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Scenarios for the Development of Ukraine's Water Infrastructure until 2035: European Approaches to Economic Modeling and Risk Analysis

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ABSTRACT

The article examines scenarios for the development of Ukraine's water infrastructure up to 2035, taking into account European approaches to economic modeling and risk analysis. It has been established that the vulnerability of Ukraine's water sector is caused by military destruction and, at the same time, long-term climate risks, which determine the framework for possible development scenarios. It is emphasized that the energy crisis is an additional barrier to the stable functioning of water management systems, since the energy intensity of water supply in Ukraine is almost twice the European average. It is determined that the tariff policy needs to be revised, taking into account a risk-oriented approach that allows increasing the system's resilience to crisis impacts. It is noted that the war has caused large-scale destruction of infrastructure and significantly increased financial needs, which are estimated at USD 11.3 billion over the next decade. It was outlined that the modernization of sewage treatment plants and water supply systems requires the largest investment costs, which are priority areas for recovery. Regional differentiation in the level of wear and tear of water supply networks was considered, which demonstrates the instability of modernization processes and significant disparities between regions. It has been found that local investment programs can temporarily improve the situation, but their unevenness creates unstable dynamics. It is emphasized that crisis conditions, in particular the war, have caused a sharp deterioration in indicators in a number of regions, which needs to be taken into account in forecast scenarios. The importance of using European risk analysis methods to model the relationship between financial, technological, and security parameters is emphasized. It is noted that the implementation of European directives into the national legal system forms the basis for harmonizing standards and creating a comprehensive development strategy. The importance of the Concept of State Programs in the Field of Water Supply and Sanitation Modernization, aimed at integrating environmental, technical, and social aspects, was determined. It was noted that the implementation of EU directives on drinking water quality, wastewater treatment, and water resource management ensures the integration of risk management and digital technologies into planning processes. It has been established that digitalization, which is actively used in EU countries, is gradually becoming a determining factor in improving the efficiency of water system management and quality monitoring. It has been emphasized that the strategic course towards European integration provides for the transformation of the industry in accordance with the principles of a "green" economy and environmental sustainability.

KEYWORDS

water infrastructure, development scenarios, risk analysis, economic modeling, sustainable development, investments, digitalization, water resources management.

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Публічне управління і політика

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Сценарії розвитку водної інфраструктури України до 2035 року: європейські підходи до економічного моделювання та ризик-аналізу

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СТАТТЯ

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АНОТАЦІЯ

У статті розглянуто сценарії розвитку водної інфраструктури України до 2035 року з урахуванням європейських підходів до економічного моделювання та ризик-аналізу. Встановлено, що вразливість водного сектору України зумовлена воєнними руйнуваннями та водночас довгостроковими кліматичними ризиками, які визначають рамки можливих сценаріїв розвитку. Підкреслено, що енергетична криза виступає додатковим бар'єром для стабільного функціонування водогосподарських систем, оскільки енергоємність подачі води в Україні майже вдвічі перевищує середньоєвропейські показники. Визначено, що тарифна політика потребує перегляду з урахуванням ризик-орієнтованого підходу, який дозволяє підвищити стійкість системи до кризових впливів. Зауважено, що війна спричинила масштабні руйнування інфраструктури та суттєво збільшила обсяги фінансових потреб, які оцінюються у 11,3 млрд дол. США протягом наступного десятиліття. Окреслено, що найбільших інвестиційних витрат потребує модернізація очисних споруд каналізації та систем водопостачання, що становить пріоритетні напрями відновлення. Розглянуто регіональну диференціацію рівня зношеності водопровідних мереж, яка демонструє нестійкість процесів модернізації та значні диспропорції між областями. З'ясовано, що локальні інвестиційні програми здатні тимчасово покращувати ситуацію, однак їх нерівномірність формує нестабільну динаміку. Наголошено, що кризові умови, зокрема війна, спричинили різке погіршення показників у ряді областей, що потребує врахування у прогнозних сценаріях. Підкреслено важливість використання європейських методик ризик-аналізу для моделювання взаємозв'язку між фінансовими, технологічними та безпековими параметрами. Констатовано, що впровадження європейських директив у національну правову систему формує основу для гармонізації стандартів і створення комплексної стратегії розвитку. Визначено важливе значення Концепції державних програм у сфері модернізації водопостачання та водовідведення, спрямованих на інтеграцію екологічних, технічних і соціальних аспектів Зауважено, що імплементація директив ЄС щодо якості питної води, очищення стічних вод та управління водними ресурсами забезпечує інтеграцію ризик-менеджменту та цифрових технологій у процеси планування. Встановлено, що цифровізація, яка активно використовується у країнах ЄС, поступово стає визначальним чинником підвищення ефективності управління водними системами та моніторингу їх якості. Наголошено, що стратегічний курс на євроінтеграцію передбачає трансформацію галузі відповідно до принципів «зеленої» економіки та екологічної стійкості.

