UDC 620.92:330.34
DOI: 10.15587/2312-8372.2018.149595

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RESEARCH OF THE SPATIAL ASPECTS OF USING RENEWABLE ENERGY SOURCES FOR SUSTAINABLE DEVELOPMENT OF THE TERRITORY

Об'єктом дослідження є альтернативні джерела енергії як основа розвитку альтернативної енергетики України. Проблемами на шляху впровадження об'єктів даної галузі є необхідність застосування запобіжних заходів для безпечного їх функціонування та менша рентабельність альтернативних джерел енергії у порівнянні з традиційними. Це пояснюється високою вартістю обладнання й суттєвими витратами на забезпечення технологічних процесів. Збільшення частки відновлюваних джерел енергії в загальному енергобалансі вимагатиме державного субсидування галузі.

Доведено, що застосування картографічного підходу дозволяє визначити оптимальні місця розташування об'єктів альтернативної енергетики з економічних позицій та врахувати низку не менш важливих факторів, зокрема, соціальний та екологічний вплив. У ході дослідження використано методи:

– картографічний – під час застосування прийомів моделювання для побудови карт альтернативних енергетичних ресурсів;

– геоінформаційний – у процесі збору та обробки інформації про ресурси, об'єкти та фактори розвитку альтернативної енергетики;

– статистичний – на етапі розрахунку енергетичного потенціалу вітроенергетичних, геліоенергетичних, геотермальних та гідрологічних ресурсів.

Представлено карти для означених вище напрямків альтернативної енергетики, надано рекомендації щодо оптимальних районів будівництва енергетичних об'єктів на прикладі Харківської області (Україна). Так, розташування:

– вітроелектростанцій рекомендується у Вовчанському, Харківському, Великобурлуцькому районах;

– сонячних електростанцій – у Близнюківському, Первомайському, Балаклійському, Ізюмському, Лозівському та Борівському районах;

– геотермальних – на півдні Барвінківського і Близнюківського, південному сході Ізюмського, Борівського та Лозівського районів.

Перспективними для розташування створів малих гідроелектростанцій у межах території дослідження є ділянки річок Сіверський Донець, Уда, Берестова, Мож, Мерла.

Розглянуто залежність економічної ефективності об'єктів вітрової, сонячної, геотермальної енергетики та малої гідроенергетики від таких факторів, як:

– відстань транспортування енергетичної сировини та готової енергії до споживачів;

– тепловтрати;

– вартість капіталовкладень у будівництво інфраструктури (ліній електропередачі, електричних підстанцій, тепломереж).

Ключові слова: *альтернативні джерела енергії, просторовий аспект, економічні фактори, картографічний підхід, сталий розвиток території.*

1. Introduction

Among the major global problems at the beginning of the XXI century is the provision of energy to humanity. One of the main thematic trends that have entered the world practice of management is increasing the efficiency of the use of energy resources. Reliable provision of the energy needs of industrial complexes is the key to the successful implementation of the concept of sustainable development.

The problem of meeting the energy needs of countries can be solved by using renewable energy. The need for its development is dictated by the gradual depletion of global hydrocarbon reserves and other fossil fuels, as well as environmental degradation and climate change. For Ukraine, which largely depends on energy imports (46 % of the country's natural gas needs and 100 % of its nuclear fuel needs are met by imports), the development of renewable energy is particularly relevant. The priority of the development of the industry is determined at the national level:

– Energy Strategy of Ukraine for the period up to 2030 [1];
– The National Action Plan on Renewable Energy for the Period until 2020 [2];
– The Law of Ukraine «On Electric Power Industry» [3];
– The Law of Ukraine «On Renewable Energy Sources» [4], etc.

However, the fate of renewable energy sources in the total consumption of energy resources in Ukraine is still insignificant (about 2.5 %), which is explained by a whole complex of reasons. And the difficult economic and political situation further hinders the attraction of investments.

Therefore, the development of scientifically based approaches to improve the economic efficiency of the introduction of renewable energy technologies for individual territories is an important scientific and practical task.

2. The object of research and its technological audit

The object of research is renewable energy sources as the basis for the development of renewable energy in Ukraine. Particular attention is paid to the study of the spatial aspect in assessing the prospects and possibilities of using certain types of renewable energy sources for specific territories.

Describing the current state of renewable energy in Ukraine, it is worth noting the significant steps taken by the state towards the adaptation of the legislative and regulatory framework to stimulate the development of this industry, in particular:

– significantly simplified procedures for obtaining licenses for the sale of energy at the «feed-in tariff» (feed-in tariffs) (including for private households using renewable energy sources and surplus are sold to the power grid);
– mechanisms for connecting such facilities to the unified power system are fixed;
– tax incentives for heat generating and cogeneration plants are determined.

The work [5] presents the results of the analysis of incentive programs introduced in Ukraine for renewable energy and proved that the size of the existing «feed-in tariffs» is sufficient to attract new investors and compensate for the high risks of doing business in Ukraine.

