

KEY DRIVERS OF PREDICTING THE GROWTH OF UKRAINE'S NATIONAL RENEWABLE ENERGY INDUSTRY

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The article explores the strategic importance of geospatial infrastructure in assessing and planning the use of renewable energy sources (RES) across Ukraine. Despite the growing need for sustainable energy development, the role of spatial data and GIS technologies in determining regional renewable energy potential remains understudied. This study addresses this gap by building an integrated GIS-based model that incorporates a variety of spatial indicators, including climate conditions, topography, solar radiation, wind speed, biomass availability, and water resources. Using spatial analysis, geospatial modelling, and multi-criteria assessment through an index approach, the study assesses how the availability, accuracy, and timeliness of geospatial infrastructure affect energy planning decisions. The results show that high-quality GIS tools significantly optimise the identification of suitable locations for renewable energy facilities. A new approach to integrating environmental and information spatial factors is proposed. The results of the study have practical value for the development of regional and national energy strategies, the creation of digital platforms for assessing the potential of renewable energy sources and guiding political decisions. The authors advocate the creation of a national open-access geoinformation platform that integrates critical spatial datasets for use by government, academic and business structures.

Keywords: *Energy planning, geoinformation infrastructure, GIS technologies, renewable energy potential, spatial analysis, Ukraine.*

1. INTRODUCTION

Given the aggravation of climate change and the rapid depletion of traditional energy sources, the transition to renewable energy sources (RES) is becoming not just an alternative, but a necessary condition for ensuring sustainable development. Ukraine has significant natural resource potential in the fields of solar, wind, hydro, and bioenergy, but its energy breakthrough is hampered by a number of structural and managerial barriers. One of the key factors determining the possibility of full integration of RES into the country's energy system is the developed geoinformation infrastructure. It provides a deep spatial analysis, accurate forecasting, rational planning and strategic decision-making in the energy sector. Despite some positive advancements, the development of geographic information system (GIS) technologies in Ukraine remains fragmented and uneven, and access to geospatial data is often limited or outdated. Prominent scientists and scholars emphasise the critical role of geoinformation support in building an effective model for the implementation of RES. In particular, researchers point to the need to combine GIS with systems for predicting the energy potential of territo-

ries, emphasise the importance of digital transformation of energy management and strategic investments in renewable energy infrastructure [1], [2].

In-depth scientific research also raises the issue of spatial unevenness of access to energy resources, the relevance of territorial planning using GIS for the location of renewable energy facilities, and also determines the potential of geoinformation technologies in the implementation of decentralised energy management [3]–[5].

At the same time, the scientific community is increasingly emphasising the need to consolidate efforts among government, academic, and private structures to create a single geoinformation energy platform [6].

In this context, the study of the relationship between the level of development of geoinformation infrastructure and the possibilities of effective development of renewable energy potential in Ukraine is of relevance. This article aims to comprehensive study the impact of the GIS factor on the prospects for the development of renewable energy, considering geographical, economic, and technological components.

2. REVIEW OF SCIENTIFIC SOURCES

Over the past decade, a powerful research discourse has emerged in the Ukrainian scientific community around the use of GIS as a key tool in the field of renewable energy. In particular, the works explore the latest spatial analysis methodologies that allow for a deep assessment of the natural potential of different regions of Ukraine for the placement of renewable energy facilities. The authors stress that

the use of GIS allows not only taking into account geographical, climatic, and geomorphological features, but also integrating these data with economic and technical parameters that directly affect the feasibility and profitability of projects in the field of green energy [7]–[9].

Particular attention in domestic research is paid to mapping areas with the highest level of solar insolation and stable wind

flows, as well as building models of spatial accessibility of energy infrastructure, such as power lines, transformer substations, and transport routes. The researchers emphasise that without a solid geoinformation support, the implementation of investment projects in the field of renewable energy risks being ineffective or economically unjustified [10]–[12].

Scientists also draw attention to the fact that modern GIS platforms open up new horizons in the planning of energy clusters, allowing one to predict development scenarios for 10–20 years ahead, taking into account climate change, urbanization trends, and landscape transformation. The works prove that it is geoinformation modelling that creates the basis for the formation of long-term energy strategies at the local and national levels [13]–[15].

