Ukraine's Water Management Complex: Opportunities for Climate Action and Sustainable Development

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Absrtact: The ratification of the Paris Climate Agreement by Ukraine envisages an increase in the ability to adapt to the negative effects of climate change, as well as promoting low carbon development so as not to endanger food production. At the same time, water resources, on the one hand, are one of the most vulnerable to climate change components of the environment from the state of which the food security of the country depends directly, and on the other - the activity of the water management complex causes the emergence of both direct and indirect carbon footprint. Therefore, an indispensable prerequisite for sustainable low carbon development is the assessment of the carbon footprint of the main sectors of Ukraine's water management complex and the identification of priority measures for their decarbonisation and adaptation to expected climate change.

The low-carbon development of the water management system should include the introduction and coordination of such measures, which, on the one hand, minimize the adverse effects of climate change on water resources and contribute to reducing the carbon footprint of water management activities, and on the other, guarantee the achievement of sustainable development goals, in particular for ensuring water and society proper sanitary conditions.

Keywords: Carbon footprint, water management complex, adaptation, decarbonisation, climate change.

INTRODUCTION

One of the current global challenges for humanity is climate change and related transformations of hydrometeorological and hydrological conditions. In the context of the formation of new socio-economic relations, this requires a qualitative solution to the problem of sustainable water supply. Due to population growth and rapid urbanization, access to quality water resources will be significantly more difficult for most consumers Introduction in the XXI century.

According to the Intergovernmental Panel on Climate Change (IPCC), the future climate will be determined by the inevitable warming caused by rising anthropogenic emissions into the environment. It is predicted that the average annual surface temperature by 2100 will increase by 2 – 5 ºC. There is a high probability that periods of sharp temperature rise and extreme hydrometeorological phenomena will occur more often and become longer.

At the same time, significant changes in climatic conditions are already being observed on the territory of Ukraine. Thus, in particular, for the period 1961 - 1990 the average annual air temperature was +7.8 ºC., then in 1991 - 2016 - +8.8 º C., and in 2007 - 2016 +9.4 º C. During the last sixty years there has been a significant increase in the average annual temperature in Ukraine relative to the climatic norm.

This leads to sharp changes in weather and an increase in the frequency and intensity of dangerous and natural hydrometeorological phenomena in the warm season (showers, thunderstorms, hail, droughts, dry winds) and in the cold (heavy snowfall, icy ground). In particular, the number of cases of natural meteorological phenomena on the territory of Ukraine is constantly growing. During 1986 - 1990 there

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were 403 cases of such phenomena, during 1996 - 2000 - 620, and from 2006 to 2010 - 779.

Among the studies of recent years to assess changes in water regime in the basins of the main rivers of Ukraine should be noted the following. Based on the analysis of long-term dynamics of average annual water runoff, forecast modeling based on regional climate models based on scenarios of climate change in Ukraine until 2050 and laid the foundations for a comprehensive approach to assessing current and possible changes in river runoff. The applied models show that a slight increase in the average annual water flow can be expected on the mountain rivers of the Crimea and in the basin of the river Kalmius - up to 2–4%. Water flow up to 10% is possible on the rivers of Polissya. The water content of the Carpathian rivers and the northern part will not change. On others, there will be a decrease in runoff. Its largest decrease (up to 12%) is possible on the rivers of the Black Sea coast. Probable changes are also in the intra-annual distribution of river runoff: increasing the runoff of the winter low and shifting the onset of spring floods to earlier dates.

As for the groundwater of Ukraine, the dynamics of their average annual level indicates an increase in depth, especially in the zone of insufficient moisture, which is within the Black Sea artesian basin and covers the Odessa, Mykolaiv, Kherson, southern Zaporizhia and the Crimean plains. In particular, during 1951 - 2017, the average annual groundwater level at the reference well № 33 in Kherson decreased by more than 2 meters.

As we can see, climate and freshwater resources are closely interrelated and determine the development of any socio-economic system, as changes in at least one of these components of the biosphere can have unpredictable consequences for another. Therefore, issues related to water supply in the context of global warming are particularly important for identifying key regional and sectoral vulnerabilities. Thus, the relationship between climate change and freshwater resources is of particular interest in the context of achieving sustainable development goals, and the dynamics of increasing dangerous hydrometeorological phenomena and increasing overall water risk require appropriate adaptation measures for all sectors of water consumption.

