

## CONSEQUENCES OF THE DESTRUCTION AT THE KAKHOVKA HYDROELECTRIC POWER PLANT FOR AGRICULTURE IN THE SOUTH OF UKRAINE

Olena Shubravska<sup>1</sup>✉, Olha Popova<sup>2</sup>✉, Kateryna Prokopenko<sup>3</sup>✉

<sup>1</sup> ORCID: 0000-0002-2109-9308

<sup>2</sup> ORCID: 0000-0003-2642-9393

<sup>3</sup> ORCID: 0000-0003-1456-4432

<sup>1, 2, 3</sup> Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine  
26 Panasa Myrnoho Street, 01011, Kyiv, **Ukraine**

### ABSTRACT

**Motives:** Ukraine's agricultural sector has suffered immense losses due to the Russian invasion. The situation worsened after the Kakhovka Hydropower Plant was undermined in the summer of 2023. It is essential to assess the devastating consequences of this destruction in order to plan the future development of the agricultural sector.

**Aim:** The aim of this study was to estimate the expected volume of agricultural production and possible scenarios of its development in the areas affected by the explosion at the Kakhovka Hydropower Plant. The study also aims to summarize the opinions expressed during the discussion on the reconstruction of the Hydropower Plant.

**Results:** In the medium term, agricultural activity in the region will be conducted on rainfed land at a scale similar to that of 2022. In the long term, there will be significant losses of almost all crop products due to changes in the structure of crops according to ecological requirements. Currently, there is no unified position on the restoration of the Kakhovka Reservoir and Hydropower Plant due to conflicting economic and environmental approaches.

**Keywords:** prospects of agricultural development, structural transformation, ecological requirements, military actions, losses suffered by farmers

### INTRODUCTION

On June 6, 2023, a terrorist attack at the Kakhovka Hydro Power Plant (hereinafter – HPP) dam by Russian military forces caused a catastrophic technological disaster with severe consequences. Over 30,000 hectares of fields (including those in the occupied territories) were flooded in the Kherson region and 100,000 tons of stocked crops were lost. The destruction of the dam

also significantly impacted the biodiversity in the area and caused irreparable damage to the Nizhnyodni-provsky National Nature Park, the Dnipro River delta, and other Ramsar areas that safeguard the unique wetland ecosystems. The Kakhovka Reservoir previously covered an area of 2.1 thousand km<sup>2</sup>, but as of August 2023, less than one-fifth of the surface, only 382 km<sup>2</sup>, was still underwater. Over 1.7 thousand km<sup>2</sup> became dry land due to the attack.

✉shubravska@gmail.com; ✉olgpomail@gmail.com; ✉k\_prokopenko@ukr.net

The areas affected by the explosion at the Kakhovka HPP are situated within Ukraine's Arid Steppe and Dry Steppe climate zones, which has a moderate continental climate with mild, little-snow winters and hot, dry summers. The destruction of the Kakhovka HPP has had a significant impact on the most vulnerable agroclimatic zone in Ukraine. Before the war, the zone was experiencing aridification of climatic conditions, i.e., a decrease in precipitation along with abnormally high temperatures that have since intensified. Domestic scientists predict that further increases in temperature and lack of precipitation in the region will lead to critical aggravation of moisture supply to biocenoses, drying of steppes, a reduction in land fertility and the total bio-productive system, and desertification of the area (Vozhegova, 2021).

The catastrophic event has had a considerable impact on Ukraine's agriculture sector, and it's essential to evaluate its effects to plan future development. The research aims to forecast the volume of agricultural production and potential scenarios of its future development in the regions affected by the terrorist attack at the Kakhovka HPP. Additionally, the study targets to summarize the discussion opinions regarding the rebuilding of the HPP.

## LITERATURE REVIEW

EU's biodiversity strategy for 2030 targets to reclaim freshwater ecosystems and natural functions of rivers and aims to recover 25 thousand km of rivers in the EU (European Parliament, 2020). This will be achieved by removing unacceptable dams and artificial barriers that have been a result of human activity in the past century. Although scientific studies on river fragmentation primarily focus on large dams (over 15 m) due to security and economic reasons, not many such dams are located in Europe (only 2.8%). The majority of the barriers are smaller structures (Garcia de Leaniz, 2020). The war in Ukraine has highlighted that large dams have become targets for terrorist activities, such as the Kakhovka Hydro Power Plant and reservoir (the water level reached 16 m),

which posed a catastrophic threat to the population, ecosystems, and the national economy.

