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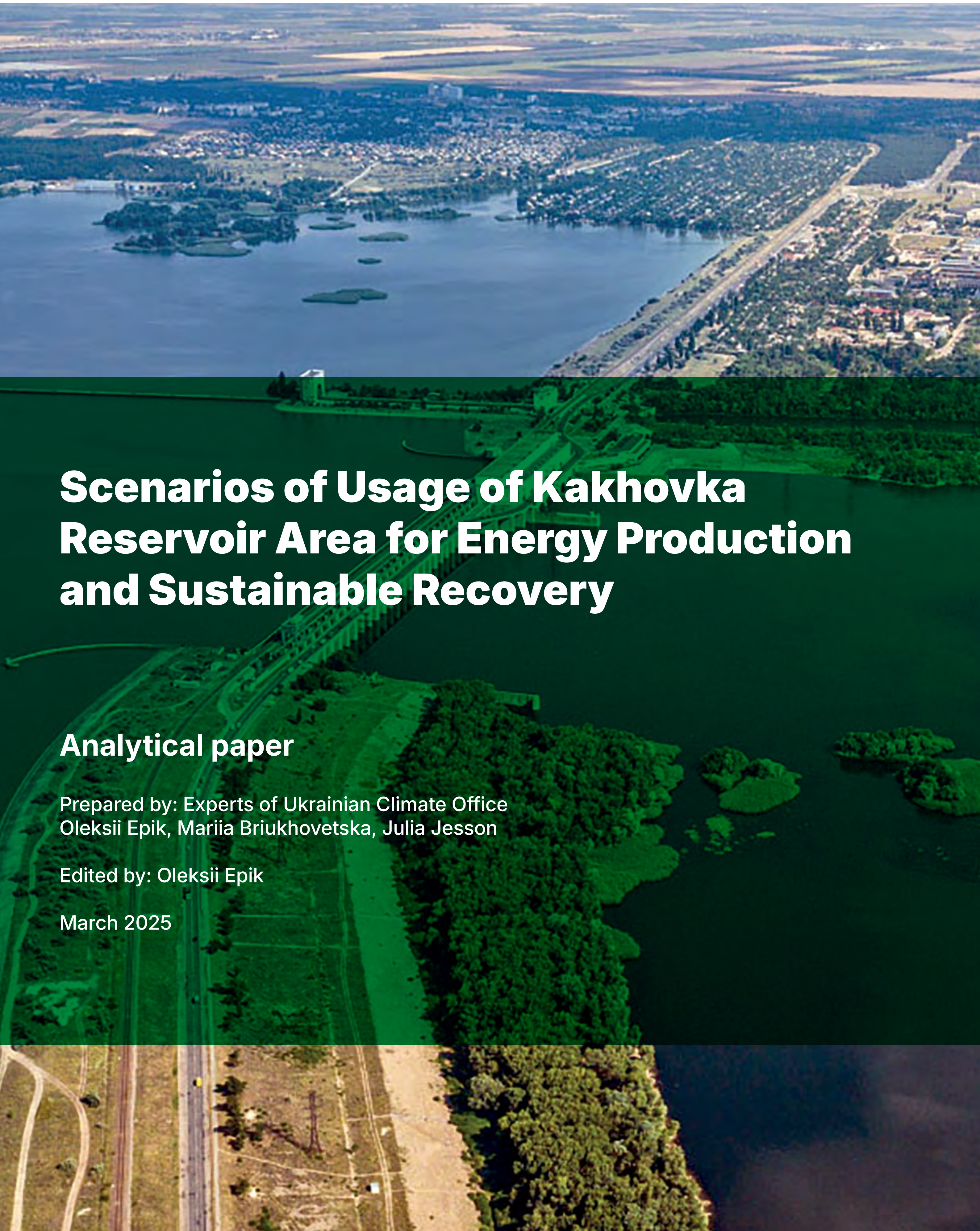

Scenarios of Usage of Kakhovka Reservoir Area for Energy Production and Sustainable Recovery

Analytical paper

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Acknowledgments

With the destruction of the Kakhovka Dam on 6 June 2023, Ukraine faced an unprecedented technogenic disaster in the 21st century, suffering devastating losses — man-made, environmental, economic, disruption of access to resources, especially water, displacement of residents, etc. While the expert community in Ukraine has worked to evaluate the extent of damage and determine the current state of the environment following the disaster another key aspect of research involves developing strategies for restoring the region, normalising economic activity and operations, and ensuring residents have access to essential public services.

At present, despite the large number of different analytics and data on the consequences of the disaster and initial recovery proposals, there is no comprehensive document containing an analysis of recovery concepts, options and scenarios, their schematic quantification, comparison with each other according to certain criteria, and conclusions on the acceptability of a particular recovery approach. This policy paper is the first attempt to put together the in-depth fragmented data on the vision of recovery from different expert groups studying the issue, to compare them impartially, and to draw preliminary conclusions on the most balanced concept of recovery based on the evidence for each and specific quantitative and qualitative assessment criteria.

The research philosophy is to simultaneously consider alternatives in terms of three basic, fundamental criteria:

1. Maximum benefit for communities: development of local potential, new jobs, development of infrastructure and production, creation of value chains for climate-neutral technologies, the possibility for communities to choose different types of local accessible energy, reduction of energy costs, assistance in overcoming energy poverty, decentralisation of energy supply, and increased security of energy supply.
2. Minimal damage to the environment: development of the region's ecosystem, promotion of biodiversity, avoidance of flooding of large areas, economic activity based on the criteria of sustainability and green recovery, circular economy, increased efficiency or reduced use of natural resources.
3. Addressing public needs at the level before the dam was blown up: water supply, access to food, access to energy, transport, local natural resources, and recreation.

In the process of working on the document, the team of the Ukrainian Climate Office involved various expert groups in the development and provision of initial data. A roundtable discussion was held with more than 35 experts with different views on restoration. The Ukrainian Climate Office and the authors of the document express their sincere gratitude to the expert community for their significant concrete contribution to the creation of this analytical document, for the materials, comments and recommendations provided during the preparation and discussions, namely PJSC «Ukrhydroenergo», the «Ukrainian Nature Conservation Group» (UNCG) and personally Oleksiy Vasylyuk, WWF-Ukraine. Special personal thanks to experts Dmytro Stefanyshyn, Mykola Kobets, Bohdan Kuchenko, Ihor Pylypenko, Artem Kolesnyk, Oleh Pashchenko, Leonid Melezhyk, Svitlana Krakovska and other specialists who contributed to the document by making suggestions and commenting on it.

List of abbreviations, terms, units of measurement

GFC – gross final (energy) consumption

TPES – total primary energy supply

toe – tons of oil equivalent

MWh, GWh, TWh – energy units, megawatt-hours, gigawatt-hours, terawatt-hours

GWel, MWel, kWel – energy installed capacity units, gigawatt-electrical, megawatt-electrical, kilowatt-electrical.

KaHPP - Kakhovka HPP

Kakhovka Rsvr – Kakhovka Reservoir

SPP/WPP – solar power plants / wind power plants

ICUF – installed capacity utilization factor

IPS of Ukraine – Integrated Power System of Ukraine

RES – renewable energy sources

BM – biomethane

COP – Coefficient of Efficiency

LCOE – levelised cost of energy, Euro/MWh - an indicator for comparing the cost of energy production (before supply) from different energy technologies over the lifetime of the project

UNCG – Ukrainian National Conservation Group

MPC – maximum permissible concentration

CMU – Cabinet of Ministers of Ukraine

1. Purpose of the analytical paper

The blow-up of the Kakhovka dam and the HPP by the Russian Federation on June 6, 2023, can be qualified as an act of ecocide (according to Article 441 of the Criminal Code of Ukraine, ecocide is a «Mass destruction of flora or fauna, poisoning of the atmosphere or water resources, as well as other actions that may cause an environmental disaster»).

The rationale behind the building of the Kakhovka HPP and the concomitant flooding of a large area (215,000 ha) was determined by the government's priorities at the time (creating a reliable water supply system for the population and industry, water supply to the Crimea, the need to produce electricity in the energy-deficient southern region and to balance the energy system, build-up of irrigation systems for agricultural development, and resolving the high water issues in the lower reaches of the Dnipro River). Commissioning of the HPP increased the electricity production for the region, which was a significant contribution in realities of the 1950s, and the dam connected the left and right banks of the Dnipro lower reaches, the reservoir became the main source for irrigation, industrial and drinking water supply in the south and southeast (which in turn enabled the surface irrigation and had a positive effect on higher agricultural productivity). The construction lasted five years, from September 1950 to October 1955.

The creation of the reservoir also caused a set of environmental, social and cultural losses and long-term impacts on the ecosystem, including negative impacts on historical heritage, as it led to the flooding of the Great Meadow (Velykyi Luh). This region was important for Ukrainian history, as it was home to the Zaporizhzhian Sich, the historical heartland of the Ukrainian statehood formation.

Over time, the use of the reservoir has led to changes in the ecosystem, such as deterioration of water quality (due to the lack of proper treatment, large amounts of accumulated chemicals, and eutrophication). Regulation of the river's water flow has changed its morphology, which has led to a partial «interruption» of the migration of anadromous and semi-anadromous fish species, caused sedimentation, the abrasion of banks by wind waves, and disrupted the local balance of the Dnipro River and the adjacent land ecosystem.

The Kakhovka HPP was one of the largest in Ukraine, with a capacity of 334.8 MWel (the fifth in Ukraine by capacity) and an average annual electricity production of 1500 GWh (ICUF of 0.5, which is a rather high figure for lowland gravity HPPs in temperate latitudes and the corresponding flow of the Dnipro River, additionally taking into account that this reservoir, due to its large area, became the largest zone of water evaporation and, as a result, the water salinity increased). At the same time, the Kakhovka Reservoir was the largest in Ukraine in terms of the shallow water area. The dam infrastructure ensured the annual regulation of the Dnipro flow, irrigation, and water supply. The through navigation on the Dnipro River was ensured, maintained and actively pursued (for commercial transportation of mainly cargoes and passengers to a lesser extent) through the lock channels available at the HPP (not all gravity-type HPPs have the infrastructure to provide the through navigation). The dam and reservoir played an important role in the regulation of seasonal fluctuations in the Dnipro River water level, and the KaHPP itself was an element ensuring the stability of the IPS of Ukraine, balancing the power system, and covering both daily and seasonal peak loads.

The environmental consequences inherent in the construction of large HPPs on lowland rivers are felt especially after the destruction of the HPP and require a comprehensive analysis and a search for an answer to the question on further actions. Do alternatives to the restoration of the KHPP exist? How can these alternatives be compared with each other? What additional environmental risks does this or that alternative pose? How can we prevent the tragedy from happening again? Is the restoration of the HPP a viable option at all, or do the associated additional environmental risks outweigh the potential benefits? Does such restoration meet the criteria of sustainability, resilience of natural ecosystems, the best international practices and those of the EU member states, and thus Ukraine's EU integration course? Are there any alternatives to restoration of the HPP in terms of environmental impact minimization, water supply, and at the same time, equivalent energy production and ensured stability of Ukrainian energy system, as it was done by the KaHPP? How can these alternatives be compared with each other? Is it possible to continue intensive agricultural activities in the region and ensure sustainable energy production without creating a new reservoir? Finding answers and alternatives, comparing them with each other based on various factors, taking into account the capabilities of modern technologies and determining the most balanced option is the purpose of this analytical document.

The authors did not aim to make a definitive recommendation on a particular alternative. They rather tried to run a preliminary analysis and compare different alternatives, while selecting the most balanced one according to certain criteria, and then to consider this alternative in more detail in terms of energy supply feasibility, versatility, ecosystem impact, CO_2 balance, required investments, project cycle, etc. We believe these options have their advantages and disadvantages, and none of them can be recommended for implementation as an individual unambiguous solution based on any set of evaluation criteria. In our opinion, only a combination of different options, which can complement each other, will be a potentially optimal solution, as shown in one of the proposed examples of the configuration of such a combined scenario.

This analysis takes into account, to the extent possible, existing plans and recommendations for the recovery of Ukraine, namely the Ukraine Recovery Plan[1] and the Green Recovery for Ukraine: Guidelines and tools for decision-makers (UNDP)[2], elaborations of the DG NEAR group[3] and others, which define, among other things, that the recovery should follow the principles of sustainability, resilience, climate neutrality, causing no additional harm to natural ecosystems (do not significant harm principle) and at the same time facilitate the development of energy production from RES. The options under consideration fit into existing plans, complement and detail them in the context of the southern Ukraine recovery associated with the blow-up of Kakhovka dam, and offer specific solutions with preliminary estimation of renewable energy production, investments, and an assessment of barriers, strengths and weaknesses.

1. https://me.gov.ua/Documents/List?lang=uk-UA&id=8f36a2d9-9611-4bff-8fa9-474da62bd28d&tag=PlanUkraini
   https://www.ukrainefacility.me.gov.ua/wp-content/uploads/2024/03/plan-ukraine-facility.pdf
2. https://www.undp.org/sites/g/files/zskgke326/files/2024-04/undp-ua-green-recovery-ukr.pdf
3. https://enlargement.ec.europa.eu/news/eu-and-ukraine-outline-plans-sustainable-reconstruction-high-level-conference-2023-11-27_en

2. Comparison of different recovery alternatives

2.1. Restoration of the Kakhovka HPP — rationale and concerns

This section will discuss the rationale, prerequisites and concerns regarding the complete restoration of the Kakhovka HPP.

The decision to build the Kakhovka Reservoir was made, among other things, as a result of the dry summer of 1946, when the main goal was to create an irrigation and water supply system for the region, which, according to Ukrhydroenergo PJSC, is also indicated by the work of the designers and the presence of the largest water intakes within the reservoir. Compared to the water amount consumed in the Dnipro River basin in the pre-war period, it was the water from the Kakhovka Reservoir that was mostly irreversibly used and transferred outside the basin. In some years, this volume of withdrawals amounted to 40% of the total within Ukraine. The water was used for irrigation in Kherson, Mykolaiv, Zaporizhzhia and Dnipro regions, as well as for industry in Kryvyi Rih, Nikopol and Marhanets. The water resources met the needs of the southern territorial and industrial complexes of Ukraine on the territories of Dnipropetrovsk, Zaporizhzhia, Kherson regions and the southern part of Donetsk region.

In the recent years of its existence, the reservoir was still the largest source of irrigation for the south of Ukraine, providing water for 30-95% of irrigation systems in Kherson, Zaporizhzhia, and Dnipropetrovsk regions[4] and provided conditions for growing various crops (for example, 80% of Ukraine's vegetables[5]). According to KSE estimations, the indirect losses of agriculture caused by the destruction of the HPP and the dam are estimated at 182 million USD per year.

After the dam was blown up[6] the agricultural irrigation system and the water supply system for industry and the population from the Kakhovka Rsvr ceased to exist as an integral infrastructure asset. In June 2023, several large-scale infrastructure projects for alternative water supply were launched on an emergency basis, using the water resources of the Dnipro Rsvr, Kremenchug Rsvr and the Ingulets River with its tributaries. As of October 2024, the water supply systems in the right-bank Kherson region and all of Dnipro region have been restored to the same level as before the Kakhovka HPP was blown up.

Rebuilding the dam could play a significant role in securing water supplies for agricultural activities in the country's southern region. However, according to experts and the State Water Agency, the system of reclamation and water supply from the Kakhovka Rsvr, which was created 70 years ago, is now morally and physically outdated, worn out, and was designed to grow other products (cotton), and its restoration will require significant additional capital investment and high operating costs (compared to a new system). The irrigation system was designed for different natural and climatic conditions 50 years ago. Over these 50 years, the current climatic conditions of the region (southern Kherson, Dnipro, Zaporizhzhia regions) have shifted towards a drier climate (steppe/savanna zone or semi-desert), so the operation of the irrigation system, which was designed for other climatic conditions and the growing of other products, is not effective for agriculture compared to more modern systems, such as drip irrigation or spot irrigation. Given the tradition of using the old irrigation system, which has led farmers in the region to focus on growing grains and oilseeds for the past 10-15 years, and the gradual increase in water and wastewater tariffs (in 2018, the tariff increased by 35% compared to 2017), farmers will potentially look for cheaper and more efficient irrigation alternatives[7] that are more suitable for current climatic conditions (drip irrigation as a more environmentally friendly and resource-efficient method that is actively used worldwide in climatic conditions similar to those in southern Ukraine.[8]

At present (October 2024), the problems of water supply to industry and population and irrigation for agriculture have already been partially solved in the region, the costs have already been incurred, and then this problem will be gradually solved with or without the restoration of the HPP dam. By the time

4. https://east-fruit.com/uk/novyny/rosiyski-terorysty-za-odnu-nich-faktychno-znyshchyly-ovochivnytstvo-i-sadivnytstvo-pivdnya-ukrayiny/.
5. https://minfin.com.ua/ua/2023/06/08/107214470/
6. Hereinafter, the terms "dam" and "dike" are used in accordance with DSTU 7735:2015 "Hydrotechnics. Terms and definitions of basic concepts": a dam is a hydraulic structure that blocks a watercourse and its valley to create a reservoir; a dike is a hydraulic structure in the form of an embankment to protect areas from flooding, enclosing artificial reservoirs and watercourses.
7. https://www.dw.com/uk/spersu-zabrali-zemlu-teper-i-vodu-naslidki-rujnuvanna-kahovskoi-ges-dla-fermeriv-pivdna/a-65887949
8. https://web.uri.edu/safewater/protecting-water-quality-at-home/sustainable-landscaping/drip-irrigation/

the KaHPP is restored (according to project cycle estimates, no sooner than 5 years after the end of hostilities in the adjacent territory), the water supply problem will be completely solved without the HPP dam. Future water supply needs must account for the lack of a reservoir this decade, requiring population and economy adjustments in affected areas. Any scenarios alternative to the construction of a HPP (including the natural recovery of the Great Meadow, the use of other RES, the use of energy crops for revegetation and energy production, economic activity on certain areas of the former reservoir floor, etc. – see clause 2.6) do not in any way prevent the construction of new modern and efficient water supply systems (in line with the present day realities) from the natural channel of the Dnipro River or other sources without flooding 215 thousand hectares of the territory with a nature conservation status. There is no definite answer to the question whether it is expedient or not, but we believe that the introduction of modern irrigation and water supply systems to replace the old one is possible without restoring the Kakhovka Rsvr, so this cannot be a key argument to restore the KaHPP dam. We believe that restoring the water supply system as it functioned before and at the cost of flooding large areas, some of which have the status of nature conservation, with a violation of the balance of the local ecosystem, when the harm to the environment outweighs the benefits of this measure, is currently inappropriate.

