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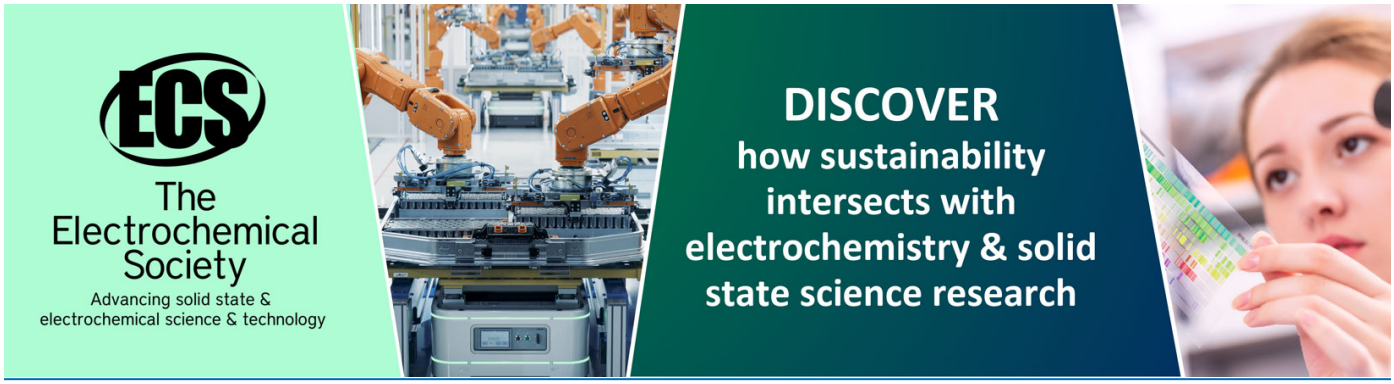

Comprehensive analysis of the energy supply potential using local types of renewable energy sources

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Abstract. Over the past decade, a steady tendency towards the increasing use of renewable energy sources in the fuel and energy complex of separate countries and regions is observed. Countries that have large hydrocarbon reserves such as the Republic of Kazakhstan are no exception. The main challenges of using renewable energy sources in these countries are related not only to their spatial and temporal variety, but also to the high cost of produced energycomparing to the traditional energy в sources based on hydrocarbon fuel. The solution to the mentioned problems can be achieved by optimizing the use of renewable energy resources, which requires a comprehensive analysis of the territory in terms of physical-geographic conditions and economic factors. The article offers methodological approaches and the results from a spatial analysis of the energy supply potential to consumers in the Republic of Kazakhstan using the cartography tools.It takes into account not only the distribution of resource potential, but also the environmental factors (specially protected natural areas, water conservation zone, etc.) limiting the installation of power plants based on RES, and the energy consumption schedule. Economic factors include the performance of typical power plants based on RES, as well as the present value of potentially generated energy.

Key words: renewable energy resource, Kazakhstan, energy generation plant output, energy demand, spatial analysis, solar energy, wind energy, Geographic Information System (GIS)

1. Introduction

Ecological issues and the climate agenda stimulate the society to develop resource-saving technologies. Renewable energy can be considered as the flagship of this trend.Even with a drastic decrease of prices for the hydrocarbon fuel, the renewable energy industry (REI) will remain relevant, particularly for the remote regions of countries with a large territory, where the central power supply is missing, and the high cost of laying the power lines stimulates an autonomous type of power supply system.

The electric energy production in the Republic of Kazakhstan (RK) is currently based on the use of fossil hydrocarbon fuel.Most of the electric energy (81%) in Kazakhstan is generated by coal power plants [1], which entail a high intensity of air pollution. One the one hand, the low population density in Kazakhstan leads to the presence of seasonal or permanent autonomous energy consumers, while on the other hand, it provides significant areas for the construction of power plants on renewable sources.The generating capacities in the RK are combined into several energy zones, between which the transmission of energy leads to significant losses (in 2018, losses were about 3 GWh/year).The steady growth of losses is caused by the aging of the network infrastructure that was created back in the days of the USSR. At the same time, the increasing energy consumption and the shortage of its own power in the Southern energy zone require a solution to the problem of "North-South" electric energy transit.

