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Spatial Analysis of Renewable Energy Sources in Lviv Region

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Abstract

The introduction of renewable energy sources makes it possible to expand the possibilities of development of branches of the national economy, in particular heat energy, to accelerate economic growth and reduce the release of greenhouse gases into the environment. Spatial analysis of renewable energy sources contributes to their effective use and allows for planning the local development of renewable energy. In this article, a spatial analysis of renewable energy sources in the Lviv region, such as wind energy, solar radiation, fuel wood, agricultural animal manure, and sewage sludge, is performed. It was established that the most promising district in terms of the availability of renewable energy sources is the Stryi district, since the amount of solar radiation and the amount of forest land in it are higher than the same indicators for other districts, in addition, the amount of sewage sludge is also one of the highest in the region. For the possibility of increasing the total share of renewable energy sources, the districts of the region can cooperate with other districts of both Lviv region and neighboring regions.

Keywords: district heating systems; wind energy; solar irradiation; agriculture animal manure; fuel wood; sewage sludge.

1. Introduction

Technologies using renewable energy sources have been actively developing in the world over the past decade. At present, they have become sufficiently competitive to satisfy part of the energy needs in various branches of the national economy, in particular, heat energy. In addition, the requirements of legislative documents emphasize the need to use local renewable energy resources. In the countries of the European Union, district heating systems are considered as a way to reduce the presence of greenhouse gases in the environment through the use of renewable energy sources [1]. In Ukraine, most of the district heating systems belong to the 2nd generation, one of the characteristics of which is the use of fossil fuels [2]. To ensure transition of Ukraine's district heating systems to energy-saving and ecological systems of the 3rd and 4th generation, it is necessary to use renewable energy sources. In addition, the Law of Ukraine "On Heat Supply" states that one of the main areas for the development of district heating systems is the use of alternative and renewable energy sources, such as the energy of the sun, wind, biogas, geothermal water, production waste. In Ukraine, methods of using renewable energy sources in heat supply systems were considered [3], [4], however, the transition of district heating systems to renewable energy sources is not possible without an assessment of available energy resources. One of the determining factors that affects the availability and energy potential of local renewable energy sources is the geographical conditions of the area. In the literature, there is already information on the analysis of renewable energy sources in some countries [5], but in the energy sector, there is no regional data that would assess the geographical conditions and specifics of the regions of Ukraine. Therefore, the spatial analysis of renewable energy sources is important for the implementation of energy-saving district heating systems and in the development of a model of the energy sector in general.

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2. Aim of work

The aim of the work is to perform a spatial analysis of renewable energy sources in the districts of Lviv region.

3. Analysis of recent research

The development of 4th generation district heating systems is important for the decarbonization of the heat energy sector and for the introduction of intelligent energy systems. Heat energy needs can largely be covered by district heating systems from a variety of available renewable energy sources. The main renewable energy sources that can be used in district heating systems are biomass energy, solar energy, wind energy, and geothermal heat.

Biomass is one of the most promising alternative energy sources and is most often used in district heating systems. The main energy resources of biomass are waste from forestry and woodworking enterprises, biomass of agricultural origin, organic industrial waste, municipal solid waste, sewage sludge and septic tanks. Depending on the method of processing, biomass is transformed into a solid (briquettes, pellets), liquid (biodiesel, biomethanol, and bioethanol) or gaseous (biogas, synthesis gas, and hydrogen) energy source [6].

In Ukraine, wood biomass is one of the main renewable sources of energy, as evidenced by its inclusion as a fuel energy option in the Energy Strategy of Ukraine for the period up to 2035. In addition, in the heating season of 2022–2023, which coincided with the time of the Ukrainian-Russian war, firewood became the main type of fuel in the frontline regions. In this regard, on November 25, 2022, the Cabinet of Ministers decided to ban the export of fuel wood, and in the frontline areas, fuel wood was even distributed free of charge among households.

In addition to fuel wood harvested by state-owned forestry enterprises, forestry waste also includes logging waste and non-liquid wood that cannot be used in processing due to low technical properties. The potential of forest wood biomass, which is accounted for and is theoretically available for energy production, is 64–80 % of the volume of wood harvesting. In addition, there is logging waste, mainly branches and wood chips, which is currently not accounted for and, according to experts of the Bioenergy Association of Ukraine, constitutes an additional 14 % of the potential. However, currently, in Ukraine, there are no developed principles of bioenergy policy, as well as principles and tools that would regulate the process of using wood biofuel for energy purposes, taking into account the results of the assessment of the available biomass potential and the requirements for achieving sustainable development [7].

