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Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
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NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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DECISION SUPPORT SYSTEM FOR OPTIMIZATION OF RES GENERATORS PLACEMENT BASED ON GEOSPATIAL DATA

Abstract. The Republic of Kazakhstan has significant deposits of fossil fuels and Kazakhstan is one of the largest energy producers among the countries of Central Asia. At the same time, Kazakhstan has one of the highest renewable energy potential in the world, evaluated as 300 to 1000 billion kWh/year. Application of renewable energy sources both at industrial and household levels, provide the transformation of the energy system to a "green state". However, these initiatives should be substantiatied by appropriate information maintenance in order to support the transformation of the country's economy to a higher quality environmental condition. The paper covers existing methods and software for processing of resource-invariant heterogeneous data which could be applied to evaluation of renewable energy. This work describes the multi-criteria decision support makining system MIGIS (multi-criteria intellectual geoinformation system) which is aimed to provide evaluation of territory suitability for RES generators installation based on spatial data. The MIGIS architecture is based on the concept of independent data processors. We considered some technical issues addressed in the process of development. Examples the task of identifying locations favorable for the installation of energy generators executed by the system are presented.

Key words: decision making support methods, geo information systems, intelligent information technologies, renewable energy, spatially distributed resources.

Introduction. In Kazakhstan, over the past 15 years, there has been a large increase in the urban population, especially in Almaty, Astana, and Shymkent. The complex of problems of the city of Almaty, arising due to its intensive growth, is about the same as that of other major cities with some special features: air pollution, due to the location of the city in the center of a mountain area, and increased seismic activity. The air basin of the city is one of the most polluted.

According to https://www.numbeo.com/pollution/rankings_current.jsp. Almaty is on the 228th place in terms of pollution index among 273 registered cities. The city is ranked 173 in terms of cumulative quality of life.

Changes in the environmental indicators of the city and improving the quality of life in general require a change in the attitude of the population to environmental problems. Ecological culture and environmental protection are a necessary element of the systems Smart City and at the same time one of the important elements to be assessed in the system of social development of a person. Environmental initiatives related such as the usage of renewable energy in large energy systems, as well as at the level of a separate household, ensure the transformation of the energy system to a “green state”. However, in the information society, these initiatives must be supported by appropriate informational support and systems that support the transformation of the country's economy to a much better ecological state and convenient for both industrial clients and individuals with “green thinking”.

The largest settlements of the Republic of Kazakhstan are connected to the centralized energy supply. However, there are significant areas that do not have access to a unified energy system. For example, the entire territory of the Aktobe region, as well as remote villages in other areas are not connected to high-voltage magistral power lines. As a result, there is a need for the construction of additional distribution networks in these areas, as well as for autonomous power generation, including those on the basis of renewable energy sources (RES) for agricultural settlements and industrial enterprises, recreation facilities, distant pasture farms, and for areas with difficult environmental conditions [1].

These disproportions, as well as developed agricultural production, implying the presence of seasonal or year-round autonomous consumers of heat and electricity, makes the use of renewable energy systems in the republic relevant [2]. Note that Kazakhstan is one of the richest countries in the world in terms of renewable energy. The size of the gross potential of different types of renewable energy on the territory of Kazakhstan is estimated varying from 300 billion to 1 trillion kWh/year, including 0.929-1.820 billion kWh/year from wind energy, 2.5 billion kWh/year from solar energy, 170 billion kWh/year from hydro energy, and 150.6 billion kWh/year from biomass energy [3]. Of course, realization of the entire energy potential is impossible. Moreover, due to the high cost of energy generators based on renewable energy sources, it is necessary to optimize criteria when choosing a location for the installation of energy generators.

This paper discusses methods for developing solutions based on expert assessments (clustering approach) and briefly describes the system developed on its basis. Unlike the existing examples described in the literature, the proposed system is a generalization of the cluster approach, applicable to calculate the suitability of the location for installation of generators of different types even in case of lack of data.

The work consists of the following parts:

The first part is a brief review of the literature, which describes the current practice of assessing the potential of renewable energy sources, including, probably the only project implementing a classification for assessing of wind energy potential.

The second part describes the multi-criteria decision support system (MCDM) for assessing the potential of renewable energy sources.

