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CREATION OF GEOINFORMATION MAPS FOR ASSESSMENT OF WIND ENERGY POTENTIAL OF LOCAL AREAS OF TURKESTAN REGION

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Abstract. Today, one of the main tasks for experts and scientists in the field of renewable energy is to conduct a geo-assessment in the construction and commissioning of wind farms, taking into account external disturbing climatic and meteorological factors. Foreign experts note that digital and innovative platforms of the new generation have given an impetus to the creation of a new information base, which has become the main tool for an adequate assessment and forecasting of the renewable energy potential using the example of local selected regions. The purpose of this study is to create geoinformation maps taking into account wind flow velocities using the example of a selected local area and an adequate assessment of the generation capacity of a wind power plant. The method of inversely weighted distance interpolation was chosen as the key method, which is oriented to obtain

the necessary data by remote measurement. This, in turn, is an original method for the preliminary assessment of the selected local area for the construction of wind power plants. In the results of the study, thematic maps were obtained based on the Esri ArcGIS application program, which visualizes wind speeds according to certain geodata gradients. The peak speed of the wind flow in the seasonal series is in December-April. The peak wind flow velocity in these seasonal ranges is approximately 18-25 m/s. Monthly and peak WPP output per year were calculated based on the System Advisor Module application program. The peak output of the wind farm for the year was 167 MW. In turn, the developed geoinformation maps in the future can become regulatory documents that include all the necessary forecast data, which allows an adequate assessment of the potential territories of the Turkestan region for the construction and commissioning of new wind farms.

Keywords: observed climate data, simulated climate data, wind velocity distribution diagram, geographic information maps, geotechnical objects

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ТҮРКІСТАН ОБЛЫСЫНЫҢ ЖЕРГІЛІКТІ ЖЕРЛЕРІ МЫСАЛЫНДА ЖЕЛ ЭНЕРГИЯСЫНЫҢ ӘЛЕУЕТІН БАҒАЛАУ ҮШІН ГЕОАҚПАРАТТЫҚ КАРТАЛАРДЫ ҚҰРУ

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Аннотация. Бүгінгі таңда ЖЭК саласындағы сарапшылар мен ғалымдардың алдында тұрған басты міндеттердің бірі сыртқы бұзылған климаттық және метеорологиялық факторларды ескере отырып, жел электр

станциясын салуда және пайдалануға беруде гео бағалау жүргізу болып табылады. Шетелдік сарапшылар жаңа буынның цифрлық және инновациялық платформалары жергілікті таңдалған өңірлер мысалында ЖЭК энергетикалық әлеуетін барабар бағалау мен болжаудың негізгі құралына айналған жаңа ақпараттық базаны құруға серпін бергенін атап өтті. Бұл зерттеудің мақсаты таңдалған жергілікті жердің мысалында жел ағынының жылдамдығын ескере отырып, геоақпараттық карталарды құру және жел электр станциясының қуатын өндіруді барабар бағалау. Негізгі әдіс ретінде қашықтықтан өлшеу арқылы қажетті деректерді алуға бағытталған кері өлшенген қашықтықты интерполяциялау әдісі таңдалды. Бұл өз кезегінде жел электр станцияларын салу үшін таңдалған жергілікті жерді алдын-ала бағалаудың өзіндік әдісі болып табылады. Зерттеу нәтижелері ESRI ArcGIS қолданбалы бағдарламасы негізінде желдің жылдамдығын белгілі бір геодеректер градиенттері бойынша бейнелейтін тақырыптық карталарды алды. Маусымдық қатарлар бойынша жел ағынының ең жоғары жылдамдығы желтоқсан-сәуір айларына келеді. Осы маусымдық қатарлардағы жел ағынының ең жоғары жылдамдығы шамамен 18-25 м/с құрайды. ЖЭС-тің ең жоғары өндірісі бір жыл ішінде 167 МВт құрады. Өз кезегінде әзірленген геоақпараттық карталар перспективада Түркістан өңірінің әлеуетті аумақтарын салу және жаңа жел электр станцияларын пайдалануға беру үшін барабар бағалауға мүмкіндік беретін барлық қажетті болжамды деректерді қамтитын құжаттарды реттеуші бола алады.

