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Socioeconomic impact of the war on the hydropower sector of Ukraine

Abstract. The invasion of Ukraine on February 24, 2022, caused significant military damage to the hydropower sector, critical for energy security and economic development. The article provided an overview of the Ukrainian hydropower sector and the war's socioeconomic impact on it in 2022-2024. Based on open source data, the research focused on large and small hydropower facilities, examining their roles in electricity generation, stability of the unified energy system of Ukraine, and water supply. The authors' findings offer insights into the extent of damage for policymakers, scientists, and sector experts.

Keywords: Ukraine, war, socioeconomic impact, hydropower, damage

Introduction

The hydropower sector plays a significant role in ensuring energy security and economic development of Ukraine. However, following the large-scale invasion of Ukraine on February 24, 2022, the hydropower sector suffered significant losses. Hydropower facilities became targets of massive attacks, resulting in infrastructure damage and disruptions in operations. These impacts led to far-reaching consequences for the country's economy, energy security, social and environmental well-being.

Among the researchers studying the impact of the war on Ukraine's hydropower are D. Stefanyshyn, D. Benatov, P. Gleick, V. Kolodezhna, O. Vasyliuk, A. Shchepaniak, E. Sumskyy and others (Kolodezhna and Vasyliuk, 2022; Stefanyshyn and Benatov, 2023; Sumskyy, 2023; Gleick, Vyshnevskyi and Shevchuk, 2023; Shchepaniak and Bazaka, 2024). They focus on particular cases of military attacks on hydropower infrastructure, particularly the small or large hydropower sector. There is a significant gap in the literature regarding a comprehensive overview of war's impact on both small and large hydropower. The study provides an analysis of the effects of the war on the hydropower sector in Ukraine. This research aims to provide a comprehensive overview of the

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hydropower sector of Ukraine, as well as the socioeconomic impact of the war on it between February 2022-May 2024. Its findings yield valuable insights for developing strategies to support the sustainable recovery and development of the Ukrainian hydropower sector.

Methods and data

The investigation utilized data from open data sources publicly available during the research period, including scientific studies, information from official government websites, articles in government journals, and reports from international and financial organizations. Access to comprehensive data on military attacks on Ukraine's hydropower sector was limited due to wartime security concerns.

Research results

The hydropower sector in Ukraine: a pre-war overview

The hydropower sector plays a crucial role in electricity generation and in fulfilling a variety of additional vital functions, such as ensuring the stability of the unified energy system and water supply of Ukraine.

Before the large-scale invasion on February 24, 2022, Ukraine had a well-developed hydropower infrastructure. The hydropower sector covered a variety of facilities, including (Stefanyshyn, 2019):

- large hydropower plants (HPP) with a capacity exceeding 10 MW,
- pumped storage power plants (PSPPs),
- small hydropower plants (SHPPs) with a capacity of less than 10 MW.

Ukraine's hydropower sector was formed by ten large hydropower plants (HPPs) with massive dams. In addition, the country had three pumped storage power plants (PSPPs), (Ukrhydroenergo, 2024).

The map of Large Hydropower Plants (HPPs) and Pumped Storage Power Plants (PSPPs) across the country is presented in Figure 1. It highlights the concentration of large HPPs along major rivers, particularly the Dnieper, the Dniester, the Southern Buh, and the Terebla Rivers.

The map is dominated by the Dnieper Cascade – a series of six reservoirs formed by dams on the Dnieper River. These dams are associated with the following large hydropower plants (HPPs): Dnipro HPP, Kakhovka HPP, Kaniv HPP, Kremenchuk HPP, Kyiv HPP, and Serednodniprovska HPP (Details regarding these HPPs and their reservoirs are provided in Table 1). This cascade extended for about 900 kilometres with a total reservoir water volume of 43,83 cubic kilometers. Together, these facilities accounted for 90.8% of the water volume of all large reservoirs in Ukraine (Zaporizhzhia State Administration, 2024).

To further explore the characteristics of Ukraine's large hydropower plants, table 1 provides specific information regarding each station and reservoir (Table 1).