One of the motives for the HPP recovery is the need for an increase in the share of renewable energy in the structure of electricity production in Ukraine and the decarbonization. For example, the National Renewable Energy Action Plan until 2030[9] sets a target of 27.1% of final energy consumption (FEC), or 11.6 million toe in absolute terms, with the large hydro generation accounting for 8300 GWh/year (or 714 thousand toe). IRENA[10] characterizes the hydropower as the most stable (and usually the cheapest in terms of LCOE) source of renewable energy with the longest life cycle among any known energy technologies. With proper maintenance, some HPPs have been operating for as long as nearly 100 years. Large hydropower generation currently (in the situation when the coal generation is destroyed) plays a key role in ensuring the stability and resilience of the Integrated Power System of Ukraine, flexibility of regulation, balancing, covering peak loads, partially covering uneven electricity supply from other RES (SPP/WPP), thus contributing to the development of other RES. Solar, wind, and other types of RES are electricity producers with unstable output (with significant daily fluctuations), while HPPs can be a source of both base-load and shunting power generation, and can regulate frequency and serve as an emergency reserve. It is obviously that the restoration of Kakhovka HPP will increase the resilience and reliability of the IPS of Ukraine, as well as contribute to the green transition and decarbonization.

On the other hand, although large hydropower generation is considered a RES, and hydropower production by large HPPs is counted towards meeting RES targets, according to European legislation, their implementation requires a detailed sustainability assessment and consideration of environmental impacts associated with the construction of dams, flooding of large areas (which may be nature conservation unique ecosystems), including impacts on biodiversity, natural ecosystems, river morphology, their fragmentation, impacts on drainage, species migration, etc. (e.g. according to the Water Framework Directive (2000/60/EC)[11] and other documents[12]). There are precedents for stopping large-scale new HPP projects based on the conclusions of the Environmental Impact Assessment (EIA), which identified negative environmental effects from large HPPs that outweigh the potential positive contribution to clean energy production[13]. Due to these factors, large-scale hydropower generation cannot be considered fully equivalent to RES on a par with other types of RES (SPP/WPP or biomass), as by definition it leads to negative environmental effects that may outweigh those of energy technology.

According to Bankwatch (EBRD)[14], restoring or increasing the capacity of the Kakhovka HPP will ensure production of additional base-load electricity and will add flexibility and resilience to Ukraine's energy system. However, it will also lead to negative changes in the region's ecosystem, flooding of adjacent areas (which violates sustainability criteria), direct and indirect losses for residents and infrastructure. Using the new Kakhovka HPP to balance and regulate high water will lead to the destruction of natural ecosystems downstream, which are already national parks and nature conservation areas of international importance.

9. https://www.kmu.gov.ua/npas/pro-zatverdzhennia-natsionalnoho-planu-dii-z-vidnovliuvanoi-enerhetyky-na-p-a761
10. https://www.irena.org/Publications/2023/Feb/The-changing-role-of-hydropower-Challenges-and-opportunities
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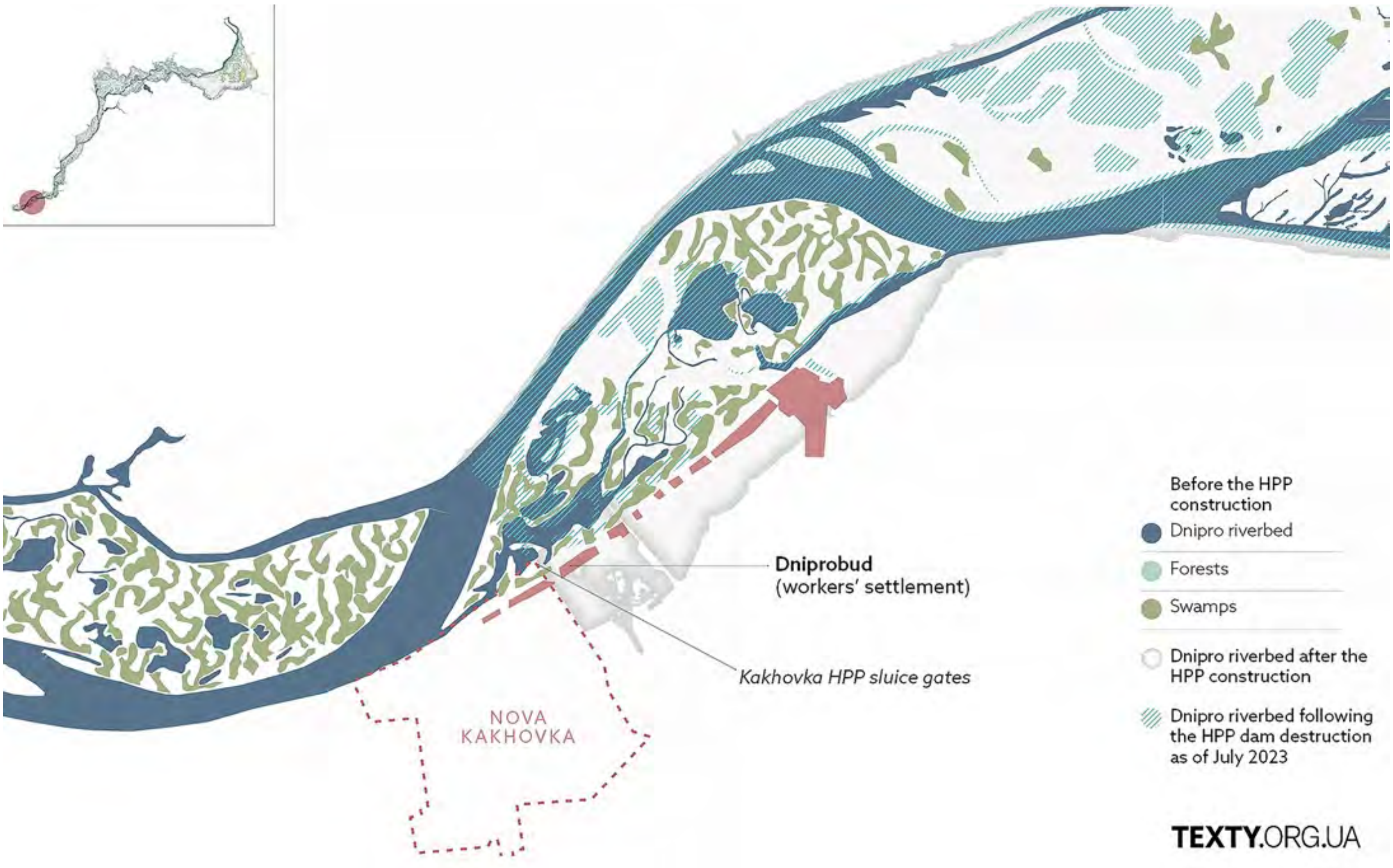
14. https://bankwatch.org/publication/why-is-rebuilding-the-kakhovka-dam-not-the-best-option-for-ukraine



Picture 1.
The Dnipro riverbed before and after the construction of the Kakhovka plant and after its destruction in 2023[15].

Filling the ZNPP cooling pond is another problem associated with the absence of the Kakhovka Rsvr. On the other hand, as can be seen from all satellite images, a detailed analysis of the newly formed Dnipro riverbed does not show any self-draining of the cooling ponds in the cold shutdown mode of the power plant; according to experts, there is enough water for cooling in this mode. Of course, when 4-5 units reach the rated operating mode (1 under routine maintenance), a situation of cooling water deficit may arise. However, as with the water supply system, restoring the reservoir is not the only option for solution. Since cooling is largely determined by the water flow through the ponds (which does not depend on the presence or absence of a reservoir, it rather depends on the hydrology of the Dnipro River, i.e. the flow of water through the river), one solution could be to install pumping equipment to deliver additional water from the Dnipro River. Some experts also believe that this will not be necessary, because the capacity of the canal connecting the cooling ponds with the Dnipro River will be sufficient for cooling.

Thus, according to Energoatom[16], the water level in the pond remains stable, although it is only enough to support the shutdown reactors. Therefore, when ZNPP power units resume operation (they have not been supplying electricity to the grid since February 28, 2022), the question of reactor cooling methods may arise, but the blow-up of the Kakhovka dam indicates the need for diversification to avoid disasters further on. The location on the bank provides for an easier access to water, and with modern technology, the efficiency of the cooler can be increased[17]).

The absence of the Kakhovka Rsvr also makes it possible to use the freed-up land to build infrastructure and bridges across the new Dnipro riverbed over time, when the high-water balance is established (and it will be possible to partially regulate with the Dnipro HPP). For example, to get from Enerhodar to Nikopol or Marhanets you need to travel 375 km, now you can build bridges and connect these territories, the existing road network can be modernized and supplemented with new bridge crossings over the revived Dnipro riverbed.

From the point of view of water transport, it is better to use the natural river channel without a dam, where there are no sluice gates and associated delays, and

15. fhttps://texty.org.ua/projects/111574/karta-velykoho-luhu-pyat-sichej-stavka-monholskoho-hana-ta-inshi-cikavi-miscya/
16. https://t.me/energoatom_ua/14478
17. https://www.dw.com/uk/zaes-bez-vodi-z-kahovskogo-vodoshovisa-naskilki-vistacit-zapasu-micnosti/a-65904115
https://www.epravda.com.ua/news/2023/09/23/704672/

Picture 2.
Water level in the ZNPP cooling pond as of 06:00 on 23 June 23[18].

which is characterized by lower wave heights. On the other hand, the reservoir created conditions for navigation due to the higher water level (which has now dropped). According to Ukrhydroenergo PJSC, the estimated navigable level was 14 meters. A decrease in the navigable level leads to disruptions in the guaranteed depths on the river stretch. This is especially important in the Zaporizhzhia area, where the approach to the sluice gate from the downstream is located in rocky formations, and the depth of this canalized section is 3.2 m from the navigation triggering level (14 m).

The rocky bed of the ship passage (35 km long) with limited depth continues to the village Bilenke berth. To ensure navigation in the natural channel of the Dnipro River in its lower reaches, several technical and engineering measures must be taken on a regular basis (regular earthworks to maintain a stable fairway, riverbed depth, bank reinforcement, etc.), which eventually can also lead to several environmental problems. We believe that navigation through the natural riverbed, provided that engineering and technical work is carried out, as evidenced by numerous examples of river use in the EU, is no worse than the use of a reservoir. The 215,000-hectare reservoirs are not built especially for shipping purposes; this is a side effect of the HPP construction, rather than a reason for its erection, and the reduction of distances due to new bridges and the removal of an obstacle in form of a huge reservoir will make the region more attractive for non-river logistics and cargo transportation, improve communication between the left and right banks of the Dnipro River, which will create an additional multiplier effect on the region's economy that will be otherwise wiped out in case of the repeated flooding.

The Kakhovka Reservoir played a significant role in supplying drinking water to the population of Kherson, Mykolaiv, Zaporizhzhia, Dnipro regions and the Crimea: The UN estimates[19] that about 700,000 people were left without drinking water after the dam was destroyed. Currently, the main water pipeline is being constructed for these regions, which will take water from the Dnipro River (Kremenchug Rsvr) to the Ingulets River and directly from the Dnipro River[20]. The Kakhovka Reservoir also filled the North Crimean Canal, which supplied more than 85% of the peninsula's fresh water. However, according to the latest data from 2013, the canal lost 70.52 million m3 or 45% due to outdated methods of water management and conservation at that time[21,22]. Poor water quality can be added to this: large reservoirs contribute to the accumulation of algae and other plants in the water, which leads to water blooms.

18. Source: Energoatom
19. https://apnews.com/article/ukraine-humanitarian-dam-water-food-cda457c3497ef4292b642c98aa99ccbf
20. https://www.facebook.com/1414642146/videos/2005182796488151/
21. https://necu.org.ua/zberezhennya-velykogo-lugu-ta-eksperymentalnyj-gidroproyekt-chy-potribno-vidnovlyuvaty-kahovsku-ges/
22. https://web.archive.org/web/20150427215527/https:/meco.rk.gov.ru/rus/file/doklad_eco_2013.pdf

Another important problem is excessive evaporation of water due to the large area of the Kakhovka Reservoir, which leads to salinisation of soil and water (the salt concentration in the reservoir is more similar to sea water than river water) and an increase in temperature. This problem cannot be solved in principle and is incompatible with the principles of sustainable development according to the EIA criteria. On the other hand, the reservoir and dam of the KaHPP played an important role in regulation of the ecological state of the lower reaches of the Dnipro River and in the processes of saltwater penetration from the sea into the mouth of the Dnipro River. The established environmental costs incurred through the Kakhovka hydro system reduced the likelihood of saltwater penetration into the river mouth, preventing a decrease in dissolved oxygen content, an increase in hydrogen sulfide content, fish kills, soil salinization, and deterioration in water quality for Mykolaiv city. The Kakhovka Reservoir served as a buffer to dilute and deposit pollutants and industrial wastewater and prevent pollution of the lower Dnipro River and the Black Sea, as well as to regulate high water and prevent flooding of Kherson city (and other cities and agricultural land along the lower reaches of the Dnipro River) during high water periods. After the dam was destroyed, flooding of some cities along the river from Zaporizhzhia to the Dnipro River's fall into the Black Sea occurred in the spring and summer of 2024 (it begins to occur at an average daily flow rate of 3500-5000 m3/s depending on the duration of the observed increased outflow), and a significant part of the area (30 to 60%, depending on the specific period of high water) of the Kakhovka Reservoir floor turned into a waterlogged swampy area for several months (from May to August).

According to preliminary data from UNCG, the substrate on the floor of the reservoir is so contaminated (especially with heavy metals) that no food can be grown there in the foreseeable future (at least 20 years). In this context, the floor of the Kakhovka Rsvr can be considered as a marginal / contaminated / abandoned / degraded land area, unsuitable for economic activity. At the same time, it may be subject to gradual long-term recovery through natural reclamation and other methods, including in certain areas, using special plants that help recover soil and reduce the concentration of harmful substances in the substrate.

2.2. Scenario of conservation and natural recovery of the Great Meadow

In this section, we will look at the process of natural recovery of the forest ecosystem and biodiversity on the territory of the former Kakhovka Reservoir and, in the long run, the emergence of a new ecosystem on these territories.

The first thing worth mentioning is the history of the construction of the Kakhovka HPP, namely the flooding of the Velykyi Luh under «Stalin's Plan for Nature Transformation», which was intended to expand industry and increase production through large-scale development of natural resources, but in fact led to significant environmental disruptions, loss of biodiversity, environmental pollution, and the imbalance or complete destruction of natural ecosystems (such as the Great Meadow [Velykyi Luh]). As a result, a huge area of the Dnipro floodplains, including fertile soil and vegetable gardens, as well as previously deforested areas, was flooded to build the Kakhovka Reservoir between 1955 and 1958. In addition, the territory of the Great Meadow is home to important cultural monuments, such as those of the Zaporizhzhian Sich, which now can be studied. Moreover, already in 2003, the 5th European Conference of Environment Ministers «Environment for Europe»[23] analyzed those large reservoirs, including the Kakhovka Reservoir, did not lead to the desired results, particularly in terms of energy, but instead more than 500,000 hectares of fertile land were lost and another 100,000 turned into the waterlogging zone.

Despite the pessimistic forecasts about the future state of the Kakhovka HPP landscapes made at the time of the tragedy[24], the current dynamics of ecological processes shows that the former reservoir is undergoing an active process of natural recovery of flora and fauna.

Academician of the National Academy of Sciences of Ukraine Yakiv Didukh gives optimistic forecasts for the recovery of biodiversity[25]. The former reservoir is now home to seedlings of various trees and shrubs, including willows, boxelder maple, green ash (Fraxinus pennsylvanica), black locust (Robinia pseudoacacia), thorny honey locust and others. *The academician argues that «the creation of willow plantations for biofuel ... is promising on this territory»*, however, further research and development of strategies to regulate ecosystem recovery are needed.

The conservation and recovery of biodiversity is at the heart of Ukraine's commitment to protect and restore ecosystems. The recovery of the Great Meadow is in line with the goals of the *Kunming-Montreal Global Program*[26]:

- Goal 2 (30% of the territory should be allocated for effective recovery by 2030).
- Goal 3 (ensure efficient management of protected areas).

Permission for the use of the territory by local communities will make it possible to implement:

- Goal 9 (equitable use of resources, especially considering the needs of vulnerable population groups).
- Goal 10 (efficient use of agricultural land).
- Goals 13 and 15 (implementation of effective legal, political and administrative measures for equitable distribution of benefits from the use of natural resources).

In the context of Ukraine's upcoming accession to the EU, the *EU Biodiversity Strategy 2030*[27], should also be taken into account, which sets ambitious goals and actions aimed at the recovery of ecosystems (defining that new ecosystems may not be recovered through the destruction of other ecosystems such as building thousands of small HPPs in the Carpathians will similarly destroy living natural rivers, or flooding an ecosystem that is being formed naturally, through the HPP rebuilding, or restoring reservoirs or floodplains that have already been drained). The Strategy emphasizes the importance of restoring degraded ecosystems to increase their resilience and ensure the provision of essential services to people and the maintenance of biodiversity. For example, clause 2.2.1 of the document states that special attention in the context of legal settlement will be paid to areas with high carbon capture and storage potential. According to the EU Nature Restoration

23. https://assembly.coe.int/nw/xml/XRef/X2H-Xref-ViewHTML.asp?FileID=10343&lang=EN
24. https://www.ukrinform.ua/rubric-economy/3721075-pidriv-kahovskoi-ges-tragedia-aka-zminit-silske-gospodarstvo-pivdna-ta-vsiei-ukraini.html
25. https://ecoaction.org.ua/dolia-kakhovskoho-moria.html
26. https://www.cbd.int/doc/c/e6d3/cd1d/daf663719a03902a9b116c34/cop-15-l-25-en.pdf
27. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0380

Directive[28], member states must restore at least 30% of the natural environments in poor condition by 2030, 60% by 2040, and 90% by 2050. However, the restoration of a large HPP with the flooding of 215,000 hectares of the natural ecosystem that has already begun to form, in our opinion, directly contradicts these requirements.

2.3. Scenario of small and floating HPPs implementation

Small hydropower generation can be considered as an alternative to the reconstruction of a large HPP. With a comparable installed capacity, such hydropower generation poses fewer risks in terms of territory flooding and negative impact on the local ecosystem of the Great Meadow, which has begun to form, and can be integrated into the natural Dnipro riverbed. Potentially, there is a possibility to gradually increase the capacity by adding clusters of new small/floating HPPs to the already built ones.

Since the Kakhovka HPP was built before all the ecosystems downstream became national parks and international conservation areas, rebuilding a new large HPP and using it to balance and regulate the water flow (especially if it is potentially more powerful than the destroyed one) will create an additional risk of ecosystem destruction by water discharges (even more than before the destruction and more intensively than clusters of small/floating HPPs). The construction of a new facility that will be harmful to important territories even more than the conservative baseline scenario (HPP before destruction) will be a violation of international requirements for sustainability of natural ecosystems, sustainable economic activity and sustainable energy production. From this point of view, small hydropower generation is seen as a potential alternative.

The Kakhovka HPP was characterized by a specific ratio of installed capacity to reservoir area (the lowest of all the HPPs in the Dnipro cascade) with a relatively high ICUF.

