Open Access

J. Glob. Innov. Agric. Sci., 2026, 14(1): 227-240
ISSN (Online): 2788-4546; ISSN (Print):2788-4538
DOI: https://doi.org/10.22194/JGIAS/26.1704
http://www.jgiass.com

Regulatory Policy of the Agricultural Sector in the De-Occupied Territories of Southern Ukraine: Challenges and Measures to Restore the Irrigation System

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Irrigation system restoration is crucial for enhancing agricultural productivity and ensuring food security. The study aims to analyze the regulatory framework and financial mechanisms for restoring irrigation systems in the de-occupied territories of southern Ukraine while addressing key challenges related to land use, water resource management, and economic recovery. The study employs a mixed-methods approach, including policy analysis, stakeholder interviews, and financial modeling. Policy documents and legislative acts are examined to assess the effectiveness of regulatory measures. Interviews with local agricultural stakeholders provide qualitative insights, while financial modeling evaluates the impact of EU financial instruments. Groundwater over-extraction, biodiversity losses, low species resilience, and finance shortages are distinguished as the critical issues preventing from restoration of de-occupied lands in Ukraine. It is defined that groundwater over-extraction leads to aquifer depletion and land degradation. The study develops policy recommendations to govern groundwater use, emphasizing the need for modern monitoring technologies, efficient irrigation techniques, and coordinated water resource management to ensure the long-term viability and resilience of irrigation infrastructure in de-occupied territories. Community-based initiatives and policy interventions are explored as essential conservation components to increase species resilience. The creation of wildlife corridors and the implementation of protected areas are defined as other key measures to mitigate biodiversity loss. The findings show that the restoration of de-occupied Southern Ukraine depends on such types of EU financial support as subsidies, grants, and low-interest loans. These funds are mainly delivered through the following mechanisms: direct government allocations, partnerships with international financial institutions like the European Investment Bank (EIB), and targeted agricultural recovery programs. The EIB as the EU lending arm is examined in the context of its role in the post-war recovery and economic resilience of Ukraine's agricultural sector, with a particular focus on Trésorerie Sociale de l'État (TSE). It is defined that TSE facilitates financial mechanisms to support agricultural enterprises, stabilizing local economies and fostering sustainable development in war-affected regions. The research highlights the interplay between European financial institutions and national regulatory policies in rebuilding Ukraine's agricultural sector.
Keywords: Agricultural lands, food security, land rehabilitation, land fertility, regulatory policy, water resource management.

INTRODUCTION

Southern Ukraine has a long history of irrigation development, shaped by its semi-arid climate and reliance on agriculture. In ancient times, communities along the Dnipro River and Black Sea steppes used primitive irrigation techniques to sustain crop production. However, large-scale irrigation infrastructure began developing in the 19th and 20th centuries, particularly during the Soviet era (Chepurda, 2017). In the early 20th century, the Soviet government initiated massive irrigation projects, constructing reservoirs, canals, and pumping stations to support collective farming (*kolkhozes* and *sovkhozes*). The North Crimean Canal, built between 1961 and 1971, became one of the most significant projects,

Kyrylov, Y. Y., Hranovska, V. H., Alieshchenko, L. O., Bolila S. Y., & Prus, Y. O. (2026). Regulatory Policy of the Agricultural Sector in the De-Occupied Territories of Southern Ukraine: Challenges and Measures to Restore the Irrigation System. *Journal of Global Innovations in Agricultural Sciences, 14,* 227-240.
[Received 12 Feb 2025; Accepted 20 Jun 2025; Published 3 Oct 2025]

channeling Dnieper River water to Crimea and the Kherson region. By the late Soviet period, irrigation covered over two million hectares, enabling high crop yields and stable agricultural production.

Following Ukraine's independence in 1991, irrigation infrastructure faced decline due to underfunding, mismanagement, and geopolitical instability. The annexation of Crimea in 2014 and ongoing conflicts disrupted water supply systems, leading to the deterioration of canals, reservoirs, and pumping stations (Hapich et al., 2024). The full-scale invasion by the Russian Federation only worsened the situation. The sector has suffered catastrophic losses due to the destruction of assets, production and distribution systems, logistics networks, infrastructure, agricultural land, and human capital. In the de-occupied southern regions, the damage to agricultural production facilities remains severe and continues to escalate due to ongoing attacks by the aggressor. After the explosion of the Kakhovka Hydroelectric Station, many farmers in southern regions of Ukraine were forced to restore their farmland while dealing with unexploded shells and debris scattered across their fields. The destruction of the Kakhovka Hydroelectric Station led to the suspension of water supply in 31 irrigation systems across southern Ukraine. As a result, 94% of agricultural land in the Kherson and Mykolaiv regions, 74% in the Zaporizhia region, and 30% in the Dnipropetrovsk region were left without water. In total, more than 1,100 km of irrigation canals were affected (Kyiv School of Economics, 2023). Only 13 irrigation ecosystems remain operating on the right bank of the Dnipro (Sobkevych et al., 2024). Voloshkina et al. (2023) studied the consequences of the emergency before its occurrence and after the dam were blown up as results of military operations. The researchers determined the processes of groundwater distribution of pollutants in treatment plants, as well as accumulators of various types of waste, their filtration from landfills of various kinds. Hutsol (2020) and Razanov & Tkachuk (2018) monitored heavy metal pollution (explosives) in moistened agricultural soils, which have a direct impact on the translocation of grain cultivation technologies, their quality and safety in the structure of crop rotation.

It should be noted that experts simulated the explosion of the Kakhovka Hydroelectric Station and came to the conclusion that the reduction of irrigation opportunities in the territories of Zaporizhia, Dnipropetrovsk, Kherson and Mykolaiv regions, while the reduction of the water level in the reservoir by 15 m could potentially lead to the loss of 14% of the export potential of Ukrainian wheat (Sobkevych et al., 2024). As for the actual situation, the combined effects of reduced irrigation, active military operations, and logistical challenges have led to an estimated decline in wheat exports. In 2023, Ukrainian wheat exports totaled approximately 16.8 million metric tons, down from 18.8 million metric tons in 2021, reflecting a reduction of more than 10% (Britchenko et al., 2022). The economic consequences of these agricultural losses are substantial. Global markets reacted to the event, and the cost of wheat rapidly increased by 3%. Ukraine's wheat exports generated USD 4.7 billion in revenue in 2021, but this figure declined sharply due to war-related disruptions (Deininger et al., 2017). Even though the loss of export revenue impacted the Ukrainian economy, it is too early to predict the consequences for global food security because 20% of grain and leguminous crops are grown in the territories of de-occupied regions in Ukraine that are under environmental and economic pressure from constant shelling by the aggressor country.

Summing up, it is safe to say that the de-occupied territories of Southern Ukraine now face additional long-term environmental and economic challenges. One of the most critical issues is the restoration of the irrigation system, which has been severely damaged or completely destroyed due to military actions. Without effective irrigation, agricultural productivity is at risk, threatening food security, economic stability, and the livelihoods of local farmers (Negoda & Novak, 2023).