As of 01.10.2018, according to the National Commission, which carries out state regulation in the fields of energy and utilities in Ukraine, the «feed-in tariff» is [6]:

– for wind farms from 191.21 to 371.79 kopecks/kW·h;
– for bioenergy facilities – 407.20 kopecks/kW·h;
– for solar power stations – from 493.95 to 1529.65 kopecks/kW·h;
– for micro, mini, and small hydroelectric power plants – from 382.41 to 637.36 kopecks/kW·h.

This is one of the highest rates in Europe. The difference in tariffs within the same industry depends on the capacity and the date of commissioning of power generating facilities.

In addition, in order to develop the Ukrainian manufacturing sector, privileges have been established, exempting enterprises that produce equipment for renewable energy from corporate income tax. As well as surcharges to the «feed-in tariff» for the use of Ukrainian-made equipment at power plants. The Law of Ukraine «On Electric Power Industry» [3] provides for exemption of bioenergy enterprises from income taxation in the following cases:

– in case of profit from the sale of produced biofuels;
– in the case of profit from the simultaneous production of electric and thermal energy and/or the production of thermal energy using biofuels.

The result of the implementation of the state policy of supporting renewable energy sources in Ukraine is the annual growth of generating capacity and energy production (Fig. 1).

According to the State Agency for Energy Efficiency and Energy Saving of Ukraine as of 01.07.2017, the total installed capacity of renewable energy facilities was 1.74 GW. And the production of electricity from renewable sources (excluding large hydropower plants) in 2017 amounted to about 2 thousand GW·h.

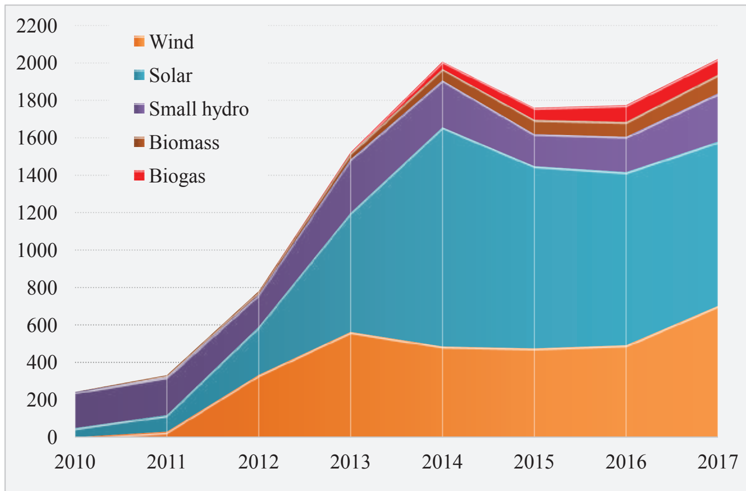

Fig. 1. Dynamics of electricity generation from renewable sources in Ukraine, GW·h, the data are given as of the end of the year (according to the data of the State Agency for Energy Efficiency and Energy Saving of Ukraine)

Fig. 1 shows clearly pronounced decline in electricity generation in 2015 and 2016. It is explained by the fact that since April 2014 electricity supplies from solar and wind power stations located in the occupied territory of the Autonomous Republic of Crimea to the unified energy system of Ukraine have been stopped.

Taking into account the provided statistics, the production of electricity from renewable sources in 2017 amounted to about 2.5 % of the total electricity consumption of the country, and taking into account large hydropower plants – about 8 %. Wind and solar power are characterized by high rates of increasing production capacity in the electric power industry.

The energy strategy of Ukraine until 2035 provides for an increase in the share of generation of electricity from renewable sources (including hydro-generating capacities) to the indicator of >13 % in 2030 and >25 % in 2035 [7]. But given the current trend in the dynamics of the production of electric energy from renewable sources, the indicators defined in the Strategy, in the authors' opinion, is too optimistic, and their achievement is possible only if the intensity of production capacity increases.

At present, the production of energy from renewable sources remains less profitable compared to traditional ones, which is explained by the high cost of equipment and the substantial costs of technological processes. Now, government financial costs for the increase in the form of a «feed-in tariff» when purchasing energy from renewable sources are offset by the lower cost of certain traditional types of energy and the installation of averaged tariff for

ISSN 2226-3780

consumers for all energy. However, an increase in the share of renewable energy sources in the total energy balance will affect the final cost of energy for consumers or require government subsidies to the industry.

The high level of dependence on state support makes renewable energy vulnerable when the economic situation in the world as a whole worsens and in Ukraine in particular. Therefore, when planning new energy facilities, it is important to look for ways to reduce the cost of their construction, operating costs, increase revenues from the sale of renewable energy and, as a result, the rate of return on investment.

