before turning to other fuels, such as municipal solid waste (MSW) and nuclear energy. In addition the Ministry of Energy researchers, [6] developed a wind resources map of Thailand and found that most areas in the country experience relatively low wind speeds except for the mountain ranges in the southern, northeastern, and western parts of the central region, which have higher wind speeds of 6–7 m/s on average. In [7], a study had conducted on the wind resources map of Thailand at various heights above the ground level and on geographic information system (GIS)-based area-selection maps for wind turbine installation purposes. The area with significant wind resources has decreased considerably in recent years although many areas suitable for wind energy development still exist across Thailand.

This paper propose to analyze the wind energy potential and determine suitable locations for wind power plant development in Thailand by using GIS considering the significant regulations for reducing the environmental and social impacts whose [8] indicated noise pollution as the greatest impact of wind turbines, followed by overshadowing and visual pollution. Most of this researches, such as [9] provided an evaluation of wind energy potential in Thailand by using an atmospheric mesoscale model and GIS. The map of unusable areas was generated and high wind energy potential located in the south of Thailand. Reference [10] assessed wind energy potential of offshore areas in Taiwan that the annual energy product was increase when the distance from the coast was an increase. In [11], GIS with suitable factors had used to select the highly suitable locations which were in the eastern and south-central portion of Knox Country and northeast Pierce country for establishing a wind farm. In [12], the offshore wind energy potential had estimated as considering economical and social criteria by using mesoscale model and GIS in Choshi. The results found the annual mean wind speed was 7.5 m/s in northern site and 5.7 m/s although the coastline. Recently, [13] used GIS and spatial multi-criteria decision analysis to determine the most appropriate sites for wind farm projects in India, and they identified the areas in the northwestern of Jodhpur district of India. Also, in reference [14] assessed the impact of wind farm integration on 132 kV Dubai transmission network by using MATLAB/SIMULINK. The results showed the excellent performance of differential relays and recommendation to maintain the main differential relays and enhance existing backup DOC/DEF scheme with telecommunication. The effective factors of wind farm operation had assessed in [15]. These factors showed the bivariate and absorbing reactive power which curses to voltage instability. Quasi-Static Time Domain Simulation (QSTDS) investigated the impact on voltage stability in [16]. It considered the problem of absorbing reactive power which is the main impact of voltage instability and Static Synchronous Compensator (STATCOM) had improved the voltage stability of system much better than Static Var Compensator (SVC).

2. Methodology

2.1 Wind speed

This study uses the annual wind velocity data collected by the government at wind measurement stations in each sub-district in 2012.

2.2 Wind power

This study uses 2 formulas for calculating the wind power potential.

The first is the wind power density formula [17]. Thailand has used this formula widely to calculating wind energy. In this research, we call this formula is Thailand formula. In this case, it is assumed that all the suitable areas can be wind turbine swept areas. Therefore, the wind power comes from the annual wind speed and the annual air density, as shown in Eq. 1.

$$P = \frac{1}{2}\rho V^3$$

Where P is the power density (W/m^2), V is the mean wind speed (m/s) and ρ is the air density (kg/m^3). Thus, wind power (W) is computed from;

$$P = \frac{p}{A}$$

$$\frac{p}{A} = \frac{1}{2}\rho V^3$$

$$p = \tfrac{1}{2}\rho V^3 A \qquad (1)$$

When p is wind power (W) and A is the area of the study. The air density was calculated from the air pressure, temperature, and air humidity.

The second formula is from a potential survey by the Japanese Ministry of Economy, Trade, and Industry [18]. In this case, it is assumed that the size of each wind turbine is 2,000 kW and the height is 80 m, which is evaluation level of wind speed. The appearance time is ranked by the annual average of wind speed based on Rayleigh distribution in each area, which is multiplied by the assumed output at each wind speed to provide annual power. In this assumption, the output of a wind turbine rises from a wind speed of 4 m/s along a growth curve and reaches 2,000 kW at around 15 m/s. In addition, some power losses are assumed, in which the available ratio is 95%, and the various power losses are 90%. The net annual power is then calculated by multiplying the annual power by 0.855 (=0.95 × 0.90). In this report, Power curve by wind speed is expected in Figure 1, and it assumed that appearance ratio of specific wind speed follows Rayleigh distribution. According to these assumptions, In these procedures, the net annual power for each annual average wind speed is approximated by Eq. 2 as follows.

$$y_p \cong -16.6x_w^3 + 325.1x_w^2 - 810x_w + 166.6 \qquad (2)$$

Where y_p represents the wind power per year (MWh), x_w is the wind speed (m/s) by assuming that the wind turbines are active 24 hours per day for 365 days.