Therefore, research in this field is essential to developing innovative solutions that balance resource flows, restore water management infrastructure, and ensure sustainable agricultural development. This article aims to analyze the regulatory framework and financial mechanisms for restoring irrigation systems in the de-occupied territories of southern Ukraine while addressing key challenges related to land use, water resource management, and economic recovery. To achieve the set aim, a mixed-methods approach was used, which consisted of policy analysis, stakeholder interviews, and financial modeling. Policy documents and legislative acts were examined to assess the effectiveness of regulatory measures, while interviews with local agricultural stakeholders provided qualitative insights. The article also resorted to financial modeling to assess the impact of EU financial instruments.

Given the above, the structure of the article is as follows: 1. Introduction, which describes the problem at hand and reviews the existing literature on irrigation policies and financial support mechanisms. 2. Materials and Methods, which detail the methodology employed in this study. 3. Results, which present the findings, including the role of regulatory frameworks and financial institutions. 4. Discussion, which describes conservation strategies and their impact on sustainable irrigation and suggests policy recommendations and future research directions. 5. Conclusions, which sum up the problems discussed and their possible solutions.

MATERIALS AND METHODS

A deep understanding of the policy of the agricultural sector in these territories of the country is determined by factors of the hierarchical structure of the state's systemic goals, which are distributed into a system of local goals to mitigate the nature of the emergence of ecological and economic challenges, which are neutralized when solving food security in the regions. Their target mission is the effective allocation of resources to agricultural production, maximizing added value and reducing environmental damage. That is, forming efficiency criteria, at each level of neutralization of ecological and economic challenges, the de-occupied territories of Southern Ukraine need to restore resources through the programs of the Common Agricultural Policy with the EU countries for the restoration and development of agricultural production in the affected regions (Nazarenko, 2015). At the same time, the interaction of the regulatory policy of the agricultural sector in the de-occupied territories of Southern Ukraine has a coordinated holistic mechanism of the agricultural policy of the EU countries, the actions of which are shown in Figure 1.

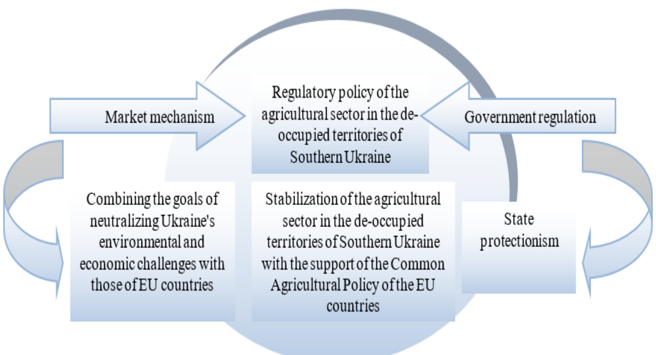

Figure 1. Interaction of the domestic regulatory policy with the EU common agricultural policy.
Source: constructed by the authors.

The combination of the goals of neutralizing environmental and economic challenges in agricultural production in the de-occupied territories of Southern Ukraine with the help of the EU Common Agricultural Policy is a very important step, which is ensured on the following principles: the formation of a single European food market to ensure the free movement of goods at uniform prices; protection of priority agricultural products on the EU market; reduction of import prices and global fluctuations in the system of export measures; receiving assistance from the FEOGA to finance the common agricultural policy.
The methodological approach to the scope and effectiveness of the regulatory policy of the agricultural sector in the de-occupied territories of Southern Ukraine is formed on the basis of the OECP methodology, which from the standpoint of systemic analysis is considered in the context of three general subsectors of state support: the totality of agricultural producers; the general provision sector (infrastructure); consumers of agricultural products (Fig.2).

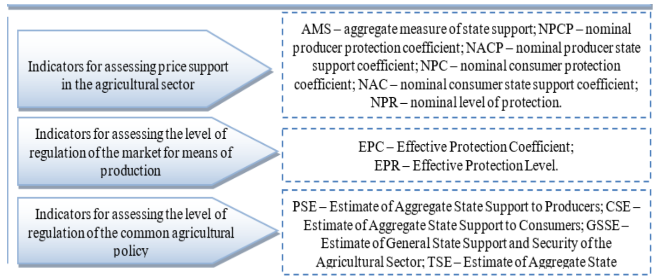

Figure 2. Regulatory policy indicators for agriculture in de-occupied Southern Ukraine with EU support under the CAP.
Source: constructed by the authors based on data (The European Parliament and the Council, 2022; OECD, 2023).

The concept of assessing the results of the regulatory policy of the agricultural sector in the de-occupied territories of Southern Ukraine with cooperation and support from EU countries under the Common Agricultural Policy is carried out on the basis of three blocks (Figure 3).

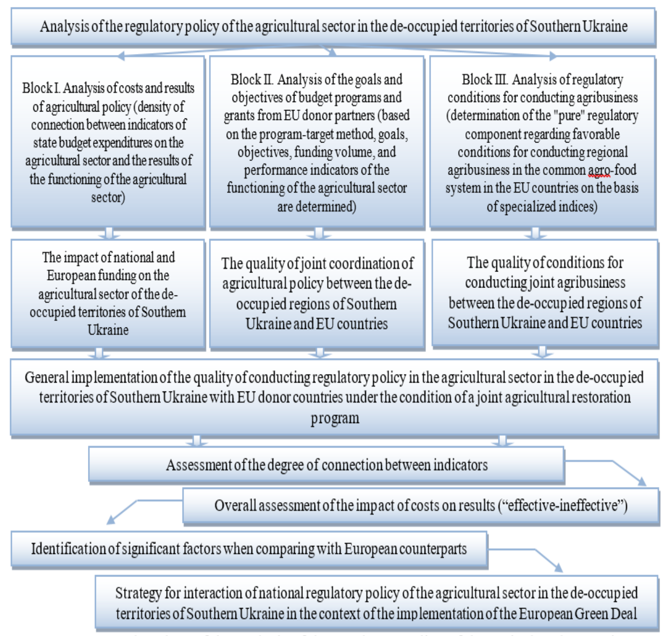

Figure 3. Flowchart of agricultural policy analysis in de-occupied Southern Ukraine with EU support.
Source: constructed by the authors based on data (The European Parliament and the Council, 2022; OECD, 2023).

It is necessary to focus on individual issues of systemic analysis and measures to restore the irrigation system, as well as to level large-scale losses after the collapse of the Kakhovka HES based on financial support from EU countries. Ensuring the recovery processes of agricultural production in the de-occupied Southern regions of Ukraine should be carried out with the help of the European Investment Bank and the following main funds: the European Regional

Development Fund (EFRD), the European Social Fund (ESF), the Cohesion Fund (Cohesion Funds), two sectoral funds (the European Agricultural Fund for Rural Development (EAFRD), the European Maritime Fund and the Fisheries Fund (EMFF). Individual regions of Southern Ukraine may receive assistance from the EU Solidarity Fund (EUSF), which helps in the event of environmental disasters (European Investment Bank, 2024).

It should be noted that the long-term ecological and economic challenges for the agricultural sector of Southern Ukraine are critical, as the water level above the hydroelectric power station dam has dropped by more than 10 meters. This has caused a complex of environmental obstacles, including: a change in the hydrology of both banks of the reservoir (the ditch-beam system, small rivers, etc.) and the network of underground watercourses to levels that formed under long-term water pressure and its infiltration in the Kakhovka HES; emptying of the bare bottom of the reservoir within 1-2 years after the disappearance of water, which led to a change in the ecosystem; loss of the source of water supply for the Left Bank of the Kherson region, as well as part of the territory of the Zaporizhia, Mykolaiv and Dnipropetrovsk regions – partial decline in the fertility of agricultural lands and their territories (Voloshkina et al., 2022).

