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Using GIS Maps to Assessing Wind Energy in Asian Countries: Finding the High Potential Countries and Examining Their Current Status and Outlook

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A B S T R A C T

Providing sustainable energy to achieve favorable economic development has attracted the attention of many governments in recent years. Renewable energies, especially wind energy, have gained considerable media attention recently due to challenges with the use of fossil fuels, including difficulty in accessing and devastating environmental impacts. Extensive efforts have been made in Asia to benefit wind energy regionally, all of which have made Asia a leader in this field. There are a few simulation results in this area, given the importance and need to compile infrastructural strategies and programs that require a thorough understanding of the current state of wind energy usage and determining its potential in different regions. Therefore, this study reports for the first time on surveys conducted on average of 20-year wind speed data collected from 2892 stations in 49 Asian countries and wind speed and power density maps obtained using Geographic Information System (GIS) software and the Boolean method. Besides assessing the problems and issues of energy consumption in countries with high potential wind energy in Asia, in this paper, we try to explore the benefits and requirements of using wind energy in these countries as well as the possibility of maximally using wind energy. According to the results, east and north of Russia, as well as west and southwest Asia are optimal regions for establishing large-scale wind plants; there is no significant potential for the use of wind energy in other regions, especially in the majority of China, ASEAN countries, and their neighboring countries.

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INTRODUCTION

In the quest for sustainable and renewable energy sources, wind energy has emerged as a pivotal player in the global transition toward cleaner and more environmentally friendly power generation (1, 2). The unique geographical and meteorological characteristics of Asian countries make them particularly interesting for the exploration and development of wind energy resources (3). This paper delves into the innovative use of GIS mapping techniques to assess the wind energy potential across various Asian nations, aiming to identify those with the highest capacity for harnessing this abundant and renewable energy source (4).

The integration of GIS technology allows for a comprehensive and spatially explicit analysis of the wind energy landscape, taking into account factors such as topography, wind patterns, and land use. By leveraging GIS maps, we seek to not only pinpoint the high-potential countries for wind energy but also to provide a nuanced understanding of their current status in harnessing this resource. This involves an examination of existing wind energy infrastructure, policy frameworks, and socio-economic factors influencing the adoption of wind power (5).

Furthermore, this paper aims to offer insights into future outlook of wind energy in these high-potential Asian countries. Through a careful examination of trends, technological advancements, and evolving policy landscapes, we intend to assess the trajectory of wind energy development in the region. Identifying challenges and opportunities, as well as proposing strategies for overcoming barriers to wind energy adoption, will be integral to the discussions presented herein.

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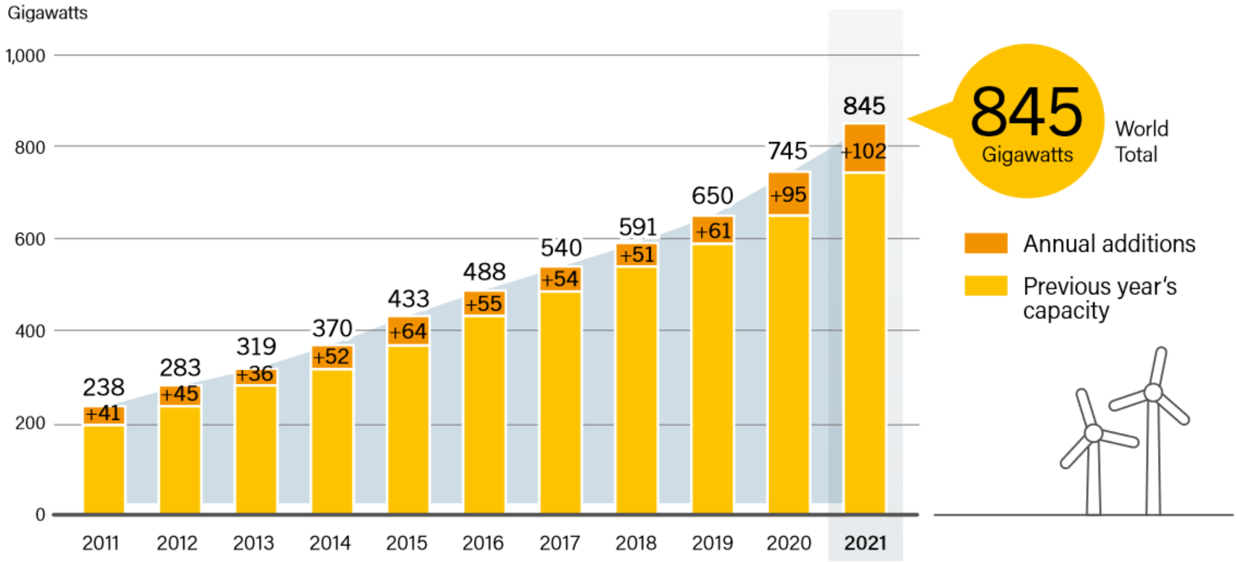


Figure 1. Global cumulative installed electricity generation capacity from wind power (in MW) (6).

As the global community intensifies its commitment to combat climate change and transition towards sustainable energy practices (7), understanding the wind energy potential in Asian countries becomes not only academically relevant but also imperative for shaping informed policies and fostering a resilient and low-carbon future. This paper, therefore, seeks to contribute to the growing body of knowledge in the field and provide valuable insights for researchers, policymakers, and industry stakeholders involved in the pursuit of sustainable energy solutions in Asian context (8).

