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Small hydropower development in Ukraine under global climate change patterns: is state economic support sufficient?

Tetiana Kurbatova (corresponding author) (PhD in Economics, Senior Lecturer, International Economic Relations Department, Sumy State University, t.kurbatova@macro.sumdu.edu.ua)

Iryna Sotnyk (Doctor in Economics, Dr. Sc. (Econ), Professor, Department of Economics, Entrepreneurship and Business Administration, Sumy State University, insotnik@gmail.com)

Oleksandr Kubatko (Doctor in Economics, Dr. Sc. (Econ), Associate Professor, Department of Economics, Entrepreneurship and Business Administration, Sumy State University, okubatko@econ.sumdu.edu.ua)

Liudmyla Gorbachova (Dr. Sc. (Econ), Head of the Department of Hydrological Research, Ukrainian Hydrometeorological Institute, gorbachova@uhmi.org.ua)

Borys Khrystiuk (PhD in Economics, Head of the Laboratory of Hydrological Calculations, Ukrainian Hydrometeorological Institute, khryst@uhmi.org.ua)

Abstract: During the last years, significant changes happened in seasonal river hydrology in Europe due to climate change. Nevertheless, according to the presented analysis, the total water runoff for hydropower generation did not change. The last fact is an important policy implication for small hydropower promotion in Ukraine because it belongs to that region and has similar climate conditions. Having analysed the hydropower potential, the paper describes the main advantages and limitations of implementing small hydropower projects in Ukraine. The cost of electricity generated by a small hydropower plant in Ukraine is determined and compared with the current feed-in tariff. The calculations show that the feed-in tariff is 1.4 times higher than the electricity generation cost, making the implementation of small hydropower plants profitable for investors. Since the state provides sufficient economic support for this sector's development, the financial and non-economic barriers significantly hinder small hydropower plant deployment are considered.

***Keywords*:** small hydropower; renewable energy; policy; feed-in tariff; LCOE; economic support; Ukraine.

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1. Introduction

In recent decades, renewable energy (RE) has been considered as a priority area of energy sector development by many national governments (Kurbatova et al., 2020). The main RE benefits include preserving fossil fuels from exhaustion, increasing countries' energy independence, and providing a transition to a low-carbon economy (Bilan et al., 2019; Horobchenko and Voronenko, 2018; Vasyllieva et al., 2019; Voronenko et al., 2017). Due to the higher cost of RE technologies in comparison to conventional ones, this industry still requires state economic support. The latter aims at ensuring the profitability of RE investments through using economic mechanisms (subsidies, grants, tax privileges, etc.) (UN, 2018; Prokopenko et al., 2015; Sotnyk et al., 2018).

The most popular RE technologies, which usually receive state support, include solar, wind, bioenergy, and hydropower. The latter often requires minimal incentives since hydropower technologies are mature and for the most part economically feasible (UN, 2018; UNIDO, 2016). However, small hydropower (SHP) development heavily depends on local water resources, which may modify their characteristics due to climate change. Construction and operation of small hydropower plants (SHPPs) may destruct the local environment causing transformations in the river water regime, shortage of water resources, etc. (Melnyk and Kubatko, 2012; Melnyk and Kubatko, 2013).

Climate change is a reason that warmer winters in Eastern Europe made more water inflows for SHPPs during the cold periods while hot and dry summers shortened water amounts during the warm seasons (Blöschl et al., 2019; Gorbachova and Khrystyuk, 2014; Gorbachova, 2014; Loboda and Bozhok, 2016). It results in changes in water runoff and consequently SHP potential (Blöschl et al., 2019). One more concern is that fluctuations in water inflows and SHPP construction influence the small rivers. The latter may suffer from slower water velocity, water eutrophication, reduced water transparency, and dissolved oxygen in comparison with higher upstream regions.

Knowledge of river water flows enables countries to develop and implement measures to protect the population and the economy from adverse effects of dangerous hydrological phenomena (floods, hydrological drought) as well as plan the optimal use of SHP potential. Other essential aspects of SHP development are keeping the environmental balance and providing sufficient economic incentives for the sector's deployment.

Ukraine shares many rivers with other Eastern European countries and faces similar problems of SHP development. Therefore, the study of the country's SHP potential, its transformation under the influence of climate change and ways of its implementation can provide useful policy implications not only for Ukraine itself but also for the neighboring states.

The domestic SHP potential use will ensure reliable electricity supply in mountainous and remote rural areas, balancing energy capacities in the power grid. In spite of the introduced state support schemes, domestic SHP deployment demonstrates slow growth, which does not correspond to the planned state RE indicators. Therefore, the study of a sufficiency of the state economic support in this field and identification of barriers faced by investors of SHPPs will contribute to further sector development.

