ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ ТА ТЕОРІЯ КОДУВАННЯ

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PRINCIPAL APPROACHES TO CREATING GEOINFORMATION SYSTEM OF RENEWABLE ENERGY SOURCES IN UKRAINE

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Анотація. Запропоновано підходи до створення геоінформаційної технології (ГІС-технології) й інструментів геоінформаційної системи виявлення й аналізу ділянок відновлюваних джерел енергії (ВДЕ) в Україні. Сформульовано основні складові ГІС-технології. Вони базуються на методах, моделях та технологіях комплексного аналізу статистичних та аерокосмічних даних з метою створення інструментів спеціалізованої геоінформаційної системи з урахуванням WEB-орієнтованого підходу. Представлені компоненти ГІС-технології призначені для розробки нових програмних й аналітичних інструментів на основі геоінформаційних систем та технологій, а також інших інструментів просторового моделювання в задачах оцінки перспективності територій України з точки зору доцільності розміщення об'єктів ВДЕ.

Ключові слова: геоінформаційна система, геоінформаційна технологія, відновлювальні джерела енергії, інтелектуальний аналіз даних.

Аннотация. Предложены подходы к созданию геоинформационной технологии (ГИС-технологии) и инструментов геоинформационной системы выявления и анализа участков возобновляемых источников энергии (ВИЭ) в Украине. Сформулированы основные составляющие ГИС-технологии. Они базируются на методах, моделях и технологиях комплексного анализа статистических и аэрокосмических данных с целью создания инструментов специализированной геоинформационной системы с учетом WEB-ориентированного подхода. Представленные компоненты ГИС-технологии предназначены для разработки новых программных и аналитических инструментов на основе геоинформационных систем и технологий, а также прочих инструментов пространственного моделирования в задачах оценки перспективности территорий Украины с точки зрения целесообразности размещения объектов ВИЭ.

Ключевые слова: геоинформационная система, геоинформационная технология, возобновляемые источники энергии, интеллектуальный анализ данных.

Abstract. The approaches to geoinformation technology (GIS-technology) and geoinformation system tools creation are proposed for detecting and analyzing the renewable energy sources (RES) areas in Ukraine. The main components of GIS-technology are formulated. They are based on methods, models, and technologies of integrated analysis of statistical and aerospace data in order to create on this basis the tools of a specialized geoinformation system, taking into account the WEB-oriented approach. The presented components of GIS-technology are intended to create new software and analytical tools based on geoinformation systems and technologies, as well as other spatial modeling tools in the tasks of assessing the prospects of Ukrainian territories in terms of the feasibility of RES power facilities placing.

Key words: geoinformation system, geoinformation technology, renewable energy sources, data mining.
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Introduction

Recently, the demand for energy resources has increased significantly. It is accompanied by climate changes due to carbon combustion products' emission into the atmosphere, which requires strengthening of Ukraine's energy policy regarding renewable energy technologies (RES).

As of today, Ukraine has adopted a number of laws that stress the priority of alternative energy in the structure of the country's energy complex and aim at developing alternative energy. Among them are:

- The Law of Ukraine "On Alternative Energy Sources" No. 555-IV concerning the legal, economic, ecological and organizational basis for using alternative energy sources, and assisting expansion of their use in fuel and energy complex;
- The Law of Ukraine "On Alternative Fuels" No. 1391-XIV concerning the legal, social, economic, environmental, and organizational basis for production (extraction) and use of alternative fuels;
- The Law of Ukraine "On Energy Saving" No. 74/94-BP concerning the legal, economic, social and ecological basis for energy saving in enterprises, associations, and organizations located on the territory of Ukraine, as well as for its citizens;
- The Law of Ukraine "On Heat Supply" No. 2633-IV concerning stimulation of heat energy production from alternative energy sources;
- The Law of Ukraine "On Regulation of Urban Development" No. 3038-VI concerning improving the investment opportunities in electricity production from alternative sources.