In Ukraine, the fastest growing sector of the economy is the agricultural sector. Therefore, it is expected to generate more and more biomass, which is needed for heat and electricity production. Ukraine owns large areas of land, but their potential, especially in the field of biofuel production, is used to a small extent. At present, types of biomass such as agricultural waste from crop and animal husbandry and energy plants have the greatest energy potential [8], [9].

The integration of solar radiation into district heating systems is becoming an increasingly common practice in some countries. The general idea of introducing solar collectors into heat networks is to partially or fully store thermal energy during the summer months [10]. To estimate the amount of solar radiation in different countries of the Earth, it is advisable to use the data of the Photoelectric Geoinformation System of the European Commission [11].

Wind energy significantly depends on external conditions, so it is characterized by uneven supply. In order to manage these resources, it is recommended to combine them with energy storage or other energy sectors. Thus, there are studies where wind turbines in combination with heat energy storage devices provide energy for the district heating systems [12]. The Global Wind Atlas was used for the determined values of the average wind speed to characterize the spatial distribution of wind energy [13].

Geothermal heat when used in district heating systems can be obtained from geothermal waters and soil of the surface layers of the Earth [14]. Geothermal waters are located at a depth of 3–5 km and have a temperature of up to 300 °C. In heat supply systems, it is advisable to use geothermal water with a temperature of 40–150 °C. Depending on the chemical composition, mineralization and temperature, it can be used in heating systems with direct use of water and in systems with the use of intermediate heat exchangers [15]. The soil of the surface layers of the Earth belongs to low-temperature sources of energy, and its temperature depends on the depth, type and humidity of the soil, and the season. Low-potential geothermal energy of the soil can be used only indirectly, by previously increasing the temperature potential of the heat carrier in heat exchangers of various types and in heat pumps.

In these studies, a spatial analysis of such renewable energy sources in the Lviv region as wind energy, solar radiation energy, biomass energy, in particular livestock waste, forestry and sewage sludge, will be performed.

4. Research results

Lviv region is located in the west of Ukraine. According to the administrative and territorial reform of July 19, 2020, Lviv region has 7 districts: Drohobytskyi, Zolochivskyi, Lvivskyi, Sambirskyi, Stryiskyi, Chervonogradskyi and Yavorivskyi. Each district is divided into territorial communities, of which there are 73 in the Lviv region [16].

The Global Wind Atlas [13] was used to determine the average wind speed in the Lviv region. This atlas provides information on wind speed in the period from 2008 to 2020 for all countries of the world, and it also displays the territorial units of the countries and their administrative settlements. While smaller territorial units are also shown for the countries of the European Union, for Ukraine at present this atlas is divided only into regions and the location of the regional center is indicated. Therefore, the approximate location of the center of the territorial community was used to determine the average wind speed in each territorial community of Lviv region. Wind speed at a height of 100 m was taken into account based on modern requirements for the height of wind turbines. Figure 1 shows the average wind speed, m/s, at a height of 100 m in the territorial communities of Lviv region.