Table 1.
Parameters of hydro power plants and reservoirs of Dnipro river cascade

Name of the HPP in Dnipro cascade	**Reservoir area,** *km²*	**Installed capacity,** *MW*	**Power/area ratio**
Kyiv HPP	922	408	0.443
Kaniv HPP	675	500	0.741
Kremenchug HPP	2250	700	0.311
Mid-Dnipro HPP	567	388	0.684
Dnipro HPP	410	1 569	3.827
Kakhovka HPP	2155	334 *(destroyed)* 520-580 *(planned)*[29]	**0.155** *(destroyed)* **0.241-0.269** *(planned)*

The table shows that even with the increase in generation, this ratio remains the lowest among other HPPs upstream. One of the alternative solutions, including the increased use of the area, could be the construction of a cascade of small/medium HPPs (sHPPs) on a section of the Dnipro River (or parallel to the Dnipro River) from Zaporizhzhia to Kherson, whose total capacity would cover the electricity needs of local communities (and supply the surplus to the IPS of Ukraine). One of the advantages of this scenario is the partial break-up of electricity production and bringing it closer to the consumer, which will enhance energy security (both in terms of more difficult striking or blowing up multiple facilities compared to a concentrated strike/blowing up one facility), minimize energy losses during transmission, and reduce the risk of a repeated disaster with a scale of destruction similar to the KaHPP. As for the economic component, although a sHPP requires more initial investment than a large-scale HPP of equivalent installed capacity, a sHPP has lower operational and maintenance costs, which helps to reduce the over-

28. https://www.europarl.europa.eu/news/en/press-room/20240223IPR18078/nature-restoration-parliament-adopts-law-to-restore-20-of-eu-s-land-and-sea
29. https://suspilne.media/540707-vidbudova-kahovskoi-ges-zajme-sist-rokiv-golova-ukrgidroenergo/

all costs of the cascade system of such HPPs (UNEP[30]). Given that the total installed capacity of the sHPP cascade may be lower than the installed capacity of the destroyed HPP, the capital investment will be lower, but the total electricity consumed by the end user, taking into account lower transmission losses, will be comparable to the output of the destroyed HPP (about 1500 GWh/year). As a result, lower costs may have an impact on the electricity tariff level and shorten the payback period for small hydropower projects. Moreover, small hydropower plants can be built and commissioned within a shorter timeframe (1-2 years) and with a simpler project cycle (in terms of documentation, design, engineering, etc.) than large power generation facilities (3-5 years), ensuring a stable electricity supply geographically close to the consumer (of course, there is also a possibility to integrate sHPPs into the Ukrainian energy system or operate in a combined mode).

Most importantly, sHPPs do not require flooding of large areas and significant changes in river morphology and therefore have a smaller negative environmental impact than large HPPs of equivalent capacity. Technically, the introduction of sHPPs on large rivers, such as the Dnipro River, can be solved, for example, through a system of technical bypass channels constructed in parallel to the main channel of the Dnipro River (partially, where possible, of natural origin in the form of the old channel or tributaries of small rivers), or directly with the damming of a part of the main channel, in the case of floating HPPs - directly in the riverbed with the construction of a complex of auxiliary technical facilities for infrastructure maintenance, repairs, transformation and transmission of electricity to the IPS of Ukraine, etc. Of course, it is currently impossible to define a specific project option or outline for the construction of such a range of facilities, as the choice of building a small or large hydropower plant (or a combination of both) depends on a comprehensive assessment of key characteristics such as hydrological conditions, terrain, environmental conditions, capital costs, technical characteristics, maintenance, project life cycle, etc.

According to IRENA[31], in addition to supplying electricity to the IPS and a lower negative environmental impact (compared to large HPPs), sHPPs also contribute to the socio-economic sustainability of local communities and local capacity building through new jobs (in the process of equipment manufacturing and supplying, engineering services for installation, maintenance and technical supervision, repairs, control and monitoring of work), intensification of entrepreneurial activity (for example, equipment manufacturing can be done locally in Ukraine, which contributes to the development of local technical and engineering potential), as well as electricity supply at the local level facilitating the decentralization of production.

Since the destruction of the Kakhovka dam and the drop in water levels currently prevents the Dnipro HPP from operating normally in some periods, the construction of a derivation HPP can be seen as a technological necessity to ensure the operation of HPPs upstream of the Dnipro River cascade. Such a hydropower plant may fall under the classification of a small hydropower plant with a capacity of 30-50 MW - an illustrative example of its location is shown in the diagram below (D. Stefanyshyn et al.)

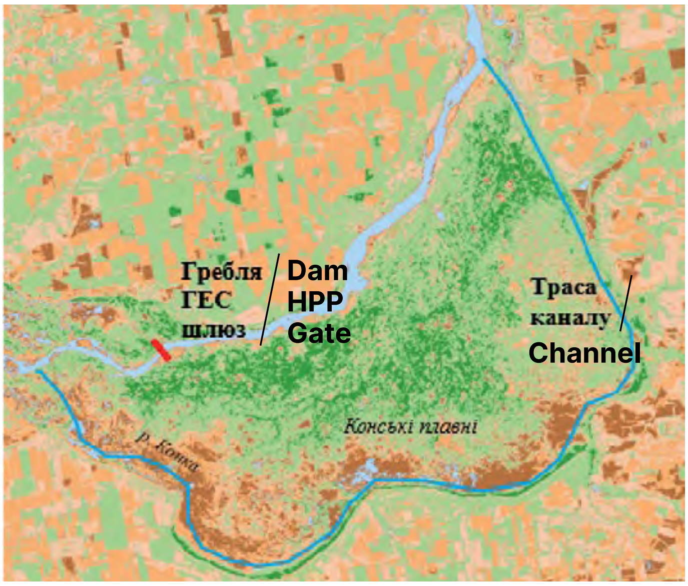
Picture 3.
Example of a derivative hydropower plant located within Khortytsia Island

30. https://www.ctc-n.org/technologies/small-hydropower
31. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2023/Sep/IRENA_Leveraging_small_scale_hydropower_2023.pdf

Picture 4.
Lower bief of Dnipro HPP, 18 of July 2023. Photo by Scott Peterson

Schematic examples of the technical implementation of small hydropower generation may also be the concepts presented below (Afanasiev S., Stefanyshyn D. et al.) In these concepts, the main role of hydraulic structures is distribution and diversion of water from the main channel, water supply, water level regulation (including for the operation of the Dnipro HPP), and flood control. These concepts do not involve extensive flooding of the entire reservoir area (10-20% of the area is flooded), and therefore have less negative impact on the natural ecosystem, but at the same time meet the key public needs of the region in terms of water supply (including agriculture), upstream hydropower plants, shipping, etc. The use of hydraulic structures as small hydropower plants is also possible to a certain extent (20-30 MWe at individual structures).

Picture 5.
Cutting off shallow waters by dams (Afanasiev S.O. (2023)): Damming of the shallow part of the Kakhovka reservoir[32]



Picture 6.
An example of the construction of a bypass water and fish passage channel within Great Meadow (D. Stefanyshyn)

32. https://www.researchgate.net/publication/376199771_ABOUT_THE_ECOLOGICAL_CONSEQUENCES_OF_THE_DESTRUCTION_OF_THE_KAKHOVSKA_HPP_DAM

2.4. Scenario of energy crop growing in certain areas of the reservoir floor

As a result of the HPP destruction, 215,000 hectares of free land appeared on the site of the reservoir, which can be used for economic purposes (as it was before, when the reservoir provided for the operation of the HPP). Since the floor of the reservoir cannot be classified as soil (because there is no soil as such), and the substrate, according to the UNCG, is so contaminated (especially with heavy metals, inorganic impurities, and various organic harmful substances) that it is difficult to find another example of land with such levels of contamination (in fact, the floor was an industrial sump for 65 years in a row), it is unlikely that this land can be reclaimed for use, for example, in agriculture without remediation. This zone can potentially be used for reforestation, organization of a recreational and resort area, as a nature reserve, for research on the natural formation of the ecosystem, and, partially, in some areas, for growing energy crops. Energy crops (especially perennial woody crops such as willow and poplar) are ideally suited for growing on waterlogged contaminated land that cannot be used for economic activities (i.e. marginal/abandoned/contaminated according to the EU classification). This alternative also allows for energy production, and thus for comparison in terms of specific indicators (energy production, CO_2 emissions reduction, investments, etc.) with other energy production options, including the rebuilding of the HPP. Let's take a closer look at this alternative.

The scenario of energy crops on a ***limited (10-20% of the area or less)*** portion of the Kakhovka Rsvr floor, either alone or in combination with other scenarios, fits into the Ukraine Recovery Plan[33], which is based on the principles of green development, climate neutrality, sustainability, restoration and reclamation, and avoidance of harmful impacts on natural ecosystems. This scenario does not involve large-scale transformations of the local ecosystem that naturally forms on the Kakhovka Rsvr floor ground, but rather can be naturally integrated into it, complement it, make it more resistant to changes, potentially restore the contaminated floor soils, and serve as a sustainable ecological source of energy from energy crop biomass. This option (alone or in combination) has several positive additional benefits for local communities in the region, namely:

1. Using local energy resources to produce energy at the local level — energy independence for communities.
2. Decentralization of energy supply — diversification of resources and increased energy security.
3. The money stays in the region and works for the community, rather than transferred to the central budget (or to other countries supplying energy to Ukraine) to pay for the energy supplied in the form of electricity, natural gas, etc.
4. Lower and stable price — local fuel (energy crop biomass) is a sustainable source, more resistant to external events and price changes than, for example, natural gas, which is a global commodity.
5. Creation of additional jobs (logistics, energy production, monitoring and care of energy plantations), reduction of harmful emissions, reduction of CO_2 emissions, attractiveness of investments into the region, creation of a local closed cycle of climate-neutral technologies — biomass supply and equipment production (boilers and additional equipment, logistics equipment, etc.).
6. The versatility of biomass as a fuel — it can be used to produce electricity, heat, fuel for transport, renewable gases, or combined solutions (for comparison, HPPs produce only electricity).
7. No binding to a specific territory — implementation is possible on separate clusters both within the territory of the former Kakhovka Rsvr and on neighboring degraded/abandoned lands requiring reclamation (mines, ash dumps, etc.).

33. https://me.gov.ua/Documents/List?lang=uk-UA&id=8f36a2d9-9611-4bff-8fa9-474da62bd28d&tag=PlanUkraini

Energy crops are plants that are especially grown on separate land plots to be used directly for energy needs or to produce secondary products (pellets / briquettes / bioethanol / biodiesel / biomethane, renewable CO_2, etc.).

Energy crops are classified as herbaceous and woody crops (SRC), annuals and perennials. Annual herbaceous plants are analogues of typical agricultural crops specially selected to redistribute plant mass from fruit to peripheral parts (trunk and leaves), such as sorghum, rapeseed, Jerusalem artichoke, and similar. Perennial herbaceous plants such as miscanthus, switchgrass, elephant grass, and silage corn are specially selected plants that have a high biomass yield from unit area per unit weight of the entire plant.

Woody plants (all of them are perennial), such as poplar, willow, paulownia, and others, are specially selected varieties of woody plants that give a mass gain per plant unit (and cultivation area) greater than their natural counterparts. All the energy crops are highly productive plants capable of sustained photosynthesis at high temperatures and in relatively unfavorable or extreme conditions (e.g., extremely dry or extremely wet conditions, in which other plants of the same class cannot achieve the same weight gain).

According to the latest data from the EU Bioplat project, the potential for growing energy crops in Ukraine on degraded, unproductive, polluted, abandoned land plots of various purposes is estimated at a minimum of 820 thousand hectaresra[34]. This is a site-specific potential that does not include other types of land that could potentially also fall under the definition of marginal / abandoned / unproductive / polluted / degraded (currently not used for many years in a row but could be used for energy crops in terms of both energy production and reclamation and restoration). The land of the Kakhovka Reservoir floor, which is currently under the jurisdiction of the State Agency for Water Resources of Ukraine, may be classified as degraded / contaminated / abandoned in accordance with the Resolution of the Cabinet of Ministers of Ukraine No. 35 dated 19.01.2022 (as amended)[35]. Since this land plot has not been used for economic activities (e.g., growing crops) and due to a long-term flooded state, it may additionally require many years of recovery and reclamation in terms of soil organic carbon composition, reduction of pollution with heavy metals and other hazardous wastes, in the context of adaptation and resilience to the climate conditions of the region (prevention of topsoil removal, erosion control in the steppe zone).

During the absorption of heavy metals by energy crops[36],and their use for, for example, direct combustion in boilers for energy production, the vast majority of heavy metals (90-95% by volume) are deposited in ash and do not undergo combustion or oxidation reactions in the boiler furnace (or other installations providing conversion of organic matter of fuel to energy — gasification, pyrolysis, torrefication, oxidation, fermentation, other), not being removed with flue gases, while a certain proportion (5-10% by volume) may be emitted from the furnace with flue gases. To clean flue gases from heavy metal impurities, well-known technologies are used, such as cyclones and scrubbers (generally for removal of solid particles), which, according to the current environmental regulations in Ukraine (which also include requirements for heavy metal MPCs[37]), are installed for large installations (district heating boilers, industrial hot water boilers, TPPs/CHPs, steam boilers for production needs, waste incinerators with an installed capacity of approx. 5-1 MW of thermal capacity (the norms are linked to energy supply)). Thus, there is no risk of an increase in the concentration of heavy metals in the atmosphere when they are absorbed from the soil of the Kakhovka Reservoir bottom. They are absorbed by energy crops and concentrated in ash after combustion (non-organic matter), which, unlike the distributed concentration over the entire area of the reservoir bottom, can be separately treated, disposed of at landfills, or reused in industry (construction, chemical, steel, iron and other metals and alloys). At the same time, the concentration of heavy metals in the soil of the Kakhovka reservoir bottom can be reduced several times over the semi-rotation period (10-15 years).

Among the various energy crops, there are many species and varieties that are highly productive (in terms of biomass production) and at the same time resistant to unfavorable growing conditions. At present, the State Register of Plant Varieties Suitable for Distribution in Ukraine contains 375 species of botanical taxa and 13790 plant varieties, including 36 varieties of energy crops, particularly several species of willow, giant miscanthus, paulownia, and rod-shaped switchgrass[38].

The varieties are owned by 20 individuals and legal entities, including research institutes of the Agrarian Academy of Sciences of Ukraine and the National Academy of Sciences of Ukraine. In total, 8 varieties of energy plants are of foreign origin, including the

34. https://bioplat.eu/webgis-tool
35. https://zakon.rada.gov.ua/laws/show/35-2022-%D0%BF#Text
36. https://www.researchgate.net/publication/341154500_Phytoremediation_of_Heavy_Metals_Using_Salix_Willows
https://www.sciencedirect.com/science/article/pii/S2666765723000960
https://pse.agriculturejournals.cz/pdfs/pse/2003/12/04.pdf
37. https://zakon.rada.gov.ua/laws/show/z0912-06#Text
38. https://uabio.org/derzhavnyj-reyestr-sortiv-roslyn-prydatnyh-dlya-poshyrennya-v-ukrayini-energetychni-kultury/

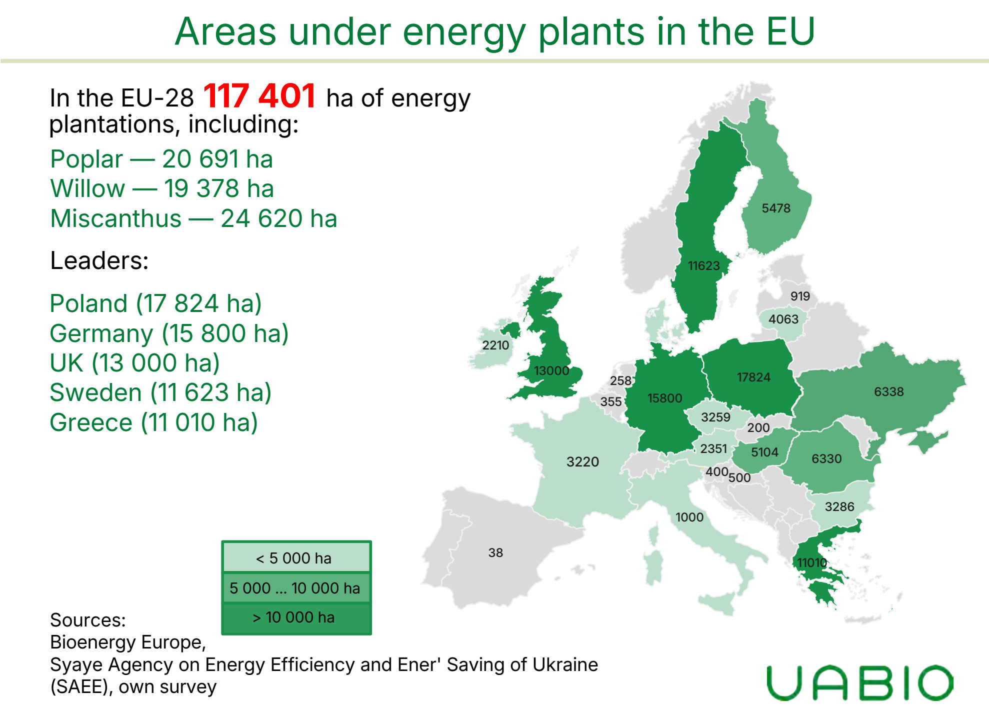
rod-shaped willow (Sweden — Wilhelm and Linnea variety), giant miscanthus (Poland - Illinois variety) and paulownia (Spain — Cotevis, Turbo Pro variety). In 2022 and 2023, two varieties of paulownia (Energy, Lidea) and one variety of giant miscanthus (Illinois) were included in the Register.

Registered plant varieties are generally suitable for cultivation in all climatic zones of Ukraine (Polissya, Forest-Steppe, Steppe). The efficiency of growing largely depends on the quality of the plant variety, soil, moisture availability, frost resistance, drought resistance, and resistance to pests and diseases.

The average yield of such crops, which is renewed in the annual cycle of their natural growth, can be up to 30 tons of dry weight/ 1 ha (in terms of 40% moisture content, this is 75 tons/ha)[39].At the same time, there are quite clear requirements to grow for specific energy crops. For example, to achieve optimal yields, tree species (willow, poplar, paulownia) require high soil moisture content (swampy soil) and a significant amount of precipitation per year (600-700 mm/year or more), while at the same time they are more vulnerable to sudden changes in temperature, droughts, and lack of plantation care in the first year of planting. Grassy species (miscanthus, silage corn, switchgrass) gravitate more to arid climates, are more resistant to sudden changes in temperature and extreme conditions (drought-resistant and frost-resistant) and are less demanding to care for (weed thinning). Preference should be given to planting material that has a history of use in the Ukrainian market, practical experience in growing, and has been tested in local climatic conditions, soils, and moisture conditions.

