



Adaptive natural resource management as a driver of sustainable economic development in Ukraine: Challenges and opportunities

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Abstract. The study aimed to analyse the impact of adaptive natural resource management on the sustainable economic development of Ukraine. Specifically, it focused on the challenges the country faces in adapting to changing environmental conditions and the strategies needed to overcome these barriers to ensure efficient resource utilisation. The research explored the role of adaptive management in addressing critical issues such as natural resource depletion, environmental degradation, and climate change, all of which significantly influence Ukraine's economic stability. Key challenges examined included water pollution, soil degradation, atmospheric pollutant emissions, and the environmental consequences of war. The analysis highlighted the potential of adaptive management to enhance the country's economic competitiveness, improve resource efficiency, and foster investment in the "green" economy. The study identified significant barriers to the effective implementation of adaptive strategies, including insufficient data for environmental monitoring, an outdated regulatory framework, and limited involvement of communities and businesses in management processes. Statistical data on water pollution, pollutant emissions, degraded land, and the environmental impact of war provided a basis for assessing the current situation. The findings also revealed opportunities to address these issues through innovative technologies, legislative improvements, and the development of financial mechanisms, such as "green" bonds and grants. The conclusions emphasised that achieving sustainable economic development in Ukraine requires institutional reforms, enhanced monitoring systems, and increased investment in environmental projects. Furthermore, international cooperation and the promotion of educational initiatives were identified as essential components for advancing sustainable development goals.

Keywords: ecological sustainability; environmental policy; national security; management strategies; ecosystem services

INTRODUCTIONS

Adaptive management of natural resources is a critical component of sustainable economic development in Ukraine, particularly in the context of climate change, environmental crises, and high levels of natural resource exploitation. The challenge of ensuring the rational use of natural resources has become increasingly urgent in light of global phenomena such as resource depletion, ecosystem degradation, biodiversity loss, and

environmental pollution. For Ukraine, this issue holds special significance due to the country's abundant natural resources, which, despite their potential, are subject to inefficient use, leading to severe environmental and economic challenges. Adaptive management, characterised by flexible and dynamic approaches to planning and resource utilisation, offers a promising solution to address these pressing issues.

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A substantial body of research exists on adaptive management of natural resources, predominantly focusing on the theoretical principles and general aspects of this approach. For instance, J. Fransen *et al.* (2024) explored the application of adaptive management in the Mathare district of Nairobi during the COVID-19 pandemic. Their study analysed how local organisations enhanced community resilience through initiatives targeting the most vulnerable populations during crises. The authors highlighted the pivotal role of citizen engagement and collective action in mitigating the adverse impacts of global disasters. In a related context, W. Wang *et al.* (2024) examined the interplay between green policies and financial development in the G7 countries. Their research assessed how environmental regulations can drive economic growth by fostering green development. Particular attention was given to how environmental initiatives attract investments and strengthen financial stability, aspects crucial for economies striving toward sustainability.

The relationship between renewable energy and natural resource conservation in developing countries was analysed by H. Zhang *et al.* (2024), who emphasised the critical role of renewable energy sources in promoting sustainable development and conserving natural resources. Their study demonstrated that the efficient utilisation of renewable resources is essential for improving environmental conditions, particularly in nations with limited natural resource availability. M. Islam & D. Chadee (2024) investigated the adaptive management of global supply chains and its influence on the resilience of suppliers in developing countries during external shocks, such as economic crises and natural disasters. Their research proposed an adaptive management model designed to maintain supplier efficiency under challenging conditions, thereby enhancing the overall resilience of global supply chains.

The efficiency of natural resource utilisation and the advancement of green economies in BRICS countries were studied by L. Fan & D. Wang (2024). Their research focused on recent innovations in clean energy and globalisation, highlighting their contributions to economic growth and the reduction of greenhouse gas emissions. The study underscored the importance of international collaboration and technological advancements in ensuring the sustainable use of natural resources. Further, Z. Gatgash & S. Sadeghi (2024) analysed the effects of various management strategies on soil quality, water resources, and the overall ecological status of watersheds. Their results demonstrated that adaptive management approaches, characterised by flexibility and responsiveness to ecosystem changes, offered significant advantages over traditional management practices. Specifically, adaptive management was associated with improvements in water quality, reductions in soil erosion, and increases in biodiversity in the areas studied.

T. Demianenko (2023) investigated mechanisms to promote the sustainable development of industrial enterprises in Ukraine, proposing models that integrate environmental and economic dimensions for achieving sustainable industrial growth. The study underscores the

critical importance of synergy between economic and environmental initiatives to drive sustainable industrial development. C. Işık *et al.* (2024) explored the influence of Environmental, Social, and Corporate Governance (ESG) factors on economic growth in East and South Asia. Their research highlights how ESG considerations can support sustainable development in regions where rapid economic growth is often accompanied by significant environmental and social challenges.

An important gap in existing research is the lack of comprehensive studies that address the local characteristics of Ukraine. This includes the impact of war on ecosystems and natural resources, the urgent need for infrastructure restoration, the adaptation of legislation, and the active involvement of communities in management processes. These factors present unique and evolving challenges that have not yet been sufficiently studied.

Thus, the aim of this study was to evaluate how adaptive natural resource management can contribute to sustainable economic development in Ukraine. It provided a comprehensive analysis of current challenges and barriers to the effective utilisation of natural resources, while exploring prospects for implementing adaptive management approaches. The study emphasised the importance of strengthening institutional and financial systems, fostering the integration of local communities and businesses, and leveraging innovative technologies to enhance resource efficiency and sustainability in Ukraine.

MATERIALS AND METHODS

The study focused on analysing the adaptive management of natural resources in Ukraine and evaluating its economic efficiency. The methodological approach employed a comprehensive analysis that integrated the examination of international experience with an assessment of the current situation in Ukraine. The research was grounded in the analysis of statistical data and the comparison of international practices. Official data from the State Statistics Service of Ukraine (2023) served as the primary source of information. A review of scientific literature enabled the identification of key principles and characteristics of adaptive management. These include flexibility, the capacity to respond promptly to changes, and the incorporation of innovative technologies.