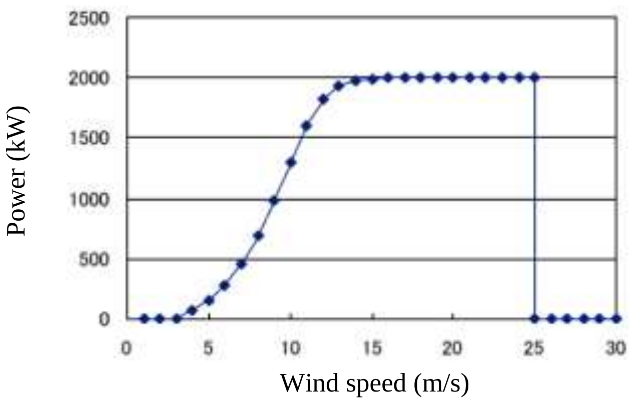


Fig. 1. Expected power curve of wind farm

2.3 GIS analysis

This study uses ArcGIS 10.1 for data analysis, which was divided into 4 case studies.

2.3.1 Normal case study

This is the base case to calculate the area and the wind potential by only deleting the exclusion criteria without any conditions.

2.3.2 Case Study I (suitable area size ≥ 2 km^2)

The minimum standard area for wind turbines is 2 km^2, i.e., wind turbines cannot be installed in areas smaller than 2 km^2. Therefore, in this case, we deleted the areas smaller than 2 km^2.

2.3.3 Case Study II (doubled buffer distance)

We adjusted the buffer distance to be twice the original buffer distance, significantly reducing the impact of noise and shadow fixture on the communities.

2.3.4 Case Study III (doubled buffer distance and suitable area size ≥ 2 km^2)

We mixed the conditions of the case study I and II to determine the appropriate wind potential and area for installing wind turbines without significant impacts on the communities.

3. Results and Discussion

3.1 Wind characteristic

Wind energy production potential is significantly higher during the monsoon in Thailand. Monsoon means the wind changed direction along with the changing seasons; summer is blowing in a certain direction and it changed to the opposite direction in winter. In the first time, it called the wind in the Arabian Sea which blows in the northeast for a period of six months and blows in the southwest for a period of six months. The most clearly monsoon is the monsoon that occurred in East Asia and South Asia. Monsoon characteristic is caused by the difference in air temperature above the ground and surface water.

In the winter season, the mainland is cooler than the ocean. It is making the high pressure on the mainland and low pressure in the ocean. The air over the ocean, which is high temperature will rise and the air over the mainland will flow in instead of it in a clockwise direction. It called the northeast monsoon starting from the end of October and ending in February. March and April are transitional months. In general, the weather looks good and dry. The northeast monsoon is characterized by clear skies and winds blowing from the sea.

In the rainy season, the wind will change in the opposite direction. The mainland is warmer than the ocean. This makes the low pressure in the mainland and high pressure in the ocean. The wind blows from the ocean at a high pressure into the mainland at a low-pressure zone in a counterclockwise direction. It called southwest monsoon brings humidity from the ocean to mainland with heavy rain, which starts at the beginning of May and continues until the beginning of October. The dominant wind directions in Thailand are shown in Figure 2.

3.2 Exclusion criteria

Exclusion criteria are used to identify the areas where developers should avoid installing wind turbines or should consider the environmental or social impacts more carefully before installation. The twenty-one areas can be divided into 3 classes according to the regulations of Thailand in 1941-2007 [7] as shown in Table 1.

