Approaches to assessing the resource potential of Central Asia in a climatic resource-constrained environment

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Abstract. The object of research in the article is the methodology of evaluation and calculation of the wind energy resource for the design of wind power plants in Central Asia. This methodology is based on the approach for determining the wind resource in conditions of insufficient climate data developed by REC “RES” of Peter the Great St. Petersburg Polytechnic University. The energy industry of Central Asia, like the world energy industry, seeks to increase the use of facilities based on renewable energy sources, which is caused by several factors: environmental, economic, social, and so on. The global energy industry is implementing a “green” energy transition, largely due to government policy, thereby several strategies and decisions have been adopted in Central Asia. At the moment, the installed capacity of renewable energy sources in Central Asia is 13747 GW. The methodology for evaluation of wind energy resources has been developed, and a resource potential has been calculated in the city of Aktau in Kazakhstan. The methodology includes a 3-level evaluation system and calculation in the WindPRO software. This methodology guarantees the accuracy of calculating the wind resource up to 90-95%.

1. Introduction

The object of research is the methodology of wind energy resources determination in Central Asia.

The purpose of this study is to develop an approach to the assessment of the wind and energy resources in Central Asia necessary for the design of wind power plants and energy complexes based on renewable energy resources to improve the energy sector in both a centralized and decentralized energy supply system.

Research objectives: 1) analyze the current state of traditional energy supply and energy supply based on renewable energy sources, determine development trends and the environmental state in Central Asia; 2) develop an approach to the assessment of wind and energy resources in Central Asia based on a 3-level approach for assessing resource potential in conditions of insufficient climatic data; 3) determine the wind energy potential by the proposed approach on the example of a feasible facility in Central Asia.

Renewable energy - the global trend in the energy sector. The main direction of the world energy development is the transition to the widespread use of renewable energy sources and the displacement of fossil fuels under the influence of changes in energy policy and the development of new technologies in the energy industry. Thus, in the modern world, there is an “energy transition”, which affects not only the energy sector but the global economy, the economy of individual countries, the environment and society as a whole (according to NREL, the production of 1 MW of wind energy prevents the emission of approximately 2600 tons of carbon dioxide).
According to the IRENA report, the capacity of renewable power plants from 2009 to 2018 increased by more than 1200 GW (Fig.1). Renewable energy is currently developing in all regions of the world: in 17 countries, renewable energy (excluding hydropower), mainly solar and wind power, exceeds 10 GW, and in 45 countries exceeds 1 GW. With hydropower, more than 90 countries have more than 1 GW of renewable power, and 30 countries have more than 10 GW. [1]

Due to the development of technologies and solving the country’s main energy problems, the dynamics of changes in the average estimated cost of electricity production over the entire life cycle of a power plant (LCOE) by world indicators for various types of renewable electricity from 2010 to 2018 is presented in the IRENA report. The largest changes are accounted for solar and wind energy, LCOE decreased significantly (in solar energy LCOE decreased to 4 times, in wind energy – 1.5 times) [1].

In many ways, the development of renewable energy due to political regulation in the energy sector (taxes, subsidies, etc.), so in 2018 the policy was applied in 135 countries, aimed mainly at:

- ensuring the availability of energy in sufficient quantities and at affordable prices;
- ensuring reliability and safety of energy supply;
- ensuring environmental friendliness (the requirement to minimize the anthropogenic impact of energy systems on the environment).

The political approach to energy in Central Asia has also changed and follows global trends. The region of Central Asia consists of five republics – Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan – and stretches from the Caspian Sea in the west to China in the east, and from Afghanistan in the south to the Russian Federation in the north. The region has a total population of approximately 71 million people, and a low population density at just 18 people per square kilometer on average. At the national level, significant variance exists in terms of total population and GDP per capita [2].

These countries have adopted strategies, concepts, and policies for the transition to green energy, for example, No. PP-3012. dated 26.05.2017 Decree of the President of the Republic of Uzbekistan on a program of measures to further develop renewable energy, increase energy efficiency in economic and social sectors for 2017-2021; No. PP-3379 dated 11/08/2017 Decree of the President of the Republic of Uzbekistan on measures to ensure the rational use of energy resources [3, 4, 5].

Central Asia is a mix of the upper, middle, and low-income economies, with heavy reliance on the extraction and export of energy products, particularly from Kazakhstan, Turkmenistan, and Uzbek-
stan. The region holds significant strategic importance due to its geographic location and natural resource endowments [6, 7, 8, 9].