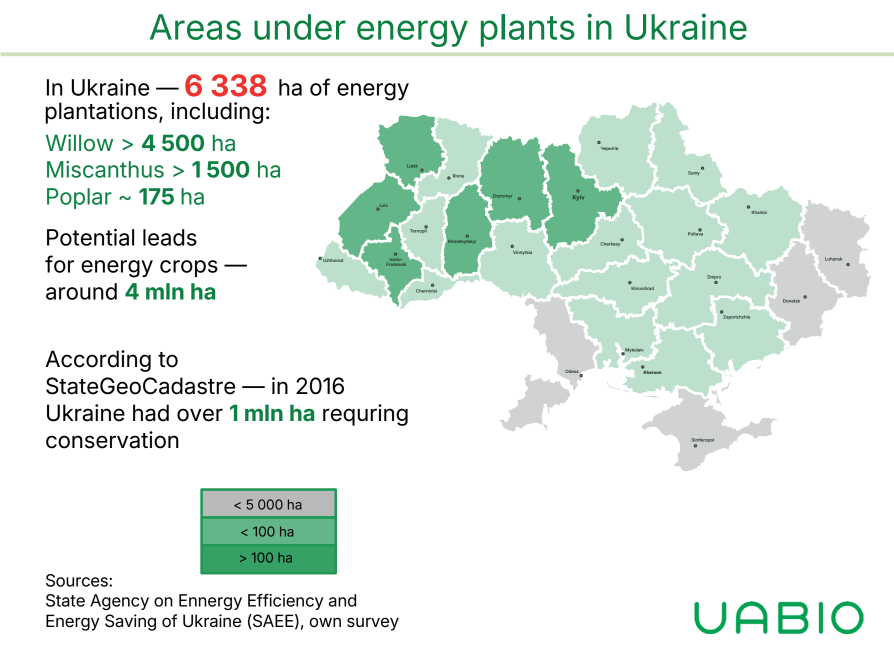
Ukraine already has experience in using energy crops for further energy production and restoration of wetlands and unproductive lands. There are dozens of companies in the market with more than 10 years of experience. The largest market players and producers of biomass from energy crops in Ukraine include the following: Salix Energy (10 years on the market), Ukrteplo LLC (5 years on the market), Yugenergopromtrans EPG, Energetic Verba LLC, Ecosolum LLC, Institute of Bioenergy Crops and Sugar Beet (the first research energy plantation in Ukraine), Intubus LLC, and others. The total area of unproductive land under energy crops is estimated (as for Dec 2024) as 6400 hectares, with biomass production of 80-120 thousand natural tons (40% moisture content) per year[40, 41]. The regional distribution of energy crop plots shows a trend towards grow mainly two types — willow and poplar — in the western and northwestern regions of Ukraine. About 2/3 of the total area under energy crops is located in two regions — Lviv and Volyn.

Таким ами (70 років дно водосховища було підводним відстійником промисловості півдня України), а також практичні наявні спроможності енергокультур щодо відновлення і рекультивації ґрунтів, високі показники генерації біомаси на одиницю площі (для подальшого виробництва енергії або інших продуктів), цей варіант розглядається далі в ряді інших як конкурентна і перспективна альтернатива.



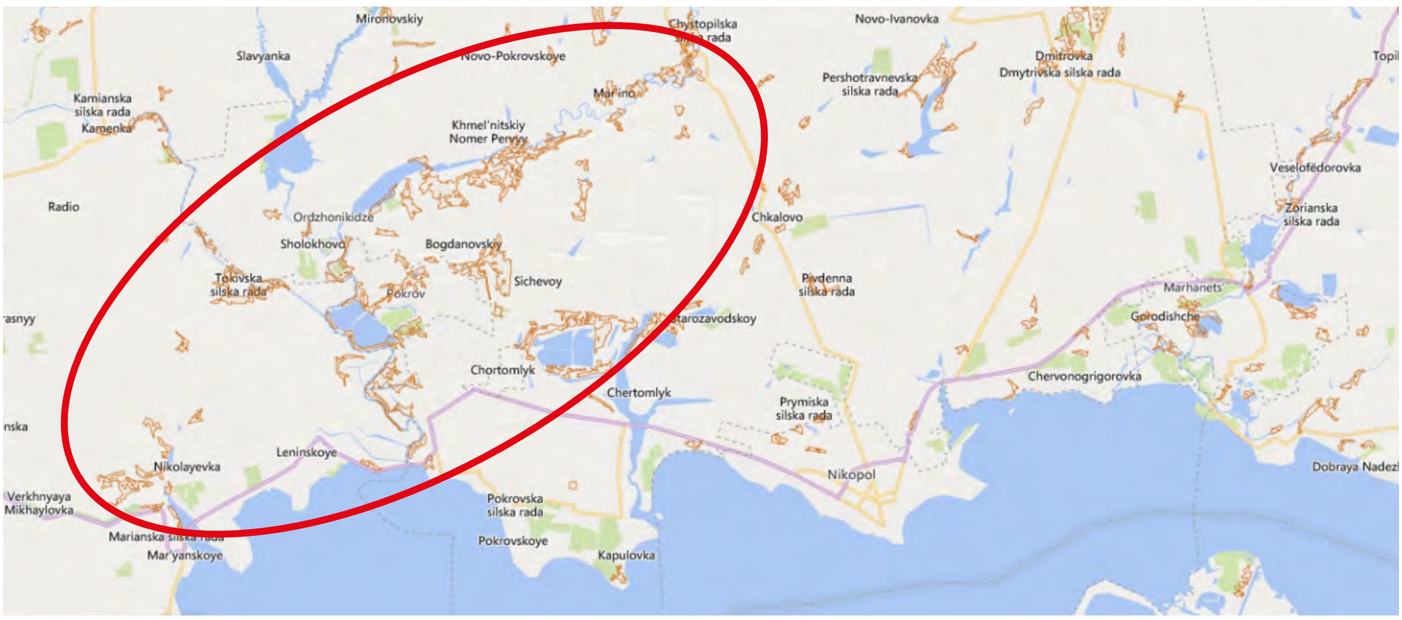
Picture 7.
Areas under energy plants in the EU

39. https://phyllis.nl/Home/Help
40. https://uabio.org/statistics/energetychni-plantatsiyi-v-ukrayini/
41. https://bioplat.eu/assets/content/documents/Ukraine/1st/Geletukha_energy_crops_08_October_2020.pdf



Picture 8.
Areas under energy plants in Ukraine

It should also be noted that in the vicinity (10-20 km) of the coastal zone of the former Kakhovka reservoir there is a cluster of marginal/abandoned/degraded/contaminated lands (some of them are dumps and abandoned mines that are spontaneously overgrown with shrub and woodland vegetation). These lands can be included in the cycle of growing energy crops for reclamation and restoration, as well as reducing the use of the reservoir bottom area (and thus increasing the share of land for natural restoration). For example, the BIOPLAT-EU project map (linked to the cadastre) identifies up to 4000 hectares of such land in the area 10-20 km from the reservoir shore (see the map of marginal land)[42].



Picture 9.
Map of clusters of degraded/marginal/abandoned/contaminated lands to the north of Kakhovka reservoir

42. https://webgis.bioplat.eu/#/map

2.5. Scenario of combined RES (solar, wind and other) implementation

For a direct comparison between two technologies of immediate electricity production — at large HPPs and using other types of RES (SPP/WPP combination) — we will also consider one more option. Ukraine has already implemented about 10 GW from RES based on SPPs/WPPs (about a half of this capacity is locate on the occupied territories of four regions of Ukraine), which averages 7-10% in the balance of average annual electricity supply (in the GFC), i.e. the same amount as from all Ukrainian HPPs, including the Dnipro HPP (which is currently disconnected from the power grid due to significant damages as a result of hostilities).

The potential of SPPs/WPPs in Ukraine is currently used by 8-10%. In the reservoir area (south of Dnipro, Kherson, Zaporizhzhia regions) the potential is somewhat higher. In 2014-2022 large-scale commercial projects of SPPs and WPPs with a unit installed capacity of up to 350 MW/project were implemented. Two of Ukraine's largest SPPs with a total capacity of 440 MW are currently operating near Nikopol (Nikopol and Pokrovsk on the territory of the mined-out quarries). Similarly to the construction of SPPs and WPPs on the lands of abandoned quarries, dumps, mines, and other degraded/polluted lands, construction on the territory of the reservoir floor can also be considered, where the land can also be considered marginal/degraded/polluted/abandoned within the meaning of the CMU Resolution No. 35 dated 19.01.2022.[43]

If we consider only the energy component, a commensurate electricity supply (in terms of final energy consumption — GFC) can be achieved by combining SPPs/WPPs with the total capacity of such a «park» at the level of 1000-1100 MW, which would occupy 2% of the Kakhovka Reservoir area (4000 hectares). The total investment in this equivalent project would amount to 2.5-2.8 billion EUR without storage and accumulation systems and up to 4.5 billion EUR with storage and accumulation systems that will provide the required level of flexibility and stability of electricity supply to the grid at the same level as Kakhovka HPP, as well as additional costs for transformation and transmission to the IPS of Ukraine. Such levels of investment are comparable to those in a new HPP, but there is no need to flood 98% of the reservoir floor.

If a larger area of the reservoir floor is utilized, i.e., with reference to the equivalent area in the energy crops scenario ***(in some land parts about 10-20% of the reservoir floor total area (20-40 thousand hectares)***, which is determined by a commensurate level of energy production from energy crops and KaHPP), the installed capacity of the SPPs/WPPs combination (in the ratio of 80/20) will be 20 GWel (twice the output of SPPs/WPPs currently connected to the IPS of Ukraine), and the total supply is estimated at 9-12 TWh/year without accumulation and storage systems and 20-24 TWh/year with accumulation (in terms of GFC). The respective investments are estimated at 27 and 36 billion EUR respectively. The investments, in addition to direct capital expenditures for the main equipment, design, engineering works and auxiliary infrastructure, also include the construction or restoration of additional electricity transformation and transmission infrastructure within the IPS of Ukraine (since the existing infrastructure and transmission capacity in the region, which are also partially damaged (or temporarily out of operation) as a result of hostilities, will not be sufficient for the scale of such a project), as well as for additional earthworks for flood protection and drainage of reservoir floor areas for the installation of equipment.

If the reservoir is restored, there is also an option to increase the efficiency of its water area use. For example, according to IRENA forecasts[44] it is possible to implement hybrid projects (wind + hydro power generation, biomass energy production, use of floating small HPPs and SPPs (submerged in winter) on the surface of the reservoir)[45]. Combination of different solutions, their integration into a single energy cluster, which increases the flexibility of supply, the stability of the power system, and energy security (multiple dispersed decentralized facilities in different locations are more difficult and often not meaningful to destroy compared to one centralized large generation facility[46]), usually provide a cheaper unit of energy produced (in terms of LCOE) and bear lower risks, which increases the investment attractiveness of projects combining different types of RES and advantages of hydro, solar, wind and biomass energy production. The capacity of SPP/WPP

43. https://zakon.rada.gov.ua/laws/show/35-2022-%D0%BF#Text
44. https://www.irena.org/Publications/2023/Feb/The-changing-role-of-hydropower-Challenges-and-opportunities
45. Analysis of combined solutions can show their potential effectiveness. When restoring the Kakhovka Reservoir, it is necessary to take into account that floating SPPs may be installed on the surface using technologies proven in the EU (by flooding for the winter period) In addition, it should be taken into account that a significant water surface in the Zaporizhzhia and Kherson regions creates zones of high and low pressure along the reservoir mirror, which facilitates the movement of air masses, and thus creates favourable areas for wind generation.
46. https://uabio.org/wp-content/uploads/2024/04/Lyst-BAU-629-shhodo-kryzovoyi-sytuatsiyi-v-energetytsi.pdf

installations on the surface of the reservoir is estimated at 500 MWe of installed capacity (annual output of about 300 GWh or additional 20% of destroyed KaHPP output), and up to 100 MWe of WPP (annual output of about 200 GWh or 15% of destroyed KaHPP output), with the corresponding investments in the range of 1.2 to 1.5 billion EUR (including additional capital expenditures for transformation into transmission to the IPS of Ukraine and earthworks for drainage and flood protection).

2.6. Comparison of scenarios

Thus, the following 5 options have been identified, which, according to the set of properties, can exist separately or complement each other and can be compared with each other according to various implementation parameters:

- Scenario of natural ecosystem recovery on the reservoir floor
- Reconstruction of Kakhovka HPP
- Small / floating HPP cascade system
- Implementation of a RES combination
- Introduction of energy crops for bottom reclamation and and biomass production

We will compare the identified options with each other against various parameters — project cycle, energy production, emission reduction, investment, energy cost, environmental damage, etc.

The comparison is based on the method of multi-criteria analysis using 18 indicators. Each indicator is assigned a score — for negative ratings (red zone) -1 or -2 points (the difference occurs when there is a significant difference between scenarios from the same assessment zone for one comparison criterion, for example, «Negative» receives -2 points, «Rather negative» -1 point, despite the fact that both ratings are in the red zone; the same logic applies to other ratings), for moderate ratings (yellow zone) — 0 or 1, for positive ratings (green zone) — 2 or 3.

Table 2.
Comparison of alternatives against defined parameters

№	Parameter	Alternative				
		(1) Scenario of natural ecosystem recovery, the Great Meadow	*(2)* Reconstruction of Kakhovka HPP	*(3)* Small / floating HPP cascade system	*(4)* Implementation of a RES combination (20%* of the area under SPP, WPP, other RES)	*(5)* Use of 20%* of the area for energy crops (reclamation and biomass production)
1.	Availability of equipment on the market for immediate purchasing	-	No	No	Yes	Yes
2.	Simplified project cycle, fast implementation and commissioning	-	No	No	Yes	Yes
3.	Life cycle length (years)	Without limits	50	40	20	20
4.	Independence from external factors (weather, precipitation, droughts, etc.)	Yes	No	No	No	No
5.	The need for an additional support mechanism	No	No	Частково	No	No
6.	Investments to produce the same amount of final energy (1 – reference scenario «Reconstruction of Kakhovka HPP»)**	0	1	1.25	0.9	0.25
7.	The ratio of alternatives by energy production (GFC) (1- reference scenario «Reconstruction of Kakhovka HPP»)	0	1.0	0.7-0.8	5.5-9.7	1.0-3.5****
8.	LCOE of produced energy (approximately), EUR/MWh (GFC)	-	35-65	60-75	60-125	50-120****
9.	CO_2 emission reduction (1 – reference scenario of natural recovery)***	1	1.25	0.9	9.5	3.5
10.	Possibility of fossil fuel replacement	No	Low	Low	Medium	High
11.	Ensuring the stability and balancing of the power system	No	High	Medium	Low	Medium
12.	Impact on sustainable decarbonization and green transition	Rather positive	Neutral	Rather positive	Positive	Rather positive
13.	Impact on the ecosystem being formed on the territory of the Kakhovka Rsvr	Positive	Negative	Rather negative	Rather negative	Neutral
14.	Impact on soil restoration	Neutral	Negative	Neutral	Neutral	Neutral / positive
15.	Impact of water supply, shipping	Neutral	Positive	Positive	Rather negative	Rather negative
16.	Versatility (production of only one type of energy or multiple, the possibility of diversification)	No	No	No	Partial	Yes
17.	Compliance with the criteria of sustainable development/ recovery	Yes	No	Partial	Partial	Partial
18.	Possibility of including renewable gases (H_2, CH_4) in the production cycle	Hi	Partial	Partial	Yes	Yes
	Total score	**15**	**14**	**10**	**14**	**19**

* 20% – derived according to the following logic: is an option that provides the amount of biomass from which, in the most conservative (worst-case) scenario, the same amount of electricity (in terms of FES) can be generated as at the HPP before destruction (1500 GWh/year), i.e. a direct equivalent alternative to a HPP in terms of electricity generation for the project life (20 years). If we consider 100% use of the area for energy crops, firstly, the energy ratio will be even more in favor of energy crops (or other alternative option — like SPP/WPP), and secondly, this will have large-scale negative consequences for the natural ecosystem commensurate with the flooding of the reservoir, which contradicts the entire logic of the analysis and notably the option of energy crops use (which, in addition to the energy effect, can potentially produce the effect of recovery and reclamation if used on certain land plots, including removing of heavy metals and sludges from soil, and prevention of additional harm to natural ecosystem and at the same time providing the same level of energy production as part of the energy demand of communities). Following the principle of equivalency of options compared, the same area is used to evaluate the SPP/WPP option. We believe that this approach is in line with the principle of conservative comparison of all the options presented (bringing them to a «common denominator»).

** Investments — for Alternative #4 (SPP/WPP), investments in storage and additional infrastructure for electricity transformation and transmission in the IPS of Ukraine are considered (including the construction of new high-voltage power lines and autotransformers within the IPS in addition to the total project investments in SPP/WPP and auxiliary equipment).

For Alternative #5 (energy crops), the entire chain is taken into account, including investments in the primary parental plantation, organization of an industrial plantation, capital expenditures for logistics, investments in technologies of biomass conversion into energy / a product for a combination of proportional split between electricity generation (25%), heat generation (25%), biofuels for vehicles (25%), production of renewable gases and other renewable products (25%).

*** The calculation of CO_2 emission reductions considers the absorption and retention of carbon on the reservoir floor (for alternative #1), which is the baseline scenario for comparison with all other options (an average sequestration rate of 2.3 tons of CO_2/ha/year is used, which is typical for forest plantations). For the other options, in addition to CO_2 absorption and sequestration (where less than 100% of the area is used), reductions from fossil fuel substitution in energy production are also considered:

- For option #2 (HPP) — reductions from grid electricity substitution, recalculated through the grid emission factor minus 100% of reductions from carbon sequestration (absorption), since 100% of the reservoir floor area is flooded.