The paper aims at estimating the possible changes in SHP potential due to the climate change and sufficiency of state economic support for SHPP construction at the example of Ukraine. In addition, it provides policy recommendations for overcoming existing barriers to the sector's development. Unlike other publications in this field, the research contributes to the evaluation of the climate change influence on SHP potential, the adequacy of SHP state economic support through the comparison of the cost of electricity generated by SHPPs with the existing feed-in tariff (FIT) and analysis of investment projects efficiency for SHPP construction.

The article's structure includes several sections. Section 2 presents the analysis of the recent literature in the SHP field. Section 3 estimates changes in SHP potential due to the climate change and describes advantages and limitations for SHP potential implementing in Eastern Europe and Ukraine specifically. Section 4 considers the present state policy aimed at promoting SHP development. Sections 5 and 6 present the methodology and the data used for the economic calculation. Section 7 discusses the calculation results and identifies the main barriers to SHPP construction and operation. The final section concludes the study and provides policy recommendations for improving SHP deployment.

2. Literature review

China is the world leader in the deployment of SHP, accounting for 51% of the world's installed capacity. Significant progress in SHP deployment has also been made by Italy, Japan, Norway and the United States (UNIDO, 2016). Therefore, a lot of publications are aimed at studying the experience and problems of SHP development in these countries.

For example, Y. Kong et al. (2015) provide a survey of SHPP exploitation in China and substantiate that SHPPs have contributed a lot to rural electrification. In their opinion, the reasonable exploitation of SHPPs in the country will accelerate the harmonic development of resources and the environment. On the other hand, M. Pang et al. (2015) estimate the SHPPs' environmental consequences for China and conclude that the eco-friendliness of SHP is questionable when it is intensively developed. Z. Cui and J. Xu (2017) investigate the drivers for SHP deployment in China that include shortcomings of legislation, raising awareness regarding the environmental protection as well as point out the priorities and suggestions for future sector's development.

Q. F. Zhang, B. Smith, and W. Zhang (2012) identify the economic factors for SHP deployment through cost analysis and propose ways for cost reduction and strategies for expanding SHPP construction in the US. K. Johnson and B. Hadjerioua (2015) conclude that despite current legal, financial, informational, and other challenges, SHP development in the US is expected to accelerate in response to recent new streamlined federal permitting processes and new financial incentives. In many cases, SHP deployment can be achieved with minimal environmental impact.

While exploring the potential of SHP development and the state of its implementation in Japan, Y. Lecler (2017) notes that the RE development in the country is extremely limited to solar power. The reason for this is the bureaucratic procedures for obtaining permits for SHPP construction and the limited participation of individuals and rural associations in these processes. Analysing the electricity generation cost by SHPP, G. Hennequin (2016) concludes that it is higher in Japan than the average world level, which proves the importance of support schemes in this field.

Thus, for the developed countries, scientists point to the significant SHP potential, which is still unimplemented. They highlight the main barriers such as lack of financial incentives, long and confusing bureaucratic procedures, possible negative ecological impacts of SHPP construction, and countering the public against SHPPs through fear of environmental deterioration. Other obstacles, which hinder SHP potential implementation in the states with different economic development level, are the low awareness of SHP social, economic, environmental, and synergetic impacts, poor SHP promotion as a climate mitigation strategy as well as an institutional incoherence to facilitate RE integration to the existing power grids (Kelly-Richards et al., 2017). Given the low levels of electrification, especially in rural areas, the large untapped SHP potential in developing countries remains a relevant issue for their national governments.

L. Nikolayeva (2016) argues that SHPP construction on the Carpathian small rivers in Eastern Europe would create the risk of changes in their hydro regime. In addition, spawning areas may be damaged and the potential of green tourism may reduce. Therefore, ecological and economic aspects should be considered when shaping the mechanisms for further SHP development.

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The shortage of own fossil fuels in Ukraine, low energy efficiency of the economy, and limited possibilities of stimulating economic development at the expense of non-renewable energy resources are essential drivers to attract RE (in particular SHP) to Ukraine's energy balance (Sotnyk et al., 2015). For example, P. Vasko and A. Moroz (2016) calculated the technically feasible potential of hydropower resources for the major small rivers in Ukraine based on certain rates of their hydropower potential use. S. Shashkov (2015) studied the SHP cost management and proposed the multipurpose use of the SHP potential by creating territorial natural and economic complexes on SHPP basis. It allows an increase in investors' incomes while reducing the risks of the SHPPs' functioning and growing their market values. P. Vasko, V. Vasko, and M. Ibragimova (2015) analyse the legal and economic mechanisms of SHP development in Ukraine and conclude about their positive influence on SHPP construction. L. Levkovska and V. Mandzyk (2016) assessed the prospective SHP growth for Ukrainian energy sector and determined the FIT as a primary incentive for the industry development.