One of the ways to prevent contamination from entering groundwater and reducing the quality of soil for growing crops is to protect against the loss of contaminated water and its filtration from destroyed land reclamation structures. An integral part of the justification for such protection is the assessment and prediction of the parameters of the filtration flow entering the underground horizons. Filtration losses in the aeration zone of a land reclamation structure are determined by the formula (1) (Bereznytska & Voloshkina, 2010):

$$q = k_{fsp} \times P/\delta \times w \qquad (1)$$

where, q – filtration losses per linear meter of the destroyed reclamation structure in the aeration zone, m/day; k_{fsp} – conditional filtration coefficient of the reclamation structure with multiple damages, m/day; P– pressure over the damaged lining of the reclamation structure, m; δ – thickness, m; w– width of the structure in cross section.

The value of the conditional coefficient of filtration damage of a melioration structure (k_{fsp}) is determined using the efficiency coefficient of the protection of the reclamation structure according to the formula (2) (Voloshkina et al., 2012):

$$k_{fsp} = \eta \times k'_{fsp} \qquad (2)$$

where, k'_{fsp} – value of the filtration coefficient of the reclamation structure at the beginning of operation, i.e. before its damage, m/s.

The efficiency coefficient of protection of a reclamation structure with conditional damage can be determined using the method (Marshall & Shevchuk, 2023):

$$\eta = \frac{2\delta}{l} \times \frac{\pi}{arch\frac{2ch(2\pi\delta/l)}{1-\sin\frac{\pi}{2}\left(1-\frac{2m}{l}\right)}} \qquad (3)$$

where, l – approximate distance between damage, m.

When there are round holes with a diameter of more than 3 mm in the damaged reclamation structure, then the protection efficiency coefficient is determined by the empirical formula (4), (Marshall & Shevchuk, 2023):

$$\eta = 1/\varpi[0.0107(d-3) + 0.024] \qquad (4)$$

where, d – diameter of the hole in the reclamation structure, cm; ω – area of the protective coating in the center of which this hole was formed, cm^2.

The filtration losses of a land reclamation structure located in the zone of incomplete soil saturation with water are determined by the formulas (5)-(6), (Akhtar et al., 2021):

$$\varrho_f = \varrho_f(1 + b/\sqrt{t}) \qquad (5)$$

$$\overline{Q}_f = k_v(1 + 0.05\frac{P_k}{w})[w + 2(P - h_f] \qquad (6)$$

$$k_v = k\left(\frac{\theta_e-\theta_{mm}}{\theta_n-\theta_{mm}}\right)^n \qquad (7)$$

where, $\theta_e, \theta_n, \theta_{mm}$– soil moisture capacity in its natural state, maximum and full; k– soil filtration coefficient; n– empirical coefficient, the value of which is equal to the value of 3.5.

The costs of unloading underground flow are determined by the formula (8), (Akhtar et al., 2021):

$$q = \frac{T(P+\delta+P_0)}{F_k+F_f+\sqrt{\frac{T_{g0}}{T_{\varepsilon 0}}}}, \qquad (8)$$

where, F_k, F_f – filtration pressure in an undamaged reclamation structure and filtration pressure in a damaged reclamation structure; T– average water conductivity of the reclamation structure, m^2/s; g_0 – critical depth of groundwater to a level equal to 0, m; ε_0– evaporation intensity on the soil surface.

Thus, when a melioration structure is mechanically damaged, intensive soil contamination occurs, which negatively affects the agricultural system, which, according to the agro-landscape approach, may not meet the requirements of ecological cleanliness and create obstacles to the rational use of agricultural land and increase their soil fertility, obtaining a high and stable harvest. That is, this technique helps to simultaneously determine the intensity of soil protection irrigation systems of agriculture with an emphasis on row-row, grain-row-row, grain-steam, grain-grass and crop rotation (Marshall & Shevchuk, 2023).

Along with the increasing needs for soil protection from polluted water and its filtration in the case of destroyed reclamation structures, the need and requirements for soil protection for growing crops and their safety are also increasing, which depends on the ecological state of the environment of their production (Khylko, 2017). It is known that the current state of the environment in some territories of Southern Ukraine is characterized by unfavorable conditions to produce high-quality plant raw materials, including cereals, due to the accumulation of various toxicants in them. Among the number of toxicants that require control in plant raw materials are heavy metals. Sources of heavy metals entering the environment are rocks, air emissions from ferrous metallurgy enterprises, motor vehicles, liquid and solid household municipal waste, organic and mineral fertilizers (Hutsol, 2020). Meanwhile, the intensive use of chemical agents in crop production creates a growing load of heavy metals on agricultural lands, which leads to the translocation of these toxic substances into grain products, which reduces their quality and creates safety for its consumption for the population (Razanov & Tkachuk, 2018).

Research on the influence of soil moisture level on the accumulation of heavy metals in winter grain crops should be carried out by varietal composition from the beginning of the tillering phase to the ripening phase. Artificial additional soil moisture during the cultivation of winter wheat and winter barley during the end of the tillering phase to the beginning of the ripening phase should be carried out by aerosol method, using the sprinkling method (Razanov & Tkachuk, 2018).

Soil samples for determining the concentration of heavy metals (Pb, Cd) are taken by the envelope method. Grain is taken by hand probe from each batch separately. Determination of heavy metals (Pb, Cd) in grain crops is carried out by the atomic absorption method. The accumulation coefficient (C_{ac}) is determined by the formula (9) (Akhtar et al., 2021):

$$C_{ac} = \frac{HM_{gcc}}{HM_s} \quad (9)$$

where, C_{ac}– accumulation coefficient; HM_{gcc} – content of heavy metals in grain of cereals; HM_s – content of heavy metals in soil.

The hazard coefficient (C_d) is determined by the formula (10) (Akhtar et al., 2021):

$$C_d = \frac{HM_{gcc}}{N_{HM}} \quad (10)$$

where, C_{ac}– accumulation coefficient; N_{HM} – norm of heavy metals in the soil.

Therefore, an important place in the regulatory policy in the agricultural sector of the de-occupied territories of Southern Ukraine is occupied by soil protection of land plots from pollution and accumulation of heavy metals in the agricultural landscape, increasing crop yields and improving the quality of crop products by improving growing technologies. Success in obtaining high stable yields under conditions of increasing energy prices can be achieved by implementing resource-saving technologies, which include a high level of agricultural technology, the application of optimal norms and doses of fertilizers, an integrated system of plant protection from diseases, weeds and pests, and the introduction of modern high-intensity varieties and hybrids.