In the context of this, in 2016 Ukraine ratified the Paris Climate Agreement, which identifies two main complementary areas to combat global warming, namely: stimulating low-carbon development of key sectors of the economy by reducing greenhouse gas (GHG) emissions from economic activities (decarbonization) and implementation of measures to adapt to expected climate change.

The concept of low-carbon development is a relatively new model of political, economic and social structure of society, aimed at reducing greenhouse gas emissions and achieving sustainable development goals. The primary task of implementing this concept is to decarbonize all areas of the economy, increase energy efficiency and ensure global ecological balance.

At the same time, studies show that there is no universal way to transition sectoral economic systems to sustainable low-carbon development. This transition is determined by the unique characteristics of each area of economic activity of society and requires specific coordinated adaptation and decarbonisation measures, which would be based on an appropriate assessment of total GHG emissions from economic activities (carbon footprint) and the main factors of its occurrence.

Therefore, the aim of the study is to assess the carbon footprint of the main sectors of the water complex of Ukraine and to identify priority measures for their decarbonization and adaptation to expected climate change.

Research methods. The analysis of the carbon footprint of the main sectors of the water complex of Ukraine can be performed using the life cycle assessment method (LCA) accredited according to international standards ISO 14044, which allows to identify the total carbon footprint of a particular production process, end product or service. Life Cycle Assessment (LCA) is performed in four main stages, namely:

1. determining the purpose and scope of the study.
2. inventory analysis of the life cycle of the final product (LCI);
3. environmental impact assessment (LCIA);
4. interpretation of the obtained results and substantiation of further directions of research.

The first stage is the collection of general information about the object of study, comparison and evaluation of the main input and output streams of its impact on the environment throughout the life cycle of the final product. In the context of our study, only one initial flow of impact was considered, namely the direct and indirect carbon footprint of water management activities at the stages of water intake, water supply, drainage and water treatment in residential, municipal, industrial and reclamation complexes (Fig. **1**).

Inventory analysis, which provides for the collection of information and quantification of input and output flows of final products at all stages of the life cycle was conducted based on data from the National Inventory of Anthropogenic Emissions from Sources and Absorption of Greenhouse Gases in Ukraine in 2017 and by determining energy consumption in major sectors oh the water complex of Ukraine.

The third stage of the method (LCA) aims to determine the magnitude and significance of the impact of the production process on the environment. In the context of this, a comparative assessment of the results obtained on the carbon footprint of water management in Ukraine and other countries, as well as on the basis of a systematic analysis of the main factors of GHG emissions in the water complex of Ukraine identified priority areas for its decarbonization.

Interpretation of the results obtained at the end of the inventory analysis and assessment of the impact of carbon footprint on the environment in accordance with the fourth stage (LCA) allowed to suggest ways and directions of adaptation of Ukraine to the expected climate change in order to minimize their possible negative consequences.

Methods. The methodological basis for the assessment of the carbon footprint of the main sectors of the water management complex was the life cycle method (LCA), by which, based on the open data of the National Inventory of Anthropogenic Emissions from Sources and Absorption by

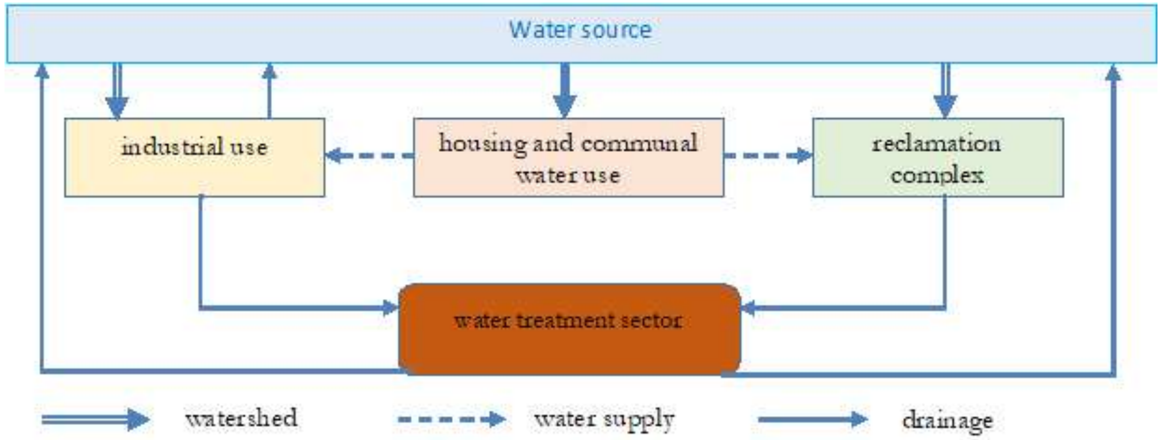

Fig. (1). The main components of water life cycle assessment in the water management complex of Ukraine.