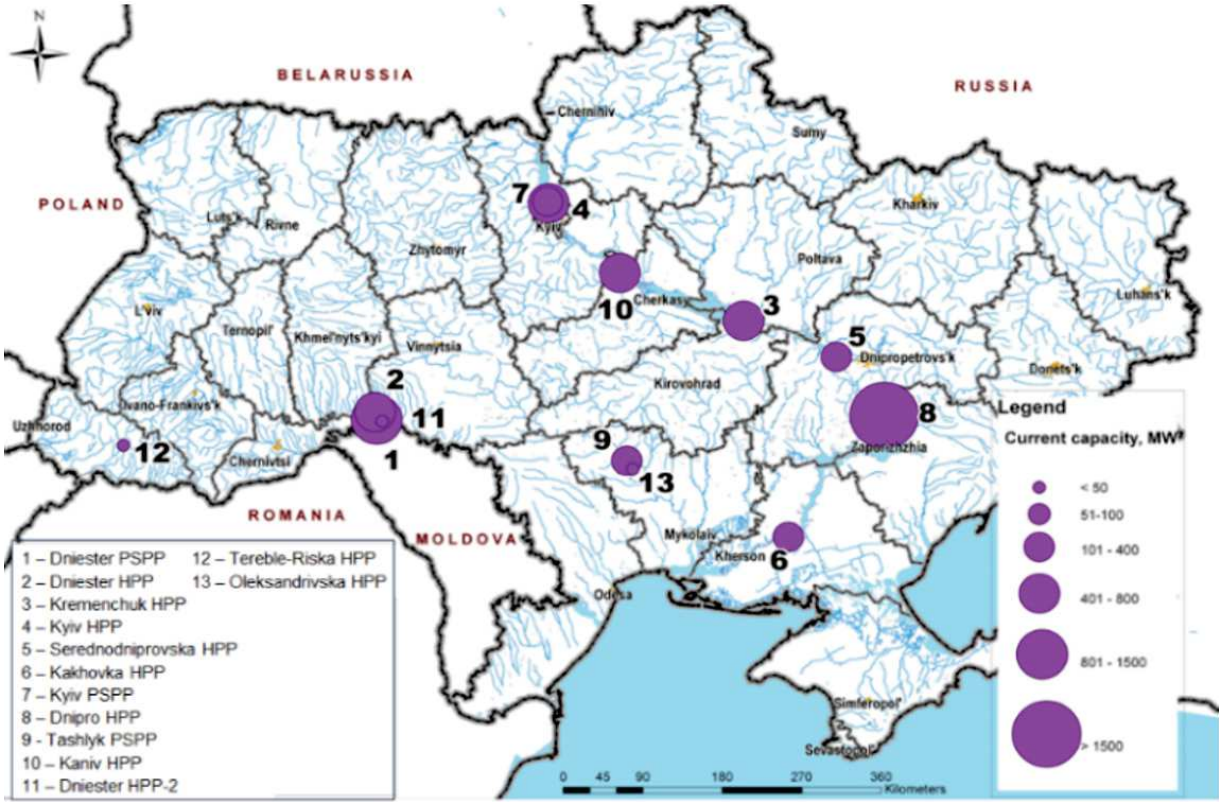


Figure 1. Large Hydropower Plants and Pumped Storage Power Plants by Capacity, Ukraine
Source: WWF (2021).

Table 1. Characteristics of 10 large HPPs in Ukraine (as of February 24, 2022)

Name of Hydropower Facility	Reservoir name	Installed power (MW)	Reservoir volume (cubic kilometers)
Dniester HPP	Dniester Reservoir	702	2.0
Dnister HPP-2		40.8	
Oleksandrivska HPP	Oleksandrivske Reservoir	25	~ 0.1
Tereble-Riska HPP	Vil'shans'ke Reservoir	27	0.24
HPPs included in the Dnieper Cascade			
Dnipro HPP	Dnieper Reservoir	1578.6	3.32
Kakhovka HPP	Kakhovka Reservoir	334.8	18.20
Kaniv HPP	Kaniv Reservoir	500	2.63
Kremenchuk HPP	Kremenchuk Reservoir	700.4	13.50
Kyiv HPP	Kyiv Reservoir	440	3.73
Serednodniprovska HPP	Kamianka Reservoir	388	2.45
Total		**4736.6**	**46.17**

Source: compiled based on data from Ukrhydroenergo, Energoatom, Zakarpattia Administration.