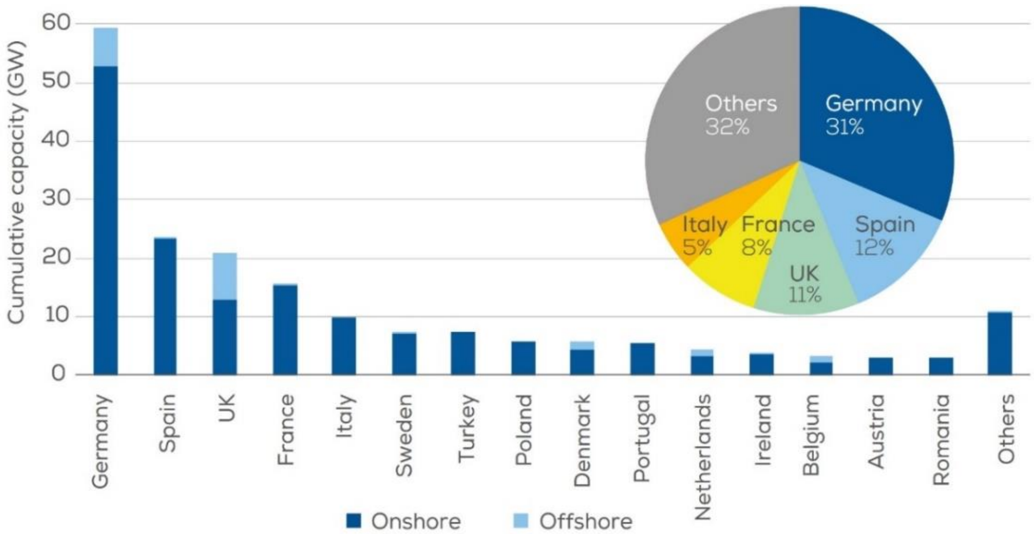
The wind energy industry has experienced the largest, most successful, and leading development in the last two decades than other renewable sources. Thus, its global cumulative capacity in 2014 has been estimated at 370 GW, with its maximum installed capacity (142 GW; 38% of the global capacity) in Asia, followed by Europe (134 GW; 36% of global capacity), and North America (78 GW; 21% of global capacity) (9). The cumulative installed electricity generation capacity from wind power globally reached 845 GW in 2021 (see Figure 1). Also, the turbines installed in 2018 can supply more than 5% of the electricity demand in the world (6). Using wind energy in the coming years will be significantly enhanced along with competitiveness in its technology. According to projection made, by 2050, wind energy will account for 25% to 30% of the global electricity supply (10).

An overview of wind energy in the world

For the first time in 2018, Bandoc et al. (11) categorized wind energy density status globally, continental, and nationally based on seven potential categories, including superb, outstanding, excellent, good, fair, marginal, and poor. The results indicated that the central-southeastern region of Asia, central-northern region of North America, Southern South America, Northern/Northwestern Europe, and northern Asia are identified as five high-potential regions worldwide. Detailed statistical analysis also indicated that Asia, north and central America, South America, Europe, Africa, Australia, and Oceania have the highest wind energy potential. Also, findings at the national level revealed that China has the highest wind potential, followed by Norway, Canada, Argentina, the United States, Chile, Russia, and Afghanistan. Africa is a distinguished continent as a function of the wind resources regime. However, the use of this renewable energy on the continent is minimal. Estimates indicate a significant potential (≈ 31% PWh) in the continent in terms of wind energy (12). South Africa, Algeria, Sudan, Egypt, Nigeria, Libya, Tunisia, Mauritania, and Morocco have significant wind potential, while Equatorial Guinea, Central African Republic, Gabon, Burundi, Benin, Liberia, and Togo have the least wind power (12). Increasing electricity demand and reducing project costs could lead to addition of 30 GW of wind energy capacity in Africa during 2018-2027 (13). Table 1 represents five African countries with the most use of wind energy and their installed and under-construction capacities (14).

Table 1. The five biggest wind markets in Africa (14)

Countries	Operational (MW)	Under construction (MW)
South Africa	1,170	840
Morocco	870	50
Egypt	750	0
Ethiopia	320	0
Kenya	14	310



	Germany	Spain	UK	France	Italy	Sweden	Turkey	Poland	Denmark	Portugal	Netherlands	Ireland	Belgium	Austria	Romania	Others
Offshore	6.4	-	8.2	-	-	0.2	-	-	1.3	-	1.1	-	1.2	-	-	0.1
Onshore	52.9	23.5	12.8	15.3	10.0	7.2	7.4	5.9	4.4	5.4	3.4	3.5	2.2	3.0	3.0	10.8
Total	**59.3**	**23.5**	**21.0**	**15.3**	**10.0**	**7.4**	**7.4**	**5.9**	**5.7**	**5.4**	**4.5**	**3.5**	**3.4**	**3.0**	**3.0**	**10.9**

Figure 2. Gross annual onshore and offshore of wind installations in Europe, 2018 (15)

In 2018, Europe's installed wind energy capacity was 178.5 GW, which is enough to supply 14% of the electricity needed in this continent (15). Among all renewable energies, wind energy in Europe has experienced the highest growth over the past decade. According to Figure 2, Germany, Spain, England, France, and Italy have provided the highest number of installed wind energy capacities and installations in Europe (15).

One of the main sources of renewable energy in Australia is wind energy. It was about 5% of the total electricity demand in 2015 (see Figure 3) (16). At the end of 2018, there were 94 wind farms in Australia with an electricity generation capacity of approximately 6702 MW of electricity (17). The registered wind energy capacity in New South Wales, Queensland, South Australia, Tasmania, and Victoria is 1503, 632, 2142, 308, and 2116 MW, respectively (18).