The key aspect in assessing RES potential capacities is choosing the optimum power systems location. An important role is played by open statistical and spatial data obtained from geological, geophysical, meteorological, and aerospace monitoring, as well as by tools of open-source and commercial geoinformation systems and technologies (GIS-technologies) as a means to support making decisions based on a set of multilevel and heterogeneous data. The use of GIS-technologies will link together industry information resources on various Ukrainian administrative bodies and will contribute to successful implementation of the Energy Strategy of Ukraine until 2035, approved by the Cabinet of Ministers of Ukraine (No. 605-r of August 18, 2017).

Objective

The objective is to present the main approaches to geoinformation technology creation for estimating the potential of renewable energy sources in Ukraine.

Problem Statement

In 2018, Ukraine became a full member of the International Renewable Energy Agency – IRENA. According to IRENA (www.irena.org), the share of renewable energy sources in the total final energy consumption of Ukraine will rise from 3% in 2009 to 13.2%-21.8% in 2030, that would result in savings of USD 175 million per year in 2030 [1].

The annual renewable power generation is conditioned by a combination of factors including RES power plant geographic location (height above sea level, terrain slope, distance to the nearest settlements, land type, etc.), technical capabilities of electrical equipment, and economic potential defined as a total amount of solar and geothermal energy, wind energy, energy of biomass, small rivers, tides, and sea waves, etc. [2-6]. According to the State Agency on Energy Efficiency and Energy Saving of Ukraine (SAEE), Ukraine has a significant technically achievable potential for energy production from RES and alternative fuels, which is more than 98.0 million tons per year (Fig. 1).

№	RES	Annual technically achievable energy potential, million tons per year
1.	Wind power	28
2.	Solar power, including:	6
2.1.	- *electric*	2
2.2.	- *heat*	4
3.	Small hydropower	3
4.	Bioenergy, including:	31
4.1.	- *electric*	10.3
4.2.	- *heat*	20.7
5.	Geothermal heat energy	12
6.	Energy of the environment	18
Total potential of traditional sorces replacement		**98**

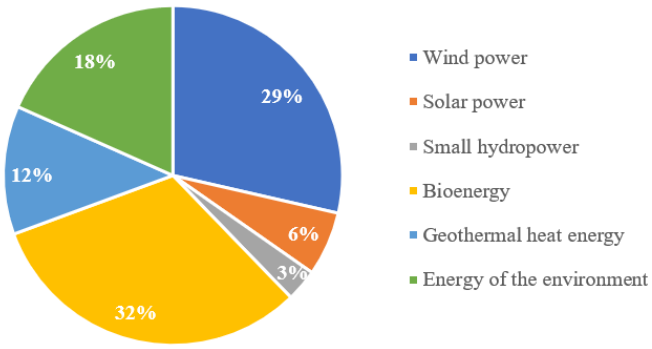

Figure 1 – Potential of renewable energy in Ukraine (saee.gov.ua)

Recent years have seen a rapid development of renewable energy in the world with an annual growth of tens of percent. The total global renewable electricity capacity in the world at the end of 2019 is more than 2.6 TW. The US and China occupy the leading positions with 1.1 TW of installed capacity, India holds third place with 137 GW of installed capacity [5]. By the beginning of 2020, the capacity of renewable energy power systems (not including hydropower) exceeded 1.4 TW. Since 2015, as many renewable power plants have been put into operation as traditional ones. During the recent 15 years, traditional power generation has developed at a rate of 2.0% per year, renewable energy generation has grown by 10-40% annually, while solar energy – by 50% per year. Investments in renewable energy sources abroad are continuously increasing (Fig. 2, Fig. 3) [1].

