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Analysis of Hydropotential and Prospects for Small Hydropower Development in Ukraine

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***Abstract* – The share of electricity generation by small hydropower plants is the least among other renewable energy sources in Ukraine, although the SHPPs were widely operated in the past. The aim of the article is to analyse the hydropotential of Ukrainian rivers and review the past and present states of small hydropower engineering in Ukraine. Moreover, the article emphasizes the main directions and gives recommendations for hydropower development in Ukraine considering ecological, economic, energy and legal issues.**

***Keywords* – Environmental impact; hydropower potential; renewable energy sources (RES); small hydropower plants (SHPPs).**

1. INTRODUCTION

Right now, Ukraine is facing an acute issue of energy security due to constant attacks and destruction of the energy system. In a normal situation, Ukraine can almost entirely meet the electricity needs of the population and industry through the operation of various types of power plants, both renewable and non-renewable. However, significant damage to the energy infrastructure causes the unstable operation of the energy system, which leads to rolling and emergency blackouts and even shutdowns of some power plants. The existing problem can be solved by development of decentralization electricity generation, which is envisaged in the Energy Strategy of Ukraine until 2035 [1]. One of the ways to distribute the electricity generation system is to use renewable energy sources, including small hydropower plants (SHPP).

The classification of SHPPs is determined by many criteria, including the method of head concentration, the layout of the main structures, the design of the hydropower plant building, power, head, and turbine impeller size. However, the key parameter for classifying small hydropower plants is the maximum installed power output of hydropower plant. There are significant differences in the classification of a small hydropower plant, mini hydropower plant, or micro hydropower plant in different countries [2]. In Ukraine small hydropower includes small hydropower plants that have installed capacity 1–10 MW, mini HPPs – from 200 to 1000 kW – and micro HPPs – less than 200 kW [3].

Even though small hydropower engineering has been used for many decades, it continues to develop globally. According to the World Small Hydropower Development Report [4],

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about 66 % of the world's small hydropower potential remains unused. In 2019, the total installed capacity of small hydropower plants with a capacity of up to 10 MW was estimated at 78 GW worldwide. The top five countries generating electricity by small hydropower plants with an installed capacity of up to 10 MW are China (41900 MW – 54 %), the United States (3612 MW – 4.6 %), Japan (3545 MW – 4.5 %), Italy (3395 MW – 4.4 %), Turkey (2961 MW – 3.8 %) and Norway (2571 MW – 3.3 %). The hydropotential of small hydropower plants in Ukraine is estimated at 375 MW, which is only 0.5 % of the world's total installed capacity [4], [5].

2. METHODS AND METHODOLOGY

The main scientific method of the present study is the analysis of scientific literature related to the problems of small hydropower development in Ukraine. Theoretical data from different sources were collected and compared to estimate the hydropotential of small and medium-size rivers in Ukraine. Based on a review of relevant articles, the past and present state of small hydropower was described. Moreover, the positive and negative issues of using small hydropower plants in Ukraine were highlighted.

3. RESULTS AND DISCUSSION

3.1. Hydropotential for development of small hydropower engineering in Ukraine

The primary energy source for small hydropower engineering in Ukraine is the hydropotential of small and medium-sized rivers, classified by catchment area (Table 1) [6]. There are more than 63 thousand small rivers and streams in Ukraine [7], [8]. Such a river system ensures an even distribution of water resources throughout the country. However, the distribution of potential hydropower resources is highly uneven. The highest share of the total technical potential is concentrated in the regions: Zakarpattia (Transcarpathia) (35 %), Ivano-Frankivsk (16 %), Lviv (12 %), Chernivtsi (6 %), Kirovohrad (4 %), and Ternopil (3 %). The lowest values are inherent in the following regions: Odesa (0.37 %), Volyn (0.27 %), Kherson (0.18 %), Chernihiv (0.16 %), Zaporizhzhia (0.05 %) (Fig. 1) [5].

TABLE 1. RIVER CLASSIFICATION

Type of river	Catchment area	Number
Large	more than 50 thousand km^2	9
Medium	2–50 thousand km^2	81
Small	less than 2 thousand km^2	63029

The numerical value of the hydropower potential varies depending on different studies. As stated by the Energy Strategy of Ukraine for the period up to 2030 [5], [9] the hydropotential of small and medium rivers is estimated by a total installed capacity of 1147 MW with annual electricity production of 4 GWh. According to other data from the Institute of Renewable Energy of the National Academy of Sciences of Ukraine [5], [10], the installed capacity is 375 MW and electricity production is 1.27 GWh per year. Finally, the specialists from PJSC 'Ukrhydroenergo' mentioned that the installed capacity of small and medium rivers of Ukraine is about 600 MW [11].

This difference in the estimation of hydropotential can be explained by using different methodologies, considering various factors such as environmental, economic, social, legal,

nature conservation, etc. However, it shows that no more than one-third of hydropotential is used (Fig. 2) [12].