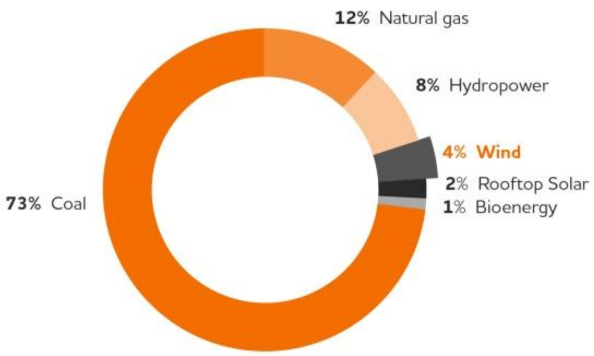


Figure 3. Electricity generation in Australia's national electricity market, 2015 (16)

North America benefits from renewable energy for large-scale electricity generation. It is one of the best regions to exploit wind energy worldwide, with abundant financial resources and skilled labor (19). Wind potential in Latin America is very high (20), where using wind energy would be ideal mainly due to relatively low population density, long distances, and the need for energy in remote areas. However, there are relatively few exploitations of wind energy in Latin America (21). It has been estimated that by 2020, Latin America's wind energy capacity will reach about 30 GW. As the world's 8th

Table 2. The five largest wind markets in the Americas (22)

Country	New installations 2018	Total installations 2018
USA	7,588	96,635
Canada	566	12,816
Brazil	1,939	14,707
Mexico	929	4,935
Argentina	494	722
Chile	204	1,621
Other Americas	220	3,605
Americas	11,940	135,041

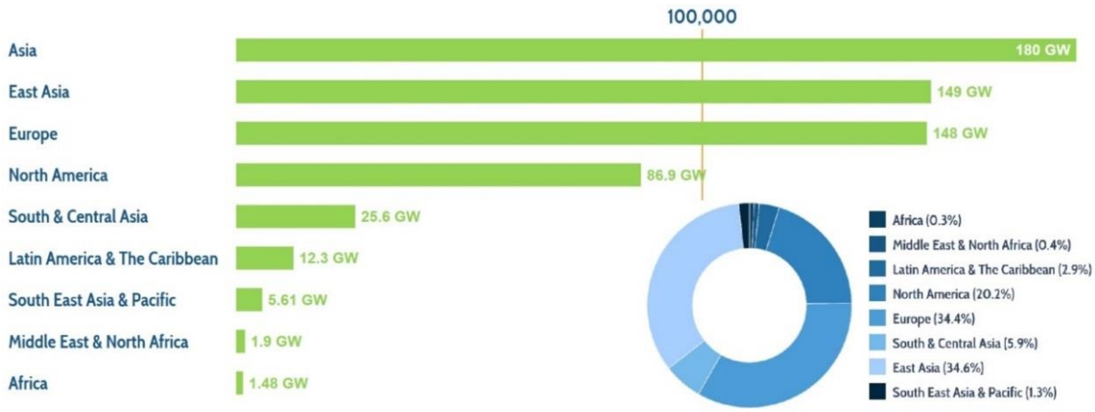


Figure 4. Wind installed capacity by region (23)

largest country in wind energy use, Brazil is located in Latin America, with a capacity of 12.77 GW (20). Table 2 presents the countries with the most wind energy use in the American continent, along with their added capacity and final capacity in 2018 (22).

Wind energy in Asia

Based on Figure 4, Asia led the world in wind turbine installations in 2015, primarily driven by the growth of wind energy in East Asian countries (23).

China's wind industry has been advancing rapidly since 2005 (24); currently, the world's largest wind energy market is active in China, with a capacity of over 188.2 GW. China benefits from significant wind potential due to the large land area as well as the long coastline (6). China has outlined various wind energy development goals within its national energy security framework to achieve sustainable economic development as part of the global community (25). China is the world leader in the wind generation market (26).

About 240 million people (19% of the total population) in India are deprived of access to electricity. India is a distinguished country as a function of the wind resources regime, so the country has the 2nd largest wind power capacity in Asia and 4th worldwide with a capacity of 35 GW. India has outlined a plan to achieve 60 GW of wind energy generation by 2022 and will install 25 GW in the next three years as well (27).

PROBLEM STATEMENT

Wind energy is one of the most available types of renewable energy that has recently attracted the attention of researchers (28). Wind power is an option to improve the economic situation in areas where there is no global power grid in those areas. The production of this energy has little impact on the environment. Nowadays, the cost of electricity generation using wind sources competes with the cost of generating electricity from fossil fuels (29).

In many countries, factors such as public acceptance, land use conflicts, and so on have prevented the use or development of wind power plants (30-33). The first challenge in designing and developing wind power plants is to identify suitable locations (34). Also, the cost of investing in wind power plants is high, and obtaining a permit is relatively complex and long. The main advantages of optimal location for wind turbines include better utilization of wind resources, reduced number of wind turbines, and the prevention of high-ground use (35). In almost all previous studies, average wind speed is the most important criterion for the location of wind power plants (36-41).

Here, the wind speed data from NASA satellite data was collected for 2892 stations in 49 countries of Asia. In the given data, the speed of wind is measured at the height of 10 m, the average time is 20 years (42), and according to the Equation [1], wind speed data have been converted to a height of 50 m (43):

$$\frac{V}{V_r} = \left(\frac{H}{H_r}\right)^{\frac{0.37-0.088\ln V_r}{1-0.088\ln\frac{H}{H_r}}} \quad [1]$$

where V is wind speed at the required height H, and V_r is the velocity at the given height H_r. The wind speed criterion is based on literature (34, 44) about 6 m/s at the height of 100 m. While Sunak et al. (45) stated that at a turbine hub height, a speed of 6 m/s is very appropriate, while a speed of fewer than 5 m/s is not appropriate. However, some references suggested speeds of 5 m/s, and 5.5 m/s (46, 47).

The best method to evaluate the wind potential in a site is the wind power density parameter, expressed in w/m^2, which indicates how much wind is used to generate electricity by wind turbines at a specific location (13). The density of wind power is computed as follows:

$$\frac{\bar{P}}{A} = \frac{1}{2}\rho\int_0^\infty U^3\, P(U)dU \quad [2]$$

In the above relation, $\bar{P}$ is the average wind power in watts, ρ is the air density in the studied area in $\frac{kg}{m^3}$, A is the

Table 3. Wind classification (34)

Power class	Potential	Power density and wind speed at 50m	
		Power (W/m^2)	Speed (m/s)
Class- I	Poor	$P_{50} \leq 200$	≤ 5.6
Class- II	Marginal	$P_{50} \leq 300$	≤ 6
Class- III	Moderate	$P_{50} \leq 400$	≤ 7
Class- IV	Good	$P_{50} \leq 500$	≤ 7.5
Class- V	Very good	$P_{50} \leq 600$	≤ 8
Class- VI	Excellent	$P_{50} \leq 800$	≤ 8.8
Class- VII	Excellent	$P_{50} \leq 2000$	≤ 11.9

swept area by wind turbine blades in m^2 and U is the average wind speed in m/s. Table 3 summarizes the wind power classification for a height of 50 m (34).