A separate niche in the scientific field is occupied by research devoted to the development of GIS modules for comparative analysis of the potential of renewable energy between regions of Ukraine. This allows identifying regions with the highest potential, determining “energy deserts” – zones where the development of RES is unlikely or economically inexpedient –, and building indicators for state policy in the field of energy decentralisation [16]–[18]. It is important to emphasise that in addition to purely technical analysis, researchers integrate social and economic factors into their models, such as the level of population support, the state of the local economy, the level of digitalisation of communities, and the readiness of regional administrations to attract investments in RES. The works show that it is the combination of spatial, technological, and socio-economic data within GIS models that is the key to the successful transformation of Ukraine’s energy system towards sustainable development [19]–[21].

Studying the impact of geoinfoenergy infrastructure factors on the potential of renewable energy sources in Ukraine is an extremely complex and multifaceted process that involves the use of the latest scientific approaches and technological methods capable of integrating a huge amount of data and information resources. Geoinfoenergy infrastructure concerns not only the technical and material infrastructure of energy systems, but also the set of geographical characteristics of territories that determine the possibilities for the development of renewable energy sources. To achieve the most accurate and relevant results, it is necessary to use multifunctional models that allow taking into account numerous variable factors that affect the potential of RES, and which are simultaneously integrated into the existing energy infrastructure of Ukraine.

The research considered in this paper is designed to provide an understanding not only of the characteristics of RES themselves, but also of their interaction with other components of the country’s infrastructure, in particular with electricity networks, transport infrastructure and other elements that may affect the effectiveness of their implementation in real conditions. When working on this topic, it is important to implement an interdisciplinary approach that allows synthesizing data from different fields of knowledge – geography, energy, economics, and technology – in order to achieve a clear picture of the impact of geo-information energy infrastructure on the potential for the use of RES in Ukraine [22]–[24].

The most important component of this study is the use of GIS modern technologies, which allow for spatial analysis of huge data sets on natural resources, economic situation, infrastructure constraints, and other important parameters that directly

or indirectly affect the development of RES. Geographic information systems are the main tool for collecting, processing, and visualising spatial data, as well as for modelling options for placing energy installations on the territory of Ukraine, taking into account such parameters as solar activity, wind speed, availability of land plots for the construction of energy facilities and proximity to existing infrastructure facilities, such as electrical networks and transport routes.

One of the most effective research methods is spatial analysis, which helps establish a correlation between natural conditions and the efficiency of energy systems. In this context, the use of GIS allows identifying the most promising areas for the installation of wind and solar power plants, taking into account not only natural conditions (for example, the average annual number of hours of sunshine or wind speed), but also access to infrastructure, such as power lines, transformer substations, and energy distribution networks. It is also important to note that such analyses allow taking into account the technical limitations of existing electrical networks, which is critical for the integration of new energy sources into existing energy systems.

In addition to geoinformation technologies, considerable attention is paid to the economic analysis of the development of renewable energy sources. The development of technical and economic models allows us to estimate the costs of building power plants and determine the economic efficiency of such projects. This includes not only capital costs for the purchase and installation of equipment, but also the costs of operation, maintenance, and long-term support of the plants. In addition, it is necessary to take into account the projected benefits of using renewable energy sources, in particular, savings on the consumption of

traditional energy resources, reduction of carbon dioxide emissions, and other harmful substances, as well as increasing the level of energy independence of the country.

Energy flow modelling is another important tool in this research. It allows predicting electricity production from different energy sources (solar, wind, bioenergy, etc.) in real-world conditions, taking into account changes in weather conditions, seasonal fluctuations in wind activity, solar radiation, and other natural factors. Energy flow models allow us to clearly show how energy systems based on renewable sources interact with traditional energy sources, how the balance of energy consumption and production is changing, and what the prospects are for ensuring energy stability in the future.

No less important is the use of remote sensing to obtain up-to-date data on natural resources. Satellite images allow quickly obtaining information about the state of natural resources, such as wind, solar radiation, and Earth's surface temperature, which is necessary for accurate prediction of the efficiency of various types of renewable energy sources in different regions of Ukraine. Thanks to the use of remote sensing technologies, one can quickly track changes in the conditions of natural resources and assess their impact on the efficiency of energy installations. All these methods used in the study allow not only comprehensively assessing the potential of renewable energy sources, but also creating a holistic picture of Ukraine's energy capabilities in the context of geo-information energy infrastructure. Data collection and processing, cost analysis, assessment of economic efficiency, forecasting energy flows, and the use of innovative technologies allow one to make accurate forecasts of the development of energy systems based on renew-

able energy sources in the near future. This creates the basis for elaborating a national strategy for the development of energy systems of Ukraine, which will be based

on innovative and sustainable approaches to energy security and the development of environmentally friendly energy sources.