An important role in this is played by the choice of the optimal location of the energy facility in terms of the available resource potential and a number of other factors. An analysis of the experience of studying the potential of renewable energy sources in Ukraine in [8] shows that the data on the volumes and territorial distribution of renewable energy resources at the regional level are not sufficient for operational planning. The results of the assessment of renewable energy resources are presented in the Atlas of the Energy Potential of Renewable and Non-Traditional Energy Sources of Ukraine (2001), the Geothermal Atlas of Ukraine (2004), and the National Atlas of Ukraine (2007). But these cartographic sources make it possible to estimate only the total potential of certain types of resources for the region. At the regional and subregional level, both the assessment of resources and their mapping is episodic. For one type of renewable energy resources, no studies were conducted that reflected their division at the regional or district level and covered all regions of Ukraine.

Accordingly, the spatial aspect of the use of renewable energy resources requires more attention and additional research on the territory of Ukraine.

3. The aim and objectives of research

The aim of research is studying the spatial aspect of the use of the energy potential of renewable energy sources by means of the cartographic method using the example of one of the regions of Ukraine.

To achieve this aim, the following objectives are defined:

1. To assess and map the technical potential of renewable energy sources (wind, Sun, rivers and geothermal energy) using the example of Kharkiv region (Ukraine).
2. To determine the most favorable areas for the placement of renewable energy facilities in the territory of the Kharkiv region.
3. To formulate recommendations on the location of renewable energy facilities taking into account resource, social, technical, economic and environmental factors.

4. Research of existing solutions of the problem

There are numerous scientific works focused on the study of various aspects of the development of renewable energy. In particular, scientists in the works [5, 9] investigate the issues of public policy aimed at supporting and financially stimulating this industry.

Many papers are devoted to the assessment of the energy potential of renewable energy: both by region (for example, in the European Union [10]) and by individual types of resources (for example, biomass [11]). The study [12] provides examples of various options for using renewable energy sources that can satisfy local needs and completely or partially replace traditional sources.

A number of scientists are working on the link between renewable energy and sustainable development of territories. In this context, the use of sustainable energy sources and energy carriers, reducing the impact on the environment, increasing efficiency and socio-economic acceptability are considered [13]. Achieving a balanced development requires the use of affordable energy sources that can be disposed of without negative impact on the environment [14]. Accordingly, energy indicators for sustainable development is developed, which are an analytical tool for assessing current patterns of energy production and use at the national level [15].

Modern national and regional strategies for energy development, as a rule, include three key components: energy conservation by users, increasing energy production efficiency and replacing fossil fuels with renewable energy sources [16]. Despite the fact that these changes are motivated by geospatial factors, the integration of models of energy systems and geographic information systems is still in its infancy [17], especially in Ukraine.

Thus, the mechanisms of spatial optimization of the field of renewable energy, taking into account economic factors in the scientific literature, are not given enough attention, therefore this issue should be investigated further.

5. Methods of research

The optimal choice of the location of the power generating equipment allows to increase the economic effect of the construction of a new energy facility by 2–3 times. The profitability of renewable energy technologies depends on the following factors:

– cost of equipment and its installation;
– rental payment for the land plot;
– tariffs for the sale of energy;
– indicators of the energy potential of the territory;
– remoteness of the united power grid and the volume of construction of additional power grids;
– distance from the potential consumer (length of heating mains);
– need to build additional transport infrastructure, etc.

The last four factors should be considered spatially, for which suggest using the cartographic method of research. An analysis of the territorial distribution of the energy potential of renewable energy sources in combination with other socio-economic factors allows to select the optimal regions for the development of individual areas of the industry. At the stage of developing a development strategy for a certain territory, such an analysis helps to identify the types of resources that are characterized by high potential.

Baseline data for the laying of maps of renewable energy results of the assessment of the energy potential of renewable energy sources – wind, solar, geothermal, hydropower. To assess the energy potential in the work applied methods of statistical analysis of multi-year data series and mathematical modeling.

The initial sources of data for estimating and mapping wind energy resources were the results of field measurements presented by average wind speed indicators determined for points that make up the monitoring network of the investigated territory. The meteorological observations of the hydrometeorological services of Ukraine and neighboring countries for the ten-year period (from 2005 to 2014) were used as the main source of statistical information. An additional source of information was the average indicators of the direction and speed of the wind of the world database of meteorological and actinometric data NASA SSE. Measurement data of wind speeds from neighboring border areas necessary for the correct interpolation of indicators in the process of mapping wind energy resources.

Practical value for wind energy has a technical potential, which is reflected through the indicator of energy production by a specific type of wind turbine for a certain time period (day, month, year). The necessity of binding to the type of equipment is due to the fact that the technical parameters of wind turbines (even of the same size, but from different manufacturers) are significantly different, so it is impossible to select certain averaged parameters for assessing the resource potential. Instead, it is possible to calculate the energy production of specific types of wind turbines, which are preferred in the national wind energy market. In Ukraine, such wind turbines are currently Fuhrländer FL2500 (Germany, power 2.5 MW) and Vestas V112 (Denmark, power 3 MW) indicate the country of installation manufacturer [18, 19].

