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The use of GIS in renewable energy specialist's learning

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Abstract. In recent years, the global trend has been to gradually shift from traditional energy sources to renewable ones, with the aim of improving the environment and preventing climate change. Geographic Information Systems (GIS) are technologies that enhance the efficiency of these renewable energy resources (RER). Modern GIS provides a wide range of functionalities for the entire decision-making process. For instance, in solar power generation, GIS can address challenges such as remote monitoring of sites designated for solar power plants and evaluating their suitability. It also enables effective management of information on station operations, real-time electricity production and distribution, and planning and management of energy production resources. As GIS continues to evolve, scientists and energy professionals are discovering more applications in the RER field. However, it's crucial to focus on training highly skilled specialists in RER to ensure GIS becomes a truly effective management tool in their professional activities. Research indicates that most student training programs in RER worldwide do not sufficiently cover GIS studies, particularly open-source software. To address this gap, the authors have developed a targeted plan for incorporating GIS into RER specialist training. The goal of this course is to familiarize future engineers with the theoretical, methodological, and technological foundations of GIS creation and operation. It also aims to help students understand the general principles of operation and acquire practical skills in using GIS to solve applied problems. The authors emphasize the importance of laboratory work, particularly using SagaGIS, to develop skills in working with raster and vector images, geospatial data analysis and decision-making, working with cartographic models and remote sensing data, and applying geoinformation methods to create structural, parametric, and thematic digital maps. The authors suggest using open GIS in training to facilitate a quality understanding for future RER specialists on the processes of creating, operating, and using GIS for real-world applications.

1. Introduction

The need for vast energy resources is crucial for human survival and development, making energy security a significant global challenge in the 21st century [1, 2]. The recent armed aggression of the Russian Federation against Ukraine has underscored the urgency of this issue, prompting many countries to focus on renewable energy resources (RER) due to rising energy prices and the need to find new suppliers and logistics channels.

Renewable energy resources refer to energy sources that naturally replenish themselves, such as solar radiation, wind, plant biomass, water flows, and geothermal sources. Utilizing RER can improve environmental conditions by reducing harmful emissions, increase a country's energy independence and security, and decrease reliance on traditional energy resources like coal, gas, oil, and refined products. However, it's worth noting that until recently, Ukraine's use of RER has been relatively low due to factors such as low and uneven energy flow density, seasonal dependence, significant investment capital intensity for such projects, and a lack of qualified experts in the field.

Enhancing education quality is a critical aspect of human development, including in Ukraine. As the modern world rapidly evolves with advancing information technologies, the domestic higher education system struggles to adapt its curricula and plans to meet market and societal demands. This issue is particularly relevant in training specialists in Electrical Power Engineering, Electrical Engineering, and Electromechanics (field of knowledge 14 "Electrical Engineering").

The educational and professional training program for students majoring in 141 "Electricity, Electrical Engineering, and Electromechanics" is designed to primarily train competitive professionals. These professionals are expected to have developed professional competencies in the field of RER and be capable of designing, creating, and operating power plants using renewable energy sources.

Currently, in Ukraine, such specialists are trained in eight higher educational institutions (figure 1). These include:

1. Chernivtsi National University named after Yuri Fedkovych
2. Kherson National Technical University
3. National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"
4. National Aerospace University M.E. Zhukovsky "Kharkiv Aviation Institute"
5. O.M.Beketov National University of Urban Economy in Kharkiv
6. National Technical University "Dnipro Polytechnic"
7. National University "Odesa Polytechnic"
8. Ivano-Frankivsk National Technical University of Oil and Gas

Education is provided according to the educational programs of the first (bachelor's), second (master's), and third (educational-scientific) levels of higher education.

According to the qualification requirements for specialists in specialty 141 "Power Engineering, Electrical Engineering, and Electromechanics", they are expected to possess knowledge and skills in various disciplines. These include mathematical and natural science cycles, electrical engineering and electrical technology, as well as computer technology. They

