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The Use of Climatic and Geospatial Data in Assessing the Potential of "Green Energy" and Designing Energy Systems with Renewable Energy Sources in the Republic of Adygea

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Abstract: The integration of green energy sources has many advantages, but their variable nature of generation introduces additional difficulties in organizing a stable supply of end-users. To solve this problem, it is necessary to use renewable energy sources (RES) assessment and forecasting models that allow not only to identify the most suitable locations for such energy systems, but also to determine the potential volumes of energy generation, taking into account seasonal features that determine the amount of incoming energy in the mountainous areas of the Republic of Adygea. However, the construction of such models requires the availability of large sets of climatic data that allow to fully assess the behavior of a particular resource in the area under consideration. The article considers the characteristics of renewable energy sources that can be obtained from open data sources and geographic information systems, the use of which will allow not only to preliminarily assess the potential of renewable energy sources, but also to manage distributed energy systems by realizing short-term forecasts, and also considers examples of such data sources, interaction with which allows to assess the potential of the selected energy resource in the study area.

Keywords: renewable energy sources, data, energy potential assessment, geographic information systems.

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1. Introduction

Active integration of renewable energy sources into existing energy systems is becoming a relevant trend in recent years in many countries of the world [*Awogbemi et al.*, 2023; *Sher et al.*, 2024]. Such an increase in the share of "green" energy in the energy systems of states leads to the emergence of hybrid distributed systems that include various energy sources that are subject to climate impacts [*Ahmed et al.*, 2024; *Simankov et al.*, 2023a]. This problem can be solved by organizing complex distributed systems that combine several types of renewable energy sources, traditional carbon carriers and energy storage systems, allowing to achieve absolute stability in the generation of the required amounts of energy [*Arabzadeh et al.*, 2024]. However, in order to effectively manage such systems, monitoring systems and predictive analytics are needed to estimate, at least in the short term, the future generation volumes when using a particular type of resources [*Simankov et al.*, 2023b; *Simankov et al.*, 2024]. In such a case, one of the most important issues is the question of obtaining all necessary parameters from various available sources. In this paper we propose to consider the key parameters of RES and other characteristics that are important in assessing the potential of "green energy" and ways to obtain them.

Research Article

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2. Materials and methods

Data is one of the key elements necessary for further analysis of the subject area, making informed decisions and final recommendations in the field of renewable energy. Geospatial datasets [*Buchatskiy et al.*, 2024] are the most widely used in the assessment of renewable energy resources to provide the necessary basis for effective decision-making, as they contain, in addition to information on renewable energy resources, information on existing infrastructure, regional and district boundaries, terrain and current land use, and some of the parameters have temporal characteristics, which is an important factor in building an assessment of the resource potential that changes over time.

Renewable energy datasets provide information on the availability and intensity of available energy: solar, wind, geothermal, hydropower, wave, tidal and biomass energy in a particular geographic location under study. The availability of most renewable energy sources is directly related to their location, and for variable sources such as solar and wind power an additional component appears — time dependence. Next, consider what data can be generated to estimate major sources of renewable energy through the use of GIS.

3. Solar energy

Solar irradiance data are most commonly reported as one of three components (or various combinations thereof):

- direct normal radiation coming directly from the sun;
- scattered horizontal radiation (diffuse) — radiation that comes in scattered (reflected) form from different directions;
- global horizontal radiation, which is the amount of energy arriving on a flat surface during the day.

In terms of time scale, the considered characteristics can have different ranges, from several minutes to hours or days, but the most popular and convenient is the representation in the form of average monthly or average annual radiation for a particular territory. Figure 1 shows the result of displaying solar radiation characteristics in the PVGIS tool [*PVGIS*, 2024], which allows us to obtain sets of raw data in the form of time series for certain coordinates and conveniently visualize them for better clarity.