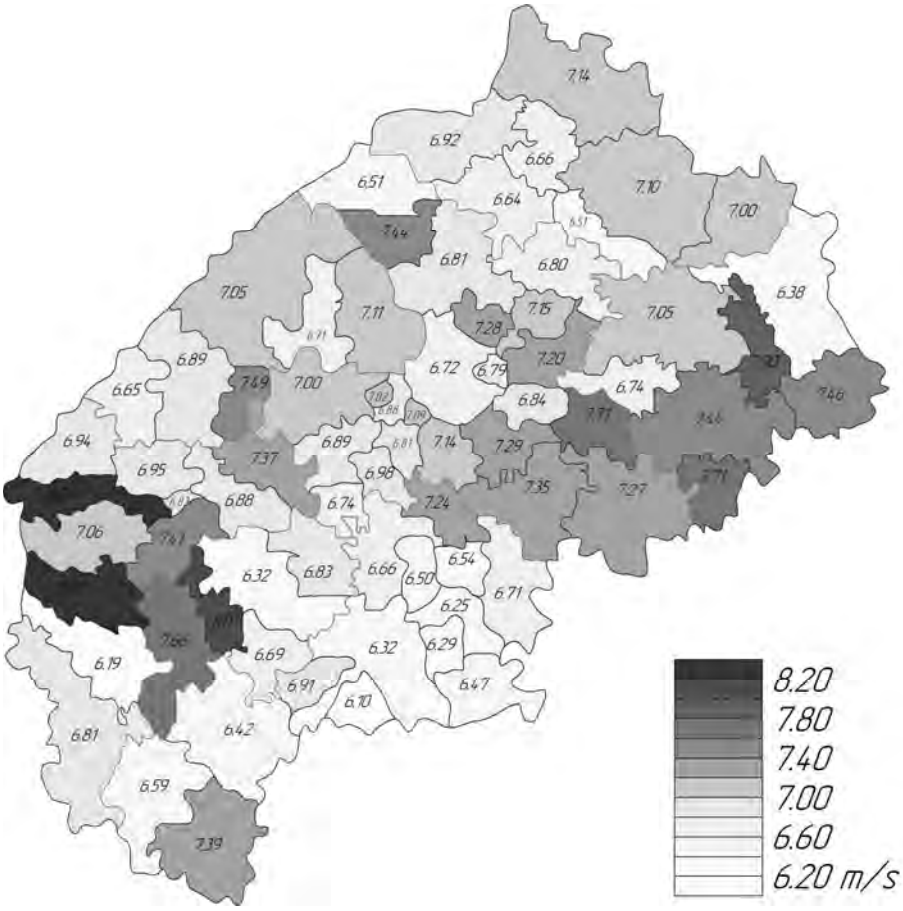

Fig. 1. Average wind speed, m/s, at a height of 100 m in territorial communities of Lviv region.

As can be seen from Fig. 1 the highest value of the average wind speed is observed in Khirivska urban community of Sambir district and is equal to 8.26 m/s, and the lowest value is in Morshynska urban community of Stryi district and is 6.1 m/s. Based on the average values of the wind speeds at a height of 100 m in the territorial communities of the Lviv region, the average values of the average wind speeds at a height of 100 m for the districts of the Lviv region were determined, the values of which are shown in Fig. 2.

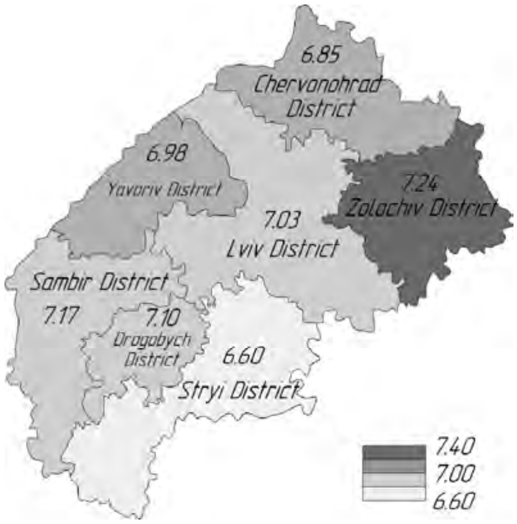

Fig. 2. Average wind speed, m/s, at a height of 100 m in the districts of Lviv region.

As can be seen from Fig. 2 the highest value of the average wind speed is observed in the Zolochiv district and is equal to 7.24 m/s, and the lowest value is in the Stryi district and is 6.6 m/s.

Data from the Photoelectric Geoinformation System of the European Commission were used to assess differences in solar radiation between districts and territorial communities of Lviv region [11]. According to [11], the highest amount of solar radiation in territorial communities of Lviv region occurs in July, and the lowest in December. Solar energy resources for each territorial community of Lviv region are presented in Fig. 3 according to the values of annual irradiation at an angle of inclination of 35° in kWh/(m^2 year), and they were chosen based on the location of the center of the territorial community.