Түйін сөздер: бақыланатын климаттық деректер, имитацияланған климаттық деректер, жел жылдамдығының таралу диаграммасы, геоақпараттық карталар, геотехникалық нысандар

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СОЗДАНИЕ ГЕОИНФОРМАЦИОННЫХ КАРТ ДЛЯ ОЦЕНКИ ВЕТРОВОГО ЭНЕРГОПОТЕНЦИАЛА ЛОКАЛЬНЫХ МЕСТНОСТЕЙ ТУРКЕСТАНСКОЙ ОБЛАСТИ

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Аннотация. На сегодняшний день одна из главных задач перед экспертами и учеными в области ВИЭ заключается в проведении геооценки при строительстве и введении в эксплуатацию ветровых электростанций с учетом внешних возмущающих климатических и метеорологических факторов. Зарубежные специалисты отмечают, что цифровые и инновационные платформы нового поколения дали импульс к созданию новой информационной базы, которая стала основным инструментом в адекватной оценке и прогнозировании энергопотенциала ВИЭ на примере локально выбранных регионов. Целью данного исследования является создание геоинформационных карт с учетом скоростей ветрового потока на примере выбранной локальной местности и адекватная оценка генерации мощностей ветроэнергетической установки. В качестве ключевого метода был выбран метод интерполяции обратно взвешенного расстояния, ориентированный на получение необходимых данных путем дистанционного измерения. Это, в свою очередь, является оригинальным подходом при предварительной оценке выбранной локальной территории для строительства ветровых электрических станций. В результате исследования были получены тематические карты на базе прикладной программы Esri ArcGIS, которые визуализируют скорости ветра по определенным градиентам геоданных. Пиковая скорость ветрового потока по сезонным рядам приходится на декабрь–апрель и составляет примерно 18–25 м/с. Были рассчитаны ежемесячные показатели и пиковая выработка ВЭС за год на базе программы System Advisor Module. Пиковая выработка ВЭС за год составила 167 МВт. Разработанные геоинформационные карты в перспективе могут стать регламентирующим документом, включающим все необходимые прогнозные данные, который позволяет адекватно оценивать потенциальные территории Туркестанского региона для строительства и введения в эксплуатацию новых ветряных электростанций.

Ключевые слова: наблюдаемые климатические данные, смоделированные климатические данные, диаграмма распределения скорости ветра, геоинформационные карты, геотехнические объекты

Introduction. Foreign experts have noted the importance of the trend of using new remote sensing tools to create an information base for choosing optimal sites for the construction and commissioning of new geotechnical facilities, in our

case wind farms, which are included in major infrastructure projects in the region (Pimenta et al, 2020; Kassem et al, 2019, Qolipour et al, 2018). The authors used 13 information levels, which include a structural hierarchy of organization, processing and presentation of information data, taking into account the environmental, technical and economic features of the proposed zones for the placement of new wind farms (Pimenta et al, 2020).

In the author's research (Kassem et al, 2019), a Kolmogorov–Smirnov distribution function was proposed for estimating wind energy density at various heights, followed by finding optimal towers for potential wind power plants. Foreign scientists have developed a mathematical model based on the HOMER (Hybrid Optimization of Multiple Energy Resources) application program (Qolipour et al, 2018) to assess the reliability and feasibility of building and commissioning new wind farms. In the course of forecasting and evaluating the scalability of energy consumption by wind farms, foreign scientists (Sathyaraj et al, 2024) selected three different sites for each location, for example, Northwestern Indiana for the plains, Northwestern Montana for the canyons, and Eastern North Carolina for the coastal zone.