3. DESCRIPTION OF RESEARCH METHODS

The research goal is to conduct a comprehensive analysis of the role of geoinformation infrastructure in identifying and utilising the potential of renewable energy sources in Ukraine, taking into account natural resources, economic factors, technological capabilities, and infrastructure constraints.

Research objectives are the following:

- to conduct a review of the current state of development of geographic information systems and their application in the energy sector of Ukraine;
- to assess the country's natural resource potential (solar energy, wind resources, biomass, and hydropower) based on spatial data;
- to investigate the infrastructure conditions that determine the effectiveness of RES implementation, including power grids, transport accessibility, and technical constraints;
- to develop an integrated GIS-based model that combines natural, economic, and social indicators to select promising areas for the location of energy facilities
- to use spatial analysis and multi-criteria evaluation methods to determine optimal locations for RES installations;
- to carry out an economic assessment of the feasibility of implementing projects in the field of renewable energy, taking into account costs, projected benefits, and the level of energy independence;
- to formulate practical recommendations for the creation of a national open access geoinformation platform to sup-

port strategic planning in the energy sector.

A comprehensive scientific approach was applied to conduct research devoted to the analysis of the prospects for the development of RES in Ukraine, taking into account the territorial remoteness of electricity consumers. The methodology involved the development of mathematical models, research of natural resource potential, study of technical limitations and economic feasibility of implementing RES in individual places. The main objective was to create a comprehensive model capable of ensuring effective planning of the placement of power plants, taking into account geographical features and energy needs of end consumers [25]–[26].

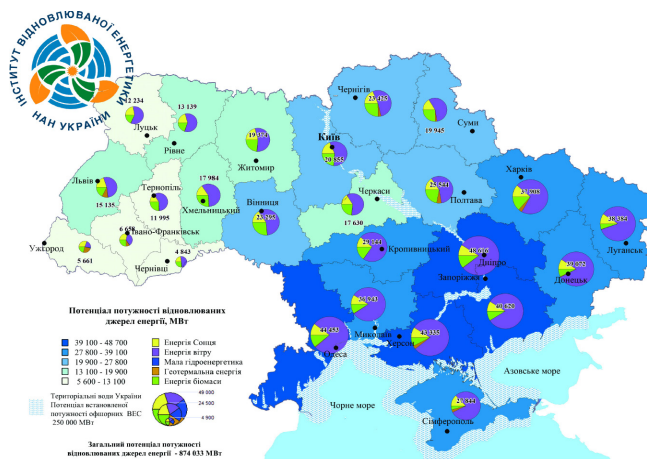
In the process of using geographic information technologies, researchers encountered a number of difficulties, in particular when working with common GIS programmes, such as ArcGIS, QGIS, GRASS, OpenOrienteering Mapper, etc. The main obstacles were the complexity of interfaces, the need for in-depth knowledge of the mathematical apparatus, knowledge of programming algorithms, adaptation to various cartographic projections, the high cost of licenses, as well as the limited availability of the necessary input data for full-fledged analysis. At the same time, the effectiveness of using mathematical computing platforms was determined, in particular MATLAB Online and MATHCAD, which are open for use, support work with

graphic information (in particular, maps), and provide functionality for performing numerical calculations. A significant advantage of such programmes is the ability to process large amounts of information, perform complex mathematical analysis of data, and provide visual representation of results. This is especially important for tasks related to optimising the placement of renewable energy facilities, assessing the effectiveness of investments and long-term energy planning.

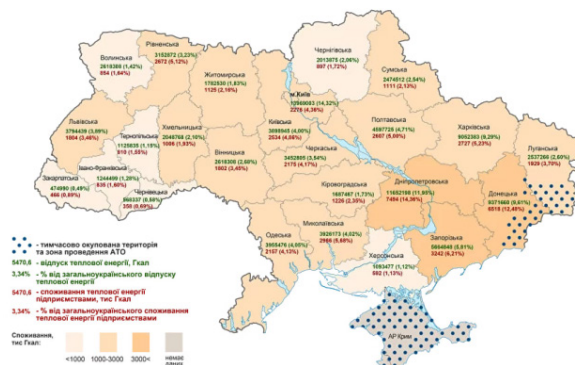
Modelling algorithm took place at the initial stage; input data were collected and pre-processed. The analysis included infor-

mation on the potential of natural resources in different regions of Ukraine (in particular, data on the levels of solar and wind radiation, climatic conditions), as well as information on the existing energy infrastructure. Special attention was paid to indicators of the remoteness of regions from the main centres of electricity consumption [2].