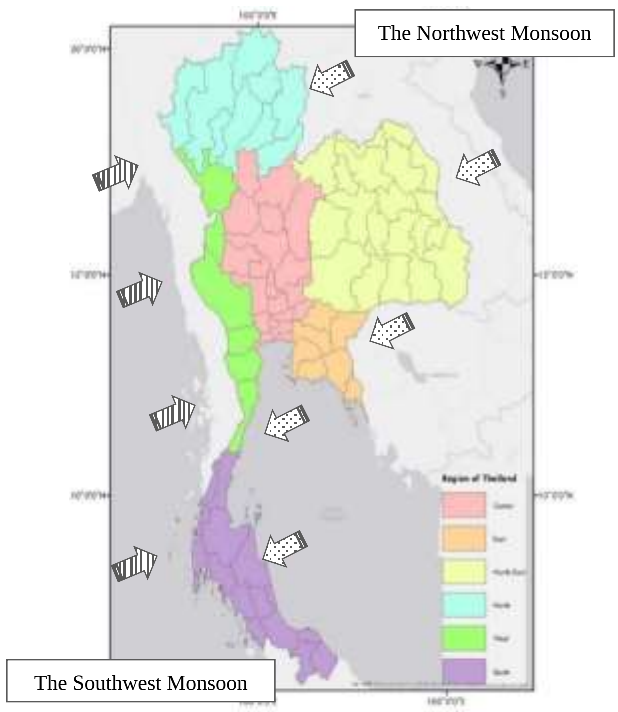


Fig. 2. Wind characteristic of Thailand

3.2.1 Stringent class

In 13 areas in this class listed in Table 1, wind turbines cannot be installed because these areas are the significant ecological, economic, social and transportation area. For example, the national park is an area that is protected by the government for conservation purposes of natural resources especially, forests and wildlife. The environmental preservation is a conservation area decided by the government, which is same the national park for preserve natural or natural ecological or the value of the cultural environment. The wildlife sanctuary is an area set up to provide the habitat for wildlife by non-attacker. The conservation purpose for protection of wildlife species for breeding, research or public education. The non-hunting area is an area designated by the government for protected wildlife species especially rare species and threatened species are able to live and natural breeding in a safe area.

Watershed-class 1A is the watershed area should be preserved as river source areas that still have a richness forest. Especially of its looks and features that may have an impact on the environment from land-use change and the watershed classification defined by the Cabinet. The historical site is an area including the oldest building and man-made building which are very useful in the history of arts, archeology and also included a place that has historical significance or contains traces of human activities.

The road prohibits individuals install anything on a highway in any manner to obstruct or damage. It able to cause a damage to the highway or inconvenience to traffic. The industrial area is an area is allocated for industrial plant and industrial facilities under control of the government with the purpose of industrial development. The airport is an area near the airport or location of facilities in the field of air navigation for safety in aviation. Natural gas pipeline underground is a necessary area that needs to avoid the impacts on the safety of underground natural gas pipelines.

3.2.2 Highly sensitive class

In four areas in this class, wind turbines can be installed under the condition that there will be no impact on the community. These areas are an ecological and social area such as; the national reserved forest is a richness forest area or potential suitability for nature conservation in order to maintain the balance of nature and the environment. Natural water resource is an ecological area that the people used for daily life in the country. These are conservation for the purpose to protect the minor water for agriculture and daily life. The rural residential community is usually a small community with low population density and there is enough space. It may be allowed for installation and operation wind turbines.

3.2.3 Sensitive class

In four areas in this class wind turbines can be installed under the condition that there will be a minor impact on the community. The pollution control zone is a maintenance of environmental area by the government because these areas are likely to have a pollution problem in a serious crisis and harmful to people's health or may cause impacts on environmental quality. The restoration forest is a lack of woods area protected by the government for the purpose of preserving and maintaining forest resources for the benefit of sustainable economic development. The recreation is an area for the purpose of recreational. The installation of wind turbines in the area or in adjoining areas may have an impact on safety and noise.

3.3 Buffer distance

Buffer distance is the distance between the boundary of the area and the wind turbine location and is determined by government regulations. The area within the buffer distance is called the “safety zone,” where the law requires that no wind turbines are installed for safety concerns. Details of the exclusion areas and mandatory buffer distances [7] are shown in Table 1.

The buffer distance around several areas, such as natural parks, wildlife sanctuaries, railways, roads, and recreational areas is 500 m, making these conservation areas safer from the effects of the construction or operation of wind turbines. The buffer distance around urban and rural residential communities is determined by the government to be 1 km, providing a reasonable distance to keep people safe from the impacts of wind turbines.

In radar stations, wind turbines may interfere with magnetic resonance in communications and transportation, which are considered only in aviation radar stations. The government designed the buffer distance for safety in air communication to be 5 km.

Historical sites are defined as the oldest man-made buildings with are very useful in the history of arts, archeology and include places with historical significance or those containing traces of human activities. The government determined 3 km be the appropriate buffer distance to prevent damage or collapse of historical sites.