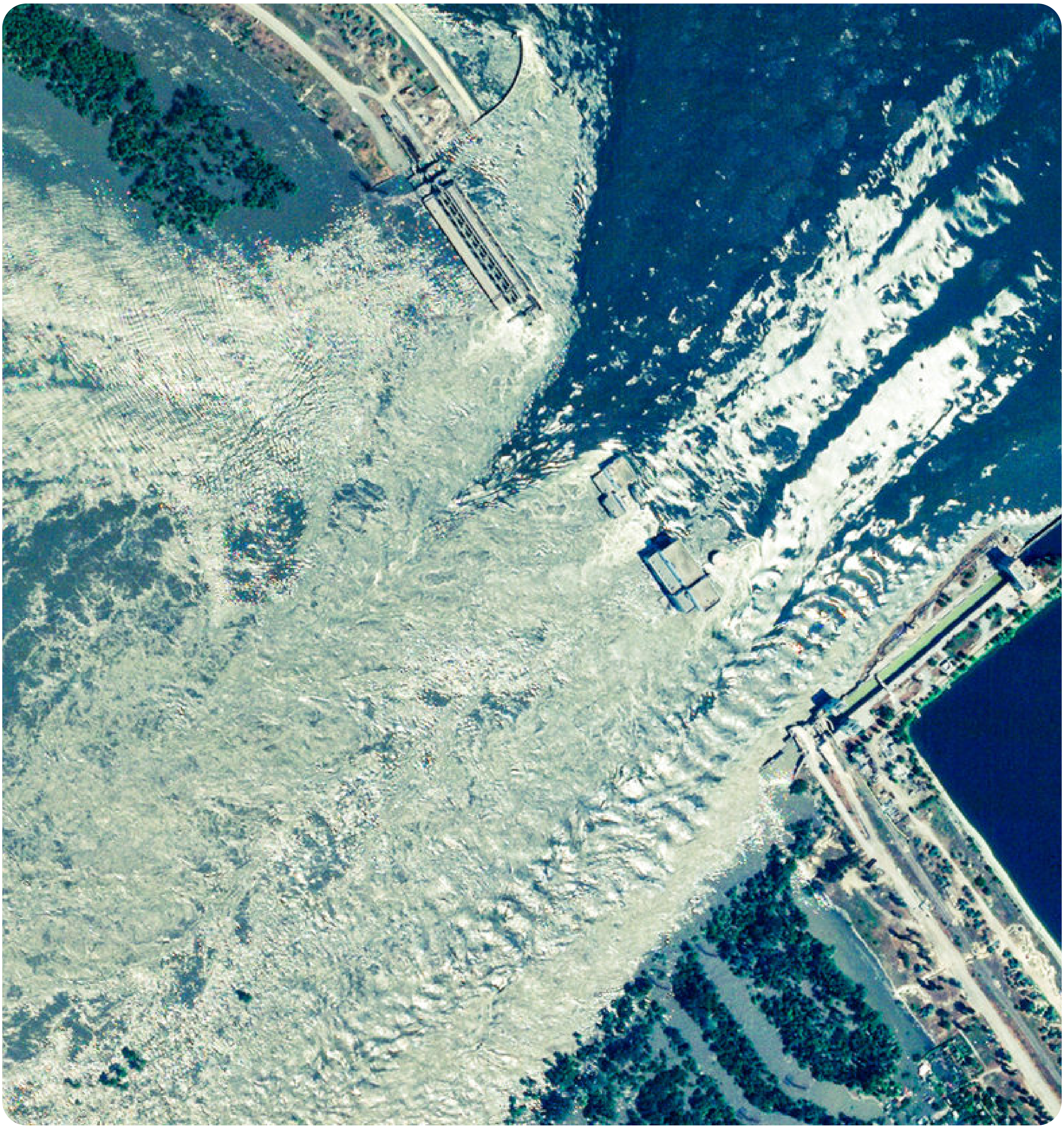
- For options #3 (small HPPs) and #4 (SPPs/WPPs) — reductions from grid electricity substitution, which is recalculated through the grid emission factor minus 50% of reductions from carbon sequestration (absorption), since the equivalent of 50% of the area is used (actually 20% is used, 50% is taken for conservatism, since carbon sequestration and absorption by a certain area may decrease nonlinearly with a decrease of the area).

- For option #5 (energy crops) — reductions from substitution of different types of energy in a combination of proportional split between electricity generation (25%), heat generation (25%), biofuels for transport (25%), production of renewable gases and other renewable products (25%)) minus 20% reductions from carbon sequestration (absorption), as 20% of the area is used (energy crops, unlike SPPs/WPPs and sHPPs, can also additionally absorb and contribute to the retention of CO_2 in the soil, so there is no difference between the actual area and the conservative estimated area, which takes into account the non-linearity of the change in absorption with the change in area).

**** For parameter #7 «energy production» — the lower figure of the range (1.0) is 100% of electricity, the higher figure of the range (3.5) is for a combination of proportional split between electricity generation (25%), heat generation (25%), biofuels for transport (25%), production of renewable gases and other renewable products (25%).

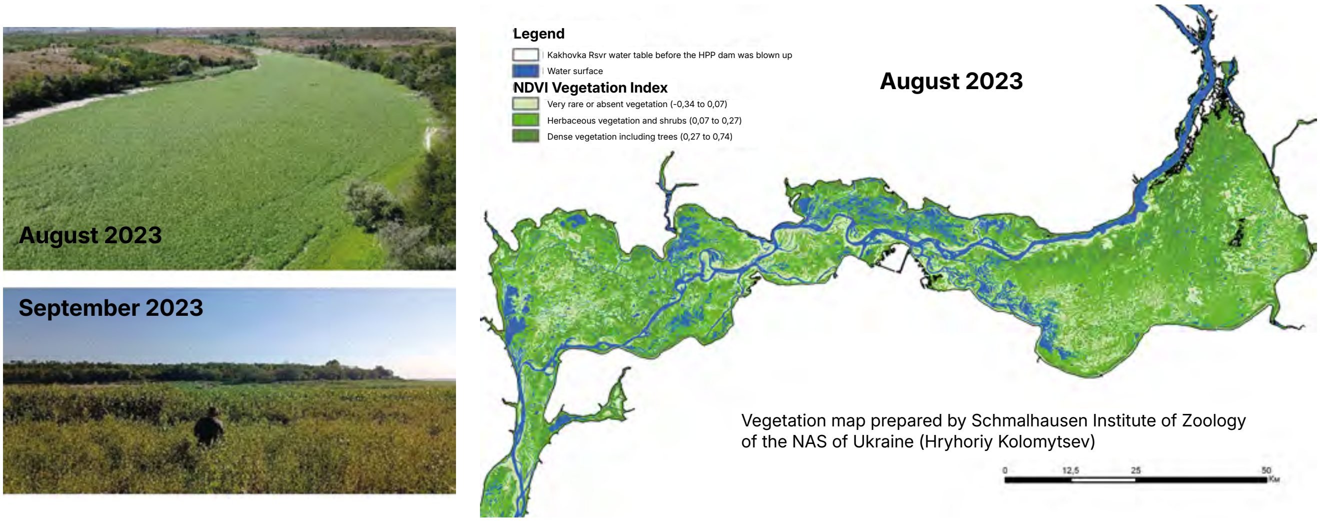
**** For parameter #8 «LCOE» — the lower figure in the range (50) is heat production (100%), and the higher figure in the range (120) is electricity production (100%).

The analysis shows that there is no clear leader or outsider among the options analysed. Each scenario has positive and negative aspects and is to some extent complementary. Formally, one of the best options is the use of a part (20%) of the Kakhovka reservoir area for growing energy crops. This scenario is the best in terms of energy production, production costs, meeting public needs, maximising benefits for communities and not causing additional environmental damage, and minimising the use of the reservoir bottom for energy production, provide possibility for recultivation and recovery of soil, reduction of concentration of heavy metals and sludges in soil via removing it by energy crops. The conditional 'second place' is occupied by a group of three scenarios — rebuilding the HPP, preserving the natural ecosystem (restoration of the Velykyi Luh natural way) and implementation of SPP/WPP on 20% of the area (of course, in practice, such a gigantic scale of SPP/WPP use on such a compact area is irrational, and the scenario on this scale is presented, as already mentioned, for the purposes of analysis consistency and equivalent comparison with other options, in particular with the energy crops scenario). Although small hydropower plants did not score enough points according to the criteria presented, they can be considered as a viable alternative in combination with other options. Let's take a closer look at the energy crops scenario and its additional benefits.



3. Analysis of the natural recovery progress on the Kakhovka reservoir floor in the context of energy crops integration

After the dam of the Kakhovka HPP was destroyed on June 6, 2023, 215,000 hectares (2155 km2) of land (formerly the bottom) were freed up on the territory of the Kakhovka Reservoir. The floor condition varies in terms of moisture level, with about 50% of the area having a moisture level ranging from swampy to open water, which is ideal for perennial woody energy crops (willow, poplar). As of August 2023, a new local ecosystem began to form on the released land of the Kakhovka Rsvr. According to the cartographic and hydrographic data of the Schmalhausen Institute of Zoology, as of August 2023, up to 50% of the territory had a vegetation index of more than 0.5, which corresponds to shrub and herbaceous vegetation, including young trees (see the map and actual images of the Kakhovka Rsvr for August-September 2023).



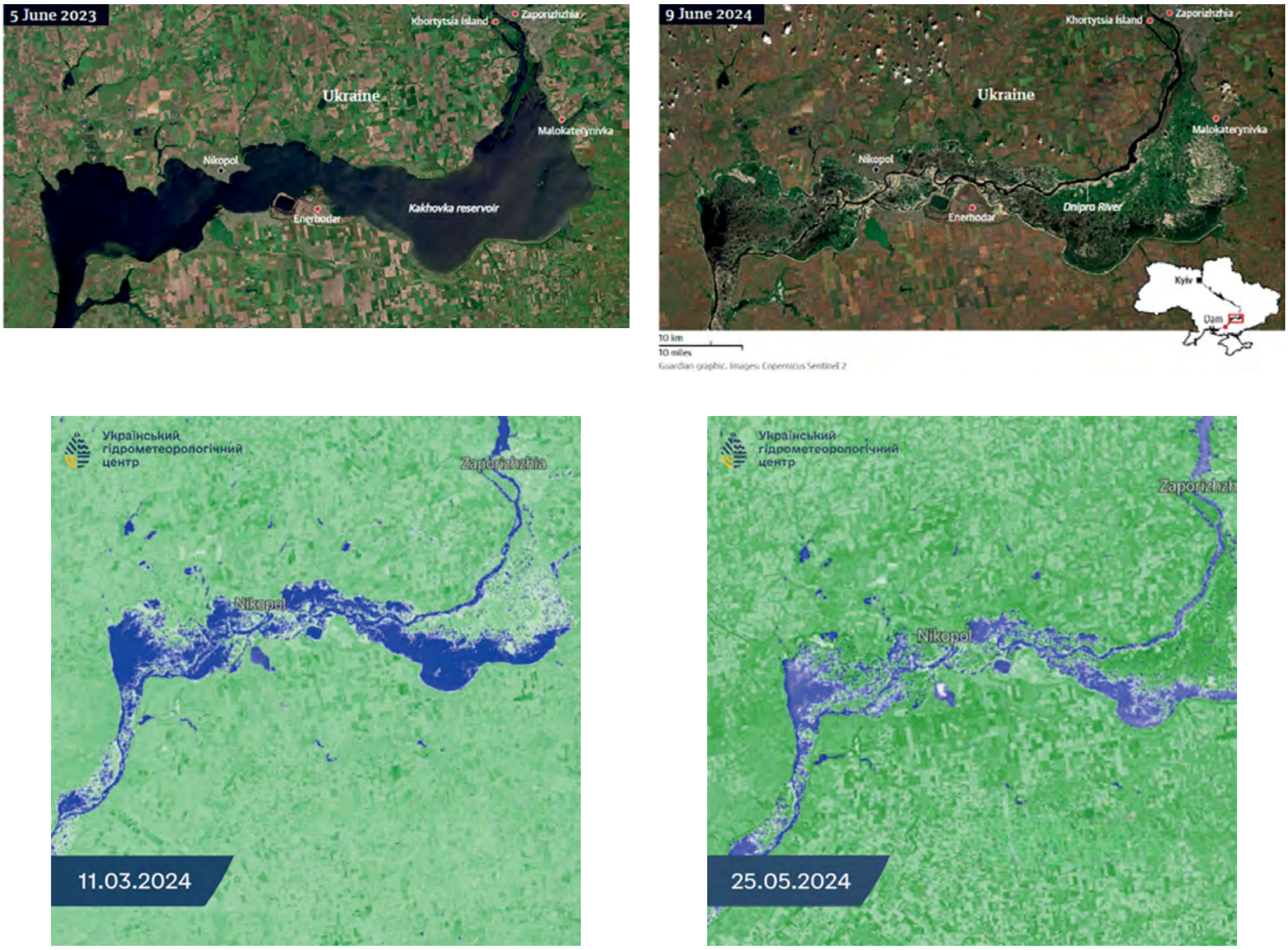
Picture 10.
Vegetation map prepared by Schmalhausen Institut of Zoology of the NAS of Ukraine (Hryhoriy Kolomytsev)

In 2023, according to the Ukrainian Hydrometeorological Center[47], the Great Meadow, a low-lying floodplain area with its unique forest ecosystem, was reviving on the site of the Kakhovka Reservoir, and the Dnipro River returned to its natural course as before 1956 (the year of the Kakhovka HPP construction).

Such a rapid rate of revegetation and the type of vegetation that develops on the released lands suggest that these lands may be potentially suitable for creating a local controlled ecosystem based on clusters of plantations of woody or herbaceous energy crops *in certain limited areas* (where they can be integrated into the natural ecosystem).

It is obvious that naturally developing ecosystems will have an increasingly complex structure and more biodiversity year after year (in areas with favorable climatic conditions, especially moisture). If energy crops are used, the development of ecosystems (or rather phytocoenoses) will be limited to the harvesting period and the rotation cycle. Over time, the difference will become apparent and will depend on the period and method of collection — the younger the age and the more frequent the collection period, the more noticeable the difference will be. A combined ecosystem based on natural plants and perennial energy crops of woody and herbaceous types will have differences in the development and biodiversity compared to natural ecosystems that develop spontaneously and chaotically on the ground, but on the other hand, it can provide a sustainable and renewable annual increase in biomass for energy production, and thus serve as an alternative to energy production at HPPs. Energy crops cultivated on separate clusters within a young natural ecosystem that is still in the process of formation (its age is 1.5 years, comparable to the period of harvesting energy crops — for example, for willow and poplar it is once every

47. https://www.meteo.gov.ua/ua/news/Richnicya-pidrivu-okupantami-Kakhovskoi-HES



Picture 11.
Vegetation map and visual assessment of phytomass growth on lands of Kakhovka Rsvr.

3 years, and the first harvest is in 3-5 years, i.e. in the first years there will be a parallel development of natural and artificial ecosystems in almost the same conditions and periods) can be integrated into this ecosystem and complement it. Depending on local conditions, they can have a mildly positive impact (soil recovery, regular control, monitoring, management of the plantation's vegetation, pest control, moisture conditions as part of the growing process), or a neutral or mildly negative impact. Thus, the integration of energy crops can represent a certain balanced option between the need for energy production and potentially negative (or neutral or in some cases positive) impact on the local natural ecosystem in the long term (for decades) and only in certain limited areas (clusters) where energy crops will be grown (up to 10-20% of the reservoir bottom).

Energy crops of woody and herbaceous type, such as willow, poplar, paulownia, miscanthus, switchgrass, silage corn, have a significant part of biomass concentrated in the upper thin part of the plant, crown, leaves, branches, which significantly influence the balance of organic carbon in the soil (with these organic plant residues that cannot be used in any other way during harvesting, organic carbon is returned to the soil after the harvesting cycle), which contributes to the conservation, control and recovery of the organic part of soil carbon, as observed in practice with industrial and research plantations in Ukraine and the EU-27 on similarly degraded/marginal lands with similar climatic conditions and, most importantly, periodically flooded moist soils with a high moisture content[48].

48. Tsapko, Y., Starchenko, O., & Vodiak, Y. (2023). Using the ecosystem services potential of Chernozem to restore war- damaged land. International Journal of Environmental Studies, 80:2, 399-409 https://doi.org/10.1080/00207233.2023.2179760
Vodiak Ya., Tsapko Yu., Kucher A., Krupin V., Skorokhod (2022). Influence of growing Miscanthus giant on ecosystem services of chernozem. Energies. Vol.15, 4157. DOI: https://doi.org/10.3390/en15114157
https://www.ndipvt.com.ua/301-viroschuvannya-energetichnoyi-verbi.html
https://www.ndipvt.com.ua/TiTAPK/2017/TiT%20APK4_2017.pdf
https://superagronom.com/articles/311-oleksandr-ganjenko-bioenergetichni-kulturi-varto-viroschuvati-na-degradovanih-gruntah
https://dspace.pdau.edu.ua/server/api/core/bitstreams/6fbe109a-149f-44b2-8df2-9f3d8fdd9d9f/content

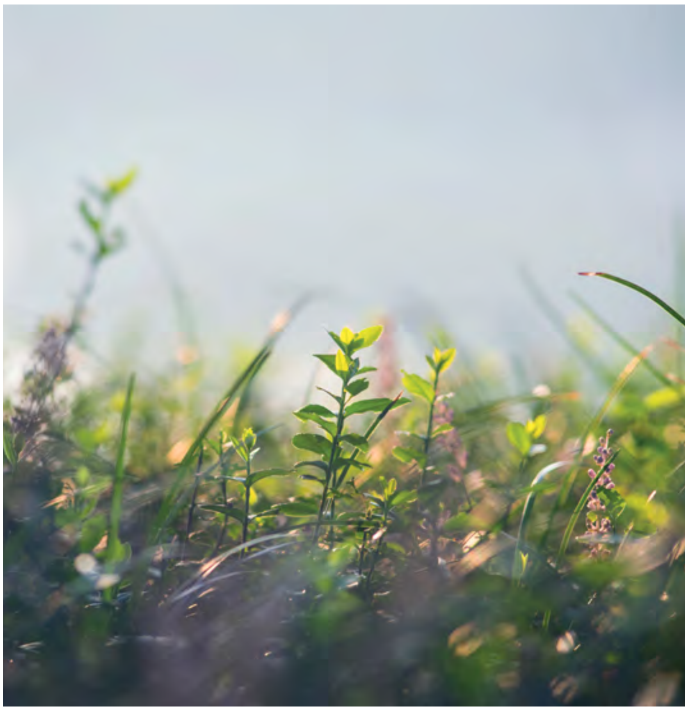
The released bottom land was not used for agricultural or other economic activities, so there is no direct competition with food production. There have been no settlements, infrastructure facilities, buildings, etc. on this land (as of March 2024), which also makes it possible to create inseparable clusters of energy crop plantations on separate designated plots.

Satellite images as of September 4, 2023, show that a new channel of the Dnipro River was already formed, and the flooded soils (bottom) of the Kakhovka Reservoir started transition from a sandy alluvial landscape to a grassy and forested one.