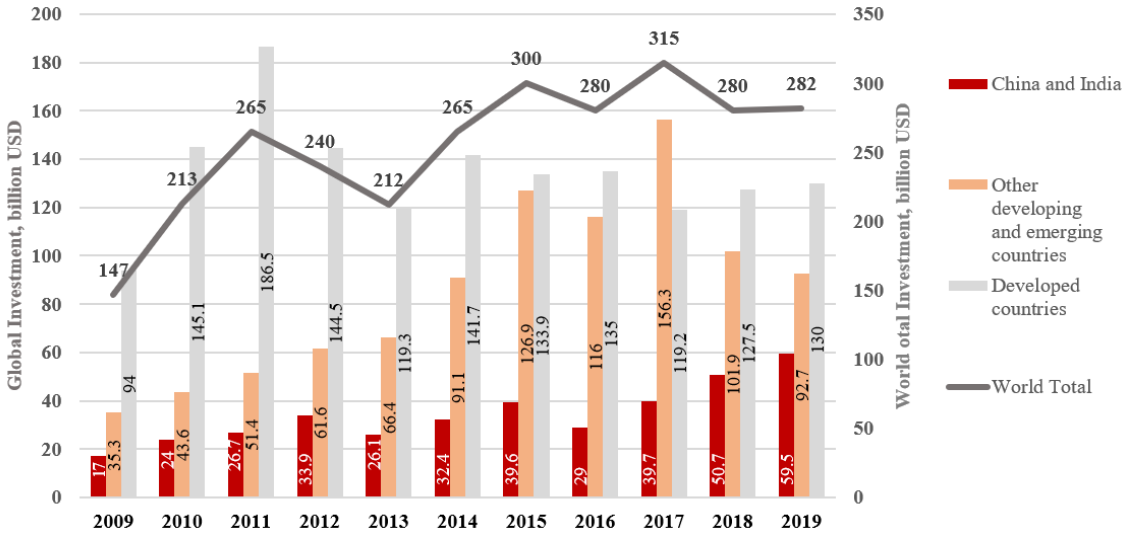

Figure 2 – Global investment in renewable power, billion USD [5]

Nowadays, annual investments in renewable energy sources reach $ 282 billion. Solar energy is especially actively invested – more than $ 131 billion per year, and wind energy – about $ 138 billion [1, 5, 7].

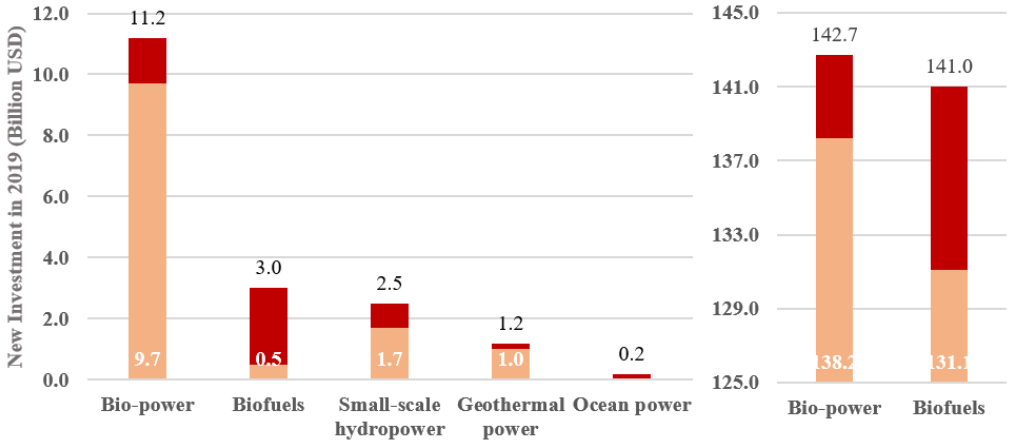

Figure 3 – Global Investment in Renewable Energy by Technology, 2019 [5]

Europe has the most ambitious plans to ensure up to 40%-contribution of RES to the total energy balance by 2040. At the same time, according to experts from the International Renewable Energy Agency, the share of renewable energy in the energy balance of Ukraine should be 13.2-21.8% by 2030 [1].

One of the reasons for accelerating the development of RES is the fact that many technologies of renewable energy generation have sharply fallen in price. At the moment, the development of photovoltaic solar energy converters has led to a reduction of the solar energy cost almost by a factor of 100 in comparison with 1980, and of wind energy cost – by a factor of 10-15.

