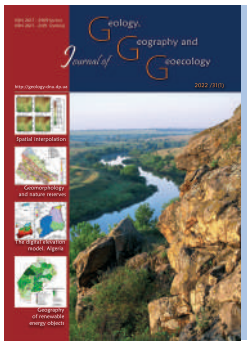

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The geographical location, current state and forecasting of development of renewable energy facilities within Lviv region

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Abstract. Ukraine, as a member of the European Energy Community, has committed itself to achieve a share of 12% renewables in its final energy generation by 2025 and a share of at least 25% by 2035 (including all hydropower and thermal energy capacities). In 2019, the share of renewables in electricity generation in Ukraine was only 4%. Renewables produce 4% of total electricity production in Lviv region. According to this indicator, the region is the leader in the Western Ukraine. The paper analyzes the geographical location and the current state of renewable energy facilities in the Lviv region and forecasting their further development. As of July 1, 2020, in Lviv region there are 67 renewable energy facilities with a total capacity of over 310 MW. Most of the renewables supply electricity to the integrated energy system at a "green" tariff. They include two wind power plants with a total capacity of 33.9 MW in Staryy Sambir district; 59 industrial solar power plants with a total capacity of over than 275 MW in 15 administrative districts of Lviv region, Boryslav and Chervonohrad cities; two mini hydropower plants with a total capacity of 0.576 MW in Drohobych and Turka districts; three mini heat and electricity production plants running on biomass and producing electricity and thermal energy (Radekhiv heat and electricity production plant with a capacity of 2.4 MW, other heat and electricity production plants with a total capacity of 3.66 MW); one biomass electricity production plant operating in the Eco-Mit LLC pig farm in the village of Batyatychi in Kamianka-Buzka district. In addition, 985 solar electricity production plants at private households were built in 20 administrative districts and 9 cities in the region. Their total capacity is over 19 MW, which is equivalent to average capacity of one industrial solar electricity production plant. The leader in the number of industrial facilities for renewable energy is Yavoriv district, where almost half of the total renewables' capacity of Lviv region is concentrated. The largest number of solar electricity production plants of private households is located in Pustomyty and Yavoriv districts, and Lviv city, whereas the lowest number in mountainous areas, particular in Turka and Skole districts. As of January 1, 2020, solar energy constituted 70% of renewable energy in Lviv region. At the same time, according to the Development Strategy of Lviv region for the period of 2021–2027, the largest share in the structure of electricity production belongs to wind energy. The development of renewable energy in Ukraine depends on the rate of "green" tariff. The actual financial stimulus has led to a rapid increase in the share of renewables in total electricity generation in Ukraine and Lviv region in particular. Promising areas for renewable energy in Lviv region are wind and bioenergy developments.

Keywords: renewable energy, renewable resources, capacity of renewable energy facilities, decarbonization, "green" tariff.

Географічне розташування, сучасний стан і прогнозування розвитку об'єктів відновлюваної енергетики в межах Львівської області

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Анотація. Україна, як член Європейського енергетичного співтовариства, взяла зобов'язання до 2025 року досягти частки енергії, що генерується відновлюваними джерелами, до рівня 12% від загального первинного постачання енергії та не менше 25% – до 2035 року (включаючи всі гідрогенеруючі потужності і термальну енергію). У 2019 році частка відновлюваних джерел енергії у виробництві електроенергії в Україні становила лише 4%. У Львівській області встановлено близько 6% таких потужностей і 4% – у структурі загального виробництва електроенергії. За цим показником регіон є лідером на заході України. У роботі проаналізовано географічне розташування і сучасний стан об'єктів відновлюваної енергетики у Львівській області та прогнозування їхнього подальшого розвитку. Станом на 01.07.2020 р. на Львівщині функціонує 67 об'єктів відновлюваної енергетики загальною потужністю понад 310 МВт. Більшість з об'єктів подають електроенергію в об'єднану енергетичну систему за "зеленим" тарифом. До них відносять дві вітрові електростанції в межах Старосамбірського району, загальною потужністю 33,9 МВт; 59 промислових сонячних електростанцій на території 15 адміністративних районів та у містах Борислав і Червоноград, загальною потужністю понад 275 МВт; дві міні гідроелектростанції в межах Дрогобицького і Турківського районів, загальною потужністю 0,576 МВт; три міні теплових електростанцій, що працюють на біомасі та виробляють електричну і теплову енергію (Радехівська ТЕС потужністю 2,4 МВт, інші теплові електростанції загальною потужністю 3,66 МВт); одна біоенергетична

установка, що працює на основі свинокомплексу ТзОВ "Еко-Міт" у с. Батятичі Кам'янко-Бузького району. Окрім цього у регіоні побудовано 985 сонячних електростанцій приватних домогосподарств на території 20-ти адміністративних районів і 9-ти міст загальною потужністю понад 19 МВт, що рівноцінно середній потужності промислової сонячної електростанції. Лідером за кількістю промислових об'єктів відновлюваної енергетики є Яворівський район, де зосереджено практично половину усієї встановленої потужності регіону. Найбільша кількість сонячних електростанцій приватних домогосподарств розміщено у Пустомитівському, Яворівському районах і м. Львів, найменша – у гірській місцевості, зокрема у Турківському і Сколівському районах. Станом на 01.01.2020 рік, у структурі виробництва електроенергії у Львівській області від об'єктів відновлювальної енергетики понад 70 % припадало на сонячну енергетику. Водночас, відповідно до Стратегії розвитку Львівської області на період 2021–2027 років, більшу частку у структурі виробництва електричної енергії відведено вітровій енергетиці. Розвиток відновлюваної енергетики в Україні залежить від ставки "зеленого" тарифу. Власне фінансове стимулювання зумовило стрімке зростання частки відновлюваних джерел енергії у загальному виробництві електроенергії в Україні та у Львівській області зокрема. Перспективними напрямами відновлюваної енергетики у Львівській області є розвиток вітрової і біоелектроенергетики.

Ключові слова: відновлювана енергетика, відновлювані ресурси, потужність об'єктів відновлюваної енергетики, декарбонізація, "зелений" тариф.

Introduction

Such leading countries as USA, Germany, Spain, Sweden, Denmark and Japan are targeting to reach up to 50 % of renewables in the total energy balance of the first half of the XXI century (IRENA, 2020). Ukraine, as a member of the European Energy Community, has committed itself to achieve a share of 12 % renewables it its final energy generation by 2025 and a share of at least 25 % by 2035 (including all hydropower and thermal energy capacities) (Energy strategy of Ukraine, 2017). In 2020, the share of renewables in electricity generation of Ukraine was only 4 %. Therefore, stimulation of renewable energy development is one of priorities in the state policy of Ukraine (Kudria, 2015).

