

**THE HYDROPOWER IN UKRAINE: ORGANIZATIONAL AND ECONOMIC
INSTRUMENTS OF STIMULATING THE GREEN ENERGY DEVELOPMENT
AND RATIONAL USE OF HYDROPOWER POTENTIAL**

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Abstract. The article focuses on the research of hydropower in Ukraine: its current state, problems, possible ways to solve them and prospects for development. The relevance of this research refers to the importance of a comprehensive study of hydropower in Ukraine as the main component of green energy, as well as the potential for the development of hydropower in the conditions of the future post-war rebuilding of Ukraine. The main research goal is to define a complex of organizational and economic instruments to stimulate the development of hydropower in Ukraine and to ensure the rational use of hydropower potential. The core research methods are analysis, comparison, systematic approach, dialectical method, methods of abstraction and concretization, mathematical and statistical methods, etc. The terminological content of the concept and peculiarities of use and protection of water resources are characterized. The growth of their scarcity for household and agro-industrial needs of Ukraine is shown. The peculiarities of the development of hydropower as a branch of energy, which provides a principle of operation based on the use of water energy, have been studied. Weak and strong points, opportunities, and threats to the development of hydropower have been identified. The main prospects for the development of the hydropower industry in Ukraine are analyzed. All possible aspects of development are divided into two groups: effective environmental management of water bodies and cost-effective environmental use of hydropower potential. Each of these areas is analyzed in the context of state policy and water policy of the largest representative of the hydropower industry. The main recommendations for the development of hydropower in Ukraine are offered, aimed at solving the problems of water management and economically justified environmental use of the hydropower potential of Ukraine.

Keywords: water resources, hydropower, hydropower potential, water policy, green energy, alternative energy sources.

1. Introduction

Recently, green energy sources have become increasingly popular. One of these sources is the energy of water movement. Accordingly, the industry that produces this energy is hydropower. Hydropower in Ukraine has not reached its maximum development. A significant part of the hydro potential is not being used at the moment. With the further development of hydropower, the construction of new hydroelectric power stations and pumped storage power plants, it is possible to extract a significant amount of relatively cheap energy. But at the same time, hydropower, being an alternative source of energy, is not a completely environmentally friendly industry. The construction of new hydroelectric power plants often requires flooding of territories, leading to a change in the natural conditions of the river. An excessive number of giant hydropower complexes can lead to irreparable damage to the hydrosphere of Ukraine. Therefore, the issue of analyzing the industry, and determining its development features, trends, prospects, and recommendations is quite complex and ambiguous, but important, given the potential for the development, and production of relatively cheap energy. Therefore, the research topic

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is relevant. It should also be noted that the topic of the research is of particular relevance in the conditions of the large-scale Russian invasion of Ukraine, which brings a range of negative social, ecological, and economic effects and forms threats to the sector development. At the same time, the hydropower industry has the potential for accelerated development in the framework of Ukraine's rebuilding in future. The definition of the organizational and economic instruments to stimulate the development of hydropower in Ukraine requires an understanding of the pre-war state of the sector, which causes the need for a fundamental analysis of its current state.

Many scientists devoted their scientific works to the problem of hydropower development in Ukraine. The scientists Vitaliy Zatserkovny and Lyudmyla Plichko study the peculiarities of public administration in the field of water management and identify the most typical problems and possible ways to solve them. The authors Petro Vasko and Maria Ibrahimova study the features and prospects of the development of small hydropower in Ukraine as a promising area for attracting additional hydropower potential. The author Iryna Barna considers hydropower potential as a promising way to achieve Ukraine's energy independence. At the same time, there is no comprehensive analysis of the hydropower sector in Ukraine with proposed ways for the effective management of water bodies and the economically feasible ecological use of hydropower potential in the scientific works of these authors. Therefore, despite the significant research works and scientific results in the sphere of hydropower development in Ukraine, the issues of comprehensive research of the current state, features and trends, urgent problems, and ways to solve them in the hydropower industry in Ukraine remain insufficiently studied, which grounds the relevance of this research.

The setting objectives of this investigation are to analyze the current state, problems, trends, and prospects of development of the hydropower industry in Ukraine, as well as to establish the main organizational and economic instruments to stimulate the development of hydropower, to characterize their features.

Research methods. Different methods, including general scientific and economic, were used to achieve the defined research goal and solve the tasks. Among the general scientific methods, the analysis of literary sources was applied to use the terminological apparatus and the theoretical and practical foundations of the study of the current state of water resources and hydropower potential in Ukraine, as well as to characterize the essence of environmental taxation.