To bring the wind speed to the height of the rotor axis of the wind turbine (100 m), analytical models of calculations are used, most often used in world practice. These are the Leyhtman logarithmic law and the Hellman exponential law, according to which the wind speed at a given height, taking into account the surface roughness coefficient, which is determined by the formulas [20, 21]:

$$V_h = V_a \left(\frac{h}{h_a} \right)^{\alpha}$$

and

$$V_h = V_a \frac{\ln h_a - \ln \alpha}{\ln h - \ln \alpha},$$

where V_h – the wind speed at the height h; V_a – wind speed at the height of the anemometer; h_a – height of the anemometer; α – a step coefficient, which depends on the roughness of the earth's surface (α=0.05–0.50), for open spaces the parameter α=1/7=0.143.

Accounting for the roughness coefficient of the terrestrial surfaces allows to bring the banner of average wind speeds to the conditions of an open area (these are the areas chosen for the placement of wind power plants). The surface roughness coefficients for ground observation points (meteorological sites) are determined from satellite images with a resolution of 3–5 m.

Potential wind energy production of a single power unit is based on the main luggage country wind speeds, reduced to a height of 100 m, for meteorological observation points. When the power curves are used (graphs of how the wind energy depends on wind speed), the technical documentation provided by the wind turbines Fuhrländer FL2500 and Vestas V112 technical documentation is used. After that, interpolation is performed using the method of inversely weighted distances in the ArcGIS software environment, and at the conclusion of maps, respectively, the contour method is used.

The technical potential of solar energy resources reflects the production of energy by a certain type of solar systems per unit area for a certain period of time. It is determined with the technical characteristics of the heliosystems (dome efficiency), the installation angle and orientation on the horizon. This indicator is the basis for assessment of economic feasibility of using solar energy and payback periods for the construction of electric or thermal power plants. Thus, for photovoltaic systems, the annual energy output is determined by the following formula [22]:

$$E = Q_S S_{PP} C_E C_{ES},$$

where E – the annual energy production by photovoltaic systems (kW h); Q_S – total solar radiation arrivals on the surface of photovoltaic panels with a plane of 1 m^2; S_{PP} – the plane of photovoltaic panels or solar collectors; C_E – equipment efficiency; C_{ES} – coefficient reflecting the proportion of the effective surface.

The baseline data for the calculation of the technical solar energy potential obtained using the RETScreen Clean Energy Management Software (RETScreen) [23] is a widely used free software package in the world for analyzing renewable energy projects developed by the order of the Government of Canada. This choice is due to the fact that for modeling the solar potential within the regions of Ukraine there is insufficient ground-based actinometric observations, which are conducted at the state hydrometeorological service. This is due to the fact that throughout the country there are only 10 meteorological stations that measure the rates of solar radiation. On the other hand, the RETScreen software application allows to calculate solar potential data for points of a regular grid of points with an interval of 0.5 degrees. For this purpose, both climatic data of ground-based measurements and parameters obtained from the NASA «Surface meteorology and Solar Energy» space agency's global satellite observation database (NASA SSE) are used. In addition, the program allows to determine the amount of energy produced, taking into account the technical characteristics of the equipment, for example, to quickly calculate the energy production by a certain type of heliosystems for a given terrain point and their installation angle.

The technical potential of solar energy resources in this work is calculated for polycrystalline photovoltaic modules with an average efficiency factor of 24.7 %, oriented to the south at an optimum angle. According to the calculations of the solar potential, a geo-information layer of the network of points was formed, on the basis of which, using the spline interpolation method, a map of the distribution of solar energy resources of the Kharkiv region was constructed later.

The assessment of geothermal resources requires taking into account, collecting and processing large arrays of geological information (on composition, fracturing, thermal conductivity of rocks on different horizons). Therefore, the results of previous assessments of the geothermal potential of the region are used in the study at the conclusion of the map of geothermal resources of the Kharkiv region. They were carried out in the framework of the European project on creation of a web-atlas of geothermal resources

ISSN 2226-3780

of Europe «The GeoElec project» (2011–2013) [24]. The information layers of this atlas data are based on national geological studies. For the territory of Ukraine, this is basically a thermometric study of wells during the exploration of hydrocarbon reserves and groundwater (the depth of most wells is 3000–4000 m). The value of the technical potential of geothermal resources was calculated by the method presented in [25].

The methodology for assessing and mapping the energy potential of small rivers differs significantly in comparison with other renewable energy sources (primarily because hydropower resources do not have a continuous distribution over the territory). It includes the use of multi-stage mathematical-cartographic modeling techniques and a whole complex of GIS-analysis tools. At the same time, the quantitative characteristics of rivers are carried out directly in the process of mapping using the tools of the universal GIS product ArcGIS. Such approach allows analytically determining the hydrological characteristics for absolutely all the rivers of the studied area, and not only for those where hydrological observations are made. Using the existing experience and experimental approbation of a number of ArcGIS functions, an algorithm was developed for cartographic modeling of the energy potential of rivers, described in detail in [26].