The development of solar and wind energy in our country received a powerful impetus with the introduction of the "green" tariff in 2008 (Law of Ukraine, 2009). The main facilities that generate renewable energy include industrial and private solar electricity production plants (SPPs), wind ectricity production plants (WPPs), small hydropower plants (SHPPs), and bioelectricity production plants.

The lion's share (65 %) of SEPPs and WEPPs is concentrated in five southern regions of the country: Kherson (16 %), Zaporizhzhia (16 %), Mykolayiv (12 %), Dnipro (12 %) and Odesa (9 %) (Buslavets, 2019). About 6 % of such capacities are deployed in Lviv region, and according to this indicator, the region is the leader in renewable energy in Western Ukraine. In recent years, we have been observing positive dynamics in total production of electricity from renewable sources, which has increased significantly from 3.76 million kWh in 2013 to 318.187 million kWh in 2019 (Pylypovych et al., 2020). Accordingly, in 2019, the share of renewables was more than 4 % in the structure of total electricity production in Lviv region (Energy, environment, 2019).

The purpose of the study is to analyze the geographical location and current state of renewable energy facilities in western Ukraine and outline perspectives for their further development. The study is aimed at highlighting current issues of renewable energy and the impact of renewables on economic development and environmental state in the region. The problems are studied on the example of Lviv region as the leading region in renewable energy in Western Ukraine.

Materials and methods

The study used data from National Commission for State Regulation of Energy and Utilities (NCRECP, 2020a, 2000b, 2000c), National Energy Company "Ukrenergo" (NPC Ukrenergo, 2020), Fuel and Energy Department for Energy Saving at Lviv Regional State Administration (Department of Fuel and Energy Sector and Energy Saving, 2020), as well as information from Ukrainian and foreign expert publications (Kudria, 2015) and the official website of the State Statistics Service of Ukraine (Energy, environment, 2019).

The ISO 14064 (ISO 14064, 2006) methodology is used in the study as a part of international standards for environmental management of the ISO 14000 series, which provides a free set of tools for quantitative assessment programs, monitoring, reporting and monitoring of greenhouse gas emissions. This standard is used in many national calculation methods, including the *UK Carbon Trust Standard*. Other standard is the *Tool to calculate the emission factor for an electricity system* of the United Nations Framework Convention on Climate Change (Tool to calculate the emission factor for an electricity system, 2018). This technique allows determining emission coefficients for energy systems.

Results and their analysis

As of July 1, 2020, Lviv region contains 67 renewable energy facilities with a total capacity of over 310 MW (Fig. 1). Most of the renewables supply electricity to the integrated energy system at a "green" tariff. They include two wind electricity production plants with a total capacity of 33.9 MW in Staryy Sambir district; 59 industrial solar electricity production plants with a total capacity of over 275 MW in 15 administrative districts of Lviv region and cities of Boryslav and Chervonohrad; two mini hydropower plants with a total capacity of 0.576 MW

in Drohobych and Turka districts; three mini heat and electricity production plants running on biomass and producing electricity and thermal energy (Radekhiv heat and electricity production plant with a capacity of 2.4 MW, other heat and electricity production plants with a total capacity of 3.66 MW); one biomass electricity production plant operating in the Eco-Mit LLC pig farm in the village of Batyatychi in Kamianka-Buzka district. The leader in the number of industrial facilities for renewable energy is Yavoriv district, where almost a half of the total renewables' capacity of Lviv region is concentrated. In addition, 985 solar electricity production plants at private households were built in 20 administrative districts and 9 cities in the region with a total capacity of over 19 MW, which is equivalent to the average capacity of one industrial solar electricity production plant. The largest number of solar electricity production plants of private households is located in Pustomyty and Yavoriv districts, and Lviv city; the lowest in mountainous areas, particular in Turka and Skole districts) (Department of Fuel and Energy Sector and Energy Saving, 2020).

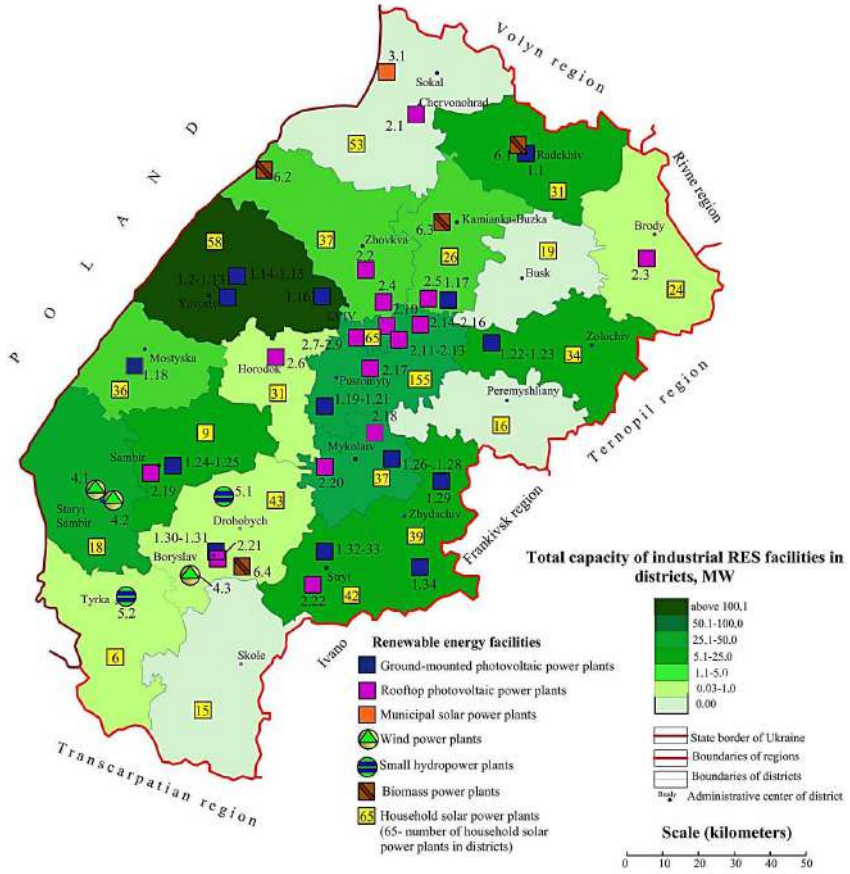

Fig 1. The geographical location and capacity of renewable and alternative energy facilities in Lviv region, as of February 2020 (NCRECP, 2020a)