D. Stefanyshyn and S. Ataev (2015) explored the possibilities of SHPP restoration in Ukraine in the context of environmental management. They advised FIT installing only for those private investors who carry out SHPP restoration or for SHPPs, the elimination of which is unjustified while preserving their basic technical parameters.

Despite many scientific publications in the RE field which discuss the hydropower deployment in the EU as a political union, in Europe in general, and Eastern Europe specifically (see for example (Capik et al., 2012; Manzano-Agugliaro et al., 2017; Năstase et al., 2017; Nikolayeva, 2016; Punys et al., 2017; Steller et al., 2020; Wagner et al., 2019)), the issue of sufficiency of state economic support for SHP deployment is still missed by researchers. The latter is urgent for Ukraine, which is trying to increase its energy independence by developing different RE technologies, including SHP.

3. Potential of electricity generation by small hydropower plants

3.1. Small hydropower potential of Ukrainian regions

Ukrainian legislation defines a small SHPP as a plant the installed capacity of which does not exceed 10 MW (Verkhovna, 2008). The natural conditions of the country are favourable for SHP development. There are about 60 thousand small rivers in Ukraine (UNIDO, 2018). According to (Cabinet, 2017; State, 2018), the domestic theoretical SHP potential is 12501 mln kWh/year, technically possible potential equals 8252 mln kWh/year (or 66% of the theoretical one), and economically feasible potential is 3340-3747 mln kWh/year (or 26.7-30% of the theoretical one). As of the end of 2019, only 242 mln kWh (or 6.5-7.2% of the economically feasible potential) were implemented (Table 1) (UNIDO, 2016; National Commission, 2020). The SHP potential implementation is the most promising in the western regions of Ukraine, where many small rivers are concentrated (see Fig. 1) (UNIDO, 2016; UNIDO, 2018).

3.2. Estimation of climate change influence on small hydropower potential

The main characteristic of the river water content is the average annual runoff, which directly influences the SHP potential and depends on climate change. While assessing whether climate change affects SHP potential, the authors have analysed the average annual water runoff based on long-term observations on the water gauges located on Ukrainian small and medium-sized rivers (EU, 2006). We considered rivers that had SHP potential and flew through the territory of other Eastern European countries. For example, the Prut river comes through the area of three states (Ukraine, Moldova, and Romania). The database included time series for 35 gauging stations of the average annual flow from the beginning of the observations up to 2018.

According to (WMO, 2009), application of graphical methods and historical data analysis is necessary to verify the statistical criteria for analysis of homogeneity and stationarity of observations' hydrological series. Therefore, a methodological approach based on hydro-genetic methods (graphical) was applied to estimate the homogeneity and stationarity characteristics (Gorbachova, 2014; Gorbachova and Khrystyuk, 2014; Zabolotnia et al., 2019). We considered two methods of mass and residual mass curves. The first one helps identify the impact of technogenic factors (canals, hydraulic structures) and changes in environmental quality (the trend presence in the data series). The second method assesses the data series' stationarity, namely the sustainability of the average value of hydrological characteristics.

We have analysed three mountain rivers and three plain rivers to estimate the annual water runoff and SHP potential. The mass curves graphs of the average yearly river runoff were created. Some examples of them are shown in Fig. 2, *a, b*. There are no important volatility points in the curves' directions, while some slight variations are related to long-term cyclical volatility (Fig. 2, *c, d*). These fluctuations do not significantly affect the overall curves trend. Consequently, we have concluded about the homogeneity of observations' series.

Long-term cyclic oscillations for both mountain and plain rivers are synchronous (see Fig. 2, *c, d*). For small and medium-sized rivers, the set of observations of the annual average flow are quasi-stationary (containing an incomplete phase of oscillations). It means that the long-term average value (runoff rate) is constant over time. Thus, despite the increase in air temperature, which is observed in Ukraine and Eastern Europe in recent decades, the quantitative characteristics of the average annual river runoff have not changed significantly. Therefore, climate change does not adversely affect the magnitude of SHP potential in the region.

3.3. Advantages and limitations for small hydropower potential implementation

Having analysed Eastern European and Ukrainian SHP specifics (Capik et al., 2012; Manzano-Agugliaro et al., 2017; Năstase et al., 2017; Nikolayeva, 2016; Punys et al., 2017; Steller et al., 2020; Wagner et al., 2019), we can name the main advantages and limitations for implementing SHP potential (Fig. 3). The mentioned obstacles significantly impede the SHP development in the region and Ukraine specifically, often offsetting numerous benefits of the SHPPs.