The third part describes some of the results obtained by the MCDM geo information system MIGIS.

The conclusion describes the possible ways of developing of the system for evaluating various spatially distributed resources.

Practice of assessing the potential of renewable energy. For economically sound use of renewable energy, it is necessary to assess the potential and select the most optimal locations and methods for collecting and processing energy, including the choice of types of generators. Such an assessment usually includes three stages.

First, the potential of renewable sources is estimated. The assessment is multi-level and includes [4]: the calculation of the theoretical (gross) potential, the evaluation of the technical potential, depending on environmental parameters, efficiency of the generator, infrastructure, etc. At the last stage, the economic potential is estimated, taking into account as many factors as possible. Since RES is mostly dependent on geographic factors, an additional step was proposed in [5] – the assessment of the geographic potential of RES. Geographic potential is defined as part of the technical potential that is geographically available and necessary in a particular region (figure 1).

Secondly, an analysis of the factors associated with the use of renewable energy is performed. Such factors include geographical (natural, geomorphological, location factors [6]), environmental, technical, economic and social. In particular, recent studies show that the problem of utilization of generators [7], landscape and aesthetic limitations manifested in areas of mass recreation [8], etc. should be taken into account. Some factors may prohibit the use of renewable energy sources, for example, territories of national parks, geographically or geophysically unsuitable territories, etc. Other factors such as the availability of cheap renewable energy sources or high energy demand may contribute to the suitability of the territory for installation of generators (figure 2). Thirdly, since the majority of RES are geographically distributed, dependent on natural and anthropogenic factors, these resources are visualized usually using geoinformation systems (GIS) [9]. There are also examples of systems that support the interactive mode of calculating the available technical potential of renewable energy sources, for example, solar energy [10].

Gross potential of renewable energy is estimated in a number of works. For example, the atlas [11] describes the methods and results of calculations of natural resources and energy potentials of the sun, wind, small water flows, peat, biomass of agricultural waste, waste of timber and wood industries of Russia.

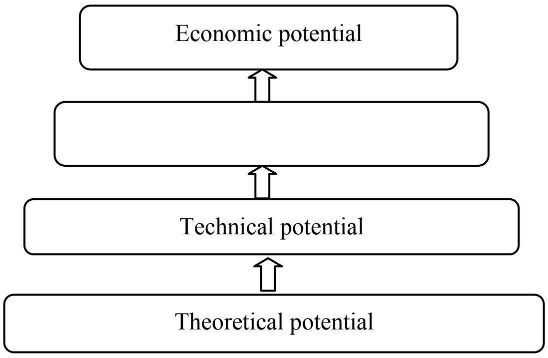

Figure 1 – Stages of the RES potential assessment

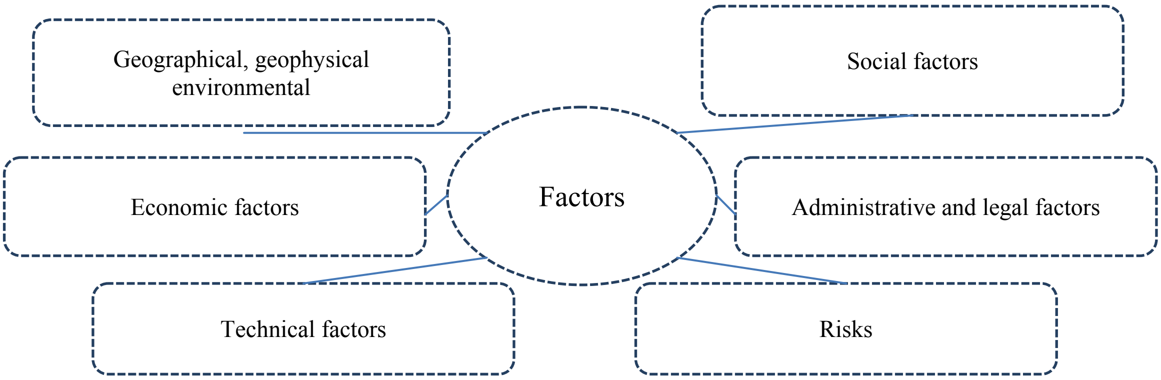

Figure 2 – Groups of factors affecting the installation of energy generators

Detailed calculation of the potential of renewable energy sources, including economic, on one of the regions of Spain is described in [12]. The potential of the forest biomass of Italy was studied in detail in [13], where all possible functions and scenarios of forest use are considered. The work [14] is an example of solving the problem of assessing the potential of renewable energy (solar and wind energy) for rural areas.