Ukraine belongs to UNECE (United Nations Economic Commission for Europe) energy region covering 17 countries in South East and Eastern Europe, the Caucasus, and Central Asia [7]. Nowadays Ukraine has large RES potential in this region and is working on attracting foreign investments. According to SAEE, in 2019 about 3.7 billion euros invested in 4500 MW of renewable electricity in Ukraine.

According to UNECE, by the end of 2016, significant (97 MW) non-hydro renewable energy facilities were put into operation in Ukraine including solar power plants with a capacity of 62 MW. During 2018, installed solar power capacity increased by 646 MW [8]. Sizable wind power potential is presented in the UNECE region, with the largest resources in Kazakhstan and Ukraine.

Ukraine sees a rapid increase in the capacity of solar power plants (SPP) (Fig. 4).

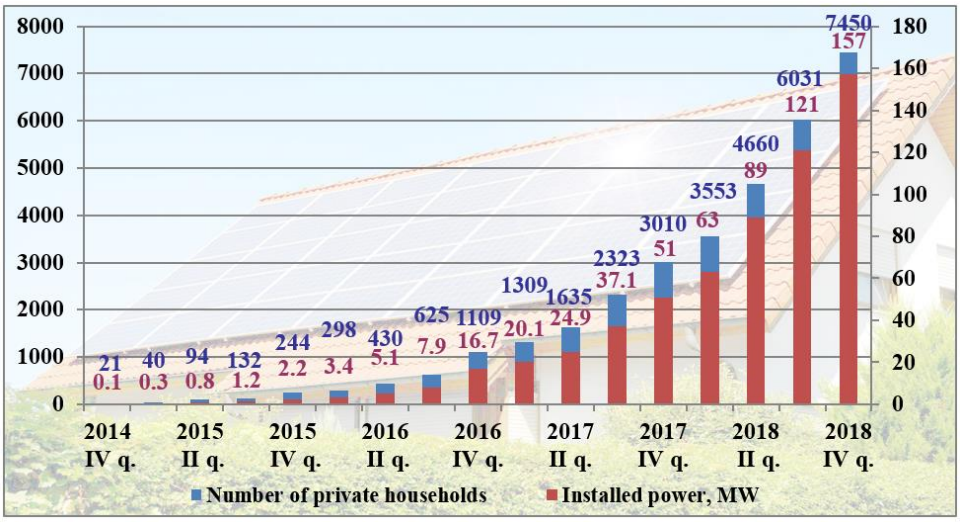

Figure 4 – SES of private households [8]

Several SPPs have been installed and put into operation, the largest of them being the Nikopol Solar Park (Dnipropetrovsk Oblast, capacity – 246 MW), Pokrovske Solar Park (Dnipropetrovsk Oblast, capacity – 240

MW), etc. (Fig. 5). The energy potential of deep heat resources in Ukraine is 20 times higher than the total energy potential of non-renewable fossil fuels such as oil, gas, coal, peat, timber, etc.

Nikopol Solar Park (DTEK), Dnipropetrovsk Oblast
Capacity – 246 MW
Consists of 750 000 operational units

Pokrovske Solar Park (DTEK), Dnipropetrovsk Oblast
Capacity – 240 MW
Consists of 874 000 operational units

Figure 5 – Solar power stations in Ukraine

According to IRENA, in 2030, the share of biomass energy in the Ukrainian RES structure will be 76% (820 PJ/year), sun and wind energy – 7% and 10% respectively. The share of hydropower energy will decrease to 4% by 2030 as compared to 32% in 2009 due to a significant increase in all other RES [1]. The heating sector will consume 73% of renewable energy, the transport sector – 7%, which significantly exceeds the figures from the SAEE forecast [1].

As stated in the *Energy Strategy of Ukraine for the period up to 2035*, by 2025, it is planned to start the Smart Grids implementation plan and create an extensive infrastructure for the development of electric transport. By 2035, RES will be developing dynamically, which will allow to increase their share in the total energy consumption up to 25% [2].