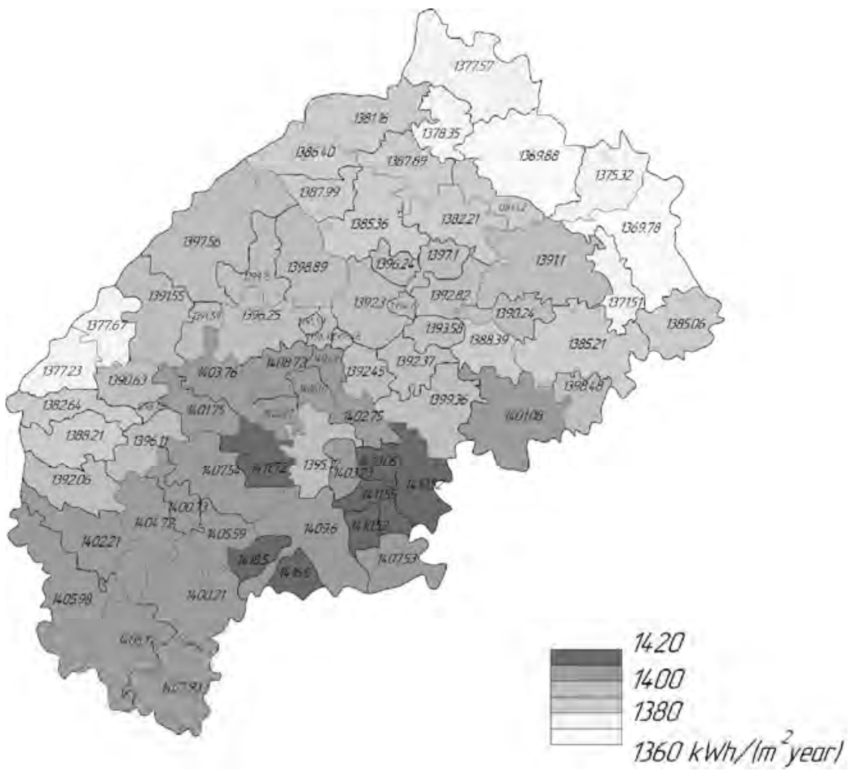

Fig. 3. The annual amount of solar radiation per 1 m^2 of the surface, which is fixed at a fixed angle of 35°, kWh/(m^2 year), in the territorial communities of the Lviv region.

As can be seen from Fig. 3, the highest value of the annual amount of solar radiation is observed in the Hrabovetska-Dulibiv community of the Stryi district (1418.50 kWh/(m^2 year)), and the lowest value is in the Brodiv community of the Zolochiv district (1369.78 kWh/(m^2 year)).

Based on the average values of the annual amount of solar radiation for the territorial communities of Lviv region from Fig. 3, the average values of the annual amount of solar radiation per 1 m^2 of the surface, which is fixed at a fixed angle of 35^o, kWh/(m^2 year), were determined for the districts of the Lviv region (Fig. 4).

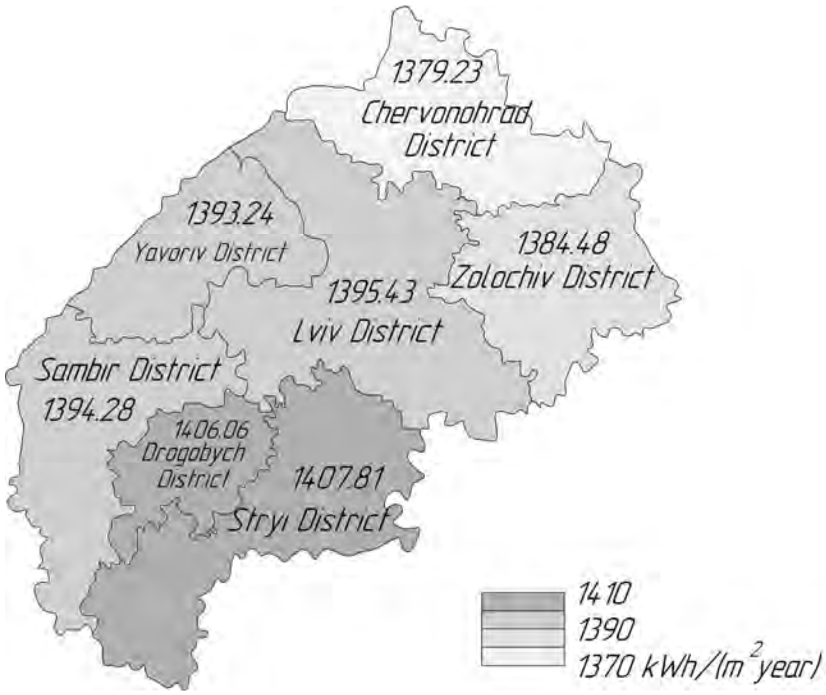

Fig. 4. The annual amount of solar radiation per 1 m^2 of the surface, which is fixed at a fixed angle of 35^o, kWh/(m^2 year), in the districts of Lviv region.