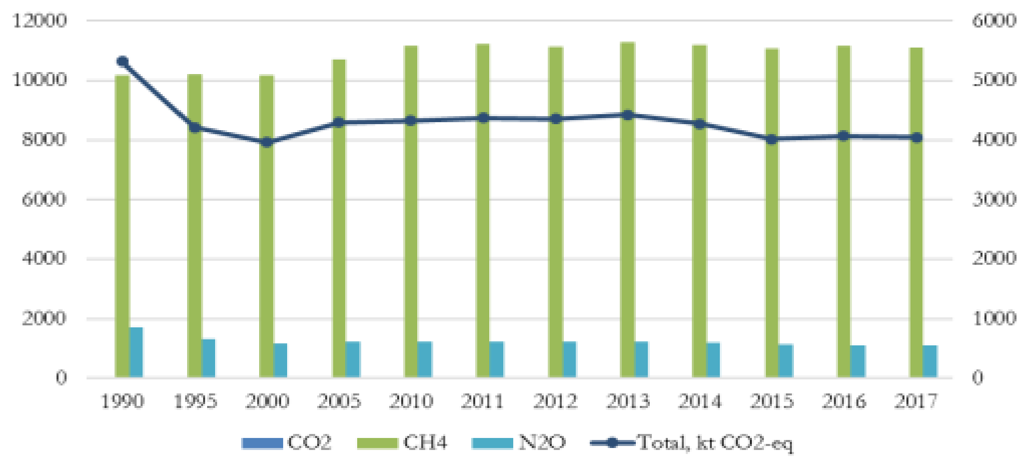

Fig. (2). Greenhouse gas emissions in the wastewater treatment and discharge sector during 1990 - 2017 kt *.

Greenhouse Gas Absorbers in Ukraine and the statistical analysis of the results of previous studies. By means of systematic analysis of the main factors of greenhouse gas emission in the water management complex of Ukraine, the priority directions of its decarbonisation and adaptation to climate change were determined.

Results of research and discussion. The largest issuer of direct GHG emissions in the water complex of Ukraine is the wastewater treatment and discharge sector. The volume and structure of emissions in this sector are presented in the National Inventory of Anthropogenic Emissions from Sources and Absorption by Greenhouse Gas Absorbers in Ukraine (Fig. **2**).

According to these data, in 2017 GHG emissions in the wastewater treatment and discharge sector reached 4.04039 million tons of CO2-eq. Which is 33.07% of the total GHG emissions in the Waste sector. Their total volume decreased compared to 1990 (5.31844 million tons of CO2-eq.) by 24.03%, and compared to 2016 by 0.64%.

The largest share in the overall GHG emission structure of the wastewater treatment and discharge sector is occupied by methane emissions from domestic wastewater - 2.18582 million tons of CO2-eq. (54.10%), emissions of nitric oxide from human wastewater are - 1.03611 million tons of CO2-eq. (25.64%), GHG emissions from industrial wastewater treatment - 818.47 million tons of CO2-eq. (20.26%).

Unlike the wastewater treatment and discharge sector, where direct GHG emissions are identified by the National Center for Greenhouse Gas Emissions, the indirect carbon footprint of other water complexes sectors of Ukraine remains uncertain. Its approximate volume can be set on the basis of the energy approach as the product of the total amount of electricity used for water management and the amount of greenhouse gas emissions in the production of 1 kW. * hour of electricity in Ukraine, as the main item of current expenditures for water management activities in such sectors as drinking water supply and sewerage, industrial and agricultural water use are electricity costs. In particular, in the general structure of operating costs of drinking water supply systems 40% are electricity costs, in the irrigation sector such costs reach 70%.

In order to determine the weighted average GHG emission in the production of 1 kW of electricity in Ukraine, a review of relevant literature sources was conducted.

According to GHG emissions in the production of electricity at coal-fired power plants range from 700 to 1000 gr. CO2-eq. kWh. The value of this indicator depends on the type of power plant, the modernization of equipment, the properties

Table 1. Determination of the Weighted Average Value of Greenhouse Gas Emissions in the Process of Electricity Production in Ukraine in 2017, CO2-eq / kWh.