In Ukraine, small hydropower plants (SHPPs) include hydropower facilities with a capacity of up to 10 MW (State Agency for Energy Efficiency and Energy Saving of Ukraine, 2024). According to the State Agency for Energy Efficiency and Energy Saving of Ukraine, these small hydropower facilities are further categorized based on their power output:

- Small Hydropower Plants: 1-10 MW capacity,
- Mini-Hydropower Plants: 200 kW to 1 MW capacity,
- Micro-Hydropower Plants: Up to 200 kW capacity.

Since 2009, Ukraine has implemented a preferential "green" tariff to promote hydropower development. This initiative has led to a substantial increase in the number of small hydropower facilities. According to WWF data, as of the end of 2020, Ukraine had 169 SHPPs operating under the green tariff (WWF, 2021). The majority of these SHPPs were located in the Khmelnytskyi region – 30 SHPPs, Vinnytsia region – 28 SHPPs and Ternopil region – 19 SHPPs, while only a few SHPPs were observed in the east. More detailed information is presented on the map: "Distribution of SHPPs eligible for the green tariff by regions, Ukraine" (Figure 2).

At the beginning of 2022, Ukraine had 177 SHPP with a total installed capacity of 120 MW (International Energy Charter, 2023).

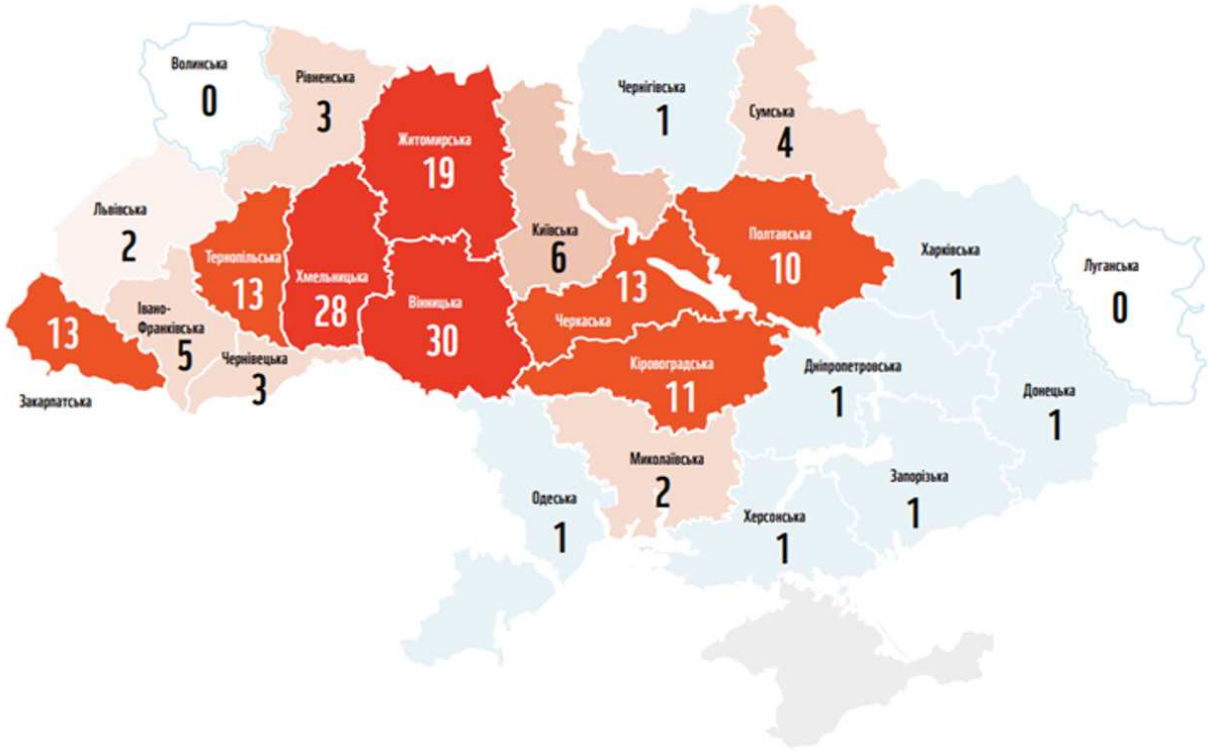


Figure 2. Distribution of SHPPs eligible for the green tariff by regions, Ukraine

Source: WWF (2021).