Components of Geoinformation Technology

Nowadays, foreign countries have accumulated successful experience of GIS-technologies use in renewable power generation [9].

The well-known foreign GIS in RES are:

1) Renewable Resources Map and Data, created in the US National RES Laboratory (www.nrel.gov), which is a geoinformation system at the national level. The Internet-version contains dynamic maps, databases, and tools allowing to analyze renewable energy sources in order to determine the most viable technologies for US conditions. The metadata files contain descriptions of data acquisition methods and calculations.

2) The Global Atlas for Renewable Energy created by IRENA (irena.org/globalatlas) provides open access to the datasets and their visualisations on wind and solar resources, as well as tools to find maps of renewable energy resources for locations across the world.

3) Atlas on Renewable Energy of Vermont (www.vtenergydashboard.org/energy-atlas) – regional GIS, developed based on ESRI ArcGIS. It includes detailed information on existing RE facilities in Vermont state (USA), as well as potential areas for building such objects. Data on the following sources are available: solar, wind, hydrothermal, small water streams, biological wastes. The information is displayed in every detail – at the level of individual buildings.

International database (DB) covering territories of various scales (NASA SSE, WRDC, SOLARGIS, METEONORM, etc.) that were developed in the last two decades can be considered as products similar to GIS. Ground-based measurement data, aerospace monitoring, and modeling results (models of general atmospheric circulation and distribution of solar radiation) serve as information basis for them. Several databases include maps of terrain and landscape types [9].

At present, the information WEB resource – UA MAP (www.uamap.org.ua) operates in Ukraine. It accumulates information on renewable energy projects and ensures communication between the initiators of such projects and investors in order to facilitate the attraction of investments in these areas. The UA MAP project was initiated by All-Ukrainian Investment and Sustainable Development Agency, with the support of SAEE, as well as the Danish Energy Agency and the Ukrainian-Danish Energy Center. This resource allows building maps of the existing RES projects' location but does not contain tools for assessing the potential of territories in terms of the possible placement of RES power plants [2].

Another Ukrainian WEB-map of renewable energy projects in Ukrainian Association of renewable energy (uare.com.ua).

Creating geoinformation technology for identifying, analyzing, and mapping prospective renewable energy sites is aimed at solving the problems of assessing the possibilities of RES effective use and can become a serious step in the development of this sector [8-11].

The main components of this technology are (Fig. 6):

1. Collecting and analyzing a complex of terrestrial and aerospace data, forming models for their representation in multidimensional post-relational databases. They should include, in particular, information of the following types: cartographic, thematic with spatial coordinates, attributive text documents, various graphics, reference materials, simulation results, computational and theoretical studies. Particular attention should be paid to the following types of energy sources: wind, solar, biomass, small water streams, hydrothermal, etc. Integrating a complex of spatial terrestrial and aerospace materials by forming the information basis of GIS in the form of thematic databases and knowledge bases [12].
2. Analyzing heterogeneous RES data on different levels. Developing criteria for the selection of sites for RES power plant installation. Identifying areas promising from the point of diverse RES presence taking into account data on existing RES plants and energy systems in a region.
3. Decision-making support based on spatial geological and meteorological data to select the right site for RES plant construction. Creating 2D and 3D maps of resource potential [13-15].
4. Developing software tools for GIS technology, equipped with modern scientific and technical tools of Big Data processing and Data Mining, considering the WEB-based approach. Conducting experimental studies and issuing recommendations on power equipment placement.

GIS technology will provide an opportunity for rapid processing of big heterogeneous data on natural resources and energy balance of the territory, which determines the demand in RES and their contribution to the energy complex. It will also provide data about energy infrastructure objects suitable for integrated use within RES facilities. GIS-technology uses tools of data mining and geoinformation data analysis. They will be used for solving tasks of perspective territories target searching and mapping by means of valid estimates and calculations.