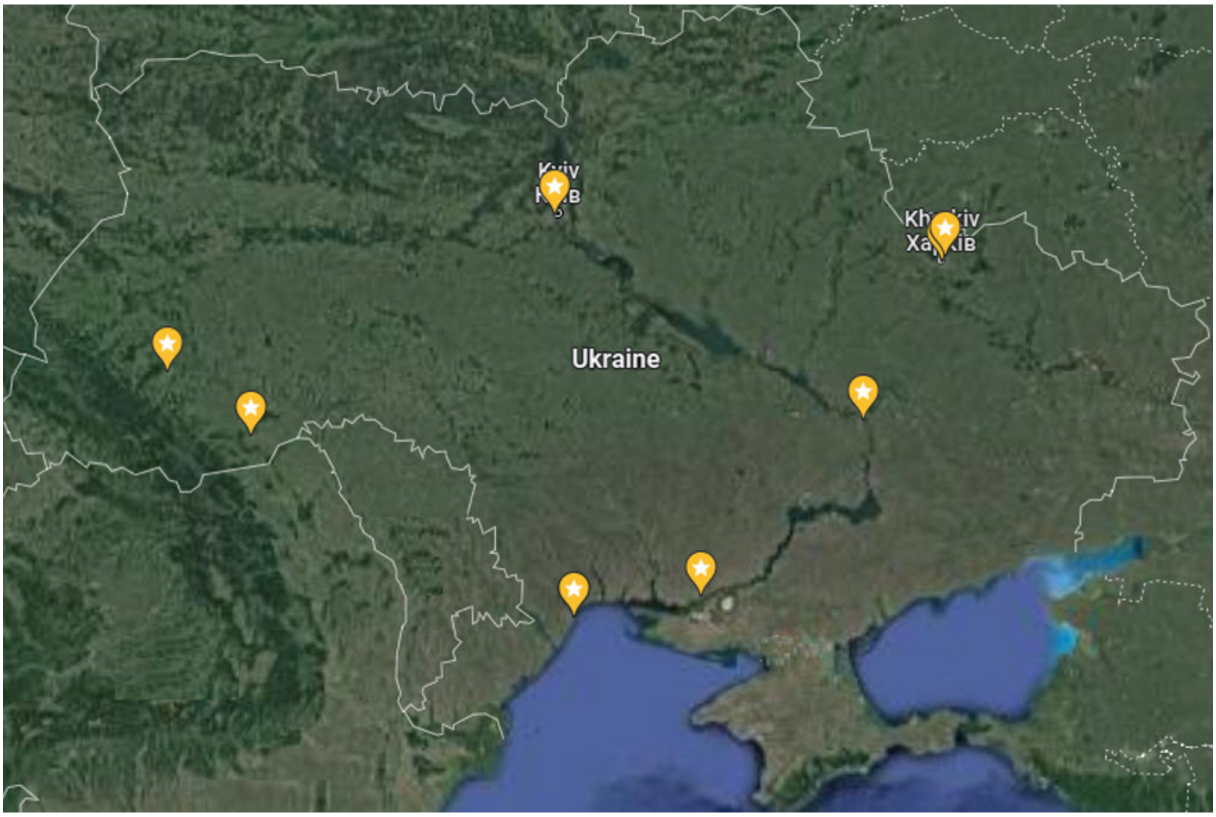

Figure 1. Territorial location of Ukrainian higher education institutions that train specialists in RER.

should also be proficient in computer and information technology for modeling and designing modern electrical equipment [3].

An examination of the curricula and educational and professional programs for specialty 141 "Electric Power, Electrical Engineering and Electromechanics" [4–11] reveals that the training program for future specialists in RER at the aforementioned higher education institutions includes disciplines in information technology. These include "Information and Communication Technologies in Electrical Engineering", "Automated Control Systems for Technological Processes in Electrical Networks", "Intelligent Systems in Energy", "Automation of Renewable Energy Plants", and "Electromechanical Technical Systems". These disciplines aim to develop the professional competencies of future professionals by teaching them to use modern IT and software to address various challenges in their professional activities.

One potential area of application for the knowledge of future specialists in the field of RER is socio-environmental. This field addresses issues related to efficient use of natural resources, environmental protection, government transparency, land management, and more. Most of these issues rely on the development, implementation, and use of geographic information systems and technologies.

The functionality of GIS includes [12]:

- Data input: This involves importing from existing digital datasets or digitizing sources.
- Data conversion: This includes converting data from one format to another, transforming map projections, changing coordinate systems, storing, manipulating, and managing data in internal and external databases, performing map metric operations, geodetic data processing operations, overlay operations, and cartographic algebra operations.

- Spatial analysis: This function provides analysis of the location, relationships, or other spatial relationships of objects. It includes visibility/invisibility zone analysis, proximity analysis, network analysis, creation and processing of digital terrain models, and analysis of objects within buffer zones.
- Spatial modeling (geomodeling): These operations are similar to those used in mathematical cartographic modeling and cartographic research methods. It also includes visualization of input, derivative or final data (cartographic visualization, design, and creation of cartographic images).
- Data output: This involves graphic, tabular, and textual documentation including its reproduction, documentation, and report generation.
- Support for decision-making processes.

Modern Geographic Information Systems (GIS) are more than just systems for automated processing of geospatial data, vectorization, and real-time visualization of objects and events. They also offer a robust set of geospatial analysis tools and strategic support for management decisions. Given these capabilities, it's surprising that there's a lack of discipline in the curricula and educational and professional programs of higher education institutions in Ukraine that would highlight the methods and ways of using GIS by RER specialists [13, 14].

Back in 2016, in the dissertation of Agapova [15], it has been observed that one of the shortcomings in the training of mapping specialists is their limited proficiency in modern cartographic GIS services. This includes web GIS, information and reference cartographic internet services, among others. It's crucial to address this gap to ensure that these specialists are equipped with the necessary skills to effectively utilize these advanced tools in their professional field. Similar opinions are found in other publications [16, 17]. And, as practice shows, as of mid-2022, this problem in Ukraine still exists.