КЛЮЧОВІ СЛОВА

водна інфраструктура, сценарії розвитку, ризик-аналіз, економічне моделювання, сталий розвиток, інвестиції, цифровізація, управління водними ресурсами.

1. Introduction

The strengthening of globalization processes and the digital transformation of society necessitate a critical rethinking of established approaches to the organization of scientific research and practical activities. As a result of such changes, there is a transformation of socio-economic relations, which in turn puts forward new requirements for the effectiveness of managerial and scientific decisions. Therefore, it is the growth of the role of knowledge and information resources and the increase in the importance of innovative technologies that determine the need to adapt scientific methodologies to new realities. In view of this, the search for optimal mechanisms for coordinating theoretical provisions with practical needs is of particular importance, which directly determines the relevance of the chosen research topic.

2. Literature Review

The analysis of recent studies and publications indicates an increased attention to the effective management of water resources in Ukraine in the context of modern economic and environmental challenges. Thus, M. Khvesyk et al. outline important directions of water policy in Ukraine and prospects for its implementation in the context of integration of European standards [1]. Instead, O. Bondar et al. emphasize the importance of financial support for the sustainable development of water supply and drainage, determining economic mechanisms to support the effective activity of the industry [2]. M. Serbov considers innovative approaches to improving freshwater management models, which contributes to increasing the efficiency of water management systems in the long term [3]. At the same time, L. Levkovska et al. focus on the role of the institutional environment in strengthening the resilience of the water sector to external risks and threats, which provides an integrated approach to management [4]. In turn, S. Melnychenko highlights the possibilities of using intelligent and digital technologies for water resources management in Ukraine, which is especially important in the context of post-war infrastructure restoration [5].

However, the issues of the development of water infrastructure in Ukraine, taking into account European approaches to economic modeling and risk analysis, are generally not covered in the scientific literature, which justifies the need for this study.

3. Problem Statement

Therefore, the article is aimed at studying the scenarios for the development of water infrastructure in Ukraine until 2035, taking into account European approaches to economic modeling and risk analysis.

4. Methods and Materials

In the process of studying the scenarios for the development of Ukraine's water infrastructure until 2035, taking into account European approaches to economic modeling and risk analysis, an integrated methodological approach was applied, combining theoretical analysis, empirical modeling and comparative method. The main method was a systematic analysis of scientific literature, which included the study of the works of domestic and foreign authors on the strategy of water policy of Ukraine, on the financial provision of water supply, as well as on innovative models of water resources management. This made it possible to outline the theoretical foundations of risk analysis and economic modeling in the face of military and climate challenges. The comparative analysis was carried out to compare the Ukrainian infrastructure with European standards, which ensured harmonization with the principles of the EU Green Deal. The study was based on official UNICEF data on climate risks, World Bank reports on global governance indicators, Ukrainian regulations and statistical indicators of the State Statistics Service of Ukraine on SDGs (Goal 6). Empirical data included estimates of network wear and tear (regional differentiation) and investment costs. This arsenal provided reasonable forecasting of scenarios, taking into account military destruction and digitalization for monitoring, which contributes to the resilience of the industry in the context of European integration.