Natural water resources are ecologically significant and the installation of wind turbines may have an impact on natural water sources such as rainwater runoff, or leaching of sediments during construction. This pollutant or sediments may be transported to neighborhoods, resulting in contamination of natural or shallow water sources. However, the government has defined a buffer distance expected to provide safety from the disturbance of wind turbines of only 100 m.

3.4 Wind power potential

This study aims to identify areas with suitable and sufficient wind potential for the installation of wind turbines. Thailand has an area of 513,000 km^2, covering 77 provinces, 878 districts, and 7,255 sub-districts. The country has a total wind power potential of 1.02×10^8 MW, as calculated by the Thailand formula, and 2,215.10 MW as calculated by the Japan formula.

Table 1. The exclusion criteria and a buffer distance

Exclusion criteria class	Criteria	Buffer distance
Stringent: *"cannot install wind turbines in every case."*	National Park	500 m.
	Environmental preservation	500 m.
	Wildlife sanctuary	500 m.
	Non-hunting	500 m.
	Watershed-class 1A	500 m.
	Road	500 m.
	Railway	500 m.
	Airport	1,500 m.
	Historical site	3,000 m.
	Industrial estate	1,000 m.
	Urban resident community	1,000 m.
	Natural underground gas pipeline	500 m.
	Radar Station	5,000 m.
Highly sensitive: *"can install wind turbines under conditions that there is no impact on the community,"*	National reserved forest	500 m.
	Natural water resource	100 m.
	Rural resident community	1,000 m.
	Land high slope > 20%	None
Sensitive: *"can install wind turbines under conditions that there has less impact on the community but not significant"*	Pollution control zone	500 m.
	Restoration forest	500 m.
	Recreation	500 m.
	Wetland	200 m.

3.4.1 Normal case study

This is the base case to calculate the area and the wind potential by only deleting the exclusion criteria without other conditions.

3.4.1.1 Normal case excluding 13 'stringent' areas

The area suitable for installing wind turbines was calculated by ArcGIS to be 316,849.91 km^2 or 61.73% of the total country area. The wind power calculated by the 59,440.91 GW and 2,136.70 MW, respectively.

3.4.1.2 Normal case excluding 13 'stringent' areas class and rural residential communities

The area suitable for installing wind turbines was calculated by ArcGIS to be 123,251.06 km^2 or 24.01% of the total country area. The wind power calculated by the Thailand and Japan formulae is 58,637.11 GW and 1,942.32 MW, respectively. The wind power potential in this case study is shown in Figure 3a.

3.4.1.3 Normal case excluding 13 'stringent' areas and 4 'highly sensitive' areas

The area suitable for installing wind turbines was calculated by ArcGIS to be 54,147.89 km^2 or 10.55% of the total country area. The wind power calculated by the Thailand and Japan formulae is 9,842.55 GW and 1,870.49 MW, respectively.

3.4.1.4 Normal case excluding 13 'stringent', 4 'highly sensitive', and 4 'sensitive' areas

The area suitable for installing wind turbines was calculated by ArcGIS to be 41,370.63 km^2 or 8.06% of the total country area. The wind power calculated by the Thailand and Japan formulae is 7,630.74 GW and 1,785.87 MW, respectively.

3.4.2 Case study I

In this case study, we deleted the common exclusion criteria and the condition of the areas smaller than 2 km^2.

3.4.2.1 Case Study I: excluding areas less than 2 km^2 and 13 'stringent' areas

The area suitable for installing wind turbines was calculated by ArcGIS to be 316,595.06 km^2 or 61.68% of the total country area. The wind powers calculated by the Thailand and Japan formulae are 59,390.80 GW and 2,002.56 MW, respectively.

3.4.2.2 Case Study I excluding areas less than 2 km^2, 13 'stringent' areas, and rural residential communities

The area suitable for installing wind turbines was calculated by ArcGIS to be 122,282.99 km^2 or 23.82% of the total country area. The wind power calculated by the Thailand and Japan formulae is 54,061.87 GW and 1,483.37 MW, respectively. Figure 3b shows the wind power potential in this case study.

