Renewable energy resources in the system of sustainable development of Carpathian region of Ukraine

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Abstract. The scientific novelty presented in this paper is to substantiate the extension of the resource potential of renewable energy sources in the Carpathian region with the creation of a set of maps in the geographic information system "Map Info". For each type of renewable energy (solar, wind, small hydropower) a number of technical issues and advantages, technological ecologically safe priorities are defined. The detailed regional calculation of wind, solar, hydropower potential for the Carpathian region of Ukraine has been performed. The spatial limitations and possibilities of introducing renewable energy sources in the sustainable development of the region are scientifically substantiated. Renewable energy scenarios are proposed.

1. Introduction
The purpose of the research is to solve the current fundamental problem of environmentally safe use of renewable energy sources in the sustainable development of the Carpathian region of Ukraine [1, 2] by developing scientific and methodological bases for strategic assessment of the potential, environmentally safe location of renewable energy sources, taking into account the sustainable development of the region [3], [4]; determination of optimum technologies of renewable energy on the example of solar, wind, small hydropower, stabilization and improvement of environment, principles of sustainable balanced development of the region [5], [6].

The relevance of scientific topics is undisputed and connected with the fact that the use of renewable energy sources is considered by the world community as one of the most promising ways of solving the growing problems of energy supply, and the sustainable development of the Carpathian region of Ukraine is a priority of the national economy [7-9].

2. Problems
The scientific novelty presented in this paper is the substantiation of technically achievable, economically feasible, ecologically safe potential of renewable energy sources in the studied territory with the creation of a set of GIS maps of the potential of renewable energy sources in the region;
definition for each type of renewable energy (solar, wind, small hydropower) a range of technical and economic issues and advantages, technologically environmentally friendly priorities [10-12].

3. Presentation of the fundamental material

3.1. Wind power potential

The Carpathian region of Ukraine is not yet sufficiently covered by wind power development, but the increase in energy production from renewable sources, including wind energy, will require the attraction –of new perspective energy territories [13]. Given that the region is environmentally sensitive due to the high concentration of nature conservation areas and sites, dense river network, high forest cover, it is necessary to increase the level of environmental safety in the implementation of wind energy projects.

The estimation of wind power potential was based on the processing of data of observations on wind characteristics at meteorological stations of Carpathian region of Ukraine and adjacent regions. After establishing the average wind speeds, it was proposed to classify the prospect of wind speeds for the purpose of wind power, which is based on the starting and calculated speeds of wind turbine of three class (low, medium and high power):

- speed up to 2 m/s - unpromising for all types of wind turbines;
- speed 2-3 m/s - low-potential for small wind turbines;
- speed 3-4 m/s - perspective for small wind turbines;
- speed 4-5.5 m/s - promising for low and medium capacity wind turbines;
- speed over 5.5 m/s - promising for any wind turbine.

Taking into account the necessity of determining the wind speed at the height of wind turbine operation, average wind speeds at altitudes from 3 to 100 m were calculated and maps of average wind speed at the given altitudes were constructed (Figure 1), which substantiated the technically achievable wind energy potential.

![Figure 1. Map of average wind speed in the Carpathian region of Ukraine at the altitude 100 m](image)
Based on the calculation of the specific wind energy potential, the most favorable climatic conditions for industrial wind power are found in the mountainous regions of Ukrainian Carpathians in the territory of Ivano-Frankivsk and Transcarpathian regions, in Roztoche – Lviv region, Khotyn – Chernivtsi region. It is advisable to locate medium-capacity wind farms in Lviv and Ivano-Frankivsk regions at Opille, Podolsk. For small wind turbines, favorable wind conditions are characterized by the overwhelming part of Lviv region (especially the northwestern and central regions), Ivano-Frankivsk (especially the northern, southwestern areas), the central part of Chernivtsi region, and the mountainous part of Transcarpathian region. The deep river valleys, protected by mountains, the overwhelming part of Transcarpathian region are unfavorable. However, when designing wind farms on a particular site, there is a need for additional field observations of wind characteristics, since the data obtained from nearby weather stations may differ due to local orographic features.

The choice of the location of the wind farm should be based not only on the wind potential. It is important to take into account spatial constraints in the study area by collecting data, analyzing them and constructing maps of environmental components that can influence or be affected by wind farms, establishing criteria of spatial constraints and their graphical representation in the form of a component and complex map of spatial constraints (Figure 2).