Fossil resources (coal, oil, gas) currently form the basis of the energy sector in most countries of the world, but they are by definition non-renewable, limited and will be exhausted shortly.

At the end of 2018, the global consumption of primary energy resources, according to the combined data of the International Energy Agency (IEA) and British Petroleum, amounted to about 13865 million tons of oil equivalent. This value includes organic resources about 11744 million toes (85% of the total energy consumption), nuclear energy 611 million tons of oil equivalent, hydropower - 949 million tons of oil equivalent, other renewable energy resources - 561 million tons of oil equivalent.

At the end of 2018, compared to 2017, oil consumption increased by 53.7 million toe (+ 1.2%), natural gas - by 167.5 million toe (+ 5.3%), coal - by 55.0 million toe (+ 1.4%). Oil production increased by 94.5 million tons (+ 2.2%), natural gas - by 163.5 million toe (+ 5.2%), and coal - 161.8 million toe (+ 4.3%) [10, 11].

On a per-capita basis, Kazakhstan and Turkmenistan are among the highest emitters of CO$_2$ within the Asia-Pacific region, while Kyrgyzstan and Uzbekistan fall within the middle range, and Tajikistan is one of the lowest (Table 1).

Table 1. Leading countries in the production and consumption of traditional energy sources in Central Asia in 2018 compared to 2017.

| Country    | Oil Production, mln tons | Natural gas Consumption, mln toe | Coal Production, mln toe | Natural gas Consumption, mln toe | Coal Production, mln toe | Natural gas Consumption, mln toe |
|------------|--------------------------|---------------------------------|--------------------------|---------------------------------|--------------------------|---------------------------------|
| Kazakhstan | 91.2 (+4.9%)              | 16.4 (+9.5)                     | 21.0 (+4.1%)              | 16.7 (+22.4%)                   | 50.6 (+4.9%)              | 40.8 (+12.2%)                   |
| Turkmenistan | 10.6 (-5.3%)             | 7.1 (-2.8%)                    | 48.7 (+6.1%)              | 24.4 (+12.0%)                   |                          |                                 |
| Uzbekistan | 2.9 (+4.5%)              | 2.6 (-3.9%)                    | 21.0 (+4.1%)              | 36.6 (-1.2%)                    | 3.0 (-11.2%)             | 3.1 (-11.1%)                    |

At the end of 2017, the installed capacity of renewable power plants in Central Asia is presented in Figure 2.
The western part of central Asia is located outside the centralized energy system (Figure 3).

![Figure 3. Central Asia area with a centralized energy system](image)

In connection with the energy and environmental situation in Central Asia, the development of renewable energy is necessary not only outside the centralized energy supply zone but also to create energy complexes based on existing energy systems [12].

2. Methods
The existing power supply systems in the world have been developed primarily for traditional centralized electricity. Large power plants generate the bulk of electricity, often based on fossil fuels, and transport it to the consumers. This prevailing system structure requires fundamental changes to adapt to reduce carbon dioxide (CO$_2$) emissions, increase decentralized electricity production, and also for energy efficiency, electrification largely due to renewable energy sources.

When creating power plants based on renewable energy sources (RES), one of the important goals is a reliable assessment of climate information. Such information is significant for estimating the predicted power production, as well as determining the extreme and operating temperature and power loads and developing power plant structures. Knowledge of reliable and predictable climatic information allows ensuring the correct selection of parameters and structure and the subsequent reliable and efficient operation [13].

To assess the climatic characteristics when choosing a location for a power plant based on RES, in particular solar photovoltaic (SPVPP) and wind power plants (WPP), justifying its parameters and evaluating economic efficiency of the construction a three-level approach is used, developed by REC “RES” of Peter the Great St. Petersburg Polytechnic University [14].

Based on this methodology, it is possible to assess the resources of renewable energy sources, including limited natural and climatic information for Central Asia.

The article proposes an approach to assessing the wind energy potential at the first level of which, based on the reference data of the hydrometeorological network (HMN) and atlases of winds with long-term average values of wind speed and direction, as well as the specific power of the wind flow
for a specific power plant location, a preliminary large-scale assessment of wind energy resources (WER) is performed. This will allow a larger assessment of the prospects of a particular place for the use of wind power plants in it.