As can be seen from Fig. 4, the highest value of the annual amount of solar radiation in the Stryi district is 1407 kWh/(m^2 year), and the lowest value is in the Chervonograd district, 1379.23 kWh/(m^2 year).

There is no information on data on the number of farm animals as of 2023 for different territorial communities or at least districts of Lviv region. According to the data of the Main Department of Statistics in the Lviv region, there is information on the total number of farm animals for the Lviv region. As of January 1, 2022, the following number of agricultural animals was calculated, thousand heads: cattle – 126.7, pigs – 435.3, sheep and goats – 29.8, horses – 23.5, poultry – 11576.9 [17]. The amount of manure produced by animals depends on their species, age, method of keeping, amount and conditions of nutrition, availability, amount and type of bedding, etc. [18]. The following values were taken as the average amount of manure per day per animal in these studies: 1 cow – 50 kg, 1 pig – 9 kg, 1 sheep (goat) – 5 kg, 1 horse – 20 kg, 1 chicken – 0.25 kg. The main characteristic of manure is its moisture content, which for different types of animals is in the range of 60–96 % [19]. Therefore, to determine the dry fraction of manure, which can be used for biogas production, in this work, the average moisture content of manure is 78 %. The results of calculating the amount of dry fraction of manure that can be obtained from agricultural animals of Lviv region are shown in Table 3.

Lviv region is one of the most forested regions of Ukraine. Forests occupy an area of 694.6 thousand hectares, which is 31.8 % of the territory of the Lviv region. Forests on the territory of the region are unevenly distributed; the main part of the forested area is in the mountainous regions of the Carpathians. The average reserve of wood mass per 1 ha of land covered with forest vegetation in the Lviv region is 260 m^3. The volume of wood harvesting in forests is determined by the "Ukrderzhlisproekt" on the basis of scientifically based calculations and approved by the Ministry of Environmental Protection and Natural Resources of Ukraine [20]. The amount of fuel wood harvested in the period from 2010 to 2020 is shown in Table 1 [16].

Table 1. Harvesting of fuel wood in the Lviv region, thousand m^3 [16].

Year	2010	2015	2018	2019	2020
Fuel wood, thousand m^3	579.3	758.4	652.3	580.9	541.0

The distribution of forest fund lands by districts of Lviv region as of 2015 is shown in Fig. 5 [20], but there is no information on the amount of fuel wood harvested for individual districts of the region. Therefore, the amount of fuel wood in these studies is determined in general for the region, with an average wood density of 600 kg/m^3 (Table 3).

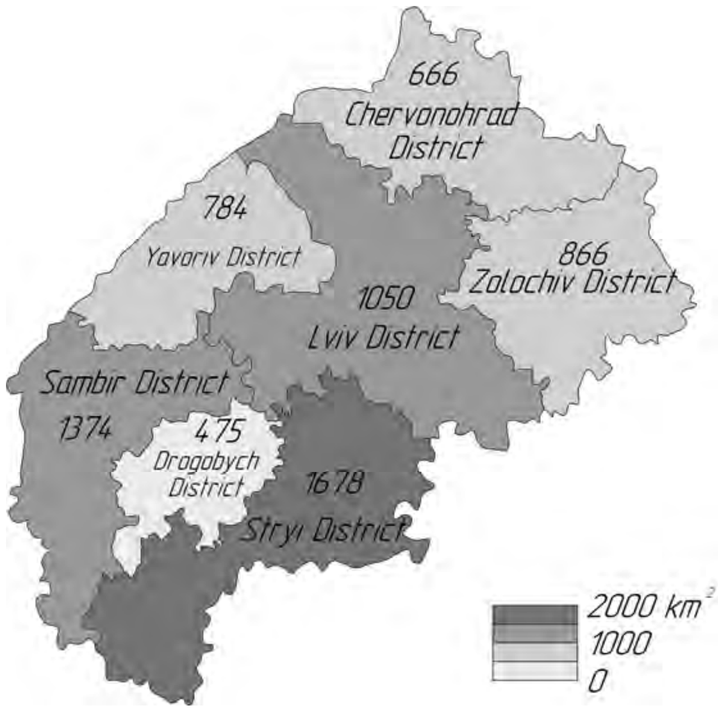

Fig. 5. Distribution of forest fund lands, km^2, by districts of Lviv region as of 2015 [18].