Legend to Fig. 1

No	Name	Power, MW
	Ground mounted solar power plants	
1.1	Radekhiv solar station	8.455
1.2	Ternovytsia 2 and 4	5.940
1.3	Ternovytsia Energy	5.797
1.4	Ternovytsia 1 and 3	5.797
1.5	Ternovytsia Sunny 2	5.797
1.6	Ternovytsia Energy 1	5.940
1.5	Ternovytsia Soniachna 1	5.940
1.6	Ternovytsia Sunlight 1	5.940
1.7	Ternovytsia Sunlight 2	5.797
1.8	Ternovytsia Solar 1	13.023
1.9	Ternovytsia Solar 2	15.537
1.10	Ternovytsia Solar Plus 1	12.831
1.11	Ternovytsia Solar Plus 2	15.537
1.12	Yavoriv-1, phase I	36.753
1.13	Yavoriv-1, phase II	36.753
1.14	Ozerna	9.900
1.15	Pryozerna	9,940
1.16	Vorotsiv	3.201
1.17	Staroyarychivska	2.745
1.18	Nagirne	1.795
1.19	Shchyrets-1	2.035
1.20	Shchyrets-2	4.488
1.21	Semenivka	1.141
1.22	Hlyniany-1	3.346
1.23	Hlyniany-2	17.952

No	Name	Power, MW
1.24	Sambirska	3.116
1.25	Sambirska-2	4.982
1.26	Pivdenna	9.949
1.27	Pivnichna	9.949
1.28	Rozdilska	19.898
1.29	Khodoriv	4.212
1.30	Boryslavska	8.452
1.31	Boryslavska-2	0.326
1.32	Dobrivlyany	5.768
1.33	Dobrivlyany-2	10.122
1.34	Gnizdychiv	2.158
Rooftop solar electricity production plants		
2.1	Chervonograd	0.628
2.2	Velykyi Doroshiv-1	1.000
2.3	Sukhovolia-1	1.037
2.4	Malekhiv	2.000
2.5	Zapytiv	0.500
2.6	Horodok	0.181
2.7	72 Heroiv UPA str., Lviv	0.220
2.8	36 Schyretska str., Lviv	0.619
2.9	Sknyliv	0.189
2.10	10 Plastova str., Lviv	0.980
2.11	2 Buzkova str., Lviv	0.700
2.12	Vynnyky-1	0.248
2.13	Vynnyky-2	1.403
2.14	Pidberiztsi	0.218
2.15	Lysynychi	no data
2.16	Chyshky	0.567
2.17	Sokilnyky	0.066
2.18	Stilsko	no data
2.19	Sambir	0.748
2.20	Boryslavska, Syntez-1	1.110
2.21	Rozvadiv	no data
2.22	Hrybovets	0.211
Community solar electricity production plants		
3.1	Variazhska	no data
Wind electricity production plants		
4.1	Staryy Sambir-2	20.700
4.2	Staryy Sambir-1	13.200
4.3	Skhidnytska (Truskavetska)	0.800
Small hydroelectric power plants		
5.1	Novoshytska	0.165
5.2	Yavirska	0.450
Bioenergy facilities		
6.1	Polove	2.400
6.2	Rava-Ruska	2.160
6.3	Batyatychi	no data
6.4	Truskavets	1.500

As of January 1, 2020, solar energy constituted 70% of renewable energy in Lviv region (Department of Fuel and Energy Complex Sector and Energy Saving, 2020) (Fig. 2). At the same time, according to the Development Strategy of Lviv region for the period of 2021–2027, the largest share in the structure of electricity production is given to wind energy (Development strategy of Lviv region for the period of 2021–2027) (Fig. 3). Besides, biothermal electricity production plants and biogas plants are planned to increase energy generation.

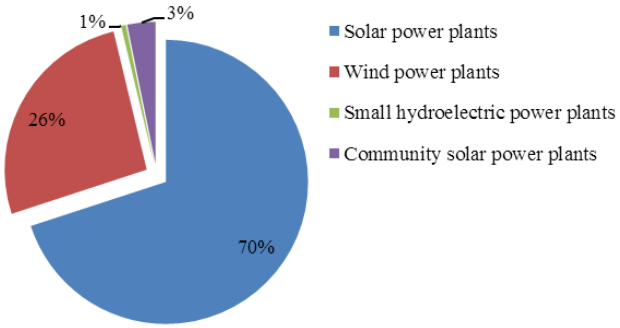

Fig. 2. The structure of electricity production by renewable energy facilities in Lviv region, in 2019 (NCRECP, 2020a)

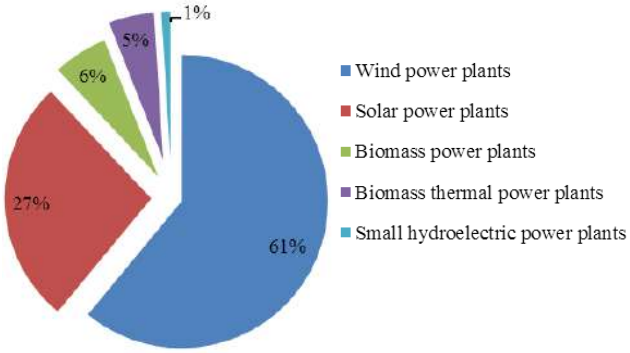

Fig. 3. . The forecast of electricity production by renewable energy facilities in Lviv region until 2023. (Development strategy of Lviv region for the period 2021–2027, 2020)

We will describe in more details the main directions in development of renewable and alternative energy in Lviv region.

Solar energy. The main natural prerequisite for the development of solar energy in a given region is availability of climatic resources for solar energy. In modern applied researches, when planning a network of SES and calculating their potential power, such indicator as global horizontal radiation (insolation) (kWh/m^2) is applied. It indicates the power of electromagnetic radiation per area square, received from the Sun in the wavelength range of the measuring instrument. In other words, it is solar radiation, integrated in time (intensity of solar radiation).