Thus, a deep understanding of the development of the agricultural sector in the de-occupied territories of Southern Ukraine is important for comparative analysis and formulation of a policy for the post-war. In addition, knowledge of the impact of the destructive irrigation system on the potential of the agricultural sector of the de-occupied territories of Southern Ukraine will direct agribusiness and the government to restore resources such as land, equipment, infrastructure, finance and innovation. This will allow monitoring gaps in the profitability of agricultural production of individual commodity producers and setting goals for improving their activities or agricultural sectors as a whole; to promote the formation of agricultural policy on land use, the introduction of technologies, subsidies, trade, etc.; to plan the area of crops for crops in crop rotation on agricultural lands, provided that mathematical models are used for calculating the hydrodynamic or filtration unit of the irrigation system and the unit for transformation and migration of soil contaminants in the porous environment of groundwater.

RESULTS

Russian troops committed another environmental crime by blowing up the Kakhovka HES on June 6, 2023, which provided annual regulation of the Dnipro River flow for electricity supply, irrigation and water supply to arid regions of Southern Ukraine. This crime caused significant damage to the population, endangering the environment, destroying natural complexes, rare species of flora and fauna, causing water pollution, causing damage to agricultural production, flooding households and agricultural lands, causing disruption of irrigation systems due to the lack of water for irrigation (Biatov et al., 2023). All these consequences posed a threat to food and water security.

It should be noted that the tragedy had a devastating impact on the agricultural sector of the Kherson and Mykolaiv regions – the scale of flooding reached 10 thousand hectares of agricultural land on the right bank, as well as several times more on the left bank of the region, which is currently under occupation. In the Mykolaiv and Kherson regions, significant areas of land of personal farms were flooded, which were used by the population to grow agricultural products, the harvest of which was completely destroyed. In total, 1066 hectares of personal farms in the Kherson region and 892 agricultural plots in the Mykolaiv region were flooded. The negative consequences of the destruction of the Kakhovka HES affected the fishing industry. In total, at least 11388.3 tons of fish were lost. In addition, the flood destroyed 85 fish farms that caught aquatic biological resources and were located downstream: 49 fish farms in the Kakhovka reservoir and 36 farms in the Dnipro-Bug estuary system. Due to the discharge of water from the Kakhovka reservoir, the total amount of losses from direct loss and loss of offspring due to deterioration of living conditions is 0.272 billion EUR (Mulska, 2022).

According to the Post Disaster Needs Assessments (PDNA), an analytical study prepared by the Ministry of Economy of

Ukraine in collaboration with the UN, as well as the World Bank and the European Investment Bank, irrigation was disrupted due to the dam failure, which resulted in crop losses of 412.8 million EUR. According to the PDNA, the financial needs for environmental restoration are 65.2 million EUR. Priority areas include demining, cleaning, surveying and assessing contaminated areas. Some environmental impacts are irreversible and can have a cascading effect on other sectors for decades (Balakrishnan, 2023).

Table 1. Directions for conservation of agricultural lands.

Directions	Result of implementation
Growing energy crops	Fast-growing trees (plantations of various types of willow and poplar) or other types of plants or grasses, which can be used as fuel. The main advantage in this case is a short growing period – from three to eight years. For some types of grass, the crop can be harvested every 6-12 months.
Use of biological and chemical agents	Cleaning of contaminated land. Specialized biological agents based on hydrocarbon-oxidizing bacteria accelerate the decomposition of petroleum products; chemical agents clean the soil of heavy metal residues and other non-tragic contaminants.
Reorientation of agricultural production to rain-fed agriculture with the cultivation of drought-resistant crops that do not require irrigation	Growing of millet and sorghum. Providing farmers with planting material for sowing these crops
Creation of greenhouse farms, as well as drilling wells and installing pumping stations near the Dnipro to partially preserve vegetable growing	Develop at the level of small-scale and peasant farms
Construction of a bridge (overlap) upstream of the Kakhovka HES	Will allow raising the water level in the reservoir to a level acceptable for water intake by existing systems and restoring water supply by existing land reclamation systems. Construction of a pipeline and pumping stations to supply water to the territory of the de-occupied territories of the Southern Zone of Ukraine

Source: generated based on data (Balakrishnan, 2023)

The most effective way to restore land is "conservation", i.e. removing land from economic use and planting perennial grasses, afforestation or renaturalization, i.e. gradual return to a natural state. Since before the war, the Southern Zone of Ukraine was among the world leaders in terms of plowed agricultural land (about 78.2% of agricultural land). Conservation will help reduce this level, and, therefore, increase the resistance of the land to erosion processes. Under such conditions, the soil will remain untouched, and a closed biological cycle of substances will be formed, and the potential fertility of the soils will increase. The potential for such development is in cattle breeding, sheep breeding, goat breeding, and horse breeding.

The directions in which it is advisable to carry out land conservation (this primarily applies to plowed land on which grain and oilseed crops were grown) are presented in Table 1.

In 2023, it was possible to initiate a recovery trend in the agricultural sector of the de-occupied territories of the Kherson region in Southern Ukraine. This was made possible by demand on the domestic market, in particular for products for the needs of the Armed Forces of Ukraine (AFU) and for the country's infrastructure restoration, improved electricity supply to consumers, relocation of production, liberalization of foreign trade, diversification of sales activities and increased exports of Ukrainian goods. However, the basis for the reconstruction of the agricultural sector of the de-occupied territories of Southern Ukraine is resource and geographical advantages. Unfortunately, such an approach to the national economy of Ukraine increases its raw materialization and does not create conditions for the realization of the potential opportunities of the territories of the Southern zone of Ukraine to generate a significant amount of income from the production of agricultural raw materials, taking into account the integration of technologies and innovations in agricultural production (Oliinyk et al., 2022).

Restoring economic dynamics in wartime requires overcoming existing problems and limitations, scaling up effective strategies for commodity producers and their recovery from the crisis. At the same time, the new vector of the regulatory policy of the agricultural sector for the reconstruction of the de-occupied territories of Southern Ukraine should be the construction of modern agricultural production on the basis of progressive technologies for solutions to the distribution of groundwater resources in the territories of precisely those regions that have restrictions on water discharges through the deliberately destroyed reservoir of the Kakhovka HES from regulated sections of the Dnipro River in accordance with environmental requirements.

The highest level of exploration of groundwater resources is noted in the Southern regions of the Steppe Zone of Ukraine (Kherson, Mykolaiv, Dnipropetrovsk and Zaporizhia regions), where the groundwater level exceeds 50%. The maximum percentage of exploration of groundwater resources was noted in the Kherson region (66%), Dnipropetrovsk region (64%), Mykolaiv region (57%) and Zaporizhia region (92%) (Ministry of Development of Communities, Territories and Infrastructure of Ukraine, 2023). Among the main river basins of Ukraine, the largest amounts of groundwater resources are in the Dnipro basin

(61%). The share of other basins is less than 18% of such waters: the Seversky Donets is only 12%, for the Azov river basins – 4.6%; for the Dniester-Southern Bug interfluves river basins – 0.5%. Groundwater reserves in the southern part of the country, and, especially, in the Kherson, Mykolaiv, Dnipropetrovsk and Zaporizhia regions for the needs of agriculture and irrigation of agricultural lands reach 12-15% (Ministry of Development of Communities, Territories and Infrastructure of Ukraine, 2023).