According to Habel et al. (2020), Southern America and Western Europe are dismantling more dams than are being built. They mostly demolish low barriers and those between 7.5 and 15 m high. In Europe, 12 large dams have been dismantled, and those that are highly depreciated will be taken apart soon. One of the decisive criteria for dismantling dams is high costs involved in updating them. The authors of the research highlight the social and economic problems and environmental consequences of dam dismantling in different countries. They also stress the importance of developing complex plans that consider the short and long-term consequences of dismantling dams and provide local communities with new directions to develop the areas previously occupied by the water reservoirs. This can supply even greater social and economic benefits.

The researchers have highlighted the importance of effective communication with local communities regarding the dismantling and updating of dams. This will help support national political decisions. Boucher and Hudson (2023) have noted that the French state authorities' inability to include the values of stakeholders in the continuum of ecosystem services has led to opposition from the community against disassembling the 36 m dam in Vezins. Referring to Manatunge et al. (n.d.), proper planning and designing (involving the public at the early stages of the process) can minimize or eliminate the disturbance and unfavorable impact of dams. The future goal is to use dams and water reservoirs for smart management of national water resources to achieve development goals.

Agricultural ecosystems are primary suppliers of food and main users of water resources. These ecosystems use from 60% to 90% of available water depending on the climate and economic development of the region (Pedro-Monzonís et al., 2015). The global area for irrigated crops is assessed as 275 million ha, demonstrating the annual growth of 1.3% (Velasco-Muñoz et al., 2019). Although it makes up only 23% of the total cultivated area, it provides 45% of the total food.

The researchers emphasize the need to follow the principle of sustainable development in agricultural water use and apply proper practices to improve crop yields and minimize water loss (Mancosu et al., 2015). It is essential to have water available for agricultural production to get sufficient and profitable yields. More investments in infrastructure development, such as dams and water supply systems, will help manage the growing demand for water from the population.

It is important to note that in the conditions of the climate change increasing, namely a decrease in rainfall and rising temperatures, agriculture in regions in the South of Ukraine without access to water resources will not be efficient. To achieve sufficient irrigation, surface water can be utilized after increasing the water level of Dnipro through the construction of a dam, as well as by using groundwater. A study (Su et al., 2021) has shown that rapid expansion of irrigated areas has led to a decrease in the level of groundwater, posing a threat to the stability of local agriculture and causing degradation of the ecological environment. This points clearly to the need of determine the degree of underground water over-exploitation and allowable water intake to protect the local ecosystem. Herman Bouwer also emphasizes the importance of protecting groundwater resources to ensure long-term water and food security for future generations (Bouwer, 2000).

Effective strategies for water resource management are essential for increasing water resource productivity and implementing sustainable farming systems (Mancosu et al., 2015). Therefore, Ukraine needs a reasonable choice of strategy to ensure sustainable development of its southern regions.

## MATERIALS AND METHODS

The study is based on a combination of general and specialized scientific methods. By analyzing the ecological aspect, the authors aimed to summarize the opinions, observations, and predictions of experts on the natural recovery of the former area of the Kakhovka Reservoir. However, since there are no calculations available on the required funding for the recon-

struction of the Kakhovka HPP and water reservoir, the conclusions reached are not fully substantiated. It is also reasonable to compare the currently available ecological and economic judgments on whether to rebuild the Kakhovka HPP and water reservoir or revive the Great Meadow National Nature Park (Velykyi Luh), which was flooded when constructing these objects.

To obtain empirical results on the transformations occurring in agricultural production in the South of Ukraine due to the destruction of the Kakhovka HPP, the authors conducted a retrospective analysis, grouping, comparative analysis, and consolidation. They analyzed the changes that have occurred in Ukrainian crop production from 2020 to 2022 based on the State Statistics Service of Ukraine data (State Statistics Service of Ukraine, 2023).