Satellite images as of November 7, 2023, show a fully formed new Dnipro riverbed and the boundaries of the Kakhovka Reservoir. It should be noted that these images already visually show the development of herbaceous, shrubby and young tree-type vegetation with a density that sometimes exceeds the neighboring areas (outside the Kakhovka Rsvr) where agricultural activities pursued on a regular basis. Such a sudden «explosion» of phytomass is

Picture 12.
Satellite images of the reservoir, September 4, 2023

not typical of the steppe zone in southern Ukraine. Conservation of the amount of phytomass (or prevention of vegetation degradation due to natural conditions), in particular by integration of energy crops in certain limited areas of these lands, can have a potentially positive effect also in the context of local rapid change of climatic conditions (over the past 20 years, the steppe zone of southern Ukraine has been gradually transitioning to savannah and sparse forests or semi-desert with corresponding fluctuations in temperature and moisture, which can negatively affect the young ecosystem of exclusively natural origin). It also included a positive effect on soil stability (prevention of removal of the organic soil layer), reducing dust pollution, and ensuring the resilience of vegetation to abrupt climate change (which naturally at the beginning of ecosystem development may be less adapted to abrupt changes in climate conditions than energy crops that are specifically bred for this purpose).[49]



49. Galitska M.A. Dynamics of soil organic carbon change in energy crops cultivation: implications for greenhouse gas residues and soil fertility. Energy efficiency and energy saving: economic, technical, technological and environmental aspects: Collective monograph / Edited by P. Makarenko, O. V. Kalinichenko, V. I. Aranchii. Poltava: Astray PE, 2019. C. 376-380 (in Ukrainian)
http://ecoj.dea.kiev.ua/archives/2021/6/11.pdf
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https://uabio.org/news/7727/
https://www.fao.org/3/a0026e/a0026e11.htm
https://www.researchgate.net/publication/251628796_The_potential_of_willow_and_poplar_plantations_as_carbon_sinks_in_Sweden
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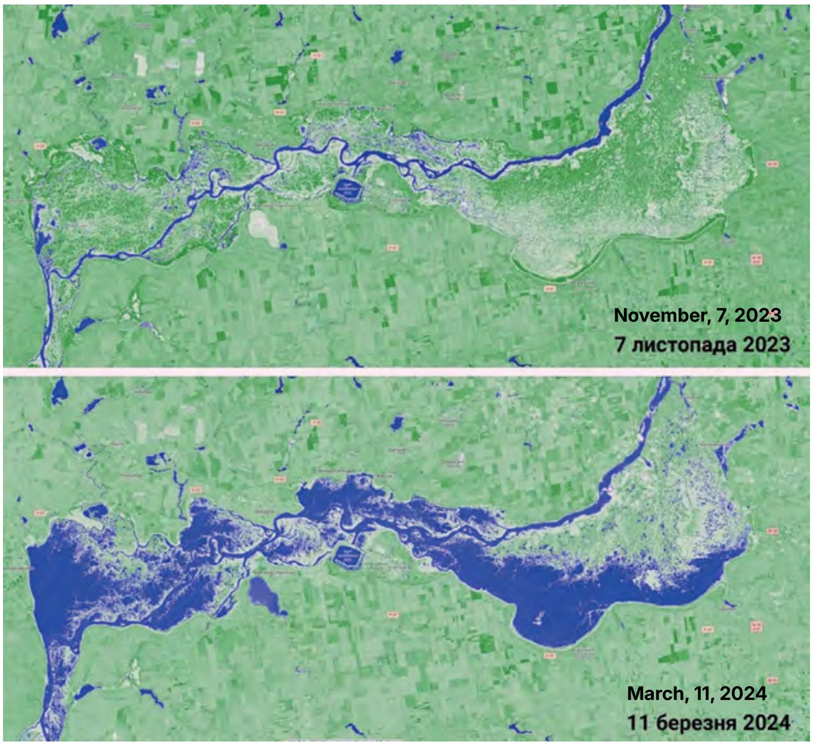


Picture 13.
The formed channel of the Dnipro River in November 23 and the map of floods on the reservoir lands in March 2014, data from the Schmalhausen Institute of Zoology of the NAS of Ukraine

The infographic based on satellite data from March 11, 2024 shows how the NDWI water index (Normalized Difference Water Index is used to identify open water areas and highlight them on a satellite image against the background of soil and vegetation) has changed from last autumn (upper image) to March 2024 (lower image). This index is determined from satellite images and allows to identify the water surface.

The first period of floods in March 2024 shows that these lands can hardly be integrated into agriculture or long-term infrastructure construction without additional regulation of the Dnipro River drainage (construction of hydraulic structures). The image of March 11, 2024 shows significant flooding of the former Kakhovka Rsvr territory, which is ideal for growing woody energy plants (willow, poplar, paulownia), but at the same time can negatively affect natural herbaceous vegetation.

Picture 14.
Willow thickets on the floor of the Kakhovka Reservoir, Kherson region, October 2023[50].

According to several monitoring and research expeditions, the reservoir floor is currently dominated by the willow, which has grown from two-six leaves in June 2023 to three meters tall in some places. The analysis was specifically carried out at the monitoring sites. In 5 months, the willow plants reached 2.5 meters in height, and the record was 3.08 meters.

50. An expedition of Kherson State University, the Institute of Botany of the NAS of Ukraine, and the Ukrainian Nature Conservation Group visited the territory of the Kamianska Sich National Nature Park.

4. Environmental experts' views on the restoration of Kakhovka HPP

Most ecologists and the scientific community consider the restoration of the Kakhovka HPP to be an ambiguous measure, irrational in terms of resource use and the current situation at the reservoir site, with a potentially harmful impact of the reservoir restoration on the local ecosystem, which has just begun to form after the reservoir dried up.[51]

For example, the results of a scientific expedition organized by the «Environment People Law» (EPL) NGO (May 2024) showed the formation of willow-poplar forests on large areas of the reservoir floor, which are protected at the European level, as they are listed in Resolution 4 of the Bern Convention and are the basis for formation of the Emerald Network of Europe. The EU Biodiversity Strategy for 2030, as well as the recently adopted EU Nature Restoration Law, envisage returning 25,000 km of rivers to their natural channels, including the elimination of ponds and reservoirs on them. In Ukraine, this process took place as a result of a disaster, but it created unique conditions for nature to recover on a scale that is apparently unparalleled in the world, so returning to the reservoir would have negative consequences for the local ecosystem. Earlier, scientists of the EPL NGO developed several scenarios[52] within the framework of the «Kakhovka Platform» initiative, calling on the government to reconsider the decision to rebuild the Kakhovka HPP, as well as appealing to the Prime Minister and the Government on the critical importance of public and professional scientific discussion of the problem before making a decision on the reconstruction of the KaHPP.

Olha Helevera, PhD, believes that restoration of the dam is inappropriate, as it will harm the emerging local ecosystem in the region.[53]

Ivan Moisienko, a board member of the Ukrainian Nature Conservation Group, believes that there are two main scenarios: either conservation of the naturally formed ecosystem or construction of a cascade of small reservoirs and HPPs that will be integrated into the natural ecosystem with minimal consequences.

Professor of the Department of Ecology at the National University of Kyiv-Mohyla Academy Yevhen Khlobystov: «...Ukraine does not need to rebuild the destroyed Kakhovka HPP». The basic problems related to water supply, sewage, and irrigation can be solved without a reservoir by using drip irrigation and new water supply systems. In addition, the HPP swamped small tributaries of the Dnipro River and the Dnipro River itself, induced the rapid development of organic matter, and contributed to secondary soil salinization due to the increased salinity of the water in the reservoir (a large mass of water evaporates in summer due to high temperatures, and water becomes more saline, similar to sea water).

At the same time, Ihor Pylypenko, professor at Kherson University, believes that without the reconstruction of the KaHPP, it is impossible to ensure the previous level of development of the region in terms of agricultural intensity, energy and water supply, and the ecosystem that is currently developing can eventually degrade into a desert or semi-desert.

51. https://www.nas.gov.ua/UA/Messages/Pages/View.aspx?MessageID=11102
https://texty.org.ua/fragments/110143/chomu-ne-slid-vidnovlyuvaty-kahovske-vodoshovyshe-i-v-chomu-koryst-zemel-sho-zyavylysya
52. https://epl.org.ua/announces/vidbudova-kahovskoyi-ges-peredchasne-rishennya-kmu/
53. https://eco.rayon.in.ua/blogs/616673-chomu-ne-slid-vidnovlyuvati-kakhovske-vodoskhovishche

The views of the All-Ukrainian Environmental League: the government's decisions on the pilot project to rebuild the Kakhovka HPP are too fast and insufficiently justified, no one in the EU would finance and implement such a project as building a new HPP and filling a reservoir as big as the Kakhovka Rsvr, because the costs required for such a project look completely irrational compared to the needs that can be met by the reservoir. Most EU countries, on the contrary, are draining much smaller reservoirs due to their environmental inexpediency and are not building new ones. For example, in the Environmental Compact for Ukraine there is, in particular, also a statement about the Kakhovka HPP.[54] One of the 50 recommendations set forth in the Compact by the international community reads as follows: take into account the opinion of scientists and the public on the future of the Kakhovka HPP regarding the possibility of its rebuilding.

According to ecologist Vadym Maniuk, as of July 22, 2024, about 150 thousand hectares of the artificially created reservoir look like this for the first time in more than half a century: a dense forest of willows and diverse flora. Wild willow species are the first «settlers» on the territory of the former reservoir.

Today there is a dense wall of young forest here. According to the ecologist, if there are no drastic changes to the Dnipro River hydraulic regime, the floodplains will no longer experience total soil drying out. In the spring and during heavy rains, the soil will be saturated with water, enough for the willow to continue to live and thrive. And later on, other trees will follow. According to the scientist, this site is already producing increased oxygen concentrations within the continent and helps regulate the climate and gas balance of the atmosphere.[55]

Picture 15.
The height of the willow reaches an average of 4-5 m, with a peak of up to 7 m in 2 years of vegetation on the floor of the Kakhovka Reservoir

The consolidated view of the National Academy of Sciences of Ukraine in a number of articles generally boils down to the scenario of ecosystem conservation without restoring the dam and the KaHPP[56].

A detailed analysis[57] of the Great Meadow recovery was conducted by the Ukrainian Nature Conservation Group (UNCG), a broader study is expected soon on the state of the soil and the ecosystem that is being formed on the territory of the dried-up Kakhovka Rsvr. The analysis notes, in particular, that «... we should not blindly ask the question «how to restore the reservoir» but instead look for solutions to quickly and rationally meet the existing needs of the government and the population using modern technologies and solutions. What are the benefits of alternative scenarios?».

54. https://www.president.gov.ua/storage/j-files-storage/01/24/65/148029c127aa3b2a3fe9f482f9226118_1707492894.pdf
55. https://texty.org.ua/fragments/113000/tut-stalosya-dyvo-yak-na-misci-kahovskoho-vodoshovysha-strimko-rozvyvayetsya-zhyttya-the-guardian/
56. https://www.nas.gov.ua/UA/Messages/Pages/View.aspx?MessageID=11102
57. https://uncg.org.ua/chomu-slid-vidrodyty-velykyj-lug/?fbclid=IwAR1f3ohsb9vRMjfKlayQsNWs8HXpWIf8migcconpqfQRM3DO2cBpkF8uKw0

The Ecodiya (Ecoaction) NGO completed a study[58] to identify the diversity of flora and fauna that is already developing or can develop on the territory of the Great Meadow, which can be lost if the area is flooded.

The restoration of the reservoir and the construction of large HPPs, such as the KaHPP, also contradicts a number of EU regulations and resolutions, such as the Nature Restoration Law[59], and the Biodiversity Strategy for 2030, and other environmental documents.[60]

Thus, based on the combination of signs and studies for the past 18 months, we believe that a return to the restoration of the Kakhovka HPP with the re-flooding of 215,000 hectares of territory where a new self-sufficient forest ecosystem is already naturally forming (and thus, as a result, its destruction through flooding) is inappropriate and harmful, contrary to international practices and legislation, even in the light of obvious benefits of this scenario in terms of water supply, navigation, balancing and sustainability of the energy system, etc. We estimate that the potential benefits of this scenario are offset at least by the direct environmental damage that would be caused to the ecosystem already partially formed on the reservoir's territory. Nevertheless, this scenario can be implemented in a limited form and in combination with other scenarios, such as the restoration of a hydroelectric power station or dam (or a cascade of small dams), whose main function would be not energy production but water supply, navigation, flood control, and the operation of the Dnipro HPP (raising the level of the lower reaches), with energy production as a secondary function. A much smaller hydropower plant (or cascade) (30-50 MW) based on mHPP technology could be built on the basis of these hydraulic structures, resulting in a smaller flooded area (10-20% of the former reservoir). That is, the marginal cost of flooding 10-20% of the territory of the Kakhovka reservoir is a solution to purely technical, but not energy problems. This infrastructure can be complemented (to produce energy at the same level as at the Kakhovka HPP and without harm or minimal damage to the environment and without flooding) by the scenario of growing energy crops in limited areas (5-10% of the area of the former reservoir bottom + 3-4% of the area of adjacent marginal lands for reclamation), as well as by separate clusters with SPP/WPP-based generation facilities (including SPP on the surface of the reservoir) in frames of combined scenario (refer to Chapter 7).

58. https://ecoaction.org.ua/dolia-kakhovskoho-moria.html
59. https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3746
60. https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en

5. Description of the energy crops use scenario

*The scenario envisages the possibility of **partial use** for Kakhovka reservoir floor lands (on limited sites, up to 10-20% of the area, which can provide quantitatively commensurate energy production compared to the final consumption of electric energy from the destroyed HPP – see below), as well as those affected by hostilities, to restore or create a new self-sufficient local ecosystem through the use of energy plants as an additional potential resource of sustainable biomass.*

Among the energy crops that are more adapted to growing in this climate zone, soil and to precipitation, we will consider 4 species — 2 herbaceous — miscanthus (perennial) and silage corn (annual) and 2 woody — willow and poplar. Paulownia, sorghum, and switchgrass are also potentially suitable for this climate zone, but they are not considered in this context. Let's also consider three cases: full use of 100% of the released lands — the theoretical maximum option (which can occur in reality using both the released lands of the reservoir and the neighboring adjacent lands), use of 85,000 hectares (40%) — the area of the right bank of the reservoir floor from the newly formed mouth the Dnipro River, which is controlled by Ukraine as of March 2024, and 42,500 hectares (20%) — a practical option for integrating energy crops into the local ecosystem. For all the options, the indicated area values do not mean planting on a single large cluster; it can be several dozen individual clusters of plantations for 10-20 thousand hectares each, separated by natural grass and forest plantations.

Input data for computation of all these options are presented in the table:

Table 3.
Input data for computation of scenarios of planting energy crops on the Kakhovka Rsvr floor

Type of energy crop	**Medium standard yield,** *t/ha/year*	**Climate zone factor**	**Moisture factor**	**Soil factor**	**Conservatism factor**	**Cycle factor**	**LCV,** *MWh/t (average for raw tons from the field)*	**TPES to FES conversion factor**
100% corn silage	120	1	1	1.05	0.9	0.33	4.25	0.8
100% poplar	35	0.93	1.073	0.9	0.9	0.75	3.65	0.8
100% willow	25	0.85	1.235	0.93	0.9	0.8333	3.9	0.8
100% miscanthus	40	1	1	0.917	0.9	0.715	4	0.8

Of course, it should be borne in mind that the required levels of moisture, both in the soil and from precipitation, can vary over time. The area is already in a zone of significant aridity, and even less available moisture is predicted in the future. Evaporation has also contributed to salinisation and the transfer of that moisture by clouds and precipitation further south-east, which could become even more arid without the reservoir. Such qualitative climatological considerations are unfortunately not currently quantified or based on climate models, but they are important to take into account in the energy crops scenario. Therefore, different types of energy crops that can be cultivated both for waterlogged soil (willow, poplar) and for drier conditions (miscanthus) are considered in the following. The implementation schedule and planting configuration must include different types of energy crop planting material and a planting scheme for different periods of time (not to plant thousands of hectares at once, but to move gradually, starting with experimental plantations of 50-100 hectares, to a nursery of 200-500 hectares and then, as the experimental database on cultivation in specific climatic conditions and soil grows, to move to industrial plantations of 500 hectares and more). All these considerations were, as far as possible, quantitatively taken into account in the coefficients of the table with the initial data based on the available experience of growing in similar climatic conditions and soils for each type of energy crop.

For each of these options, it is further possible to calculate the annual amount of energy that can be obtained using biomass grown on energy plantations (in terms of primary energy contained in the biomass — TPES, and final energy — GFC). This calculation includes the annual renewable biomass growth of energy crops in the rotation cycle characteristic of each type. For the sake of simplicity, a rotation cycle of 20 years is assumed for all the energy crops (in reality, for willow and poplar, it can be up to 27 years).

Table 4.
Amount of energy from energy crops – TPES and GFC for 1 year and for a rotation cycle of 20 years for the maximum scenario with 210,000 ha

Energy crop type	**Primary energy of fuel (TPES),** *GWh/year*	**Primary energy of fuel (TPES), for 20 year,** *GWh*	**Final energy (GFC),** *GWh/year*	**Final energy (GFC) for 20 years,** *GWh*
100% corn silage	101,210	667,983	80,968	534,386
100% poplar	21,684	325,266	17,348	260,213
100% willow	17,990	299,824	14,392	239,859
100% miscanthus	27,730	396,540	22,184	317,232

This amount of energy can further be compared to the amount of energy that would potentially be generated at Kakhovka HPP if the dam were to be restored. For example, we know how much energy was produced by the Kakhovka HPP before it was destroyed. Over the lifetime of Kakhovka HPP and in the last 3 years before the war, 2019-2021 and in 2022, the average annual electricity production fluctuated at around 1500 GWh/year[61] with an installed capacity of 334 MW (thus, the ICUF is 55%, which fits within the upper limit of the ICUF for gravity large HPPs on flat rivers with a height difference of up to 20 m on hydraulic units and the corresponding hydrology (water flow) of the Dnipro River. If the restored new Kakhovka HPP is similar in terms of installed capacity and ICUF, it will produce 30,000 GWh of electricity over 20 years.

Knowing the amount of energy from energy crops and the amount of energy from the HPP, we can compare these two values (expressed as GFC).

Table 5.
Ratio of final energy from energy plants to final energy produced at the potential Kakhovka HPP (expressed as final energy consumption – GFC)

Energy crop type	**Ratio for the 20-year cycle (GFC)**			**Ratio for 1 year (GFC)**		
	210,000 ha 100%area	85,000 ha 40% area	42,500 ha 20% area	210,000 ha 100% area	85,000 ha 40% area	42,500 ha 20% area
100% corn silage	**17.8**	**7.2**	**3.6**	54.0	21.8	10.9
100% poplar	**8.7**	**3.5**	**1.8**	11.6	4.7	2.3
100% willow	**8.0**	**3.2**	**1.6**	9.6	3.9	1.9
100% miscanthus	**10.6**	**4.3**	**2.1**	14.8	6.0	3.0

61. https://uhe.gov.ua/media_tsentr/novyny/kakhovska-ges-65-rokiv-na-varti-energetichnoi-bezpeki

Thus, in addition to certain benefits from growing energy crops described above, for the scenario of conservative use of 20% of the released land (42,500 ha) for all energy crops, the energy yield of a 20-year rotation cycle is 1.6 (for willow)-3.6 (for corn silage) times higher than that of Kakhovka HPP expressed as final energy (GFC). The use of biomass (as a universal fuel that can be used to produce heat, electricity (including in the power system balancing mode), liquid biofuels, renewable gases, and other products) prevails over the use of electricity (as one type of energy) from HPPs.

We deliberately refrain from citing negative impacts of large hydropower generation on biotypes, biodiversity, climate processes, and local ecosystems, considering it equivalent to biomass (although large hydropower generation is not quite a full-fledged RES according to the IRENA and IEA classification, its additional negative environmental impacts (externalities) sometimes exceed its positive impacts as a RES).

Thus, the following benefits of the scenario with energy crop plantations on local clusters of the Kakhovka Reservoir floor can be identified:

1. Higher energy output than for an HPP using a much smaller area (10-20% of the released area).

2. Creation of a sustainable controlled local ecosystem that will complement and contribute to the conservation and formation of climate-resilient natural ecosystems.

3. No flooding of large areas with the corresponding impact on biodiversity and destruction of land potentially suitable for other activities (including agricultural activities in the future with multiplier effects for local communities and the Ukrainian economy).