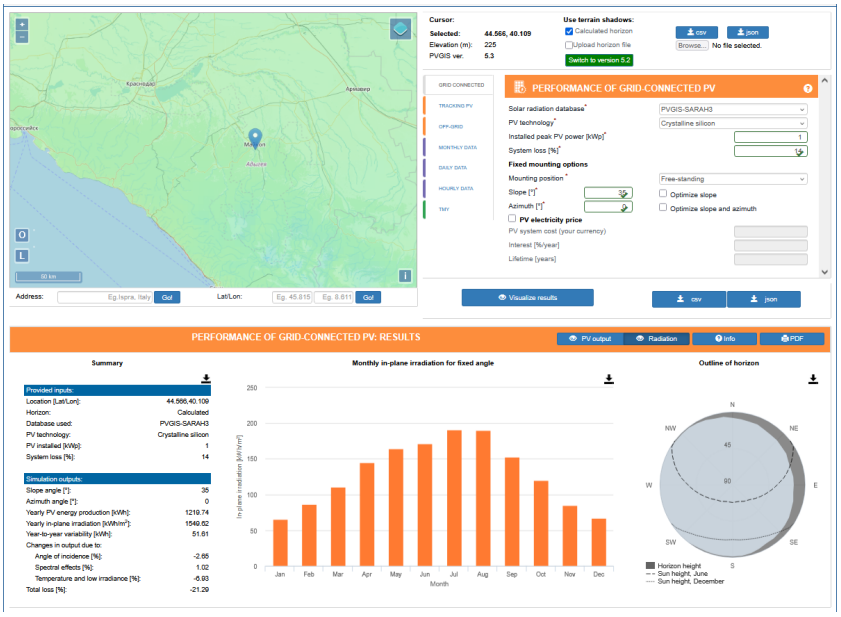

Figure 1. Solar radiation data in the PVGIS tool for the territory of the city of Maykop (Republic of Adygea) [*PVGIS*, 2024].

3.1. Wind energy

Typically, wind resource data are more complex than solar irradiance data, and their use requires high spatial resolution data. A second important aspect is the need to obtain information on wind speeds at different heights, sometimes called hub heights. These values are typically 30, 60, 80, 100 and 120 meters, representing the most common heights for installing wind turbines. Similarly, wind speed data can have different time scales, from a few minutes to annual averages. Figure 2 shows the values of annual average wind speed for 10- and 150-meters altitude obtained with the Global Wind Atlas tool [*Global Wind Atlas*, 2024].

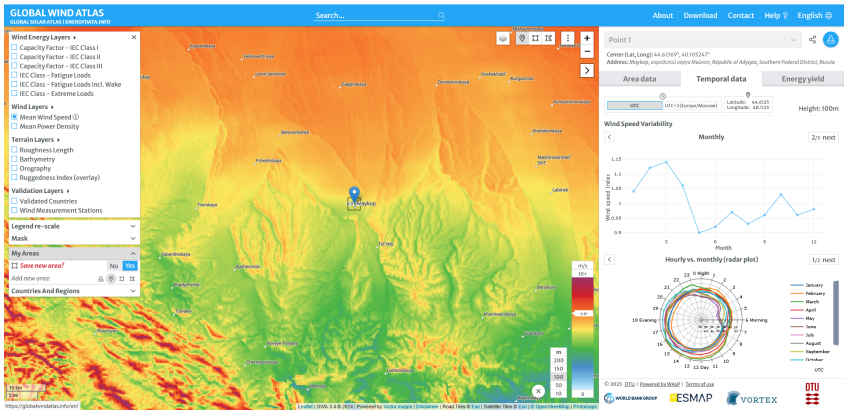

Figure 2. Map of mean wind speed distribution and monthly mean wind speed values for the city of Maykop (Republic of Adygea).

3.2. Geothermal energy

Geothermal energy has one of the highest efficiency factors among all renewable energy sources, reaching 70-80% [*Nkinyam et al.*, 2025], but its distribution is very limited and requires serious investments for the creation of energy systems, therefore it is most often used precisely for heating various premises [*Buchatskiy et al.*, 2023], rather than for the production of electricity. Data on geothermal deposits do not contain a large number of indicators, and the basic information includes the location of such wells, their depth, and the temperature of the water or steam coming out. As a rule, such maps show those sources that are already in use, and the area of use of this type of energy is very limited due to the strict connection to the areas with the presence of such deposits. Not for all sources of geothermal energy can be determined their potential, so, recently to geothermal energy include the energy of heat pumps [*Gaur et al.*, 2021], which convert the natural heat of the earth at a certain depth, but the energy potential when using such technology can not be calculated analytically for each case because of a large number of factors, and it can be determined only for a specific area. Various approaches can be used for assessment [*Zhang et al.*, 2023], including the use of GIS, for which data from open sources can be transferred to a tool for further processing and utilization. Open source energy distribution atlases such as the energy atlas (Geothermal Potential) can be used as open sources [*Geothermal Potential*, 2024] or Open Geoscience Computing Repository [*Open Geoscience…*, 2024].