There are a number of examples of a detailed analysis of a territory that take into account, among other things, economic factors of the use of renewable energy sources [15,16].

A methodically close approach was applied in the dissertation work [17], where a combination of factors influencing the placement of energy generators was classified according to the degree of influence on decision making. A somewhat extended taxonomy of the factors mentioned is shown in figure 2.

Currently, a number of large scientific schools have been created that assess the potential of renewable energy sources and visualize them using web technologies in the USA (National Renewable Energy Laboratory - NREL) [18], Europe (European Commission for Renewable Energy [19]), Russia (GIS "Renewable energy sources in Russia" [20]), international level (International Renewable Energy Agency [21]). The preliminary work done in the Republic of Kazakhstan allowed us to offer a methodology for assessing the potential of renewable energy sources based on open data sources and specific methods of aggregating factors [22,23].

However, in order to successfully apply existing cartographic data, its additional analysis is required in order to assess the economic potential of renewable energy, and the systems described above implement only a part of the analysis related to a particular type of energy and to a specific territory.

Combining the above-mentioned methods within a single system is necessary and useful for analyzing a territory from the point of view of different factors.

Multi-criteria decision support system for assessing the potential of renewable energy. The developed system (multi-criteria intellectual geographical information system - MIGIS) provides functions for storing, processing, visualizing and analyzing data. The system based on MCDM method BaFAHP [24]. The proposed software architecture is scalable in terms of functional and technical capabilities by adding new computing power and storage.

In the process of research and development of the system the following problems were taken into account:

1) The heterogeneity of data. This problem is related to both the data format and data sources. As for data formats, two fundamentally different forms of spatial data must be taken into account: vector and raster data, each of which has a number of different technical implementations. Data sources, in turn, provide data in different formats with different temporal and spatial resolutions.

2) Scalability. Since the system takes into account a large number of factors (up to 70) presented as high-resolution data, which need to be processed and analyzed separately, as well as aggregated together, significant computational power is necessary.

3) User base. The system should be developed for different users including researchers and enthusiasts, developers and business/industry.

These requirements must be met, while preserving the integrity of the security of the system, taking into account the various roles of access and permissions, as well as the ability to manage spatial data in different regions.

The main functionality of MIGIS is implemented using data processors (DP), the number of which is highly scalable. Although DP can perform any tasks, three categories of data processors can be distinguished:

Import data processors (IDP). Used to analyze data from any external sources, including files, external databases, API, etc.

Data Normalization Processors (NDP) Due to the heterogeneity of the data, it is difficult to suggest universal DP for normalization. Therefore, an extensible set of NDP is a feasible solution.

Data Aggregation Processors (ADP). The data obtained as a result of the work of IDP and NDP must be consolidated to obtain an assessment of the territory. Aggregation of data and factors can be performed on the basis of different mathematical models. Therefore, the extensible list of ADP will allow to expand the functionality of the system. The outcome of the MIGIS system is a set of maps linked to a geographic region (country, region, etc.).

Data and results. The developed system was used for a number of computational experiments for checking and analyzing the developed model of aggregation.Since aggregation requires normalized data, and the problem of normalizing heterogeneous data relies on expert judgment, the system was also used to visualize and analyze the proposed methods for normalizing and adjusting their parameters based on experimental results.

Figure 4 shows an example of several displayed layers, including vector layers (a map of railways and buildings) and raster (two layers with statistics of different daily wind speeds). Figure 3 also shows part of the system interface – a navigation panel on the left, which also to navigate through other system menus and panels, and also contains a list of regions, factor groups and layers.

Layers in figure 3:

Blue lines (vector) – railways.

Black dots (vectors) are polygons showing the locations of buildings.

The green and purple scale raster layer is a map showing the average number of days per year with wind speeds of less than 2 m/s and more than 10 m/s.