The role of hydropower in Ukraine

The hydropower sector plays a crucial role in electricity generation and ensuring the stability of the unified energy system and water supply of Ukraine.

Ukraine's hydropower sector had a significant installed capacity. The total installed capacity of HPPs and PSPPs in the United Energy System of Ukraine was 7350 MW (Ukrhydroenergo, 2024). According to the International Energy Agency (IEA), the amount of electrical energy generated from hydropower in Ukraine was 6,5% of total electricity production in 2021 (IEA, 2024; Figure 3).

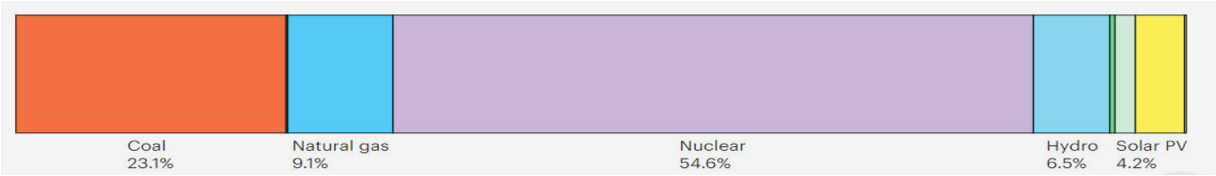


Figure 3. Electricity generation sources, Ukraine 2021

Source: IEA (2024).

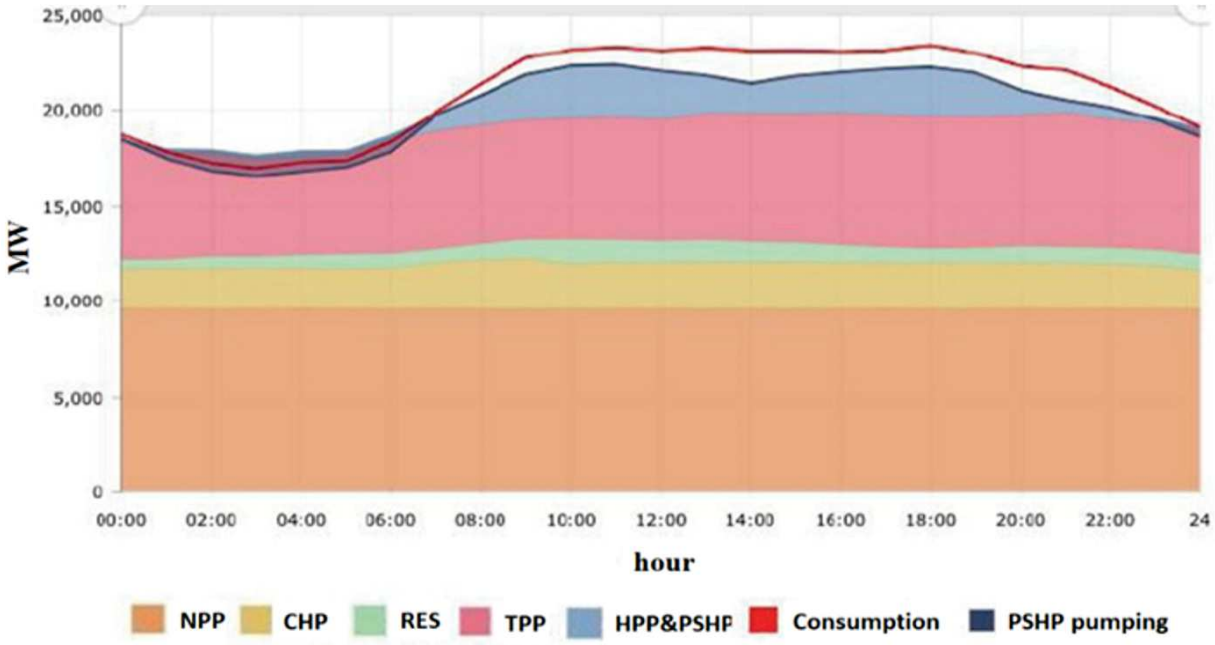
Among the most powerful of Ukraine's HPPs was the Dnipro Hydropower Plant (Dnipro HPP). Dnipro HPP boasted an installed capacity of 1578,6 MW as of February 2022.