3.4.2.3 Case Study I excluding areas less than 2 km^2, 13 'stringent' areas, and 4 'highly sensitive' areas

The area suitable for installing wind turbines was calculated by ArcGIS to be 52,758.34 km^2 or 10.28% of the total country area. The wind power calculated by Thailand and Japan formulae is 9,565.98 GW and 1,207.41 MW, respectively.

3.4.2.4 Case Study I excluding areas less than 2 km^2, 13 'stringent' areas, 4 'highly sensitive' areas, and 4 'sensitive' areas

The area suitable for installing wind turbines was calculated by ArcGIS to be 39,819.78 km^2 or 7.76% of the total country area. The wind power calculated by the Thailand and Japan formulae is 7,325.42 GW and 1,070.21 MW, respectively.

3.4.3 Case study II

In this case study, we deleted the common exclusion criteria and the condition of the adjusted buffer distance to be twice from the original.

3.4.3.1 Case Study II excluding double buffer distances and 13 'stringent' areas

The area suitable for installing wind turbines was calculated by ArcGIS to be 175,338.49 km^2 or 34.16% of the total country area. The wind power calculated by the Thailand and Japan formulae is 32,858.32 GW and 1,709.59 MW, respectively.

3.4.3.2 Case Study II excluding double buffer distances, 13 'stringent' areas, and rural residential communities

The area suitable for installing wind turbines was calculated by ArcGIS to be 24,534.08 km^2 or 4.78% of the total country area. The wind power calculated by the Thailand and Japan formulae is 25,735.43 GW and 938.41 MW, respectively. The wind power potential in this case study is shown in Figure 3c.

3.4.3.3 Case Study II excluding double buffer distances, 13 'stringent', and 4 'highly sensitive' areas

The area suitable for installing wind turbines was calculated by ArcGIS to be 6,311.72 km^2 or 1.23% of the total country area. The wind power calculated by the Thailand and Japan formulae is 1,165.32 GW and 579.56 MW, respectively.

3.4.3.4 Case Study II excluding double buffer distances, 13 'stringent' areas, 4 'highly sensitive' areas, and delete 4 'sensitive' areas

The area suitable for installing wind turbines was calculated by ArcGIS to be 4,510.95 km^2 or 0.88% of the total country area. The wind powers calculated by the Thailand and Japan formulae are 834.70 GW and 523.24 MW, respectively.

3.4.4 Case study III

In this case study, we deleted the common exclusion criteria and the condition of the areas smaller than 2 km^2 and the adjusted buffer distance to be twice from the original.

3.4.4.1 Case Study excluding areas less than 2 km^2, double buffer distances, and 13 'stringent' areas

The area suitable for installing wind turbines was calculated by ArcGIS to be 174,628.14 km^2 or 34.02% of the total country area. The wind powers calculated by the Thailand and Japan formulae are 32,552.46 GW and 1,510.35 MW, respectively.

3.4.4.2 Case Study III excluding areas less than 2 km^2, double buffer distances, 13 'stringent' areas, and rural residential communities

The area suitable for installing wind turbines was calculated by ArcGIS to be 23,580.66 km^2 or 4.59% of the total country area. The wind power calculated by the Thailand and Japan formulae is 25,491.35 GW and 468.36 MW, respectively. Figure 3d shows the wind power potential in this case.

3.4.4.3 Case Study III excluding areas less than 2 km^2, double buffer distances, 13 'stringent' areas, and 4 'highly sensitive' areas

The area suitable for installing wind turbines was calculated by ArcGIS to be 5,565.40 km^2 or 1.08% of the total country area. The wind power calculated by the Thailand and Japan formulae is 1,153.48 GW and 187.73 MW, respectively.

3.4.4.4 Case Study excluding areas less than 2 km^2, double buffer distances, 13 'stringent' areas, 4 'highly sensitive' areas, and 4 'sensitive' areas

The area suitable for installing wind turbines was calculated by ArcGIS to be 3,816.88 km^2 or 0.74% of total country area size. The wind power calculated by the Thailand and Japan formulae is 710.67 GW and 142.34 MW, respectively.