Comparative results were obtained for all three locations using the System Advisor Module (SAM) application program. In the author's work, the method of energy distribution coefficient (Aziz et al, 2023) is proposed, which is an effective method for conducting an adequate assessment in selected potential territories in the construction and commissioning of new wind farms. This method was applied to three different windy areas (mild, moderate, and very windy) with hourly wind data over a 10-year period. Foreign scientists have noted the importance of identifying key clustering points (Choi et al, 2024) as an effective monitoring strategy to ensure the safe and efficient operation of wind energy systems.

In scientific research (Kılıç et al, 2025), the authors proposed an artificial neural network method that allows processing static data on wind speed, which is the main estimating parameter when finding optimal locations for wind power plants. During the study of the selected potential territories, forecast values were obtained for creating a wind speed distribution map using GIS technologies. In the author's work (Bertolina et al, 2024; Khan et al, 2025), a simple and deterministic model is proposed for generating a synthetic hourly time series of wind speed based on a typical meteorological year. When forecasting intraday wind speed changes, an hourly modeling approach is used. As a result, a synthetic hourly time series was generated for a typical year, which has a high degree of consistency between the model and real data. Foreign scientists have developed a reliable research method based on systematic threshold criteria to improve data quality, which allows us to get an idea of spatial coverage, station selection and deviations. The study extracted the main parameters from the spatial data layers (wind speed, density, height of distribution), which are necessary to assess potential selected regions in the construction and commissioning of new wind farms.

A new floating wind technology is proposed (Umoh et al, 2024; Zhang et al, 2020), which makes it possible to pinpoint the suitability of the sites under consideration for the construction and commissioning of new wind farms.

Domestic authors have developed geoinformation maps (Ren et al, 2023; Wang et al 2023) assessing the prospects and possibilities of building a renewable energy power plant in the context of regions using the example of the Turkestan region.

Materials and methods of research.

Today, the Turkestan region is becoming one of the largest production sites and is being transformed into the main economic zone of the Republic of Kazakhstan. In this regard, the region is faced with the issue of providing the population and industrial structures with high-quality, reliable and efficient electric energy. One of the key tasks in this area is the creation of new generating, local energy hubs, taking into account the potential characteristics of the regions of the Turkestan region. Zhetysuysky, Shauldersky, Suzaksky, Otrarsky districts and the city of Turkestan have great potential in generating electric energy from wind.

Fragments of the map – scheme of the Turkestan region with an indication of the projected wind farms are shown in Figure 1.

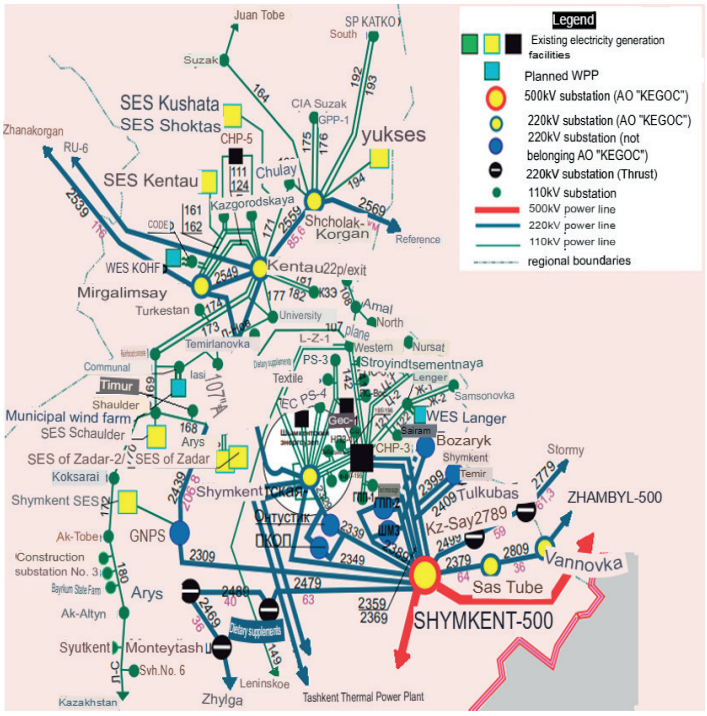

Figure 1 - A fragment of the map-scheme of the Turkestan region with an indication of the projected wind farms