Used hydropower potential and the number of operating small hydropower plants by regions and rivers is also uneven as shown in Figure 1. For example, the hydropower resources of the Tisza River basin are among the largest per unit area of a catchment in Ukraine. This is because the surface runoff here reaches about 40 ($L \cdot s^{-1} \cdot km^{-2}$), and the elevation difference between the mountainous and valley parts of the basin is on average 1500 m. However, there are currently only five SHHPs in the basin [13]. Zakarpattia region has the largest hydropotential among all regions in Ukraine, but it is used only in 12 % [5], [10]. Conversely, although the Vinnytsia region has about 6 %, Khmelnytsky and Cherkasy regions have about 2 % each of the hydropower potential of the country, more than 90 % of their technical hydropotential has been developed in comparison with data from [5], [10]. This picture of uneven development of hydropower potential is due to the presence of hydroelectric power plants left over from the 20th century.

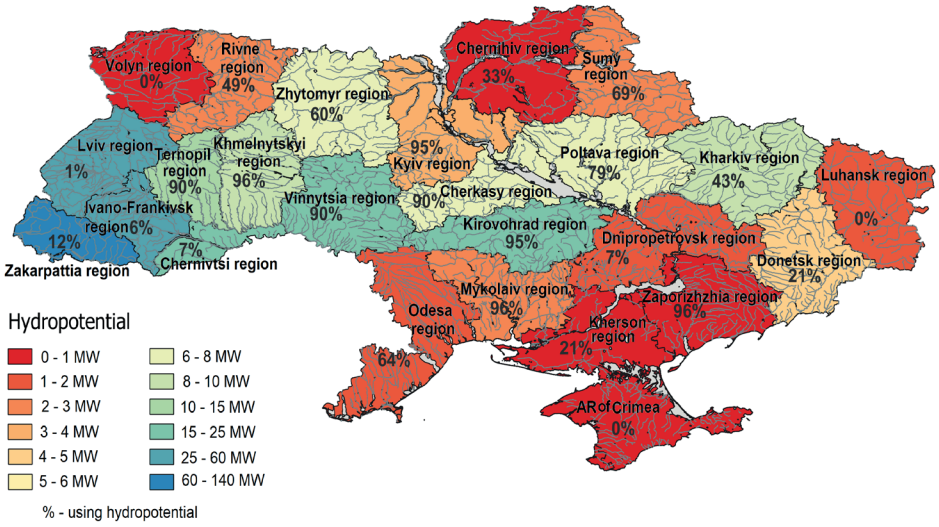


Fig. 1. Hydropotential for development of small hydropower engineering by regions of Ukraine (as data source [5]).

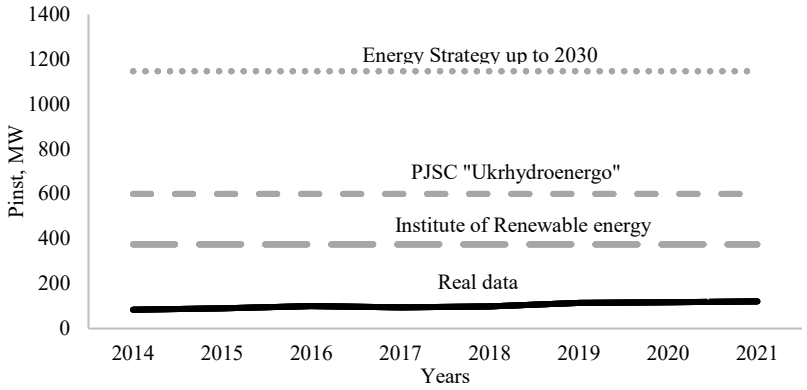


Fig. 2. Comparison of hydropower potential development data depending on installed capacity.

3.2. Past and present states of small hydropower engineering in Ukraine

The development of small hydro power in the country dates back to the beginning of the twentieth century: in 1924 there were 84 small hydro power plants with a total capacity of 4000 kW, and in 1929 their number had increased to 150 (with a total capacity of 8400 kW) [14]–[16].

In the western regions of Ukraine, there were dozens of water mills on some rivers, equipped with small generators of 5–25 kW. These were simple micro-hydropower plants that mainly supplied local electricity needs.

By 1950, 956 small hydropower plants were in operation in Ukraine, and new ones were being built. With the construction of large hydro, heat and nuclear power facilities, the role of small hydropower engineering has diminished significantly. As a result, almost all small hydropower plants had been decommissioned and dismantled. In addition, small hydropower plants which were supposed to be built on irrigation systems and reservoirs were not constructed. Of the total stock of small hydropower facilities in Ukraine in the 1980s, 150 small plants remain and only 49 were operated [14]–[16].

Since 1995, the interest in small hydropower engineering has increased again. Some existing SHPPs were reconstructed and modernized and some SHPPs were built new. Most of the work on restoring of small hydropower plants was carried out in Vinnytsia, Cherkasy, Khmelnytsky, Ternopil, and Zhytomyr regions [16]. For this reason, as of today, there are 108 operating small hydropower plants in these regions [17], i.e., 60 % of the total number of all SHPP, while the technically achievable hydropower potential of small rivers in there is about 15 % of the total [5]. Zakarpattia, Lviv, Ivano-Frankivsk and Chernivtsi regions have the highest hydropotential of 867.9 million kW·h of electricity per year, which is 68 % of the total potential of small rivers in Ukraine. However, there are only 23 small hydropower plants [17] with a total installed capacity – 21.6 MW, i.e., the hydropower potential of mountain rivers in these regions is used by power engineers by only 5.8 % [5].