As can be seen from Fig. 5, the largest amount of forest fund land is in Stryi district and is 1,678 km^2, the smallest amount of forest fund land is in Drohobytsky district (475 km^2).

In Ukraine, more than 50 % of people use centralized water supply and drainage systems. Sewage water is treated at sewage treatment plants. The capacity of sewage treatment plants in the Lviv region is shown in Table 2 [16]

Table 2. Capacity of sewage treatment plants in the Lviv region, million m^3 [16].

Year	2000	2005	2010	2015	2018	2019	2020
Capacity of sewage treatment plants, million m^3	386.3	326.5	330.2	269.2	278.8	281.7	365.3

During wastewater treatment, a significant amount of sediment is formed, which accumulates on sludge sites and has a negative impact on the environment and people's lives. In the world, sewage sludge is used in agriculture, in the production of building materials, to obtain energy by burning the sludge, and in the aerobic and anaerobic transformation of sewage sludge. In Ukraine, 3 million tons of sewage sludge is produced per year, and only 5 % is used in agriculture, the remaining 95 % of sewage sludge is land filled [21]. In Lviv in 2020, an agreement was signed [22] on the construction of a biogas plant, in which sewage sludge from Lviv's sewage treatment plants will be used to generate biogas. The generated biogas is planned to be fed to a cogeneration plant for the combined production of electricity and thermal energy. Commissioning of the biogas plant in accordance with the contract was planned for June 2023, but first Covid-19, now the Ukrainian-Russian war are holding back the implementation of the project. When converted to dry matter in Ukraine, water treatment facilities produce 150 g of sediment after primary settling tanks and 80 g after secondary sedimentation for each cubic meter of wastewater entering for treatment [23].

The capacity of sewage treatment plants of individual cities and former districts of the Lviv region are given in [16]. According to these data, the capacity of sewage treatment plants in new districts of Lviv region was formed and is shown in Fig. 6.

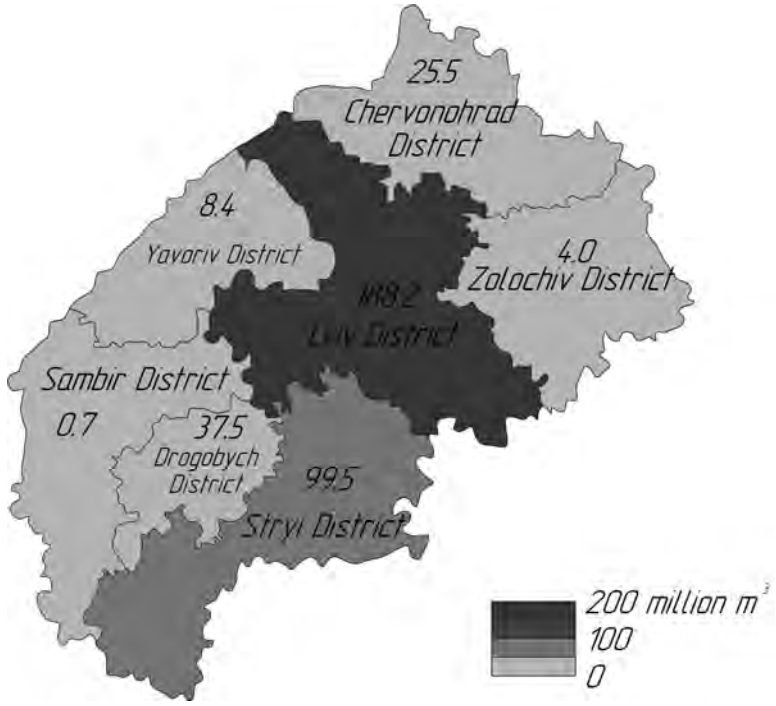

Fig. 6. Capacity of sewage treatment plants by district of Lviv region, million m^3.