The ratification of the Kyoto Protocol has served as a trigger for the formation of institutional conditions for the development of REI in Kazakhstan. The development of this energy industry started in 2009, when the Law №165-IV «On support of the use of renewable energy sources (RES)» has been adopted. In 2013, a center of calculation and analytics was created to ensure the purchase and sale of electric energy from RES; together with the European Reconstruction and Development Bank and the Asian Development Bank, a concept for the transition of the RK to a green economy was developed.The implementation of the concept assumes the fulfillment of several targets with a maximum increase in power capacity of wind (up to 1200 MW) and solar (up to 1100 MW) power plants by 2025. To a certain extent, the renewable energy plants will be used to replace the old thermal power plants (TPP) [2].

As in many countries, to achieve these targets, the RK has adopted mechanisms of state support and incentives for the industry. Until February 2018, a mechanism of fixed tariffs was functioning in the RK to stimulate the use of RES. This mechanism was replaced by the auction trading.

As a result, from 2014 to 2018, a positive dynamics of installed power capacities and energy production from RES is observed, the maximum growth was in wind power plants (WPP), in second and third places are small hydroelectric power plants (HPP) and solar power plants (SPP), respectively (table 1).

Table 1. The volume of generation and the share of electricity production by renewable sources of the total generation in the Republic of Kazakhstan (compiled by the authorsbased on data [2,3]).

Year	The volume of electricity generation from renewable energy plants, million kWh (WPP/SPP/SmallHPP/BioTPP)	The share of electricity generation from RES in the energy balance(%)
2016	271/86/81/-	0.98
2017	335/90/144/-	1.07
2018	398/138/242/1	1.26

Thus, Kazakhstan is a state with atypical conditions for the active development of renewable energy.However, despite the significant reserves of fossil fuels, the country actively stimulates the development of REI, where wind and solar energy are almost equally considered as the leading industries of renewable energy. To assess the possible role of renewable sources in energy supply, it is necessary to assess the potential for energy supply to the regions of Kazakhstan based on REI.The energy supply potential means the share (%) of electricity consumption that can be provided by generating electric energy based on RES.The energy supply potential is determined by: the needs for energy supply in a given area; the productivity of renewable energy plants; the restrictions on the use of stations (installations) for power generation based on RES; competitiveness of energy from RES in a given area.

2. Methodology and initial data

2.1General characteristics of regional electricity consumption in the RK

The electricity industry in Kazakhstan is a combination of the following sectors: production, transmission, supply, consumption and other activities in the field of energy supply. As of 01.01.2019, there are 138 power plants operating in the Republic with a total installed capacity of 21901.9 MW[1]. A significant number of regions are characterized by energy deficiency (table2).The Akmola region is characterized by the maximum negative electricity balance among the regions of Kazakhstan, the deficit of electric energy amounted to 4792 GWh/year.

Table 2. Electric energy balance for the period of 2013-2019 by regions of the RK (compiled by the authors based on data [4]).

Region of the RK	The balance of electric energy production and consumption, GWh/year				
	2014	**2015**	**2016**	**2017**	**2018**
Pavlodar	23528	17808	16594	22706	26194
Karagandy	-1696	-713	-608	-1283	-2160
Almaty	-4222	-3590	-2467	-3043	-3758
Akmola	-4991	-4679	-4653	-4603	-4792
East-Kazakhstan	-807	197	1393	1432	569
Aktobe	-1453	-1750	-1754	-2289	-2522
Mangystau	205	210	230	-27	187
Atyrau	-172	-222	-276	-208	-521
Kostanay	-3800	-3176	-3299	-3627	-3889
Turkestan	-2807	-3166	-3189	-4035	-4104
Zhambyl	-1180	-637	-339	-815	-2014
West-Kazakhstan	-182	-313	-107	134	214
North-Kazakhstan	1029	1171	1527	1499	1416
Kyzylorda	-1178	-1191	-1286	-1312	-1250
Total	2332	2274	1764	4527	3569

The largest amount of the electric energy is generated and consumed in the Pavlodar region, which is the main donor of the electric energy in Kazakhstan. The balance flow to the Russian Federation and Central Asia in 2018 was 3566 GWh and 2.8 GWh, respectively.