In 2009, the law on the "green tariff" came into effect, which encouraged the development of renewable energy sources, including small hydropower plants, the number of which began to gradually increase (Fig. 3). Therefore, in 2021 there were about 177 small hydropower plants in Ukraine [17] (Fig. 4).

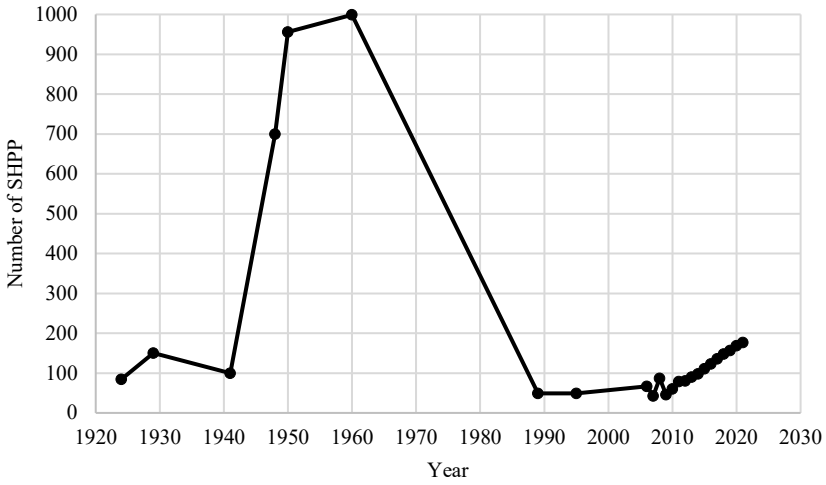


Fig. 3. Operation of SHPPs in Ukraine during 1924–2021 (as data source [15], [17]).

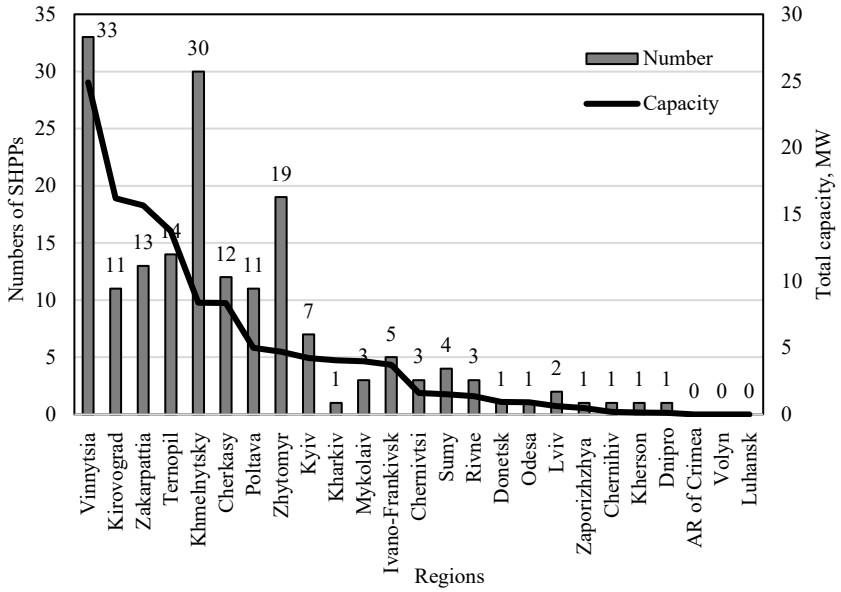


Fig. 4. Current number of SHPPs and total capacity by regions (as data source [17]).

3.3. Benefits on the Ukrainian economy

The advantages of small hydropower engineering development for the national economy of Ukraine can be characterized as follows [1], [18]–[21].

3.3.1. Clean source of energy.

SHPPs are a clean renewable energy source, which means that fossil fuels are saved and CO_2 emissions into the atmosphere are avoided during generation. According to [22] hydropower generation is one of the cleanest energy sources (Table 2). However, it should be noted that there are still emissions into the atmosphere, especially during construction [23].

TABLE 2. LIFE CYCLE EMISSION FACTORS FOR ELECTRICITY GENERATION FROM DIFFERENT TECHNOLOGIES [22]

Energy source	**CO_2-eq**	**NO_x**	**SO_2**
Electricity output, kg/MWh			
Hard coal	660–1050	0.3–3.9	0.03–6.7
Lignite	800–1300	0.2–1.7	0.6–7
Natural gas	380–1000	0.2–3.8	0.01–0.32
Oil	530–900	0.5–1.5	0.85–8
Nuclear power	3–35	0.01–0.04	0.003–0.038
Biomass	8.5–130	0.08–1.7	0.03–0.94
Hydropower	2–20	0.004–0.06	0.001–0.03
Solar energy	13–190	0.15–0.40	0.12–0.29
Wind	3–41	0.02–0.11	0.02–0.09

3.3.2. Quality electricity generation

Small hydropower plants improve the quality and reliability of electricity supply by regulating frequency, voltage and power reserve. They are characterized by high efficiency in converting available hydropower resources into electricity (efficiency reaches 0.7...0.9 and above) [20] and high flexibility that is unattainable for many other technologies.