5. Results and Discussion

According to UNICEF research [6], Ukraine's vulnerability in the field of water resources is not limited to the direct consequences of military destruction, as it also covers basic climate risks. It is important to emphasize that these risks are long-term in nature and determine the scenario boundaries of the future development of water infrastructure. The concentration of toxic substances in rivers is recorded, which is 30–40 times higher than the permissible standards, while climatology experts warn that, in the absence of large-scale interventions, the country may face the need to import drinking water by 2050. An example of the criticality of the situation was the destruction of the Kakhovka hydroelectric power plant, which deprived about a million people of access to drinking water and caused restoration costs in the amount of more than USD 700.93 million. USA. Such a catastrophe demonstrated that unexpected external factors can instantly destroy the achieved level of water security, and therefore need to be taken into account in economic modeling and risk analysis.

In this context, an additional risk factor is the energy crisis, which significantly complicates the functioning of water management systems. It is important to note that the energy aspect is not an isolated phenomenon, since it directly affects the quality, stability and economic efficiency of water supply. It should be noted here that water and energy security are interdependent, which necessitates an integrated approach to their research.

Today, in Ukraine, the energy intensity of water supply reaches 1.01 kWh/m^3, which is almost twice as high as the European average of 0.5–0.7 kWh/m^3. This difference indicates the technological backwardness of a part of the water supply system, as well as a significant burden on its economic component. Since the first months of the war, the cost of electricity for enterprises has increased by 55%, the cost of chemicals has increased by 269%, and the price of chlorine has increased eightfold. Combined with the tariff freezing policy, this has led to the fact that the level of reimbursement of operating costs fluctuates only in the range of 55–65%, while in the countries of the European Union their full coverage is achieved [6]. Thus, the energy factor directly determines the possibilities of implementing scenarios for the modernization of Ukraine's water infrastructure.

It is worth emphasizing that such a disproportion forms the prerequisites for an in-depth revision of tariff policy and the introduction of economic models that combine the principles of fairness with the requirements of financial stability. The transition from traditional approaches to tariff setting to models based on risk-based forecasting allows taking into account internal and external shocks faced by the system. The introduction of risk analysis methods in tariff modeling can ensure the adaptability of the water supply system to crisis conditions and make it possible to predict the consequences of future shocks for the economy.

Within the framework of this approach, it should be taken into account that the deepening of the crisis was largely due to the war, which accelerated the destructive processes in the water sector. The consequences of hostilities were manifested in the direct physical destruction of infrastructure, as well as in the increase in the cost of its restoration. Therefore, the prospects for recovery appear no less extensive than the scale of destruction, which necessitates systematic scenario planning. This means that the sector's development strategy should provide for the restoration of destroyed facilities and the comprehensive modernization of existing systems, taking into account future risks. Thus, the total need for financing reconstruction is estimated at USD 11.3 billion. over the next decade. The largest investment needs are for the modernization of sewage treatment plants (USD 1.9 billion) and the renewal of water supply systems (USD 1.6 billion), while ensuring sustainable energy and operational functioning will require another USD 2.8 billion. USA. These indicators demonstrate that the destruction of energy infrastructure significantly complicates the recovery of the water sector, creating complex challenges for public policy [6].

In turn, it is precisely such multi-factor dependencies that confirm the expediency of using European risk analysis methods, which make it possible to model the relationship between financial, technological and security aspects of development. It is important to emphasize that the integration of risk management into planning processes creates opportunities to identify more realistic recovery scenarios and align them with international practices.

Taking into account the amount of necessary funding and investment priorities, it is advisable to consider the state of the existing water supply infrastructure, because it is its analysis that allows you to objectively assess the scale of deterioration of networks and determine priority areas of reconstruction (Table 1).