Production Method Electricity	Electricity Generation		Greenhouse Gas Emissions (CO2-eq / kWh))		Total GHG Emissions, Million Tons	The Weighted Average GHG emission in the Production of 1 kWh.	
	Structure,%	Amount, Billion kWh	Gram	Ton		Gram	Ton
NPP	55,1	85,63	35	0,000035	3		
TPP (coal)	36,9	57,34	1000	0,001	57,34		
HPP	6,8	10,57	33	0,000033	0,35	146,14	0,000146
WES / CES / BES	1,2	1,86	50	0,00005	0,093		
Total	100	155,4			60,783		

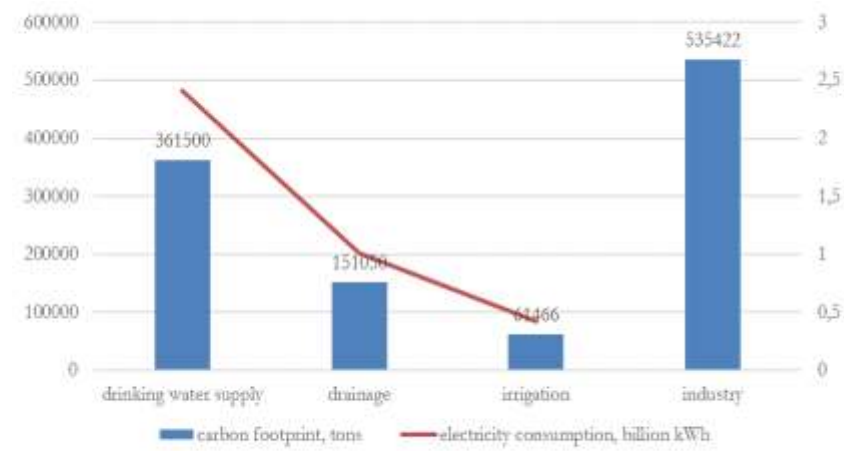

Fig. (3). The volume of electricity consumption and the "carbon footprint" of the functioning of the main sectors of the water complex of Ukraine.

of coal and so on. GHG emissions from electricity generation at nuclear power plants are 25 - 40 gr. CO2-eq. kWh and depend on the grade of uranium ore, the method of uranium enrichment, the design features of the station.

Similar emissions at wind power plants range from - 5 - 96, at hydroelectric power plants - 2 - 33, at solar - 50 - 116, bioenergy - 50 - 550 gr. CO2-eq. As in the general structure of electricity production in Ukraine, its generation at wind (wind), solar (SES) and bioenergy (BES) stations in 2017 was only 1.2%, we used the generalized average GHG emission at such stations 50 gr. CO2-eq. kWh.

In general, the data used for the calculations, which were obtained as a result of 10-year studies performed using the Global Emission Model for Integrated Systems (Global Emission Model for Integrated Systems) and coincide with the results of other studies (Table **1**).

Thus, the weighted average value of GHG emissions from electricity production in Ukraine in 2017 was 146.14 gr. CO2-eq. kWh.

The total cost of electricity for the operation of water supply and sewerage systems according to the National Report on the quality of drinking water and the state of drinking water supply in 2017 amounted to 3.417 billion. kWh / year. Thus, the indirect carbon footprint of this sector of VGK of Ukraine amounted to 512550 tons of CO2-eq.

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According to the approved passport of the budget program for 2017 of the Ministry of Ecology and Natural Resources of Ukraine under KPKRK 2407050 to ensure the operation of irrigation and drainage systems was planned to use 420.6 million kWh. electricity per year. Therefore, the indirect carbon footprint of the reclamation system is 61466,484 tons of CO2-eq. The total indirect carbon footprint of the drinking water supply and reclamation sectors is 422,966 tons of CO2-eq. At the same time, according to the State Statistics Service of Ukraine, the total water intake in 2017 in these two sectors amounted to 2723 million m^3. Thus, the indirect carbon footprint of the use of 1 m3 of fresh water in these two sectors amounted to 155.33 gr. CO2-eq. As there are currently no generalized statistics on the amount of electricity used to provide industrial water supply, it is with this indicator that it is possible to determine the targeted carbon footprint of fresh water used for industrial needs. In 2017, 3447 million m^3 were used for production needs, so the carbon footprint of this sector is approximately 535,422.51 tons of CO2-eq. (Fig. **3**).