Among the graphical information used to present the spatial potential of electricity production from RES and energy consumption levels in individual power systems, the relevant data illustrated in Fig. 1 were selected.



a



b

Fig. 1. Maps of distribution of electricity production from RES (a) and electricity consumption (b) in Ukraine [2].

In the process of creating cartographic materials used in the research, the authors mostly did not indicate which system of cartographic projection was applied. This significantly complicates their accurate use for further analysis. Therefore, at the initial stage of the work, all maps were standardised in scale according to the maximum geographical dimensions of Ukraine: the maximum length from west to east is approximately 1,316 km, and from north to south – 893 km.

For the convenience of further calculations and spatial analysis, the studied territory was conditionally divided into a grid of squares with a fixed side length (the value is indicated separately). After that, the graphic files of the maps were converted into a 4-bit format, which made it possible to classify the territory according to the intensity of the parameters presented on the maps. As a result, depending on the type of map, Ukraine was divided into 4 or 6 zones, which reflected, respectively, the potential for electricity production from renewable sources or the level of electricity consumption [27], [28].

The maps obtained after processing became the basis for the formation of spatial data sets reflecting the distribution of RES potential and the nature of energy consumption across the territory of Ukraine. The corresponding visualisations are presented in Fig. 2.

The analysis of these data demonstrates an important pattern: the regions with the highest potential for electricity generation from renewable energy sources tend to be geographically different from the main areas of intensive energy consumption. Such spatial and structural asymmetry means that to meet the energy needs of the main consumers of electricity, it will have to be transported over significant distances, which, in turn, will lead to significant elec-

tricity losses during transmission. This requires a detailed analysis of technical, economic, and infrastructure solutions to minimise losses and optimise the country's energy system.

Obtaining the distribution of electricity production and consumption from RES in Ukraine allows us to determine possible energy losses during transmission. To determine the share of energy transmitted from one region of Ukraine to another, the following dependence is proposed:

$$WT_{j,i}^{k,n} = W_{j,i}^R \frac{W_{k,n}^C}{\sum P^C}, \quad (1)$$

where $W_{j,i}^R$ – RES generation potential of the region with coordinates; j, i ; $W_{k,n}^C$ – consumption capacity of the region with coordinates; k, n ; $\sum P^C$ – the total capacity of the country's power system.

The given dependence is based on the assumption of a direct proportional dependence of the share of consumption of the country's regions on the total capacity of the country's power system:

$$\sum_{k=1, n=1}^{k=89, n=131} \frac{W_{k,n}^C}{\sum P^C} = 1. \quad (2)$$

A scheme for calculating losses during energy transmission from the generation region j, i to the consumption region k, n is shown in Fig. 2.

To calculate energy losses that occur during the transmission of electricity from regions of generation to regions of active consumption, the study used methodological recommendations for determining technological losses of electrical energy in elements of electrical networks. These recommendations are based on the provisions of approved regulatory documents that

regulate the procedure for conducting such calculations according to the current legislation of Ukraine [26], [27]. In particular, the study used documents SOU-N EE 40.1-37471933-82:2013 – “Methodological recommendations for determining technological costs of electric energy in transformers and power transmission lines”, as well as SOU-N EE 40.1-00100227-96:2014 –

“Methodological recommendations for analysing technological costs of electric energy and selecting measures to reduce them”. These documents were put into effect on 1 January and 1 June 2014, respectively, as official regulatory sources recommended for use in Ukraine [26].

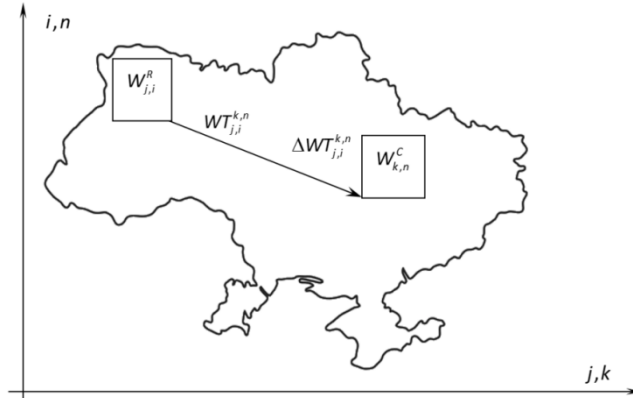


Fig. 2. Scheme for calculating potential RES losses during energy transfer from the generation region to the consumption region.