3.3.3. On grid and off grid operation

The SHPPs can operate as part of the energy system of Ukraine as an additional source of coverage in the power system of peak electricity deficit as well as can be operated in off grid mode – for individual consumers. According to the Energy Strategy of Ukraine up to 2035 [1], the development of distributed renewable energy should be encouraged. Small hydropower plants are an important element of distributed generation by influencing the operation of power grids. In addition, as a source of electricity, they can be used to regulate voltage and control power flows to reduce transmission losses and improve electricity quality [24].

Moreover, SHHPs showed promising results in electricity supply for local consumers. Due to the constant attacks on the energy system of Ukraine and its significant destruction, the isolated operation of several small hydropower plants in Vinnytsia, Sumy and Chernihiv regions was tested. The SHHPs were operated separately from the energy system and supplied electricity to only a few settlements near the plants. The test results were successful, making it possible to supply electricity to the maximum possible number of consumers located near small hydropower plants in case of special emergency power outage schedules [25].

3.3.4. Economic attractiveness

Building or reconstruction of SHPPs requires relatively low costs and short construction time, which allows private investors to accelerate their profit. Unlike other types of RES, the main machinery for small hydropower plants is manufactured in Ukraine where it is several times cheaper and of the same quality as similar equipment made in Europe. Moreover, if Ukrainian turbines and generators are used, the state provides additional payments [26], [27]. The lifespan of a hydropower plant can reach 75 years or more with acceptable specific investments compared to alternative technologies, low operating costs, total payback of investments (subject to the feed-in tariff) within 4–5 years, and profitability of up to 30 % and more [20].

3.3.5. Further benefits and uses of reservoirs

Water accumulation for the complex needs of the national economy.

Practice shows that a reservoir created for operating small hydropower plant can be used for other purposes. In particular, fish farms are being established, recreation centres are being built in the adjacent territories, and water from the reservoir can be used for both technical and drinking water supply, as the water quality does not change, but rather the opposite – the water passing through the turbine is enriched with dissolved oxygen during aeration, which helps to activate chemical and biological self-purification of water and has a positive impact on the natural regime of the river [28].

Regulation of water flows and protection of territories and settlements from floods.

Many rivers in Ukraine have pronounced floods and flash floods, which flood the surrounding areas and cause destruction to the local population. In the case of a SHPP with a reservoir, the reservoir manages to partially delay and reduce flood flow, which helps to avoid

or significantly reduce material damages. Recently, scientists have been considering SHHPs as one of the effective measures to adapt to climate change, which in Ukraine resulted in a decrease in flood flow and an increase in the number of flash floods and their flow volumes. A river basin approach to water management is applied to reduce the negative impact. It limits the negative economic and social consequences, and mitigates the effects of climate change and increases energy capacity [29].

3.4. Negative side from SHPPs

Despite the significant advantages, the use of small hydropower plants also has disadvantages [2], [19], [20]. The fact is that some hydropower plants in Ukraine were designed, built, and operated in such a way as to cause the maximum possible damage to the river, its ecology, the state of the riparian areas, and the livelihoods of the local population [20].

3.4.1. Impact on the environment

The construction of a small hydropower plants has many different environmental impacts depending on the location and schemes of SHPPs [30]. Since most schemes of hydropower plants in Ukraine require the construction of a weir or dam for impounding water, the reservoir can lead to

- flooding the adjacent areas,
- influencing vegetation,
- changes in the hydrological regime of the river [31].

Moreover, due to the regulation of the river by reservoirs or weir barriers, the water flow velocity in the river decreases, which can lead to the siltation of some areas and the overgrowth of algae and reeds. In addition, constructing a dam without a fish passage structure will impede fish migration, especially in mountainous areas.

3.4.2. Decreasing of water in the river

Some mountainous rivers in Ukraine are characterized by low water levels during drought periods. Unfortunately, there have been cases when all the water from the river was transported to the powerhouse of the hydropower plant through pipelines, causing a section of the riverbed to dry up and leaving the local population without water.

3.4.3. Dependence of electricity generation on hydrological and meteorological conditions

Climate change causes an uneven distribution of runoff throughout the year, which can lead to a reduction in the efficiency of equipment and electricity production during droughts, especially when it concerns hydropower plants that operate without a reservoir [2].

Therefore, to minimize the negative influence of reconstructing old or building new SHPPs on the environment, many domestic laws and programs on the protection, preservation, and rational use of natural resources, as well as international treaties, conventions, and protocols, must be taken into account [32]. Moreover, a national strategy for promoting small hydropower plants, including the strong environmental policies, must be developed to clarify ecological issues investors could face while reconstructing or building small hydropower plants.

3.5. Prospective of small hydropower engineering development with taking into account environmental issues

The consequences of massive hydropower construction, including socio-environmental problems that accompany the construction and operation of hydropower facilities, are already well studied. There is a clear trend in world practice to take them into account as much as possible in the assessment of economically efficient hydropower potential and in design decisions [33].