To ensure the possibility of realizing RES geoinformation system in Ukraine, special attention should be given on the one hand, to studying the state of existing geoinformation products in the countries leading in this area, to identifying their basic features, advantages, and disadvantages, and to create on this basis a structure of GIS. On the other hand, the focus should be on mapping the known RES in Ukraine, on analyzing their structure, geographic location, utilization efficiency, economic feasibility, etc. [9].

The second component of research is concerned with the development of software and hardware architecture at all data processing stages, and in particular – the structure and composition of the database.

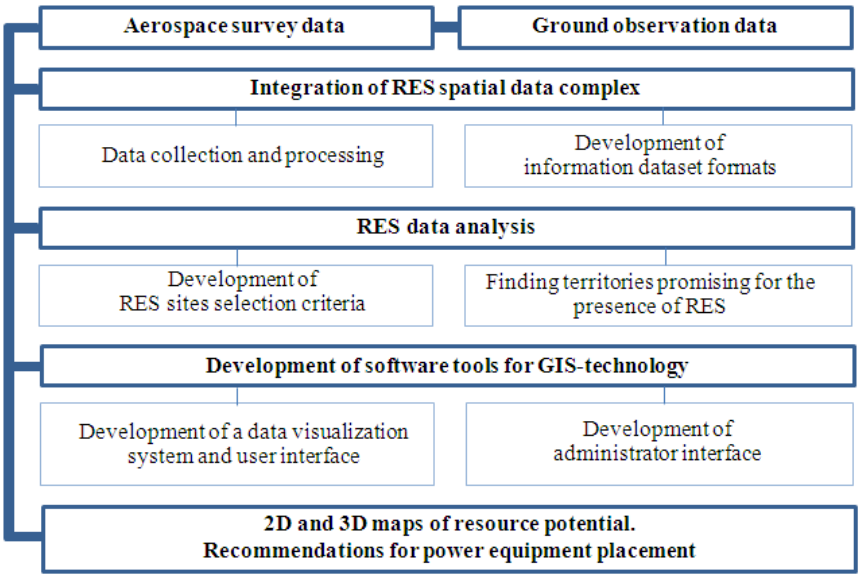

Figure 6 – The main components of the project for RES GIS-technology creation in Ukraine

The third component of the work includes the development and implementation of geoinformation analysis methods for a complex of spatial and attributive data based on the WEB-oriented approach. WEB-component will provide easy access to the project data for their prompt update and analysis [9, 13]. The creation of the WEB-interface will provide decision makers with an opportunity to gain access to databases information content. Besides reports and analytic materials, the results of spatial and attributive data analysis, as well as the maps of

RES spatial distribution will be presented on the WEB-portal with the ability to update them in real-time mode. The cartographic component of the WEB-portal will contain tools of queries and sample creation, comparative analysis, etc. All results will be downloaded by a user from the portal for their further analysis and decision-making.

The fourth component consists of conducting work on the country regions zoning with the purpose to identify areas prospective for the presence of renewable energy sources and suitable for their use in renewable power generation.

Software Tools of RES GIS-Technology

RES GIS software tools comprise two main components: tools for data collecting, storing, processing, and manipulating; and tools for geoinformation analysis and visualizing a set of spatial and attributive data taking into account the WEB-based approach (Fig. 7).

The software implementation of integrated RES data processing can be based on the use of specialized GIS tools such as ESRI ArcGIS, Quantum GIS (QGIS), ERDAS Imagine, ENVI, GIS GRASS, GIS SAGA, etc. The standard GIS toolkit can be supplemented and extended using a software implementation of analysis and modeling methods, for example, using the ERDAS IMAGINE Modeller tool, the Python scripting language in ESRI ArcGIS and QGIS, the GDAL, OGR, Numpy, SciPy, and Matplotlib library tools, etc.

WEB-interface for visualizing maps of perspective territories can be realized on the basis of existing cartographic services, in particular, a WEB-server based on GeoServer, Google Maps JavaScript API. GeoServer uses a Java Virtual Machine and allows publishing results of aerospace survey processing (thematic maps, synthesized image), presented in a raster (e.g., GeoTIFF) and vector (e.g., ESRI Shapefile) formats using different coordinate systems. GeoServer allows connecting to the ESRI ArcGIS ArcMap 10 and specifies the data presentation styles. Google Maps API technology based on HTML and JavaScript will allow visualizing thematic information on the available Google map data, such as vector maps and colorful synthesized images.