Total groundwater extraction in 2021 in Ukraine before the explosion of the Kakhovka HES was 1132.401 thousand m^3/day, which is 6.9% of the total groundwater reserves (excluding the resources of the temporarily occupied territory of the Kherson and Zaporizhia regions, as well as the Autonomous Republic of Crimea). The highest production in the South of the country was noted in the territory of the Zaporizhia region controlled by Ukraine (3.2%), in the de-occupied territories of the Kherson region (5.8%), the lowest – in the Mykolaiv region (0.9%), in the Dnipropetrovsk region (0.5%) (Ministry of Development of Communities, Territories and Infrastructure of Ukraine, 2023). In 2022, the total groundwater production in Ukraine before the explosion of the Kakhovka HES decreased by 15.6% and amounted to 955,390 thousand m^3/day, which is 6.3% of the total water reserves (excluding the resources of the temporarily occupied territory of the Kherson and Zaporizhia regions, as well as the Autonomous Republic of Crimea). Production in the Dnipropetrovsk region of Southern Ukraine was 0.5% of 4.3% of underground reserves per day, in the Ukrainian-controlled territory of the Zaporizhzhia region – 0.2% of 2.1% of total reserves per day, in the Kherson region – 0.03% of 5.2% of total reserves per day, in the Mykolaiv region 0.1% of 0.6% of total reserves per day (State Statistics Service of Ukraine, 2024). In 2023, after the explosion of the Kakhovka HES, the situation in the Southern regions of Ukraine worsened due to the lack of groundwater discharge into the irrigation system of the Black Sea artesian basin. The use of groundwater for irrigation of agricultural lands completely disappeared from 2023 compared to the level of 2022 (-100%)

Table 2. Groundwater production and use in existing basins of Ukraine in 2021-2023, %.

Groundwater basins	Ground water extraction, %	Groundwater use, %				Groundwater discharge without use, %
		economic goals	production and technical goals	agricultural purposes	irrigation	
2021						
Hydrogeological province of the folded region of the Ukrainian Carpathians	16.1	15.6	18.3	74.4	76.5	5.9
Volyn-Podilskyi artesian basin	36.6	37.1	11.3	14.7	-	46.7
Ukrainian Shield Fractured Water Area	16.3	7.9	20.2	7.4	-	24.4
Dnipro-Donetsk artesian basin	13.4	15.1	6.7	6.2	1.8	1.8
Black Sea artesian basin *	11.6	8.4	7.3	5.4	2.4	14.2
2022						
Hydrogeological province of the folded region of the Ukrainian Carpathians (excluding the occupied Luhansk region)	4.3	4.2	6.4	-	100	1.2
Volyn-Podilskyi artesian basin	50.3	52.9	22.1	15.2	-	59.3
Ukrainian Shield Fractured Water Area	8.3	80.2	34.0	6.7	0.7	13.2
Dnipro-Donetsk artesian basin	20.6	20.5	17.7	2.9	1.2	22.9
Black Sea artesian basin (regions are distinguished: Kherson (de-occupied territory), Zaporizhia (controlled territory of Ukraine), Mykolaiv, Odessa)**	2.6	2.6	4.6	4.1	1.3	0.1
2023						
Hydrogeological province of the folded region of the Ukrainian Carpathians (excluding the occupied Luhansk region)	3.4	3.1	6.3	-	27.4	1.5
Volyn-Podilskyi artesian basin	27.1	20.3	5.5	15.7	-	22.6
Ukrainian Shield Fractured Water Area	18.4	14.6	38.0	3.4	0.3	3.3
Dnipro-Donetsk artesian basin	22.0	17.3	16.7	0.2	0.1	19.7
Black Sea artesian basin (regions are distinguished: Kherson (de-occupied territory), Zaporizhia (controlled territory of Ukraine), Mykolaiv, Odessa)**	2.9	2.9	4.5	-	-	0.1

Source: built by expanded by data (Ministry of Development of Communities, Territories and Infrastructure of Ukraine, 2023).
Note: * - excluding the resources of the temporarily occupied territory of the Autonomous Republic of Crimea, ** - excluding the resources of the temporarily occupied territory of the Kherson and Zaporizhia regions, as well as the Autonomous Republic of Crimea

(Ministry of Development of Communities, Territories and Infrastructure of Ukraine, 2023).

Table 2 presents the dynamics of changes in groundwater production and use in existing basins of Ukraine, with a focus on the share of territories in those regions of the South of the country that are de-occupied and suffer from constant shelling by the aggressor country.

Before the full-scale war, the Kherson region, a leading region in the production of grain, sunflower, vegetables and melon crops, was one of the largest exporters of agricultural products in Ukraine. Now agriculture in this region needs help. The

Table 3. Estimated cost of the drip irrigation project for agricultural crops under the support of the EIB and European funds for 2023-2024.

Crop	Arable land area, thousand ha	Forecast yield increase, tons/ha	Average rate of return on advanced capital, %	Discount rate, %	Forecast project cost (investment amount), million EUR
Winter wheat	250	2.2	25.0	30.5	1871.0
Soybean	150	1.9	45.0	40.5	969.5
Sunflower	100	1.1	110.0	73.0	687.0
Cucumbers	20	15.0	100.0	68.0	188.3
Total	520	x	x	x	3715.8

Source: calculated by the authors

Table 4. Economic efficiency results from the implementation of the drip irrigation project under the support of the EIB and European funds for 2023-2024.

Crop	Net present value, million EUR	Net present value per 1 ha, EUR	Discounted payback period, months	Profitability index
Winter wheat	2098.9	8395.6	53	1.12
Soybean	655.2	4368.0	93	0.68
Sunflower	897.4	8974.0	45	1.31
Cucumbers	9574.4	47872.0	4	50.85
Total	13225.9	25434.4	16	3.56

Source: calculated by the authors

Table 5. Simulation analysis of crop yields and in general by crop rotation, 2023-2024.

Indicators	Winter wheat	Post-harvest corn	Potatoes	Grain corn	Buckwheat	Spring barley	Grain corn	Green peas	Winter wheat	Average value by crop rotation
Option #1 (without irrigation)										
Mean	60.4	32.2	50.6	59.0	8.7	29.8	89.1	222.8	58.7	50.6
Standard deviation (error)	0.9	1.8	5.3	7.8	2.3	13.4	17.5	53.6	3.9	5.8
Coefficient of variation	0.015	0.056	0.106	0.133	0.259	0.087	0.196	0.241	0.067	0.115
Minimum	57.6	26.5	33.6	34.1	1.6	26.6	33.8	53.1	46.2	32.1
Maximum	63.2	37.8	67.2	83.4	15.8	33.0	143.5	389.8	71.0	68.7
P(E<=0)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P(E<=MIH(E))	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008
P(M(E)+s<=E<=max)	0.158	0.158	0.158	0.158	0.158	0.158	0.158	0.158	0.158	0.158
P(M(E)-s<=E<=M(E))	0.341	0.341	0.341	0.341	0.341	0.341	0.341	0.341	0.341	0.341
Option #2 (irrigation with mineralized water)										
Mean	66.2	35.6	52.5	75.9	14.3	31.5	92.3	282.7	62.8	57.7
Standard deviation (error)	1.1	1.0	1.7	3.7	2.5	19.4	14.9	45.1	2.3	5.4
Coefficient of variation	0.017	0.029	0.032	0.049	0.173	0.120	0.161	0.159	0.036	0.094
Minimum	62.7	32.3	47.2	64.1	6.5	35.6	45.3	139.9	55.6	40.5
Maximum	69.7	38.9	57.7	87.6	22.0	42.2	138.6	423.2	70.0	74.6
P(E<=0)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P(E<=MIH(E))	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008
P(M(E)+s<=E<=max)	0.158	0.158	0.158	0.158	0.158	0.158	0.158	0.158	0.158	0.158
P(M(E)-s<=E<=M(E))	0.341	0.341	0.341	0.341	0.341	0.341	0.341	0.341	0.341	0.341

Source: calculated by the authors

aggressor country has turned the wealth of the Kherson region into deserts and burning places. All lands are 95% mined, agricultural enterprises are destroyed, agricultural machinery is burned and stolen, warehouses and production facilities are destroyed. However, after the de-occupation, agricultural enterprises immediately set about restoring their territory.