Lviv region is located in a zone where global horizontal radiation, according to the informational resource *SolarGIS,* fluctuates within 1.100–1.150 kWh/m^2 (SolarGIS. iMaps, 2020) (Fig. 4). Compared to other regions of Ukraine, Lviv region is in the fourth zone with the lowest rate of solar radiation intensity. At the

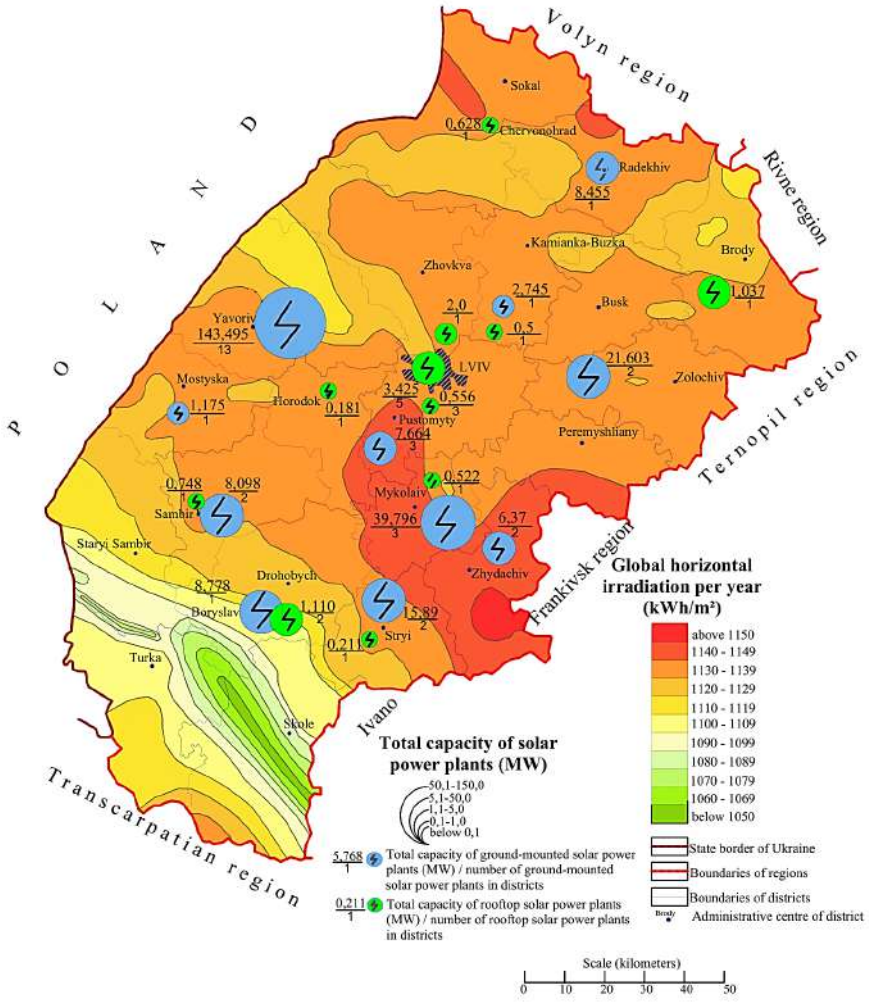

Fig. 4. Global horizontal radiation in Lviv region and total capacity of industrial (ground mounted and rooftop) solar electricity production plants within administrative districts (Lopushanska, 2019)

same time, Lviv region is one of the leaders in SES deployment in western Ukraine. In general, insolation index in Lviv region is of 1.120–1.130 kWh/m^2. The highest numbers (over 1.140 kWh/m^2) are typical for south-eastern plain areas of the region (Zhydachiv, Mykolaiv, Pustomyty districts) (Lopushanska, 2019).

The first industrial solar electricity production plant in Lviv region started operating at the end of 2012 in Ralivka village, Sambir district. This 3.116 MW plant was built by Eco-Optima LLC together with Czech investors on a piece of land unsuitable for agricultural production with an area of more than 20 hectares. In December 2016, a license was received and a "green" tariff was agreed for the rooftop Boryslav SES "Syntez-1" with a capacity of 1.14 MW. Generally, the green tariff rates for each business entity in Ukraine that uses renewable energy sources are set on the basis of a resolution of the National Commission for State Regulation of Energy and Utilities and published quarterly on its official website (NCRECP, 2020b).

Today there are 59 industrial SES in Lviv region. The distribution of electricity production from them is uneven. The largest capacity (140 MW) is generated by 15 SESs, which were built in Yavoriv district near the village of Ternovytsia. These power plants are located in the quarry and dump areas of Yavoriv state mining and chemical enterprise "Sirka". Solar energy stations in Mykolayiv (39.8 MW), Zolochiv (21.6 MW) and Stryy (15.9 MW) districts also are singled out with their significant capacities. There are no industrial SESs in the mountainous areas of the region, neither in Peremyshliany nor Busk districts.

Most industrial solar electricity production plants in the region are located in the area with sufficient insolation (1.130–1.139 kWh/m^2), except Boryslav SES, which is located on the edge of the mountainous part of the Carpathians, where the insolation rate is relatively lower (1.110–1.119 kW year/m^2). Eight stations were built in the area with the highest insolation rate (Pustomyty, Mykolaiv and Zhydachiv districts), but their total capacity is much lower than the capacity of stations built in Yavoriv district.

In recent years, the number of private SES in the region is growing. The first private SES with a capacity

of 4 kW and 10 kW were built in 2014 in Solonka village in Pustomyty district. A significant leap in the deployment of household SES has taken place since August 2018. Most of them are in Pustomyty district (155 private households), as well as in Lviv city (65) and Yavoriv district (58). This is due to the developed energy infrastructure that enables to connect new ground mounted or rooftop household SES, as well as due to a relatively higher level of income in Lviv city and the mentioned districts. As for the cities of regional subordination in Lviv region, most private SES are deployed in cities of Drohobych (21), Stryy (19), and Boryslav (18). As a rule, a positive trend towards increase of private households SES is observed in every district of Lviv region. This is due to higher public awareness and interest for green energy. A significant number of residents invest in household SES because of the availability of state support programs for soft loans, opportunity to sell excessive electricity at a "green" tariff, and in order to receive environmentally friendly electricity.

It is planned to expand the network of municipal SES in Sokal district, to build 9 more ground mounted and 18 rooftop industrial SES in the region in the future period of 2020–2024 (Plan of Distribution System of the PJSC "Lvivoblenergo", 2020) (Fig. 5). However, given the insignificant solar potential of Lviv region and the introduction of "green auctions" from January 1, 2020 for SES with a capacity of more than one MW, interest of investors to fund in renewables in the region may rapidly fall down.