A summary table on the distribution of wind speed in the Turkestan region by region is presented on the figure 2.

station	wind of speed			Number of cases by speed gradations														
	middle	max	date	0-1	2-3	4-5	6-7	8-9	10-11	12-13	14-15	16-17	18-20	21-24	25-28	29-34	35-40	40>
	1,5	17	112	2059	519	201	91	30	7	13								
	2,1	28	45	1256	1111	366	122	39	9	7								
	2,1	28	221	1112	1470	215	67	5		1	13	24	11	2				
	1,6	16	73	1719	984	159	51	5	1	1								
	3,3	28	55	1042	1059	362	170	41	28	5	49	108	46	10				
	1,6	22	104	1748	910	190	49	15	3	3	2							
	1,6	22	45	1799	673	273	98	39	24	4	3	4	3					
	1,8	20	45	1726	842	203	90	36	15	2	2	4						
	3	28	196	880	1115	523	200	75	58	35	1	30	3					
	2,7	28	55	862	1309	452	190	54	41	4	3	5						
	2,6	21	154	599	1741	473	87	16	2	2								
	1,5	20	31	1707	1065	109	23	2	10		3	1						
	1,9	14	119	267	2628	25												
	1,8	24	31	1572	1133	145	16	13	10	17	10	4						

Figure 2 - Summary table on the distribution of wind speed in the Turkestan region

The average annual distribution of wind speed in the Turkestan region according to the meteoblue weather station is shown in Figure 3.

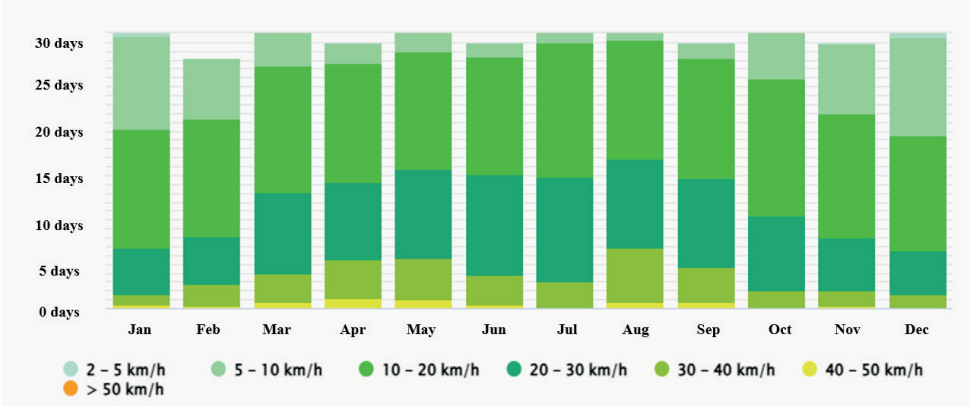

Figure 3 - Average annual wind speed in Turkestan region according to meteoblue weather station

The average wind speed data for the Turkestan region indicates those days in the month during which the wind speed reaches a certain value. An interesting example is the Tibetan Plateau, where the monsoon causes prolonged powerful winds from December to April and calm air flows from June to October.

The rose of wind speeds in the Turkestan region according to the meteoblue weather station is shown in Figure 4.