The system method was used to determine the components of the hydropower industry in Ukraine, structure a set of tools for stimulating the development of hydropower and characterize the place of the hydropower industry in other spheres of human life, in particular in the environmental sphere. The analysis was used to determine the main trends and problems, development recommendations, advantages, disadvantages, opportunities and threats to hydropower in Ukraine. The comparison was used to characterize the current state of water resources and hydropower potential of Ukraine in comparison with other countries, as well as to compare different approaches to stimulate the development of hydropower in Ukraine. The dialectical method was applied to consider all features and trends of hydropower development in Ukraine, influencing factors in their interaction and contradictions. The abstraction and concretization were used to highlight essential features and recommendations for the development of the hydropower industry in Ukraine. Among the economic methods, combining historical and logical methods was used to determine all historical features and regularities of the development of hydropower in Ukraine. The mathematical and statistical methods were applied for calculation, analysis, and visual presentation (diagrams, graphics) of the characterized indicators of hydropower development in Ukraine.

2. Theoretical part

Water resources are reserves of surface and groundwater in water bodies that are used or can be used. Among the main users of water resources are agriculture and industry (Hnedina, Nahorny, 2021). But now, in Ukraine, as in the rest of the world, the problem of a coming shortage of water resources due to global climate change is acute.

The greatest manifestation of climate change is global warming. From 1975 to 2019, the growth rate in average annual air temperature in Ukraine was from 0.61 to 0.82 °C/10 years. The identical figure for other countries is slightly lower: from 0.47 to 0.59 °C/10 years in neighbouring former Soviet countries, from 0.34 to 0.47 °C/10 years in Europe (NAAS, 2020). Such climate change influences the surrounding habitats and components of the environment. The main impact of climate change on water resources refers to (Romashchenko et al., 2020):

Ø redistribution (destruction) of territorial and temporal localization of water resources (radical

destruction of water resources of the steppe zone in Ukraine is forecasted by the end of the century);

Ø change in the oxygen regime of water resources, as a result of which, for example, the decomposition of petroleum products is several times slowed down;

Ø accelerated decomposition of toxic harmful substances (phenols and others);

Ø modification of runoff formation processes;

Ø change (deterioration) in living conditions of biota of ecological biotopes.

Studies conducted by the Ukrainian Hydrometeorological Center confirm the existing changes in the water supply of the territory of Ukraine and predict further reductions in the runoff. According to this study, from 1991 to 2015, the territory of Ukraine with sufficient and excessive moisture decreased by 10 % and now covers only 22.5 % of the total area. Dry and very dry zones, on the other hand, have spread to another 7 % of Ukraine's territory and now cover 29.5 % of the area. Such processes can be generally described as the disappearance of the territory of excessive moisture in the Ukrainian Polissya and the desertification of the southern lands. In the medium term (until 2050), the AIB scenario projects an increase in areas with a scarcity of moisture to 56 % and a restriction of areas with excessive moisture. In the long run, the situation will deepen, and the climatic water balance will decrease by an average of 150–160 mm (NAAS, 2020). Ukraine's water resources are catastrophically low (1,000 cubic meters), one of the lowest in Europe. For comparison: Canada – 94.3 thousand m³, USA – 7.4 thousand m³, Germany – 1.9 thousand m³ (NAAS, 2020). This indicator varies greatly in some regions of Ukraine. In the Carpathians, it is the highest, and in the steppe zone – the lowest, and the values differ almost 60 times.

Certain environmental problems, in particular in terms of water resources, are specific to each country. The developed western countries integrate effective strategies to address environmental issues, manage water resources and minimize and limit the negative effects of global warming. In Ukraine, however, effective water management policies are underdeveloped. According to the Environmental Performance Index (developed by the Center for Environmental Policy and Law at Yale University), which characterizes the effectiveness of implemented environmental solutions, in terms of water resources, Ukraine ranks 60th among 180 countries with a value of 14.1 (for comparison: Denmark – 100.0, Luxembourg – 98.5, Switzerland – 96.7) (Yale, 2020).

The shortage of water resources poses a great threat to the national economy, as water resources are actively used in the national economy, in particular in industry. Hydropower is one of the areas of active use of water resources of rivers. Hydropower is a “branch of renewable energy, as well as a set of large natural and artificial subsystems that serve to convert the kinetic energy of water into electricity” (Ukrhydroenergo). The main feature of hydropower is renewable sources. In addition, the processes of conversion of hydropower into electricity are accompanied by high efficiency (0.7–0.9 and even higher) (Vlasyuk, Stefanishin, 2018).