3.5 Wind potential comparison with other countries

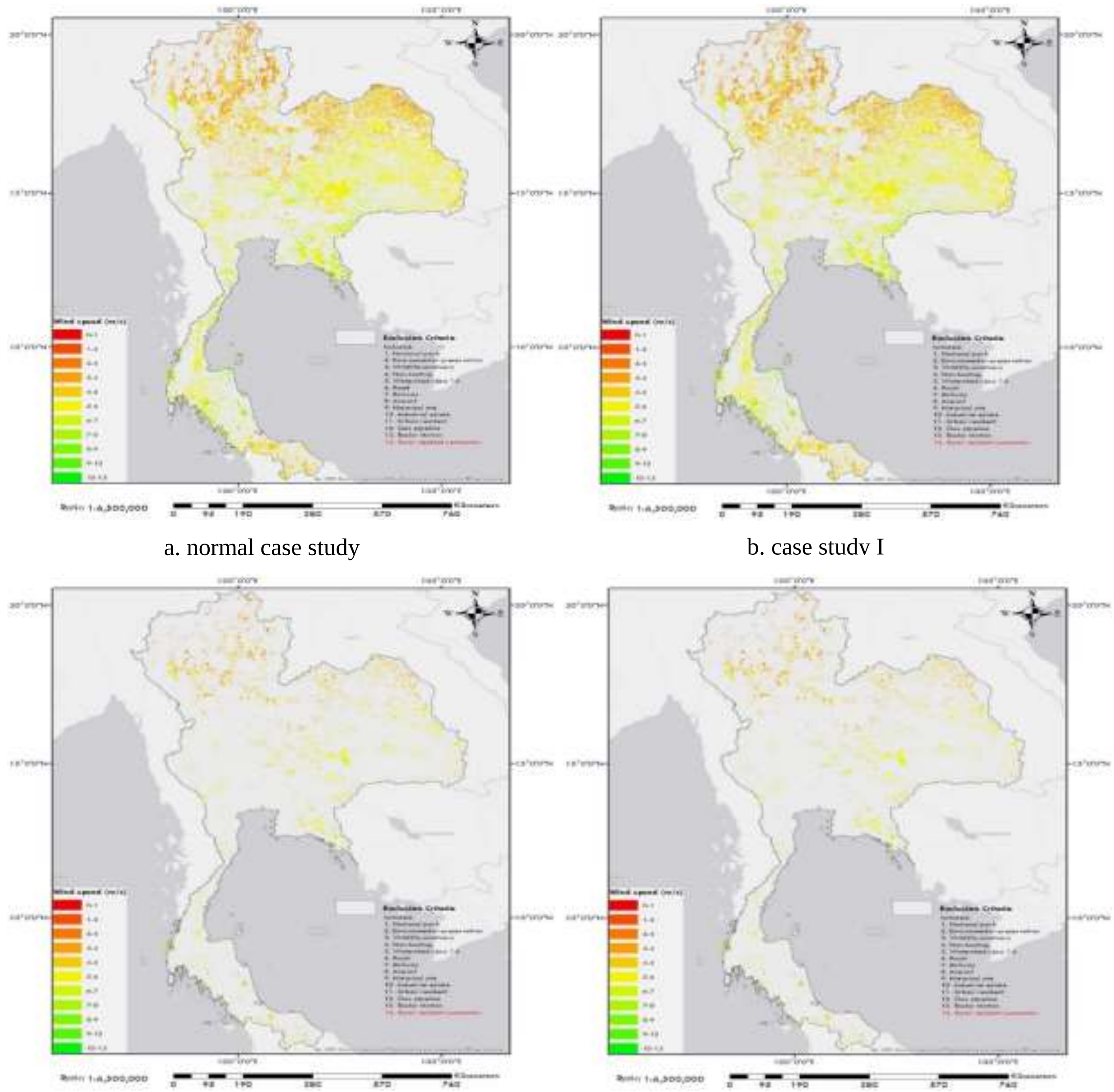
The comparison with previously researchers estimated the wind power potential of various countries shown in Figure 4 indicates that Thailand has a medium country area but a low potential for producing electricity from wind, especially compared to Japan. Japan has a smaller area than Thailand but has higher wind potential for electricity because Japan is an island country. Thus, there is wind around the country and no other countries block the wind. Japan has the potential to receive a full monsoon and tropical cyclones, in contrast with Thailand. Even though the southern part of Thailand has both the northwest and southwest monsoons all year, southern Thailand is limited by its national park status; southern Thailand is an abundant natural resource that should be preserved. Thus, Thailand cannot install wind turbines in many areas in the south of the country. On the other hand, Japan is in the developed countries group, which have been developed new and suitable technologies for the country to maximize the benefits of wind energy, such as by the installation of wind turbines in the sea. In contrast, it is difficult to construct such as offshore wind turbine technology in Thailand because of the lack of specialist expertise. Furthermore, some people in rural residential communities are not educated and lack any basic knowledge of wind energy.