At the national level, the use of GIS is regulated by a number of regulations, including the concept of the National Automated System "Open Environment" [18], the Concept of Digital Competencies [19], and the Law of Ukraine "On National Geospatial Data Infrastructure" [20].

As Ukraine is in the process of automating various aspects of social and environmental spheres of activity, it is important to pay attention to the need for high-quality training of highly qualified specialists not only in geodesy, land use, and management but also in RER. These circumstances require higher education institutions to strengthen the geographic information vector of their students. Among other things, modern GIS and software should be used in educational practice to best meet the educational goals and professional competencies of future RER specialists.

2. Materials and methods

The field of geoinformatics in Ukraine is relatively young, and consequently, there is a scarcity of robust methodological support for educators in this discipline [12, 21, 22]. The majority of existing scientific and methodological developments in this area primarily focus on the design and application of Geographic Information Systems (GIS) to solve practical scientific and real-world problems [17, 23–32].

For instance, Volkov [23] highlights that environmental management presents a classic spatial problem where source information comprises both spatial and attributive data, collectively providing insights into environmental quality.

Zatserkovny [24] systematically organizes the fundamental aspects of geographic information technologies and systems, emphasizing the creation and preservation of electronic maps through these technologies. The presentation delves into the models and algorithms that underpin spatial analysis in GIS and explores software tools for data integration and technology implementation.

Mokin et al. [25] describe the integration of mathematical models into surface water monitoring practices using GIS. They detail a range of methods, techniques, algorithms, and software tools applied to critical applications in flood water monitoring and the modeling of ecological processes in aquatic ecosystems within Ukraine.

In a different context, Iatsyshyn et al [33] discuss the implementation of a specific course titled "Methods and Means of Environmental Monitoring of the Surface Layer of the Atmosphere" to train future professionals in ecology and environmental protection using specialized software and modeling systems. This experience offers valuable insights that can be considered when developing the curriculum for the course "GIS for RER's specialist".

It is worth noting that, when exploring the use of GIS in the context of Renewable Energy Resources (RER), international experiences can provide valuable insights. For instance, Marcu [34] investigates the use of a GIS system model based on ArcGIS tools to assess the potential of RER, especially in the establishment of new power plants utilizing solar and geothermal energy sources.

Additionally, Jeong and González-Gómez [35] explore the incorporation of a web application into the STEM education system. This application aids in assessing the suitability of biomass plant locations, allowing students to evaluate multiple alternatives and make informed decisions regarding biomass settings at various operational levels. The authors emphasize the importance of employing such tools to realize the "lifelong learning" strategy.

Furthermore, the combination of Earth remote sensing (ERS) with modern GIS techniques for studying RER capabilities is highlighted in [36]. The authors investigate the optimal locations for renewable energy sources across the globe, emphasizing the simplification and streamlining of RER research processes through remote sensing methods and GIS.

To provide organizational and methodological support for the pedagogical process, textbooks, manuals, laboratory workshops, and other educational materials have been developed (e.g., Pavlenko [37], Svitlychnyi and Plotnytskyi [38], Shipulin and Kucherenko [39]). These resources offer valuable information on GIS concepts, structures, types, and construction specifics, along with practical recommendations and case studies for a range of applied tasks. However, they require adaptation to suit the training programs within the RER field.

The growing number of studies in this area underscores the increasing importance and relevance of GIS in contemporary society. Nevertheless, many of these advancements are primarily targeted at experienced professionals in environmental management and may not readily translate into educational contexts for specialty 141 "Electric Power, Electrical Engineering, and Electromechanics". This analysis reveals a gap in the use of GIS as a means to develop professional competencies in RER specialists.

In light of these findings, it is essential to address the disparity between national higher education standards for RER specialists and the current practices used to cultivate professional competencies in future professionals. One potential solution is the development and integration of a GIS course into the curriculum for specialty 141 "Electric Power, Electrical Engineering, and Electromechanics".

The research methods employed in this work encompass analysis, systematization, the examination of practical experiences, comparative analysis, and the selection of specialized software, utilizing export valuations methodology. SAGA GIS and Google Earth served as the tools for processing geospatial data and fostering the professional competencies of RER specialists.

3. Results

The cultivation of professional competencies among future specialists in Renewable Energy Resources (RER) entails a multifaceted approach that encompasses the adoption of environmentally sustainable practices to harness the georesource potential of the environment. This process necessitates a comprehensive integration of various natural sciences, including physics, chemistry, biology, ecology, construction, geology, geography, mathematics, mechanics, computer technology, information and communication technologies, as well as proficiency in information systems and artificial intelligence.

Upon scrutinizing the educational programs and curricula of higher educational institutions in Ukraine, particularly within the discipline of specialty 141 “Electric Power, Electrical Engineering, and Electromechanics” it becomes evident that the training of future RER specialists predominantly emphasizes the utilization of natural and technical sciences, while the fundamental sciences receive comparatively limited attention.