The first stage involves the preparation of the initial geo-information data layers – digital elevation model (DEM) and a cartographic layer of the runoff module, on the basis of which derived data layers are created – the components of the cartographic model of the hydrological network. The indicator of the flow module shows the value of the amount of water flowing into the river channel per unit of time per unit of the catchment area.

At the second stage, based on the DEM, cartographic modeling of the hydrological network (lines of watercourses/riverbeds and watersheds) is carried out using the Hydrology tool group of the ArcGIS Spatial Analyst add-on module. Subsequently, based on the map data layer, the direction of the flow and the map of the flow module, the resulting layer of the total flow is constructed, which shows for each cell of the resulting raster the amount of water «flowing» through it (water flow).

The third stage involves the creation of derived geo-information data layers, including the locations of the sources and mouths of rivers, the value of the absolute height of the terrain and the water flow at these points. The confluence points of the tributaries divide large rivers into sections in those places where the water discharge index varies significantly.

At the fourth stage, using the function «Field Calculator», the gross (theoretical) and technical potential of rivers (and their individual sections) are calculated on the basis of data on absolute heights and water flow in sources and estuaries. Calculations of the theoretical potential of rivers are presented by indicators power and specific power of the water flow. The power of the water flow N_i for the i-th stretch of the river is determined on the basis of the equation [27]:

$$N_i = 9.81\frac{\left(Q_{i_1}+Q_{i_2}\right)}{2}\left(H_{i_2}-H_{i_1}\right), \quad \text{[kW]},$$

where Q_{i_1} and Q_{i_2} – the average long-term water consumption at the beginning and end of the i-th river or part of the river, m^3/s; H_{i_2} and H_{i_1} – the absolute heights of the initial and final point of the i-th section of the river, m.

The specific power of the river or its section N_s is determined by the following formula [28]:

$$N_s = \frac{N_i}{L_i}, \quad \text{[kW/km]},$$

where N_i – the capacity of the i-th section of the river; L_i – its length on the ground, km.

Next, the technical energy potential of the rivers (potential energy production) is calculated, taking into account the efficiency of the hydropower equipment – the turbine and the generator, the power factor utilization of the watercourse, depends on the seasonal fluctuations of the river flow. In this study, a simplified system for calculating the technical potential of the hydropower resources of rivers is used. The value of the theoretical potential is multiplied by the number of hours (calculations are performed for the summer period) and by the utilization factor of the theoretical potential, depending on the power of the water flow in the river. According to the methodology presented in [27], the following values of the theoretical potential utilization factor are taken: for rivers with a water flow less than 1 MW – 0.15, from 1 to 2 MW – 0.2, more than 2 MW – 0.35.

At the last stage, according to the results of the calculations, maps of the hydropower potential of the rivers are concluded.

6. Research results

According to the results of the assessment of the wind energy potential of the Kharkiv region, taking into account the technical parameters of the Fuhrländer FL2500 wind turbine, a map is drawn showing the differences in its distribution over the region's territory (Fig. 2). The highest indicators of energy potential are observed in the northern, central and northwestern part of the region, the lowest – in the western and southwestern parts, which is associated with the orographic conditions of the area.

It should be noted that the connection of wind power plants and large solar power plants in most cases is possible only to power lines and distribution substations with a voltage level of 110 kV. Connecting to networks of lower voltage can create overloads, additional restrictions during transportation of the energy produced and at the centers of its consumption. For economic reasons, wind power facilities should be located as close as possible to the power lines of the corresponding voltage, which significantly reduces the cost of capital construction of the facility. Therefore, the grid of the technical wind energy potential is additionally represented.

According to the high energy potential and availability of the electrical system, the location of wind power stations in the Vovchansk, Kharkiv, Velykyi Burluk districts, partly in the Pechenihy, Chuhuiv, Nova Vololaha, Derhachi, Bohodukhiv and Krasnokutsk districts is recommended.

The noise created by wind turbines and the potential threat of blades separation limits the installation of large wind turbines and territories of populated areas, objects of natural reserve fund and historical and cultural heritage, as well as within the 300–500-meter zone around them. This distance meets the requirements of safety and avoids the acoustic effects on residents of nearby communities. The exact dimensions of the protection zone are set for each wind energy facility separately, and the distance to the wind turbines should be such that the noise level from the equipment does not exceed the background environmental noise. According to the standards in force in Ukraine, the normal noise level does not exceed 55 dB in daytime and 45 dB at night, the maximum allowable is 70 and 60 dB, respectively. Wind farms are forbidden to locate close to airports and military bases for possible interruptions in radio communications.