4. Public policy to promote electricity generation by small hydropower plants in Ukraine: drivers, results, and barriers

The RE development targets are declared in the Energy Strategy of Ukraine for the period up to 2035 "Security, Energy Efficiency, Competitiveness". The document installed the expected green energy shares in the country's energy mix as 12% and 25% in 2025 and 2035 respectively (Cabinet, 2017).

In order to achieve these goals, the government has implemented support scheme (FIT, tax and customs privileges), which are the same for all RE technologies (Trypolska, 2019).

Feed-in tariff. In accordance with the Law of Ukraine "On Electricity Market" (Verkhovna, 2019), the FIT is used for purchasing green electricity, in particular generated by SHPPs with the total installed capacity 10 MW or less.

The Law of Ukraine (Verkhovna, 2019) provides a fixed allowance to the FIT for using equipment and components of domestic production in the construction of SHPPs. For SHPPs, which were put into operation from July 1, 2015 to December 31, 2024 with the use of equipment produced in Ukraine at the level of 30% and 50%, the allowance rates are 5% and 10% respectively. The validity period of the FIT support scheme to promote RE development is set till 31.12.2029.

Tax and customs privileges. According to the Ukrainian legislation (Customs, 2012; Tax, 2011), equipment and components used for SHPP construction that have no Ukrainian analogues exempt from customs duties and value added tax.

The implementation of the mentioned mechanisms has positively influenced on the SHP deployment. As of the end of 2019, there were 157 SHPPs in Ukraine, and their total number 2.2 times exceeded the same indicator in 2011. The total installed capacity of SHPPs put into operation in 2019 was 111.5 MW that 1.6 times exceeded the indicator of 2011. The electricity generated by SHPPs in 2019 amounted to 242 mln kWh that was 16,1% higher in comparison with 2011 (Table 1).

In spite of the stable positive trends in SHPPs development, there were fluctuations in the generated electricity volumes during the analysed period. The reason was the low water runoff of Ukrainian rivers, which reached its minimum in 2015 (National power, 2015).

As of the end of 2019, SHPPs took the third position (9.3%) in the total mix of the electricity generated from RE sources in Ukraine, yielding only solar and wind power plants (Fig. 4). However, the green electricity share in the county's energy mix was only 7.3%. It is an extremely low indicator that does not correspond to world trends in RE development (National Commission, 2020). Thus, electricity generation in Ukraine is still based on conventional technologies, which covered 92.7% of electricity demand in the country at the end of 2019.

5. Methodology

Since the FIT is a primary mechanism to promote SHP deployment, the government should keep its level high enough to cover the green electricity generation cost and provide profit to the SHPP owners. Therefore, it is expedient to calculate the cost of electricity generation by a SHPP to compare it with the current FIT rate. This will ascertain that the FIT is adequate.

Calculation of the cost of electricity generated by a SHPP is carried out using the method of Levelized Cost of Energy (LCOE) (IEA, 2011; IRENA 2012). The LCOE reflects a fixed electricity tariff, whereby the discounted income from the electricity sale to a consumer equals to the discounted expenditures during the SHPP lifecycle (Trypolska, 2014; Xiaoling and Boqiang, 2014).

We consider the following components of the electricity cost: investment and operating expenses, the amount of electricity generated by a SHPP, a discount rate, and the decommissioning costs. Using these indicators, the calculation formula can be presented as follows:

$$LCOE = \frac{\sum_{t=0}^{n} \left((I_t + Q_t + D_t) \cdot (1+r)^{-t}\right)}{\sum_{t=0}^{n} \left(E_t \cdot (1+r)^{-t}\right)}, \qquad (1)$$

where *LCOE* is the electricity generation cost throughout the SHPP lifecycle, EUR/MWh; D_t is the SHPP decommissioning cost in year *t*, EUR; E_t is the amount of electricity generated by the SHPP in year *t*, MWh; I_t is investment expenditures in year *t*, EUR; Q_t is operating costs in year *t*, EUR; *n* is the SHPP lifecycle term, years; *r* is a discount rate; *t* is a year of the implementation of SHPP investment project.

The minimum FIT for electricity generated by the Ukrainian SHPP is calculated as (Verkhovna, 2019):

$$FT_{min} = RP \cdot k \,, \tag{2}$$

where FT_{min} is the FIT to purchase electricity generated by the SHPPs, UAH/kWh; *RP* is a retail electricity price for consumers of the second class voltage as of January 2009 (0.58 UAH/ kWh); *k* is the FIT rate.