The imperative for future specialists in the RER field to acquire proficiency in Geographic Information Systems (GIS) is well-founded, driven by professional requirements, societal significance, and the growing demand within the field. This competency aligns with the imperative to foster a holistic understanding of renewable energy and its sustainable integration into our environment (figure 2).

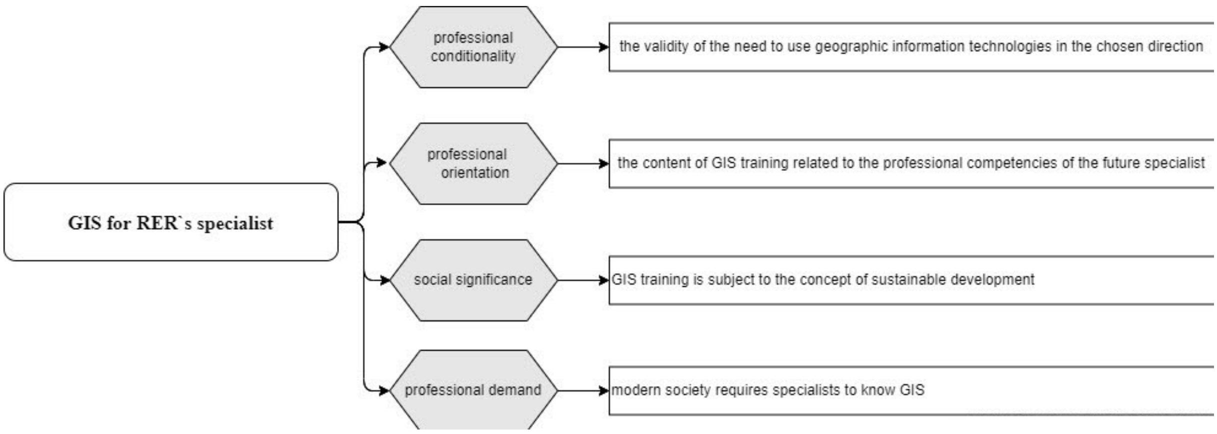

Figure 2. Justification of the need to study the discipline “GIS for RER’s specialist”.

The course titled “GIS for RER’s specialist” is dedicated to the exploration of fundamental principles related to contemporary computer systems for mapping and geospatial analysis of real-world objects and events. Its overarching objective is to advance the pursuit of energy balance through the utilization of alternative energy sources. GIS represent cutting-edge tools that facilitate decision-making across both time and space domains. Their functionality relies on current information processing methods and is simultaneously accessible to a broad audience thanks to visualization technologies.

The primary aim of this course is to familiarize future engineers with the theoretical, methodological, and technological underpinnings of geographic information systems. Students will acquire a comprehensive understanding of the general principles governing GIS operation while also honing practical skills for employing GIS to address practical challenges. These tasks encompass:

1) equipping applicants with the knowledge and skills essential for proficiently operating modern geographic information systems;
2) cultivating the practical competencies of future specialists, enabling them to effectively utilize standard geographic information systems to address real-world challenges, including:
   - use of mapping skills in the design and operation of alternative energy stations;
   - use of instruments of geospatial measurements on the earth’s surface, assessment of the suitability of land allocation for alternative energy stations;
   - vectorization and geometrization of areas allocated for renewable energy sources;

Table 1. Priority goals of implementation of the discipline "GIS for RER's specialist" in the educational process of training specialists in the field of RER (author's development).

Number of goal group	The name of the goal group	Detailing goals in the group
I	Cognitive goals	• understanding of the complexity of the issue of energy production from alternative sources; • the ability to perceive and identify cause-and-effect relationships and to understand the key importance of the need to maintain energy balance through the use of alternative energy sources; • formation of the ability to understand analogies and model descriptions of problems; • formation of the ability to abstract thinking, analysis and synthesis; • development of critical thinking skills.
II	Valuable goals	• acquisition of skills of caring and responsible attitude to things, phenomena, robots, environment; • use of GIS in the context of sustainable development.
III	Operational goals	• developing the ability to solve specialized problems and solve practical problems during professional activities in the field of RER; • acquisition of skills to work individually and in a team with tasks of different nature; • learn to actively use modern information technologies in the educational process and further professional activity.

- analysis of climatic conditions and their impact on the geo resource potential of the environment;
- remote monitoring of sites and operation of the alternative energy station;
- management of information on electricity generation and distribution in real-time;
- planning and management of energy production resources.

The inclusion of the course "GIS for RER's specialist" within the educational curriculum for training professionals in the RER field serves three overarching sets of objectives, as outlined in the table 1.

The course "GIS for RER's specialist" is typically offered during the 5th to 7th semesters of the first (bachelor's) level of higher education. Given the paramount significance of this discipline, it is recommended for inclusion among the normative courses with a professional orientation.

The lecture component of the course is structured to provide applicants with theoretical foundations related to GIS development and utilization. It encompasses the exploration of key types of GIS, their architectural aspects, and hardware and software requirements. A summary of lecture topics offered for future RER specialists is presented in table 2.