**Figure 2.** Algorithm for selecting the site of the wind farm
Three types of constraints are required: orographic, technical and environmental constraints by setting spatial exceptions and environmentally safe distances. The terrain has an impact on wind-climatic resources and the possibility of carrying out the construction of wind turbines due to the emergence of dangerous ex-dynamic phenomena. Technical limitations – is the accessibility of the site and suitability for construction and operation. Areas for which large tracts of land are to be cleared for road construction may not be profitable. This also applies to energy system objects, such as transmission lines, and sites located at a considerable distance from them will require a lot of expense. The construction and operation of wind farms can lead to the death of birds and bats due to collisions with wind farms, displacement from their habitats and impact on migration [14]. The construction of the wind farms also affects the quality and aesthetic appearance of landscapes and can lead to a decrease in the recreational value of the site. The main factors that require a ban on the location of the wind farms in rural and landscape and recreational areas and keeping a safe distance from them are the visual impact, the noise, the effect of shimmer shimmer and the spread of ice. There is a likelihood of wind turbines being affected by radar systems, landing systems or aircraft preparation areas [15].

As a result of summarizing information on environmental components that may affect or be affected by wind farms, it is proposed to exclude territories that have:
- slope more than 25%;
- the distance to the road network more than 3 km;
- the distance to the grid more than 5 km;
- the distance to reserves less than 1000 m;
- other territories and sites of NRF less than 400 m;
- the distance to wetlands less than 1000 m;
- the distance to large and medium-sized rivers, lakes, reservoirs, ponds of 3 ha less than 400 m;
- the distance to forests less than 400 m;
- the distance to villages and recreational areas of settlements less than 1000 m;
- the distance to airfields less than 10 km.

3.2. The potential of solar energy
Recently, there has been a growing interest in using photovoltaic panels (PVPs) to generate electricity by converting solar energy. The amount of electricity produced over a certain period of time depends directly on the insolation, if the inflow of total solar radiation per unit area of the horizontal surface per unit time [16].

According to the calculations made by the authors, the area of the Carpathian region of Ukraine has sufficient economically viable solar insolation potential, which makes it possible to build solar photovoltaic power plants (SPP) (Figure 3).
Figure 3. Annual total solar radiation in the Carpathian region of Ukraine

Analysis of the SPP operation in Lviv and Ivano-Frankivsk regions showed that a 1 MW power plant per year can produce about 1 million kWh of electricity [17].

The algorithm of the software product in terms of estimation of solar energy potential is presented in Figure 4.
Panels of polycrystalline and monocrystalline elements are used on the existing SPP. With an investment value of €1 million per 1 MW of peak SPP capacity, the return on investment is about 7 years [18].

Modules or module plates are used for SPP in most SPP of Chinese production of both polycrystalline and single crystalline photovoltaic cells. Panels of both types are successfully operating at the SPP in Lviv region.

The issue of land lease is an environmental constraint for SPP projects. About 2.5 hectares of land have to be rented per 1 MW. In the Carpathian region, areas under SPP must bypass agricultural land, recreational and tourist use, buffer zones of nature reserves. Important, as in the case of wind farms, is...
the scheme of connection of the SPP to the electricity grids. At considerable cost of connection (more than 15% of the cost of SPP) the decision on closing of the project can be made. SPP projects take into account the urban conditions and limitations of the local architecture department.

3.3. Hydropower potential

According to the calculations, the Carpathian region of Ukraine is the largest potential region of small hydropower in the country, the most effective for their use, and therefore should be considered as a priority in the implementation of the program of small hydropower. The technogenic and ecologically safe hydropower potential of the Carpathian region of Ukraine is presented in Figure 5.

![Figure 5. The technogenic and ecologically safe hydropower potential of the Carpathian region of Ukraine](image)

In general, the territory of the northeast slope of the Carpathian region of Ukraine is no less attractive than the southwestern one, in terms of quantitative and qualitative characteristics of hydropower potential. The total gross capacity of small-scale hydropower resources in the Lviv, Ivano-Frankivsk and Chernivtsi regions is 2828.42 thousand kW. As a result of the conducted researches it is possible to conclude that the specific potential hydropower resources are directly proportional to the height of the terrain. The gross hydropower potential is increase SPP with the size of the river. On the whole, the largest reserves of hydropower (in thousand kWh per 1 km² of territory) are in Transcarpathian region. The second region in terms of hydroelectric power capacity in the
Carpathian region is Ivano-Frankivsk. Almost comparable potential is the southern part of the Lviv region, within which the right-bank tributaries of the Dniester are located.