Despite the potential of small hydropower plants (SHPPs) to contribute to Ukraine's energy balance, their current role remains limited. SHPPs accounted for only 0.1% of the country's total electricity production in 2021 (International Energy Charter, 2023). This figure reflects the installed capacity of these power plants, which was approximately 120 MW.

Hydropower plays a significant role not only in terms of electricity production in Ukraine. Potashnyk S. emphasizes that hydropower in Ukraine also plays a crucial role in ensuring the stability of the national Unified Energy System. It provides the system with highly maneuverable capabilities to regulate daily load profiles, covering peak demands and filling night slumps. Additionally, hydropower serves as an emergency reserve of electricity (Potashnyk, 2014).

According to Ukrhydroenergo, pumped storage hydropower plants (PSHPs) are pivotal in covering peak loads during morning and evening consumption peaks in Ukraine. They pump water at night and utilize it during the day for electricity generation, as shown in Figure 4.

It is important to highlight another significant role of hydropower in Ukraine – addressing the tasks of providing water supply to the population and industry, water transportation, irrigation, fisheries, and recreation. For instance, during an interview with the governmental newspaper "Uryadovy Kuryer", Landau Y. emphasized that thanks to the water resources of the Dnieper River with a cascade of hydropower reservoirs, water



NPP – Nuclear power plant
CHP – Combined Heat and Power
RES – Renewable energy source
TPP – Thermal power plant
HPP – Hydroelectric power plant
PSHP – Pumped storage power plant

Figure 4. Daily Electricity Production / Consumption Schedule for 08.02.2021

Source: Ukrhydroenergo (2024).

supply is ensured for the population, industry, agriculture, and irrigation in areas where nearly 70% of Ukraine's population resides (Uryadovy Kuryer, 2023).

As mentioned earlier, hydropower reservoirs are essential in water resource management. These reservoirs serve as vital sources for various water-dependent activities. The Kakhovka HPP had the largest reservoir volume in Ukraine. At the start of the war in February 2022, the Kakhovka Reservoir contained an impressive 18,18 cubic kilometers of water. This capacity illustrates the significant water storage capabilities of Ukrainian reservoirs.

Impacts of the war on the large-scale hydropower sector in Ukraine

As a result of military operations, colossal damage was caused to the large hydropower sector of Ukraine. The harm to large hydropower plants (HPP) during the war was not fully disclosed due to security concerns. However, open-source intelligence, including expert reports and images, demonstrates extensive demolition of dams, power plants, and other infrastructure (Gleick et al., 2023).

Since the start of the full-scale invasion, attacks have targeted most of Ukraine's large hydropower plants, with some plants controlled by the Russian occupiers, such as the Kakhovka HPP (Vasilyuk and Simonov, 2022). In chronological order, the most significant military attacks on the main facilities of Ukraine's HPP, information about which is publicly available, are listed:

- 2023, June 6. The enemy attacked the Kakhovka HPP (Stefanyzyn and Benatov, 2023),
- 2024, March 21. It was an attack on the Dnipro HPP. As the general director of Ukrhydroenergo Ihor Syrota noted, 20% of Ukrhydroenergo's regulating capacity was lost due to damage to Dnipro HPP. Damage assessments are ongoing. (Tunyk-Friz, 2024),
- 2024, March 29. The enemy attacked the Dniester HPP and the Kaniv HPP (Tarasovsky, 2024).