Table 1. Share of worn-out water supply networks in the total length of water supply networks, percent (SDG indicator 6.1.3)[1]

Region	2015	2016	2017	2018	2019	2020	2021	2022	2023
Ukraine	***34.0***	***35.3***	***34.9***	***33.3***	***38.3***	***38.2***	***33.0***	***34.8***	***36.5***
Autonomous Republic of Crimea	…	…	…	…	…	…	…	…	…
Vinnytsia	28.5	28.5	31.2	29.8	29.8	29.5	30.1	25.5	25.5
Volyn	39.3	39.1	47.0	46.5	57.6	56.3	54.9	51.6	58.3
Dnipropetrovsk	47.2	47.5	43.7	37.4	37.4	37.3	37.5	36.9	37.0
Donetsk	– [1]	– [1]	72.3	54.6	61.6	63.0	– [2]	56.8	58.5
Zhytomyr	30.1	30.0	30.0	30.0	31.5	31.7	31.6	31.5	31.8
Transcarpathian	11.0	10.8	10.8	12.3	12.2	12.6	13.0	13.2	12.8
Zaporizhzhia	37.3	35.5	34.2	33.1	34.1	35.6	– [2]	50.9	52.1
Ivano-Frankivsk	27.5	27.1	27.5	24.7	24.1	23.6	24.5	30.7	34.5
Kyiv	15.4	15.2	14.9	14.2	14.2	14.2	14.1	13.9	27.5
Kirovohrad	46.9	45.6	49.5	47.6	46.6	42.1	52.5	50.7	49.5
Luhansk	51.8	– [2]	60.5	58.9	61.1	56.6	– [2]	– [2]	– [2]
Lviv	42.2	50.1	49.9	49.7	46.0	45.5	42.6	40.7	39.6
Mykolaiv	25.8	23.7	20.1	20.2	27.3	29.7	29.6	32.8	31.6
Odessa	39.3	37.5	36.3	37.5	37.6	37.4	30.0	30.0	25.7
Poltava	28.6	28.7	28.9	29.0	29.2	19.5	29.0	42.0	41.5
Rivne region	19.8	19.5	19.9	18.7	22.9	23.6	23.6	19.6	20.4
Sumy	21.9	24.1	30.0	18.7	24.3	26.7	28.6	27.6	26.9
Ternopil	38.6	34.2	34.1	34.4	35.0	35.4	48.1	48.0	47.9
Kharkiv	45.7	44.2	44.3	46.1	48.2	49.4	– [2]	52.8	51.4
Kherson	27.0	40.8	30.1	36.3	36.8	36.3	– [2]	29.5	39.5
Khmelnytskyi	34.1	34.1	37.1	35.8	35.3	33.2	30.6	30.1	30.5
Cherkasy	18.7	30.1	29.0	29.5	28.1	33.2	33.2	37.8	36.5
Chernivtsi	28.7	28.1	27.8	27.6	27.4	27.3	26.7	24.5	21.7
Chernihiv region	25.5	34.9	33.7	34.0	37.3	37.3	42.3	42.9	41.5
Kyiv	41.4	42.5	43.5	44.5	45.8	46.5	47.3	48.1	49.7
Sevastopol	…	…	…	…	…	…	…	…	…

[1] Indicator target value for 2030: 30.

[2] Data missing.

Source: Compiled based on [7].

The analysis of the dynamics of the share of worn-out water supply networks in Ukraine in 2015–2023 indicates the instability of the process of modernization of the water supply system. On average in the country, this indicator ranged from 33.0% (2021) to 38.3% (2019), which indicates the absence of stable trends to reduce depreciation. At the same time, the target value of the SDG indicator 6.1.3 for 2030 is set at the level of 30%, that is, even in the most favorable period, the indicator remains higher than the target, which indicates the need for accelerated network renewal. Thus, already at the level of national trends, there is a lag behind international targets, which requires the use of scenario forecasting.

The regional distribution demonstrates significant differentiation, which further illustrates the uneven development of water supply systems. The lowest depreciation rates were observed in the Transcarpathian region (10.8–13.2%), Kyiv region until 2022 (about 14%), as well as in the Chernivtsi region (21.7–28.7%). At the same time, critically high values were recorded in other regions. In particular, in Donetsk and Luhansk regions in 2017–2019, the share of worn-out networks exceeded 60%, which is due to the physical aging of infrastructure, the consequences of hostilities and insufficient funding for repair work. In the city of Kyiv, there is a steady increase in depreciation from 41.4% (2015) to 49.7% (2023), which indicates the accumulation of problems in the capital's infrastructure and complicates the prospects for its modernization.