The indicator *k* directly depends on the year of putting a SHHP into operation. For example, *k*=1.94 for SHHPs put into operation from 01.01.2017 till 31.12.2019; *k*=1.75 for SHHPs put into operation from 01.01.2020 till 31.12.2024, and *k*=1.55 for SHHPs put into operation from 01.01.2025 till 31.12.2029 (Verkhovna, 2019).

Protecting SHPP owners from inflation, every month the National Energy and Utilities Regulatory Commission reviews minimum FITs by converting them to the EUR at the official exchange rate as of January 1, 2009. The Commission uses the following algorithms:

$$\text{If UAN / UAN 01.01.2019} > 1, \ \text{FT} = \text{FT 01.01.2019} \cdot (\text{UAN / UAN 01.01.2019}), \tag{3}$$

$$\text{If UAN / UAN 01.01.2019} \leq 1, \quad \text{FT} = \text{FT 01.01.2019}, \tag{4}$$

where *FT* is the FIT as of the date of its revision, UAH/kWh; *FT 01.01.2009* is the FIT as of January 1, 2009, UAH/kWh; *UAH* is the hryvnia-euro exchange rate of the National Bank of Ukraine (NBU) as of the date of the FIT revision, UAH; *UAH 01.01.2009* is this exchange rate as of January 1, 2009, UAH (UAH 10.86 to 1 EUR).

The SHPP project payback period is calculated by the formula:

$$PP = \sum_{t=1}^{n} CF_t \ \geq \ IC_{0,} \tag{5}$$

where *PP* is the SHPP project's payback period; IC_0 is the initial investment in the zero period (year), EUR; CF_t is a net cash flow in year *t*, EUR; *n* is a lifecycle term of the SHPP project, years; *t* is a year of the SHPP project implementation.

6. Data

The technical and economic data for the LCOE calculation at the example of an average SHPP in Ukraine are presented in Table 2 (PJSC "Ukrhydroproject", 2019; Hydrotechproject Ltd, 2019; USELF, 2014; IEA, 2011; IRENA, 2012).

At present, Ukrainian commercial banks do not offer affordable long-term lending for RE projects. The attraction of financial resources for the SHPP construction on acceptable terms is available under the Ukraine Sustainable Energy Lending that is a credit line of the European Bank for Reconstruction and Development (USELF, 2019). In this research we assume that the SHPP will be implemented under this credit programme.

The discount rate was calculated at 12% in EUR considering the weighted average cost of capital and the country' risk premium (Damodaran, 2020). While comparing Ukraine to other countries, the discount rate here is quite high due to the high risks of doing business caused by the military conflict in the Ukrainian East and the economic situation instability.

7. Results and Discussion

Applying the methodology presented above, the LCOE has been calculated as 77.01 EUR/MWh (0.08 EUR/kWh). Considering the official exchange rate of NBU as of January 1, 2019 (UAH 31.71 = EUR 1) (National Bank, 2019), this indicator equalled 2441.98 UAH/MWh (2.44 UAH/kWh).

For the SHPP put into operation from 01.01.2017 to 31.12.2019, the minimum FIT assessed according to the formula (2) was 1.13 UAH/kWh.

Using these data and comparing the NBU's hryvnia-euro exchange rate as of 01.01.2019 and 01.01.2009, we calculated the FIT as of 01.01.2019 according to the algorithm (4). We got the result 3.30 UAH/kWh (0.1 EUR/kWh). It means that the FIT for the SHPP exceeds the electricity generation cost evaluated with the LCOE method 1.4 times. Therefore, the FIT value adequately covers the cost of green electricity generation by the SHPP in Ukraine.

It is worth emphasizing that we averaged the actual data for the SHPP economic calculations. Since SHPP projects are very individual, it is necessary to refine the estimates for each case. However, as the FIT is 1.4 times higher than the green electricity generation cost, one can conclude about a certain reserve of financial strength for such projects, even if their energy generation cost will be slightly higher than the average values given in Table 2.

Considering the formula (5), the payback period of the SHPP investment is 5.8 years that is a perfectly acceptable for investors. While calculating this indicator, we used the same average annual amount of electricity generated by the SHPP due to the difficulty in forecasting the precise annual water runoff of small rivers in Ukraine.

Overall, the research results indicate that the current FIT rates for the SHPPs in Ukraine covers all the costs and provides profit for the SHPP owners. Domestic FITs installed for SHP and other RE technologies are ones of the highest in Europe (Orlyk and Dats, 2019). Therefore, the payback period for the vast majority of RE investment projects is acceptable and does not exceed 7 years. However, this economic support costs a lot for the state budget. That is why the national government plans to introduce a new mechanism based on green auctions to reduce green electricity prices in 2021. Due to many barriers, green auctions are still not in force. This uncertainty is one of the reasons that prevent investors from implementing profitable SHPP projects in Ukraine.