The most disastrous impact on the hydropower sector of Ukraine was experienced on June 6, 2023, when the dam of the Kakhovka HPP was destroyed due to military operations. The destruction of the dam had significant long-term socioeconomic consequences, particularly:

- significant economic losses: the Ukraine Rapid Damage and Needs Assessment report states that "approximately US$ 2.79 billion in direct damage to infrastructure and assets as a result of the event and losses exceeding US$ 11 billion" (World Bank et al., 2024),
- social and environmental threats: among the main threats were the flooding of the surrounding territories, fossil and industrial facilities, environmental pollution (Greenpeace, 2023), significant loss of water resources, energy generation, and balancing (Stefanyzyn and Benatov, 2023). The flooding affected 100 000 residents (World Bank et al., 2024). The flooding and pollution caused the death of many plant and animal species, harming the region's biodiversity. Approximately 10 000 hectares of agricultural land were lost, irrigation was destroyed, and water supply was partially stopped in several affected areas (Shchepaniak and Bazaka, 2024).

Despite the enemy's regular attacks on the hydropower facilities of Ukraine and the damage caused, as of April 2024, the large hydropower facilities remain capable of covering peak loads (DiXi Group, 2024).

Impact of the war on small-scale hydropower sector in Ukraine

The full-scale invasion of Ukraine, which began in February 2022, has had a strong negative impact on the national small hydropower (SHPP) sector (Figure 5).

As of June 2023, 4% of all SHPPs in Ukraine had been destroyed or damaged as a result of military operations. An additional 1% of SHPPs were located on the territory that was no longer under the control of Ukraine (Kyiv School of Economics Institute, 2023).

The war also had a significant impact on the development of new SHPPs in the country. There has been a sharp decline in the construction of new SHPPs. In the two years, from 2022 to 2023, four new SHHPs received a green tariff. Despite the Carpathian region's high potential for SHPP development (Uryadovy Kuryer, 2023), most of the new SHPPs have not been constructed in this region.

The ongoing war in Ukraine has affected the small hydropower sector of Ukraine, especially in territories that have been and continue to be under temporary occupation or active hostilities, including Kyiv, Kharkiv, Luhansk, Donetsk, and Kherson regions

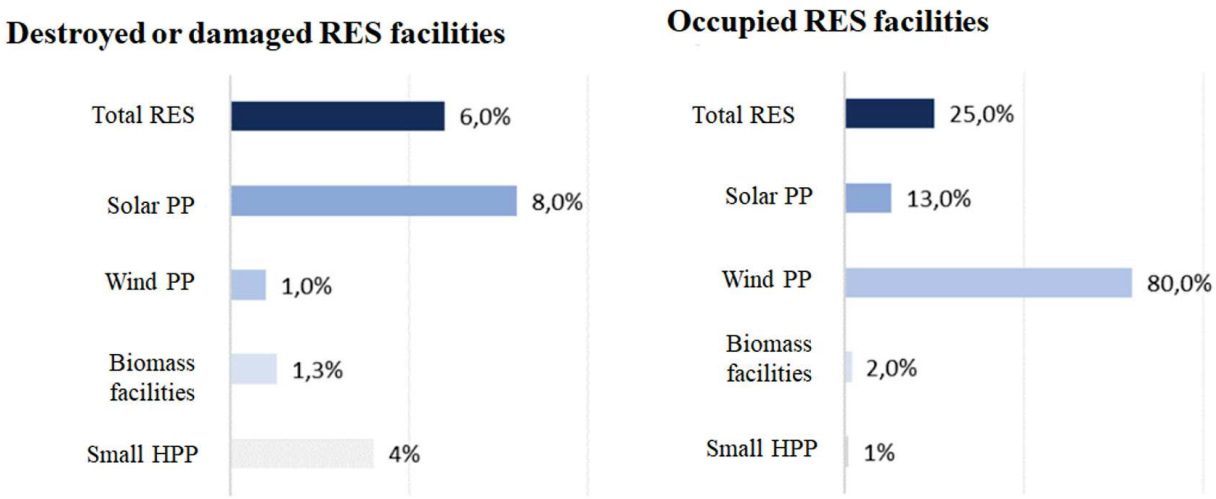


Figure 5. Number of damaged and occupied renewable energy sources as of June 2023

Source: International Energy Charter (2023).

(Sumskyy, 2023). Considering the security limitations imposed by the war, the full extent of the socioeconomic consequences of the destruction of Ukraine's SHPPs remains uncertain. However, the destruction of the dam of Oskil SHPP can be considered to illustrate the potential consequences.