3.3. Biomass energy

When it comes to assessing the potential of bioenergy resources, an important factor is the use of GIS to extract additional attributes: agricultural land area, forest area, number of livestock facilities and livestock population [*Okedu et al.*, 2024; *Ukoba et al.*, 2023]. Let us consider the characteristics needed to assess the renewable energy potential at different levels:

- meteorological data — an example of such meteorological datasets is the typical meteorological year (TMY) [*Fan*, 2022], which can be used to identify key seasonal dependencies in energy inputs;
- land use and land ownership — using these parameters it is possible to determine the areas actually available for RES implementation and those areas where it is not possible to locate any generation facilities;
- population and density data — such information allows to determine in which of the locations it is more convenient to locate generation facilities and what shares of energy they can cover in real conditions;
- data on energy and transmission infrastructure.

For example, tools such as Bioenergy Simulator [*IRENA*, 2025] can be used to assess bioenergy resources to determine the primary potential of bioenergy resources for a selected area.

3.4. Small hydropower

When assessing small hydropower potential, there is a lack of baseline datasets, so either hydropower distribution atlases have to be used or measurements have to be made independently. There are therefore two approaches to data collection:

- data modeling — obtaining sets of parameters to be studied using various models (empirical, semi-empirical);
- data measurement — obtaining the necessary parameters to assess the potential at a particular location using meteorological equipment and other measuring tools [*Buchatskiy et al.*, 2020].

The second approach is a more accurate tool for obtaining data, although it requires certain costs and time to accumulate the necessary data set. In order to collect data, metering equipment must be installed directly on the generation system being operated, and the configuration of the metering equipment will be highly dependent on the type of hydroelectric plant used. For power generation on small streams, small plants are most suitable, but off-the-shelf solutions often use a large elevation difference [*Berrada et al.*, 2019] to provide the necessary pressure level, which is not always feasible in the field and available terrain conditions, so the best solution was the realization of an in-house prototype generating device that can be used to study the flow patterns of small mountain streams. To be able to assess the potential of small hydropower, the authors developed an autonomous complex for collecting the parameters of microhydropower plant operation for use in the conditions of mountainous regions [*Onishchenko et al.*, 2024]. As a result, the complex allows for the offline collection of microhydropower plant operation characteristics:

- the flow rate of the river;
- the generated voltage at the generator and the solar panel used;
- the current consumed by the load (generator and solar panel);
- ambient air temperature and humidity.

A view of the parameter acquisition device for microhydropower estimation is shown in Figure 3.

Figure 3. Autonomous installation for collecting microhydropower parameters.

4. Conclusion

The paper considers aspects of applying data from various sources in renewable energy assessment and decision-making, considers the main parameters for the main types of RES and identifies tools that allow to extract these data. As a result, it is possible to form the following approach, presented in Figure 4 [*Cox et al.*, 2018], describing the main stages of data utilization in the field of green energy.

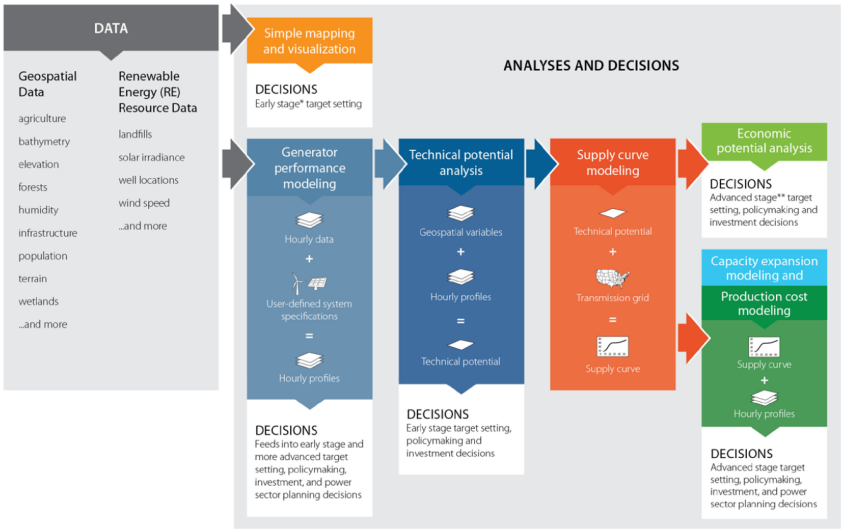

Figure 4. The relationship between geospatial data, analysis, and decision-making in renewable energy generation [*Cox et al.*, 2018].

Aspects of data acquisition in case of their absence in open sources are also considered, and an example of a complex for collecting microhydropower parameters developed by the authors is given. Extracted data from open sources, or synthetic data obtained with the help of various models can be successfully used to assess the theoretical and technical potential of the studied type of "green" energy, while the data obtained from real measurement complexes can be used to build forecast values of energy generation volumes.

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