To increase the investment attractiveness of the SHP sector, the state policy should be aimed at eliminating financial and non-economic obstacles which inhibit the large-scale SHP development, namely:

– the lack of available long-term lending for SHPP construction. Although some Ukrainian commercial banks have special lending programmes for financing RE investment projects (Oschadbank, 2019; UkrGasBank, 2019), none of them are applied to SHPPs. That is why potential investors cannot attract financial resources on favourable terms;

– lack of a stable regulatory framework in the RE field. Permanent introduction of amendments to regulatory acts concerning changes in the FIT rates, obligations to the local component of SHPP equipment, conditions for SHPP connecting to the power grid, requirements of land allocation for SHPP construction, the transition to a new support scheme of green auctions to promote RE development undermine investors' confidence and bear the risks of curtailing their activities in Ukraine;

– the state of the power grids. The technical status of electricity grids is critical; about 40.5% of them and 37.6% of transformer substations have been used for more than 40 years and need to be reconstructed or replaced. It makes it impossible to quickly absorb a significant amount of electricity generated by RE plants including SHPPs;

– lack of promoting electricity consumption from RE sources among the population and enterprises. The Ukrainian FIT aims exclusively at stimulating green electricity generation but not its use (Kurbatova and Skibina, 2019; Sotnyk et al., 2020). Thus, it is reasonable to extrapolate international experience in applying the tools for green energy demand formation. It can be done through the introduction of mandatory consumption quotas;

– the bureaucratic barriers to getting permits regarding land allocation, the FIT, acquisition of membership on the Wholesale Electricity Market, etc. (Flanders, 2018);

– active resistance from the public and environmental organisations due to the negative ecological influence of the SHPPs.

8 Conclusion

An important issue for hydropower development is the prospective changes in water resources, which determine the SHP potential. During the last 30 years, there are debates about fluctuations of river water resources associated with climate change. Our research shows that possible future changes in the water runoff of small and medium-sized rivers of Eastern Europe and Ukraine are expected to be insignificant. It is especially true for the Carpathian rivers.

The paper proves that the Ukrainian rivers have an intra-annual redistribution of water runoff, while its yearly value remains relatively stable and does not seriously affect the SHP potential. Regarding the plain rivers in the low-water phase, there are reduced water amounts during the spring flooding period, and higher water flows during the summer-autumn period. For the mountain rivers, the low-water phase is characterized by reduced water amounts during the snow and rain flood period, and higher water flows during the rain flood period. Therefore, there are no natural obstacles to SHP development caused by climate change.

A comparative study on evaluating the cost of electricity generated by SHPPs and the corresponding FIT established in Ukraine has verified that the FIT is 1.4 times higher than the electricity generation cost. It makes the construction and operation of SHPPs profitable for investors. The payback period is also quite acceptable for green energy projects and does not exceed 6-7 years. On the one hand, it means that the Ukrainian government provides sufficient economic support for SHP development, which is expressed in the FIT and tax and customs privileges.

On the other hand, despite the large available SHP potential of the country, the dynamics of the sector development in 2011-2019 indicates slower growth compared to other types of RE sources, for example, solar and wind power generation. The reason is many financial and non-economic barriers faced by investors and owners of SHPPs. In particular, a significant obstacle is the lack of available long-term lending for SHPP construction. Loans offered by Ukrainian financial institutions do not exceed 5 years, which is not acceptable due to the longer payback period of SHPP projects. In this regard, along with keeping the FIT rates and existing economic privileges, it is expedient to introduce special state lending programmes for SHPP construction.

Development and implementation of the long-term state strategy for SHP sector deployment, which is fixed by law and enhanced with economic instruments, will help to reduce the uncertainty and risk of doing energy business in Ukraine. It will contribute to increasing the confidence of potential investors in the unchangeable game rules at the energy market and stimulate them to invest in SHPP construction. In the Energy Strategy, it is advisable not to limit the state's benchmarks to achieving the green energy share in the total electricity mix, but to implement step-by-step state support measures for both investors and other SHP market players that provide technical, informational, financial and other project services.

Considering the possible negative environmental consequences of the SHPP construction, improving regulatory documentation concerning state requirements for SHP projects is an essential prerequisite for further sector development. This documentation should be consistent with environmental legislation and provide transparent mechanisms for state and public control over SHPP construction and operation. In addition, it is appropriate to create regulatory levers that should be applied by the state to prevent and resolve conflicts, which may arise between agriculture, fishery, electricity generators, and biodiversity as a result of the SHPPs' operation.