Oskil SHPP is located in the Kharkiv Oblast on the Oskil River, a left tributary of the Siverskyi Donets River. Its capacity is approximately 4 MW. It stands on the Oskilsky Reservoir, constructed to ensure the water regime of the Siverskyi Donets – Donbas channel (Lystopad, 2024). As a result of military operations in 2022, the dams of several reservoirs along the Siverskyi Donets River, including the Oskilsky Reservoir dam, were damaged. It caused an artificial flood downstream (Gleick et al., 2023). A rapid release of approximately 0,36 cubic kilometers of water from the reservoir also impacted the Oskil SHPP's operation (Kolodezhna and Vasyliuk, 2022).

The destruction of the dam of Oskilsky Reservoir has far-reaching socioeconomic consequences, particularly:

- **significant economic losses:** preliminary estimates indicate that the losses caused by the destruction of the Oskilske Reservoir and related infrastructure amount to approximately 3.7 billion hryvnias (Lystopad, 2024);
- **social and environmental threats:** flooding of adjacent territories, loss of biodiversity, and disruption of energy and water supply systems have all contributed to increased disease risks, posing a significant threat to public health, particularly in vulnerable communities (Kolodezhna and Vasyliuk, 2022).

Conclusion

The war since February 2022 has significantly impacted the Ukrainian hydropower sector, resulting in far-reaching socioeconomic consequences. The destruction of both large and small hydropower facilities has posed substantial economic losses,

social disruptions, and environmental threats, including flooding of the surrounding territories, loss of water resources, disruption in energy generation and balancing, loss of biodiversity and environmental pollution, and a threat to public health. The loss of hydropower facilities will have long-term risks for the country's energy security and ability to meet future needs. Given the war's significant impact on Ukraine's hydropower sector, urgent and targeted measures must be taken to restore or replace damaged hydropower facilities. At the national level, a strategy needs to be developed to ensure the future sustainability of the hydropower sector, including strengthening infrastructure protection and introducing new technologies to balance the country's energy needs.

Literature

DiXi Group (2024). Prokhodzhennya osinno-zymovykh periodiv 2022-2024 rr. Stan enerhosystemy. Available online: https://dixigroup.org/analytic/prohodzhennya-osinno-zymovyh-periodiv-2022-2024-rr-stan-energosystemy (access: 29.08.2024).

Gleick, P., Vyshnevskyi, V., and Shevchuk, S. (2023). Rivers and water systems as weapons and casualties of the Russia-Ukraine war. Earth's Future, 11 (10). DOI: https://doi. org/10.1029/2023EF003910

Greenpeace (2023). Kakhovka flooding: Soil and water bodies may not be used for food production or as drinking water reservoirs for many years. Available online: https://greenpeace.at/cee-press-hub/significant-drop-in-water-levels-in-kakhovka-reservoir-risks-nuclear-safety (access: 29.08.2024).

IEA (2024). Sources of electricity generation. Available online: https://www.iea.org/countries/ukraine/electricity (access: 29.08.2024).

International Energy Charter (2023). Ukrainian energy sector evaluation and damage assessment. Available online: https://www.energycharter.org/fileadmin/DocumentsMedia/Occasional/2023_05_24_UA_sectoral_evaluation_and_damage_assessment_Version_X_final.pdf (access: 29.08.2024).

Kolodezhna, V., Vasyliuk, O. (2022). Should the Oskil Reservoir be rebuilt after the war? Ukraine War Environmental Consequences Work Group.

Kyiv School of Economics Institute (2023, June). Zvit pro pryami zbytky infrastruktury ta nepryami vtraty ekonomiky vid ruynuvan vnaslidok viyskovoyi ahresiyi Rosiyi proty Ukrayiny stanom na cherven 2023 roku.

Lystopad, A. (2024). Podviynyy zlochyn: v 50-kh radyans'ka vlada stvoryla Oskil's'ke vodoskhovyshche, znyshchyvshy vse zhyve navkolo things arou. Available online: https://ursamedia.com.ua/history/podvijnyj-zlochyn-chy-ponese-rosiyja-vidpovidalnist-za-ecozid-na-kharkivshuni (access: 29.08.2024).