Geographic information systems (GISs) have been widely used in recent years because they combine distinct data to accomplish defined purposes such as solar and wind resources assessment (34, 44, 48). In the present study, the Inverse Distance Weighted (IDW) technique (Equation [3]) is used in GIS software to predict wind speeds between meteorological stations because their data are not directly measured. The technique determines the value of a cell with an unknown value using the weighted combination of a set of points with a known value. In this method, weight is an inverse function of distance.

$$\text{IDW local mean} = \frac{\sum_{i=1}^{n} \frac{\text{Value}_i}{(\text{Distance}_i)^n}}{\sum_{i=1}^{n} \frac{1}{(\text{Distance}_i)^n}} \quad [3]$$

In the above equation, the power n is a positive number assumed to be 2 in the present study (34). The n parameter allows the user to control the importance of known points based on the distance to unknown points. In other words, if the parameter n is increased, the importance of points closer to the unknown point will enhance, but the mapped surface will be more uneven. Figure 5 shows the impact of n on surface flatness and predicted parameter value.

RESULTS

In Figures 6 and 7, the average wind speed and wind power density at the height of 50 m are presented for all countries in Asia. Further, the necessity of using wind energy and its development recommendations in countries with a wind speed of more than 6.37 m/s were studied.

Based on the results of Figures 6 and 7 in Table 4, Asian countries prone to using wind energy are divided into two categories. The first one is related to countries with wind speeds of more than 10.4 m/s, and the second rank is related to countries with wind speeds between 7.68 to 10.4 m/s.

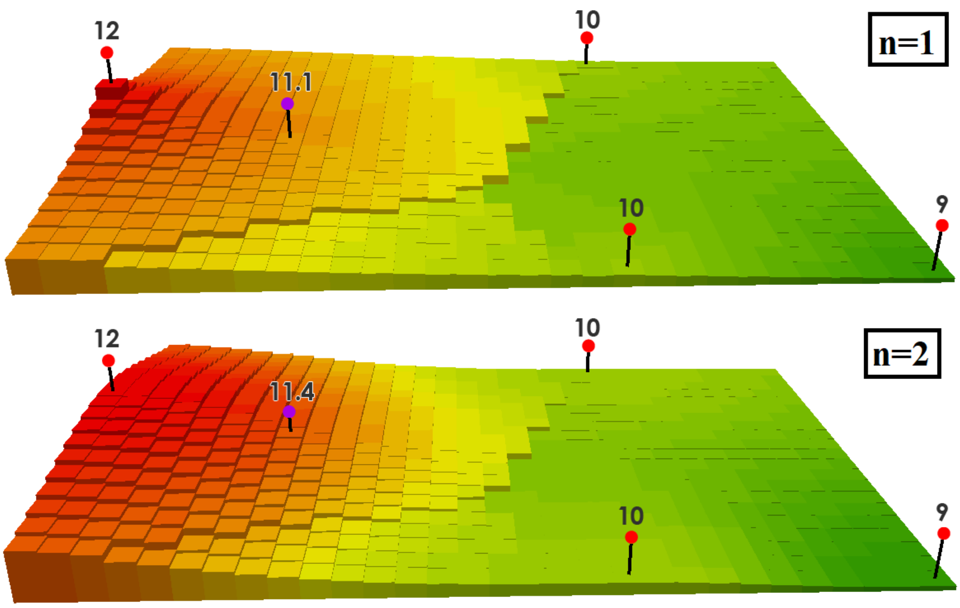


Figure 5. The impact of parameter n on surface flatness and predicted parameter value