In the mentioned methods, the calculation of losses is carried out separately for each element of the electrical network, including power lines, transformers, auto-transformers and reactors. The calculations are based on the analysis of active and reactive electricity flows at the corresponding metering points, which are located on the boundaries of connection to individual network elements. In this case, such factors as electromagnetic processes, heat losses, insulating properties, and the influence of climatic conditions are taken into account [27]–[29].

In addition, the method allows correctly taking into account the errors that arise in cases where the measurement points do not coincide with the boundaries of the balance belonging of the objects. This ensures the accuracy of the modelling of energy

losses and allows forming justified technical and economic solutions for optimising the structure of electrical networks, in particular when integrating renewable energy sources into the distributed energy system [26].

$$\Delta W^{(P)} = a \cdot I^2 \cdot R \cdot k_f^2 \cdot T^P + P_{y,n} \cdot T_H, \quad (3)$$

where

a – the coefficient depending on the type of network (three-phase, single-phase);

I – an average effective value of the current in the network element;

R – active resistance of the network element;

k_f^2 – an average effective value of the current in the network element;

$P_{y,n}$ – conditionally constant active energy losses in a network element, which depend on voltage and do not depend on current strength;

$Q_{\sigma,i}$ – conditionally constant reactive energy losses in a network element, which depend on voltage and do not depend on current strength.

$$\Delta W^{(q)} = a \cdot l^2 \cdot X \cdot k_f^2 \cdot T^p + Q_{y,n} \cdot T_H. \quad (4)$$

The use of the dependence is significantly limited by the need to determine the reactive and active resistances of network elements, which depend on a number of structural elements of the power transmission line. At the same time, the use of economic current density allows determining power losses under the conditions of choosing the average voltage and the material of the power transmission line conductors.

$$\Delta WT = l^2 R = \left(\frac{P}{U} \right)^2 \rho \frac{LUi}{P} = \rho \frac{P}{U} Li, \quad (5)$$

where

ρ – resistivity;

P – power($WT_{j,i}^{k,n}$);

L – transportation distance.

For the selected stage of the development of the algorithm for determining losses, the shortest path for transmitting electrical energy is proposed.

$$L = \Delta l \sqrt{(i-n)^2 + (j-k)^2}, \quad (6)$$

where Δl is a map breakdown step.

Further development of the loss determination algorithm will take into account the density and direction of Ukraine's power supply networks by recognising power line maps. The results of power losses for individual regions are shown in Fig. 3.

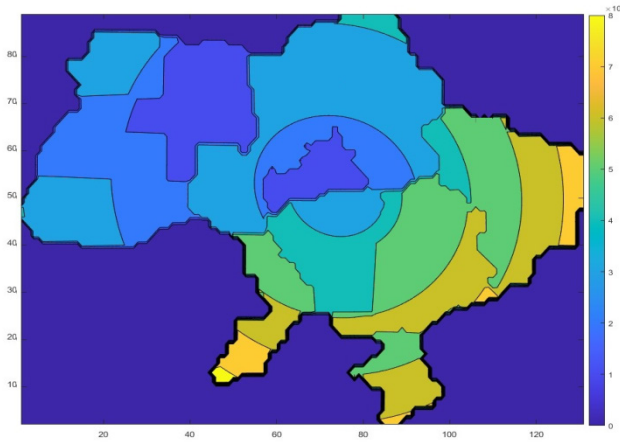


Fig. 3. Maps of the distribution of losses predicted during the transmission of electricity from renewable sources, taking into account the remoteness of consumers.

The analysis of the distribution map of absolute losses of electricity during transmission from renewable sources, taking into account the remoteness of consumers, shows that the location of generators and their remoteness significantly affect the level of losses. The lowest total losses

are characteristic of the central regions of Ukraine, while the highest are expected in the eastern and southern regions. The most promising areas for the development of generation from renewable energy sources are areas with an average level of losses, close to large centres of consumption, in

particular the Dnipropetrovsk region and the northern part of the Odessa region [27], [28].

To assess the optimal locations of RES, a mathematical model was created in the MATHCAD software, which takes into account natural potential, capacity, and distance to consumers. The model allowed assessing the potential of various energy sources and their combinations to select the most effective options for regional development. Optimisation calculations in the MATLAB environment helped determine the most advantageous locations for power plants, taking into account economic aspects such as infrastructure costs and accessibility for consumers [29]–[32].

