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### **THE ROLE OF GREEN TECHNOLOGIES IN ADDRESSING THE ECOLOGICAL PROBLEMS OF THE CASPIAN SEA**



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## THE ROLE OF GREEN TECHNOLOGIES IN ADDRESSING THE ECOLOGICAL PROBLEMS OF THE CASPIAN SEA

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### ABSTRACT

This article examines the ecological challenges facing the Caspian Sea and the transformative potential of green technologies in mitigating these issues. As the world's largest enclosed water body, the Caspian Sea is highly vulnerable to ecological threats, including oil extraction, industrial waste, and the impacts of climate change, which have severely disrupted its ecosystem. The study aims to highlight these ecological problems and demonstrate how green economy technologies can contribute to the sea's environmental protection. Specifically, the article analyzes the effectiveness of eco-friendly water purification technologies, biological innovations, and other sustainable practices in restoring the region's ecological balance. Additionally, it evaluates current projects and initiatives addressing these challenges, offering insights into their impact and potential scalability. By exploring these solutions, the paper underscores the critical role of green technologies in securing the long-term sustainability of the Caspian Sea's environment.

**Keywords:** Climate change, Caspian Sea, "Zero Waste" program, Bioremediation, Electrocoagulation

**JEL code:** Q01, Q56, Q25

### INTRODUCTION

The Caspian Sea, as a water basin of special strategic importance to the world, possesses a unique ecosystem. Its rich natural resources and geopolitical position are vital for the economies and ecological stability of the regional countries. However, in recent decades, the Caspian Sea has faced significant ecological problems due to various anthropogenic impacts. Industrial activities, particularly oil and gas extraction, as well as increasing population density, have negatively affected the sea's water resources, biodiversity and the resilience of its ecosystem.

The concept of a green economy aims to align economic development with ecological security based on the principles of environmental sustainability. In this context, the development of a green economy plays a crucial role in the protection of the Caspian Sea's environment. The application of a green economy in the protection of the Caspian Sea's environment can only be achieved through the joint efforts of regional states, international organizations and partner countries. This model of cooperation is essential not only for ensuring

environmental security but also for protecting the economic and ecological interests of the region's countries.

Furthermore, the article will present concrete statistical indicators and examples regarding the role played by the Republic of Azerbaijan in this matter, as well as the promotion of a green economy at the regional scale. The analyses provided in this article aim to deepen the understanding of the importance of cooperation and a green economy for the ecological protection of the Caspian Sea and to guide future activities in this field.

## MAIN ECOLOGICAL PROBLEMS OF THE CASPIAN SEA. THE EFFECTS OF CLIMATE CHANGE

Climate change has significant impacts on the sustainability of ecosystems and biodiversity on a global scale. This global issue poses a substantial threat to the Caspian Sea region, where ecological balance is particularly sensitive. The Caspian Sea, the largest enclosed water body in the world, has unique biological and geological characteristics, its ecosystem highly vulnerable to the effects of climate change. In this section, we will analyze the effects of climate change on the Caspian Sea and evaluate the significance of these impacts using statistical data.

One of the key factors directly influenced by climate change is the sea level of the Caspian Sea. Sea-level fluctuations, as reported by the Eurasian Research Institute in 2022, demonstrate the immediate physical effects of climate change on the Caspian Sea, exacerbating coastal erosion and ecological stress (Figure 1).