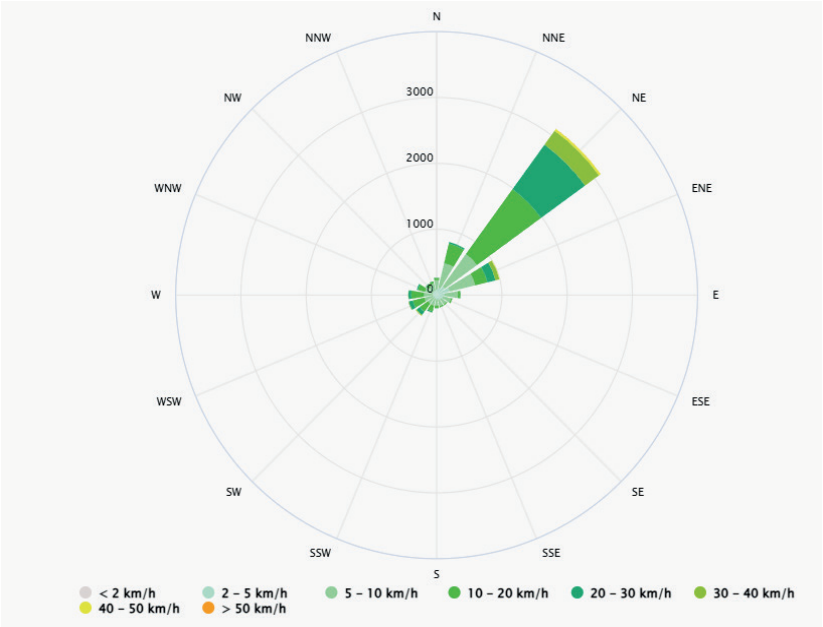

Figure 4 - A rose of wind speeds in the Turkestan region according to the meteoblue weather station

The wind speed rose in the Turkestan region indicates how many hours per year the wind blows from a certain direction. Example - SW: The wind blows from the southwest (SW) to the northeast (NE). Cape Horn, the southernmost point in South America, is characterized by a strong westerly wind, which significantly impedes passage from east to west, especially for sailing vessels. Climate data was obtained using modeling in the API environment.

На рисунке 5 представлена среднегодовые статические данные по распределению скорости ветра в среде экспериментального наблюдение.

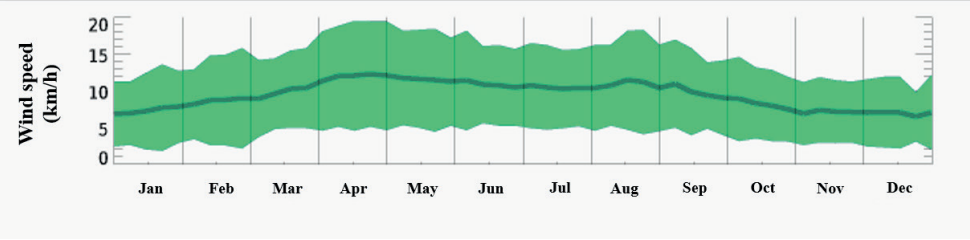

Figure 5 - Average annual static data on the distribution of wind speed in the experimental observation environment

The margin of error between the modeled data and the observed data is approximately 5-10%.

When constructing geographic information maps, the method of inversely

weighted distance interpolation was applied. During the construction of the map, such points as the average annual and seasonal wind speeds, wind roses, turbulence parameters, wind flow densities and stratification parameters and characteristics of the microscale wind distribution were taken into account (Faiz et al, 2025).

In turn, the value of the interpolated parameter is determined as follows:

$$V(P_0) = \frac{\sum_{i=1}^{n} \frac{V(P_i)}{d(P_0, P_i)^p}}{\sum_{i=1}^{n} \frac{1}{d(P_0, P_i)^p}}, \quad (1)$$

V(P□) - the interpolated wind speed at a point where there are no measurements

$V(P_i)$ - wind speed at the measured point,

$d(P□, P_i)$ - distance between points,

p - exponent (usually 1-3, often 2),

n - is the number of nearest stations or measured points.

In turn, the 2nd degree makes it possible to reduce the effects of remote stations, maintain the local structure of the wind field, and subsequently make it possible to create thematic maps for a preliminary assessment of wind potential.