The proposed mathematical model

for determining losses is based on the assumption of energy transmission along the shortest path (6). However, the actual transmission of electrical energy is tied to the existing energy infrastructure, which is based on the Ukrainian power system (Fig. 4). The Ukrainian power system is a branched power system with a high share of nuclear generation, a significant potential for renewable sources and the need for modernisation due to wear and tear and war damage. To determine losses (3) of the energy potential of renewable sources in Ukraine, it is necessary to take into account the actual distance of energy transmission, which differs significantly from the straight-line trajectory (6).

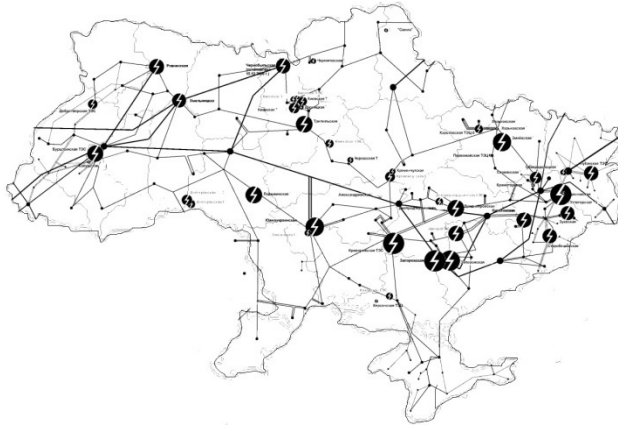


Fig. 4. Diagram of the electricity network of Ukraine.

To take into account possible options for increasing the transportation distance, the following calculation model is proposed (Fig. 6), which takes into account the existing infrastructure of the electricity network

of Ukraine (Fig. 5). When transferring a certain amount of energy from the generation zone (j, i) to the consumption zone (k, n) (Fig. 2a, b), two points correspond, respectively (a, b) :

$$(a; b) = (j; i),$$

$$(a; b) = (k; n).$$

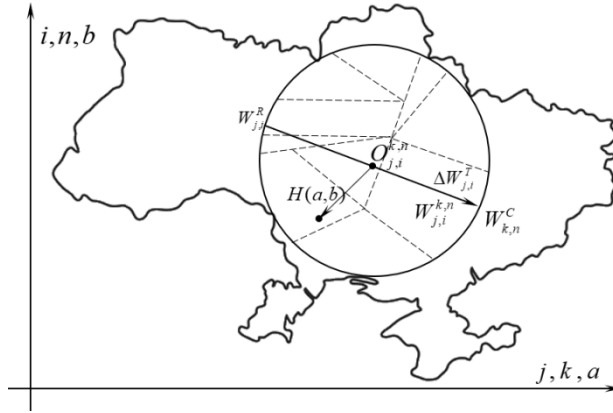


Fig. 5. Scheme of the calculation model of the impact of geoinformation data on the infrastructure of the power system of Ukraine.

For possible options, the zone is in the form of a circle centred at a point:

$$O\left(\frac{n+i}{2}; \frac{k+j}{2}\right),$$

with radius

$$r = \frac{1}{2} \sqrt{(n-i)^2 + (k-j)^2}.$$

The regions O are analyzed, which are divided into a monochrome 1-bit format similar to the previous one (Fig. 7). The analysis takes into account two conditions: distance from the centre $H(a;b)$ and cluster colour (white or black):

$$\begin{cases} R_H = \sqrt{(a-x_o)^2 + (b-y_o)^2} \leq r; \\ c_{a,b} = 1. \end{cases}$$



Fig. 6. Diagram of the Ukrainian electrical network after recognition and formation of a data array.

The ratio of the number of clusters with network elements to the total number of clusters shows the level of network density of a

given region for transporting electrical energy in a certain direction from (j, i) the generation zone to the consumption zone (k, n) :

$$\rho_{j,i}^{k,n} = \frac{N_{c_{a,b}=1}}{N_0},$$

where $N_{c_{a,b}=1}$ is the number of clusters with network elements; N_0 is the total number of clusters.