**Figure 1: The Caspian Sea water level over the years**



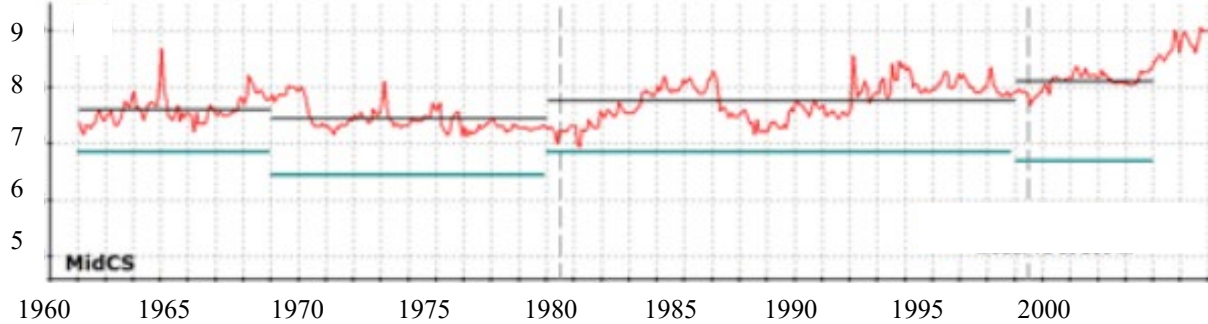
The Caspian Sea water level over the years								
Year	1940	1950	1960	1970	1980	1990	2000	2010
Level	-27.9	-28.2	-28.5	-28.4	-28.8	-27.6	-27.2	-27.5

**Source:** Eurasian Research Institute

The greenhouse effect, a primary driver of climate change, is causing a steady rise in the Caspian Sea's temperature. Experiments conducted between 1976 and 1978 further confirmed the impact of climate change on the Caspian Sea. According to official data from the European

Geosciences Union, the temperature in the Caspian Sea has been rising rapidly since the late 20th century (Figure 2).

**Figure 2: Average temperature of the central part of the Caspian Sea**

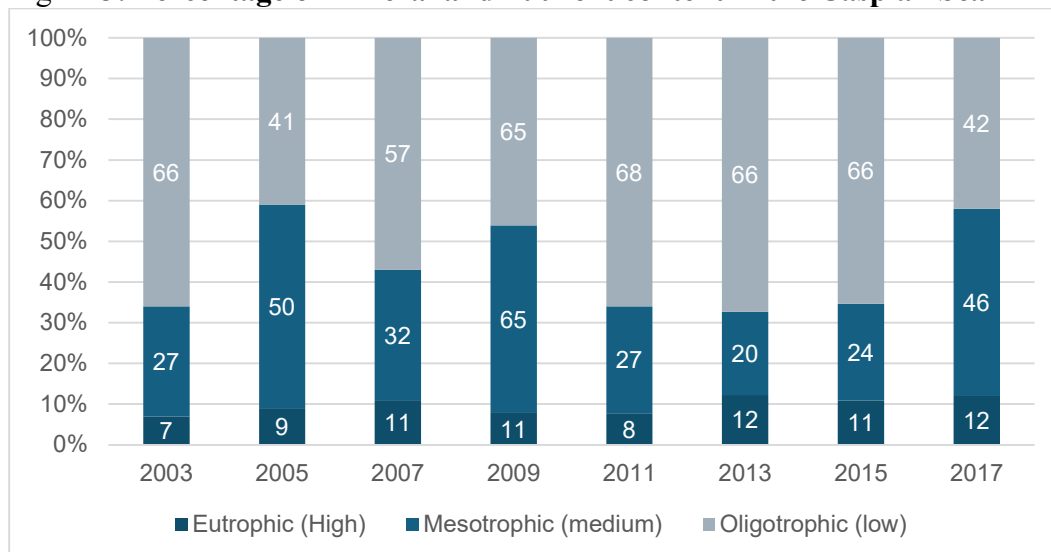


Average Temperature of the Central Part of the Caspian Sea (in Celsius)									
Year	1960	1965	1970	1975	1980	1985	1990	1995	2000
Temperature	7	7.2	7.1	7	7.2	7.3	8	8.1	9

**Source:** European Geoscience Union (2019)

According to the Caspian Environment and Arts Centre, this warming has led to a decrease in oxygen levels in the sea and a deterioration in biodiversity. As a result, the eutrophic layer, considered the nutrient-rich layer of the sea, constitutes only about 10% of the sea (Graphic 3), which is considered very unfavorable for marine life.