The 2nd degree is considered a compromise and provides a stable surface for the distribution of wind characteristics.

In our case, the wind data error was ±0.5–1.2 m/s.

Results and discussion

The interpolated wind speed distribution graphs were developed using the ICON data model. When developing a thematic map based on the ICON data model, the elements can be effective or illustrative graphical representations of intentions (Faiz et al, 2024). For example, they can be used to navigate an interface or present interactive elements - on their own or in combination with text content. Optimal seasonal data for the construction and commissioning of new wind farms were obtained based on the seasonal wind speed distribution schedule from December to March.

The following Figures 6,7,8,9 show geoinformation maps of wind speed distribution from December to April.

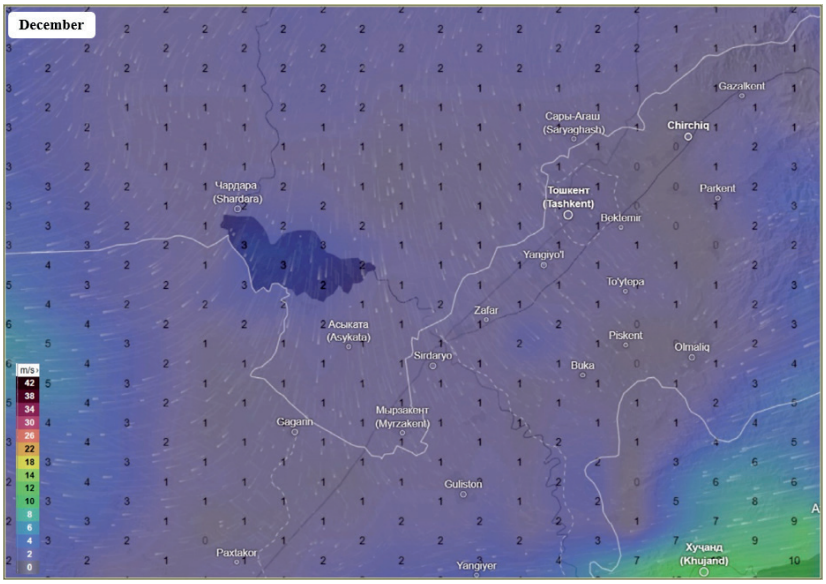

Figure 6 - Geoinformation maps of wind speed distribution for the month of December

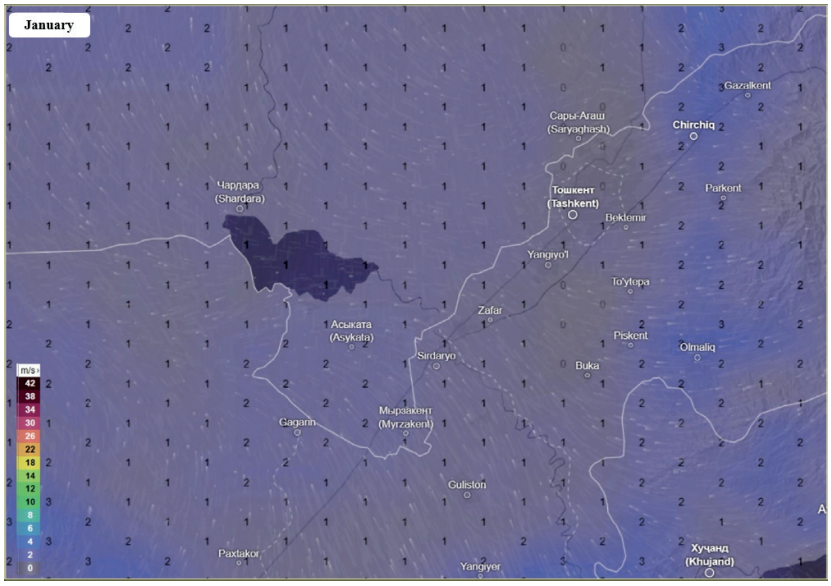

Figure 7 - Geoinformation maps of wind speed distribution for the month of January