Farmers, risking their lives, began to enter the fields and demine the land on their own. The result is many cases of undermining agricultural enterprise workers in their fields. In 2022, the area of agricultural land in the territory of the de-occupied Kherson region is 520 thousand hectares, of which 56.4 thousand hectares (more than 10%) are demined. By the end of 2023 In the Kherson region, the total area of demined lands was approximately 50% of agricultural land. During this period, more than 60 thousand hectares of agricultural land were sown, of which 23.5 thousand hectares were of the grain group, as well as 35.7 thousand hectares of industrial crops, of which 31.7 thousand hectares were sown with sunflower.

Harvesting due to the lack of grain-harvesting equipment was longer than the usual technological cycle. This affected the quality and quantity of harvested grain. In 2023, agricultural enterprises harvested grain and leguminous crops from an area of 16.7 thousand hectares; 46.1 thousand tons were threshed, with an average yield of 27.6 c/ha, of which 27.6 thousand tons of wheat were harvested, with a yield of 30.0 c/ha, barley – 16.0 thousand tons, with a yield of 25.6 c/ha. In addition, rapeseed was harvested on an area of 2.43 thousand hectares, and 4.0 thousand tons were threshed with a yield of 16.4 c/ha (State Statistics Service of Ukraine, 2024).

In the pre-war period, vegetable and melon crops were grown in the Kherson region on an area of over 60 thousand hectares. Now only 2.6 thousand hectares remain under these crops. That is, the Kherson region, before the invasion of the aggressor country into its territory, fully met the needs of consumers on the domestic market. Today, vegetable products are supplied to Kherson from other regions. Retail chains have mainly already reoriented to products from the Odessa and Mykolaiv regions or EU countries. The problem is that the main producers of vegetable crops were enterprises of the left-bank Kherson region, which is currently occupied. That is, this is 90% of the area – 40 thousand hectares of vegetable crops and 21 thousand ha of melon crops. In the de-occupied territory of the right-bank Kherson region, there are only 200 hectares of land plots for vegetable crops (products are grown by households). Unfortunately, large-scale production of vegetables at enterprises is not carried out (Ministry of Agrarian Policy and Food of Ukraine, 2023).

DISCUSSION

Studying the potential for the development of the agricultural sector in the affected regions of Southern Ukraine in the context of inventing measures to restore the irrigation system is objective for several reasons. First, using filtration calculation methods, the parameters of the filtration flow of the irrigation system, which enters the underground horizons and affects soil fertility, are determined. Therefore, from the standpoint of protecting irrigation system structures, it is recommended: first, to use specific algorithms of logarithmic configurations that allow determining potential risks of soil contamination and crop yield loss; second, to assess the condition of irrigation system facilities from the standpoint of an individual approach to determining their impact on the efficiency of using crop rotations on agricultural lands (i.e., their level of pollution after the ecological disaster – the explosion of the Kakhovka hydroelectric power station), as a critical environment for bioresources. Within the framework of the external regional policy of the agricultural sector of Ukraine, as a candidate country for accession to the EU, support from the EU countries is provided through the Instruments of Preparation for Accession. Therefore, the stabilization of the regional policy of the agricultural sector in the de-occupied territories of Southern Ukraine with the support of the Common Agricultural Policy of the EU countries is seen, in our opinion, through certain instruments (Figure 4).

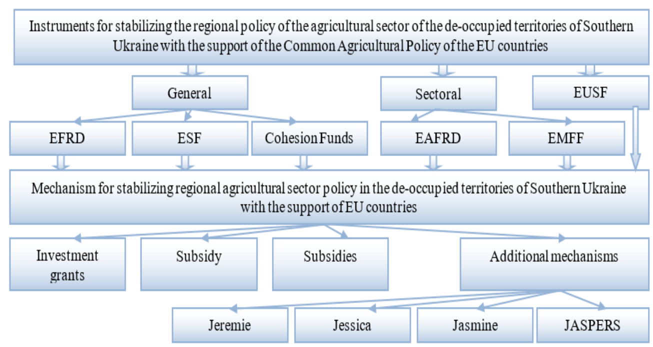

Figure 4. Stabilizing agricultural policy in de-occupied Southern Ukraine with EU CAP support.

Source: constructed by the authors based on data (The European Parliament and the Council, 2022; OECD, 2023; Wishlade et al., 2014).

The collapse of the Kakhovka hydroelectric power station dam caused Ukraine losses of over 12.1 billion EUR, the restoration of which requires 5.53 billion EUR. The tragedy led to the flooding of 620 km^2 of land within the Kherson and Mykolaiv regions. During the restoration of these territories, it is necessary to adhere to the principle of "rebuild better than before". The largest number of financial resources should be invested in the energy and housing sectors of the economy of the Southern zone of Ukraine. In 2023-2024, 1.82 billion EUR was invested in these territories (in housing, water supply and sanitation) (Figure 5).

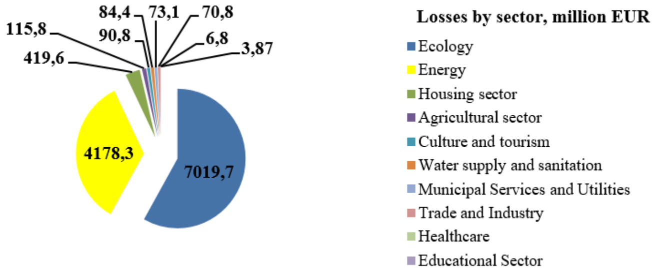

Figure 5. The amount of damage in the de-occupied regions of Southern Ukraine in 2023, million EUR.

The ecosystem of Kherson and Mykolaiv regions in Southern Ukraine suffered losses of 7.1 billion EUR. This money is needed for demining, cleaning, surveying and assessing contaminated areas. In addition, 37 thousand houses were damaged in 2023. These are mainly private households in suburban areas and rural areas, 15% of which are beyond repair. The amount of damage is estimated at 1.2 billion EUR. More than 1.7 billion EUR is needed to use a "green" approach (housing restoration and social services).. Meanwhile, the tragedy at the Kakhovka hydroelectric power station significantly affected the agricultural sector of Southern Ukraine: damage to the agricultural and fishing sectors is estimated at 406.6 million EUR, and the lost harvest due to irrigation disruptions reached 413.0 million EUR. This sector of the economy can be restored in just ten years and for 197.3 million EUR (Figure 6).