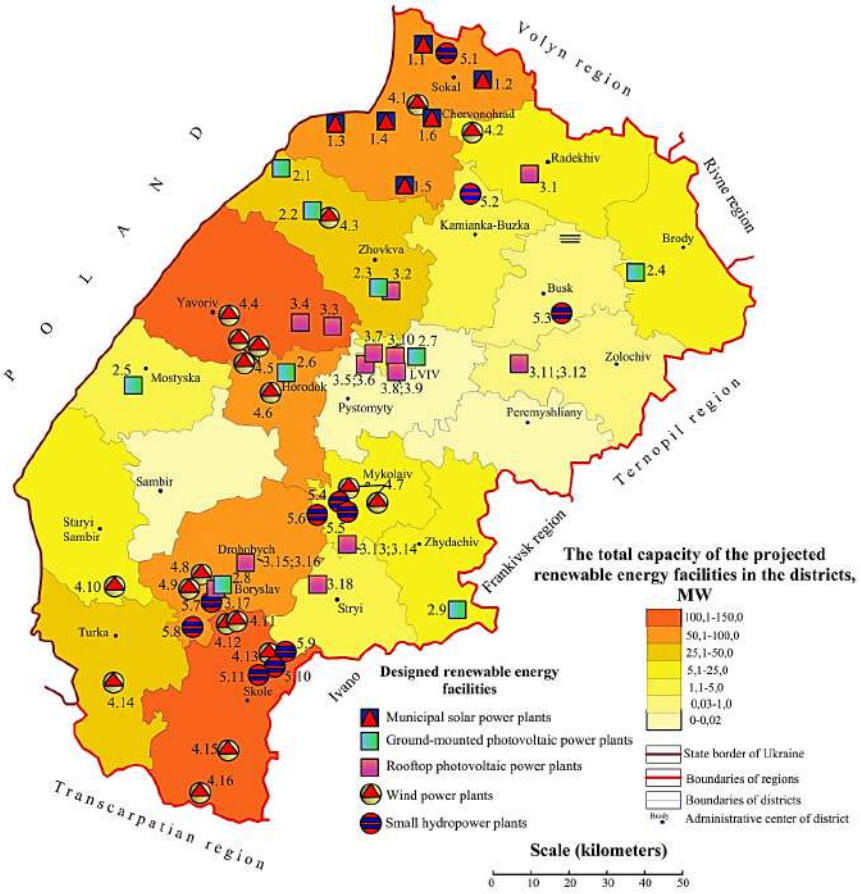

Fig. 5. The geographical location and capacity of the projected renewable energy facilities in Lviv region for the period of 2020–2024 (NCRECP, 2020c)

Legend to the Fig. 5

No	Name	Power, MW
Community solar electricity production plants		
1.1	(Khorobriv	2.00
1.2	Tartakiv	4.00
1.3	Korchiv	2.00
1.4	Belz city council	2.00
1.5	Velyki Mosty	4.00
1.6	Chervonohrad	2.50

No	Name	Power, MW
Ground mounted solar electricity production plants		
2.1	Rava-Ruska	4.50
2.2	Dobrosyn	9.98
2.3	Kulykiv	3.00
2.4	Zabolotsi	6.00
2.5	Nahirne-Buhovychi	1.60
2.6	Horodok	1.20

No	Name	Power, MW
2.7	Vynnyky	2.00
2.8	Boryslav	9.00
2.9	Volodymyrtsi	9.90
Rooftop solar electricity production plants		
3.1	Vuzlove	2.00
3.2	Zvertiv	1.30
3.3	Zhornyska	1.00
3.4	Ivano-Frankove	1.20
3.5	Lviv, Danylo Apostol str.	1.70
3.6	Lviv, Schyretska str.	0.36
3.7	Lviv, Dozvilna str.	0.04
3.8	Lviv, Zelena str.	0.08
3.9	Lviv, Buzkova str.	0.70
3.10	Lviv, Pekarska str.	0.045
3.11	Hlyniany-1	0.40
3.12	Hlyniany-2	0.40
3.13	Kyivets-1	0.996
3.14	Kyivets-2	0,996
3.15	Drohobych-1	0.74
3.16	Drohobych-2	0.56
3.17	Boryslav	no data
3.18	Lanivka	no data
Wind electricity production plants		
4.1	Sokalska	45.20
4.2	Pozdymyr	15.00
4.3	Bobroyidy	14.00
4.4	Yavoriv Energo 2	50.00
4.5	Yavoriv Energo	150.00
4.6	Cherlianske Peredmistia	1.50
4.7	Yarom-4	18.00
4.8	Yarom-6	6.60
4.9	Opaka village	50.00
4.10	Yasenytsia Power	no data
4.11	Skolivska (Ltd. Orivska WPP)	53.20
4.12	Skolivska (Ltd. Skolivska WPP)	60.00
4.13	Yarom	7.00
4.14	Karpatska	36.00
4.15	Yarom-1	10.00
4.16	Skolivska	40.00
Small hydroelectricity production plants		
5.1	Ulvivok, Sokal Reservoir	0.98
5.2	Dobrotvirska SHEP, Dobrotvir	no data
5.3	Storonybaby	no data
5.4	Lypytsi (Kolodruby)	0.20
5.5	Lypytska (Hirska)	0.20
5.6	Nyzhnie Syniovydne (Hirske)	no data
5.7	Boryslavska	0.36
5.8	Dovhe	2.00
5.9	Nyzhnia Stynava	no data
5.10	Nyzhnie Syniovydne	no data
5.11	Verhnie Syniovydne	no data

An important environmental factor in the development of renewable energy in the world is the decarbonization of electricity production. Combustion of fossil fuels (natural gas, coal, peat, etc.) generates a significant amount of greenhouse gas emissions. Therefore, a lot of countries are switching to alternative energy sources that operate without emissions and produce a significant amount of electricity.

Standards and methodologies *Tool to calculate the emission factor for an electricity system* of the UN Framework Convention on Climate Change (Tool to calculate the emission factor for an electricity system, 2018) were used to assess the reduction of greenhouse gas emissions in Lviv region. This techniques allows to determine emission factors for energy systems. According to the calculations, in 2019 during the operation of SES there was a reduction of CO_2 emissions by 184.0 thousand tons per year (Table 1).

Wind energy. Wind energy resources of the region are classified with relation to average annual wind speed and the average annual Mean Wind Power Density at altitudes of 10 m, 50 m, and 100 m from the ground (Energy: Past, Present and Future, 2013). Mean Wind Power Density, measured in W/m^2, depends on the average wind speed, rush wind flow (gust) and variability, air density, local terrain factors, etc.