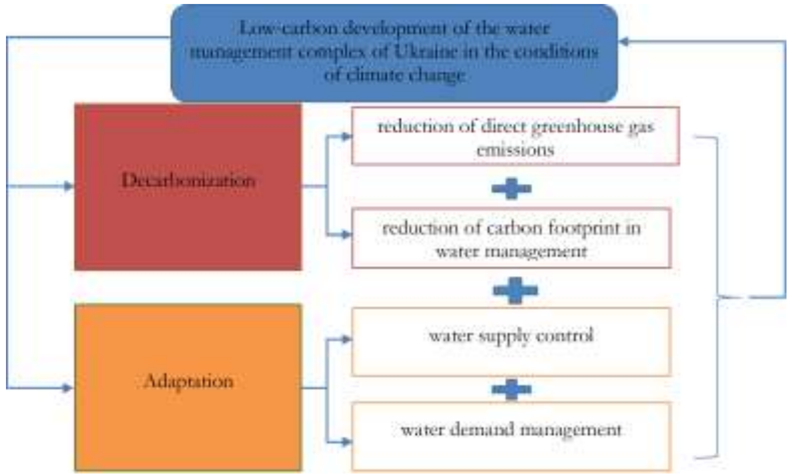

Fig. (4). Directions of low-carbon development of the water management complex of Ukraine,

Thus, the carbon footprint of the main sectors of Ukraine's water complex in 2017, according to our calculations, was equal to 5.15 million tons of CO2-eq, which is 1.6% of the total greenhouse gas emissions in Ukraine in 2017. This figure is slightly lower than similar, which was calculated, for example, for the United States. In particular, according to the total carbon footprint associated with the transportation, use, treatment and heating of water in the main sectors of the US water sector was 290 million tons of CO2-eq, which was 5% of total greenhouse gas emissions in the US in 2007.

In general, in different countries of the world, the carbon footprint associated with water management activities varies, as a rule, in the range of 2 - 5% of the total GHG emissions. The slightly lower level of the share of carbon footprint in Ukraine's overall GHG emissions structure is explained by two main factors:

1. In our study, due to the lack of generalized data, the energy consumption of private households for final water consumption is not taken into account related to heating water for personal needs, operation of washing machines and dishwashers, operation of bathrooms, etc. At the same time, these energy consumption can account for more than 50% of the total energy consumption associated with water management activities;
2. The share of electricity generated by thermal power plants in the United States reaches 65-70%, while in Ukraine 35 - 40. This significantly increases the carbon footprint of production of 1 kWh of electricity, and hence the carbon footprint of water management.

In the context of this, we can identify two main areas of low-carbon development of the water complex of Ukraine. The first concerns the direct reduction of direct GHG emissions, in particular in the field of water treatment. The second involves the implementation of measures aimed at minimizing the indirect carbon footprint of water management activities by increasing the overall energy efficiency of the relevant infrastructure.

In addition, in order to achieve the goals of sustainable development of water management, it is necessary to carry out adaptation measures for global climate change in the field of water supply, which can be aimed at regulating the demand for water resources or their supply. The former contribute to improving the efficiency of water use, usually through the widespread use of economic instruments and the introduction of new technologies. These include: accounting, limiting and standardizing water use, setting water prices, developing water markets and trading in virtual water, implementing re-sequential water use systems, and more. Measures aimed at regulating the supply of water resources include, first of all, increasing the useful volume of reservoirs, water abstraction from surface watercourses and underground sources, water transportation, etc. (Fig. **4**).

Since the main part of the carbon footprint in the water complex of Ukraine (4,040 million tons of CO2-eq) is generated in the field of wastewater treatment, the priority measures for decarbonization of the water management complex should be aimed at modernizing the relevant water treatment infrastructure. Such measures include:

- introduction of new production technologies in order to reduce water consumption and wastewater production;
- stimulating the development and use of new methods of water treatment;
- introduction of an integrated wastewater management system in order to ensure their reuse.