**Figure 3: Percentage of mineral and nutrient content in the Caspian Sea**

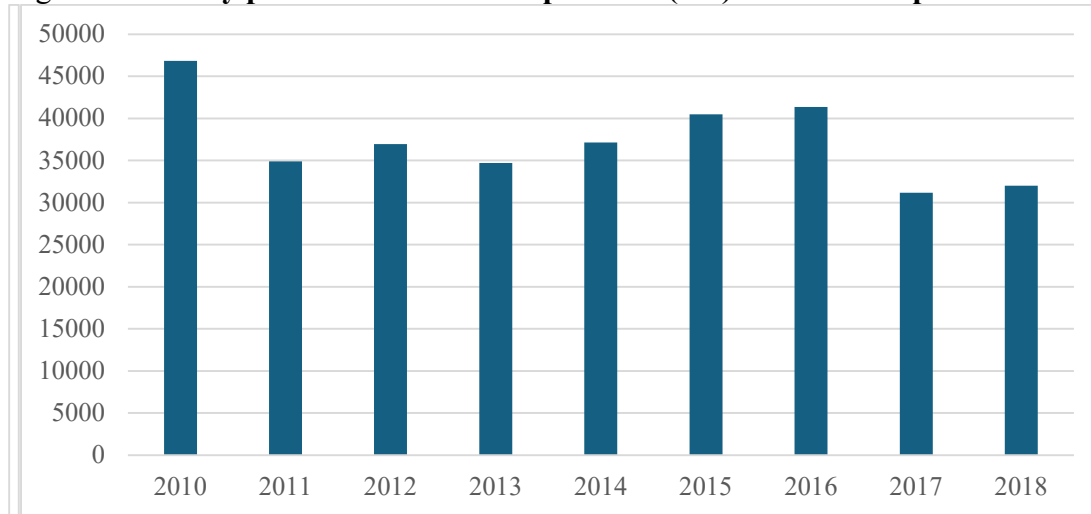


**Source:** Modabberi et al., 2020, *Environmental Research Letters*

The warming has also led to the destruction of fish species and other marine life in the colder water regions of the sea. Changes in the Caspian Sea's ecosystem, particularly the increase in algal and shifts in the food chain, are significant issues. Climate change is a major

factor contributing to these changes. The rise in temperatures and changing weather conditions have led to an increase in algal and disruptions in the food chain balance. These changes reduce the quality of ecosystem services, negatively impacting the biodiversity and functions of the ecosystem. This, in turn, has adverse effects on fishing industry, another important economic resource of the sea (Figure 4).

**Figure 4: Fishery production in the Caspian Sea (ton) Kazakhstan part**



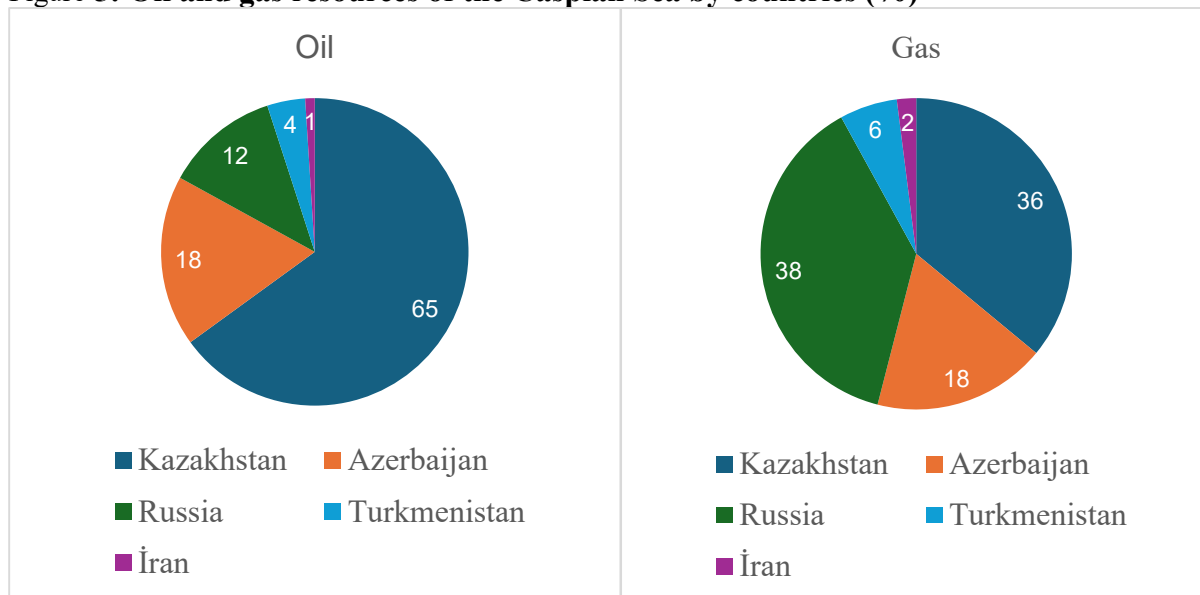
*Source: Eurofish International Organisation*