Systematic and problem analysis was conducted to outline the key challenges associated with implementing adaptive approaches in natural resource management. The underlying causes of these challenges were identified, and their potential ecological and economic consequences for the state were predicted. Factor risk analysis was employed to evaluate the risks and barriers to implementing adaptive management. This method facilitated the identification of critical issues, including latent factors influencing data variables, and allowed for an assessment of both external and internal factors impacting the effectiveness of adaptive management.

A multifactor analysis was used to examine the impact of adaptive management on economic development. This

analysis assessed the relationship between the adoption of adaptive strategies and improvements in the economic productivity of various regions. It enabled the identification of influencing factors and provided a basis for predicting management outcomes to support social and economic growth and sustainable development. Examples of adaptive management implementation in different countries, including Ukraine, Sweden, Norway, and Canada, were analysed. The findings highlighted numerous benefits of adaptive management, particularly its role in the efficient utilisation and preservation of natural resources.

The study examined the impact of innovative technologies on the effectiveness of adaptive management of natural resources. The potential applications of satellite monitoring, geographic information systems (GIS), the Internet of Things (IoT), and Big Data for collecting and processing information on the state of natural resources were explored. Their role in monitoring changes in soils, water resources, and forests was analysed, alongside the potential for predicting risks and developing optimal management solutions using artificial intelligence. Predictive methods were employed to determine the prospects and primary directions for implementing adaptive management of natural resources in Ukraine.

Data systematisation and processing were conducted using SPSS and Excel software tools, enabling the analysis of key trends, identification of correlations among various indicators, and assessment of the impact of adaptive management on natural resource sustainability. The analysis incorporated both quantitative and qualitative aspects, ensuring a comprehensive approach to the study.

RESULTS

Theoretical foundations of adaptive natural resource management

Adaptive management of natural resources is a concept centred on a flexible and dynamic approach to decision-making within the inherent uncertainty of natural ecosystems. This approach involves continuous monitoring of resource conditions and the timely adjustment of management strategies in response to new data and external changes. In scientific literature, adaptive management is often described as a “learning-by-doing process” aimed at mitigating environmental degradation risks while ensuring sustainable resource use. Its defining feature is the integration of scientific knowledge, management practices, and feedback to enable continuous improvement of decisions (Fernandes *et al.*, 2021).

A key principle of adaptive management is flexibility, which allows for rapid responses to changes in ecosystem and resource conditions – an essential capability in the face of global uncertainties, such as those posed by climate change.

Integrativeness refers to the coordinated interaction among various sectors – economic, social, and environmental – and across governance levels: national, regional, and local. A focus on the long-term perspective ensures that the needs of future generations are considered in alignment with sustainable development goals. The involvement of stakeholders, including communities, businesses, scientists, and government entities, is another critical element, enhancing the effectiveness of management measures. Finally, continuous monitoring of resource conditions and a robust feedback loop enable the refinement of strategies in response to emerging challenges and the outcomes of prior actions.

Adaptive management plays a crucial role in advancing the global Sustainable Development Goals (SDGs). Under SDG 13 (Climate Action), adaptive management enables rapid responses to changing climate conditions, mitigating negative impacts on ecosystems and human communities. Key strategies include implementing sustainable natural resource management practices, developing innovative technologies to reduce greenhouse gas emissions, and improving energy efficiency. In the context of SDG 15 (Life on Land), adaptive management supports the restoration and conservation of biodiversity, protects land from degradation, and maintains healthy ecosystems. These efforts are foundational for ensuring food security and enhancing the resilience of local communities. Adaptive management relies on continuous ecosystem monitoring, using collected data to refine management policies and practices. This dynamic approach helps safeguard natural resources for future generations (Intergovernmental Panel on..., 2014; Food and Agriculture..., 2019).

Community engagement and the incorporation of traditional knowledge are integral to promoting social justice and reducing inequalities in resource access. Adaptive management fosters equitable resource distribution, reducing social disparities and contributing to sustainable development. Integrating traditional knowledge into modern natural resource management techniques not only supports ecological balance but also strengthens the sustainability of local livelihoods, reducing vulnerability to environmental and social crises.

Modern challenges in natural resource management

Modern challenges in natural resource management arise from a combination of global and local factors that significantly impact ecosystems and the natural environment. These factors generate new threats to sustainable development and underscore the need for integrated approaches to addressing environmental issues. Table 1 presents an overview of the key challenges in natural resource management along with their environmental and economic consequences.

Table 1. Key challenges in natural resource management

Challenges	Reasons	Consequences	Impact on the economy of the country
Resource depletion	Over-extraction, demand growth	Raw material shortage, rising costs, threat to economic stability	GDP decline resulting from increased energy import costs, rising energy prices, and job losses in the extractive industries

Table 1. Continued

Challenges	Reasons	Consequences	Impact on the economy of the country
Environmental degradation	Pollution, overexploitation of land and water systems	Productiveness deterioration, ecosystem destruction, threat to biodiversity	Decreasing agricultural yields, increased costs of ecosystem restoration, and diminished export potential in the agricultural sector
Climate change	Greenhouse gases, reduction of natural CO ₂ absorption capacity	Temperature increase, frequent extreme weather events, reduced yields, economic losses	Rising costs for agrochemical treatments, declining agricultural yields, financial losses from natural disasters (floods and droughts), and infrastructure deterioration
Population growth	Population outbreak, urbanisation growth	Increasing pressure on natural resources, demand growth for energy, food and water	Rising infrastructure costs, increasing resource scarcity, economic instability
Environmental pollution	Industrialisation, lack of proper waste processing	Ecosystems destruction, pollution of water, air and soil	Increased costs for environmental clean-up and restoration, rising healthcare costs
Inefficient resource management	Insufficient planning, corruption, lack of transparent mechanisms	Uneven resource distribution, natural areas degradation	Investment attractiveness decrease, increased risks of economic losses, irrational use of the budget
Military actions	Armed conflicts, political instability	Infrastructure destruction, pollution, inability to use natural resources	Significant economic losses, rising recovery costs, reduced access to strategic resources

Notes: GDP – gross domestic product

Source: developed by the authors

One of the primary challenges in natural resource management is the growing demand for resources driven by demographic pressure. The rapid increase in the global population has led to heightened demand for food, water, and energy, placing additional stress on natural resources, particularly in countries with high levels of urbanisation and intensive industrial production. This has resulted in the depletion of natural resources, especially non-renewable ones such as minerals, oil, and natural gas. In Ukraine, this issue is particularly acute regarding the depletion of energy resource deposits, such as coal, necessitating an urgent transition to alternative energy sources. These processes pose significant economic risks for countries reliant on the export or import of such resources. The shortage of raw materials leads to increased extraction and processing costs.