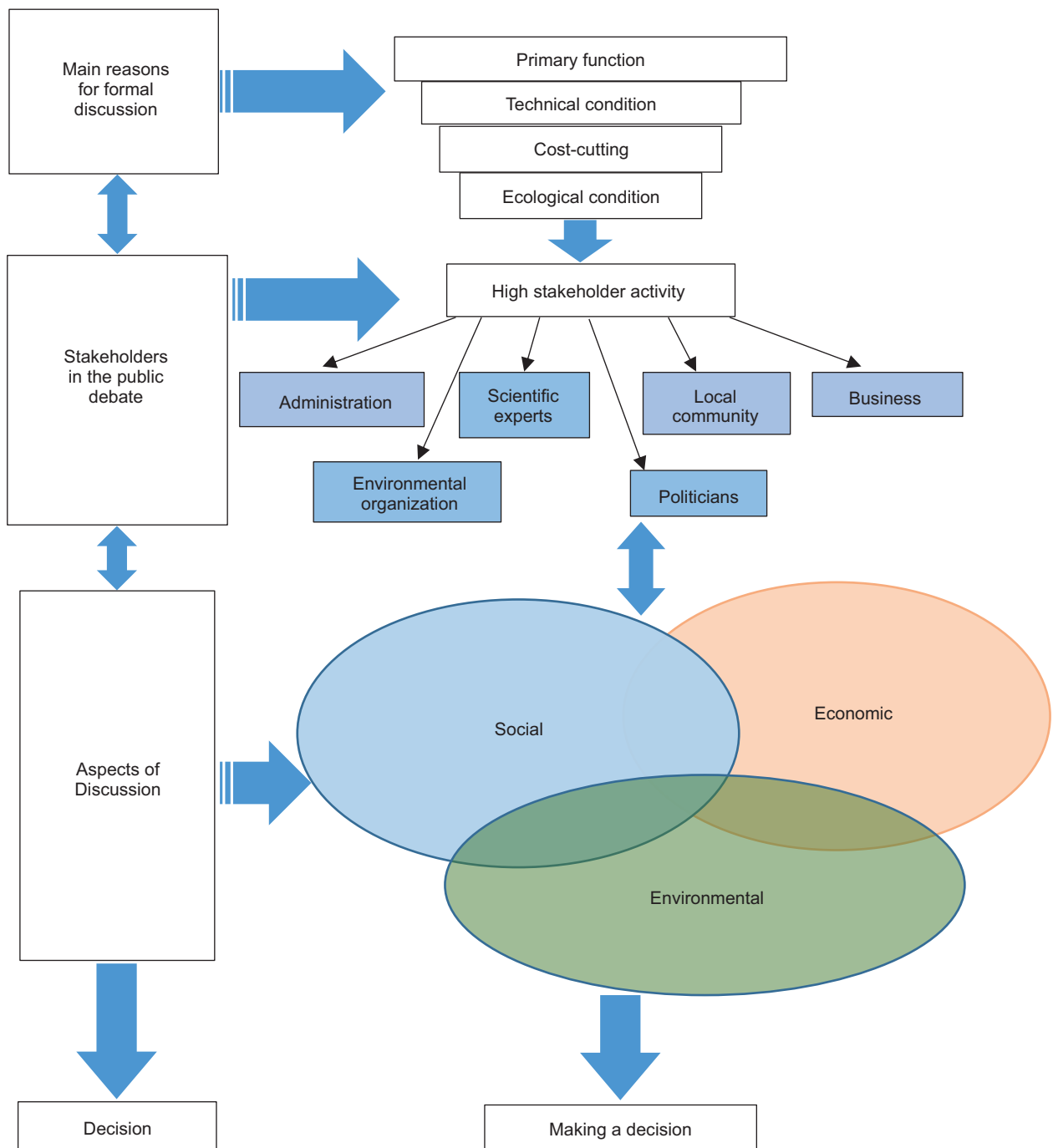
To assess effects of the Kakhovka HPP's undermining on the future development of crop production in the southern region, the authors proposed the following hypotheses:

- in the short and medium term, the production activity in the region will take place on rainfed lands, equal to that of 2022;
- in the long term, scenarios for crop production development in the area affected by the desiccation of the Kakhovka Reservoir and water outflow can be based on two options – one that prolongs the current situation that is a basic scenario, and another that considers the recovery of the irrigation system and production greening. The latter is an optimistic scenario.