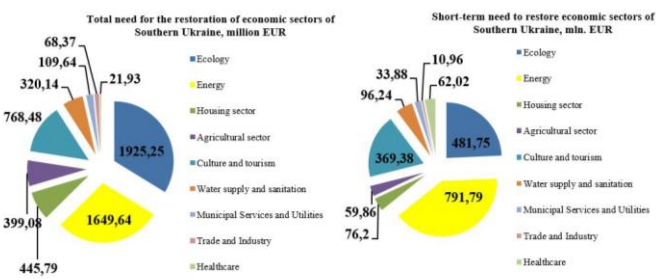

Figure 6. General and short-term needs for the restoration of economic sectors in 2023-2024, million EUR.

The developed program for the restoration of the Kakhovka HES provides for three stages: immediate restoration for 2023-2024, medium-term – for 2025-2030, long-term – until 2033. A significant problem is limited access to territories not controlled by the country on the left bank of the Dnipro River, which affects the assessment of the extent of damage and the comprehensive restoration of damaged agricultural infrastructure. Attention in the short term is focused on ensuring the return of displaced people and improving social infrastructure in rural areas. Immediate restoration is required for such basic services as electricity and gas supply, as well as preventing further damage to biological resources and cultural heritage. Investment needs at this stage are approximately 1.99 billion EUR; 2.46 billion EUR is provided for the restoration of territories in the medium term (housing sector, energy and infrastructure of agriculture, fisheries). In the long term, the restoration of the cultural and energy sectors is envisaged – 1.07 million EUR. It must be recognized that in the pre-war period, that is, in 2021, the contribution of the Kherson region to the country's GDP was 1.6%, Mykolaiv – 2.3%, Zaporizhia – 4.2%, Dnipropetrovsk – 10.7%. The largest sectors of the Kherson region's economy were agriculture, processing industry and trade. The region provided more than half of the rice production in Ukraine (57.7%), as well as significant shares in the cultivation of eggplants (39.2%), melons (33.5%) and tomatoes (27.3%), the cultivation of grain crops, in particular wheat and barley (29.2%), sunflower (13.0%) (State Statistics Service of Ukraine, 2024). During wartime, the regulatory policy of the agricultural sector of the de-occupied territories of Southern Ukraine (especially the Kherson region) is based on the Common Agricultural Policy of the EU countries, which is the country's first approach to supporting and restoring agriculture through grant financial assistance. But in a broader format, the indicators for assessing agricultural support in the de-occupied territories of the Kherson region should compare domestic and European prices, with the determination of the level of taxation or subsidizing of producers.

Using quantitative indicators of state support for the agricultural sector, used by OECP to compare and determine the degree of state influence on the agricultural market, a vector of national regulatory policy has been determined to neutralize environmental and economic challenges in agricultural production in the de-occupied territories of the Kherson region in southern Ukraine (OECP, 2024). It is aimed at restoring the irrigation system, exchanging and regenerating agricultural lands, restoring agricultural infrastructure, with the help of grant support from EU countries to increase the volume of the agricultural market (Figure 7).

The Government of Ukraine is closely cooperating with the European Investment Bank (EIB) and European funds to attract grant resources for the implementation of infrastructure, energy, environmental and investment projects (including irrigation projects for the revival of agriculture in the de-occupied territories of the Kherson region in the South of the country), (Ministry of Finance of Ukraine, 2023a).

In the third quarter of 2024, the total amount of financial resources provided by the EIB and European funds in Ukraine, both in the public and private sectors (including the agricultural sector), is more than 8.22 billion EUR. The project portfolio of the EIB and European funds in the public-private (agricultural) sector of Ukraine is 26 projects – 5.81 billion EUR. Of these, 23 projects are being implemented – 5.28 billion EUR. Within the framework of the implementation of these projects in the third quarter of 2024, 3123.45 million EUR were selected, in 2023 – 286.97 million EUR and in 2022 –1888.63 million EUR. In addition, as of the 3rd quarter of 2024, 2 projects are under implementation, which are intended to expand assistance for the restoration of the irrigation system of Southern Ukraine, – 19.86 million EUR, financed by the E5R Fund Grant (E5R Fund Administrator – EIB), of which 9.17 million EUR has already been selected (Ministry of Finance of Ukraine, 2024).

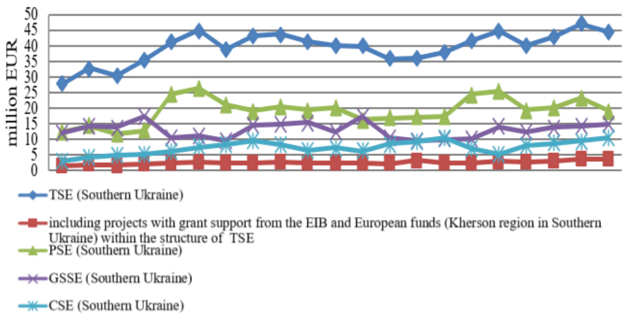

Figure 7. Grant support from the EIB and TSE for 2022-2024, million EUR.

Source: calculated based on data (National Bank of Ukraine, 2023; Ministry of Finance of Ukraine, 2023a; European Investment Bank, 2024).

According to the relevant indicators, comparative values of the coefficient of nominal support for agricultural producers (EPC) of the Kherson and Mykolaiv regions in the South of Ukraine were calculated, which involves the use of (the ratio between the gross income of producers at the gate (taking into account support) and the gross income at border prices (adjusted to the level of prices at the gate of producers)) and the coefficient of nominal protection of producers (EPR), which is defined as the ratio between the average price received by producers at the gate (taking into account payments per ton of current production) and the price at the border (adjusted to the level of prices at the gate of producers) (Figure 8).

It should be noted that the coefficients of support and protection of agricultural producers have a multidirectional differentiation in regional policy between the de-occupation territory of the Kherson and Mykolaiv regions for the period under study. The level of support for agricultural producers of the Kherson region since 2024 exceeds the threshold within 13-14% compared to the Mykolaiv region; the level of targeted protection and real financial assistance from European partners exceeds the permissible threshold within 2% to 11% compared to the Mykolaiv region, in which this indicator does not reach the value of 1.0.

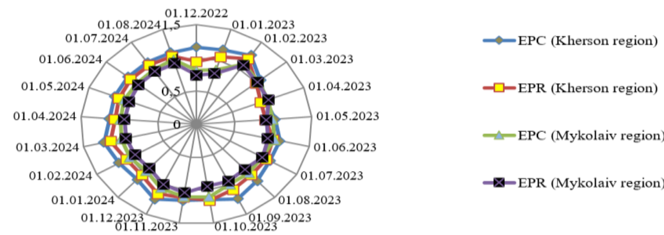

Figure 8. Support (EPC) and protection (EPR) coefficients of agricultural producers of Kherson and Mykolaiv regions of Southern Ukraine for 2022-2024.

Source: calculated based on data (National Bank of Ukraine, 2023; Ministry of Finance of Ukraine, 2023a; European Investment Bank, 2024).