2.2Performance assessment of wind and solar power plants

At the assessment of the potential for energy supply based on RES, an analysis of resources and the productivity calculation of the projected plants should be carried out.In order to estimate the gross energy potential, the NASAPOWER climate database [5] was used as the initial data. The NASAPOWER database contains data arrays about the incoming solar radiation on a horizontal surface, temperature, wind speed at different heights and other characteristics significant for solar and wind energy industry on a regular spatial grid (1x1)°.The data are presented in the format of daily sum (for solar radiation), average daily values (for temperature, wind speed, etc.) for each day of the period from 1983 to the present. To obtain the resource characteristics of solar and wind energy on the territory of Kazakhstan, the sequences of data on the arrival of solar radiation and wind speed for 1983-2005 were used.As a result, the average annual and seasonal daily sums of the total solar radiation, the average annual values and the frequency of the wind speed for each cell of the spatial grid (1x1)° were calculated, with the following generalization up to the grid (2x2)°.It was shown that inter-annual variations in characteristics of radiation and average wind speeds range are from 2% to 13%.Further, it was assumed that the accuracy of estimating the stations productivity is determined by inter-annual variations in resource characteristics and lie within the same limits.

In this research, to calculate *the performance of solar and wind power plants*, typical stations of the same power capacity (15 MW) with the following technical characteristics were selected:

−a solar power plant (SP) consisting of the photo-voltaic modules (PVM) with a unit power of 265 W, a surface area of 1.65 m^2, an efficiency of 16.2% and inverters with an efficiency that varies in the range of 89-98% depending on the PVM power;

−wind power plant (WP), consisting of wind turbines (WT) of the Nordex N 27-50 model with a rated power of 150 kW each, a mast height of 50 m and a wind wheel diameter of 27 m.

For the spatial analysis of the productivity of solar and wind power plants (technical potential), the density of the generated energy per unit surface area (1 km^2) (specific productivity) was considered(figure 1,2). In this case, the minimum possible distance between WT/PVM at the station

sites was assumed (1 WT/km^2, 143 PVM/km^2).The calculated specific energy generation for the territory of the RK: from 63 to 342 MWh/year/km^2 for the WPP, and from 41 to 68 MWh/year/km^2 for the SPP (Figure 1, 2).

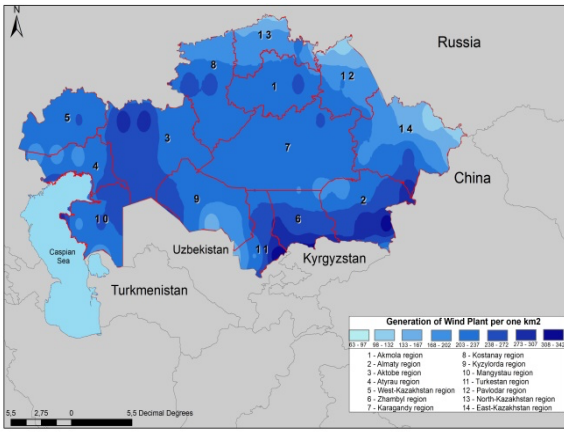

Figure 1. Generation ofWP, MWh/km^2 for 2018 (compiled by the authors).

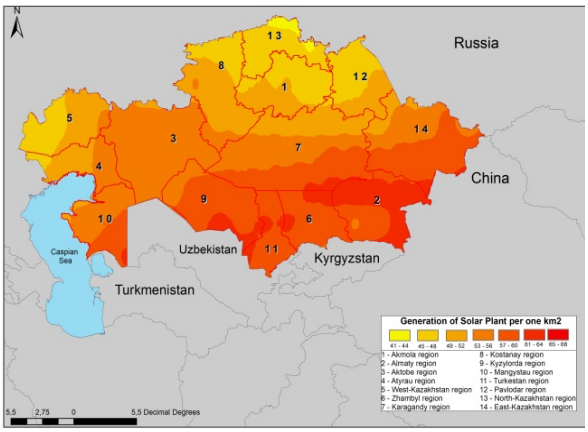

Figure 2. Generation of SP MWh/km^2 for 2018 (compiled by the authors).