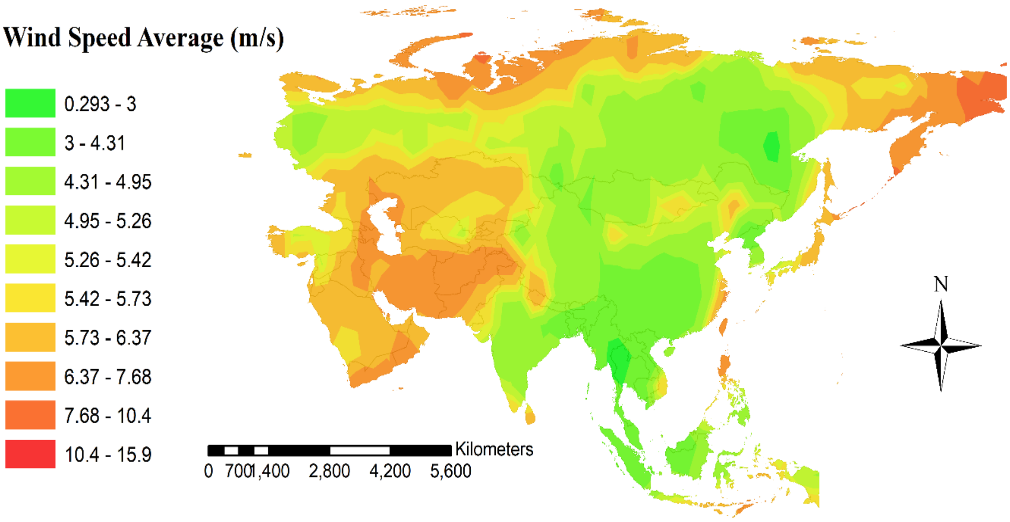


Figure 6. Average wind speed at 50 m high for Asian countries

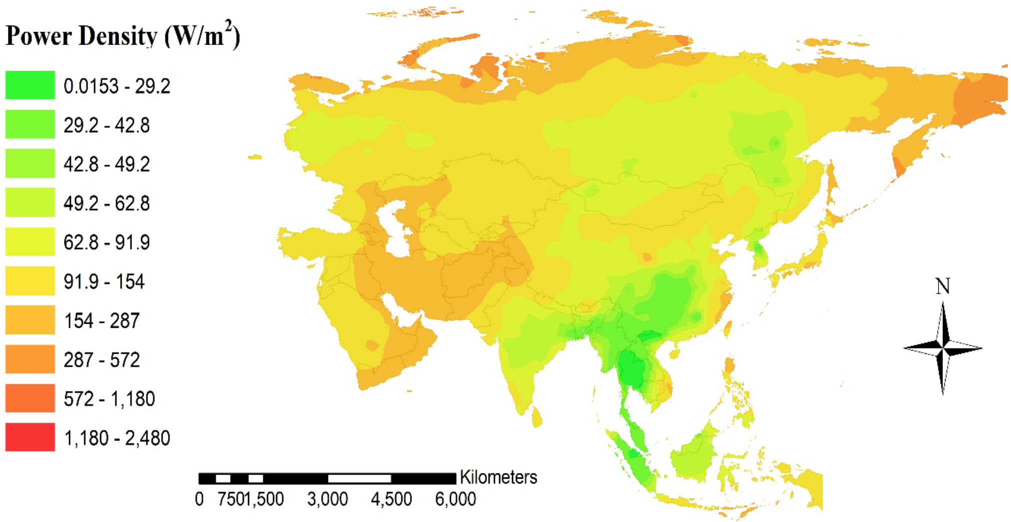


Figure 7. Wind power density at 50 m height for Asian countries

Table 4. Ranking of Asian countries

Rank	Countries	Wind speed (m/s)
First	Russia	> 10.4
Second	Philippines, Taiwan, East Timor, Yemen, Oman, Saudi Arabia, Iraq, Iran, Afghanistan, Pakistan, India, Turkmenistan, Tajikistan, China, Azerbaijan, Armenia, Georgia, and Kazakhstan.	7.68-10.4

First-rank countries

As can be seen from the results of Figures 6 and 7, although the Russian Southern, Central, and Western regions do not have significant potential for using wind energy, a small region in the east of Russia has the best potential for wind power in Asia.

The results also indicate the high potential of wind energy in the region between the west and southwest of Asia. In other parts, especially in most parts of China, as well as in the ASEAN countries and their adjacent countries, wind potential is not noticeable.

Russia

Due to economic development in Russia, the country must have a fundamental review in the field of energy production (49, 50). Recent studies have suggested that Russia should create new energy centers in the country's east (50). According to the results of the previous work (51), it is recommended that these centers be in the field of wind energy. Although after natural gas, wind energy can be the cheapest energy source in Russia, unfortunately, today, the role of renewable energy in Russia's electricity production is about 0.05% (52), which has a wind power of only 11 MW (51). In this regard, the Russian government, with financial support and wind technology development, should seek to attract large wind turbine manufacturers (53, 54).

Second rank countries

Eastern, Northern, and adjacent to Caspian Sea in Russia, the north of Philippines, Taiwan, East Timor, the southern half of Yemen, the southern half of Oman, a small area of southeastern Saudi Arabia, eastern Iraq, more than 80% of Iran, almost all of Afghanistan (except the small area On the border between Uzbekistan and Turkmenistan, the northern half of Pakistan, a small area in northern India, a small area in southeastern Turkmenistan, the southern half of Tajikistan, a very small area in western China, all of Azerbaijan, the eastern half of Armenia, a small area in eastern Georgia and western Kazakhstan are in the second priority of using wind energy on the Asia continent. In the following, further exploring the current state of wind power in these countries, the potential for using this energy, and the future plans of these countries to use renewable energy with a focus on wind energy will be addressed.

Philippines

Nearly 76% of Philippines' energy sources are fossil fuels, and the rest is renewable energy (55). Today, Philippines faces growing energy concerns (55, 56); therefore, trying to triple the share of renewable energy by 2030 (57). This seeks the most suitable type of renewable energy for rural areas. It should be noted that Philippines' electricity is one of the most expensive in Asia (58), and the authorities have stated that wind electricity tariffs are cheaper than solar electricity tariffs (57). Since the contribution of wind and solar power in Philippines is less than 0.4% , it is recommended that the government invest more in wind power. Of course, it should be noted that after Hydro, the government has invested heavily in the wind energy sector (59).

Taiwan

An annual wind energy production in Taiwan in 2030 is estimated to be 11343 GWh (60) which is very suitable for a country dependent on energy imports that is vulnerable to energy security (61). It has been argued that wind energy is the best option because of the environment and the second-best option in view of financially for renewable energy in Taiwan (62, 63). It has been argued that by reducing taxes, helping private sector investors, and the optimal maintenance plan, Taiwan, in addition to using the benefits of reducing environmental pollution, can be needless from the energy imported by offshore wind energy (64). Therefore, considering the challenges and strategies of wind energy in Taiwan, it seems that a solution for further development of this country would have great potential for wind energy (61).

East Timor

In East Timor, details of energy access objectives at various national, regional, etc. levels are not specified, while for the improvement of electricity-related services, a detailed study of the potential of renewable energy, especially wind, is necessary (65). The cooperation of the private sector and the government to meet the energy needs of the welfare community in East Timor is very important and has a positive impact on economic growth (66). It has been stated in previous work that East Timor has a good potential for wind energy (66), and in the development plan by 2020, it is decided that 50% of East Timor's energy requirements will supply by renewable energy from wind and solar resources (67).