Mean Wind Power Density and wind speed indicators at the level of 1–50 m are more important in studying the wind potential for the deployment of home wind turbines. Modern industrial electricity production plants typically use wind at altitudes above 100 m above the surface. According to the informa-

Table 1. Calculations of CO2 emission reductions in Lviv region for main sources of renewable energy, as of 1.01.2020

Indicators	Solar power plants	Wind power plants	Small hydroelectric power plants
Industrial capacity, MW	206.216	33.900	0.576
Power factor,%	17	50	80
Expected growth of electricity production, GW	230.00	86.36	1.83
Auxiliary costs,%	0	0	2
Expected amount of electricity supplied to the grid, GW	230.00	86.36	1.83
Baseline emission factor, t	0.8	0.8	0.748
Baseline emissions, thousand tons of CO_2	184.00	69.09	1.37
Designed emissions and leakages	0	0	0
Total emissions reduced, thousand tons of CO_2 per year	184.00	69.09	1.37
Total, thousand tons of CO_2 per a year	254.45		

tional Internet resource *Global Wind Atlas 3.0,* the average Mean Wind Power Density for the territory of Ukraine at the altitude of 100 m is 293 W/m^2, and the average wind speed is 7.49 m/s (Global Wind Atlas, 2020). According to experts, the use of wind turbines in Ukraine for electricity generation in industrial scale is most effective on the Azov-Black Sea coast, in Odesa, Kherson, Zaporizhzhia, Donetsk, Luhansk, Mykolayiv regions, Crimea and the Carpathians (Energy strategy of Ukraine, 2017).

As for Lviv region, the wind potential at a height of 100 m is as follows: Mean Wind Power Density is 371 W/m^2 (from 193 W/m^2 to 549 W/m^2), the average wind speed is 6.6 m/s (5.44–7.75 m/s). The best areas to deploy wind power plants in Lviv region are Volyn Height, Skyb Carpathians (over 424 W/m^2), Pre-Carpathian Height, Podil Height (over 321 W/m^2) and the San River area. They belong to Sokal, Staryy Sambir, Skole, Turka, Mostyska, and Drohobych administrative districts.

It should be noted that despite the high wind potential in the mountainous part of the region and in Podil Height, the possibilities of deploying wind power plants there are limited due to availability of nature reserves and areas of the Emerald Network.

The development of wind energy in Lviv region began in 1997 with the construction of Skhidnytsia (Truskavets) wind electricity production plant, which was built to study the efficiency of wind electricity production plants in the Carpathians. It is a pilot wind electricity production plant with total capacity of 750 kW. The electricity production plant has seven American wind turbines of the USW 56–100 type, manufactured in Ukraine under license.

Staryy Sambir-1 wind electricity production plant (two turbines) with a total installed capacity of 6.6 MW started operating in 2015 and will supply electricity at a "green" tariff until 2030. This is the first wind electricity production plant in Western Ukraine and in the mountainous area of Ukrainian Carpathians. Wind electricity production plant "Staryy Sambir-2" (Strilbychi village) with a capacity of 20.7 MW was deployed in 2017. Thus, today there are two industrial and one experimental wind stations with a total capacity of 34.65 MW in Lviv region today.

In future, in accordance with the Development Strategy of Lviv region for the period of 2021–2027, it is planned to build 16 more wind electricity production plants in eight districts of the region with a total installed capacity of over 505 MW (Fig. 5). This capacity of the wind electricity production plants is comparable with the capacity of Dobrotvir Power Heat and Electricity Production Plant. The largest capacities are planned to be commissioned in Yavoriv (2 facilities with 200 MW) and Skole (4 facilities with 160.2 MW) districts.

In general, the development of wind energy is promising for the region. However, modern wind turbines are extremely expensive when compared to solar panels. There is a number of restrictions for their deployment. In particular, it is important to take into account the impact on the avifauna and chiroptera fauna of the surrounding areas. Another important aspect is a significant number of special documents needed to put a wind electricity production plant into operation.

Methodology used: *Tool to calculate the emission factor for an electricity system* (2018) allows determining the emission coefficients for energy systems. According to calculations in 2019, a wind electricity production plant reduces CO_2 emissions by 69.1 thousand tons/year by reducing fuel combustion (see Table 1).

Small hydropower energy

Energy of small rivers is a mechanical energy of a water flow where water moves down along the slope because of its mass. This energy is used at hydroelectricity production plants. In general, in Ukraine, small hydroelectricity production plants are facilities of up to 10 MW, mini-hydropower plants are from 0.1 to 1.0 MW, and micro-hydropower plants – up to 0.1 MW. Depending on water pressure, the facilities perform functions of a dam, derivation and mixed functions.

According to experts, the hydroelectricity potential of Lviv region is 1.814 million kWh per a year that is the second best rate in Ukraine after Zakarpattia region (4.523 million kWh/year) (Samchenko, 2018). The mountainous terrain contributes significantly to hydro potential of the region.

The first small hydroelectricity production plant in Lviv region was built in Storonybaby village of Busk district in 1911. Seven small hydroelectricity production plants operated in Lviv region last century, five of which are already not operational today. As of 2020, only two SHEPPs are operational in the region: Yavirska SHEPP on the Stryy River (Yavora village, Turka district) and Novoshytska SHEPP on the Bystrytsa River (Novoshychi village, Drohobych district). In 2019, Yavirska SHEP generated 1.256.8 thousand kWh of electricity and Novoshytska SHEPP – 570.8 thousand kWh.

In accordance with the Small Hydroelectricity Development Program of Ukraine, there were identified sites for the construction of 34 micro- and mini-hydroelectricity plants with a total capacity of 24 MW (Samchenko, 2018) in Lviv region by 2020. However, these measures were not implemented. At the beginning of 2020, new projects were developed for construction of 11 SHEPPs in Lviv region. Most of them should be located in the river valleys: the Dniester River (2 SHEPPs in Mykolayiv district), the Stryy River (3

SHEPPs in Drohobych and Skole districts), the Opir River (1 SHEPP in Skole district), and the Western Buh River (1 SHEPP in Busk district), Stynavka River (1 SHEPP in Stryy district). In addition, it is planned to build a hydroelectricity production plant at existing reservoirs in the cities of Boryslav and Dobrotvir, and in Ulvivok village, Sokal district (see fig. 5).

It should be noted that modern scientific, technical and environmental studies of the areas near small hydroelectricity production plants indicate on low efficiency of SHEPP operation and unreasonable use of the "green" tariff. One of the biggest environmental problems is a significant reduction in water flow in river sections, located downstream from small hydropower plants. Such dramatic water loss is associated with the fact that business entities fill the reservoir to generate electricity and therefore reduce water flow downstream.

For example, we have analyzed the impact of the Yavirska SHEPP on changes in water flow in the Stryy River. We compared the dynamics of daily water flow loss in low water (2003) and high water (2008) years in two hydrological sections: in Zavadivka village (upstream from the SHEPP) and Yasenytsia village (downstream from the SHEPP). It should be noted that the distance between two hydrological sections is 24 km, and on this section, 14 first-order streams, 13 second-order streams, 8 third- and higher-order streams, including such wide rivers as the Yablunka and the Yasenytsia, flow into the Stryy River. Thus, this section of the riverbed has a dense water supply network, is well supplied with water, and water flow loss in the lower section should be higher than in the upper section.