The primary objective of laboratory and practical sessions within the course is to facilitate the mastery of methodologies and contemporary technologies employed for data processing and conversion into GIS. These sessions serve as platforms where students can reinforce, broaden, and deepen their knowledge acquired during lectures and through independent study of relevant literature. During these hands-on classes, applicants develop practical proficiency in GIS utilization.

The laboratory component of the “GIS for RER’s specialist” course relies on the utilization of an open-source system, specifically SAGA GIS. The rationale for selecting this system is expounded below.

Upon analyzing university curricula in the domain of “Geoinformation Systems” across various specializations, it becomes evident that the majority of educational practices employ proprietary GIS software, predominantly from the ArcGIS product family [14]. These proprietary systems necessitate paid user licenses. The appropriateness of employing specific software within the educational framework hinges on the instructor’s proficiency and experience in teaching geographic information systems. There is a widespread belief that the Environmental Systems Research Institute’s ArcGIS software lineup is a global leader in GIS development and implementation. Consequently, utilizing these products in the educational process is deemed to bestow students with a competitive edge in the job market. It is noteworthy that, according to the analytical platform G2 Crowd, the top three most commonly used GIS systems globally are: 1) Esri ArcGIS; 2) Google Earth Pro; 3) BatchGeo [40].

Conversely, while ArcGIS products serve as valuable corporate GIS solutions, their license costs render them inaccessible to small and medium-sized businesses, government budgets, and other organizations within our country. Consequently, we believe there is a substantial risk that students equipped solely with ArcGIS skills (given its convenience, thoughtful design, and round-the-clock support) may encounter difficulties working within other software environments. In their developmental stages, they might instinctively attempt to emulate the principles of the familiar system.

In our view, it is advisable to cultivate students’ proficiency with both proprietary and open-source GIS. This approach will substantially enrich students’ practical experience and enable them to grasp the mechanisms of geospatial data transformation, regardless of the specific GIS type employed.

Open-source software refers to software whose source code can be accessed and modified by users. Key attributes of open-source software include free distribution, accessibility to the source code, and permission to modify or alter the source code. The primary driving force behind the growth of the open GIS sector globally is the inherent limitations of proprietary GIS systems. These limitations extend to the inability to cater to all market demands, especially within the realm of small or non-profit organizations, such as research laboratories, educational institutions, and government agencies, that lack the financial resources to procure the requisite number of licenses. This situation is particularly relevant in Ukraine, where there is a clear recognition of the importance and necessity of GIS across various domains. Nevertheless, the tangible resources for implementing GIS are often insufficient. Consequently, relying solely on the study of ArcGIS or MapInfo, even at an advanced user level, is not deemed essential in preparing future computer science specialists for the job market. Hence, we emphasize the necessity of integrating open GIS into the educational process.

Broadly, open GIS can be categorized into three classes: desktop (installed on a computer), web-based (accessible through a web browser), and spatial databases (containing geospatial data). For the purposes of this discussion, we will focus on open desktop GIS. The global landscape boasts a vast array of over 350 open desktop GIS solutions. Among the most prevalent worldwide are QGIS, GRASS GIS, Whitebox geospatial analysis tools (Whitebox GAT), SAGA GIS, gvSIG, ILWIS, uDIG, and MapWindow GIS (as per GISGeography’s 2022 report [41]).

Table 2. Content of the lecture part of the discipline "GIS for RER's specialist".

Name of topics	Issues included in the topic
Topic 1. General information about geographic information systems	Subject, goals, and objectives of the course. Definition of GIS. Basic terms and concepts (concept of a map, spatial objects, scale, spatial coordinates, map scale, vector, and raster models). History of GIS development and current state. Areas of application of GIS.
Topic 2. Geographic information systems and technologies	A set of methods for using spatially distributed information. The role of satellite technologies in the development of GIS. Approaches to GIS classification. Characteristics of the main types of GIS. Advantages and disadvantages of working with GIS. Typical GIS structure. Basic functionality. Characteristics of the main subsystems. Hardware and peripherals. Information support of GIS work.
Topic 3. Data entry and processing in GIS	The role of data in GIS, their types, and forms of presentation. Data sources (space images, maps, aerial, photo, and orthographic images, attribute data, geodetic survey data). GIS data collection and processing technology. Spatial models and data structures. Raster and vector data models.
Topic 4. Coordinate systems	Topographic data binding. Geographical coordinates, positions of points on the Earth's surface. Attributive description. Cartographic projections. Types of projections and their classification. Their connection and transformation. Topographic basis of geological maps and their nomenclature.
Topic 5. Conversion of graphic information into digital in GIS	Methods of digitizing raster images. Scanning and creating raster data structures. Necessity and methods of conversion of vector and raster information. Layered presentation of information. Stages of creating a digital map model. Structure of digital topographic, parametric, and thematic maps.
Topic 6. Analysis of spatial data	Data aggregation, cartographic overlay (vector layer, points on polygons, lines on polygons, polygons on polygons, raster layer). Spatial interpolation (classification of methods). Surface analysis (calculation of topographic attributes, calculation of slope and exposure, visibility analysis). Network analysis (the task of finding the optimal path, route tracing, salesman task, model "identification – allocation").
Topic 7. Tools for visualization in GIS	Visualization of data with the help of surfaces. Relief visualization methods (2D, 3D, in conditions of blur, dynamic). Using the matrix format of electronic card data. Representation of surfaces in three-dimensional space.
Topic 8. Working with remote sensing data	Earth remote sensing (ERS) data collection and decryption technology. The main features of ERS data collection and decryption technology. ERS data decryption functionality in modern GIS.