Yemen

Various reports have indicated that using renewable energy directly impacts economic growth and the reduction of environmental pollutants in Yemen and leads to sustainable growth (68). Fuel subsidies in Yemen are more than health subsidies, and there is an 81% difference between the price of gasoline in Yemen with the global average (69). Most Yemeni populations do not have access to electricity, and renewable energy has no share in its energy production (70). Considering the high potential of wind energy in Yemen (71-74), considering barriers and challenges seems important. Although so far, researchers have paid less attention to this issue (75). The reports indicate that the potential of wind power in Yemen is 308722 MW (76), and it is planned that by the year 2025, about 15% of the country's electricity will be supplied by renewable energies (75).

Oman

Oman is a growing region where its economy depends on fossil resources, and it is recommended for the future of Oman to use the wind, which has the highest efficiency among renewable resources (77). According to the findings, the southern part of Oman has the highest potential for wind power (78), which is in line with the findings of the present work. It is also stated that the cost of wind power production in south Oman is lower than that of the north (79). Renewable electricity in Oman is, of course, more expensive than the national electricity grid because of its subsidy on the grid (80). It is recommended that Oman government invest in wind energy to avoid the threats posed by the cost increase of fossil fuels and increasing environmental emissions (81).

Saudi Arabia

Currently, Saudi Arabia's electricity generation is mainly based on crude oil, which grows by 7% annually (82). So the government plans to provide 20% of electricity from renewable energy, especially wind, and the sun, by 2030

(83) in which the wind power share is 9 GW (84). Wind power in Saudi Arabia is growing fast, and it is noted that the East of Saudi Arabia, with a mean wind speed of 7.5-8 m/s, has great potential for wind energy (85). Unfortunately, despite this good wind energy potential, it has not been used enough (85). Therefore, studying the potential of renewable energy, especially wind energy is necessary for Saudi Arabia (86).

Iraq

It is reported that Iraq has a small annual wind speed. But the country's energy production will improve if wind energy is combined with solar energy (87). Studies have recently been conducted on the study of the potential of wind energy in Iraq (88-90) so that comprehensive and strategic planning can be done on the use of wind energy. It has been mentioned that Iraq has the potential to use small wind turbines to provide lighting for streets and other similar uses (91). Its production potential in eastern Iraq is more than elsewhere (92), which is in line with the findings of the present work.

Iran

So far, many studies have been carried out on the potential of using wind energy in Iran by the authors of the present work (93-98). It has been stated that Iran has an excellent wind potential, and 41% of 91 million kWh of produced renewable electricity is wind power (99). Recently, many studies have been done on using wind turbines with a horizontal axis (100, 101) and wind turbines with a vertical axis (102, 103) in Iran, which are in the household, agricultural, industrial, and wind farms. These studies are useful for the use of wind energy (93). Another application of these studies is to allow foreign and domestic investors to invest in this field (104).

Afghanistan

Afghanistan's annual wind energy potential is estimated at 342521 GWh, which is 2.5 times higher than its solar potential (44). It is mentioned that 15.93% of Afghanistan has an average annual wind speed of more than 6 m/s, most of which are in the western provinces of Hirat, Farah, and Nimroz (44). Afghanistan, despite having one of the lowest energy consumption rates in the world (105), needs to increase its energy access to develop (106), because of its high wind power potential (44, 107), the use of wind energy is recommended. Due to low operating costs, technical simplicity, and short installation time, wind power usage is a desirable solution for remote areas of Afghanistan (96, 108).

Pakistan

The study of wind power potential and economic analysis shows that in Pakistan, the development of wind projects is necessary to provide the power needed by local communities (109). This is because Pakistan relies on fossil fuels to generate electricity, and more than half of its population has no access to electricity (110), which has led some researchers to assess wind power and evaluate the future status of wind energy in Pakistan (111-115). Nowadays, the share of renewable energy in Pakistan's electricity generation is only 2.2% (116), while the wind potential is 346,000 MW, which, unfortunately, only 308 MW are in operation (117, 118). In one study, evaluations showed that wind energy is the most appropriate renewable energy source for Pakistan to exit the current energy crisis (109).

India

Renewable energies account for 12% of India's total energy capacity, of which 70% is related to wind energy (119). The wind potential in India is estimated to be 3400 GW (120), of which 32.78 GW was installed in 2017, representing 6.4% of the total installed capacity in the world (121). Despite a large number of projects and studies that have made India the world's fifth largest wind power (122), it has been overlooked that India is the best place to use wind energy (121). This issue illustrates the necessity and importance of the present work.

Turkmenistan

Turkmenistan has a high wind potential (about 10 GW) among Central Asian countries (123), and the wind speed is about 6 m/s in the height of 30 m (124). Some also stated that the wind energy potential in Turkmenistan is equal to that of fossil fuels (125). One reason why Turkmenistan has studied wind energy less than other types of energy is that most of the population receives gas and electricity free of charge and the rest of the population pays the lowest energy prices in the world (126). Considering that in Turkmenistan, very little attention has been paid to the issue of renewable energy and especially wind energy, and only about 0.2% of its electricity is supplied by renewable sources (127), unlike in other Central Asian countries, there are still no basic rules regarding renewable energies (such as national grid access, tax breaks, etc.) (123), the results of this work can be very useful.

Tajikistan

Although Tajikistan has good potential for renewable energy, it has serious backwardness in this field (128). The unstable economy, low-energy tariffs, and the lack of foreign investment required for renewable development are among the factors behind backwardness. Although Tajikistan is currently strongly facing an energy crisis (129), very few studies have ever been done on Tajikistan's wind energy potential. It was stated that studying and investing in wind energy can help the country's energy needs and export some of it (130). Among renewable energies in Tajikistan, wind energy has the most barriers to implementation (131). Considering the above issues, more studies are needed on wind energy in Tajikistan.

China

China is the world's largest CO_2 producer, and the development of wind energy is a major strategy in China to reduce environmental pollution (132). China is the world leader in wind energy (26) and plans to reach 400 and 1000 gigawatts in the years 2030 and 2050, respectively (133). Since China has ambitious goals for wind energy in pursuit of sustainable social and economic development (25), further studies on the identification of suitable wind energy areas will help policymakers in this area (134). Since assessing wind resources is critical to wind turbine selection, site planning, economic predictions, and financial estimates (135, 136), the need for recent studies such as the present work is seen. In 2016, the installed capacity of China was 1.6 GW (137).