## RESULTS

### Position on the importance of rebuilding the Kakhovka HPP and Reservoir for the Ukrainian economy

There is no agreement on the necessity of rebuilding the Kakhovka Reservoir and HPP for the Ukrainian economy. This highlights the conflict between economic, social, and ecological approaches.



**Fig. 1.** Scheme of the official discussion on the decision about large dams  
 Source: own elaboration based on Habel et al. (2020).

The Ministry of Agrarian Policy and Food of Ukraine believes that growing cereals using an extensive model may be an option, but it will result in significant yield losses. Vegetable growing is in a dire situation because without water from the Kakhovka Reservoir, this branch of agriculture is unsustainable. Water from the reservoir was used to irrigate 80% of the land where vegetables were grown, including almost all thermophilic fruits in Ukraine. In 2023, farmers on the right bank stated that they would switch to crops that do not require irrigation, such as wheat, barley, rape, and sunflower, and reduce their soybean production. Rainfed farming is a new prospect. Given the significant impact of the project on the ecological, social, and economic development of the southern region, a broad discussion according to the scheme shown in Figure 1 is reasonable.

The Ukrainian government is in favor of rebuilding the Kakhovka HPP and is proposing a fifteen-year ban on transfer into ownership and use of land previously occupied by the reservoir. Two draft laws have been submitted to the Verkhovna Rada of Ukraine to restore the reservoir and protect the land from misuse. The government has approved a two-year testing project to rebuild the Kakhovka HPP (Cabinet of Ministers of Ukraine, 2023).

An expert from the World Wildlife Fund emphasizes the need to partially fill the reservoir with a smaller volume of water to restore a portion of Velykyi Luh between Zaporizhzhia and Nikopol. However, most ecology specialists support the idea of completely restoring Velykyi Luh, which was flooded during the construction of the Kakhovka Hydroelectric Power Plant. This is due to the high costs required for revival, while rebuilding the reservoir would be much more beneficial. A research group from Kherson State University has concluded that creating floodplain forests in the area and reviving the Kamianka River are promising prospects. As long as no anthropogenic impact is made, groups of plants that are typical for the environment will revive. The vegetation map of the area of the dried Kakhovka Reservoir, composed by using the Normalized Difference Vegetation Index (NDVI), shows that within 2.5 months of the

undermining of the Kakhovka HPP, the naked landscape has become green. The value of the index averaged 0.18, which corresponds to that of grass vegetation, according to studies by H. Kolomytsev.

It's important to highlight that rehabilitating Velykyi Luh, which was formerly part of the Kakhovka Reservoir, could greatly contribute to Ukraine's green initiative as it aligns with the country's environmental and climate goals under European Green Deal. By committing to such green projects, such as those for environmental protection and climate change, Ukraine may be able to restructure a portion of its debt through mechanisms like debt-for-climate swaps and debt-for-nature swaps (International Foundation "Vidrodzhennia", 2023). Similar agreements have been made in the past, such as the redemption of Bolivia's debt in exchange for the conservation of millions of hectares in the Amazon basin and the restructuring of Poland's debt in 1992, which allocated costs for protecting the country's biodiversity, managing waste, reducing greenhouse gas emissions, and preventing soil pollution. To encourage and attract investments in economic activities that are beneficial for ecological and climatic goals, Ukraine is advised to develop and implement a green taxonomy.

### **Assessment of the social and economic consequences of the Kakhovka HPP explosion for agriculture in the South of Ukraine**

Economists agree that the South of Ukraine needs significant water resources for its development which proves the reasonability of, at least partial, but still rebuilding of the Kakhovka Reservoir.

Before its undermining, the Kakhovka Reservoir provided water for irrigation channels in Dnipropetrovsk, Zaporizhzhia, and Kherson regions. However, the lands in Mykolaiv region did not rely on the Kakhovka Reservoir for water. The agricultural sector in these regions mainly focused on crop production, particularly cereals and vegetables. The most commonly grown vegetables were tomatoes, cabbage, onions, peppers, and aubergines, while melons and

stone fruits also held a significant share. Among cereals wheat, barley, rapeseed, rice, soybeans, corn, and sunflowers were grown using intensive technologies. Significant volumes of agricultural crops were grown under irrigation conditions in Kherson and Zaporizhzhia regions.