The results of the analysis showed that in the autumn-winter period of a low water year in 2003, in particular on some days in October, November and December, in Yasenytsa section, water flow loss was lower than in the Zavadivka section (Fig. 6). The analysis carried out in the summer of 2008 confirmed that the results of water flow loss in two sections are close, and on some days in August and November they are lower in the lower section (Fig. 7).

Such fluctuations in loss of water flow are dangerous both for the river ecosystem and for ecosystem of the station reservoir, and especially for hydro biological, thermal conditions, as well as for oxygen and bio productive regimes (Mykitchak, Shtupun, 2017). In addition, reduced water flow in a mountain river poses a social risk, as the Stryy River basin is a source of water supply for domestic, industrial and recreational needs of the population.

Among the existing projects for the construction of SHEPPs on the Stryy River, the project in Dovhe village, Drohobych district, where the construction of a 2 MW station is planned, is of a particular concern. A scientific analysis of the Environmental Impact Assessment report on the construction of this facility and relevant river channel regulation works on the Stryy river (Construction and operation of small hydroelectricity production plant (SHEPP) capacity to 2.0 MW, 2019) showed that it contains numerous inaccuracies and false information. Therefore, we believe that due to the inefficiency of this station and significant environmental risks for the aquatic environment and floodplain area of the Stryy River, the construction of this facility is inadequate.

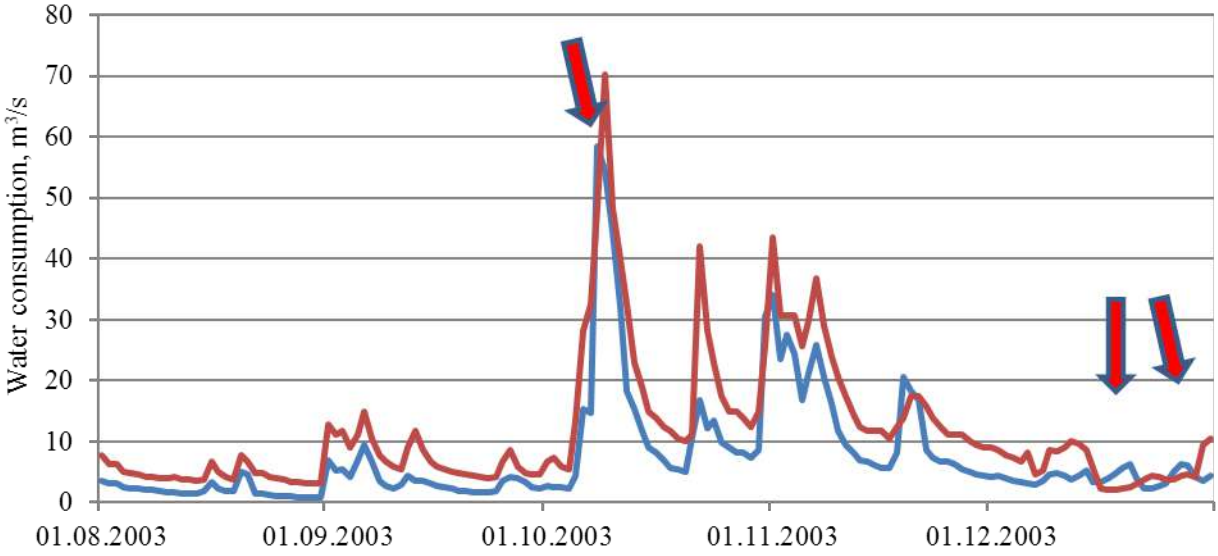

Fig. 6. Dynamics of daily water flow loss for river sections located upstream and downstream from Yavirska SHEPP in low water year of 2003 (blue line – Stryy River, Zavadivka village; red line – Stryy River, Yasenytsia village) (Pylypovych, Ivanov, Mykitchak, & Shtupun, 2020)

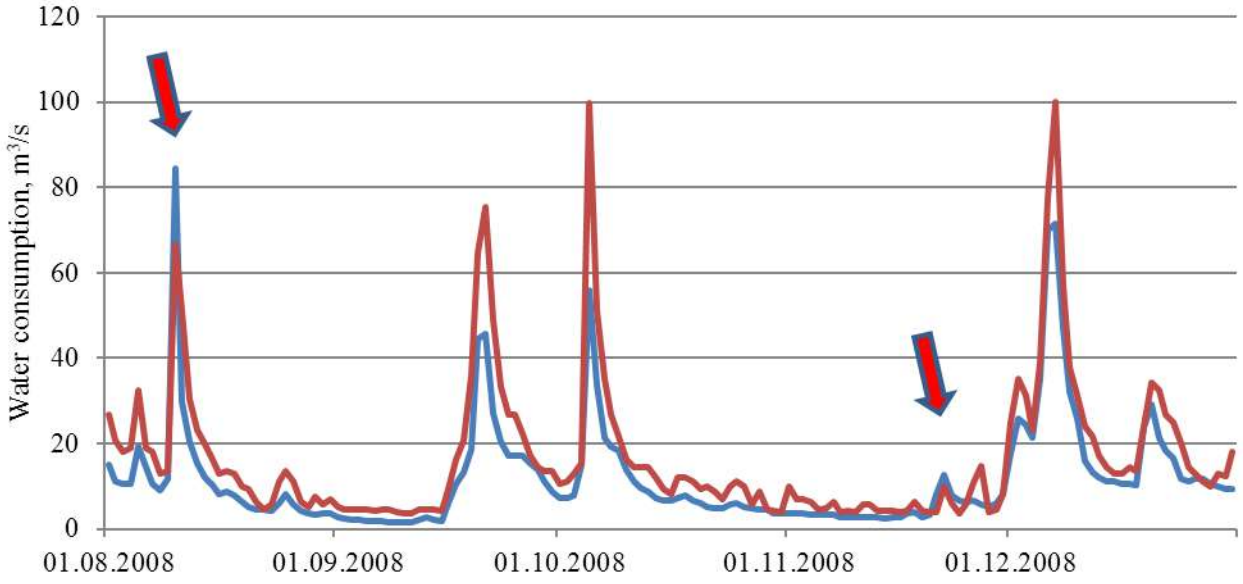

Fig. 7. Dynamics of daily water flow loss for river sections located upstream and downstream from Yavirska SHEPP in a high water year of 2008 (blue line – Stryy River, Zavadivka village; red line – Stryy River, Yasenytsia village) (Pylypovych, Ivanov, Mykitchak, & Shtupun, 2020)

Thus, small hydroelectricity production plants may have low economic but significant negative environmental impact. Despite widespread calls for the feasibility of using "green" energy, comparing results of the amount of produced electricity with the amount of environmental losses are clearly not in favor for the construction of small hydroelectricity production plants. After all, the volume of SHEPPs electricity production is insignificant, but their location on natural areas with great environmental value, causes significant environmental losses. Given the climate change, clearly visible in Ukraine, artificial loss in water flow, caused by SHEPPs, is dangerous and unjustified.