The density-adjusted transport length (6) is the inverse of the network density of a given region.

$$L = \frac{\Delta l}{\rho_{j,i}^{k,n}} \sqrt{(i-n)^2 + (j-k)^2}.$$

Figure 7 illustrates the algorithm for studying the impact of geoinformation data of the power system infrastructure on the potential of renewable energy sources in Ukraine. The image processing algorithm for energy production and consumption maps includes a number of sequential stages aimed at converting visual information into structured data for spatial analysis of energy processes. In the first step, the images are scaled to a single scale, which provides an accurate spatial comparison of energy production and consumption maps. Next, the image bit depth is unified – the colour depth is reduced (for example, to 2 bits or 4 bits), which allows optimising the amount of data and ensuring unified processing. In the third stage, the images are converted into two-dimensional numerical arrays, where each pixel value corresponds to a specific colour, which is associated with the intensity of production or consumption. The next step is to interpret these colour values by linking them to physical quantities, such as the amount of energy in kWh/km², according to the legends of the source maps. After that, a four-dimensional array is formed, which contains data on the network density of a given region. Such a structure allows obtaining a comprehensive description of the density of the energy network in the studied region. The final stage

is the calculation of the energy potential losses of renewable energy sources in different regions based on the three arrays formed, which allows identifying areas with excessive generation, inefficient use or structural imbalances in the energy network. This approach can be implemented in GIS software using the above-mentioned image processing tools – MATHCAD and MATLAB [56]–[71].

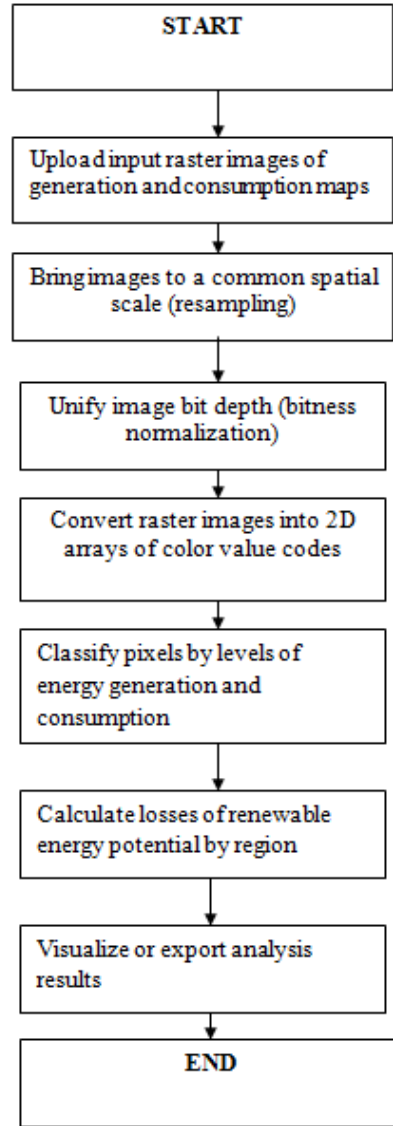


Fig. 7. Algorithm for studying the impact of geoinformation data on the power system infrastructure.

Figure 8 presents the results of modelling in the form of a map of energy potential losses, taking into account the impact of

geoinformation data on the infrastructure of the Ukrainian power system.

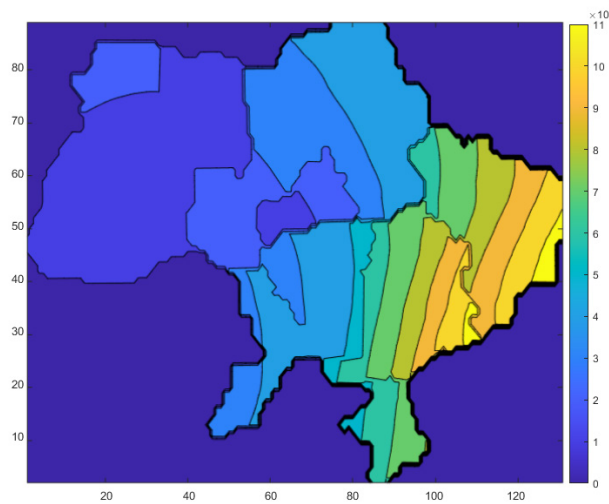


Fig. 8. Modelling results of energy potential losses taking into account geoinformation data of the energy infrastructure of Ukraine.

The map presents the spatial distribution of energy potential losses in Ukraine, formed taking into account the geoinformation characteristics of energy infrastructure facilities. The image demonstrates the zoning of regions by the level of losses: from the minimum values (shades of blue in the west and centre of the country) to the maximum (shades of yellow and orange in the eastern regions [29]–[31]). The largest losses are observed in the eastern part of Ukraine, which may be associated with a high density of infrastructure facilities, consumption, or transportation losses. Contour lines on the map indicate the gradation of loss values, which allows identifying transition zones. This approach allows one to visualise the impact of spatial features of the power system on the efficiency of energy supply in different regions of the country.