The data presented in Table 1 indicates that in Zaporizhzhia and Kherson regions, significant portions of arable land have been under occupation, resulting in a critical reduction in the area of irrigated land available for crop cultivation in 2022. However, in Dnipropetrovsk region, the cropping area, including the irrigated portion, has not seen much reduction. In 2022, only 8.1% of the irrigated land in Zaporizhzhia and 4.7% in Kherson regions were left for production on the government-controlled territory. This means that 80% of all irrigated land in Ukraine was not used for production activity due to military actions.

The destruction of the Kakhovka HPP by Russian forces worsened the situation even further. This caused long-term and medium-term risks for agrarian production, as most of the irrigated lands in Zaporizhzhia and Kherson regions and over one-third of the area of Dnipropetrovsk region were supplied with water from the Kakhovka Reservoir.

In the short term and medium term, it is unlikely that the land in the South of Ukraine, currently is under occupation, will be available for agricultural activity. This is because it is polluted with explosive objects and degradation caused by hostilities.

The authors reached this conclusion after examining available data on the rates of recovery of agricultural lands on the deoccupied and frontline territories. In particular, January – February 2023 FAO

survey showed that 95% of agricultural land in small agrarian farms (up to 250 ha) disposal are polluted in Kherson region (KSE Agrocenter, 2023).

Landmine clearance and restoration of land fertility in areas affected by bullets and mines can be quite expensive and time-consuming. It can cost around \$1780 per hectare to complete the three stages of demining. Kyiv School of Economics conducted a survey and used data from the State Statistics Service of Ukraine and FAO to estimate that small farmers alone would require over \$250 million to clear their agricultural lands. High advanced costs can become a significant barrier for producers, as 72% of them have already experienced a sharp drop in income (over 50%) due to the hostilities (KSE Agrocenter, 2023).

It is currently difficult to predict the long-term impact of the catastrophic event at the Kakhovka HPP on agriculture. The reduction of cropping areas and yield capacity due to weather risks also must be taken into account. This means that negative consequences can be observed not only in the irrigated fields in Kherson, Zaporizhzhia, and Dnipropetrovsk regions directly but also in the adjacent territory due to climate deterioration.

Furthermore, there is currently no agreement on how to recover the water balance and ecosystem in the next few years. In the short and medium term, agricultural production will likely occur on drylands in a volume similar to 2022. The most significant losses will be experienced by farmers in Kherson and Zaporizhzhia regions. However, in Dnipropetrovsk region, which is less dependent on the Kakhovka Reservoir and less damaged, irrigated lands can be recovered in the medium term. Taking into account

**Table 1.** Loss of agricultural lands due to hostilities in the zone of the Kakhovka Reservoir

Regions	Sown area – total, thousands hectares			Irrigated lands, thousands hectares			Share of the zone of impact of the Kakhovka Reservoir in 2021 (estimation), %
	2021	2022	Index 2022 vs. 2021, %	2021	2022	Index 2022 vs. 2021, %	
Ukraine	20,198.7	16,433.2	81.4	429.2	84.2	19.6	75.1
Dnipropetrovsk	1,326.9	1,322.5	99.7	16.9	14.8	87.6	37.4
Zaporizhzhia	1,226.4	294.9	24.0	55.6	4.5	8.1	99.3
Kherson*	921.0	132.2	14.4	265.5	12.5	4.7	96.4

\* agricultural enterprises data.

Source: calculated using the data from the State Statistics Service of Ukraine

**Table 2.** The expected output of the main kinds of crops by agricultural enterprises in a short and medium period in the regions suffering from the Kakhovka HPP destruction, thousand centners

Types of crops	Production		Expected production	
	2021	2022	short term period	medium term period
Grain and legumes including	86,305.9	28,082.1	27,600	27,900
wheat	54,987.8	18,522.1	18,440	18,470
corn	14,643.1	5,623.9	5,390	5,555
barley	13,684.6	3,462.1	3,430	3,440
Soya	3,151.7	155.1	125	125
Rapeseed	6,098.7	4,153.0	4,135	4,145
Sunflower	25,070.9	10,833.6	10,805	10,810
Vegetables grown in the open	6,366.9	761.0	750	800

Source: Authors' calculation using the data from the State Statistics Service of Ukraine.

such assumptions Table 2 provides an estimate of the anticipated agricultural production in the regions affected by the Kakhovka HPP disaster in the short and medium term.