The ability to overlay different data allows you to simultaneously analyze several different factors.

In the current implementation, several sets of layers are loaded into the system, which are necessary for making decisions when deploying RES generators. The data includes:

– Layers of vector data from open source OpenStreetMap project. This data includes: the location of roads and railways, waterways, reservoirs, glaciers, buildings, and information from the land-use registry;

– NASA SSE (Solar Meteorology and Solar Energy) data layers — raster data, including average, maximum, minimum, and consistency statistics for solar radiation, air temperature, atmospheric pressure, humidity, and wind speed;

– Layers obtained by processing the source data.

Data loaded by IDP is normalized. Implemented NDP providing the following types of normalization: linear, threshold and threshold with linear interpolation (figure 4).

Aggregation. The aim of the system is to support decision-making in the area of installation of renewable energy generators in the form of aggregated layers (maps) indicating areas favorable for the installation of a specific energy collection system.

For data aggregation, two ADPs are currently implemented on the basis of a multiplicative model and a Bayesian algorithm using subjective probabilities estimated in the course of knowledge extraction from

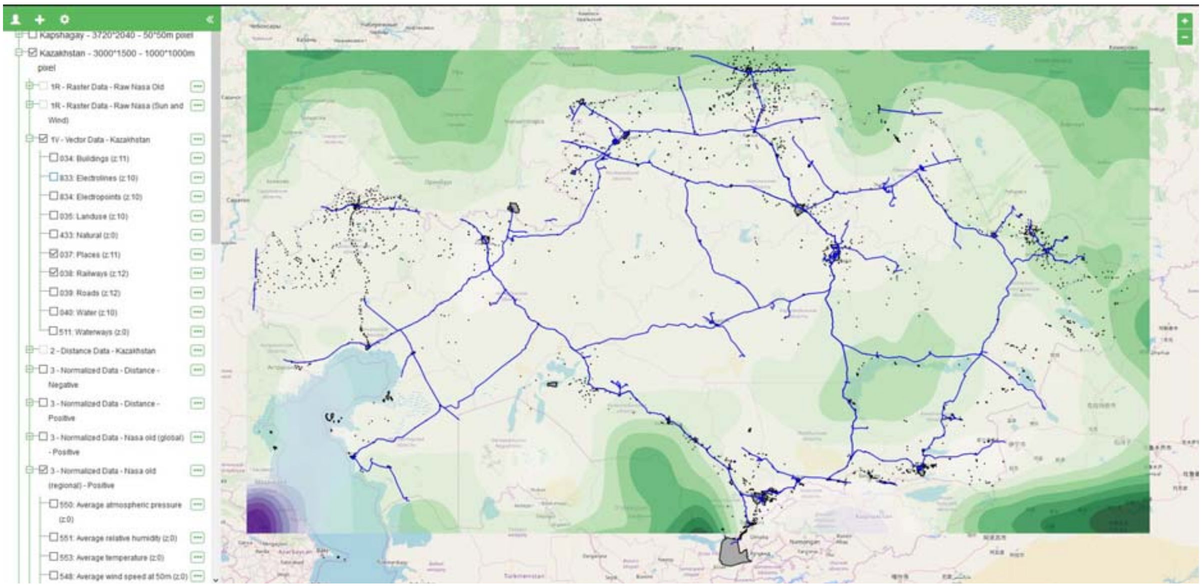

Figure 3 – Example of displaying multiple layers

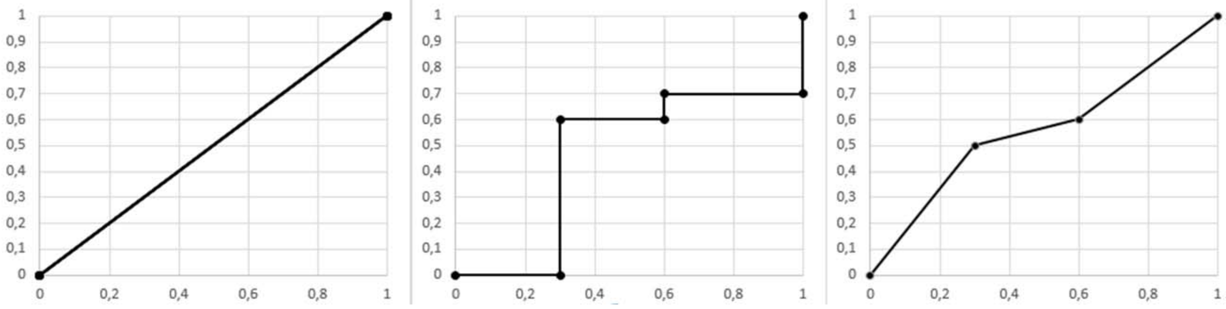

Figure 4 – Examples of the response function of the implemented normalization algorithms
(linear, threshold and threshold with linear interpolation)

experts. The peculiarity of the Bayesian inference model is that it allows one to obtain not only a single value, but two subjective probabilities corresponding to the positive and negative hypotheses about the feasibility of installation of RES generator. In addition, the model works in the case when estimates of some factors are absent.