These alarming trends underscore the urgency of adopting green technologies to mitigate climate change's effects on the Caspian Sea and safeguard its ecological and economic resources.

### **THE IMPACT OF INDUSTRIAL AND OIL WASTE**

The Caspian Sea region's economy heavily relies on the oil and gas industry, which is vital for the energy security of its coastal countries (Figure 5). This industrial sector is particularly significant in terms of energy resources for Azerbaijan, Kazakhstan and Turkmenistan. However, the intensification of the use of these resources has led to severe ecological problems in the Caspian Sea's ecosystem. Industrial waste, especially waste generated during oil extraction and processing, has resulted in the introduction of large amounts of pollutants into the sea's water resources.

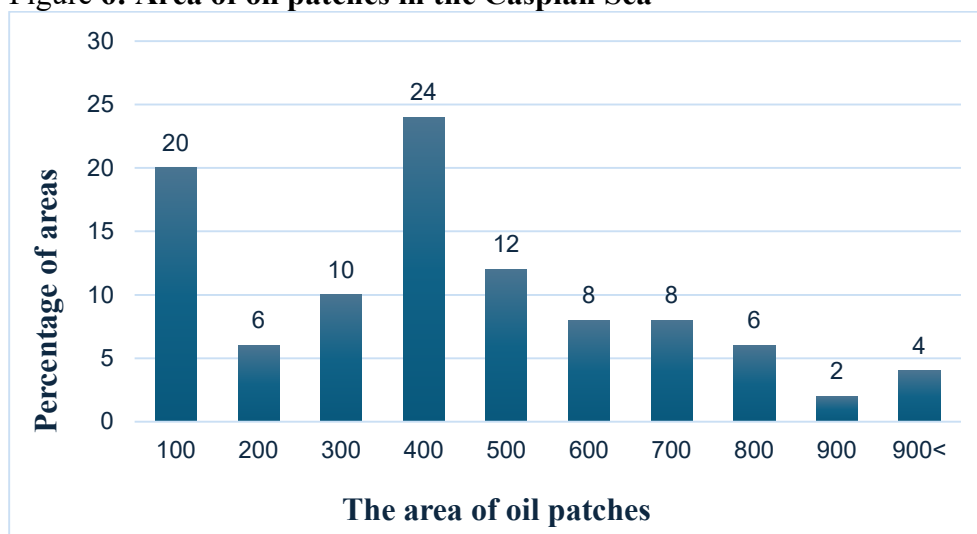
**Figure 5: Oil and gas resources of the Caspian Sea by countries (%)**



**Source:** US Energy Information Administration (2012).

Due to the impact of oil waste and other pollutants, large-scale oil patches have been observed in the sea's water and sediment layers. These oil patches disrupt marine habitats, suffocate aquatic life, and reduce the sea's overall biodiversity, posing a long-term threat to the ecological balance. Some oil fields in the Caspian Sea, where tectonic processes occasionally occur, have increased the frequency of leaks, leading to more severe ecological problems. According to official data from MDPI, large oil patches ranging from 100 to 900 square kilometers have been observed in the Caspian Sea, with approximately 24% of the studied patches covering areas of 400 square kilometers (Figure 6). These patches pose a significant threat to the Caspian's ecological state and strong winds continually expand the oil spills.