It is worth emphasizing regions with unstable dynamics, where depreciation indicators show sharp fluctuations. In the Volyn region, the figure increased from 39.3% in 2015 to 58.3% in 2023, while in the Poltava region in 2020, depreciation temporarily decreased to 19.5%, but in 2022–2023 it increased sharply to more than 40%. Such fluctuations are explained by local investment programs and uneven distribution of resources for the modernization of networks. Therefore, regional dynamics

confirm the need for a systematic approach, which provides for long-term financing and coordination with national development strategies.

Particular attention is drawn to the fact that in 2021–2022, a significant deterioration in indicators was recorded in several regions (Zaporizhzhia, Kharkiv, Cherkasy regions). Such dynamics coincide with the period of aggravation of the economic and security situation, which indicates the high vulnerability of water infrastructure to crisis conditions. At the same time, in the Kyiv region in 2022, there was a sharp increase in the depreciation rate, almost twice (from 13.9% to 27.5%), which is associated with military destruction and partial decommissioning of networks. This emphasizes that crisis factors directly affect infrastructure resilience and should be taken into account in forecast scenarios until 2035.

A comparative analysis of the regions shows that even in the presence of positive examples (Zakarpattia, Chernivtsi regions), the general dynamics do not correspond to strategic guidelines. This indicates the need to change approaches to planning investments in the modernization of networks. Therefore, the use of scenario forecasting based on European approaches to economic modeling and risk analysis will allow identifying the most vulnerable regions and optimizing the allocation of financial resources. It is at this stage that it becomes important to involve international partners and practices that can ensure the proper quality of planning and standardization of processes.

In this context, the project "Water for the Future – Modern Standards for the Restoration of Water Supply Infrastructure" [8], which was implemented with the support of grant funding from the Slovak Agency for International Development (Slovak Aid), is indicative. The initiator of its implementation was the Slovak company Esol s.r.o., while the Association "Ukrvodokanalekologia" was identified as a partner in Ukraine. The main task of the project was to develop a comprehensive regulatory document "Standards for the design and construction of water infrastructure" with the definition of the principles of planning, construction and operation of water supply, sewerage and wastewater treatment facilities.

In this context, the implementation of European legal acts in the national regulatory system, which is an important step in the harmonization of Ukrainian legislation with European norms, is of particular importance. Therefore, Ukraine has undertaken to implement directives, norms and standards, among which an important place is occupied by Council Directive 91/271/EEC "On Urban Wastewater Treatment" of May 21, 1991 [9]. It defines the basic requirements for the collection, transportation and treatment of wastewater in settlements, which directly correlate with the needs of modernization of domestic treatment facilities and sewerage systems.

At the same time, the implementation of this directive and other EU regulations is regulated by the Action Plan for the Implementation of the Association Agreement between Ukraine, on the one hand, and the European Union, the European Atomic Energy Community and the Member States, on the other. The relevant plan was approved by the Resolution of the Cabinet of Ministers of Ukraine No. 1106 dated October 25, 2017 [10]. In particular, the document provides for the development of draft government regulations aimed at implementing technical and investment programs for urban wastewater treatment, which determines the direct direction of the transformation of the industry. It is this regulatory framework that becomes the basis for scenario planning for the development of water infrastructure in Ukraine.

It is worth noting that the harmonization of national standards with EU directives creates conditions for the transition to a new level of water infrastructure management. According to modern European approaches, economic modeling in this area should take into account technical parameters, as well as a set of risks associated with climate change, military destruction and the growth of energy intensity of the industry. As a result, the integration of standards and risk analysis provides an opportunity to form scenarios for the development of Ukraine's water infrastructure, which will increase its sustainability, investment attractiveness and compliance with European practices.