One possible solution addressing the climatic and other issues is shifting the economy of the South of Ukraine from arable farming to grassland animal breeding, which is sustainable in the current climate and justified given the progressing processes of desertification in the region. Alternatively, the costs intended for rebuilding the Kakhovka HPP could be used to build advanced pump stations to supply water for industry and agriculture directly from the Dnipro River instead of the reservoir. The application of water-saving technologies, such as drip irrigation, can also contribute to the development of intensive farming, including vegetable and fruit growing in the region.

### Scenarios of agrarian sector development in the zone of the desiccated Kakhovka Reservoir

Therefore, taking into account that in order to make a decision regarding the further water supply of the three regions of Ukraine, which were part of the zone of influence of the Kakhov reservoir, specialist research is needed. As the final scenario of the region's development in the long term is currently unknown, two trends in the development of the agricultural sector can be predicted. They can be implemented regardless of the decision made about the source of water supply. At the same time it is worth noting

that the agrarian sector in Dnipropetrovsk region, which was least affected by hostilities and is less dependent on water supply from the Kakhovka Reservoir (about 6 thousand ha), will maintain and even strengthen its pre-war development trends.

The first (basic) trend of development proposes:

- accessibility of agricultural lands in the three regions at the pre-war levels (including mine clearing and land recovery);
- restoration of old irrigation systems and the use of currently operating production technologies;
- strengthening of the adverse effects of climate change, which will result in further temperature rise and aridization. These trends can only be slowed down, and climatologists have long warned about them;
- conservation of the pre-war structure of cropping area and providing part of the land with irrigation.

Crop production volume can probably be maintained at the level of 2020, which was the driest in the pre-war period.

The second trend of development that is optimistic and in compliance with environmental requirements proposes the following actions:

- clearing mines and recovering land to make the total area of agricultural lands accessible at the pre-war level;
- optimizing agricultural landscapes, as stated in the Resolution of the Cabinet of Ministers of Ukraine of January 19, 2022 „On approval of the Concept of National Target Program of Use and Protection of Land”, which will involve a decrease of the area

- of agricultural lands of researched regions (by up to 5560 thousand ha (63.5% of the total area), arable land by up to 3880.7 thousand ha (69.8% of the total area of agricultural lands);
- ensuring compliance with environmental requirements at enterprises, which will result in transformations in the structure of agricultural lands and cropping areas;
  - implementing drip irrigation as the most efficient technology for water utilization to ensure maximum yield;
  - introducing the required technological and resource decisions to increase the level of realization of the genetic potential of the seeding material productivity up to 70%.

Table 3 shows estimates based on these assumptions.

**Table 3.** The expected output of the main kinds of crops by agricultural enterprises in the long run in the regions suffering from the Kakhovka HPP destruction, thousand centners

Types of crops	Production 2021	Expected production	
		Basic scenario	Optimistic scenario
Winter wheat	54,750.5	43,000	50,800
Corn	14,643.1	7,700	22,000
Barley	13,684.6	11,300	15,400
Soya	3,151.7	2,550	5,700
Rapeseed	6,098.7	6,800	3,850
Sunflower	25,070.9	18,500	11,550

Source: Authors' calculation using the data from the State Statistics Service of Ukraine.

The estimates indicate that the implementation of structural changes in line with environmental requirements (optimistic scenario) could result in a significant decrease in certain crops production. For instance, agricultural enterprises may lose 7–10% in wheat production, sunflower – 45–55%, and rapeseed production may also decrease. It is also recommended to reduce the area under corn. However, its production can rise due to the increase yield if it is grown under irrigation. In recent years, the yield of corn in these regions was one of the lowest,

because it, like soybeans, needs enough moisture. Therefore, in the calculations, the share of corn recommended for the Steppe zone in the structure of crops was significantly reduced in favor of wheat, which was due to the greater need for corn in water resources. This situation is essential because the current share of cropping area used by enterprises for growing industrial crops (mainly sunflower) is at an unacceptable level of 50%, depending on the region, and violates environmental requirements (Shubravska & Prokopenko, 2022). While this provides fast economic benefits, it causes land degradation and yield reduction in the long run.