The results of the study confirm the key importance of geographic information

systems in the process of strategic planning for the development of renewable energy in Ukraine. The use of spatial data has significantly increased the accuracy of determining the territories with the greatest potential for the placement of solar, wind, and bioenergy installations.

The application of a multi-criteria approach has shown that combining natural, infrastructural, and socio-economic factors in a single model provides more informed decision-making. This is especially important for minimising risks associated with uneven access to resources and technical limitations of existing energy networks.

The study has also demonstrated that modern GIS platforms not only optimise location selection, but also open up opportunities for long-term forecasting of energy cluster development. This approach forms the basis for regional and national strategies that take into account climate change,

urbanisation processes, and landscape transformation.

At the same time, a number of problematic aspects have been identified:

- limited access to current geospatial data;
- uneven development of GIS technologies in different regions;
- insufficient integration of socio-economic indicators into the energy planning process.

4. CONCLUSION

This article has examined the impact of geo-informational energy infrastructure factors on the potential of renewable energy sources in Ukraine, which is extremely relevant in the context of modern global challenges such as climate change, depletion of fossil fuel reserves, and the need to transition to more sustainable and environmentally friendly methods of energy production. An important aspect of the study has been the integration of data with the country's energy infrastructure, which allows understanding how natural resources and existing energy networks interact to ensure sustainable development in the field of renewable energy. The use of GIS technologies to map solar radiation, wind activity, temperature regimes, and other natural factors makes it possible to more accurately determine the places with the greatest potential for installing solar and wind power plants. This allows public and private investors to make informed decisions about the location of such facilities, while reducing the economic risks associated with an improper choice of location for investment.

In addition, an important result of this research is the development of mathematical models that allow predicting the

Thus, the proposed approach to the use of geoinformation infrastructure can become the basis for creating a national open platform that will unite key spatial data and ensure effective interaction among government, scientific, and business structures. This will contribute not only to increasing the efficiency of the implementation of RES, but also to the formation of a sustainable and independent energy system of Ukraine

efficiency of renewable energy sources in Ukraine, taking into account not only natural conditions, but also the technical capabilities of the existing energy infrastructure. For example, GIS can be used to accurately model energy flows, which allows determining the most suitable areas for installing new energy installations, as well as assessing how these installations will interact with other elements of the energy network, including power lines, transformer substations, and other important infrastructure elements.

In addition, a significant achievement of this study is the use of remote sensing data, satellite imagery, and weather forecasts, which allows for real-time monitoring of natural conditions and adjustment of energy project development strategies. This reduces the likelihood of forecast errors and makes renewable energy development more adaptive to changing conditions, such as fluctuating weather conditions, changes in energy demand, and socio-economic changes.

Thanks to the use of interactive technologies and mathematical models, it was possible to identify the most promising regions for the development of renewable energy

in Ukraine, taking into account the availability of natural resources, the availability of energy infrastructure, and the possibility of connecting new energy sources to existing energy networks. This approach allows significantly increasing the efficiency of energy project implementation, as well as reducing the costs of their implementation, as it involves reducing the risks associated with incorrectly selected areas for construction.

The analysis of the research results confirms that Ukraine has a significant potential for the development of renewable energy sources. The use of modern technologies to identify and forecast this potential allows for more effective management of the country's energy resources, ensuring environmental stability, reducing dependence on energy imports, and creating new jobs in the field of renewable energy. In addition, this process allows for sustainable economic development, reducing greenhouse gas emissions, and improving the overall environmental condition of the country.

In general, the results of this study can serve as a basis for further scientific research

and practical developments in the field of energy and ecology, in particular for the creation and improvement of policies that will promote the sustainable development of renewable energy sources in Ukraine. Given the significant development of modern technologies and growing support from the state, Ukraine has a real opportunity to become a leader among Eastern European countries in the field of energy innovations, contributing to sustainable development and ensuring energy independence for the coming decades.

The infrastructure of energy networks is also an important factor that significantly affects the ability to integrate renewable energy sources into the overall energy system. Its technical condition determines whether the energy system can efficiently and safely handle additional electricity flows from renewable energy sources and ensure the stability of energy supply. Therefore, along with the development of renewable energy sources themselves, it is necessary to modernise energy networks to ensure their ability to cope with new challenges.

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