Figure 5 shows an example of the result of aggregation of factors using the developed algorithm based on the Bayesian model (Bayesian ADP) for the territory of Kazakhstan in the area between the cities of Almaty and Kapshagay. The factors affecting the theoretical feasibility of installing wind generators, in particular, the distance to buildings, power lines, electrical infrastructure, roads, water objects, data from the land use registry, the registry of national parks, reserves, data on the average wind speed at an altitude of 50m are considered. Green zones correspond to high values of the positive hypothesis (generator deployment is feasible), and red zones - negative (wind turbine deployment is not feasible or impossible).

Currently, with a given set of factors, the results of the algorithms can be used as a preliminary basis for decision making. For example, it is clear in which areas it is forbidden to deploy the generators. At the same time, the map shows some aggregated indicators of the total infrastructure and residential/commercial presence, taking into account roads, energy infrastructure and settlements. Figure 5 (right) shows a map of two hypotheses overlaid - positive (green) and negative (red), which is one of the features of the developed aggregation algorithm. At the same time, the values of these two hypotheses are not reduced to a simple inversion of the first to the second, and can be used independently in a detailed analysis of the territory.

The simplest way to verify the proposed model and the system implemented on its basis is to compare the locations of existing generators and the forecast that the model made. Figure 9 shows the locations of the wind - (left) and solar (right) power generators in the area of the Kapshagay reservoir (Kapshagay city). It can be seen that the existing power complexes are located in the green zones predicted by the system.