4. Establishment of a sustainable land management system for a rotational cycle of at least 20 years in clusters integrated into the natural ecosystem (for a longer run in future).

5. Preservation or improvement of soil fertility after the end of the energy crop rotation cycle, reclamation of contaminated soils, and annual monitoring of their condition.

6. Development of the bioenergy sector in the region, which has significantly suffered from hostilities and needs rebuilding of infrastructure (with a corresponding increase in energy consumption) and at the same time has insufficient sustainable potential of local woody biomass.

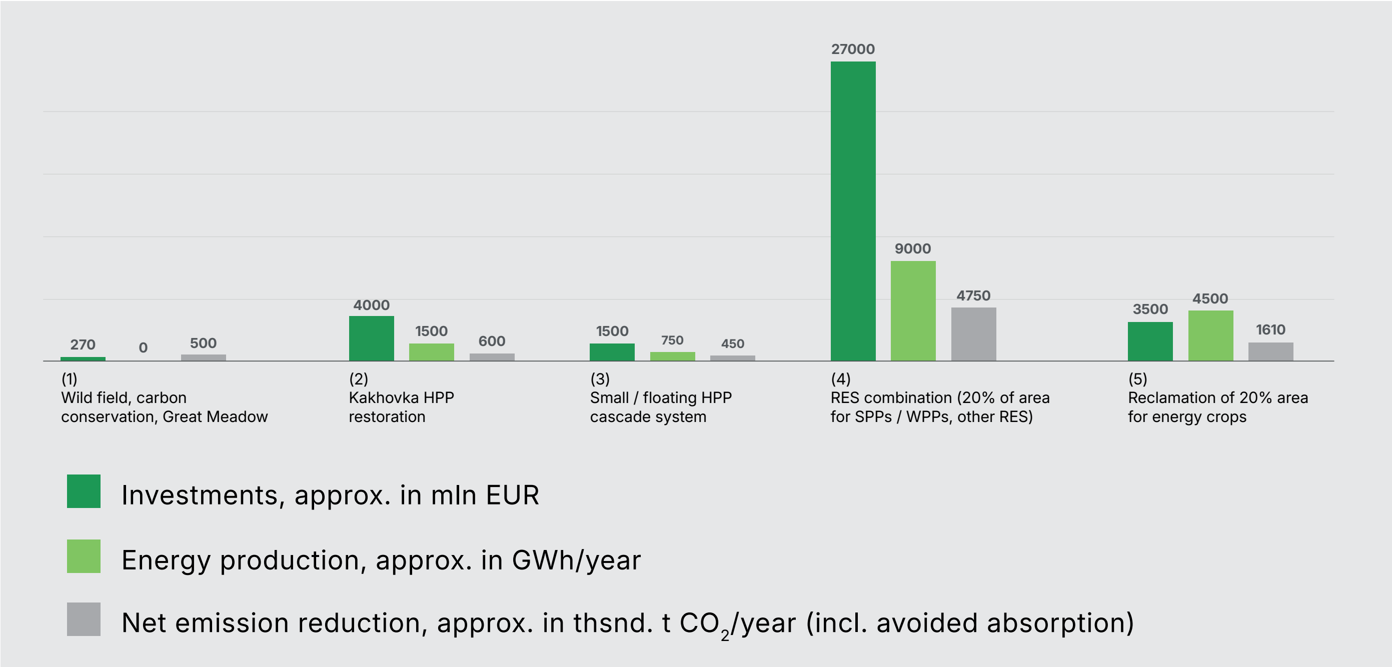
7. The versatility of biomass as a fuel that can be used in the production of heat, electricity, biofuels for vehicles, and other products (renewable gases, pellets, bio-oil, renewable commercial CO_2).

8. Decarbonization of the energy sector, and particularly the agricultural sector, contributing to the achievement of Ukraine's goals of decarbonization, climate neutrality and green recovery through sustainable technologies without disturbing the state of emerging forest ecosystems.

It should be noted that on March 16, 2024, the Cabinet of Ministers adopted Resolution No. 286[62] on the prevention of improper use of land that was occupied by the Kakhovka Reservoir. The Resolution prohibits the formation, transfer for ownership or use, and change of the designated purpose of land plots on the lands that were occupied by the Kakhovka Reservoir for the period of martial law and for five years after its termination or cancellation, except for the transfer for use, change of designated purpose of land plots for the purpose of further restoration of the Kakhovka Reservoir and construction of hydraulic structures.

62. https://www.kmu.gov.ua/news/uriad-pryiniav-postanovu-pro-zapobihannia-netsilovomu-vykorystanniu-zemel-iaki-zaimalo-kakhovske-vodoskhovyshche

Picture 16.
Comparison of scenarios in terms of initial investment and CO_2 emission reductions, final energy production



The investments for the Great Meadow option include the notional costs of research, fostering of breeding and cultivation of flora and fauna of the ecosystem, costs of security, tourism and recreation; and for the SPP/WPP combination option — also the costs of additional infrastructure for transformation, transmission, and supply of electricity (in addition to direct project costs); for the energy crops option — the total investment in the entire chain from plantation (including replanting after 20 years, i.e. two rotation cycles (40 years of project life)) to technologies for conversion of biomass into energy/products, which are proportionally divided between electricity generation (25%), heat generation (25%), biofuels for transport (25%), and renewable gas production (25%). All figures for investments, emission reductions, and energy production are approximate and allow for comparison of scenarios, but for a more accurate analysis, additional calculations and feasibility studies are required, taking into account the specifics of each type of project.

Based on the set of three parameters, the energy crops scenario has better performance compared to other scenarios and it is more versatile, on the one hand, as it has no direct ties to the territory of the former KHPP reservoir (it can be implemented on other marginal / unproductive / abandoned / degraded / polluted lands subject to reclamation in the region, such as local quarries, dumps of mining and processing plants), and no ties to the electricity supply infrastructure or to a type of energy as an output product (biomass from energy crops is a universal raw material that can be used for production of both heat and electricity, as well as other renewable products for further transformation (biomethane, renewable gases, solid and liquid biofuels, etc.)), and on the other hand, as shown above, it is characterized by a lower negative impact on the environment (and in some cases, a positive impact of reclamation and recovery on soils) compared to the other four options.

6. Versatility of the energy crops scenario

The presented scenario can be considered versatile, since it can be implemented without direct ties to a part of the Kakhovka Reservoir floor area, but in the same region on other lands that are located close to the reservoir floor in terms of geography and soil properties (marginal/abandoned). This, among other things, is determined by the specifics of the region in which the scenario is proposed, namely the following factors

1. The presence in the immediate vicinity (20-30 km, mainly in Kryvyi Rih and Marhanets territorial communities) of other lands or clusters classified as marginal/abandoned/polluted, namely:

   - Quarries that have already been decommissioned and require reclamation (currently overgrown with wild willow and poplar species), or those that have been exhausted and are being prepared for conservation in the near future, dumps of quarries, mines, mining and processing plants (GZK) that require reclamation. The total estimated area of decommissioned quarries and dumps is about 1,500 hectares, and those that will be decommissioned soon – up to 1,000 hectares. The main quarries are those associated with mining and processing plants (Pivden GZK, Pivnich GZK, Ingulets GZK, Chkalovskyi GZK, potentially uranium ore mines (Zhovti Vody, Vilnohirsk) etc.).

   - Local landfills of solid domestic wastes (SDW) with higher-than-average morphological composition indicators of inorganic industrial waste in Ukraine (as the region itself is highly industrialized and industrial waste is taken to local landfills), which are also subject to closure and reclamation (some have already been closed but not reclaimed). The estimated area at a distance of 50-100 km from the reservoir (right bank of the Dnipro River) is up to 500 hectares.

   - Lands degraded as a resulting of permanent hostilities – destroyed forest plantations, agricultural land, certain areas of cities and towns that need restoration/reclamation on both sides of the Dnipro River. The area of such lands on the right bank in a 10 km deep and 100 km long strip along the reservoir is estimated at 1,500 hectares.

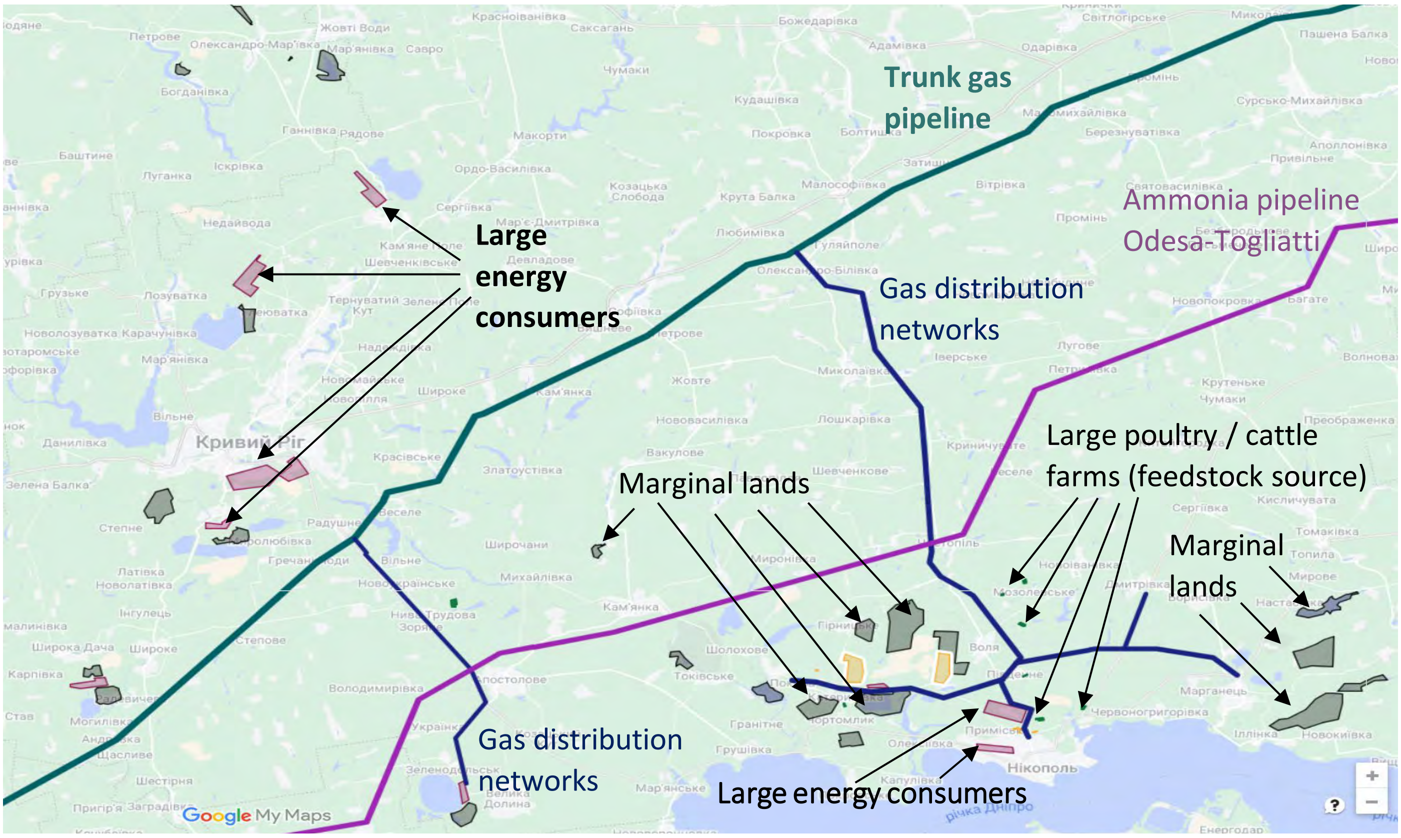
2. Developed infrastructure of renewable energy generation facilities (SPPs/WPPs) at a distance of up to 50-100 km from the reservoir, which makeskes it possible to implement integrated projects for the combined use of energy from RES and energy crops within a single cluster.

3. Availability of large-scale additional sources of biomass in the region — harvesting crop residues of agricultural activities (corn, grain straw, sunflower), the region is agriculturally developed, with clusters of fields of several large agricultural holdings concentrated compactly along the reservoir, which are both producers of biomass resources and potential consumers of the energy produced. The total indicated annual potential in the area of 100 × 50 km from the reservoir is estimated at 450-550 thousand tons (100-120 thousand toe/year of primary energy). In addition, there are sources of biomass from livestock waste (manure and manure water) — from poultry complexes (the largest poultry complex in Ukraine — Dniprovskyi – 7 km from the reservoir), cattle farms, pig farms (Strong-Invest Agro Holding "KSG-Agro", Niva Trudova, which also has fields nearby, "Zootechnology" (Novoraysk)), the total indicated potential is estimated at 140-150 thousand toe/year).

4. Industry, which is a potential large consumer of energy produced from energy crops, a potential site with existing infrastructure and land for the implementation of a complex project using different types of the biomass and integration of RES. The main ones are Nikopol Ferroalloy Plant, ArcelorMittal, Kryvyi Rih Cement, ArcelorMittal Technology Park, Pivden GZK and other mining and processing plants, local CHP/TPPs, and other enterprises in Kryvyi Rih, Nikopol, Marhanets, and Zaporizhzhia. ArcelorMittal and Kryvyi Rih Cement have already expressed interest in implementing integrated RES projects, including for firing kilns (partially implemented at Kryvyi Rih Cement's kilns using sunflower husk waste) and for the production of biomethane (and other renewable gases) for steel making technology, to meet their own energy needs (combustion at the plant's CHP) or to supply into the gas grid. Thus, existing enterprises can

act as investors or co-investors in energy plantations, also as part of reclamation of their own infrastructure of dumps and closed mining and processing plants (within the same ownership, which simplifies the project cycle).

The total area of land that may be subject to reclamation in the area next to the Kakhovka Reservoir (100×50 km) is currently about 2,000 hectares, and those that will be subject to reclamation in the near future add another 2,800 hectares, for a total of 4,800 hectares, i.e. 15% of the area for the scenario of 20% of the Kakhovka Reservoir floor area for energy crops. The main difference is the greater dispersion of areas, which can increase the value of biomass from energy crops due to higher costs (mainly due to more complex logistics and economies of scale). Therefore, in this case, since there are fewer biomass resources from energy crops, it is advisable to consider a vertically integrated closed-cycle project as a comprehensive RES project rather than just a project of growing energy crops as a separate type of activity and selling biomass as the final product. This can be realized as a cluster with the integration of local SPPs/WPPs (or adding new ones), using existing manure and agricultural waste as additional raw materials. The production outputs can be various products — heat, electricity, cold energy, biomethane, biogas, digestate, organic fertilizers, liquid biofuels (I-III generation), bio-oil, renewable hydrogen or other gases, renewable CO_2 (absorption) for further commercial use. The integrated renewable gas project has another advantage, as the region has a developed gas infrastructure with some of the largest individual consumers of natural gas in Ukraine (i.e., high capacity of gas distribution networks and the Dnipro-Kryvyi Rih-Tiraspol gas pipeline, which does not limit the project scale), and the Dnipro-Port Yuzhne (OPZ)-Odesa ammonia pipeline for potential export of green hydrogen (as shown on a scheme of the compact location of the mentioned infrastructure in the area near the ex-Kakhovka military base, developed by the authors of the study[63]).



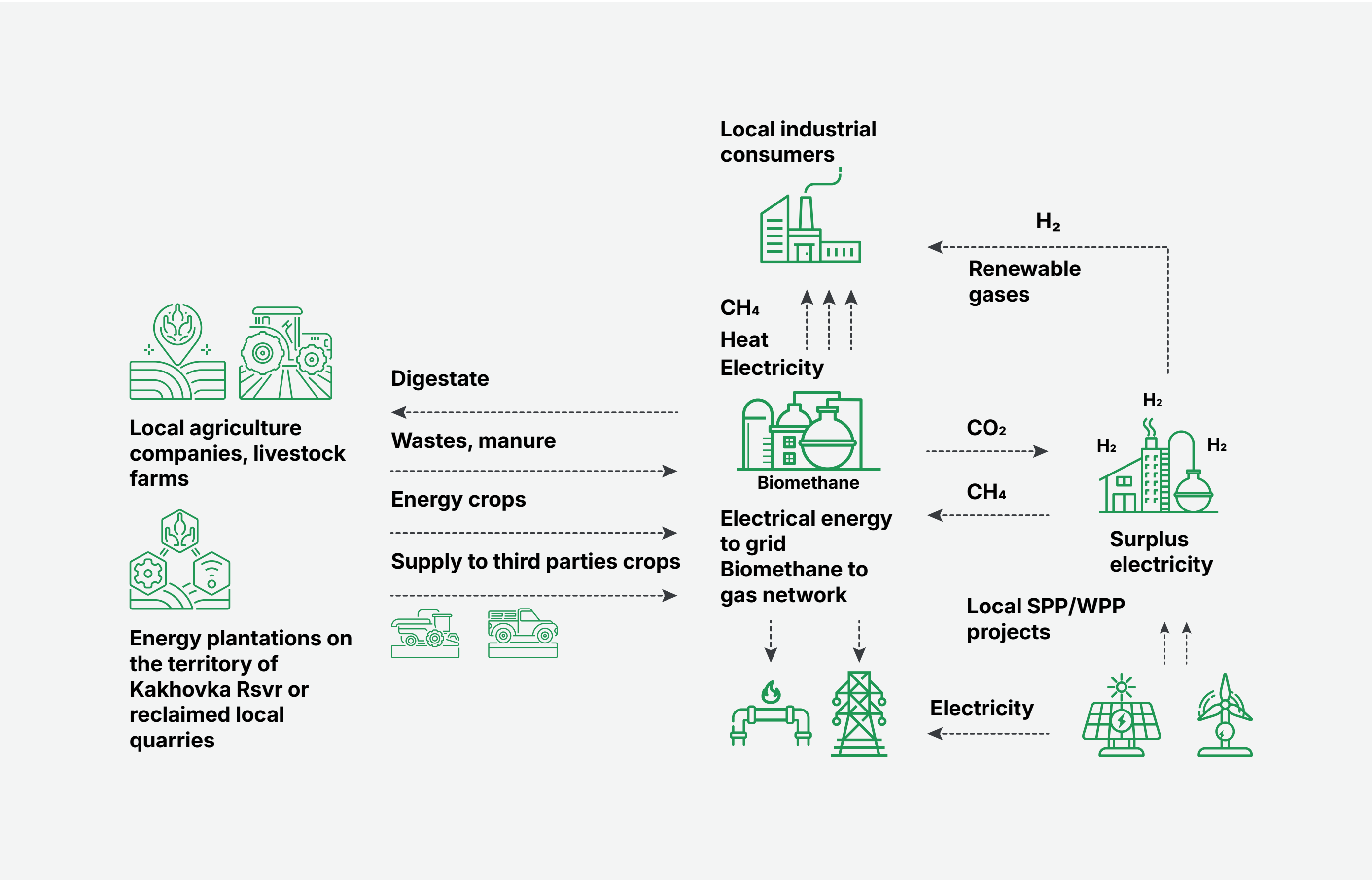
Picture 17.
Territorial location of infrastructure and potential areas of degraded and marginal land for recultivation near the Kakhovka reservoir

For example, a biomethane production project based on the scenario of 4800 hectares for energy crops (corn silage) and other available biomass in the region can have a scale of up to 20 million nm^3/year of biomethane equivalent (within one cluster), and a by-product can be the production of renewable CO_2 (when biogas is treated to biomethane) — up to 15 million m^3/year (which is also a direct absorption of CO_2 emissions). In case of using a certain share of capacities for RES that is «freely» available in the region (as its intake into the grid is periodically limited by the operator due to the current state of the grid and other factors), such a project can produce up to 80 million nm3 of renewable hydrogen, which can eventually produce additional 20 million m^3 of biomethane (the process of methanation of hydrogen and CO_2, the Sabatier reaction).