Table 3. Comparative characteristics of the functionality of open desktop GIS [16].

Features	GIS							
	QGIS [42]	GRASS [43]	Whitebox GAT [44]	SAGA GIS [45]	gvSiG [46]	ILWIS [47]	uDIG [48]	MapWindow [49]
Year of development	2002	1982	2009	1990	2004	1980s (since 2007 – open license)	2004/2005	1998
Purpose and functionality	cartography (creation, design, modeling), support for raster, vector, geospatial analysis, plug-ins for automation of procedures	created, analysis of image and graphics design, geospatial analysis, data management support for raster, vector, satellite data	educational and research goals, geospatial analysis, vectorization and image processing tools, spatial filters, multicriteria project evaluation	teaching and research goals, geospatial analysis, cartography, support for raster, vector, satellite data	3-D visualization, geospatial analysis in real-time, cartography, support for raster, vector, satellite data	cartography, support for raster, vector, geospatial analysis, geospatial data management, 3-D visualization	creation of vector maps, their scaling, complex vector visualization, geospatial data management	cartography, geospatial analysis, support for raster, vector
Number of available tools	>500	>300	>400	>600	>200	>100	>100	>100
Supported operating system	Windows, Linux, Mac OS X, Android	Windows, Linux, Mac OS X	Windows, Linux, Mac OS X	Windows, Linux, Mac OS X	Windows, Linux, Mac OS X	Windows	Windows, Linux, Mac OS X	Windows
Programming language	C++	C	Python, JavaScript	C++, Python	Java	C++	Java	MS Visual C
Availability of translation of accompanying documentation	Ukrainian – partially	-	-	-	-	-	-	-

Table 3 provides a comprehensive overview of these systems' general characteristics.

Evidently, the functionality offered by these open GIS solutions is on par with their commercial counterparts. These open GIS systems undergo regular updates and continued development, as evidenced by an analysis of available installation versions and the frequency of updates. Architecturally, open GIS systems exhibit a multilevel modular structure, akin to proprietary counterparts. Most open GIS applications have modest hardware requirements and are compatible with a range of operating systems, except for ILWIS and MapWindow GIS, which are exclusively compatible with Windows.

A noteworthy aspect of the considered open desktop GIS applications, as indicated in table 3, is their diversity in programming languages. In their current iterations, they support scripting in a variety of languages familiar to students, including Python, R, Perl, C#, PHP, among others.

An examination of the user interface within open GIS reveals that while they may slightly trail behind ArcGIS and MapInfo in terms of convenience and user-friendliness (intuitiveness), they still offer accessible options. Practical experience demonstrates that SAGA GIS is particularly user-friendly and comprehensible for undergraduate students [16]. In contrast, mastering the tools and functionalities of GRASS GIS may pose a greater challenge due to the need for students to possess basic skills and an understanding of the principles underpinning this GIS, given its continuous procedure implementation and operational command utilization.

Following a comprehensive analysis and considering the objectives associated with cultivating professional competencies in the course "GIS for RER's specialist", the author's team has selected SAGA GIS as the primary toolkit for the course. Key rationale:

- SAGA GIS (abbreviation for System for Automated Geoscientific Analyzes) – specialized software designed for scientific geospatial analysis and modeling of open-source data [50];
- availability of the necessary functionality for training needs. The following types of data are supported: bitmaps, tables, and databases, ERS data, vector objects (points, lines, polygons, shapes, TIN classes, etc.), metadata;
- legal and free use of software for the needs of the educational process. Use under the GNU General Public License;
- technical and hardware requirements of GIS;
- completeness of the description of technical documentation.

Working with digital terrain models in the SAGA GIS environment is possible with the help of tool libraries. The system (according to the latest version of the official SAGA-GIS Tool Library Documentation v 8.5.1) has the following key class sets: Climate and Weather – a group of tools for processing and analyzing climate and weather data (includes 32 tools); Garden – a group of tools for working with fractals, exchanging data with web services, adding elements of gamification (10 tools); Grid – a group of tools for working with raster objects (118 tools); Imagery – a group of tools for clustering, classification and other processing of vector images (59 tools); Import / Export – a set of tools facilitating data import and export (117 tools); Projection – a group of tools for working with projections of objects and surfaces, transformation of coordinate systems, presentation of geospatial data in recognized formats (32 tools); Shapes – a group of tools for working with vector objects and data (122 tools); Simulation – a group of tools for modeling processes (40 tools); Spatial and Geostatistics – a group of tools for spatial analysis and geostatistics (50 tools); TIN – a group of tools for processing triangulation irregular network (8 tools); Terrian Analysis – a group of tools for terrain analysis (101 tools); Visualization – a group of data visualization tools (19 tools).