First, existing plants can be reconstructed and modernized to increase electricity production by SHPPs [34]. The other direction for the development of hydropotential is to use already existing hydraulic structures, water reservoirs, flood regulating, and control structures. After all, hydraulic structures that create head drops have hydropower potential. Hence, it is advisable to try to use them to generate environmentally friendly electricity. It is believed that the most profitable small hydropower plants will be those that use the existing head (ready-made retaining hydraulic structures), which were built earlier for other purposes (water supply, fish farming, recreation), but which are now expediently used for the creation of small hydropower plants [15], [35]–[36].

Using existing structures is favourable both from economic and environmental sides. According to foreign data, the costs of constructing new small hydropower plants are distributed as follows [36]:

- hydraulic structures and buildings 45–50 %,
- main equipment 25–35 %,
- automation and control equipment 15 %,
- costs for the infrastructure of the territories 5–10 %.

When using a ready-made waterfront structure, construction costs are reduced by 30–40 % [36]–[37]. Since the creation of water reservoirs has the most significant negative influence from SHPPs on the environment, in many cases of existing hydraulic structures, there will be no additional negative effect.

Moreover, existing hydraulic structures and reservoirs contribute to developing of a network of micro-hydropower plants. Such powerplants require small discharge (even fewer than cubic meters per second) and head with meters or a few tens of meters [38]. Micro hydropower plants have the same benefits as small ones. Nevertheless, new technologies and approaches to the management of water resources allow to decrease negative impact on the environment.

The world is actively implementing SHPP projects at commissioned water supply and wastewater facilities, which is a relatively new trend for Ukraine [39]. In 2018, a ‘pilot project’ of SHPP was launched in the Poltava region, which was built about 9 km west of Poltava and operates on the return water of the Suprunivka Wastewater Treatment Plant [27]. Such technologies have many advantages. As they are already situated on existing structures, they do not need financial expenses for building dams, water intakes, pipes, or other hydraulic structures and reservoirs, which avoids new land flooding and negative effects on the environment.

With using existing structures for small HPPs, the possibility of building new HPPs on small and medium rivers is still available, although with accounting laws of environmental protection. Considering the national and international documents in the environmental field, recommendations for selecting sites for constructing small hydropower plants were developed. According to them the four categories of territories have been proposed for both the prohibition and construction of small hydropower plants [15]:

I Category of ‘exclusive zone’,
II Category of ‘undesirable zone’,
III Category of ‘possible zone’,
IV Category of ‘construction zone’.

From hydropotential point of view, the region of the Carpathian Mountains, especially the Zakarpattia region, is the most favourable. However, this region contains many natural and national parks and other protected areas (Fig. 5).

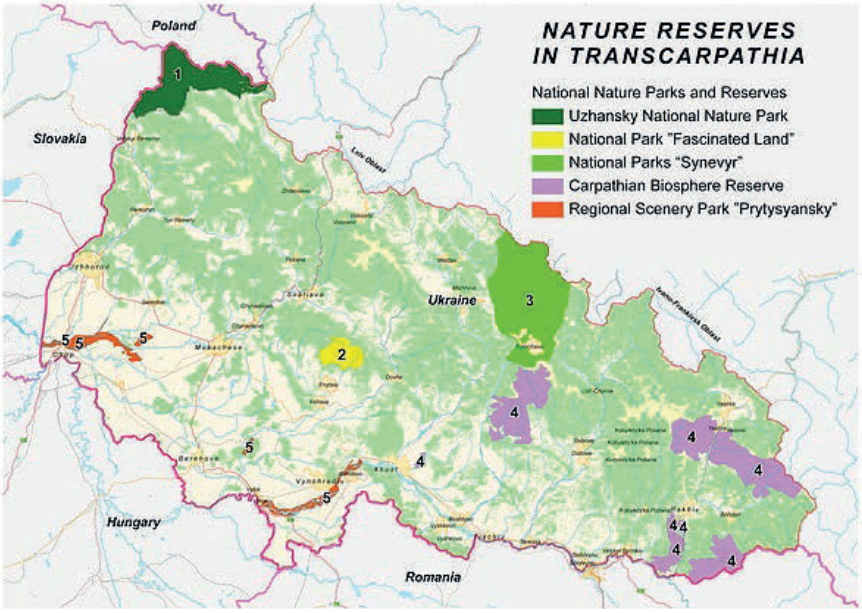


Fig. 5. Nature Reserve Fund of Zakarpattia region [40].

Therefore, to build new SHHPs in Ukraine the investors should take into account these recommendations [15], [30]:

- Prioritize the restoration of destroyed and abandoned small hydropower plants, as well as the reconstruction and capacity increase of existing small hydropower plants, and only then consider the construction of entirely new small hydropower plants;
- Preference should be given to locations in the middle or lower sections of mountain rivers, that usually belong to III and IV categories;
- For building new SHPPs use eco-friendly technologies to minimize the negative environmental influence.

4. CONCLUSION

Ukraine has considerable hydropotential for the development of small hydropower engineering. The country has many rivers and a significant water resources potential. In addition, Ukraine has the necessary infrastructure and technical capabilities to develop hydropower generation. The development of hydropower is an essential step towards

achieving energy security, reducing emissions from fossil fuels and increasing electricity production by renewable energy in Ukraine.