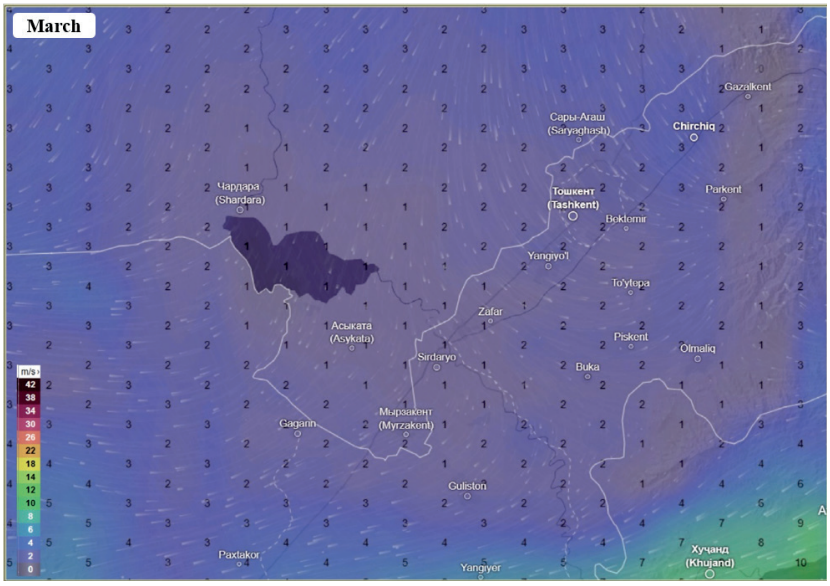

Figure 8 - Geoinformation maps of wind speed distribution for the month of March

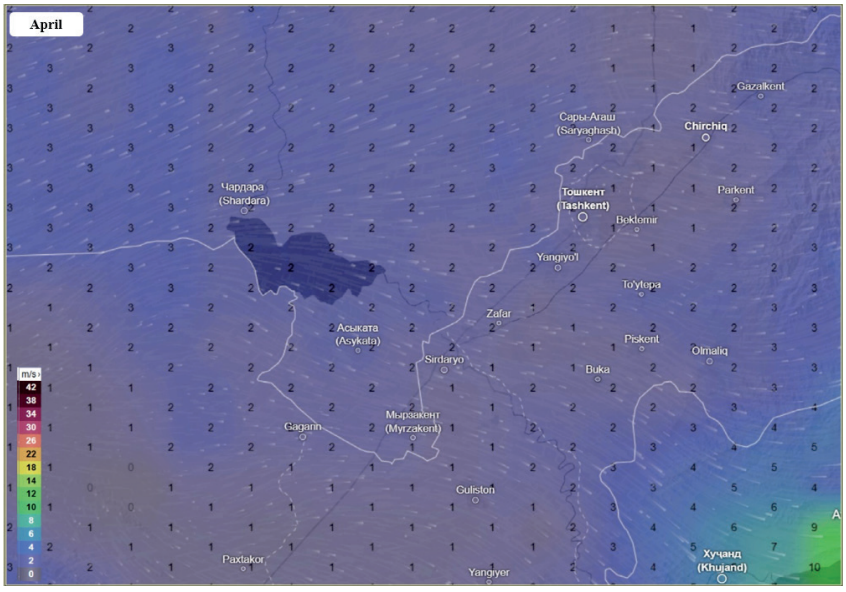

Figure 9 - Geoinformation maps of wind speed distribution for the month of April

The developed geoinformation maps show that in the seasonal distribution of wind speed across the regions of the Turkestan region, the average value is 8-15 m/s.

As a result of the data obtained, monthly data on the generation of electric energy from wind power plants were determined. The diagram of the monthly WPP output for the year is shown in Figure 10.