Solar power stations and solar systems for providing hot water supply can be oriented both to the centralized power supply and to the local consumer. At the same time, an equally important factor is the presence of open areas for their installation, including non-shaded roofs of houses within settlements. It is undesirable to establish solar power plants on agricultural land, because during the long overlap of land from the sun's rays their degradation occurs, as well as near the enterprises, which atmospheric emissions reduce the level of transparency of the atmosphere.

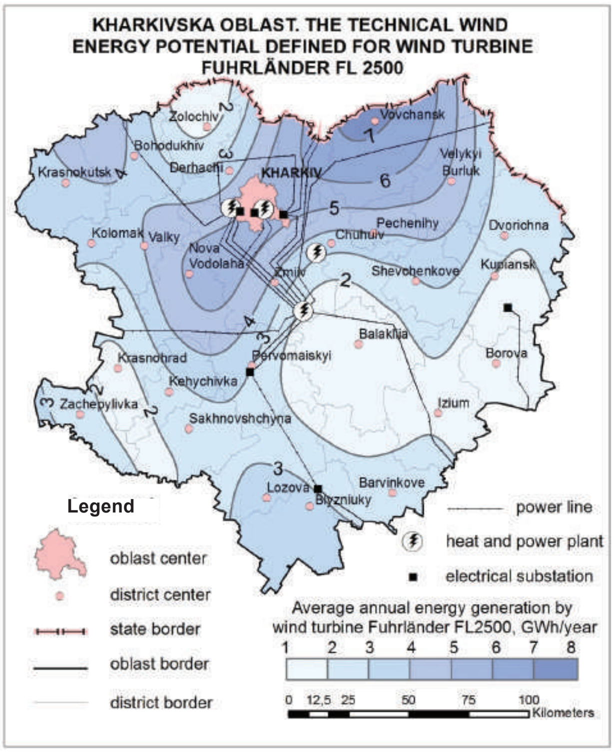

Fig. 2. Technical potential of wind energy resources of the Kharkiv region (oblast) for the Fuhrländer FL2500 wind turbine

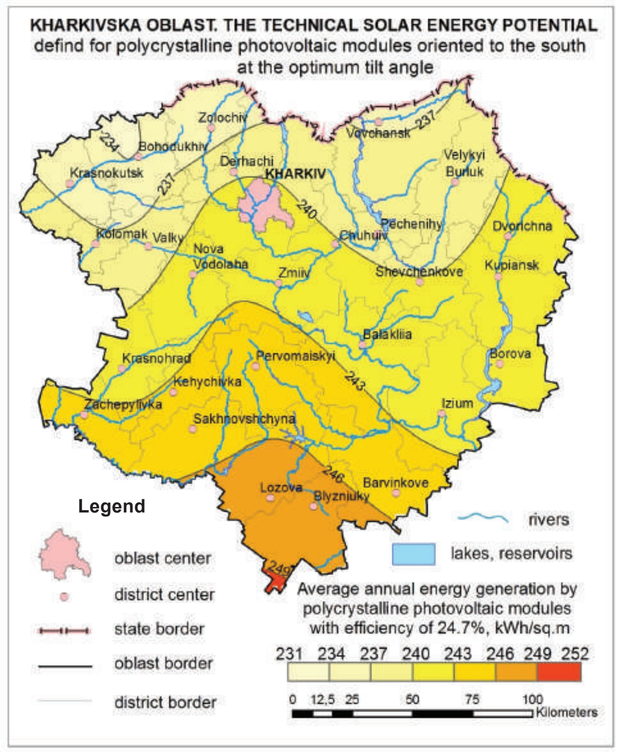

Fig. 3. Technical potential of solar energy resources of the Kharkiv region (oblast)

Although the death rate of birds and bats from collisions with wind turbines according to research results [29] is low, it is undesirable to locate wind farms on bird migration routes and in areas where rare avifauna species are spread.

Fig. 3 presents the results of the assessment of the technical potential of the solar energy resources of the Kharkiv region for polycrystalline photovoltaic modules oriented to the south at the optimum angle (the inclination angle of the photovoltaic modules at which the greatest amount of solar radiation enters during the year). The increase in the potential of solar energy resources is observed from north to south and is subject to latitudinal law.

The most favorable conditions for the placement of industrial solar power plants are characterized by Lozova and Blyzniuky districts, where the annual energy production by polycrystalline photo module can be from 245 to 250 kW·h/year from 1 m^2. High power plants are better placed closer to large electrical substations and more powerful transmission lines in Blyzniuky, Pervomaiskyi, Balakliia, Izium, Lozova and Borova districts. However, solar electricity and heat generating installations for private households can be effectively used throughout the region.

Construction of powerful geothermal power plants, as is the case with wind energy, is more profitable to carry out near the existing power system. Considering the indicators of the energy potential of the subsoil (Fig. 4) and the location of the power grid (Fig. 2), for the construction of geothermal power plants the best in the Kharkiv region are the south of Barvinkove and Blyzniuky, southeast of Izium, Borova and Lozova districts. Since the thermal power potential of geothermal energy is proportional to electric power, thermal power plants at geothermal sources can be created to meet the thermal energy needs of settlements, which are the centers of these areas.