An equally critical environmental challenge is pollution, which manifests in several major forms: waste disposal and recycling, particularly of plastics; transport and industrial emissions into the atmosphere; and chemical pollution of soils and water bodies. These factors not only threaten ecosystem health but also result in considerable economic losses. Reduced agricultural productivity, rising healthcare costs, and expenses for cleaning polluted water resources are direct consequences of environmental degradation. Man-made disasters, along with air and water pollution, can lead to economic losses by reducing the quality of life and labour productivity, as well as increasing expenditures on treating diseases caused by pollution.

Environmental degradation resulting from the depletion of natural resources significantly exacerbates challenges in Ukraine. One of the most pressing issues is the destruction of fertile soils due to erosion, intensive agricultural practices, and the improper use of fertilisers. According to the Ministry of Agrarian Policy and Food of Ukraine (State Statistics Service..., 2023), approximately 40% of the country's agricultural land is affected by erosion, making it

a primary factor in declining land productivity. Currently, over 10 million hectares of arable land are classified as degraded. This directly impacts national food security by reducing both the quantity and quality of agricultural products. The Food and Agriculture Organisation (Bélanger & Pilling, 2019) reported that soil erosion in Ukraine results in the loss of 5-7 million tons of fertile soil annually, which diminishes crop yields and heightens dependence on chemical fertilisers. The intensive and uncontrolled use of fertilisers and pesticides further contributes to soil pollution, exacerbating the problem. Soil contamination by chemicals is one of the most severe environmental issues in Europe, and the costs associated with land remediation and restoration are substantial. Experts estimate that Ukraine loses up to 3% of its GDP annually due to land degradation, representing a significant economic burden for the country.

Water resource pollution in Ukraine is another critical issue, with far-reaching implications for water quality, access to clean water, and economic stability. Approximately 20% of water resources are at risk of contamination, primarily due to agricultural activities, including the runoff of pesticides and chemical fertilisers. This not only degrades conditions for irrigation but also increases the costs of water purification. Industrial waste, agro-industrial runoff, and urban drainage further contribute to the pollution of rivers and lakes in many regions. Water scarcity, driven by inefficient use, adds to the problem. Per capita, Ukraine has only about 1,300 cubic meters of water available annually – significantly below the European standard and the global average of approximately 2,500 cubic meters. Furthermore, 60% of Ukraine's water resources are polluted, adversely affecting public health and increasing water treatment costs (State Statistics Service..., 2023).

The consequences of soil degradation and environmental pollution have significant social implications. In Ukraine, the risk of food crises is rising due to the deterioration of

soil and water quality, leading to a decline in stability within rural areas. Since agriculture serves as the primary source of income for many rural families, land degradation exacerbates poverty and intensifies social tensions in these communities. Over time, the depletion of arable land and limited opportunities for sustainable agriculture may drive migration from rural areas to urban centres, further aggravating issues of urbanisation and overpopulation in cities.

Ukraine also faces critical challenges concerning its forest resources. Uncontrolled deforestation and a shortage of forest resources diminish the ecosystem's capacity to regulate the climate, purify air, and sustain biodiversity. Illegal logging is a persistent problem; according to the State Agency of Forest Resources of Ukraine (2024a), this activity results in the annual loss of over 10 million cubic meters of forest. Data from the Food and Agriculture Organisation (Bélanger & Pilling, 2019) indicate that forest cover in Ukraine is declining at an approximate rate of 1% per year. If this trend continues, it will lead to substantial biodiversity loss and diminished ecological resilience. The degradation of forest ecosystems has a compounding effect, reducing their ability to recover and sustainably support climate regulation and biodiversity preservation. The lack of effective measures to control deforestation and promote forest restoration threatens to increase greenhouse gas emissions while diminishing forests' capacity to sequester carbon. This, in turn, accelerates the progression of climate change.

Climate change is intensifying existing environmental and economic challenges in Ukraine while introducing new threats. Rising average annual temperatures, shifting precipitation patterns, and the increased frequency of droughts and floods are significantly impacting agricultural productivity, limiting access to water resources, and heightening risks to infrastructure. According to the UK's National Meteorological Service, average annual temperatures in Ukraine could rise by 1.4-3.1°C by 2050, surpassing the global average rate of climate change (Wilson *et al.*, 2021). This warming trend will heavily affect agriculture, a cornerstone of Ukraine's economy, particularly by reducing crop yields.

The National Institute for Strategic Studies reports that climate change is already decreasing the yields of staple crops such as wheat, corn, and barley. For example, a severe drought in southern Ukraine during 2020 led to a 30-40% reduction in corn yields, resulting in economic losses of approximately USD 3.5 billion (Gusarova, 2020). Additionally, climate change is increasing the frequency and intensity of floods in western Ukraine, leading to significant economic repercussions. The 2020 floods in this region caused damage to infrastructure and agriculture valued at over UAH 2 billion (State Statistics Service..., 2023).

Climate change also facilitates the spread of pests and plant diseases, further reducing agricultural yields and increasing crop protection costs. According to the Ministry of Agrarian Policy and Food of Ukraine, the cost of agrochemical treatments could rise by 15-20% by 2030 due to these factors. This imposes additional economic burdens

on farmers, particularly in regions where agriculture constitutes the primary source of income. The contrasting effects of droughts in the south and floods in the west of Ukraine exacerbate economic losses and deepen regional disparities, leading to greater economic and social imbalances. Given that agriculture contributes approximately 10% of Ukraine's GDP, the ongoing impacts of climate change pose a substantial threat to the country's economic stability (State Statistics Service..., 2023).