In this context, the Concept of the State Target Environmental Program for the Technical Modernization of Wastewater Disposal and Wastewater Treatment Enterprises in State or Municipal Ownership for the Period up to 2034, approved by the Order of the Cabinet of Ministers of Ukraine dated February 7, 2025, No. 91-r [11], is of particular importance for the strategic development of the industry. The main goal of this program is to protect the environment from the negative impact of wastewater discharges through the construction and reconstruction of wastewater disposal enterprises and treatment facilities, the introduction of innovative technical solutions, as well as the formation of economically attractive conditions for the implementation of investment projects in the field of

wastewater. An important component is also increasing the level of access of the population to centralized wastewater disposal services, which meet modern environmental and social requirements.

The consistency in the implementation of this program creates the basis for the formation of a comprehensive institutional architecture in the field of water infrastructure. The use of the latest technological solutions allows integrating environmental and economic aspects of the industry's development, which ensures a gradual transition to a circular economy model in water supply and sanitation. This increases the sector's resilience to external challenges, in particular climate and energy risks, which are decisive in forecasting development scenarios until 2035. In this way, national strategic documents begin to serve as tools for the practical implementation of European approaches.

Attention should also be paid to the draft order of the Cabinet of Ministers of Ukraine "On Approval of the Concept of the State Target Social Program for the Improvement of Drinking Water Supply in Ukraine for the Period until 2035" [12]. The need for its adoption is due to the lack of effective state programs aimed at providing the population with high-quality and safe drinking water. The document is based on a program-targeted approach, which provides for the development of centralized water supply systems, taking into account European standards and norms.

The draft act defines strategic goals, priorities and expected results, including increasing the level of coverage of the population with centralized water supply, ensuring proper quality of drinking water, as well as the introduction of modern technologies for managing water supply systems. In addition, the draft document specifies the mechanisms and resources that should be involved to achieve the objectives [12]. Thus, the formation of an interconnected system of environmental and social programs creates the basis for the development of integrated scenarios for the development of water infrastructure, taking into account technical and economic factors, as well as long-term challenges of sustainable development.

In this context, the application of a program-targeted approach in the field of drinking water supply opens up new opportunities for modeling scenarios for the development of water infrastructure until 2035. Therefore, the combination of environmental programs with technical modernization and social projects creates significant boundaries for the analysis of risks and potential results, which allows assessing their impact on the quality of life of the population, compliance with EU standards and resilience to global challenges. An important step in this direction is the implementation of Ukraine's European integration course, which provides for the implementation of the provisions of Directive (EU) 2020/2184 of the European Parliament and of the Council of December 16, 2020, on the quality of water intended for human consumption into national legislation [13]. This Directive sets high standards for the safety and quality of drinking water, orienting Member States to form a comprehensive system of control, monitoring and management, which is based on the principles of preventing risks to public health. Its implementation in Ukraine will contribute to the harmonization of domestic water legislation with EU legislation and the formation of long-term prerequisites for improving the quality of life of the population.

Integration of the provisions of Directive (EU) 2020/2184 into national practice is a prerequisite for increasing the efficiency of economic modeling in the field of water supply and sanitation. At the same time, the introduction of European standards for drinking water quality requires a rethinking of the financing system of the industry, modernization of laboratory and technological capacities, as well as the development of institutional control mechanisms. This, in turn, will ensure a comprehensive approach to risk management in the water sector and increase its adaptability to internal and external challenges.

From this perspective, special attention should be paid to the experience of implementing the EU Water Framework Directive and the Floods Directive, which defined ambitious benchmarks for water resources management in Europe and became a model for other regions of the world. Their effective implementation involves taking into account the economic component, which ensures the introduction of the principles of economic feasibility, cost optimization and long-term financial stability [14, p. 56].

European experience also demonstrates that digitalization is gradually becoming a determining factor in improving the efficiency of water resources management. In particular, the EU-funded DWC project confirmed that the use of digital technologies can provide timely and more accurate monitoring of the state of water systems. Before the implementation of the project, the spread of such technologies was hindered by the lack of convincing business models and a proper evidence base for their effectiveness. Within the framework of the initiative, five major European cities – Berlin, Copenhagen, Milan, Paris and Sofia – were united as test sites for testing new solutions in the field of monitoring.

Particular attention was paid to the old urban infrastructures, where sewerage and storm water systems function together, which leads to the risks of sewage entering rivers during heavy rains [15].