It can be observed that the generation of the wind power plants is 1.5-5 times higher than the specific productivity of the solar power plants (for the selected types of SPP and WPP).

2.3Limitingfactors.

In order to assess the potential of energy supply, the influence of limiting (specially protected natural areas, forests, settlement, water bodies, key bird areas, buffer zones of settlements, etc.) andfacilitatingfactors (power lines, road network and electrical substations) has to be taken into account.The tools of spatial analysis allow to exclude the territories, where the construction of power plants is prohibited, from consideration and to calculate the area of available territories.In this study, power lines were considered as a facilitating factor.After the allocation of available territories on the basis of the factors mentioned above, an additional restriction of the territory (no further than 5 km from power lines) was introduced due to the high cost of the power lines construction.As a result, the data on the areas available for construction were obtained.According to the obtained results, significant land resources for the placement of power plants based on RES are held by the following regions: Karagandy - 33 131 km^2 for the WPP and 34 271 km^2 for the SPP, Akmola - 27 445 km^2 for the WPP and 29 357 km^2 for the SPP, and Pavlodar - 22 111 km^2 for the WPP and 22 614 km^2 for the SPP.

2.4Assessment of power supply potential

Subsequently, the value of electricity generation by solar and wind power plants was calculated and compared with the value of electricity consumption in the regions of Kazakhstan, taking into account the calculated values for the available areas. The total potential of the energy supply for the entire Republic is 43% (44975 GWh/year) for the WPP and about 11% (11023 GWh/year) for the SPP, if they occupy all permitted territories (Figure 3).

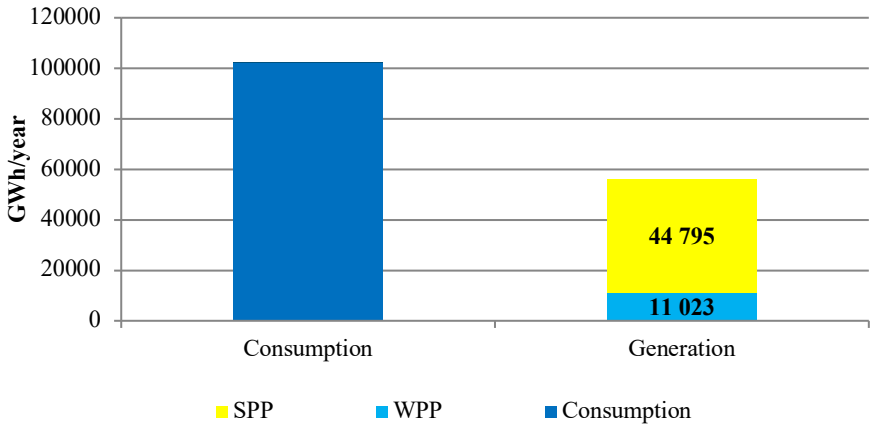

Figure 3. Electricity consumption and productivity of the WPP and the SPP in the RK (compiled by the authors).

If the regional potential of energy supply is considered, then the annual output of the WPP in the permitted territories can potentially satisfy all the needs for electricity in the regions with relatively low total electricity consumption such as North Kazakhstan and Kyzylorda regions.Zhambyl, West Kazakhstan, Kostanay and Akmola regions also have a high potential for energy supply from RES. In these regions more than 65% (1 295-5 898 GWh/year) of consumed electricity can be satisfied by the renewable energy (Figure 4).