The war in Ukraine has led to profound social and economic consequences that directly impact natural resource management and the country's sustainable development. According to the Kyiv School of Economics (2022), Ukraine's economic losses from the war in 2022 exceeded USD 600 billion. Estimates indicate that the country's GDP in 2023 decreased by 35-40% compared to 2021, significantly affecting all sectors, particularly agriculture, which traditionally contributed around 10% of GDP. This loss of economic stability hinders the implementation of adaptive natural resource management strategies, as insufficient financial resources make it challenging to pursue environmental initiatives and ensure sustainable development.

Hostilities and occupation in eastern and southern Ukraine have resulted in the loss of approximately 25% of agricultural land. This has significantly disrupted food production; for instance, grain output in 2022 fell by 37%, according to the Ukrainian Agribusiness Club (2023). Rising domestic food prices have further limited access to basic food products, underscoring the urgency of developing adaptive natural resource management strategies to address shifts in production and consumption patterns. Furthermore, environmental damage caused by the war is estimated to exceed USD 10 billion, including water pollution from explosions and infrastructure destruction.

More than 1,200 cases of environmental pollution resulting from military actions have been documented, significantly degrading the quality of water and soils. Restoring ecosystems affected by the war will require the adoption of new environmental standards and management strategies to ensure sustainable post-war development. The war has also triggered substantial population displacement. According to the United Nations High Commissioner for Refugees, more than 8 million people have been internally displaced, and approximately 7.8 million Ukrainians have left the country (About 1.5% on..., 2024). This large-scale movement poses additional challenges for natural resource management in host regions. Local communities must address increased demand for resources and services, requiring the adaptation of existing management models. Effective adaptive approaches must account for these changes, providing support for displaced populations and host communities alike.

Post-war reconstruction in Ukraine will require substantial investment, with estimates suggesting that approximately USD 38 billion will be needed to restore infrastructure and ecosystems in the coming years (Ukraine rapid assessment..., 2023). The integration of innovative

technologies into the agricultural sector, alongside the implementation of environmental regulations, will be essential to minimising the negative impact on natural resources. Adaptive natural resource management should serve as a cornerstone of recovery efforts, ensuring the alignment of economic, social, and environmental priorities.

However, ineffective policy and resource management pose significant challenges. The absence of robust mechanisms for regulating resource use, coupled with corruption in environmental governance and conflicts of interest among public, private, and governmental sectors, undermines efforts toward sustainable resource management. These issues exacerbate environmental degradation, result in inefficient resource utilisation, and lead to economic losses that are ultimately borne by state and local budgets. Ukraine's natural resource management system faces multiple challenges, including climate change, environmental degradation, and economic instability. Addressing these requires the development and implementation of comprehensive and adaptive strategies that promote sustainable development. Effective management practices must prioritise ecosystem preservation and resilience, while simultaneously bolstering economic stability.

Economic impact of adaptive natural resource management

Adaptive management of natural resources has a substantial economic impact, optimising resource utilisation, enhancing economic competitiveness, and attracting investments in the “green” economy. One of the primary benefits of adaptive management is the efficient use of resources, which not only reduces costs but also ensures the preservation of resources for future generations. In Ukraine, where water scarcity is a pressing issue, adaptive management can facilitate a more equitable distribution of water across regions and economic sectors. This approach helps prevent crisis situations during dry periods and droughts, mitigating economic losses caused by natural disasters and improving water availability for agriculture and industrial enterprises.

A key component of adaptive management is the integration of innovative technologies to boost productivity in agriculture and industry. For instance, implementing precision agriculture systems in Ukraine, such as soil moisture monitoring and automated irrigation technologies, can significantly reduce water and fertiliser use. Experts estimate that adopting these technologies could lower irrigation costs by 20-30% and improve crop yields by 15-20% (Kononenko *et al.*, 2024). This not only reduces production costs for agricultural producers but also enhances their competitiveness in both domestic and international markets. Adaptive management also fosters cost reductions in

industry. For example, modernising thermal power plants with energy-efficient technologies has resulted in a 10-15% reduction in energy consumption, positively affecting overall production costs (Kononenko *et al.*, 2024).

Adaptive management plays a critical role in attracting investments in the “green” economy. Ukraine is experiencing significant growth in energy projects focused on renewable energy sources. International assistance programs, such as Horizon Europe (2020), provide financial support for initiatives in renewable energy and energy efficiency. As a result, Ukraine is implementing projects that reduce reliance on fossil fuels and lower greenhouse gas emissions. For instance, in 2021, over 300 MW of renewable energy capacity was brought online, contributing to reduced energy costs and improved environmental conditions (Konechenkov, 2022). Such investments not only cut energy expenses but also generate new jobs, positively influencing the economic conditions of various regions.

Adaptive management also helps mitigate economic risks associated with the inefficient use of natural resources. In Ukraine, one of the primary threats is water resource scarcity in southern regions, which poses significant risks to agricultural productivity and economic stability. Implementing adaptive water resource management strategies enables the optimisation of water usage, minimises losses, and prevents shortages during critical periods. A key element of adaptive management is continuous monitoring and control of resource utilisation. This allows for timely responses to fluctuations in supply and demand, significantly reducing economic losses caused by the inefficient use of water, land, and energy. Moreover, it helps avoid excessive environmental pollution.

Through adaptive management, Ukraine can further integrate its economy into the international environmental and economic framework. The implementation of international environmental agreements, such as the Paris Agreement on Climate Change, necessitates the adoption of effective mechanisms for managing natural resources. These include deploying energy-efficient technologies, expanding the use of renewable energy sources, and reducing greenhouse gas emissions. Participation in global initiatives, such as the Horizon Europe program and “Green Bonds”, enables Ukraine to secure financing for the development of sustainable technologies. These investments not only mitigate economic risks but also enhance the country's environmental performance. The adoption of such initiatives promotes the modernisation of production facilities, improves energy efficiency, and reduces dependence on imported energy sources, thereby strengthening Ukraine's economic stability. Table 2 summarises the economic impacts of adaptive natural resource management.