In this context, the management of wastewater flows during heavy rains, the quality control of river waters, the optimization of operating costs and infrastructure investments, as well as the safe treatment and reuse of municipal wastewater in agriculture, have become important tasks for the participating cities. An important result of the cooperation was that the DWC project interacted with other European initiatives, such as SCOREwater and Fiware4Water, which made it possible to form a long-term impact on the water quality monitoring system and prepare a policy document identifying gaps in legislation and recommendations for their elimination [15]. Therefore, digitalization appears as a strategic factor in scenario forecasting of the development of water infrastructure in Ukraine.

These results are of fundamental importance for the formation of new approaches to scenario forecasting of water infrastructure development. The combination of digital technologies and economic modeling creates conditions for improving the accuracy of risk assessment, which is especially important for countries with a high level of deterioration of networks, in particular, Ukraine. In the future, the implementation of such solutions can optimize the cost of modernizing systems and prevent environmental crises in the event of an increase in the intensity of climatic phenomena [16].

At the same time, water resources management is gradually transforming into one of the basic elements of Europe's green transformation. This is due to the urgent need to ensure a balance between water quality, environmental sustainability and preservation of public health. Climate change exacerbates the problems of floods, droughts and water scarcity, which actualizes the need to restore wetlands and floodplains to maintain biodiversity and expand the range of ecosystem services. In this context, regulatory documents, including the Water Framework Directive [17] and the Nature Restoration Act [18], attest to the strengthening of regulatory impact on the protection of aquatic ecosystems and lay benchmarks for achieving ambitious environmental goals.

With the growing importance of environmental policy, an important step is to focus on regulatory instruments aimed at modernizing water supply and sewerage systems. In this sense, the Urban Wastewater Treatment Directive (UWWTD) [19], which is an important component of the European Green Deal, is of particular importance. It provides for a significant strengthening of standards for the purification and control of new types of pollutants, in particular PFAS compounds and excess nitrogen. Combined with projected infrastructure investments of USD 476 billion. By 2030, this indicates the transition to a new stage of water management in Europe, characterized by a high level of technologization, strengthening environmental standards and a long-term focus on sustainability [20].

At the same time, for Ukraine, the analysis of these processes is indicative but practical. Firstly, it demonstrates the possibility of integrating digital technologies into the system of water quality monitoring and risk forecasting. Secondly, it allows us to take into account the EU's experience in strengthening regulatory standards and providing an appropriate financial basis for the implementation of investment projects in the water sector. This experience highlights the importance of combining technological, economic and regulatory tools to ensure the sustainable development of water infrastructure. Thus, the outlined European approaches can become the basis for modeling scenarios for the development of Ukraine's water infrastructure until 2035, taking into account the potential risks caused by internal institutional constraints and, at the same time, global environmental challenges, which allows the formation of a comprehensive analytical space for strategic planning, investment optimization and increasing the sector's resilience to external and internal threats.

6. Conclusions

The analysis showed that the scenarios for the development of Ukraine's water infrastructure until 2035 should be formed taking into account certain risks, among which the consequences of military destruction, energy challenges, technological backwardness of systems and the growth of climate threats are decisive. At the same time, it was found that the high level of deterioration of water supply networks, significant differentiation of regional indicators and imbalance in tariff policy significantly limit the potential for modernization. In this regard, the integration of European approaches to economic modeling and risk analysis is of particular relevance, since they allow determining the optimal scenarios for recovery and development, taking into account financial, technological and security factors. An important element of such integration is the implementation of EU norms and directives, which creates an institutional basis for the harmonization of national policies

with sustainable development standards. In addition, the introduction of a program-targeted approach, the development of digital monitoring technologies and the focus on the principles of the circular economy form the prerequisites for increasing the industry's resilience to crisis conditions and ensuring long-term investment attractiveness. As a result, the prospects for the modernization of Ukraine's water infrastructure are determined by a combination of European practices, national strategies and innovative technologies, which makes it possible to build a comprehensive management model aimed at achieving the goals of sustainable development and guaranteeing water security of the population.

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