The most common characteristics of hydropower in Ukraine are (Ukrhydroenergo):

- the total number of rivers is about 63 thousand with a total length of almost 206 thousand km. (115 of them are rivers over 100 km long);
- average reserves of fresh water are estimated at 94.1 billion m³. 92.6 % of it is the river runoff;
- The United Energy System of Ukraine in the field of hydropower is represented by 10 high-capacity hydropower plants (over 10 MW), 4 PSPs, and about 50 low-capacity hydropower plants (up to 10 MW).

Fig. 1 shows the dynamics of energy consumption based on hydropower.

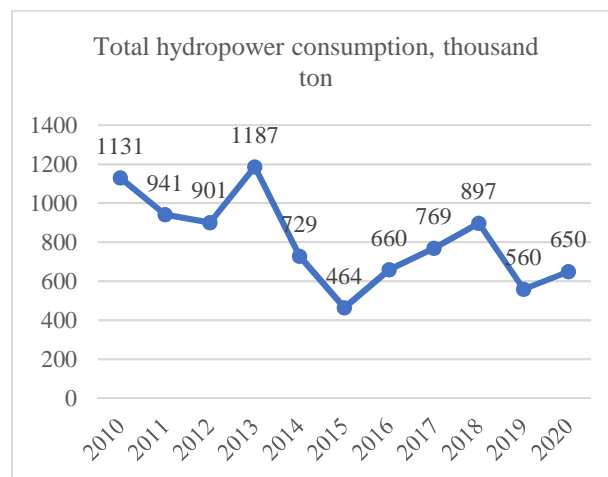


Fig. 1. Total hydropower consumption
(State Statistics Service of Ukraine, 2021)

We can see that during 2015–2017, the overall trend of hydropower consumption grew: from 464 thousand tons to 879 thousand tons. In 2013–2014, there was the most rapid decline in consumption (from 1187 tons to 464 tons).

It is estimated (Klimenko et al., 2013) that the theoretical hydropower potential of Ukraine is over 44 billion kWh. 17.5 billion kWh of them refer to economic hydropower potential. At this stage, Ukraine

uses 11 billion kWh, which is 62 % of the economic hydropower potential. Consequently, the Ukrainian hydropower system has great potential for development. The economies of developed countries are usually characterized by a high level of development: 84 % of the economic potential is used in Italy, 95 % – in France, and 85 % – in Switzerland. Therefore, the main development of hydropower in Europe is seen in small hydropower, systems and projects to combat/overcome the effects of global warming.

Climate change also has a great impact on the formation of hydropower potential. As already mentioned, global warming leads to the destruction (change) of water resources, and thus limits the possible economic benefits of their use. According to forecasts (Lehner et al., 2005), under the baseline scenario, the EU's hydropower balance will decrease by 25 % and Ukraine's – by 35 % from the current state. Accordingly, new approaches and methodologies for the assessment and management of water resources are being developed to maintain the hydropower potential at the appropriate level.

The scientists (Obodovsky et al., 2016) describe a comprehensive approach based on the separation of a fourth component of the total hydropower potential – ecosystem hydropower

potential. This component is characterized by the deduction from the economic potential of those water resources, the preservation of which in its original form is important from the standpoint of ecology. After all, it should not be assumed that hydropower has no negative aspects, such aspects are (Klimenko et al., 2013):

- § loss of flooded fertile land;
- § flooding, soil erosion;
- § sometimes, loss of cultural sites (ancient cemeteries);
- § destruction of many representatives of the river fauna due to changes in natural living conditions;
- § costs of construction and maintenance of dams;
- § resettlement costs.

In the source (Petrakov, Hnedina, 2017), the authors make a list of indicators that are appropriate when analyzing the impact of alternative energy sources on the environment. These indicators assess both the direct impact of energy based on renewable energy sources on the environment (greenhouse gas emissions, other harmful emissions into the atmosphere) and economic feasibility in terms of environmental activities.

The above overview of hydropower in Ukraine is summarized using SWOT analysis (Table 1).