Table 2. Economic impact of adaptive natural resource management

Category	Economic impact	Management result
Efficient use of resources	Reducing costs for water use, land use, energy consumption; increasing productivity	Optimisation of water supply in agriculture, reduction of energy costs through energy-efficient technologies

Table 2. Continued

Category	Economic impac	Management result
Increasing competitiveness	Reducing production costs, improving innovation, increasing exports	Modernisation of enterprises, introduction of “green” technologies into production
Investment promotion	Attracting financing for sustainable development, increasing investment in renewable energy and environmentally friendly projects	Using green bonds to finance renewable energy
Prevention of natural and man-made disasters	Reducing economic losses due to natural and man-made disasters, reducing infrastructure restoration costs	Implementation of early warning systems, modernisation of infrastructure to increase disaster resilience
Reducing dependence on imported resources	Reducing costs for importing energy resources and raw materials, increasing the country’s energy and resource security	Development of domestic energy sources, use of renewable energy sources, efficient water use
Social and economic sector	Increasing social stability through the creation of new jobs and reducing social costs	Creating “green” work places, financing projects in agriculture, investing in education and science
Sustainable economic development	Increasing economic stability through sustainable resource use, preserving ecosystems and improving the environmental situation	Investments in sustainable development, use of renewable resources, long-term sustainable development policy

Source: developed by the authors

Adaptive management of natural resources is a vital tool for a country’s economic development, promoting the rational use of resources and mitigating environmental risks. It relies on continuous monitoring of ecosystem conditions, analysis of the collected data, and rapid adjustments to management decisions. This approach enables real-time consideration of changes in ecosystems, optimising the costs associated with their preservation and restoration. The efficiency of natural resource utilisation improves with the integration of innovative technologies and flexible management practices, which helps reduce resource depletion. Additionally, adaptive management minimises the expenses linked to the impacts of natural disasters and environmental degradation. The economic benefits are evident in increased profitability in resource-dependent sectors such as agriculture and forestry. Adaptive management also facilitates investment in the “green” economy and fosters the development of sustainable business models. By reducing reliance on resource imports, it strengthens the country’s economic and energy security. In summary, adaptive management of natural resources has a profound economic impact, ensuring the rational use of resources and reducing environmental risks.

Examples of adaptive natural resource management

Adaptive natural resource management in Ukraine is still in its early stages, but pilot projects already implemented demonstrate the effectiveness of this approach. One notable example is the “Integrated Water Resources Management in Dnipro River Basin” project, supported by the United Nations Development Program (UNDP). This initiative applied integrated strategies for water resources management, including water quality monitoring, community involvement, and the use of innovative treatment technologies. The results showed substantial improvements in water resource management, particularly in reducing water pollution levels. Through the implementation of water quality monitoring and wastewater treatment systems, the

concentrations of heavy metals, such as lead and mercury, in the Dnipro River decreased by 18-22% compared to initial levels. Additionally, the project achieved a 15-20% reduction in organic pollutants, as measured by biological oxygen demand (UNDP, 2024).

Another significant achievement was the improved access to high-quality drinking water. Modernisation of water treatment systems and the construction of new treatment plants provided over 500,000 residents in various regions of the Dnipro basin with access to cleaner and safer water. The introduction of advanced purification technologies significantly reduced concentrations of harmful bacteria, such as coliphages, ensuring drinking water met high safety standards. These efforts not only improved public health but also positively impacted the ecological stability of the region. By reducing water pollution and enhancing the quality of water resources, the project significantly improved the ecosystem health of the river and its surrounding water bodies. This contributed to the restoration of biodiversity in the Dnipro basin, reinforcing the ecological sustainability of the region (State Agency of Water Resources of Ukraine, 2017).

Another example of adaptive resource management can be seen in forestry efforts, particularly in the Carpathian region of Ukraine. Programs aimed at reducing illegal deforestation and implementing advanced monitoring systems using satellite technologies have been actively developed and implemented. Several key initiatives to combat illegal logging and restore forest plantations have yielded significant results in this region. One notable example is “Forests for the Future” program, launched with the support of international organisations, including the United Nations Development Program and “Ecology and People” International Fund. This program leverages satellite technologies to monitor forest conditions and detect illegal logging activities. The Earth Observation for Sustainable Development system enables real-time forest monitoring, allowing for rapid responses to unauthorised activities. Since the introduction of these technologies, Ukraine has

recorded a reduction of over 30% in illegal deforestation compared to the period prior to the program's implementation. As of October 2024, reforestation efforts in the Carpathians had been carried out over an area of 2,900 hectares, with over 3,300 hectares expected to be completed by the end of the year. In 2024, it was planned to plant 14 million seedlings (State Agency of Forest Resources of Ukraine, 2024b). This approach represents an essential step toward sustainable development and the preservation of the Carpathians' natural resources.

Adaptive management of natural resources has demonstrated substantial economic benefits in several countries, including Sweden, Norway, and Canada. Its effectiveness lies in reducing economic risks, enhancing the resilience of natural resources, and ensuring sustainable economic flows across various sectors. This analysis examines the economic benefits of adaptive management in each of these countries and identifies additional areas where it has been successfully implemented.

Sweden has emerged as a leader in adaptive forest management. By employing an integrated approach that considers environmental, social, and economic dimensions, Sweden has significantly improved the balance between biodiversity conservation and the economic benefits derived from its forest industry. These well-established forest management practices ensure forest health while maintaining sustainable productivity. Such measures minimise losses from illegal logging and the depletion of forest resources, thereby enhancing long-term economic gains. In addition to forestry, adaptive management in Sweden extends to the energy and agricultural sectors. In agriculture, adaptive practices enable effective responses to climate change, increasing resilience to droughts, improving crop yields, and reducing economic risks. In the energy sector, Sweden's investments in renewable energy sources are supported by adaptive management strategies that optimise energy production and consumption, reduce costs, and improve overall system efficiency. The economic benefits of adaptive management in Sweden are evident in enhanced forestry productivity and the sustainable use of natural resources. These practices contribute to the country's strong competitiveness in the global markets for wood products and clean energy (Swedish Forest Agency, 2024).

In Norway, adaptive management plays a pivotal role in fisheries, where continuous monitoring of fish populations and the regulation of catch quotas form the foundation for the sustainable development of the fishing industry. This approach helps maintain stable fish population levels, prevents resource depletion, and ensures consistent incomes for fishermen and fish processing enterprises (ICES, 2024). Over the long term, it enables the country to avoid economic losses associated with overfishing while ensuring stable revenue from the export of fish products. Adaptive management is also applied in Norway's energy sector, particularly in hydroelectric power, which is a cornerstone of the country's economy. Advanced technologies for monitoring water resources are used to optimise the operation of

hydropower plants, reducing energy production costs and improving the efficiency of water use. Additionally, adaptive management has been implemented in forestry and tourism. Monitoring systems in these sectors help balance environmental preservation requirements with the economic benefits derived from tourism and forest resources.