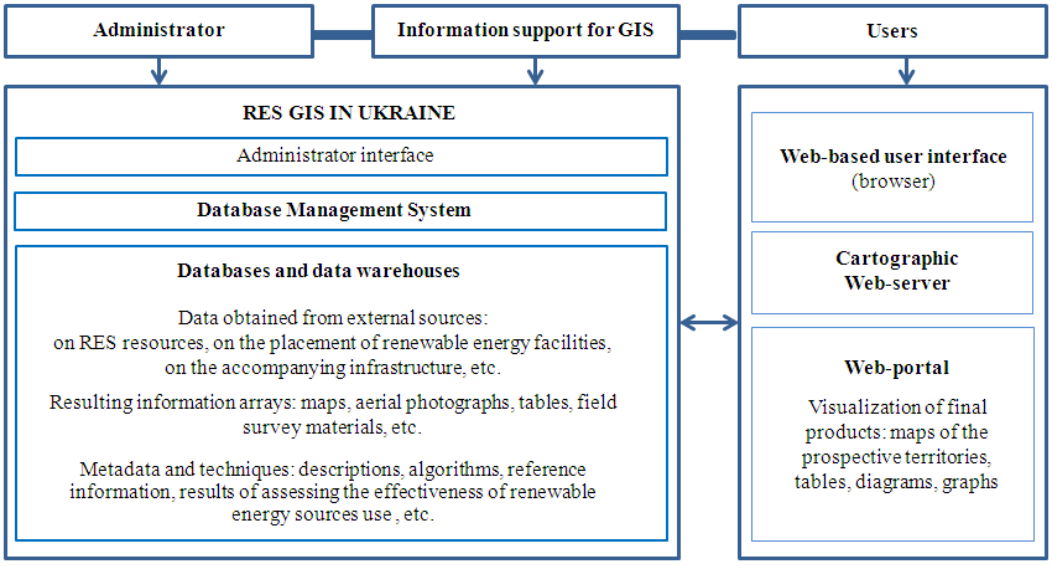

Figure 7 – The basic software components of the project focused on RES GIS-technology creation in Ukraine

The developed geoinformation technology and components of the geoinformation system are realized as part of the specialized RAPID (Recognition, Automated Prediction, Interpretation of Data) GIS, which is a powerful tool for the integrated analysis of spatial data based on Data Mining mathematical apparatus [16].

Conclusions

One of the ways to develop the energy sector of Ukraine is to assess the possibility and effectiveness of renewable energy sources use for regions' energy supply based on datasets covering both natural resources of the territory and its economic characteristics. In this connection, the task of creating specialized technological and software tools for processing, transforming, and analyzing data to estimate RES potential is urgent. The main approaches to geoinformation technology development for estimating RES potential based on the use of a complex of different-level and heterogeneous spatial data from ground-based observations and aerospace surveys aimed at creating 2D and 3D resource potential maps are presented. This will link together the industry information resources for different administrative units of Ukraine.

The creation and implementation of appropriate specialized geoinformation technology and GIS tools will help to expand the network of RES power plants and increase the efficiency of Ukraine's energy supply.

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ОСНОВНІ ПІДХОДИ ДО СТВОРЕННЯ ГЕОІНФОРМАЦІЙНОЇ СИСТЕМИ ВІДНОВЛЮВАНИХ ДЖЕРЕЛ ЕНЕРГІЇ В УКРАЇНІ

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ОСНОВНЫЕ ПОДХОДЫ К СОЗДАНИЮ ГЕОИНФОРМАЦИОННОЙ СИСТЕМЫ ВОЗОБНОВЛЯЕМЫХ ИСТОЧНИКОВ ЭНЕРГИИ В УКРАИНЕ

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