Table 1

SWOT analysis of the hydropower industry of Ukraine*

Strengths	Weaknesses
1) Water resources in the context of hydropower are renewable. 2) Mobility of technological systems of hydropower complexes. 3) High efficiency of technology.	1) Violation of some important ecosystems. 2) Additional losses on resettlement, and support of the operation of hydropower plants.
Opportunities	Threats
1) Availability of significant untapped hydropower potential. 2) Development of small hydropower systems. 3) Improvement of technological equipment of hydropower, further increase of efficiency.	1) Reduction of water resources due to global warming. 2) Breaking dams poses a threat to the population.

* Source: formed by the authors

All aspects of hydropower development in Ukraine refer to two main areas:

- effective ecological water bodies management;
- economically feasible ecological use of hydropower potential.

At this stage, managing water bodies means, first of all, minimizing the negative impact caused by

global warming. To achieve such goals, the UN considers two main strategies (The United Nations):

- 1) *Adaptation*. A passive water body conservation algorithm, the main plot of which can be expressed: “at this moment, we cannot stop or at least slow down global warming, therefore, we must minimize its negative impact”, assumes a comprehensive,

integrated approach which should be implemented in the economic, technological and environmental spheres. The adaptation strategy has two main directions of implementation:

Ø extensive direction, the essence of which is the creation of additional water reservoirs (an inefficient direction leads to additional depletion of the water system);

Ø intensive direction, the essence of which is to carry out a set of measures to improve the efficiency of water consumption and environmental protection of water resources (a more efficient direction does not increase the exploitation of the environment).

2) *Deceleration*. An active algorithm for the conservation of water resources, the main plot of which can be expressed: “the key to eliminating the impact of global warming lies in eliminating global warming itself”, is a more complex, lengthy, all-encompassing methodology. It requires a mandatory collective solution to the problem since it is impossible to eliminate global warming at a local level. Certain steps are being taken in this direction as more and more countries understand the real danger and irreversibility of the consequences of climate change. Specific examples of such steps are Kyoto Protocol, Paris Agreements, COP26, etc.

For Ukraine, as a developing country, the adaptation approach is more appropriate. The deceleration strategy, of course, must also be integrated; all major aspects of international climate agreements must be implemented.

Ukraine has developed a Strategy for the Development of Ukraine's Water Policy for 2020–2050. This strategy identifies the following most significant problems of water resources management (MEPR, 2021):

§ only 1000 (84 %) of the 1185 centralized water supply/sewerage companies have treatment facilities that fully perform wastewater treatment in only half of the cases;

§ freshwater shortage, which is typical for 13 regions of Ukraine;

§ pollution of water bodies annually more than 2 million tons of harmful substances;

§ the disappearance of more than 10.000 small rivers in the period from 1991 to 2019 due to the extremely extensive use of land for agricultural purposes (arable land accounts for 54 % of Ukraine's territory; in Europe the average is not more than 35 %);

§ unequal access to water (only 30.1 % of the rural population is connected to the centralized water supply);

§ significant anthropogenic risk to water bodies;

§ imperfect legislation in the field of water management (for example, there are no responsibilities or funding mechanisms for river basin management plans).

To address these issues, the Strategy offers a number of solutions, the most important of which are (MEPR, 2021):

✓ reconstruction and modernization of existing industrial complexes related to water bodies;

✓ setting the goals of water policy in accordance with the CSB;

✓ determination of the system of numerical indicators for evaluating the results of achieving the set goals;

✓ strengthening state control over the water situation in Ukraine;

✓ developing effective approaches to risk assessment and management;

✓ improving the legislation in the field of water policy, bringing it to European standards.

Analyzing the strategy of development of water policy of Ukraine, we can state that, its goals are fully consistent with the adaptive strategy of combating climate threats, global warming.

There are many examples of effective solutions to save water bodies from global warming. For example, in Scotland, residents of the cities where small and medium-sized rivers flow planted about 250.000 trees around these rivers (The Guardian, 2022). By 2035, they plan to plant about a million trees. Such solutions will allow the biocenoses of the country's rivers (for example, the salmon ecosystem) to continue to exist even in the face of climate change.

Another example of an effective water policy is Switzerland. By the early 1960s, no more than 14 % of wastewater had been treated. Now, the situation has changed dramatically. More than 97 % of wastewater is treated with high quality. The Swiss bathe even in the city rivers, which is rare for developed countries. Such achievements are the result of awareness of the importance of water conservation. To create such a cleansing industrial complex, huge investments were required, but the government of the country realized that a bright future is possible only if the country's water bodies are preserved.