Canada serves as a prime example of adaptive management in water resources. In the Fraser River Basin, water level monitoring and climate risk forecasting systems have been implemented to enable timely responses to changes in water levels and the adaptation of water use strategies. These measures mitigate the risks of flooding and drought, delivering significant economic benefits to agriculture and other water-dependent sectors such as energy and industry. Adaptive management is also widely applied in Canada's forestry sector, particularly in combating forest fires. Utilising satellite technologies and forest monitoring systems, the country can respond rapidly to fire threats, reducing suppression costs and ensuring the economic stability of the forest industry. In agriculture, adaptive management is used for land management and climate change adaptation, helping to mitigate economic risks associated with droughts and other natural disasters (Government of Canada, n.d.). This approach enhances agricultural resilience, ensuring more stable crop yields even under changing environmental conditions. The economic effectiveness of adaptive management in Canada is evident in reduced costs for disaster mitigation, increased crop productivity, and the sustainable development of water and forest resources enabling the country to maintain high productivity in these industries.

A comparison of Ukraine's approach to adaptive management with international models reveals significant differences. The primary challenges facing Ukraine include the lack of a systemic approach, insufficient funding, and a weak legislative framework. In contrast, countries like Sweden and Canada actively utilise innovative technologies and ensure the involvement of all stakeholders in their adaptive management strategies. Ukrainian programs, however, often remain limited to the pilot project stage, without transitioning to widespread implementation. Another key difference lies in the scale of funding. International models benefit from substantial investment, often supported by international grants and institutional mechanisms.

Although Ukraine has made some progress in adaptive management, the experiences of other countries highlight areas for improvement in national strategies. Adopting international best practices, such as integrating innovative technologies, strengthening resource monitoring and control, and fostering active community involvement, could significantly enhance the situation in Ukraine.

Challenges in implementing adaptive management

Adaptive natural resource management in Ukraine faces several significant challenges that hinder its effective implementation and development. One of the most pressing issues is the lack of comprehensive data and monitoring systems. Ukraine's limited network of natural resource

observation points makes it difficult to make informed decisions and respond promptly to environmental changes. The absence of accurate and up-to-date information on ecosystem conditions, pollution levels, water resource distribution, and other critical indicators results in the inefficient use of natural resources and complicates the planning of sustainable development strategies.

Another significant challenge is the underutilisation of modern technologies, particularly Geographic Information Systems (GIS) and automated monitoring systems. GIS is a powerful tool for collecting, analysing, and visualising data on natural resources, yet its application in Ukraine remains limited. The absence of integrated, national-level natural resource monitoring systems further complicates the adaptation of management strategies to dynamic environmental conditions. Modern technologies, including GIS and automated systems, have the potential to enable prompt responses to environmental changes and provide predictions of their consequences. However, widespread implementation is hampered by underfunding and a lack of adequately trained personnel. management in Ukraine (Vasenko, 2023).

The environmental consequences of the war present another critical challenge, significantly worsening the state of the environment in Ukraine. Military actions have caused severe damage to ecosystems, including water pollution, forest destruction, soil contamination with toxic substances, and disruptions to natural processes. Restoring these ecosystems requires substantial efforts, with adaptive natural resource management serving as a crucial element of the rehabilitation process. However, the unstable situation in the country and limited access to affected areas make the implementation of such initiatives

particularly difficult (Pylypovych & Petrovska, 2023). Another significant issue is the low level of involvement from communities and businesses, which hinders the effectiveness of adaptive management. Local communities and businesses should actively participate in decision-making regarding natural resource use, but they often lack sufficient environmental awareness or interest in sustainable development. Many communities do not have the necessary knowledge for effective resource management, while businesses frequently prioritise short-term economic gains over the adoption of sustainable practices (Shevchenko, 2012).

An outdated regulatory framework further impedes the implementation of adaptive management. Ukraine's legislative system often fails to meet modern requirements for environmental protection and the sustainable use of natural resources. Existing laws rarely incorporate innovative technologies or strategies designed to adapt to climate change. This lack of clear and contemporary regulations results in legal uncertainty, complicating the execution of long-term environmental projects.

Financial constraints are another major barrier. Effective adaptive management requires significant investments in areas such as technology implementation, monitoring systems, ecosystem restoration, and infrastructure development. However, Ukraine has limited access to financing for these projects, which significantly slows their progress. Many environmental initiatives depend on government funding or support from international organisations, but economic difficulties and political instability often render these resources unavailable. Table 3 provides a summary of the most common challenges encountered when implementing adaptive natural resource management in Ukraine.

Table 3. Challenges in implementing adaptive natural resource management

Challenge	Challenge description	Economic impact of implementing adaptive management
Lack of qualified personnel	Insufficient level of training of specialists in the field of ecology and new technologies	The shortage of qualified personnel hinders the implementation of innovative technologies and adaptive management, leading to delays in natural resource management projects and reducing their efficiency. This, in turn, has a negative economic impact.
Low effectiveness of state policy	Public policy often lacks sufficient clarity and effectiveness in addressing sustainable development and adaptive management	Ineffective policies obstruct the implementation of adaptive strategies and innovations, resulting in slower economic development and worsening environmental conditions. This, in turn, leads to additional costs for resource restoration and further losses to the national economy.
Incoordination between central and local authorities	Lack of effective coordination between different levels of government (central and local authorities) in matters of natural resource management	The lack of coordination between management bodies impedes the implementation of effective decisions and delays the response to changes in ecosystems, resulting in economic losses across various sectors.
Low level of environmental awareness	Many citizens and businesses lack sufficient awareness of the importance of environmental issues and sustainable development	Insufficient environmental awareness among citizens and businesses undermines the effectiveness of environmental practices, encouraging irresponsible use of natural resources. This leads to high restoration costs and diminishes the effectiveness of environmental policies.
Low cooperation between business and science	Lack of effective cooperation between businesses and scientific institutions in the development and implementation of sustainable technologies	The lack of integration between scientific developments and business practices slows innovative progress, reduces the effectiveness of natural resource management technologies, and results in missed economic opportunities.