National Energy and Utilities Regulatory Commission of Ukraine (2024). Register of electricity industry facilities and consumer power installations (including active consumers) using alternative energy sources for electricity generation.

Potashnyk, S. (2014). Current state, problems, and prospects of hydropower development in Ukraine. National Institute for Strategic Studies.

Shchepaniak, A. S., Bazaka, R. V. (2024). The Kakhovka Hydroelectric Power Plant disaster: Analysis of environmental and socioeconomic consequences and features of post-war recovery of the region. Materials of the II All-Ukrainian Scientific and Practical Conference, March 13, 2024

(p. 45-47): Publishing House of the National University of Bioresources and Nature Management of Ukraine. ISBN 978-617-8351-98-4.

State Agency for Energy Efficiency and Energy Saving of Ukraine (2024). Hidroenerhetyka. Available online: https://saee.gov.ua/uk/ae/hydroenergy (access: 29.08.2024).

Stefanyshyn, D. (2019). Feasibility analysis of construction of new hydropower plants in Ukraine taking into account the risk of unused possibilities. Environmental Safety and Natural Resources, 31(3), p. 33-45. DOI: https://doi. org/10.32347/2411-4049.2019.3.33-45

Stefanyshyn, D., Benatov, D. (2023). Katastrofa na Kakhovskomu vodoskhovyshchi: prychyny i naslidky, yaki ne obhovoryuyut. In Handbook of the XXI II International Science Conference "Ecology. Human. Society", p. 244-247. Available online: http://ecoconference.kpi.ua/article/view/296768/290287 (access: 29.08.2024).

Sumskyy, E. D. (2023). Analiz vplyvu viyskovykh podiy v Ukrayini na diyalnist malykh hidroelektrostantsiy ta sytuatsiya z prodazhu elektroenerhiyi za »zelenym taryfom«. Ukrainian Hydropower Platform.

Tarasovsky, Y. (2024). Tsilyamy Rosiyi tsiyeyi nochi buly Kanivska ta Dnistrovska HES. Forbes Ukraine. Available online: https://forbes.ua/news/tsilyami-rosii-tsiei-nochi-buli-kanivska-ta-dnistrovska-ges-zelenskiy-29032024-20221 (access: 29.08.2024).

Tunyk-Friz, V. (2024). Cherez poshkodzhennya DniproHES vtracheno blyzko 20% potuzhnostey Ukrhidroenerho. Ekonomichna Pravda. Available online: https://www.epravda.com.ua/news/2024/03/23/711535 (access: 29.08.2024).

Ukrhydroenergo (2024). Hidroenerhetyka [Hydropower]. Available online: https://uhe.gov.ua/diyalnist/gidroenergetika (access: 29.08.2024).

Uryadovy Kuryer (2023). Doktor tekhnichnykh nauk holovnyy radnyk PrAT „Ukrhidroproekt" Yuriy Landau: „U pislyavoyenniy perebudovi elektroenerhetyka, yak bazova haluz, vidihravatyme klyuchovu rol u stabilnomu zrostanni ekonomiky". Available online: https://ukurier.gov.ua/uk/articles/doktor-tehnichnih-nauk-golovnij-radnik-prat-ukrgid (access: 29.08.2024).

Vasyliuk, O. V., Simonov, Y. (2022). Hydroelectric dams as weapons: virtual and actual. Ukraine War Environmental Consequences Work Group. Available online: https://www.researchgate.net/publication/364677621_Hydroelectric_dams_as_weapons_virtual_and_actual (access: 29.08.2024).

World Bank, Government of Ukraine, European Union, and United Nations (2024). Ukraine Rapid Damage and Needs Assessment (RDNA3): February 2022 – December 2023. Available online: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099021324115085807/p1801741bea12c012189ca16d95d8c2556a (access: 29.08.2024).

WWF (2021). Onovlena infohrafika shchodo suchasnoho stanu maloyi hidroenerhetyky Ukrayiny (2017-2020).

Zaporizhzhia State Administration (2024). Diyi u razi proryvu hidrosporud Dniprovskoho kaskadu. Available online: https://zrda.gov.ua/dii_u_razi_prorivu_gidrosporud_dniprovskogo_kaskadu/ (access: 29.08.2024).