The comparison of wind power potential between Thailand and other countries can conclude that Thailand has a medium area but a low potential for producing electricity from wind. The geography of Thailand means that there are high mountains surrounding the country. While Thailand has both the northwest and southwest monsoons all year, the mountains block the wind. Thus, the average wind speed of the country is relatively low. Other reasons for the lack of wind energy development is the lack of specialists and knowledge, and that some rural communities are not educated. If Thailand could introduce new wind turbine technologies, such as offshore wind turbines, it would be possible to increase its potential for generating electricity from wind power in the future.

3.6 Discussion

As described above, the exclusion criteria for installing wind turbines follow the Thai regulations and can be divided into 3 classes for 21 criteria. The 'stringent' class includes 13 criteria such as areas of significant ecological, economic, social, and transportation importance where the owner of the project cannot install wind turbines in every case. The 'highly sensitive' class has 4 criteria. These areas include ecologically and socially important area. In this class, the owner of the project must have permission to install wind turbines in these four areas, but they must prove that the project has no impact on the community. The 'sensitive' class has 4 criteria, including pollution control zones, restoration forests, recreational areas, and wetland. The owner can install wind turbines in this area but they must prove that the project will have only a minor impact on the community around the project site. In this investigation conducted GIS analysis of four case studies to find locations with sufficient wind potential for wind turbine installation and a summary of the GIS results is presented in Table 2.

The first case was the normal case study, for which the most suitable area for wind turbine installation was located in the northeastern of Thailand, corresponding to 8.06% of the total country area and an annual wind speed of approximately 5.22 m/s. The second case, Case Study I, found that the most suitable area with wind speed around 5.25 m/s. However, the area was 7.76% of the total country area size; smaller than in the normal case study.



a. normal case study   b. case study I

c. case study II   d. case study III

Fig. 3. Wind potential with condition stringent class and rural resident community

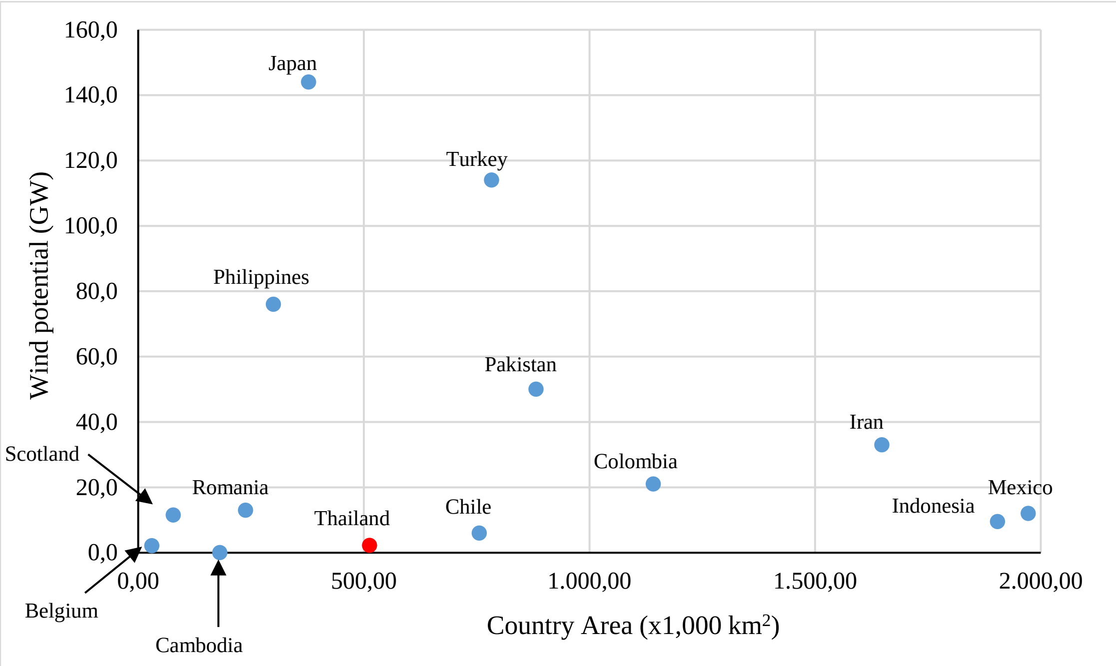


Fig. 4. The comparison between wind potential and country area size in another country