Creation of regional chains and clusters supporting SHP development, which bring together the owners of energy facilities, energy equipment manufacturers, designers, construction and engineering companies, financial institutions, public environmental organisations, and local authorities, can significantly contribute to the implementation of the SHP projects. Sharing successful SHPP experience will help to reduce the biased attitude of the population and business agents to the expected environmental consequences of SHPP operation and enhance SHP development.

Simplification of administrative procedures (privatisation and lease of the SHPPs and related hydraulic structures, land allocation for their construction, reduction of the number of permits for new SHPP construction, SHPPs connecting to power grids, etc.) will persuade potential investors to make a decision in favour of new SHPP construction and contribute to the energy independence of the country along with gaining significant profits.

Considering the proposed directions of the SHP state support improvement, the prospects for further research in this field are the substantiation and implementation of complex long-term lending programmes for SHPP construction and the development of corresponding legal acts for the SHP deployment.

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Figure 1 Hydropower potential of small rivers of Ukraine by regions (Kudrya et al., 2011)

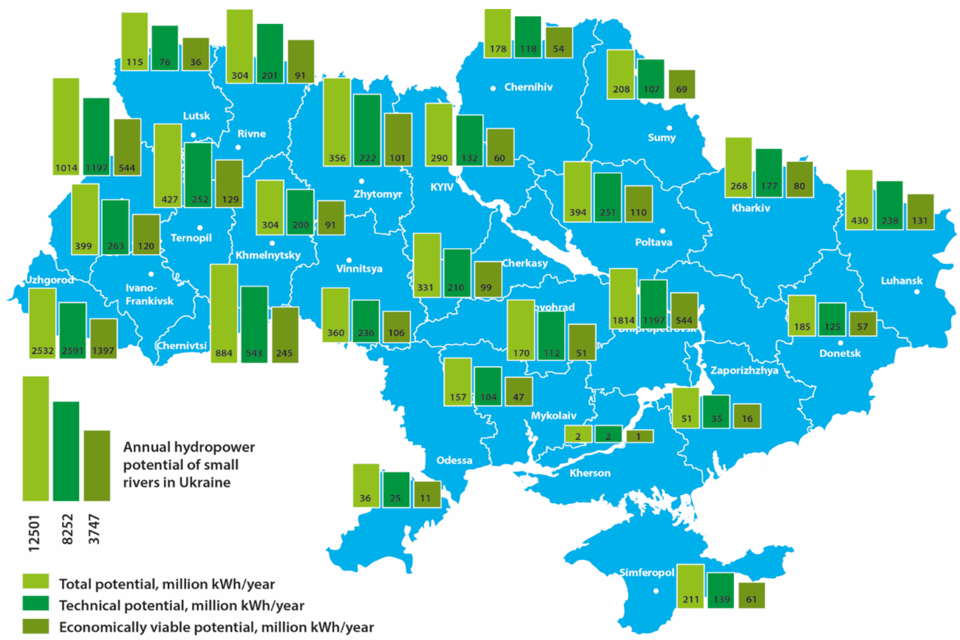
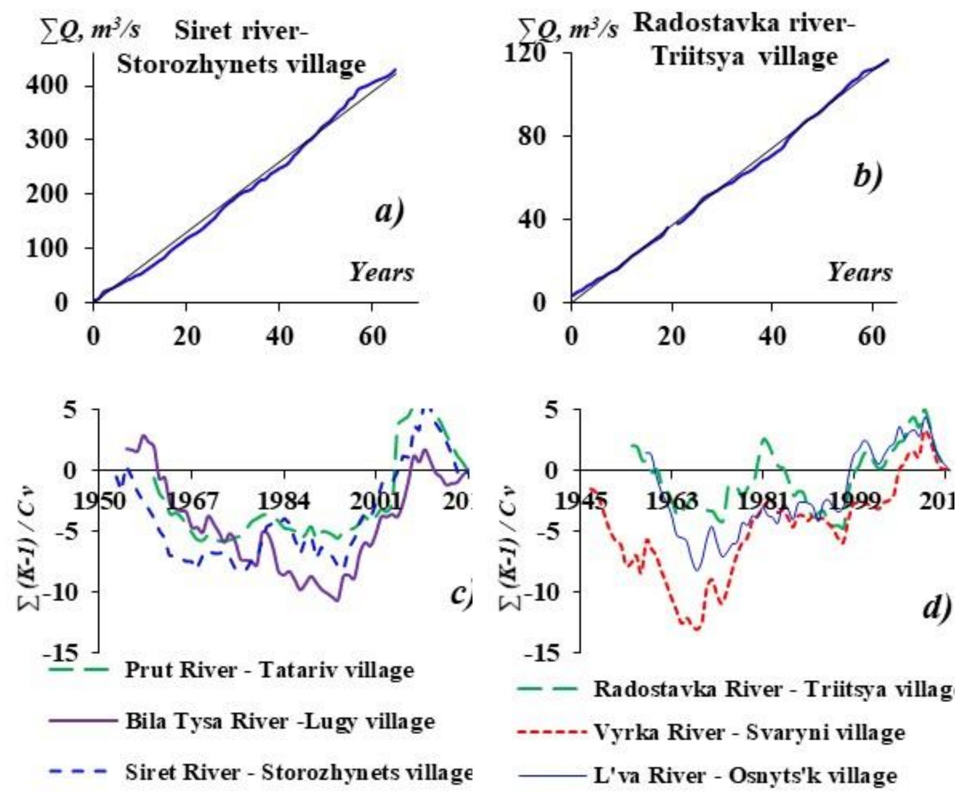