At the second level of the regional assessment of WER, after selecting a perspective area, mesoscale numerical modeling of the wind flow at an arbitrary height above ground level is performed. When modeling, the following data are used: - satellite data on wind speed and direction, mesoscale digital elevation model with a resolution of 0.5-10 km, and mesoscale digital roughness model with a resolution of 0.5-10 km. As the initial data of the wind regime, long-term (30 years or more) hourly data of wind speed and direction are used.

At the third level, micro-scale modeling of the wind flow is carried out and technical WERs are determined.

The climatic information about the temperature, maximum, minimum, average annual, and the average seasonal values of precipitation, etc. is necessary to the proper identifying of the equipment assortment. The resource information consisting of wind energy data: wind speed, wind direction, specific wind flow capacity at the altitudes of 2 m, 10 m, 50 m, 100 m, terrain, and the surface roughness is necessary for the development of WPP projects, determining the WPP energy production, the locating of the WPP and the WT placement as a component of that system. The resource information is one of the most important in the developed methodologies [15, 16].

The climate and resource geospatial data derived from the National Aeronautics and Space Administration (NASA) Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) datasets [17, 18]. These datasets potentially provide a suitable source of weather and renewable resource data.

The NASA MERRA-2 contains data starting from 1980 with worldwide coverage. The datasets provide hourly data with a spatial resolution of about 55 kilometers in latitude (0.5 degree of latitude x 0.625 degree of longitude).

3. Results and Discussions
The Republic of Kazakhstan has significant wind energy resources. Using the developed methodology (Figure 4), it was determined that an average annual wind speed of more than 7 m/s is observed in an area of more than 50,000 square kilometers at an altitude of 80 meters. In the area of the Dzhungar Gate, the average annual wind speed is 9.7 m/s at an altitude of 50 meters, and the density of the wind flow is about 1100 W/m². In the southern part of Kazakhstan, the average annual wind speed is 7-8 m/s at an altitude of 50 meters with a wind flow density of about 600 W/m². In the central part of Turkmenistan, the wind flow density is about 7 m/s, and in the western part, it is about 8 m/s with a wind flow density of 500-700 W/m². The average annual wind speed in Uzbekistan is 7 m/s at an altitude of 50 meters. In the mountainous regions of Tajikistan and Kyrgyzstan, the average annual wind flow density is more than 9 m/s with a wind flow density of more than 1100 W/m². The data obtained indicate that these areas are expedient and perspective for the creation of power plants based on the use of wind energy.
Figure 4. Three-level methodology for assessing wind energy resources in Kazakhstan

On the example of Aktau-city in the south-west of Kazakhstan, using the WindPRO software package and the developed methodology, a map of the distribution of wind energy resources is constructed. The methodology for estimating wind potential in the WindPRO software package is presented in Figure 5. The composition, the location of power plants, and their output can be calculated based on the received map depending on the required parameters.

Figure 5. The sequence of the WindPRO software applying for wind energy calculations
In the calculation of the natural and technical wind energy potential, this software product allows to take into account the terrain relief, the roughness of the underlying surface, certain obstacles, and already existing wind turbines. In parentheses are the names of objects in the software product, through which these steps were performed. The use of the WindPRO software allows accurately and reliably to determine wind energy resources, optimize WPP configuration solutions, technical, energy, and economic indicators, including in conditions of insufficient climatic information.

A methodology for assessing the wind energy resources of Central Asia developed and proposed to help solve the problem of power supply and increase energy and environmental safety. The technique allows to determine the resources in the proposed location of the power plant, even in conditions of limited natural and climatic information. The implementation of energy supply systems based on renewable energy sources will reduce CO₂ emissions, and in a distributed location of consumers, reduce the cost of building power lines through the use of local energy sources.

4. Conclusions
1. The current state of traditional and renewable energy supply was analyzed and trends in the development and the environmental state in Central Asia were determined.
2. In the main countries of Central Asia, hydropower is the main renewable energy source. Other types of renewable energy require development, but according to the availability of renewable energy resources, these areas are attractive and perspective for the development of renewable energy.
3. A methodology for assessing wind energy potential under conditions of limited natural and climatic information using the WindPRO software package has been developed.
4. The main principles for the initial data preparation and information necessary for the creation of wind power plants have been proposed based on the developed methodology.
5. Based on the developed methodology on the example of Aktau-city in the south-west of Kazakhstan, a map of the distribution of wind energy resources is constructed.
6. The implementation of the methodology will increase the reliability of the design process optimization and become a convenient expert tool in substantiating the WPP parameters and design as a part of power systems for quality improvement.

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