Table 2. The summary of GIS results

Case study	Delete items	Suitable area size (sq.km)	Percentage (%)	Wind power (MW) Thailand formula	Wind power (MW) Japan formula
Policy target	-	-	-	3,002 (AEPD:2015)	
Normal case	Class ST	316,849.91	61.73%	5.94E+07	2,136.70
	Class ST + Rural	123,251.06	24.01%	5.86E+07	1,942.32
	Class ST + HS	54,147.89	10.55%	9.84E+06	1,870.49
	Class ST + HS + S	41,370.63	8.06%	7.63E+06	1,785.87
Case study I (suitable area size ≥ 2 sq.km.)	Class ST	316,595.06	61.68%	5.94E+07	2,002.56
	Class ST + Rural	122,282.99	23.82%	5.41E+07	1,483.37
	Class ST + HS	52,758.34	10.28%	9.57E+06	1,207.41
	Class ST + HS + S	39,819.78	7.76%	7.33E+06	1,070.21
Case study II (buffer distance 2 times)	Class ST	175,338.49	34.16%	3.29E+07	1,709.59
	Class ST + Rural	24,534.08	4.78%	2.57E+07	938.41
	Class ST + HS	6,311.72	1.23%	1.17E+06	579.56
	Class ST + HS + S	4,510.95	0.88%	8.35E+05	523.24
Case study III (suitable area size ≥ 2 sq.km. and buffer distance 2 times)	Class ST	174,628.14	34.02%	3.25E+07	1,510.35
	Class ST + Rural	23,580.66	4.59%	2.55E+07	468.36
	Class ST + HS	5,565.40	1.08%	1.15E+06	187.73
	Class ST + HS + S	3,816.88	0.74%	7.10E+05	142.34

*ST = Stringent, HS = Highly sensitive, S = Sensitive

The third case, Case Study II showed that the suitable area with an annual wind speed is 5.86 m/s, and the suitable area is 0.88% of the total country area size. The fourth case, Case study III found that the most suitable areas specifically over 0.87% of the country, with an annual wind speed of around 5.22 m/s. The presented results are calculated by the wind power density formula in all four cases. The maximum and minimum wind power potential were 5.94×10^7 MW and 8.24×10^5 MW, which were different from the other formula. On the contrast, as calculated by the accuracy formula of the Ministry of Economy, Trade, and Industry of Japan were lower than the policy target of 3,002 MW, that was approximately 2,100 MW and 500 MW, in all four case studies. This calculation considers the wind turbine size for installation, which is 2 MW per wind turbine, and the availability ratio of the wind turbine. Thus, the precise results concluded the policy target was not appropriate. This situation was difficult to achieve the target in future. Although the government has been supporting, then efforts to harness potential wind power across the whole country are not enough to reach the policy target.

GIS widely used to identify a suitable area for wind power plant development including Thailand. Such as [9] and [19] presented the coastal part along the Gulf of Thailand of southern part was suitable for wind power plant development. In this paper indicated the suitable locations with sufficient wind speed conditions and excluded significant criteria of environmental and social impacts located on the southern part of Chiang Mai, northern and mostly in the central part of Nakhon Ratchasima, northeastern Thailand.

4. Conclusions

The main aim of this paper is to analyze a wind energy potential and identify suitable locations for wind power plant development. In this investigation, significant criteria follow the regulations have been studied and simulated by GIS.

The results demonstrate that the total wind energy potential was 2,215 MW when excluded restriction areas to analyze the wind energy potential and suitable locations, including significant environmental, land use, public utilization, slope, and wetland. The wind energy potential was 1,942.23 MW. Areas in the southern portion of Chiang Mai province and the central portion of Nakhon Ratchasima province were considered highly suitable for wind power plant development. Although Thailand has significant wind energy source during the monsoon all year. Nevertheless, the amount of wind energy potential was quite a low compared with the other countries due to the low wind speed in the country. As such, it was necessary to ensure the policy targets conform to realistic estimates of wind power potential, aiming to locate wind power plants in appropriate areas to avoid adverse environmental and social impacts on local communities.

In this paper was could obtain an accurate formula and information about wind energy potential without significant criteria for researchers who are active in wind energy development field.

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