A promising area for developing small hydropower engineering is the creation of SHPPs on existing hydraulic construction and reservoirs and the return water of technological processes with residual head.

Projects for the construction of new and even rebuilding of existing small hydropower plants should use new technologies and approaches to ensure minimal environmental impact.

The increase in the number of small hydropower plants will help to ensure the energy security of other types of electricity generation and fulfil the energy needs of local communities. Moreover, it will contribute to the policy of distributed generation, which is quite relevant in case of significant damage to the energy system of Ukraine.

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REFERENCES

[1] Pro skhvalennya Enerhetychnoyi stratehiyi Ukrayiny na period do 2035 roku 'Bezpeka, enerhoefektyvnist′, konkurentospromozhnist'. (On the approval of the Energy Strategy of Ukraine for the period until 2035 'Safety, energy efficiency, competitiveness') [Online]. [Accessed: 30.03.2023]. Available: https://zakon.rada.gov.ua/laws/show/605-2017-p#Text (In Ukrainian).

[2] Riabenko O. A., Lutaiev V. V. Suchasni tendentsiyi v budivnytstvi malykh hes v Ukrayini. (Modern trends in the construction of small hydropower plants in Ukraine. Hydropower engineering of Ukraine). Report at the 24th International Scientific and Technical Conference 'The main directions of updating the Energy Strategy until 2030'). *Hidroenerhetyka Ukrayiny* 2012:2. [Online]. [Accessed: 30.03.2023]. Available: http://dspace.nbuv.gov.ua/bitstream/handle/123456789/141402/12-Ryabenko.pdf?sequence=1 (In Ukrainian).

[3] Zakon ukrayiny. Pro rynok elektrychnoyi enerhiyi. (Law of Ukraine on the electricity market). [Online]. [Accessed: 30.03.2023]. Available: https://zakon.rada.gov.ua/laws/show/2019-19#Text (In Ukrainian).

[4] Liu D., Liu H., Wang X., Kremere E. World Small Hydropower Development Report 2019. United Nations. Industrial Development Organization; International Center on Small Hydro Power. 2019. [Online]. [Accessed: 30.03.2023]. Available: https://www.unido.org/our-focus-safeguarding-environment-clean-energy-access-productive-use-renewable-energy-focus-areas-small-hydro-power/world-small-hydropower-development-report

[5] Kudri S. O. (ed). Atlas enerhetychnoho potentsialu vidnovlyuvanykh dzherel enerhiyi ukrayiny. (Atlas of the energy potential of renewable energy sources of Ukraine). Kyiv: Institute of Renewable Energy of the National Academy of Sciences of Ukraine, 2020. [Online]. [Accessed: 30.03.2023]. Available: https://www.ive.org.ua/wp-content/uploads/atlas.pdf (In Ukrainian).

[6] Vodnyy kodeks Ukrayiny. (Water code of Ukraine). 1995. [Online]. [Accessed 30.03.2023]. Available: https://zakon.rada.gov.ua/laws/show/213/95-вр#Text (In Ukrainian).

[7] Palamarchuk M. M., Zakorchevna N. B. Water Fund of Ukraine: Reference manual. Edited by Khorsva V. M., Aliiev K. A. Kyiv, Nika-Centre, 2001.

[8] Small rivers of Ukraine: Handbook. Edited by A.V. Yatsyk. Kyiv. Urozhay, 1991.

[9] Energy Strategy of Ukraine for the period up to 2030. Verkhovna Rada of Ukraine. [Online]. [Accessed 30.03.2023]. Available: https://zakon.rada.gov.ua/laws/show/n0002120-13#Text 11

[10] Bryl A. O., Vasko P. F., Moroz A. V. Tekhnichnyy potentsial hidroenerhetychnykh resursiv malykh richok Ukrayiny z urakhuvannyam pryrodookhoronnykh obmezhen′. (Technical potential of hydropower resources of small rivers of Ukraine with regard to environmental restrictions). *Hydropower engineering of Ukraine* 2019:3–4:47–51. https://uhe.gov.ua/sites/default/files/2019-12/13.pdf (In Ukrainian).

[11] Karamushka O. M. Mala hidroenerhetyka – osnova podal′shoho sotsial′no-ekonomichnoho rozvytku zakhidnoyi Ukrayiny. (Small hydropower engineering – the basis for further socio-economic development of western Ukraine). *Hydropower engineering of Ukraine* 2021:1–2:13–16. https://uhe.gov.ua/sites/default/files/2021-08/6.pdf.