63. https://www.google.com/maps/d/edit?hl=uk&mid=1mgEvIGS-BMn_S8wsnt_oZDcXUBieLD8&ll=47.98428283294925%2C33.399955465924315&z=10

The total investment in such an energy cluster project (40 million m3 of biomethane or 20 million m3 of biomethane + 80 million m³ of renewable hydrogen) could amount to 150-220 million EUR (including 35-45 million EUR of investments in two rotations of the 4800 ha corn silage energy plantation), depending on the equipment configuration and other factors, the total energy production (in the GFC) may amount to 20-25 thousand toe/year. This energy has a number of advantages over electricity from the HPP, as it is more flexible, independent of climate and weather, and can be used to balance the power system. For comparison, investments in the reconstruction of the Kakhovka HPP could amount to 3-5 billion EUR with energy production of 120-130 thousand toe/year.

As an example, the implementation of an energy cluster, where an energy crop plantation will play a supporting role supplying raw materials, may look like this:



Picture 18.
Implementation of the energy cluster

Such an energy cluster is more versatile in terms of both raw materials and output products compared to any other individual energy production option considered. It should also be noted that the use of energy crops for fermentation is more acceptable if it is confirmed that the concentration of heavy metals and other pollutants in the soil of the Kakhovka reservoir basin is significantly higher than the norm. In this case, the organic and inorganic parts of the feedstock will be separated by the biogas/biomethane digestion process and either partially decomposed or bound, or settled as a digestate (which, depending on the concentration of pollutants, can be reused in recycling, for example, returned to fields as organic fertiliser or to the reservoir bottom soil for its reclamation, as well as an additive in the production of construction materials).

7. Combined recovery scenario

In order to combine the analysed restoration alternatives, a «compromise» or so-called combined restoration scenario is proposed. It takes into account the positive features of each analysed option and offsets certain inherent disadvantages of each option. In addition, in the combined scenario, each alternative complements each other in terms of energy production, meeting public needs, maximising benefits to communities and not causing additional environmental damage, and minimising the use of the reservoir bottom area.

After analysing the various combinations, the following configuration of the combined option is proposed, using all the options considered in a certain proportion:

1. Implementation of technical hydraulic structures (with bypass channels) for 3 purposes of meeting public needs (without energy production): flood control, water supply, and navigation.

   Where possible, and where it does not interfere with navigation, introduce additional small hydropower generation at the technical hydraulic structures — up to 10-20 small hydropower plants (installed capacity 50 MWel (see Section 2.3), electricity output 150 GWh/year) to ensure 10% of the equivalent energy output of the KHPP. The estimated area of flooding for these purposes based on similar projects is up to 20,000 ha (9.3% of the total area). This is a significant area of flooding, but it is the minimum (or close to the minimum) price for restoring water supply (especially for the left bank), flood control and navigation.

2. Use of SPP/WPP to provide up to 50% of the equivalent energy output of KHPP (700 GWh/year) in the following configuration:

   - Installed capacity of SPP — 400 MWel, electricity output (GFC) — 350 GWh/year, area — 400 ha (0.2% of the area of the reservoir).

   - Installed capacity of the wind farm — 200 MWel, electricity output (GFC) — 400 GWh/year, area — 100 ha (0.05% of the total area).

   This component is purely energy-related, on the one hand, with minimal use of the area, and on the other hand, with reference to the scale of energy production before the KHPP was blown up.

3. Use of energy crops to produce 1950 GWh (GFC) in the following configuration:

   - 650 GWh for electricity in combination with other technologies (covering 100% of the equivalent electricity production of KHPP).

   - 650 GWh of heat for local communities (50% in cogeneration mode with electricity production).

   - 650 GWh for energy products (biogas, biomethane, liquid biofuels, solid biofuels).

   The total area of such a cluster of energy crops is 12,000...15,000 hectares, of which 4,000 hectares are on marginal lands for recultivation and recovery outside the reservoir (closed mines, dumps, quarries), and 8-11 thousand hectares on the reservoir (3.7...5% of the reservoir area).

   A component of combined production of electricity, heat and other energy using the minimum area of the reservoir and the maximum area of neighboring marginal lands.

4. The rest of the reservoir area (85%-86%) is left for natural recovery.

Table 6.
Summary indicators of the combined recovery option

Recovery option	Installed capacity, *MWel*	Energy output (GFC), *GWh/year*	% of KHPP energy	Utilised reservoir area, *ha*	% of reservoir area utilisation
Implementation of technical hydraulic structures	-	-	-	20 000	9.3%
Implementation of additional small hydropower generation at technical hydropower facilities	50	150	10%	0	0%
Use of SPPs/WPPs (reservoir area, where possible, SPPs — above-water)	400 SPPs + 200 WPPs	350 SPPs + 400 WPPs	40%	400+100	0.2+0.05%
Use of energy crops (reservoir area and neighbouring marginal lands)	-	3 x 650	3 x 40%	11000	5%
Natural recovery	-	-	-	183 500	85.5%
TOTAL	**-**	**1550 (electricity) + 1300 (heat/other)**	**100% (electricity) + 80% (heat/other)**	**215 000**	**100%**

8. Sources of special-purpose funding for restoration and reclamation projects on the territory of the former reservoir

The energy crops scenario has another advantage – potentially wider financing opportunities compared to the restoration of a large hydropower plant, as it involves the implementation of green reclamation technologies, circular economy, renewable energy production and meets the fundamental requirements of the green transition and the European Green Deal, as well as sustainability and biodiversity criteria. Such projects can usually be financed from separate programs and funds that specialize in financing certain types of projects, support both pilot, demonstration and commercial projects, and include provision of grant funding (which improves the economic indicators of the project). At the same time, the likelihood that IFIs will finance large-scale hydropower generation due to the flooding of large areas that are currently not flooded, the negative impact on the emerging local ecosystem, the negative impact on biodiversity, and the failure to meet certain sustainability criteria is low or zero. Centralisation of production also poses security risks for potential international investors. Most IFIs have now refused to finance large hydropower generation (only long-term projects under construction in China and Brazil), which carries high reputational risks for the IFIs and Ukraine.

The main potential investors in the energy crops option may include IFC, World Bank, EBRD, UNDP/UNIDO funds, specialized programs such as GEF, European Climate Foundation as well as national investors. Common traits of all these funds are their clear criteria for project selection (availability of a fully bankable project feasibility study), focus on projects generating direct reductions in greenhouse gas emissions (this is the main selection criterion – «climate friendly/mitigation projects») and do not finance large centralized energy sector, respectively, such technologies as large HPPs, coal-fired power generation, and nuclear power plant construction.

Table 7.
International and national programs for financing restoration projects (which do not finance the restoration of large HPPs but do finance green projects of various types)

Name	Type	What is covered	Who is eligible?
Access to Energy Fund – Energy for growth	Fund	The ultimate objective of the AEF is to support private sector projects involved in the generation, transmission or distribution of energy to ensure sustainable access to energy services in emerging markets and developing countries. Bioenergy activities supported: Generation, transmission or distribution of energy.	
European Investmen Bank	loans, guar-antees, equity investment s and advisory service	The Bank aims to support projects that promote the priorities and objectives of the European Union. It prioritises support to six areas, namely climate and environment, development, innovation and skills, small and medium-sized businesses, infrastructure and cohesion. Bioenergy: Switching fossil fuels, Waste management, Renewable energy (i.e. biomass) and Biogas.	Large and small-scale investment projects contributing to EU policy objectives.
USAID-CTI Private Financing Advisory Network (PFAN)	Financing funds	Clean energy, solar, wind, hydro, biomass, biofuels, waste to energy, biogas.	Small and midsize enterprises & micro-projects which provide climate change adaptation benefits and seek an investment in the range of USD 1 million to USD 50 million. Projects that promote gender mainstreaming aspects within internal operations and market facing activities. Project developer should commit himself to implement PFAN advice. The project should lead to GHG potential reduction.
Eastern Europe Energy Efficiency and Environment Partnershi (E5P)	Grants	District heating Energy efficiency in public buildings (schools, kindergartens, hospitals) Energy saving measures in residential housing Renewable energy (including biomass) Street lighting Water and wastewater treatment Solid waste management Urban transport.	Municipal sector projects.
ESFC Investment Group	Loans	Biomass energy projects such as thermal power plants and district heating systems in agricultural municipalities.	Large-scale projects involving the private or public sector.
Copenhagen Infrastructure Partners (CIP)	Joint ventures, debt financing,	All of CIP's funds invest in renewable energy infrastructure projects which assist in transitioning the global economy into a net-zero emissions scenario by 2050. Biomass projects incl.	

Donor	Comments	Link to the web-site	Link for proposals submission
51% of the shares held by the Dutch State and 49% held by commercial banks, trade unions and other members of the private sector.	Mainly focused on Africa, however Ukraine is also in the list of the supported countries (5 projects were implemented https://www.fmo.nl/world- map?search=&re-gion=ua&year=&p rojects=allProjects&sec-tor%5B%5D=3).	Link	Link
EU	No special formalities are involved for the submission of applications and the EIB does not require its borrowers to complete set forms or questionnaires. Project promoters are required to simply provide the Bank's Operations Directorate with a detailed description of their capital investment together with the prospective financing arrangements to allow the EIB to assess whether the project adheres to the set lending objectives and has a well-developed business plan.	Link	Contact information
PFAN is a global, multilateral public private partnership initiated by USAID and the Climate Technology Initiative (CTI) in cooperation with the UNFCCC Expert Group on Technology Transfer (EGTT). PFAN is hosted jointly by the UNIDO and REEEP. Activities are mainly funded by Governments of countries which include Australia, Sweden, and the USA, int. organizations and private sector.		Link	Application process
EU	The E5P is a €408 million multi- donor and multi-IFI Fund operating in Ukraine, Armenia, Azerbaijan, Georgia and Moldova. It was initiated during the Swedish Presidency of the European Union in 2009. It aims at supporting high impact energy efficiency and environmental investments in the Eastern Partnership countries.	Link	
ESFC Investment Group,		Link	Application form
		Link	

Table 7.(continuation)
International and national programs for financing restoration projects (which do not finance the restoration of large HPPs but do finance green projects of various types)

Name	Type	What is covered	Who is eligible?
IFC programs	Grants / loans	• Climate-smart agriculture. • Regenerative agriculture. • Alternative production practices. • Adoption of innovation and technologies. • Sustainable aquaculture production. • Conservation or restoration to create. • biodiversity credits for meeting mitigation requirements. • Nature-based solutions for solar farms.	Projects in developing countries profitable • In the private sector. • Technically sound with good prospects of being profitable. • Benefit the local economy. • Environmentally and socially sound, satisfying ifc`s environmental and social standards as well as those of the host country. iFC does not lend directly to micro, small, and medium enterprises or individual entrepreneurs, but many of investment clients are financial intermediaries that lend to smaller businesses.
Global environment facility	Grants	GEF priorities: To achieve the objectives of multilateral environmental agreements, it is required that the GEF support country priorities that are ultimately aimed at tackling the drivers of environmental degradation in an integrated fashion. For this reason, the focal areas (Biodiversity, Climate Change, Land Degradation, International Waters, and Chemicals and Waste) remain the central organizing feature in the GEF-8 Programming.	Eligible country: Countries may be eligible for GEF funding in one of two ways: a) if the country has ratified the conventions the GEF serves and conforms with the eligibility criteria decided by the Conference of the Parties of each convention; or b) if the country is eligible to receive World Bank (IBRD and/or IDA) financing or if it is an eligible recipient of UNDP technical assistance through its target for resource assignments from the core (specifically TRAC-1 and/or TRAC-National priority: The project must be driven by the country and be consistent with national priorities that support sustainable development. Financing: The project must seek GEF financing only for the agreed incremental costs on measures to achieve global environmental benefits. Participation: The project must involve the public in project design and implementation, following the Policy on Stakeholder Engagement and the respective guidelines.
EBRD	Loans/ guarantees	• Agribusiness Energy efficiency. • Natural resources. • ower and energy. • Small and medium-sized enterprises.	To be eligible for EBRD funding, the project must: • Be in an ebrd country of operations. • Have strong commercial prospects. • Involve significant equity contributions in-cash or in-kind from the project sponsor. • Benefit the local economy and help develop the private sector. • Satisfy banking and environmental standards.
BIOFIN	Grants	Biodiversity related activities.	Governments, civil-society, vulnerable communities, private sector.

Donor	Comments	Link to the web-site	Link for proposals submission
	Biodiversity finance guidance from IFC	Link	How to apply
World Bank	Guidelines for small-grant projects	Link	
	EBRD already provided loan to Lan- oil LLC build the first greenfield, privately owned, biofuels project	Link	Guide
UNDP	Methodology	Link	

Under these financing schemes, similar projects have been financed to restore unproductive lands, grow energy crops, small-scale biogas production projects, restore small communities with the help of renewable energy sources, etc. (the implementation of large HPPs is not financed).[64]

In addition to these special-purpose financing programs for green projects and sustainable infrastructure recovery projects (without additional negative impact on regional ecosystems), it should be borne in mind that the Big Recovery Portal has already been established to finance recovery projects compliant with sustainability criteria.[65] The EU will introduce independent control over the expenditures for recovery of Ukraine, and the on-line platform — the Big Recovery Portal — will monitor spendings and project implementation independently of the government.

The Delegation of the European Union to Ukraine.[66] could be another potential donor (co-investor) in the project. Thus, work on a new project to monitor the costs of recovery projects (involving the Center for Economic Strategy, the Institute for Economic Research and Policy Consulting, and the Public Organization «Technology of Progress») has already started, which will preliminarily analyze in particular various options for recovery or non-recovery of the KaHPP.

Of course, the next steps for the selected scenario or pool of scenarios should include a detailed feasibility study in an international format (e.g. EBRD, IFC), which would comprehensively present the cost-effectiveness calculations, parties involved, specific equipment, and calculate the multiplier effects on the economy. Such a feasibility study may also include a detailed quantitative comparison of several options, as was previously done in this policy paper.

64. Case study: BioVill-bioenergy villages (cross-border cooperation) in Serbia, Croatia, Macedonia, Romania, Slovenia funded by Horizon 2020
Case study: BioEnergy Farm II. The aim is to develop the biogas micro-installation market. These activities can increase the amount of renewable energy produced on farms by 60 MW. European Union, Intelligent Energy for Europe
65. https://brp.org.ua/en
66. https://www.eeas.europa.eu/eeas/%D0%BF%D1%80%D0%BE%D1%94%D0%BA%D1%82%D0%B8_uk?s=232

Conclusions

1. The analysis showed that the best scenario in terms of a set of indicators is the combined recovery scenario, which includes the use of all options to complement each other. The hydrotechnical part of this scenario includes the construction of technical hydraulic structures to be used exclusively for water supply, navigation, flood control, operation of the upstream hydroelectric cascade, prevention of water salinisation, fisheries in the region and solving related problems, while the energy part is mainly covered by other technologies (energy crops, solar/wind farms, small hydroelectric power plants on technical hydraulic structures) with minimal use of the reservoir area and maximum energy output. In this scenario, up to 86% of the reservoir area is left for natural ecosystem recovery.

2. According to the selected criteria, the best individual recovery scenario is formally the use of individual cluster sites (up to 10-20% of the Kakhovka reservoir bottom area) for growing energy crops. This option is the most balanced in terms of maximum benefit to communities, minimum environmental damage, and meeting public needs at the level before the Kakhovka HPP was blown up. It combines, on the one hand, the possibility of integration into the local ecosystem and contribution to its sustainable restoration and sustainability (soil restoration, absorption of heavy metals, sludge, and other inorganic sediments, and their concentration in ash after combustion). On the other hand, it ensures the generation of biomass as a renewable energy source to produce an equivalent (or greater) amount of energy to the PSP. The second place among the individual scenarios is taken by a group of three options - rebuilding the KHPP, natural restoration of the Velykyi Luh, and construction of a combination of SPP/WPP on 10-20% of the reservoir. According to a set of indicators, the best option of the three is the natural restoration of the Great Meadow.

3. 3) The ratio of energy that can be obtained from energy crops grown on 20% of the reservoir bottom area and the amount of energy from the restored KHPP is in the range of 1.6-3.6, depending on the type of energy crops, climatic conditions, moisture conditions, soil types (20-year rotation cycle) and 1.9-10.9 (recalculation for 1 year). Investments in a plantation project of this scale amount to 250-300 million euros, taking into account the entire chain from plantation to energy (or biomass products) supply — 3.5-4.0 billion euros. This is commensurate with the investment in the rehabilitation of the KHPP (3-5 billion euros). CO_2 emission reduction from the energy crops scenario for the entire chain is 1.6 million tonnes of CO_2-eq/year (on average for a 25-year rotation cycle), and for KHPPs - 0.6 million tonnes of CO_2-eq/year.

4. Compared to natural recovery, preliminary estimates based on practical data for existing energy crop plantations in Ukraine (for the last 10 years) and abroad (for the last 30 years) show that the use of energy crops on marginal / contaminated / abandoned / degraded lands which may include some areas of the reservoir bottom, has either a neutral or insignificant positive impact (in terms of integration of economic activity into the local ecosystem, restoration and reclamation of contaminated soil, management and monitoring of these areas). At the same time, 85-90% of the reservoir area is left for natural recovery, and there is no need to flood 215,000 hectares of the protected area (where a new ecosystem is already developing naturally), which would lead to irreversible negative consequences for the region's environment and entail high reputational risks for Ukraine as a whole.

5. The option of introducing energy crops is universal both in terms of conversion and production of various types of energy and in terms of the possibility of being partially tied to the reservoir territory. It can also be implemented in the same region for the reclamation of degraded lands (abandoned quarries, mining dumps, landfills, areas affected by military operations, etc.) in combination with other options and be an integral part of an energy cluster for the combined production of various renewable products (heat and electricity, renewable gases, organic fertilisers (digestate), renewable CO_2, etc.), which is facilitated by the region's significant agrobiomass resources, developed electricity transmission and natural gas transportation infrastructure, large industrial energy consumers, and large-scale renewable energy projects already implemented (SPPs/WPPs). This scenario is thus not opposed to others, but rather can be a baseline for recovery in combination with others or complementary to other alternatives.

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