As already indicated, another direction in the development of hydropower in Ukraine is associated with the cost-effective environmental use of the country's hydropower potential. This requires solving several problems. The National Institute for Strategic

Studies has identified the most significant problems in the development of the hydropower industry in Ukraine (Sukhodolia et al., 2014). Let's organize and review them:

1) Economic factor:

Ø the use of mainly credit funds for the development of the industry;

Ø lack of sustainable funding for hydropower projects;

Ø economically inexpedient placement of hydroelectric power plants and pumped storage power plants, the complicated transmission of electricity.

2) Social factor:

Ø absence, the outflow of specialized specialists in the hydropower industry;

Ø negative perception by territorial societies of the construction of hydropower facilities (alienation of some territories is required, changes in the ecology of the region, etc.);

Ø possible negative environmental impact on the environment.

3) Safety factor:

Ø the threat of a man-made disaster at industry facilities with insufficiently formed protection systems;

Ø the risk of a terrorist organized criminal attack on the strategic facilities of the industry.

Accordingly, certain goals are set that will help solve these problems (Sukhodolia et al., 2014):

• development of infrastructure capacities of the industry through the construction of new hydroelectric power plants and pumped storage power plants, reconstruction and modernization of existing ones;

• development of the legal framework in terms of safety, and operation of hydropower facilities;

• improvement of protection systems for hydropower facilities;

• revival of small hydropower, commissioning of new SHPP facilities;

• improvement of the state energy policy in terms of monitoring the hydropower industry and the development of intellectual capital.

It should be noted that ecology must be taken into account as a separate factor. The energy sector is

not environmentally friendly as the use of traditional energy sources negatively affects the environment, including water resources. Therefore, it is important to transfer to clean energy sources.

The main company in the industry, PJSC “Ukrhydroenergo”, declares adherence to the principles of ecology

Thus, the company's sustainable development program defines the following priorities:

§ development of high-quality design environmental documentation;

§ development of the company's technical complex through modernization and restructuring;

§ improving the tightness of equipment containing oil.

When assessing the impact on the environment, according to PJSC “Ukrhydroenergo”, the following components should be taken into account:

- climate and microclimate;
- geological environment;
- soil;
- air environment;
- water environment;
- animal and plant world;
- reserved objects;
- objects of historical heritage.

The company emphasizes that cross-border cooperation is very important in combating climate change (Ukrhydroenergo). First of all, it should be manifested at the legislative level through the implementation of the European legal framework in terms of water policy. In addition, international cooperation with individual countries is also important.

3. Results and Discussion

As already mentioned, the main solutions for the development of hydropower can be implemented in two directions: *effective ecological water bodies management* or *economically feasible ecological use of hydropower potential*. Taking into account these aspects, we defined the core recommendations for the development of hydropower in Ukraine (Table 2).

Table 2

Core recommendations for the development of hydropower in Ukraine*

Problem	Recommendations
1	2
<i>Effective ecological water body management</i>	
Fresh water scarcity in many regions	1) Development of innovative technologies (desalination of seawater, iceberg water, artificial forest in the desert, etc.). 2) Stimulation of the economical use of water. 3) Delegation of obligations to assess the tightness of the technologies used.