Each SAGA GIS tool is derived from a key set of a system class, and has a standard interface for the system, but specific functionality (data processing algorithm, input and output data, configuration parameters, etc.).

If necessary, SAGA GIS provides the ability to download third-party Load Tool Libraries from open data sources. The cycle of laboratory work of the discipline “GIS for RER’s specialist” includes:

Lesson №1. Comparison of proprietary and open geographic information systems (at the student’s free choice);

Lesson №2. Comparison of desktop, mobile, and web GIS functionality. Introduction to Google Earth software implementations;

Lesson №3. Mastering the skills of creating and editing your own vector map (for example, Google Earth Pro);

Lesson №4. Introduction to the functionality of open GIS (for example, SAGA GIS);

Lesson №5. Working with raster images in a GIS environment (for example, SAGA GIS);

Lesson №6. Working with vector images in the GIS environment (for example, SAGA GIS);

Lesson №7. Conversion of graphic information into digital in GIS (on the example of SAGA GIS);

Lesson №8. Geocoding and vectorization in GIS environment (on the example of SAGA GIS);

Lesson №9. Working with ERS (satellite imagery) data in a GIS environment (for example SAGA GIS).

For example, in the second laboratory work, future RER specialists will get acquainted with the capabilities and interface of the Google Earth product line. Educational tasks are:

1) finding by name, coordinates, and other attributes of alternative energy facilities (applicants are offered different options for work);
2) acquaintance with the available styles of displaying maps and objects on them (styles “Earth”, “Researcher”, “Everything”, “My Map”; modes: 2D, 3D, “street mode”; cloud animation). When working with the “My Card” style, students configure the card of the alternative energy object found in item 1;
3) determination of the distance from the object of alternative energy found in item 1 to settlements (other objects), measurement of spatial parameters of placement of the object of alternative energy (figure 3). Comparison of the obtained measurement results with real technical indicators, the establishment of the reasons for possible deviations;
4) calculation of the potential% of satisfaction of energy needs of the population of the nearest settlement by the object of alternative energy (indicators of real power applicants can find on the Internet);
5) perform tasks 1-3 in web, desktop, and mobile (optional) versions of Google Earth. Comparison of functionality, and conclusions.

In the SAGA GIS Raster Imaging Skills (Laboratory №5), students are asked to analyze climatic conditions and assess the geo resource potential of the environment to house alternative energy stations in the region (applicants are offered different jobs options). For example, for the task of obtaining electricity from the kinetic energy of raindrops (as a way to renew the energy of autonomous power sources of radio devices) in Ukraine, the student performs the following tasks:

1) Master the skills of cutting, combining, overlaying, and mathematical processing of data from raster images;
2) To assess the precipitation levels in Ukraine based on global monitoring reports for the year 2021 (figure 4);

Figure 3. Measurement of the area of SES "Starokozache" (Ukraine, Odesa region) using Google Earth.

3) Assess the possibility of using raindrops to generate electricity according to the data obtained;
4) Draw conclusions about the feasibility of the whole and the priority regions of the installation.

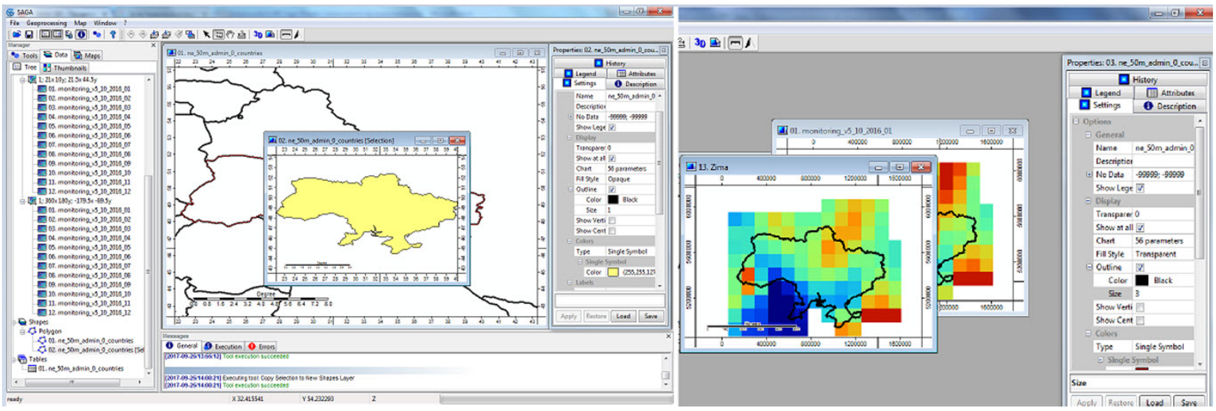

Figure 4. Determining the average level of precipitation in Ukraine in the 4th quarter of 2022 year (December, January, February).