In determining the locations of heat generating facilities and cogeneration plants, it is necessary to take into account the level of energy losses during energy transportation. It is also important to increase the cost of building heating mains when a power facility is removed from consumers. As practice shows, the area of heat and power supply of consumers is limited to a radius of 10–15 km, and in particularly favorable conditions – 25–50 km [30].

As a result of the analysis of the energy potential of the rivers of the Kharkiv region (Fig. 5), it is found that small rivers which length is 10–20 km are characterized by the highest energy potential, which is explained by significant differences in height along the channel (the fall of the river). However, their use for the establishment of hydroelectric power plants (HPP) in most cases is impossible or economically unprofitable due to low rates of water flow in the summer period [31].

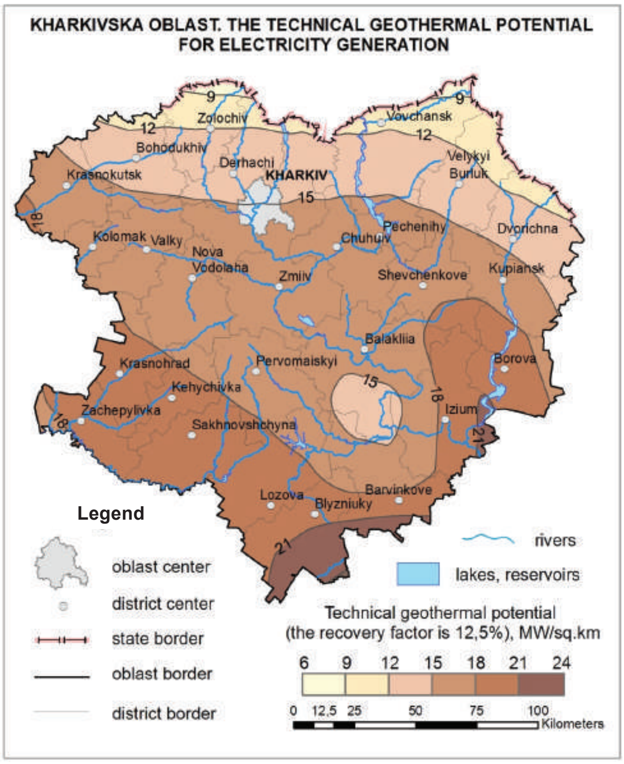

Fig. 4. Technical potential of the geothermal resources of the Kharkiv region (oblast) for the electricity generation

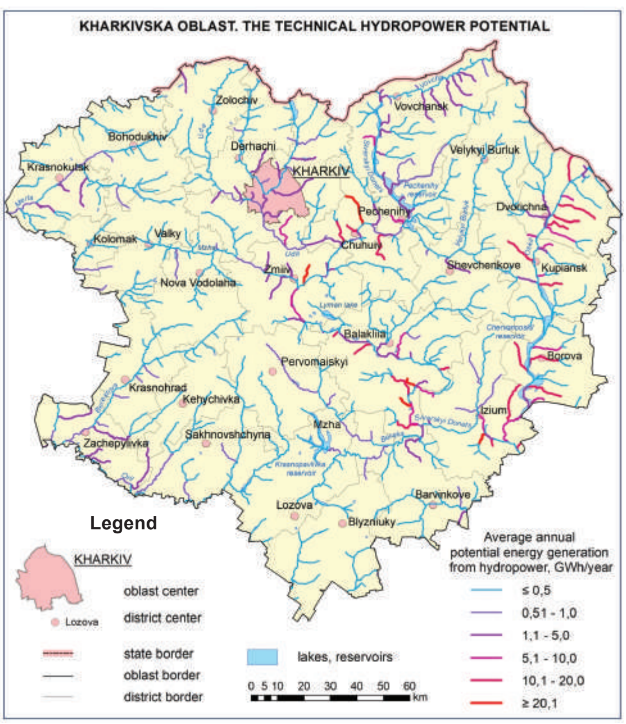

Fig. 5. Technical energy potential of the rivers of the Kharkiv region (oblast)

Within Ukraine, the construction of small hydropower plants is economically feasible on rivers, where water consumption is more than 2 m^3/s [32]. Accordingly, it can be argued that the Siverskyi Donets, Oskol, Uda, Lopan, Kharkiv, Orel, Berestova, Bereka, Merla, Mzha, Vovcha, Velykyi Burluk rivers have an annual water flow sufficient to establish small hydropower plants. However, the hydropower potential of rivers and the possibility of its use depend not only on the values of water flow. No less important are the parameters of seasonal fluctuation of runoff, the fall of the river (water pressure), and other natural, social, economic, and environmental restrictions of the area.