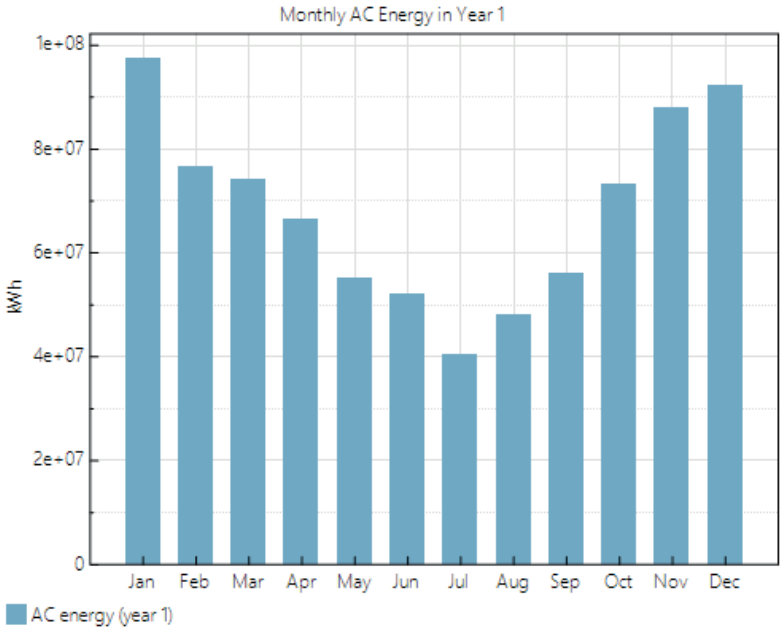

Figure 10 - The diagram of the monthly WPP output for the year

The peak output of the wind farm is approximately 166,889 MWh. The diagram of the peak generation of wind farms is shown in Figure 11.

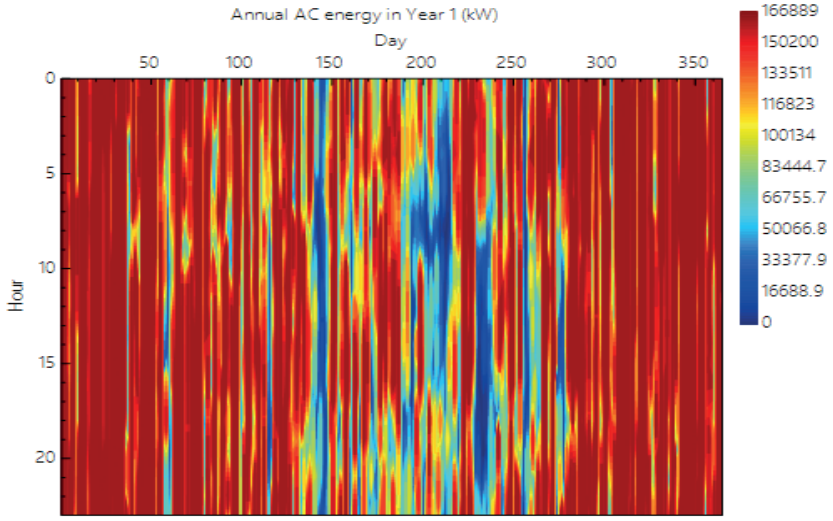

Figure 11 - Diagram of peak WPP output for the year

The calculations were performed using the System Advisor Module.

Conclusion. Today, scientists and experts in the field of energy are faced with the question of finding key ways to develop energy infrastructure, including green energy in the Republic of Kazakhstan.

The article reviewed a number of foreign experiments and experiments in creating optimal sites for the construction of wind farms using digitization of the obtained data on the distribution of wind speed.

The analytical data presented in the materials and research methods, as well as the developed geoinformation maps based on the Esri ArcGIS application program, confirms that most areas located in the Turkestan region have a huge energy resource in the construction and commissioning of solar power plants.

As a result, the monthly and peak WPP output for the year was calculated based on the System Advisor Module application program.

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