As can be seen from Fig. 6, the capacity of sewage treatment plants differs significantly by region. Everything depends on the presence and length of the centralized sewage system in the settlements. The lowest value of the capacity of sewage treatment plants is in the Sambir district and is 0.7 million m^3/year, and the largest is in the Lviv district, which is equal to 188.2 million m^3/year. The amount of sewage sludge depends on the capacity of treatment facilities. The greater the capacity of treatment facilities, the greater the amount of wastewater produced during their treatment. Therefore, the largest amount of sewage sludge is in the Lviv district and is equal to 8.70 t/(km^2 year), and the smallest is in the Sambir district and is equal to 0.05 t/(km^2 year) (Table 3).

The general distribution of potential renewable resources by districts of the Lviv region is given in the Table. 3.

Table 3. General distribution of potential renewable resources in the districts of Lviv region

District	Drohobytskyi	Zolochivskyi	Lvivskyi	Sambirskyi	Stryiskyi	Chervonohradskyi	Yavorivskyi
Area, km^2	1454	2887	4978	3247	3891	2997	2377
Solar irradiation, kWh/(m^2 year)	1406.06	1348.48	1395.43	1394.28	**1407.81**	1379.23	1393.24
Wind speed, m/(s year)	7.10	**7.24**	7.03	7.17	6.60	6.85	6.98
Fuel wood, t/(km^2 year)	14.86						
Manure resource, dry matter, t/(km^2 year)	50.7						
Sewage sludge resources, t/(km^2 year)	5.93	0.31	**8.70**	0.05	5.88	1.96	0.81

As can be seen from the Table 3, none of the districts of the Lviv region is a leader in terms of the number of potential renewable sources. Stryi district is a promising district for the availability of renewable energy sources, since the solar radiation value and the amount of forest land in it are higher than the same indicators for other districts; in addition, the amount of sewage sludge is also one of the highest in the region. The second district in terms of the number of renewable energy sources is Lviv. It has the highest amount of sewage sludge and other indicators are at high levels. It should also be noted that the discrepancy between the values of solar radiation and wind speed does not differ significantly for different districts of Lviv region. The biggest difference is in indicators of sewage sludge. Due to the lack of statistical data on fuel wood and manure resources for each of the districts of the Lviv region, they were assumed to be the same for all districts. For the possibility of increasing the total share of renewable energy sources, the regions of the region can cooperate with other regions of both Lviv region and neighboring regions.

5. Conclusion

In this article, a spatial analysis of renewable energy sources such as wind energy, solar radiation, fuel wood, manure of agricultural animals and sewage sludge in the districts of Lviv region is performed. After the analysis of literary sources, it was established that there is no data for the districts of the Lviv region regarding the available potential of some resources biomass, in particular, fuel wood, agriculture animal manure, etc. For the possibility of widespread introduction of renewable energy sources, it is necessary to introduce the accounting of available biomass resources in the regions and districts of Ukraine and their distribution by various branches of the national economy, in particular heat energy. It was established that the most promising district in terms of the availability of renewable energy sources is the Stryi district, since the amount of solar radiation and the amount of forest land in it are higher than the same indicators for other districts, in addition, the amount of sewage sludge is also one of the highest in the region. To ensure the increase in the total share of renewable energy sources, the districts of the region can cooperate with other districts of both Lviv region and neighboring regions.

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Просторовий аналіз відновлюваних джерел енергії Львівщини

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Анотація

Упровадження відновлюваних джерел енергії дає змогу розширити можливості розвитку галузей народного господарства, зокрема теплоенергетики, прискорити економічне зростання та зменшити надходження парникових газів у довкілля. Просторовий аналіз відновлюваних джерел енергії сприяє ефективному їх використанню та дає можливість планувати місцевий розвиток відновлюваної енергетики. У статті виконано просторовий аналіз відновлюваних джерел енергії Львівської області, таких як енергія вітру, сонячне випромінювання, паливної деревини, гною сільськогосподарських тварин та осаду стічних вод. Встановлено, що найперспективнішим районом за наявністю відновлюваних джерел енергії є Стрийський район, оскільки кількість сонячного випромінювання та кількість земель лісового фонду у ньому перевищують ці самі показники для інших районів. Крім того, кількість осаду стічних вод також є однією із найвищих у області. Щоб збільшити загальну частку відновлюваних джерел енергії, райони області можуть співпрацювати з іншими районами як Львівської області, так і сусідніх областей.

Ключові слова: системи централізованого теплопостачання; енергія вітру; сонячне випромінювання; гній сільськогосподарських тварин; паливна деревина; осад стічних вод.