[12] Statystyka shchodo rozvytku vidnovlyuvanoyi enerhetyky. (Reports on the Promotion and Use of Energy from Renewable Sources in Ukraine). [Online]. [Accessed 30.03.2023]. Available: https://saee.gov.ua/uk/content/informatsiyni-materialy

[13] Obodovskiy O., Danko K., Pochaievets O. Assessment of hydropower potential of the Tisza river basin. *Journal of Education, Health and Sport* 2017:7(5):486–496. http://dx.doi.org/10.5281/zenodo.800727

[14] Karamushka O. M. Mala hidroenerhetyka Ukrayiny. Stratehiya ta potochni problemy rozvytku pohlyad asotsiatsiyi 'ukrhidroenerho'. (Small hydropower engineering in Ukraine. Strategy and current development issues. The view of the Association 'Ukrhydroenergo'). *Hydropower engineering of Ukraine* 2012:4:52–55. [Online]. [Accessed 30.03.2023]. Available: http://dspace.nbuv.gov.ua/bitstream/handle/123456789/141441/17-Karamushka.pdf?sequence=1

[15] Yermilov S. (ed.)., Vovchak V., Teslenko O., Samchenko O. Mala hidroenerhetyka Ukrayiny. Tom 1. Tekhnolohichni osoblyvosti malykh HES. (Small hydropower engineering of Ukraine. Analytical review. Volume 1). Kyiv, 2018. https://energyukraine.org/wp-content/uploads/2018/05/Otchet-MGES1.pdf

[16] Nikitorovych O. V., Zhytnyk V. G. Mala hidroenerhetyka ta yiyi rozvytok v Ukrayini. (Small hydropower engineering and its development in Ukraine). *Hydropower engineering of Ukraine.* 2013:2:18–21. http://dspace.nbuv.gov.ua/bitstream/handle/123456789/141476/06-Nikitorovich.pdf?sequence=1 (In Ukrainian).

[17] Obyekty vidnovlyuvanoyi enerhetyky. (Renewable energy facilities). [Online]. [Accessed 30.03.2023]. Available: https://www.energo.ua/ua/assets (In Ukrainian).

[18] Yatsyk A. V., Yatsyk V. A., Basyuk T. O. Upravlinnya rozvytkom ta efektyvnistyu vykorystannya maloyi hidroenerhetyky v Ukrayini. (Management of development and efficiency of small hydropower use in Ukraine). *Hydropower Engineering of Ukraine* 2011:3–4:7–10. http://dspace.nbuv.gov.ua/xmlui/bitstream/handle/123456789/57950/03-Yatsyk.pdf?sequence=1 (In Ukrainian).

[19] Stoyan O. Y. Doslidzhennya stanu rozvytku maloyi hidroenerhetyky ukrayiny: osoblyvosti, tendentsiyi, enerhetychnyy potentsial. (Study of the state of development of small hydropower in Ukraine: features, trends, energy potential). *Investments: Practice and Experience* 2015:3:116–120. http://www.investplan.com.ua/pdf/3_2015/27.pdf (In Ukrainian).

[20] Vlasiuk Y. S., Stefanyshyn D. V. Pro problemy ta perspektyvy maloyi hidroenerhetyky v Ukrayini. (On the problems and prospects of small hydropower in Ukraine). *Mathematical Modelling in Economics* 2018:1:126–138. http://dspace.nbuv.gov.ua/bitstream/handle/123456789/161996/11-Vlasiuk.pdf?sequence=1(In Ukrainian).

[21] Dovhaliuk O. M., *et al.* Zastosuvannya malykh hes dlya zabezpechennya rezervu potuzhnosti v chas pik elektroenerhetychnoyi systemy. (The use of small hydropower plants to provide power reserve in the peak hour of the electric power system). Bulletin of the National Technical University 'KhPI'. Coll. sci. papers. Ser: Energy: Reability and Energy Efficiency. 2018. [Online]. [Accessed 30.03.2023]. Available: http://repository.kpi.kharkov.ua/bitstream/KhPI-Press/48626/1/vestnik_KhPI_2018_10_Dovhaliuk_Zastosuvannia.pdf

[22] Turconi R., Boldrin A., Astrup T. Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations. *Renewable and Sustainable Energy Reviews* 2013:28:555–565. https://doi.org/10.1016/j.rser.2013.08.013

[23] Pang M., *et al.* Environmental life cycle assessment of a small hydropower plant in China. *Int J Life Cycle Assess* 2015:20:796–806. https://doi.org/10.1007/s11367-015-0878-7

[24] Kovalchuk O. A., Nikitorovych O. V., Lezhnyuk P. D., Kulyk V. V. M ali hes v lokal′nykh elektrychnykh systemakh z rozoseredzhenym heneruvannyam. (Small hydropower plants in local electrical systems with dispersed generation). *Hydropower Engineering of Ukraine* 2011:1:54–58. http://dspace.nbuv.gov.ua/bitstream/handle/123456789/57925/14-Kovalchuk.pdf?sequence=1 In Ukrainian.

[25] Enerhetychna Detsentralizatsiya – Rozoseredzhena Heneratsiya! (Energy Decentralisation – Distributed Generation!). [Online]. [Accessed 30.03.2023]. Available: https://iclub.energy/blog/yurij-kasich/tpost/fyz5ufdeg1-energetichna-detsentralzatsya-rozoseredz In Ukrainian

[26] Law of Ukraine on alternative energy sources. (Pro al′ternatyvni dzherela enerhiyi). [Online]. [Accessed 30.03.2023]. Available: https://zakon.rada.gov.ua/laws/show/555-15#Text (In Ukrainian).