Standards and methodology used: *Tool to calculate the emission factor for an electricity system* of the UN Framework Convention on Climate Change. This methodology allows determining the emission coefficients for energy systems. According to calculations in 2019, during the operation of one SHEPP, CO_2 emissions are reduced by 1,367.1 tons/year by reducing fuel combustion (see the Table 1).

Biomass energy

Lviv region has a significant potential in such a form of an alternative energy source as biomass. The concept of biomass or "renewable organic energy" means such organic substances that can be used to produce heat, electricity, and liquid organic fuel (Energy strategy of Ukraine, 2017). These are by-products, waste and residues of forestry and agriculture (pellets, wood chips, sawdust, sunflower husk, straw, etc.), fishery, and technologically related with them industries, as well as a component of industrial or household wastes that can undergo biological decomposition.

According to experts, the total energy potential of biomass in Lviv region is 2,604.8 million m^3, which is more than double the consumption of natural gas (1.169 million m^3). Having established the production of biodiesel, bioethanol, biogas from organic wastes, the region may completely refrain from the consumption of natural gas (Bashinskaya, 2017). In general, the total technically achievable potential of biomass of Lviv region is 1.12 million tons of conventional fuel per a year, which is 3.3 % of the national figure.

Today, there are three mini- heat and electricity production plants (HEPPs) in the region, which are running on biomass and producing both electricity and heat. Mini-HEPPs in Radekhiv district (Polove village) uses wood processing waste from Mebel-Service LLC (Hoholiv village). Its electric production capacity is 2.4 MW and its heat production capacity is 7.5 MW. It provides thermal energy to the wood drying chamber, as well as to operational facilities. In addition to heating, the steam turbine also generates electricity, which is distributed to the unified energy system of Ukraine.

The other two biomass HEPPs are managed by "Rava-Ruska Teplostantsiya" Ltd. Thanks to this project, four coal-fired boilers in Rava-Ruska city were converted to use wood chips as fuel. One more TPP is located in Truskavets and provides thermal energy to the Pearl of Prykarpattia sanatorium, which makes it possible to replace 420,000 m^3 of gas per year.

Additionally, there is one bioenergy unit in Lviv region at Eco-Meat LLC pig-breeding farm in the village of Batyatychi, Kamianka-Buzka district. There are also 15 enterprises in Kamianka-Buzka, Zolochiv, Radekhiv, and Drohobych districts, which are specializing in the production of fuel briquettes and pellets from wood and other natural raw materials (straw, sunflower stalks,

sunflower husk, corn, etc.). Such fuel briquettes and pellets are used in private households for heating residential premises.

Conclusions

Based on the analysis of location, current state and perspectives of renewable energy facilities development in Lviv region, the following conclusions have been made:

1. The analysis of geographical preconditions for the development of renewable energy in Lviv region showed that the region is not well supplied with renewable resources. A significant growth in the development of renewable energy is caused by such factors as introduction of economic incentives and interest of local investors. In case of changes in legislation on economic incentives for renewable energy, further development of renewable energy would depend solely on the investors' interest.
2. Solar energy has been rapidly developing in the region since 2016. First of all, the impact on the development of solar was due to lower market prices for equipment. Unfortunately, Lviv region is not well supplied with solar resources compared to other regions of Ukraine. Solar energy is developing in two directions: industrial and private households.
3. Wind energy is represented by two industrial and one experimental electricity production plants. The highest wind potential in the region is fixed in the area of Skyb Carpathians, Volyn, Pre-Carpathian and Podil Heights, and River San area. High cost of wind electricity production plant equipment and need for an environmental impact assessment procedure slow down the development of wind energy. In case of favorable economic factors in the region, deployment of wind power plants, with a total installed capacity of over 500 MW, is planned.
4. According to experts, the hydroelectricity potential of Lviv region is 1.814 million kWh per a year that is the second place in Ukraine after Zakarpattia region. A significant part of the hydro potential accounts for the mountainous part of the region. It should be noted that modern scientific, technical and environmental studies on areas near small hydroelectricity production plants indicate on low efficiency of SHEPP operation and unreasonable use of the "green" tariff. One of the biggest environmental problems is a significant loss in water flow in riverbeds, located downstream from small hydroelectricity production plants. The water flow loss is because reservoirs are filled with water in order to generate electricity. Only two SHEPPs are operative in Lviv region: Yavirska SHEPP (Stryy River) and Novoshytska SHEPP (Bystrytsia River).
5. Biomass energy has a significant potential as an alternative energy source. According to experts, the total energy potential of biomass is 2,604.8 million m^3, which is more than double the consumption of natural gas. Today, there are three mini-HEPPs in the region, running on biomass and producing both electricity and heat.
6. The development of renewable energy in Ukraine depends on the rate of "green" tariff. The financial stimulus has led to a rapid increase in the share of renewables in total electricity production in Ukraine and in Lviv region in particular. New challenges that have arisen since January 1, 2020 with the introduction of "green auctions" for some renewable energy facilities, where the installed capacity exceeds a certain limit, pose a risk for new projects.
7. Unfortunately, due to the COVID-19 pandemic and a number of other factors, since March 2020, the development of large projects in the region has been suspended due to a significant risk of losses and unprofitability. It is difficult to predict the future state of solar energy in Lviv region, because the region is not well supplied with solar resources, and instability in the country may affect the deployment of solar stations. At the same time, close attention should be paid to the analysis of projects for the construction of small hydroelectricity production plants, which have relatively low capacities and low economic effect, but have a significant negative impact on the environment. Promising areas for renewables in Lviv region is the development of wind energy and bioenergy.
8. The total installed capacity of the projected renewable energy facilities is over 640 MW. The most promising areas for the use of renewable sources in Lviv region are the development of wind and bioenergy. Since, before constructing of a wind electricity production plant, it is mandatory to undergo the environmental impact assessment procedure, in the next five years, according to the Unified Register of Environmental Impact Assessment (http://eia.menr.gov.ua), constructing 14 wind farms with the installed capacity of over 500 MW is planned.

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