The indirect carbon footprint of other sectors of the water management complex directly depends on the level of electricity consumption and the overall efficiency of water supply and sewerage systems. At the same time, Ukrainian water supply networks are characterized by an extremely high level of wear and tear, which causes water losses in water supply systems, which in 2017 reached 60% of the supply (Chernihiv region), and on average this figure was 35%. As a result, the total cost of lost water in water supply systems is UAH 7.8 billion, and the total carbon footprint of lost water in the networks is 106 thousand tons. Thus, reducing the leakage of water from the networks by at least 10% will reduce the corresponding carbon footprint by 30 thousand tons of CO2-eq. annually. (Fig. 5). In addition to replacement, according to the summary of the data presented in 2017, the

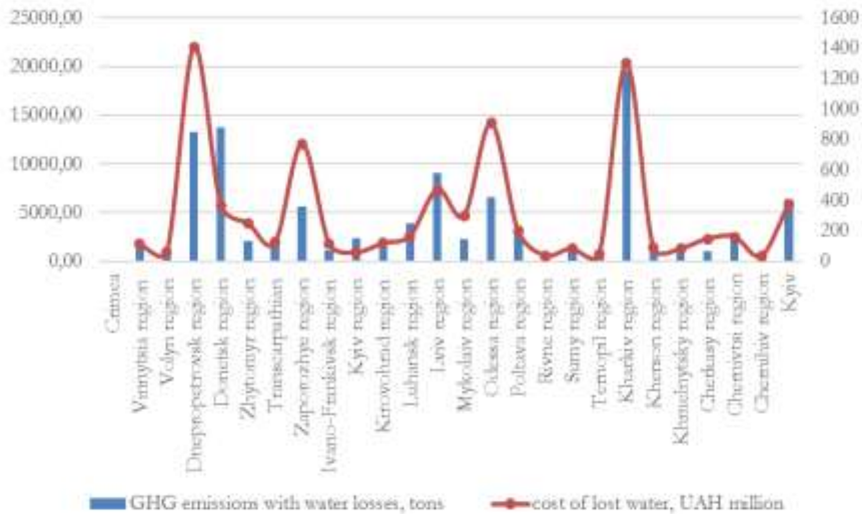

Fig. (5). Greenhouse gas emissions and the cost of lost water in water supply systems in the regions of Ukraine in 2017.

total number of pumps in the country's water supply systems (excluding Donetsk region) was - 14,909 units, of which 3441 or 23.1% needed replacement, during the year - 1262 were replaced or 36.7% of demand.

Given the above, the priority measures to reduce the level of indirect carbon footprint of the water complex of Ukraine should be the replacement of worn-out water supply networks and modernization of pumping equipment in the sector of housing and communal water supply. In the reclamation complex, an effective method for reducing the indirect carbon footprint is the introduction of drip irrigation systems, which reduce the use of water by 50-500%, electricity (50-70%), fertilizers (20-50%). Irrigation efficiency reaches 85–90%, as water enters directly into the root system of plants, the surface area of which is from 40 to 60% of the total area. Also, evaporation losses are reduced and there are no losses from peripheral water runoff. A promising area for decarbonization of reclamation and industrial complexes is the introduction of wastewater (gray) water systems for irrigation in special areas - agricultural irrigation fields and production needs in reusable water supply systems.

The use of wastewater in particular in agriculture is one of the measures of integrated use and protection of water resources, because the soil is able to treat wastewater, increasing its own fertility.

At irrigation by sewage three tasks are solved: removal and clearing of the polluted waters; their use in the fields for artificial soil moisture; application of a large amount of mineral, organic and bacterial fertilizers to the soil. Taken together, this can significantly reduce the level of carbon footprint in water management.

A significant level of the impact of climate change on the state of water resources necessitates the development and application of appropriate methods of adaptation of water supply systems in the context of the implementation of the concept of low-carbon development of the water complex of Ukraine. These methods can be conditionally structured by two approaches: infrastructural or water supply management and institutional or water demand management.

However, the implementation of decarbonisation measures of the water complex of Ukraine imposes additional requirements on the priority of application of certain methods of adaptation. For example, most extensive methods of managing the demand for water resources allow relatively quickly to attract significant amounts of water resources to achieve sustainable development goals, but their use also causes additional greenhouse gas emissions and causes irreversible changes in natural ecosystems.

Therefore, a characteristic trend of recent decades is the combination of advantages of infrastructural and ecosystem approaches to water management, which gave impetus to the development of a system of water supply management methods based on green infrastructure, which should be a priority in the context of implementing low-carbon development.

Green water management infrastructure in general is a set of natural or restored natural ecosystems that complement, increase or improve the level of water supply services of traditional water management infrastructure. The most typical examples of green water infrastructure are: wetlands, forest protection zones, permeable pavement, restored river floodplains, etc.