Table 3. Continued

Challenge	Challenge description	Economic impact of implementing adaptive management
Corruption and poor governance	Problems with corruption and inefficiency in natural resource management	Corruption and inefficient management result in the misallocation of budget funds to untargeted projects and delays in implementing adaptive strategies. This leads to long-term economic consequences, including high resource restoration costs and inefficient use of natural resources.
Resistance of enterprises	Traditional industries (energy, industry, agriculture) often resist the introduction of new, more sustainable practices due to the high costs of modernisation	The resistance of enterprises in traditional industries to innovative approaches reduces the economic efficiency of implementing adaptive natural resource management. This results in greater environmental harm and missed opportunities for economic growth in sustainable development sectors.
Lack of integrated natural resource monitoring systems	Ukraine lacks modern integrated natural resource monitoring systems that would ensure timely and accurate data collection	The absence of such systems complicates natural resource management, leading to errors in planning and decision-making. This negatively impacts economic outcomes and can result in financial losses.
Outdated regulatory framework	The regulatory framework governing natural resource management is outdated and does not meet modern challenges	Outdated regulations hinder the adoption of new technologies and adaptive management, resulting in economic losses due to inefficient resource use and slowing innovation development.
Insufficient funding	Lack of sufficient funding for the implementation of projects in the field of natural resource management	Insufficient funding limits the ability to implement adaptive management and develop new technologies, which in turn reduces economic competitiveness and increases the costs of restoring natural resources.
Environmental consequences of war	The war has inflicted significant damage on ecosystems and natural resources, complicating their recovery	The consequences of war generate additional economic costs for ecosystem and resource restoration, while also causing losses in agriculture and other sectors, negatively impacting the country's overall economic development.

Source: created by the authors

Adaptive natural resource management in Ukraine faces numerous challenges, including insufficient monitoring and data, ineffective use of new technologies, low efficiency in state policies, and an unstable legal framework. Many of these issues stem from a shortage of qualified personnel, a lack of coordination between government agencies, low environmental awareness among citizens and businesses, and the risk of corruption. These factors have a significant economic impact, delaying the implementation of adaptive strategies and leading to substantial economic losses. To achieve sustainable development, it is essential to address these challenges in a comprehensive manner by enhancing the effectiveness of policies, modernising infrastructure, and ensuring adequate personnel training.

Prospects for implementing adaptive management in Ukraine

The prospects for adaptive natural resource management in Ukraine include several key areas that can optimise resource use and support the country's sustainable development. The first step involves developing a natural resource monitoring system using innovative technologies. The integration of GIS, satellite monitoring, and digital models will enable real-time data collection and processing regarding the state of ecosystems. The use of these technologies will facilitate the prompt detection of environmental changes, prediction of trends, and timely responses to emerging risks. Economically, this will result in reduced costs for ecosystem restoration and minimised economic losses caused by the irrational use of resources. Furthermore, the implementation of such technologies will enhance the transparency

of management processes and attract additional investments, as international partners prioritise accurate and transparent data when funding environmental initiatives.

The second important area is the adoption of digital technologies, specifically Big Data, the Internet of Things (IoT), and artificial intelligence (AI), for natural resource monitoring. IoT technologies can create integrated systems that gather data from various sources, such as soil moisture sensors, river water levels, or forest temperature. This will lead to more precise data and forecasts, which will improve long-term resource planning. Additionally, the implementation of AI will automate data analysis and decision-making processes, enhancing efficiency. The economic impact of these technologies includes optimised resource use, reduced energy costs, and improved efficiency in agriculture, energy, and other industries.

To ensure the effective implementation of adaptive management, it is crucial to undertake institutional reforms aimed at strengthening control over natural resource use and ensuring their sustainable management. The creation of a unified database on natural resources, the improvement of the regulatory framework, and the integration of adaptive approaches at all levels of government will significantly reduce corruption risks and minimise administrative costs. The economic benefits of such reforms include increased efficiency in natural resource use, the creation of favourable conditions for investment and the development of a "green" economy, as well as more stable long-term economic growth.

An important area of focus is the development of financial mechanisms to support adaptive management,

such as the use of “green” bonds, grants, and concessional loans for financing environmental projects. Attracting international investments and leveraging environmental funds will facilitate the financing of infrastructure projects aimed at implementing sustainable technologies across various sectors, including energy, agriculture, and water management. This will generate additional employment opportunities and stimulate the development of new, innovative technologies within the country.

In conclusion, the successful implementation of adaptive natural resource management in Ukraine requires a focus on integrating new technologies, instituting institutional reforms, and developing financial mechanisms. These efforts will significantly enhance the efficiency of natural resource use, reduce economic risks, and ensure the sustainable development of the country over the long term.

DISCUSSION

The results of the study confirmed that adaptive management of natural resources can significantly enhance the environmental and economic sustainability of a country. For example, the study found that the key issues related to water management and land degradation were consistent with the findings of P. Mperejekumana *et al.* (2024), who highlighted the importance of integrating climate change adaptation into the water-energy-food nexus to ensure sustainable development in the East African Community. Similar to that study, the authors emphasised that without active adaptation to environmental challenges, countries may face significant risks to economic development. Additionally, the results underscored the importance of employing innovative technologies to improve natural resource management. This aligns with the findings of M. Anas *et al.* (2024), who noted that the adoption of “green” financial technologies and innovations could play a key role in conserving natural resources and promoting environmental sustainability. They noted that such approaches are vital for enhancing environmental quality in the context of diminishing natural resources.

However, the study also revealed some differences. For instance, S. Saud *et al.* (2024) emphasised the importance of an integrated approach to natural resource use and economic complexity as a driver for “green” growth in the European Union. In contrast, the study highlighted significant barriers to implementing similar strategies in Ukraine, particularly insufficient infrastructure and an inadequate legislative framework, which hindered the adaptation of these concepts to the local context.