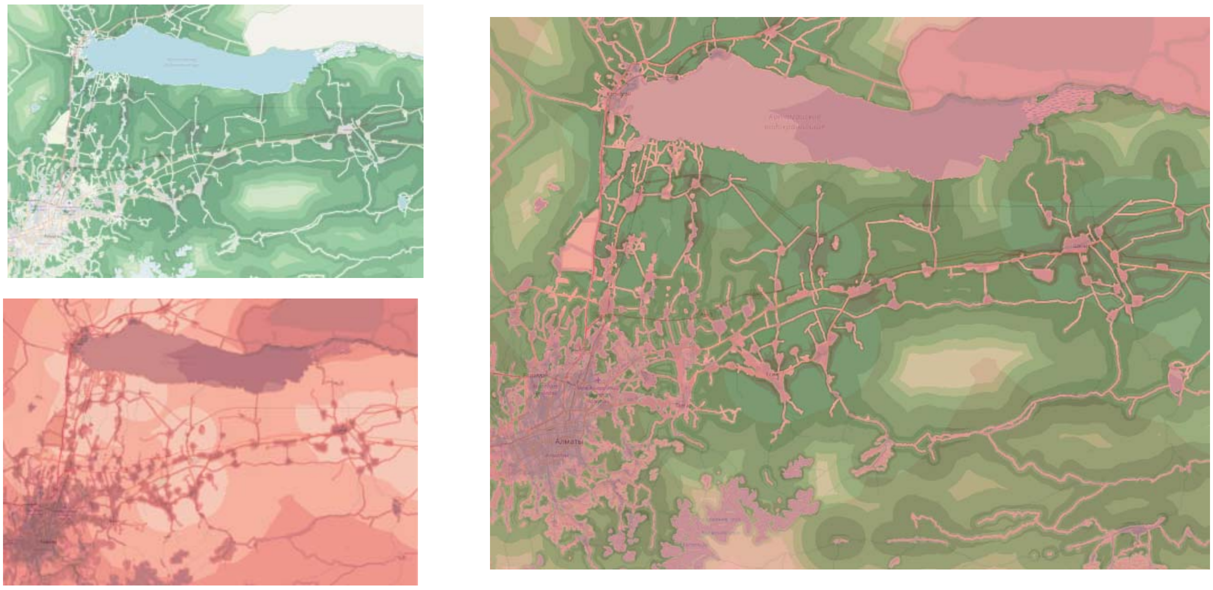

Figure 5 – Example of aggregation of criteria using the Bayesian model. Left: above - the result of the calculation for the "positive" hypothesis, below for the "negative". Right map is combining both hypotheses

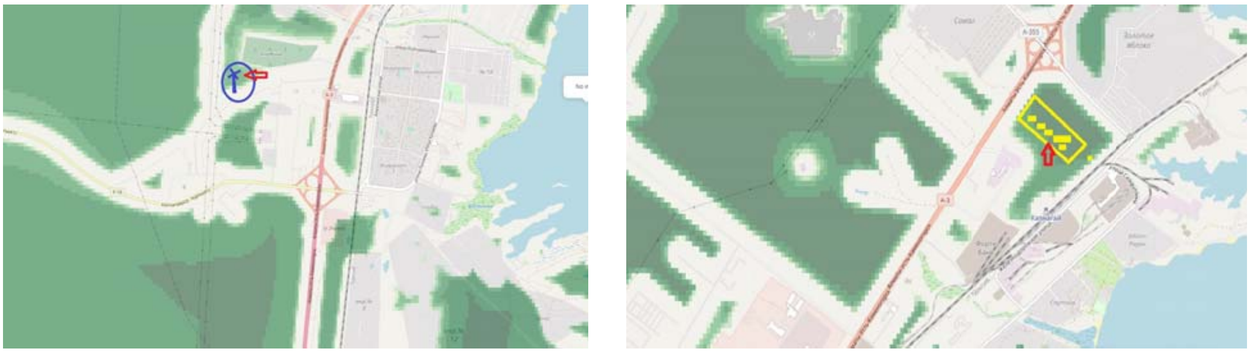

Figure 6 – Placement of wind and solar power generators in the area of Kapshagai (placement areas are marked by arrows)

More detailed information about the operation of the system can be found at http://migis.kz (username "observer", password "migispassword").

Conclusion. Despite the great potential of renewable energy sources in Kazakhstan, it is a complex task to utilize it optimally. Therefore, it is necessary to choose places in the Republic where the use of RES would be most useful. Pure technical considerations are not enough for a detailed analysis of these areas, since the choice of location for the construction of energy generators is influenced by many different factors that must be evaluated and consolidated in a generalized assessment.

The paper presents a prototype of the multi-criteria decision support system MIGIS. The system allows assessing the suitability of the sites for the installation of RES generators using several methods of consolidating expert estimates and the gross energy potential (currently, two types of aggregation are used: the multiplicative method and the hybrid method using Bayesian output). The MIGIS architecture is based on a system of unified modules, which will make it relatively easy to increase functionality by adding data processors and aggregators.

Since the problem of decision-making, including the automatic allocation of resources and management, is becoming increasingly important, we can expect growth in scientific and industrial demand for systems like the MIGIS described above, designed to support decision-making in the analysis and assessment of spatially distributed resources.

The system architecture, based on the concept of independent data processors, allows the system to be expanded in terms of data sources, solving problems of calculating the energy potential on the basis of more accurate mathematical models and algorithms for consolidating estimates of various factors.

From the point of view of software and hardware implementation, the system is distributed (cloud) and modular. These features make it relatively universal both in terms of the data being processed and in terms of the functions implemented.

The system provides the ability to store-process heterogeneous data, extend processing power, parse data from external sources. The ability to build Data Processor cascades is supported.

The Bayesian model of inference, used to aggregate heterogeneous data, provides subjective probabilities of two hypotheses (pro and con). The model remains operable in case of incomplete data, when it is impossible to obtain estimates of some criteria. The accuracy of the forecast deteriorates, however, the model makes it possible to estimate this deterioration.