[27] Myklebust A., Jakobsen A., Sviderska A. Roadmap for small-scale hydro power projects in Ukraine. Investment guide. 2016. [Online]. [Accessed 30.03.2023]. Available: https://nucc.no/wp-content/uploads/2016/08/Roadmap-for-small-scale-hydro-power-projects-in-Ukraine-.pdf

[28] Bryl A. O., Vasko P. F., Moroz A. V. Regulatory and legal aspects of the use of hydropower potential of return waters of technological processes in Ukraine under the "green" tariff for generated electricity. *Renewable Energy* 2021:1(64):59–69. https://doi.org/10.36296/1819-8058.2021.1(64).59-69

[29] Yatsyk A.V., Tomiltseva A.I., Pashenyuk I.A. Ekolohichni aspekty vyrishennya rozvytku maloyi hidroenerhetyky v umovakh hlobal′noho poteplinnya (na prykladi richok pivdenyy buh ta ros′. (Environmental aspects of solving the development of small hydropower in the context of global warming (on the example of the Southern Bug and Ros rivers)). *Hydropower engineering of Ukraine* 2016:1–2:67–70. http://dspace.nbuv.gov.ua/bitstream/handle/123456789/141647/14-Yatsyk.pdf?sequence=1 (In Ukrainian).

[30] Zeleňáková M., Fijko R., Diaconu C. D., Remeňáková I. Environmental Impact of Small Hydro Power Plant – A Case Study. *Environments* 2018:5(1):12. https://doi.org/10.3390/environments5010012

[31] Šarauskienė D., Adžgauskas G., Kriaučiūnienė J., Jakimavičius D. Analysis of Hydrologic Regime Changes Caused by Small Hydropower Plants in Lowland Rivers. *Water* 2021:13(14):1961. https://doi.org/10.3390/w13141961

[32] Yermilov S. (ed.)., Vovchak V., Teslenko O., Samchenko O. Mala hidroenerhetyka Ukrayiny. Tom 2. Tekhnolohichni osoblyvosti malykh HES. (Small hydropower engineering of Ukraine. Analytical review. Volume II). Kyiv, 2018. http://energyukraine.org/wp-content/uploads/2018/05/Otchet-MGES2.pdf (In Ukrainian).

[33] Stefanyshyn D. V. Deyaki krytychni zauvazhennya ta propozytsiyi shchodo pidtrymky staloho rozvytku hidroenerhetyky v Ukrayini. (Some critical remarks and proposals to support the sustainable development of hydropower in Ukraine). *Hydropower engineering of Ukraine* 2018:1–2:6–12. http://dspace.nbuv.gov.ua/bitstream/handle/123456789/141764/03-Stefanishin.pdf?sequence=1 (In Ukrainian).

[34] Stefanyshyn D.V. Sotsial′noekolohichni problemy vidnovlennya ta modernizatsiyi malykh hidroelektrostantsiy v Ukrayini. (Social and environmental problems of restoration and modernisation of small hydropower plants in Ukraine). *Hydropower Engineering of Ukraine* 2015:1–2:18–22. http://dspace.nbuv.gov.ua/bitstream/handle/123456789/141608/04-Stefanishin.pdf?sequence=1

[35] Bartle A. Hydropower potential and development activities. *Energy Policy* 2002:30(14):1231–1239. https://doi.org/10.1016/S0301-4215(02)00084-8

[36] Khlapuk M. M., Shynkaruk L. A. Protypavodkovi akumulyuyuchi yemnosti v baseyni Verkhn′oho Dnistra ta mala hidroenerhetyka. (Flood storage tanks in the Upper Dniester basin and small hydropower). *Hydropower engineering of Ukraine* 2018:1–2:75–78. http://dspace.nbuv.gov.ua/bitstream/handle/123456789/141781/20-Khlapuk.pdf?sequence=1 (In Ukrainian).

[37] Ryzhyi V. M. Otsinka mozhlyvosti budivnytstva minihes pry isnuyuchykh hreblyakh na prykladi hidrovuzliv v zhytomyrs′kiy oblasti ta pecheniz′koho hidrovuzla v Kharkivs′kiy oblasti. (Assessment of the possibility of building mini-hydroelectric power plants at existing dams on the example of hydroelectric power plants in Zhytomyr region and Pechenizkyi hydroelectric power plant in Kharkiv region). *Hydropower engineering of Ukraine* 2016:1–2:45–50. [Online]. [Accessed 30.03.2023]. Available: http://dspace.nbuv.gov.ua/bitstream/handle/123456789/141642/09-Ryzgiy.pdf?sequence=1 (In Ukrainian).

[38] Quaranta E., Revellia R. Gravity water wheels as a micro hydropower energy source: A review based on historic data, design methods, efficiencies and modern optimizations. *Renewable and Sustainable Energy* 2018:97:414–427. https://doi.org/10.1016/j.rser.2018.08.033

[39] Bousquet C., Samora I., Manso P., Rossi L., Heller P., Schleiss A.J. Assessment of hydropower potential in wastewater systems and application to Switzerland. *International Journal Renewable Energy* 2017:113:64–73. https://doi.org/10.1016/j.renene.2017.05.062

[40] Заповідні території. (Protected areas). [Online]. [Accessed 30.03.2023]. Available: http://carpaty.net/?page_id=183 (In Ukrainian).