Continuation of Table 2

1	2
Ineffective, underused cleaners	1) Allocation of state funding for research into modern purification technologies. 2) Grant support for cleaning technology projects. 3) Increasing responsibility for non-use of cleaning technologies. 4) Fiscal methods (taxes, benefits, etc.) for regulating the use of treatment technologies.
Regular pollution of water bodies with harmful substances	1) Development of approaches for the independent determination of the volumes of harmful substances with which the enterprise pollutes water bodies. 2) Increasing responsibility for pollution of water bodies.
The presence of anthropogenic risk generated by the hydropower industry	1) Formation of a territorial system of hydropower facilities, taking into account the environmental situation. 2) Development at the theoretical and practical levels of technical, economic and social approaches to minimizing anthropogenic risks.
Violation of the oxygen regime of water bodies	1) The use of piece gardening technologies near water bodies.
Violation of biodiversity of flora and fauna of water bodies	1) Expansion of the system of protected areas. 2) Artificial settlement of certain objects with specific animal species.
Imperfection of systems for monitoring the state of water bodies	1) Additional funding for monitoring the state of water bodies, ensuring transparency of funding. 2) Introduction of automated technologies for monitoring the state of water bodies.
Unequal access to fresh water for different population groups	1) Additional funding for programs aimed at achieving equal access to water resources. 2) Laying central water supply channels to secluded villages.
Imperfect legislation in the field of water policy	1) Analysis of the experience of water policy in the legislative plan of the advanced European countries. 2) Expansion of the development of documents regulating the ecological situation of water resources.
Insufficient public attention to the problem of water protection	1) Carrying out educational activities on the importance of environmental protection of water bodies.
<i>Economically feasible ecological use of hydropower potential</i>	
Small share of hydropower potential utilization	1) Development of the SHPP network, determination of points where such complexes can be equipped without significant harm to the environment.
Low level of security of strategic facilities in the hydropower industry	1) Perception of hydropower facilities as strategic facilities with a sufficient risk of criminal and terrorist actions, especially in war conditions. 2) Integration of additional systems for early detection and protection against possible malicious impact.
High risk of man-made disasters	1) Increasing control over the technical quality of systems in the hydropower industry. 2) Development of mathematical models for predicting man-made disasters in the hydropower industry, additional funding for such projects. 3) Development of rapid response systems for possible man-made disasters in the hydropower complex.
Negative impact on the environment	1) Modernization and development of technologies used, achieving their maximum environmental friendliness. 2) Giving preference to places with natural water level differences but with a poor location in terms of energy delivery.
Small number of specialists in the industry	1) Support for education in the hydropower industry, additional budget places subject to mandatory work in the industry. 2) Further introduction of the dual form of higher education. 3) Expansion of the advanced training system in the hydropower industry (for example, at research institutes).
Activation of international cooperation in the field of hydropower	1) Finding compromises to resolve existing conflicts 2) Cooperation in the field of hydropower with other neighbouring countries.
Low activity of the investment environment	1) Popularization of hydropower projects, their possible profit. 2) Creation of favourable conditions for investment in the hydropower industry.
Assistance to the development of river sections	1) Establishing a minimum of payments guaranteed by the company owner of the HPP (PSPP) to the local territorial society on the terms of land lease. 2) Optimization, specific assistance in resettlement, payment of compensation in case of flooding of new territories.

*Source: formed by the authors

The main results of the conducted research are:

- the current state of water resources and hydropower potential of Ukraine is characterized;
- problems, trends are analyzed, and prospects for the development of the hydropower industry of Ukraine are defined;
- the main conceptual and theoretical ways of stimulating the development of the hydropower industry in Ukraine are described.

The scientific novelty of the research in comparison with the research works on the given topic of other authors lies in the comprehensive analysis of the current state, problems, trends, and prospects for the development of the hydropower industry in Ukraine.

4. Conclusions

The article examines the potential and prospects for the development of the hydropower industry in Ukraine. The current state of water resources is analyzed. The supply of water resources is low. At the same time, there is a process of redistribution and destruction of water resources, primarily caused by global warming. It is predicted that the areas with moisture scarcity will have increased to 56 % by 2050. The chemical and biological conditions and the oxygen regime of water resources are also changing. A separate threat to water resources is the pollution of water bodies. Only 62 % of the hydropower potential is used in Ukraine, but its further expansion is going on without taking into account environmental factors, which poses a certain threat to the Ukrainian hydrosphere. The hydropower sector needs modernization and quality renewal.

The main strategies for effective management of water bodies (adaptation and deceleration) are analyzed. The first strategy involves a temporary reduction of the effects of global warming on water resources. The second one involves active actions aimed at overcoming global warming. For developing countries, to which Ukraine belongs, the adaptation strategy is more applicable in the first stages. In accordance with this strategy, the Strategy for the Development of Water Policy of Ukraine for 2020–2050 was formed. This strategy defines a number of problems and possible ways to solve them, but it does not sufficiently take into account the environmental aspect.

Among the core ecological problems of water bodies and limitations for the use of hydropower

potential are a freshwater scarcity in many regions; ineffective, underused cleaners, regular pollution of water bodies with harmful substances, the presence of anthropogenic risk generated by the hydropower industry, low level of security of strategic facilities in the hydropower industry, high risk of human-made disasters etc. A complex of recommendations is proposed for the development of hydropower in Ukraine in terms of water bodies management, including the improvement of state financing and investment mechanisms, the use of green technologies, educational measures, etc.

The prospect of further research refers to the investigation of the impact of the large-scale Russian invasion of Ukraine on the ecological safety of water resources and the development of hydropower in Ukraine. Possible vectors of further research are aimed at the analysis of the damage caused, as well as at the potential of the hydropower industry of Ukraine in the reconstruction of the national economic complex.

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