In our opinion, the implemented methods and models can be used to support decision making not only in the area of application of the RES, but also other types of spatially distributed resources [25].

The main problem in using the developed system in practice is low accuracy and general lack of the data. Some data obtained from open sources, for example, the values of incident solar radiation and wind speed from the NASA SSE database, are presented in a degree grid and averaged to monthly mean, which does not give a detailed idea of the spatial and temporal distribution of these characteristics. The data of the Open Street Map on Kazakhstan's infrastructureis not complete, and in case of water resources the data are erroneous. Therefore, one of the tasks of further research may be the task of creating more reliable arrays of initial data. The second task, the solution of which can improve the accuracy of recommendations, is the development of a system that combines decision support methods based on expert assessments and machine learning methods. In this context, a good example is the windcat.ch. project, in which, using deep learning on the data of currently installed wind generators, the suitability of territories for wind generators installation is predicted.

Despite the noted shortcomings, a comparison of the results obtained with the actual installation of the generators shows that the proposed model and the system developed on its basis are able to predict areas favorable for the placement of power generators based on RES. Evaluation of the accuracy of the forecast and its improvement is the task of further research.

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ҚОРШАҒАН ОРТА БОЙЫНША ЭНЕРГЕТИКАЛЫҚ ЖЕЛІЛЕРДІ ОРНАТУ ЖӨНІНДЕГІ ОПТИМАЛДЫ ПАЙДАЛАНУШЫЛАРДЫ ТАҢДАУ ТУРАЛЫ ШЕШІМ-ҚОЛДАНУ МҮЛІК-КРИТЕРИЯЛЫҚ ҚОЛДАУ ЖҮЙЕСІ

Аннотация. Қазақстан Республикасында қазба отынының елеулі кен орындары, сондай-ақ Орталық Азиядағы ең ірі энергия өндірушілердің бірі бар. Сонымен бірге, Қазақстан жылына 300-1000 млрд. КВт.сағ. Деп бағаланатын жаңартылатын энергия көздері (ЭКЖ) бойынша әлемдегі ең бай елдердің бірі болып табылады. Жаңартылатын энергия көздерін кең ауқымда да, жеке үй шаруашылығында да қолдану энергия жүйесінің «жасыл» мемлекетке айналуын қамтамасыз етеді. Дегенмен, бұл бастамаларды еліміздің экономикасын сапалы экологиялық жағдайға айналдыруға қолдау көрсететін тиісті ақпараттық қолдау арқылы қолдау қажет. Жаңартылатын энергияны пайдалану мүмкіндігін бағалау үшін пайдаланылуы мүмкін ресурстық-инвариантты гетерогенді деректерді өңдеудің қолданыстағы әдістері және бағдарламалық қамтамасыз ету қарастырылған. ЭКЖ қолдану есебі жалпы, техникалық, географиялық және экономикалық потенциалдарды бағалау жолымен орындалатыны көрсетілген. Көптеген жағдайларда әзірлемелердің авторлары басқа елдердегі (Испания, Греция, АҚШ) жаңартылатын энергия генераторларын орналастыруға ықпал ететін және кедергі келтіретін факторлардың жиынтығын ескеретін шешімдер қабылдауды қолдаудың жергілікті жүйелерін қалыптастырады. Сонымен бірге, қалыптасқан практика мақала авторлары әзірлеген (BaAHPF) шешім қабылдауды көпкритериалды қолдаудың түпнұсқалық моделіне негізделе алатын ЭКЖ генераторларын орналастыру бойынша шешім қабылдауды қолдаудың әмбебап жүйесін ұсынуға мүмкіндік береді, біріншіден, екі баламалы гипотезаны қарауға және екіншіден, ақпараттың жетіспеушілігі жағдайында жұмыс істеуге мүмкіндік береді. Бұл ретте, осыған басқа елдерден айырмашылығы Қазақстан үшін ЭКЖ-нің үлкен жалпы потенциалымен қатар, халықтың тығыздығы төмен және жергілікті географиялық және геофизикалық жағдайлар туралы ақпараттың жетіспеушілігі бар орасан зор аумақтар тән. Ұсынылған модель айтыла өткен кемшіліктерді біршама дәрежеде жеңуге мүмкіндік береді. Осы негізде жасалған көп критерийлік зияткерлік геоақпараттық жүйе көп критерийлерді шешуге қолдау көрсету жүйесі сипатталған. Тәуелсіз дербес деректер процессорларының тұжырымдамасына негізделген MIGIS архитектурасы қарастырылып, даму үдерісінде шешілген кейбір техникалық мәселелер қарастырылады және жүйе жұмысының мысалдары энергия генераторларын орнату үшін қолайлы жерлерді анықтау міндеттерінде беріледі. Ілеспелі географиялық, геофизикалық және экономикалық ақпараттың жетіспеушілігіне байланысты осындай жүйелерге тән шектеулер айтылған. Алдағы зерттеулерде аймақты жіктеуді орындауға мүмкіндік беретін Машиналық оқыту әдістерін қосымша қолдану ұсынылды.