The development of a network of green infrastructure for sustainable water supply has a number of advantages over traditional methods of overcoming the problem of water deficit. In addition to meeting the growing needs of the population and the economy in water resources, the construction of relevant facilities significantly improves the overall condition of aquatic ecosystems, which, in turn, increase the flow of relevant services and benefits. In particular, the ecological capacity and resilience of the territory is increased, which is extremely important in conditions of unpredictable climate change, biodiversity of natural ecosystems is supported, manifestations of dangerous geomorphological phenomena such as soil erosion, karst processes, shoreline erosion, etc. are prevented.

From an economic point of view, green infrastructure reduces the pressure on existing water supply facilities, which has a positive effect on the level of their depreciation and avoids the need for their early modernization, which will require significant investment resources. In addition, the level of ecosystem services and benefits provided, in contrast to extensive methods of attracting water resources into economic circulation, tends to increase over time. If we consider the advantages of this approach in the socio-political aspect, it should be noted that green infrastructure is a necessary element of the formation of a modern comfortable living environment, especially in large cities.

It should also be noted that the adaptation of Ukraine's climate change to climate change is also not possible without the use of a set of socio-political and economic measures. An effective incentive to increase the rationality of water consumption is, in particular, increasing the fee per unit of water used with increasing total water consumption, the introduction of penalties for excessive pollution of water resources, differentiation of water fees depending on water use and water intake.

All of the above areas of low-carbon development need to be integrated into one water policy system, which should be implemented at the international, national, regional and local levels. Such water policy should be implemented, in our opinion, on the basis of three key principles: integrated use of existing and promising approaches to ensuring low-carbon water management, integrated water resources management, awareness of their key ecosystem value and role.

CONCLUSIONS

As a result of the study, the relationship between climate change and freshwater resources, which is of particular interest in the context of achieving sustainable development goals, is analyzed. It is proved that the dynamics of increasing the number of dangerous hydrometeorological phenomena and the growth of overall water risk due to global warming require appropriate adaptation measures for all sectors of water consumption in the implementation of low-carbon development strategy.

It is substantiated that the main principle of implementation of the concept of sustainable low-carbon development of the water sector is the introduction and coordination of such measures, which on the one hand should minimize the negative effects of climate change on water resources and reduce the carbon footprint of water management, and on the other, in particular regarding the guaranteed provision of society with clean water and proper sanitary conditions. In this context, the process of decarbonization of the water sector should be aimed at creating conditions and implementing measures for its low-carbon development and provides for the reduction and, in the long run, prevention of greenhouse gas emissions from water management to mitigate climate change and preserve aquatic ecosystems.

It is established that in the overall structure of GHG emissions the share of carbon footprint of water management in 2017 was 1.6%, and taking into account the potential carbon footprint of end-use processes, it may increase to 3%. At the same time, in absolute terms, this is 5.15 million tons of CO2-eq GHG, a significant part of which can be avoided.

To this end, a methodological approach to determining the carbon footprint of water supply systems is proposed, based on which it is established that the amount of annual GHG emissions from lost water in water supply systems reaches 106 thousand tons, and the cost of lost water in water supply systems is 7.8 billion UAH.

Based on the assessment of the carbon footprint of the main sectors of water management, priority mechanisms and measures for their decarbonization are proposed. In particular, such measures in the water treatment sector, which is the main emitter of methane in the water complex of Ukraine include: technical re-equipment of water treatment facilities, introduction of regenerated water systems, creation of closed industrial water supply systems through public-private partnership mechanisms. Priority measures for decarbonisation of other sectors of the water complex of Ukraine include: modernization of water supply networks and pumping equipment, introduction of drip irrigation systems and reversible water use, formation of integrated water resources management systems.

It has been proven that the development of a network of green infrastructure for sustainable water supply has a number of advantages over traditional methods of water resources management in the context of implementing a strategy of low-carbon development and adaptation to climate change. The construction of relevant facilities significantly improves the overall condition of aquatic ecosystems, which, in turn, increase the flow of their services and benefits. In particular, the ecological capacity and stability of the territory increases, the manifestations of dangerous hydrometeorological phenomena are prevented, which is extremely important in the conditions of unpredictable climate changes.

In order to implement the priority measures of adaptation and decarbonisation of the WGC of Ukraine, it is necessary to harmonize the existing and future plans of integrated river basin management with the key principles of the concept of low-carbon development.

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