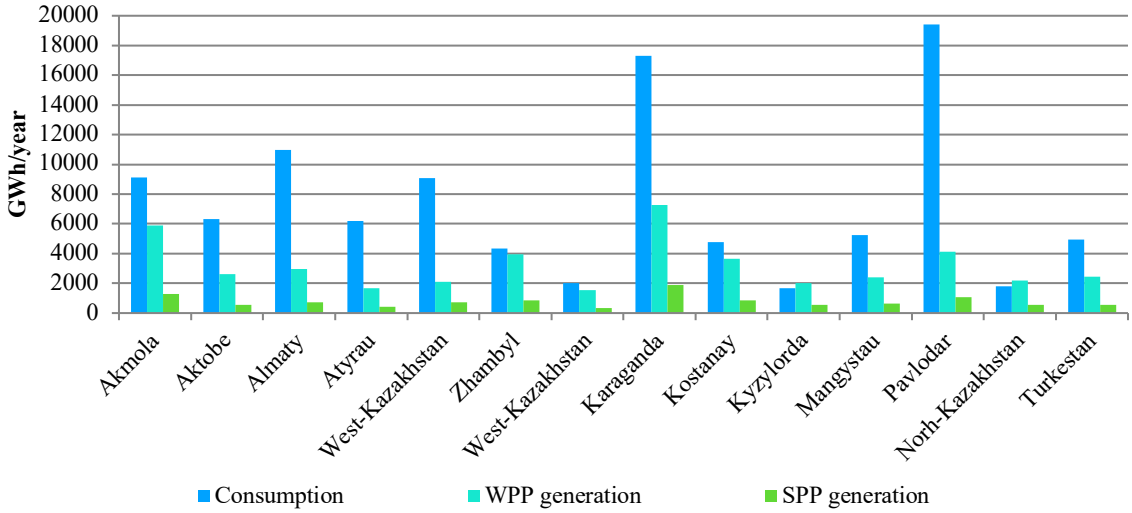

Figure 4. Electricity consumption and productivity of the WPP and the SPP in the RK regions (compiled by the authors)

The most promising for the use of the SPP are Kyzylorda, Zhambyl and North Kazakhstan regions, where the solar power plants can potentially provide from 20 to 32% (544-873 GWh) of consumed electricity.

2.5 Economic assessment

The Levelized Cost of Energy (LCOE) was used as a key characteristic for the cost assessment of electricity generated by solar and wind power plants.The assessment of capital (equipment costs) and operating (equipment delivery, construction, operation of power plants) costs for the SPP was carried out on the basis of estimate documents for the construction of the Kosh-Agach solar power plant (Republic of Altai, the Russian Federation) that was built in 2014, taking into account the inflation and changes in the PVM cost for the past period.

The capital and operating costs for the construction and operation of the wind power plants were taken from the current estimates of international analytical agencies [6]. The discount rate was taken equal to 10%, while the service life was taken to be 20 years.

As a result, the present values for the SPP and the WPP were0.078USD/kWhand0.012 USD/kWh, respectively (The transfer was made according to the rate of the Central Bank of Russia dated 29.09.2020 (1 USD = 78.6713 RUB)).The cost price of electric energy in the Kazakhstan wholesale market of energy and power generated by using the traditional fuel is 0.007-0.034 USD for individuals and 0.009-0.072 USD for legal entities (the minimum - the maximum daily rate). Thus, the cost price of energy generated at solar and wind power plants, taking into account the estimated nature of the calculations, is close to a competitive.

3. Conclusion

The Republic of Kazakhstan actively develops the renewable energy industry, the created institutional conditions, including the developments programs. The legislative framework and methods of supporting renewable energy industries have led to an increase in the installed power capacity of renewable energy power plants.The highest specific productivity in Kazakhstan is characterized by the wind power plants, the energy generation by which, according to the estimates, is several times higher than the energy generation by the solar power plants, which is determined by the spatial distribution of resources for these types of RES.

The potential of energy supply based on solar and wind energies in the regions of Kazakhstan varies in wide ranges (from 5% to 90%).At the same time, the wind power plants in each region of the RK can potentially cover a significant share or full needs in the electricity supply.The solar power plants are characterized by a significantly lower potential of energy supply, and can only be used as an additional source of the energy. The Kyzylorda, North Kazakhstan and Zhambyl regions have the maximum integrated potential of the energy supply based on RES.

The results of the conducted economic assessment of the generated electricity based on wind and solar energy generation indicatetheir competitiveness.

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