Түйін сөздер: шешімдерді қолдау әдістері, геоақпараттық жүйелер, зияткерлік ақпарат технологиялары, жаңартылатын энергия, кең таралған ресурстар.

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СИСТЕМА ПОДДЕРЖКИ ПРИНЯТИЯ РЕШЕНИЙ ДЛЯ ВЫБОРА ОПТИМАЛЬНЫХ МЕСТ УСТАНОВКИ ГЕНЕРАТОРОВ ЭНЕРГИИ НА БАЗЕ ВИЭ

Аннотация. Республика Казахстан имеет значительные месторождения ископаемых видов топлива, а также является одним из крупнейших производителей энергии в странах Центральной Азии. В то же время Казахстан является одной из самых богатых стран мира с точки зрения ресурсов, возобновляемых источников энергии (ВИЭ), оцениваемых в 300-1000 млрд кВч в год. Применение ВИЭ как в крупном масштабе, так и на уровне отдельного домовладения обеспечивают трансформацию энергетической системы к "зеленому состоянию". Однако эти инициативы должны подкрепляться соответствующим информационным обеспечением, обеспечивающим поддержку трансформации хозяйства страны к качественному экологическому состоянию. Рассматриваются существующие методы и программные средства для обработки ресурсоинвариантных гетерогенных данных, которые могут быть применены для оценки возможностей использования возобновляемой энергии. Показано, что расчет применимости ВИЭ выполняется путем оценки валового, технического, географического и экономического потенциалов. В большинстве случаев авторы разработок в других странах (Испания, Греция, США) формируют локальные системы поддержки принятия решений, учитывающих совокупность факторов, способствующих и препятствующих размещению генераторов возобновляемой энергии. Вместе с тем, сложившаяся практика позволяет предложить универсальную систему поддержки принятия решений по размещению генераторов ВИЭ, которая может базироваться на оригинальной модели многокритериальной поддержки принятия решений, разработанной авторами статьи (BaAHPF), позволяющей, во-первых, рассматривать две альтернативные гипотезы и, во-вторых, работать в условиях недостатка информации. При этом, в отличие от других стран для Казахстана, наряду с большим валовым потенциалом ВИЭ, характерны огромные территории с низкой плотностью населения и недостаток информации о местных географических и геофизических условиях. Предложенная модель позволяет в некоторой мере преодолеть указанные недостатки. Описывается разработанная на этой основе многокритериальная система поддержки принятия решений MIGIS (multi-criteria intellectual geoinformation system), обеспечивающая оценку территории с точки зрения установки генераторов энергии использующих ВИЭ. Рассмотрена архитектура MIGIS, основанная на концепции независимых процессоров данных, освещены некоторые технические вопросы, решённые в процессе разработки, приведены примеры работы системы в задаче выявления мест благоприятных для установки генераторов энергии. Упомянуты ограничения, присущие такого рода системам, которые связаны с недостатком сопутствующей географической, геофизической и экономической информации. В дальнейших исследованиях предложено дополнительно использовать методы машинного обучения, которые позволяют выполнить классификацию территории.

Ключевые слова: методы поддержки принятия решений, геоинформационные системы, интеллектуально-информационные технологи, возобновляемая энергия, пространственно распределенные ресурсы.

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