During the tasks of this laboratory №5, students learn to work with a raster form of data representation (grid), in particular: cut and paste images, overlay one image on another, perform mathematical operations on grid data (eg, search for maximum or minimum values, etc.), change the pixel size and volume, etc.

All laboratory works are logically interconnected, as a result of their performance future specialists in the field of RER acquire skills in GIS, develop skills in working with raster and vector images, develop knowledge of analytical processing of geospatial data and decision making, gain experience in cartographic models and ERS data in terms of solving specific applications of renewable energy.

4. Discussion

Renewable and unconventional energy sources are crucial for the sustainable development of the global community. The shift towards cleaner and renewable forms of energy is driven by a wide range of objectives, including advancing economic development, improving energy security, enhancing energy access, and mitigating climate change. In recent years, there has been an active search for new improvements to existing technologies in this area, bringing them to a cost-effective level and expanding the scope of use. GIS has been found to have great potential for use in RER.

The use of GIS is gaining momentum in Ukraine, driven by several factors. Firstly, the reform of most branches of government aims to make their work more transparent and efficient. Secondly, the development of an appropriate legislative framework and a unified strategy for the development of the digital economy is underway. In Ukraine, the utilization of GIS predominantly exhibits the following defining traits:

- narrow coverage (there is a significant growth potential);
- tendencies to develop their own software products based on existing GIT;
- GIS is not universal in nature, but is aimed at solving specific problems;
- the use, for the most part, of information and reference and cartographic functions, insufficient use of the potential of the analytical capabilities of modern GIS;
- these systems are known for their cross-platform compatibility, reliance on web services and cloud technologies, as well as seamless integration with geospatial databases.

Among the constraining factors and the main problems of GIS development in Ukraine we can name:

- slowness in the organization and implementation of reforms;
- low level of informatization in the country as a whole;
- problems with the system of legal and regulatory support for the development of GIS. It should be noted that in Ukraine there are practically no standards in the field of GIS development, which forces developers to create their own ideology, architecture, and standards for geodata information models for each project. Thus, the level of technological solutions is directly dependent on the knowledge and experience of developers, which, of course, does not contribute to the effective implementation and high-quality use of GIS;
- economic and other problems in the country do not allow most enterprises to introduce modern GIT into their activities due to their cost and the long period of return on investment.

It is obvious that the intensive introduction of GIS into the work of modern subjects of the RER sphere at all levels of government (from the state to a separate enterprise) is one of those factors that can lead to a predictable increase in efficiency and effectiveness of their work. We believe that in the near future, GIS solutions that meet the following requirements will be relevant for Ukrainian business: they will provide an opportunity to solve problems that are important for enterprises in a complex; focused on medium and small businesses, respectively, will be more accessible financially; will have a structure (platform) that will ensure ease of integration of GIS into the existing information infrastructure without additional investment; use the tools (methods, technologies, methods, etc.) of artificial intelligence, IoT, Big Data, which will reduce potential risks from doing business and increase the level of operational stability, profitability, and work efficiency; will be "transparent" for both users and investors.

In this context, the development of highly skilled professionals in the RER sector necessitates the incorporation of GIS-focused coursework within the educational programs and curricula of the specialization known as "Electric Power, Electrical Engineering and Electromechanics" (specialty 141).

The paper proposes the content and technology of teaching such a discipline, which is called "GIS for RER's specialist". Its purpose is to acquaint future specialists in the field of RER with the theoretical, methodological, and technological bases of the creation and operation of geographic information systems, master the general principles of work, and gain practical skills in using GIS to solve a number of RER's issues. Mastering the material of this discipline will provide training for highly qualified specialists capable of working with GIS, in particular with raster and vector images, able to perform analytical processing of geospatial data and make decisions based on it.

When selecting GIS tools for the course, the primary focus is on employing systems licensed under the GNU General Public License. The advantages of incorporating open-source GIS in higher education institutions are as follows:

(i) *Cost Savings*: There is no requirement to purchase licenses, reducing financial burdens.
(ii) *Enhanced Student Competencies*: Students gain proficiency in using various GIS tools and learn to combine them to address practical challenges.
(iii) *Comparable Functionality*: Open-source GIS offerings boast functionality on par with their commercial counterparts.
(iv) *Hardware Flexibility*: Most open-source GIS software operates efficiently without demanding high-end hardware specifications.
(v) *Cross-Platform Compatibility*: Open-source GIS supports operation across different operating systems, ensuring versatility in usage.

Future research will focus on exploring the potential use of open web GIS and spatial databases in the educational process. A study comparing the functionalities of proprietary and open desktop GIS would improve the quality of teaching the discipline "GIS for RER specialists".

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