The study results revealed that the primary challenges related to water management and land degradation were consistent with the findings of T. Li *et al.* (2024), who emphasised the need to address multiple stressors to ensure sustainable livelihoods in dryland ecosystems. This highlights the importance of an integrated approach to resource management, which is particularly crucial for Ukraine, where environmental challenges demand comprehensive solutions. Additionally, the study results confirmed the

significance of utilising renewable energy sources and fostering innovation in agriculture. These findings coincide with those of G. Aziz *et al.* (2024), who emphasised the critical role of renewable energy and the agricultural sector in promoting sustainable economic growth and a green environment. Both studies stress that without a transition to sustainable energy, countries may struggle to achieve long-term sustainable development.

The findings regarding the negative impact of climate change on agriculture in Ukraine are consistent with the study by H. Jie *et al.* (2023), which examined the relationship between sustainable energy policies, social and economic development, and ecological footprint. The authors noted that insufficient renewable energy policies can exacerbate environmental problems, supporting the results of this study, which highlight the need for reform in the energy sector. Additionally, the study by E. Ali *et al.* (2021) found that implementing a green economy can be an effective pathway to sustainable development in various countries, including Ghana. The findings also suggest that Ukraine needs to adopt elements of a green economy to address its existing environmental challenges. Furthermore, the study by K. Uralovich *et al.* (2023) emphasised that environmental education is a key factor in achieving sustainable development and environmental sustainability. This aligns with this research, which underscored the importance of raising environmental awareness among the population to ensure the successful implementation of adaptive natural resource management.

The study by F. Ahmed *et al.* (2022) also emphasised the role of institutional quality and financial development in ensuring sustainable economic growth. Their research found that insufficient government support and an imperfect legal framework hinder the implementation of adaptive strategies, a finding that aligns with the results of the authors mentioned earlier. Further analysis of the study results suggests that adaptive management of natural resources can support financial development, as highlighted by A. Raihan (2024). The author noted that economic progress, natural resources, and capitalisation are essential for financial development, which confirms the findings of our study that underscore the need to leverage natural resources to improve the country’s financial stability. The study by M. Basheer *et al.* (2023) also highlighted the importance of cooperative adaptive management in the face of climatic and social and economic uncertainties. This research concurs with this, stressing that for effective natural resource management, Ukraine must implement mechanisms that consider the specificities of local ecosystems and engage communities in the decision-making process.

In summary, our research confirms the importance of adaptive natural resource management for sustainable economic development in Ukraine. These findings are consistent with international studies but also reveal unique challenges specific to the country. This underscores the need to develop adaptive management strategies that take into account the particularities of the Ukrainian context.

CONCLUSIONS

The study on the impact of adaptive natural resource management on the sustainable economic development of Ukraine identified key problems, barriers, and prospects for implementing this approach in national practice. The analysis revealed that adaptive management is an effective tool for optimising natural resource use, enhancing environmental sustainability, and ensuring long-term economic development. Specifically, it was found that the main barriers to the implementation of adaptive management in Ukraine include the lack of up-to-date data on the state of natural resources, insufficient use of modern monitoring technologies, low environmental awareness among communities and businesses, and an outdated regulatory framework. These factors hinder the implementation of sustainable management strategies, reduce resource efficiency, and increase environmental risks. However, the study also highlighted the potential to overcome these barriers through the adoption of innovative technologies, such as GIS, satellite monitoring, and climate change forecasting models.

The results indicated that the implementation of adaptive management could lead to reduced water and energy costs, improved agricultural productivity, and enhanced competitiveness for the Ukrainian economy. For example, the use of precision agriculture technologies could reduce fertiliser and water costs by 20-30%, while the modernisation of water treatment systems could decrease pollution

levels by 15-20%. Developing integrated natural resource monitoring systems using modern technologies would improve the accuracy and timeliness of management decisions. Involving communities and businesses in the implementation of adaptive management, through educational initiatives and financial incentives, will help raise environmental awareness and foster responsibility in resource use. Furthermore, improving the regulatory framework to emphasise adaptive approaches and innovations is essential for creating favourable conditions for sustainable development. Overall, adaptive management facilitates a balance between economic growth and environmental conservation, which is critical in the context of current climate change challenges.

An important area for future research is examining the environmental consequences of war on natural resources and developing adaptive mechanisms for ecosystem restoration after conflicts. To improve outcomes, it is essential to enhance the use of modern technologies, such as GIS and automated management systems, and to promote effective financial instruments that ensure sustainable development.

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CONFLICT OF INTEREST

None.

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Адаптивне управління природними ресурсами як чинник сталого економічного розвитку України: проблеми та перспективи

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Анотація. Повномасштабне вторгнення російських військ в Україну 24 лютого 2022 року призвело до суттєвих змін на українському ринку праці, що потребують детального аналізу та розуміння їх подальшої динаміки. Мета цієї роботи – з'ясувати, як вплинули зміни демографічної структури національного ринку праці на макроекономічні показники України. Завдяки таким методам, як статистичний аналіз, порівняння, синтез та прогнозування, було проведено дослідження актуальних демографічних та економічних показників. У результаті дослідження була отримана та проаналізована статистика вимушеного переміщення біженців як усередині України, так і за її кордон з урахуванням віку, статі, освіти та інших демографічних показників – всього було релоковано, мінімум, 12 мільйонів українських громадян, 75 % з яких є працездатними, а більше половини мають високу професійну кваліфікацію. Окремо було вивчено інформацію щодо молоді та студентства, які продовжують або починають навчання за кордоном, та сформовано висновки щодо їх асиміляції у новому суспільстві та вірогідності їх повернення в Україну. У процесі аналізу умов зростання показників безробіття, була порахована кількість підприємств, що припинили свою діяльність через бойові дії чи тимчасову окупацію – як у географічному розрізі, по областях, так і за формою власності підприємств. Виявилось, що на сході України кількість закритих суб'єктів підприємницької діяльності сягає 80 % та, в тому числі, майже третина фізичних осіб-підприємців припинили свою діяльність. Також було спрогнозовано умови повоєнної відбудови України з урахуванням долі біженців, які повернуться, та перспектив вступу країни до Європейського Союзу. Практична значимість цього дослідження полягає в оцінці впливу змін структури ринку праці на економіку України. Результати роботи можуть бути корисні державним структурам, що вже зараз формують стратегію повоєнного відновлення України

Ключові слова: макроекономічні показники України; валовий внутрішній продукт; індекс відновлення ділової активності України; ринок праці; демографія