The optimization of the cropping area structure of enterprises requires a ten-fold increase in the amount of land used for vegetables. This will result in a growth of vegetable production, given there is sufficient irrigation. However, it is difficult to predict the total expected volume of these products because it depends on the current market situation and the structure of vegetable production.

The losses experienced by the agrarian sector during the war had a significant impact on Ukrainian regions. Before the war, the regions mentioned accounted for 14.4% of the country's agricultural output. However, the impact of agriculture on the gross domestic product varied across the regions. For instance, in the pre-war period, the share of agriculture was 6.7% in Dnipropetrovsk region, which was less affected by the hostilities and the destruction of the Kakhovka HPP. In contrast, in Zaporizhzhia region, it was 10.5%, and in Kherson region, it was 33.1%. The agricultural production in Kherson region was heavily dependent on water supply from the Kakhovka HPP and therefore suffered the most significant impact from its explosion.

According to the authors' rough estimates, the losses suffered by agricultural businesses due to military actions and flooding caused by the destruction of the Kakhovka Hydroelectric Power Plant in Kherson, Zaporizhzhia, and Dnipropetrovsk regions amounted to at least \$2.9 billion in 2022, as the value of agricultural products not received by them. In 2023, the losses of agricultural products



were estimated to be around \$3 billion. These three regions have already not received agricultural products worth \$6 billion over the two years of the war. It is important to note that this figure does not include losses incurred due to damaged machinery, infrastructure (incl. destroyed elevators, irrigation facilities), livestock, poultry, buildings, mine clearing, or the cost of recovering agricultural lands. In the post-war period, it will be necessary to assess the value of land recovery and the feasibility of performing these works. There is a probability of refusing to use of the most affected agricultural lands

Based on the above expectations of a decline in production in the regions affected by the destruction of the Kakhovka HPP, the following measures should be taken:

- speed up the development of selection and increase the level of realization of the genetic potential of crop varieties and hybrids. This will have a significant impact on the agrarian sector's operation, as the amount of products obtained and the required qualities of crops for subsequent deep processing depend on proper seeding materials.
- in the medium and long run, abandon the previous systems of water supply and invest in the installation of irrigation point systems that use less water and contribute to the optimization of growing technologies.
- consider the changes in agro-climatic conditions of crop growing in the region and adapt production accordingly. In particular, fast and excessive accumulation of heat can reduce the vegetation period, stimulate premature ripening of crops, and result in a decline in yield.

## CONCLUSIONS

The formation of floodplain forests in the area where the Kakhovka Reservoir used to be, as well as the recovery of Velykyi Luh, are crucial for optimizing the ecosystem and landscape in the southern part of Ukraine. These unique conditions in Europe are highly valued because the floodplain

willow and poplar forests are protected under the Bern Convention. Additionally, restoring rainfed farming and transforming the structure of agricultural production in the desiccated Kakhovka Reservoir zone can have a positive impact on soil conditions, making it an opportunity for agricultural greening in the region.

At the same time, the development of agricultural production in the area requires at least a partial restoration of the Kakhovka Reservoir to provide irrigation. Obviously, this probability is extremely small even in the medium term. So, agricultural activities there will be carried out on the scale of 2022 on rainfed lands. Thus, the losses caused by the war, submergence and flooding after the destruction of the Kakhovka HPP to the agricultural enterprises of the region will increase annually. According to the authors' approximate estimates this will make almost \$3 billion (as the value of not received agricultural products).

In the long run, both scenarios of development will lead to a decline in the production of traditional crops such as cereals and oilseed. This decline will be particularly noticeable in the basic scenario. However, in the optimistic scenario, the fall in production, mainly sunflower and corn, will be related to the structural transformation of agriculture in the region in compliance with the environmental requirements necessary for sustainable development.

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