Azerbaijan

One of the goals of Azerbaijan is to enter the list of developed countries by 2025 (138). In this regard, the Azerbaijani government has made many efforts for sustainable development (139, 140). The conducted studies indicate that wind energy potential in Azerbaijan is very satisfactory as an alternative energy source and therefore recommends extensive use of wind energy in this country (141, 142). The reason for this is that in 2016, the country's economy was in recession for the first time in the past two decades, which saw the need for renewables to reduce oil dependency (143). The current unwillingness to use wind energy and other renewable energy in Azerbaijan is mainly due to cheap natural gas (144). In 2015, the amount of wind energy produced in Azerbaijan was 4.6 GW, which doubled from the last year (140), but it is still deficient. Therefore, the Azerbaijani government has decided to provide 9.7% of the total energy using renewable energies by 2020 (140). If Azerbaijan uses all its wind energy potential, it will store 0.8 million tons of fuel annually.

Armenia

A large part of Armenia's energy depends on fossil fuels and energy imports (145), and the government intends to invest in using renewable energy (146, 147). In this regard, a law was passed in 2013 that, during the first 15 years of the renewable energy plant, 100% of its electricity should be purchased at a guaranteed price, estimated at $ 0.08 per kilowatt of wind power (148). In 2014, Armenia's wind power production capacity was 3.7 GWh, accounting for 0.06% of the total electricity production(146). It is argued that Armenia has the potential to produce 1640 GW of wind energy (149). Further studies in the field of wind energy in Armenia can help the Ministry of Energy and Natural Resources in its strategic direction.

Georgia

In 2015, the share of renewable energy in the electricity supply basket in Georgia, around 80%, was the highest in the world, most of which was hydroelectric (150). Studies have shown that Georgia has a good potential for wind power (151), in which a 20.7 MW wind power plant in Georgia was launched in 2016 (152), which annually prevents the emissions of 5 tons of greenhouse gases (153). With an annual average of wind speed up to 15 m/s in some places, its energy average production is 4160 GWh/year (154). It was mentioned that the southern mountains of Georgia have a good wind potential, which contradicts the results of this work, which shows that East Georgia has a good potential.

Kazakhstan

Today, Kazakhstan's economy and energy system heavily depend on hydrocarbon resources (155, 156). The results of the studies in Kazakhstan show the urgent need for policies and actions to support the development of renewable energies (157, 158). It has been stated that the wind power in Kazakhstan, with a potential of about 1.8 TW (159) and the suitability of half the country for producing wind energy (156), can help reduce the dependency on energy imports and improve energy security in the country (160-162). Unfortunately, despite the potential of wind energy, the use of wind energy in Kazakhstan continues to be hindered by reasons such as the cheap cost of fossil fuels and low tariffs for domestic electricity (156-158, 160-163). However, it should be noted that the government plans to build new wind power plants with a capacity of 793 MW by 2020 (164). Because in Kazakhstan, the capacity of wind power is 1820 billion kWh/year, which is 95.38% of the total capacity of all types of renewable energy (165, 166). Finally, it is noted that Kazakhstan is ranked first in terms of the amount of available wind energy per capita (165).

Finding suitable places to use the wind energy

Asia's continent is the fastest-growing region in terms of wind power (167). A wind Atlas is required to calculate the amount and power of wind in Asia. It also helps governments apply ambitious, realistic, or effective supportive goals (12). Factors such as the periodicity of available wind and the identification of suitable and windy areas are challenges in using wind energy. Other challenges include severe financial needs for the development of wind power plants and the existence of subsidies for fossil fuels (168).

Identifying areas susceptible to the construction of wind power plants is complicated and requires decisions involving human error. Such errors can be reduced by GIS (169-171). In this regard, it should be noted that wind farms should be placed where the maximum wind speed is available because wind turbines operate at an average wind speed of more than 3 m/s (172, 173). Therefore, it is essential to choose the best places to build wind power plants (41, 46, 174). Today, GIS is used to study the potential of wind energy in local dimensions (29, 48, 175, 176), national dimensions (39, 177-180), and regional dimensions (12, 181). GIS is also used to analyze key indicators, provide an effective policy, and analyze wind energy in areas where ground measurements are impossible (182).

In Figure 8, the regions with high wind power in Asia, at 50 m elevation at speeds more than 6 m/s, are shown with the number 1 and inappropriate areas with zero. As can be observed in Figure 8, the central, southern, and western parts of Russia, a large part of China, Mongolia, and India, as well as almost all the countries of Southeast Asia (ASEAN region), are not suitable for wind power use. Also, the central region of Turkey, northern Syria, as well as a very small area in eastern Uzbekistan and southern Kazakhstan, are among the areas of inappropriate use of wind energy on a large scale.

These results can have a significant impact on the decision-making process of Asian governments to create a positive investment and to expand wind energy further. Unfortunately, until now, except in China and India, very little wind power has been produced in Asia (183). It should be noted that in Asia today, there is technology, production capacity, design experience, and maintenance operations for managing and developing large-scale wind farms more than before shows the need for the present work.

In Table 5, regions with high potential for wind energy have been presented (71). Iran, Oman, and Yemen are among these regions, which align with the results of the present work in identifying high-potential areas in the Asian continent.