The destruction of the dam and the emptying of the Kakhovka reservoir caused a number of significant problems with water supply in the southern regions of Ukraine, including, in addition to the direct destruction of structures and energy infrastructure, lack of access to water supply facilities, the washout of toxic substances and biological contamination of water, the washout of pesticides from fields, the destruction of warehouses for various purposes, dehydration and redistribution of water in the region. The Kherson region is characterized by an arid climate and is largely dependent on the irrigation system for agriculture. The government’s firm position under the Common Agricultural Policy with the EU on supporting the de-occupied territory and restoring the irrigation system allows for addressing the environmental and economic challenges of agricultural production, as well as pursuing a balanced policy on implementing climate-oriented agriculture within the framework of regional environmental protection programs and EU grants, rebuilding a new Ukrainian village, and “conserving” the production of agricultural raw materials (products) with low added value.

As part of the financing of one irrigation project from the EIB and European funds, data on assessing the quality of irrigation water use in arid soil and climatic conditions of the Kherson region are presented and the results of ecological and economic efficiency from the project implementation are summarized (Ministry of Finance of Ukraine, 2023b). The project implementation is based on drip irrigation technology to obtain an economic effect while simultaneously reducing the anthropogenic load on the ecosystem of the de-occupied territories. The development of a drip irrigation system project considers the analysis of the irrigation source, which involves assessing the quality of natural (surface and groundwater) waters according to agronomic, environmental and technical criteria in accordance with national standards in force in Ukraine. According to these standards, irrigation water is divided into three classes: I (suitable), II (limitedly suitable), III (unsuitable). Class I water can be used for irrigation without any restrictions, while the use of class II water involves the application of measures to prevent soil degradation or improve water to class I. Class III irrigation water can be used only after improving its quality indicators to class II or I (Kucher et al., 2018).

The methodology for economic justification of the irrigation project involves determining the average yield indicators of each of the studied agricultural crops and calculating its potential increase after installing a drip irrigation system based on average data. The estimated total cost of the project is 3715.8 million EUR. The expected additional profit is calculated based on the additional income that agricultural producers will be able to receive from the increase in yield after the implementation of drip irrigation systems. Depreciation is determined using the straight-line method in accordance with the project life cycle, which is five years. The discount rate is calculated based on the weighted average data between the profitability of the advanced capital and the loan investment rate from the EIB (22.0%), considering the forecast inflation (7.0%). The profitability of the advanced capital is determined for each agricultural crop, considering the actual average indicators. In 2023 the average cost of a drip irrigation system is 7145.77 EUR/ha. Considering the actual composition and structure of arable land, as well as market conditions, the project envisages the cultivation of four crops (wheat, soybeans, sunflowers and cucumbers) on an area of 520 thousand ha (Table 3).

The generalized results of the calculation of discounted indicators of approximate economic efficiency (Table 4) indicate the efficiency of the proposed drip irrigation project. At the same time, in terms of specific types of products, the analyzed efficiency indicators turned out to be quite different, which indicates a different level of investment attractiveness of drip irrigation. Thus, the most effective may be the cucumber drip irrigation project, while the soybean drip irrigation project may be ineffective under current investment conditions.

The assessment of the economic efficiency of using drip irrigation in agriculture of agricultural producers of the Kherson region, who have restrictions on access to groundwater during the cultivation of various crops, was carried out using the Monte Carlo method and simulation modeling of crop yields was performed under two project options: 1) without irrigation (without an irrigation project); 2) under conditions of irrigation with mineralized water (under an irrigation project). The results of statistical analysis confirmed the hypothesis that the model sample corresponds to the normal distribution of crop yields both in the option without an irrigation project and in the option with an irrigation project (Table 5).

However, as we observe, the economic efficiency of different crops does not have the same amount of additional profit (loss) from yield increase compared to the control per 1 ha of area (Figure 9).

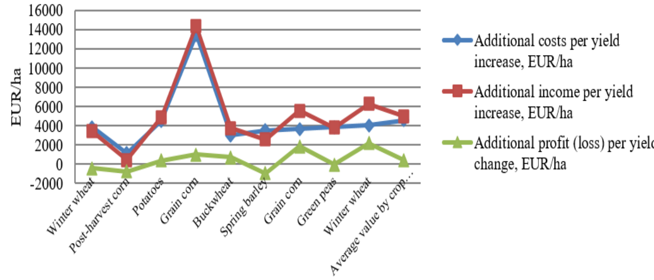

Figure 9. Additional profit (loss) from yield increase at the minimum value compared to one ha of sown area and one crop rotation, 2023-2024, EUR/ha.

Source: constructed by the authors

Thus, in the case of a minimum yield increase from irrigation with mineralized water, the greatest additional profit can be achieved when growing winter wheat sown after peas for green mass (2221 EUR/ha), corn for grain after spring barley (1886 EUR/ha) and after potatoes (993 EUR/ha) at an average value for crop rotation of 450 EUR/ha. At the same time, growing spring barley, post-harvest corn, winter wheat and peas for green mass turned out to be economically inefficient according to the criterion of additional profit per 1 ha of the corresponding area. The effectiveness of the implementation of the irrigation project with drip irrigation considers all possible ecological and economic risks, as well as the positive impact of irrigated water of class I on the condition of soil and technical irrigation systems. The use of drip irrigation technologies can contribute to increasing crop yields and saving water irrigation in the face of climate change. Such a project can be used for small, medium and large agricultural producers.

***Conclusion*:** Armed conflict has severe environmental consequences, particularly for agriculture. The destruction of infrastructure, such as the Kakhovka dam failure, leads to loss of fertile land, water shortages, and ecological imbalance, threatening food security in Ukraine's de-occupied territories. To rebuild the agricultural sector, policies must focus on resilience, adaptation to EU regulations, and export facilitation. Key financial measures should include extending the "Affordable Loans 5-7-9%" program, modifying grant conditions to support small and medium-sized agribusinesses, and providing one-time compensation for lost harvests. Support should also target individuals with land plots for personal farming and housing in affected regions. State incentives for family farms should be reinstated, alongside subsidies for farmers and water user organizations managing reclaimed lands. These subsidies should fund irrigation system restoration and modernization, ensuring efficient agricultural production amid climate challenges. Non-refundable financial aid should cover up to 25% of irrigation system costs and up to 50% for pumping station reconstruction. A comprehensive recovery strategy, backed by financial and regulatory support, is essential for revitalizing Ukraine's agriculture and securing long-term sustainability in the war-affected regions.

CRediT author statement: Yurii Ye. Kyrylov: Writing - Review & Editing, Methodology, Validation; Viktoriia Hr. Hranovska: Writing - Original Draft, Software; Liudmyla O. Alieshchenko: Conceptualization, Formal analysis, Investigation; Svitlana Yu. Bolila: Data Curation, Project administration, Resources; Yurii O. Prus: Supervision, Visualization.

Funding: Neither funds nor grants were received to support this article.

Consent to participate: Not applicable.

Consent for publication: All authors submitted consent to publish this research article in JGIAS.

Conflict of interest: All authors declare no conflict of interest related to this article.

SDGs addressed: Zero Hunger; Clean Water and Sanitation; Decent Work and Economic Growth; Industry, Innovation, Infrastructure; Climate Action.

Policy referred: National Regulatory Measures on Water and Land Use; EU Financial Instruments and Support Mechanisms; Environmental and Conservation Policies; Technological and Monitoring Policy Recommendations.

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