In terms of volumes of technical potential, perspective for locating hydropower stations within the study area are:

– sections of the Siverskyi Donets River – north of Balakliia and in the southern part of the Balakliia District;
– Udy River – west of the Chuhuiv;
– Berestova River – Zachepylivka area;
– Mzha River – to the west of Zmiiv;
– Merla River – upstream and downstream from Krasnokutsk.

Sufficient hydropower potential is also characterized by Oskol River, but the potential of this river is almost completely used Chervonooskil hydroelectric station. Promising is the electrification of the dam of the Pechenihy reservoir, located on the Siverskyi Donets River near the Pechenihy village.

However, the main potential sites for the location of small hydropower stations are concentrated in the central, most densely populated part of the region. On the one hand, the proximity of the HPP location to the consumer is a positive thing, and on the other hand, the settlements create additional restrictions on the construction of reservoirs. In addition, the implementation of projects for the construction of hydropower plants in these areas may be limited by the presence of objects of the nature reserve fund and geological conditions, which requires additional research at the local level.

7. SWOT analysis of research results

Strengths. The strengths of the research include:

1. There is a clear state policy, regulatory framework providing incentives for the development of renewable energy (feed-in tariffs, mechanisms for connecting industry facilities to the unified energy system, tax incentives for heat generating and cogeneration plants).

2. All national strategies, plans, roadmaps, and development concepts related to the fuel and energy complex provide for an increase in the share of the use of renewable energy sources in the total energy balance.

3. The spatial approach, which involves analyzing the distribution of the energy potential of renewable energy sources in combination with other socio-economic factors, allows to select the optimal regions for the development of individual areas of the industry. At the stage of developing a strategy for the development of a certain territory, it helps to identify the types of resources that are characterized by high potential. Presentation of the assessment results of the potential of renewable energy sources in a cartographic form is the most visual and accessible for perception.

Weaknesses. The weaknesses of the research include:

1. Insufficient amount of resources and investments to increase the production capacity of renewable energy in Ukraine.

2. Considering the political aspect and the high dependence of the country's energy sector on natural gas supplies, in the past two years, the emphasis of national policy has been somewhat shifted to a policy of increasing domestic gas production (the concept of development of the gas producing industry in Ukraine). At the same time, the development of renewable energy is not given enough attention.

3. In general, the information support of renewable energy in Ukraine lags behind the level of foreign countries. Comprehensive studies of the potential of renewable energy at the regional and subregional levels for all regions of the country have not been conducted.

Opportunities. The opportunities for research include:

1. The acquisition of industrial value of new types of resources, the creation of new technologies and equipment can in the future ensure both the development of the fuel and energy complex and associated industries.

2. The wide capabilities of geo-information technologies determine the popularity and distribution of various applications and specialized geo-information systems that allow for the rapid assessment, modeling and visualization of energy indicators of renewable energy resources. They also take into account local factors affecting the feasibility of using renewable energy resources.

3. It is advisable to create on the Internet mapping web services, web atlases and web GIS, in which information on renewable energy resources is presented in the form of interactive map data layers. Such resources contribute to the promotion of renewable energy among the general population and attract investment in the industry.

Threats. Research threats include:

1. Low rates of development of renewable energy, which may lead at a certain time of the energy crisis and increase dependence on energy imports.

2. Without introducing the necessary measures, the use of each of the renewable energy industries can have negative consequences for the environment. Thus, noise pollution and the death of birds are negative aspects of the development of wind power, changes in river ecosystems and the death of ichthyofauna – small hydropower, soil degradation – solar power, etc.

8. Conclusions

1. The presented maps of wind, solar, geothermal energy and small hydropower give an idea of the potential development of renewable energy in the Kharkiv region. Local authorities can apply cartographic data when concluding strategies and plans for socio-economic development, and interested investors – when choosing a construction area and type of energy resource. In the future, it is advisable to conduct similar studies of the potential of renewable energy sources for all regions of Ukraine and create a single electronic web-mapping service that would combine and provide all the necessary information in open access.

2. Optimal areas for the construction of renewable energy facilities in the Kharkiv region have been determined. So, location:

- wind power plants are recommended in Vovchansk, Kharkiv, Velykyi Burluk regions;
- solar power plants – in Blyzniuky, Pervomaiskyi, Balakliia, Izium, Lozova and Borova;
- geothermal power plants – in the south of Barvinkove and Blyzniuky, southeast of Izium, Borova and Lozova districts.

Perspectives for locating small hydropower stations within the study area are sections of the Siverskyi Donets, Udy, Berestova, Mzha, Merla rivers.

3. It is proved that the application of the cartographic approach allows to determine the optimal location of renewable energy facilities taking into account a number of factors. Social, technical, economic and environmental factors are considered that influence the choice of location of energy facilities, as:

- distance to the potential consumer;
- features of connection to the united power grid;
- possible impact on the environment and human activity.

Relevant recommendations on the location of wind, solar, geothermal energy and small hydropower facilities at the regional level are formed.

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