Ecological restrictions on the location of the hydroelectric power station take into account the impact on the nature-protected territories, the risks of devastating floods, the proximity of the lands of historical, cultural, recreational and health-improving purpose SPP [19], [20]. The longitudinal profiles of the major year were analyzed; the choice fell into areas of abrupt change in the longitudinal profile with a steady increase in the partial slope (within the middle and lower reaches of the year). Consideration was given to the proximity of settlements that would become potential energy consumers, with higher capacity of HPP corresponding to places with a higher concentration of consumers. In addition, the connection of the HPP to the grid is cost-effective 2-5 km. Thus, the complex influence of the above factors made it possible to identify promising sites for the placement of small-, mini-, micro-hydro power plants (MHPS) within the Carpathian region. Taking into account all of the above, the areas of prospective location of MHPS in terms of engineering-geological, hydrological, hydropower, and economic conditions at the level of pre-project recommendations were divided into three types: favorable, promising and problematic. The following should be distinguished among each type of sites: micro HPP (up to 100 kW), mini HPP (100-1000 kW), small HPP (1-5 MW) sites (Figure 6).

![Figure 6. Perspective areas of environmentally safe location of MHPS](image-url)
- Ground based wind farms;
- Solar photovoltaic installations;
- Small hydroelectric power plants (<10 MW).

Technologies that are not currently covered by the Green Tariff have not been considered and the prospect is not considered. Those technologies that are under development or are not publicly available are not considered for the reason that the likelihood that their development will be completed in the near future is considered to be rather low [21].

The process of developing scenarios for the development of each of the identified types of renewable energy (wind, solar, small hydro) includes several steps:
- the identification of those areas of the Carpathian region where the development and use of the above-mentioned sources of renewable energy will be technically and environmentally feasible [22], which will be confirmed by the results of the SPP made at a properly high level. Certain areas will not be considered if, for example, the available resources are not sufficient to ensure the viability of the project [23];
- the defining the characteristics of typical projects, such as the likely size, area, technologies used [24];
- the identification of specific factors that may affect the scale and classification of projects, or the potential for development of these territories [25].

Table 1 lists the renewable energy and technology characteristics that are most likely to be used in the scenarios included in the review.

| The source of energy | The characteristic of the source | The perspective regions | The categories of technologies or “the projects” |
|---------------------|----------------------------------|-------------------------|-----------------------------------------------|
| Wind                | Wind with a density exceeding 250 W/m². | Western Ukraine - especially along the Carpathian Range | Stations with modern wind turbines with a capacity of 2.0-3.0 MW each. |
|                     |                                  |                         | – Small stations (< 20 MW or 7-10 turbines) |
|                     |                                  |                         | – Medium stations (20-100 MW or 10-50 turbines) |
|                     |                                  |                         | – Large stations (> 100 MW or more than 50 turbines) |
| Sun                 | Solar radiation with optimum tilt for photo capture by galvanic elements | Green tariffs can ensure the profitability of such projects in most of the region | Ground based installations of different power levels. |
|                     |                                  |                         | – Small (1-5 MW) |
|                     |                                  |                         | – Medium (5-20 MW) |
|                     |                                  |                         | – Large (> 20 MW) |
| Small HPS           | River drainage and existing hydropower facilities | Carpathian region (Dniester, Prut and Tisza river basins) | The implementation of hydropower projects is limited by the definition adopted for small hydropower plants in the green tariff scheme (<10 MW capacity) |
|                     |                                  |                         | – Small hydropower plants without reservoir |
|                     |                                  |                         | – Small hydroelectric power plants with dams (<10 MW). Installations that require low runoff costs (water-lift boom or water intake structure) at high water head are also possible. |
|                     |                                  |                         | – Modernization / reconstruction of existing hydropower facilities |
4. Conclusions

The paper presents a part of scientific researches on development of methodology of environmentally safe use of renewable energy sources taking into account the sustainable development of Carpathian region of Ukraine. The calculation of wind, solar, hydropower potential for the whole territory of Carpathian region was performed. The technically achievable, economically feasible, ecologically safe potential of renewable energy sources in the studied territory is substantiated. The spatial limitations and possibilities of introducing renewable energy sources in sustainable tourism and recreational development of the region are scientifically substantiated. The scientific novelty presented in this paper is to substantiate the extension of the resource potential of renewable energy sources in Carpathian region with the creation of a set of maps in the geographic information system "Map Info". For each type of renewable energy (solar, wind, small hydropower) a number of technical issues and advantages, technological ecologically safe priorities are defined. Renewable energy scenarios are proposed.

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