CONCLUSION

Many growing economies are located in Asia. This has provided Asian countries with a significant need for electricity generation, especially from renewable sources. In many Asian countries, however, directing on wind power plants is not entirely economical due to the low

Table 5. Areas with wind power of more than 100 W/m^2 at a height of 10 m (71)

Country	Station	U10 (m/s)	P10 (Watt)
Iran	Ahar	6.033	134.517
Iran	Bandar Abbas	6.008	132.852
Iran	Birjand	5.558	105.182
Iran	Khalkhal	5.992	131.750
Iran	Mianeh	5.883	124.732
Iran	ParsAbad	5.975	130.653
Iran	Tabriz	6.092	138.457
Iran	Takab	5.508	102.369
Egypt	El Tor	6.808	193.299
Egypt	Hurguada	6.467	165.633
Oman	Thumrait	5.900	125.795
Yemen	Aden	5.575	106.131

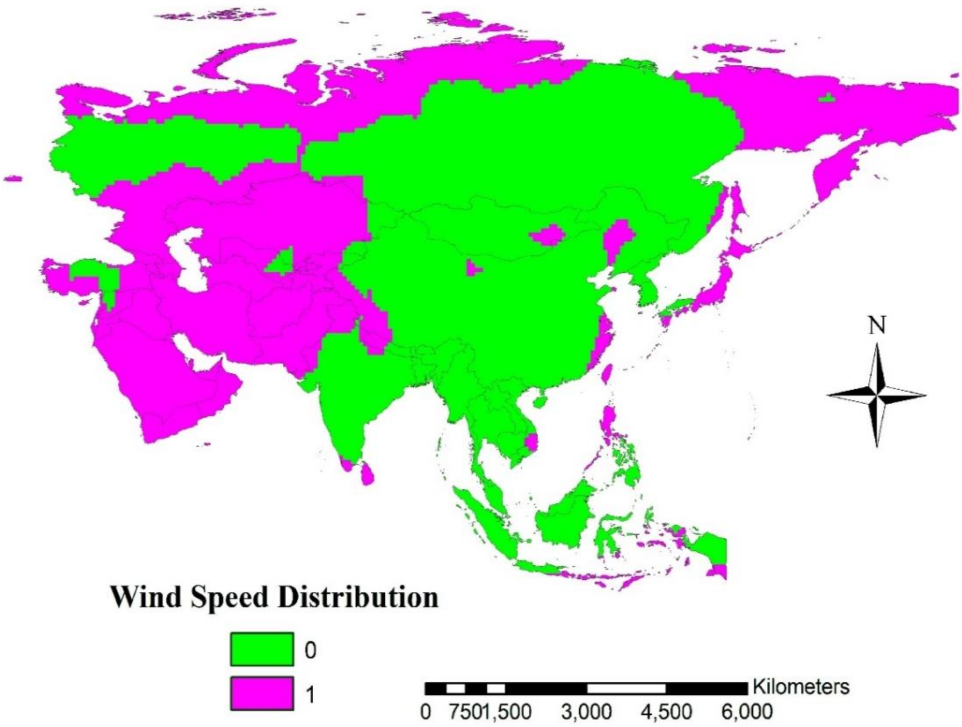


Figure 8. High potential regions for exploiting a large scale of wind power in Asia

cost of grid electricity and neglecting the social costs of fossil power plants. Using wind energy can lead to the generation of new jobs, besides economic prosperity, so this study aims at investigating highly potential regions relying on an average of 20-year wind speed data collected from 2892 stations in 49 Asian countries using GIS software and the IDW technique. The main results were:

- A small region in the east of Russia has the best wind power potential in Asia.
- Eastern, Northern, and adjacent to Caspian Sea in Russia, the north of Philippines, Taiwan, East Timor, the southern half of Yemen, the southern half of Oman, a small area of southeastern Saudi Arabia, eastern Iraq, more than 80% of Iran, almost all of Afghanistan (except the small area On the border between Uzbekistan and Turkmenistan, the northern half of Pakistan, a small area in northern India, a small area in southeastern Turkmenistan, the southern half of Tajikistan, a very small area in western China, all of Azerbaijan, the eastern half of Armenia, a small area in eastern Georgia and western Kazakhstan are in the second priority of using wind energy on the Asia continent.

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CONFLICT OF INTEREST

There is no conflict of interest.

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Persian Abstract

چکیده

تامین انرژی پایدار برای دستیابی به توسعه اقتصادی مطلوب در سال های اخیر توجه بسیاری از دولت ها را به خود جلب کرده است. با توجه به مشکلات استفاده از سوخت‌های فسیلی منجمله محدود بودن و تاثیرات مخرب زیست‌محیطی آنها، در سالیان اخیر توجه زیادی به انرژی‌های تجدیدپذیر و بخصوص انرژی باد شده است. در قاره آسیا نیز تاکنون تلاش‌های بسیاری جهت استفاده از انرژی باد به‌صورت منطقه‌ای شده که باعث گردیده‌اند در این زمینه، قاره آسیا پیشتاز باشد. علی‌رغم لزوم تدوین راهبردها و برنامه‌های زیربنایی و اصولی که مستلزم شناخت کامل وضعیت کنونی استفاده از انرژی باد و تعیین پتانسیل آن در نقاط مختلف است، دیده می‌شود که کمبود شدید اطلاعات و شبیه‌سازی در این زمینه وجود دارد. لذا در کار حاضر برای نخستین بار با استفاده از نرم‌افزار GIS و روش بولین، بررسی‌ها بر روی داده‌های میانگین ۲۰ ساله سرعت باد برای ۲۸۹۲ ایستگاه در ۴۹ کشور آسیا انجام شده و نقشه‌های سرعت و توان باد بدست آمده‌ند. در کار حاضر ضمن ارزیابی مسائل و مشکلات مصرف انرژی در کشورهای دارای پتانسیل انرژی بادی مناسب در قاره آسیا، با بیان مزایا و الزامات استفاده از انرژی برق بادی در این کشورها، امکان استفاده هر چه بیشتر انرژی بادی مورد بررسی قرار گرفته است. نتایج بررسی‌ها نشان دادند که شرق و شمال روسیه و همچنین غرب و جنوب غربی آسیا، مکان‌های مناسب استفاده از نیروگاه‌های بادی در مقیاس بزرگ هستند و در سایر نقاط مخصوصا اکثر نقاط کشور چین و همچنین کشورهای حوزه ASEAN و کشورهای مجاور آنها، پتانسیل باد قابل توجه نمی‌باشد.