Figure 2 Mass (a, b) and residual mass curves (c, d) of the average annual runoff for the selected Ukrainian rivers



Mountain rivers ***Plain rivers***

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Figure 3 Advantages and limitations for implementing SHP potential (Capik et al., 2012; Năstase et al., 2017; Steller et al., 2020; USAID, 2018)

Implementation of SHP potential

Advantages

– predictability and availability of operating modes, high manoeuvrability of SHP capacities;
– the use of SHPPs for covering peak loads, control frequency and power, mobile emergency reserve in the Unified Energy System of Ukraine;
– vast experience in the successful use of SHPPs, development and design of the hydro turbine and electrical technical equipment, construction and operation of SHPPs on both the mountain and plain rivers;
– the suitability of the SHPPs' use in mountainous and rural areas, which allows electricity supply in these territories;
– compactness, ergonomics and minimal environmental impact of the SHPPs provided that location their location is chosen correctly;
– protection by means of SHPPs of adjacent settlements against floods, promotion of their regular water supply, development of the fish industry;
– electricity generation without the use of fossil fuels and CO_2 emissions.

Limitations

– the presence of a seasonal factor in the work of SHPPs with winter-yearly recessions and the autumn-spring peaks of energy generation;
– possible negative environmental impact of SHPPs including flooding large territories, extinction of valuable fish species, land fertility declining, etc.;
– high investments in SHPP construction due to the creation of complex hydraulic structures and the need for unique equipment for each SHPP;
– long terms of designing and obtaining permits that prolong the investment cycle of SHPPs and reduce the investment attractiveness of the industry;
– the high cost of connecting the remote SHPPs to the electric grids.

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Figure 4 The structure of the total mix of electricity generated from RES at the end of 2019, % (National Commission, 2020)

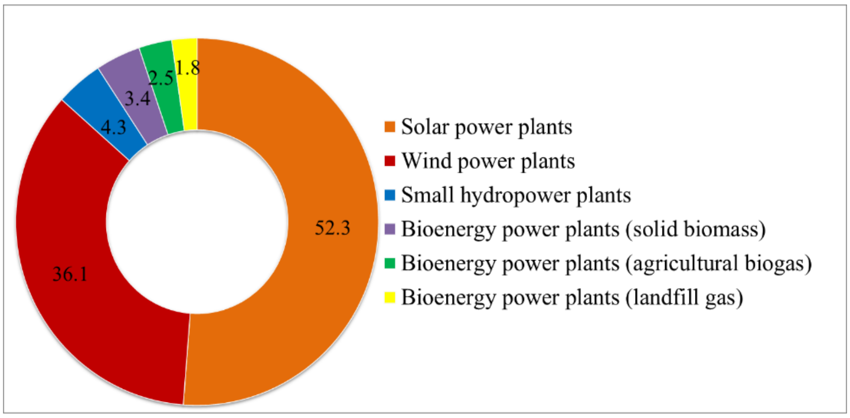

Table 1 Key indicators of the SHHPs development in Ukraine in 2011-2019 (National Commission, 2020)

Indicator	2011	2012	2013	2014	2015	2016	2017	2018	2019
Number of SHPPs, units	73	80	90	102	114	125	137	149	157
Installed capacity of SHPPs, MW	70.8	73.4	75.3	80.2	86.9	90.0	94.6	98.6	111.5
Amount of electricity generated by SHPPs, mln kWh	203.4	172	286	250.7	171.6	189.3	194.8	241.6	242.0

Table 2 The technical and economic characteristics of an average SHPP in Ukraine

Characteristic	**Value**
Total installed capacity	1 MW
Annual electricity generation	4850 MWh
Duration of the construction	1 year
Lifetime duration	30 years
Estimated investment cost	2320000 EUR
Operation and maintenance costs	62573 EUR/year
Cost of decommissioning	116000 EUR