**Figure 6: Area of oil patches in the Caspian Sea**

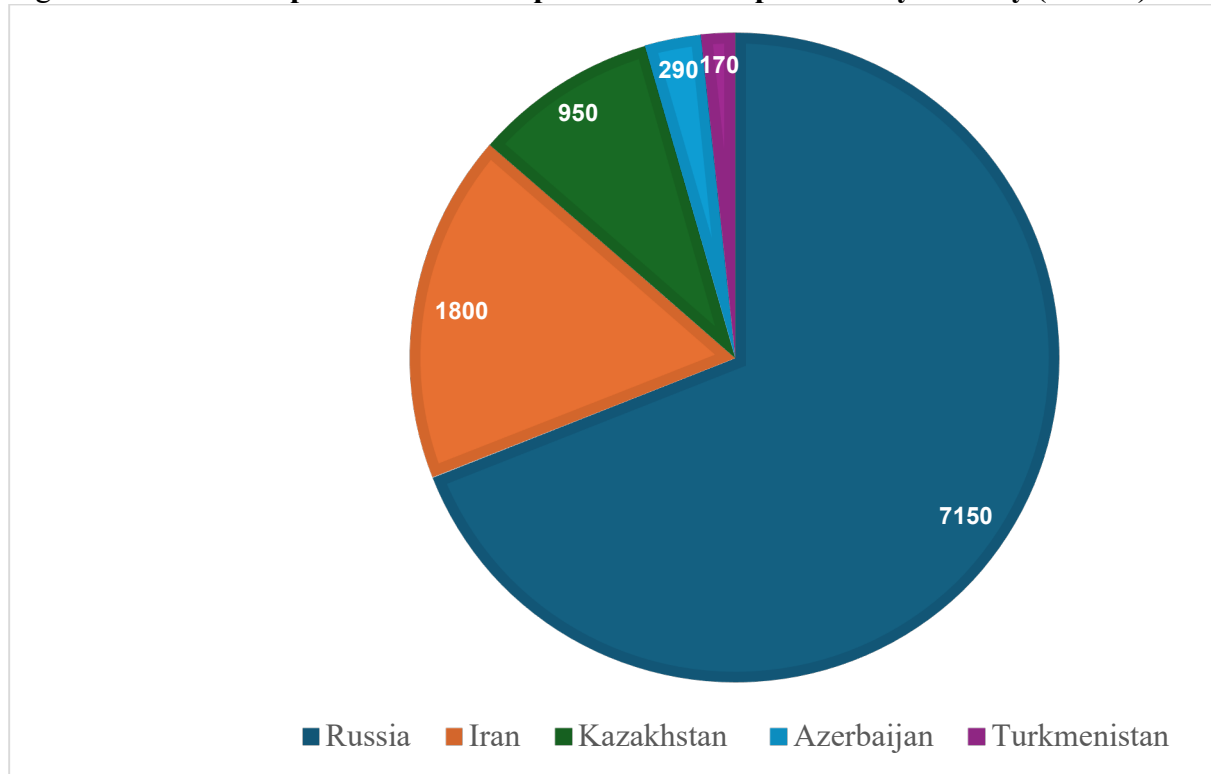


**Source:** Mityagina & Lavrova, n.d

In addition, the increase in plastic waste in the Caspian Sea region poses a serious environmental threat. A significant portion of the plastic waste dumped into the sea consists of household and industrial waste, which, when not properly managed by the coastal countries, flows uncontrollably into the water bodies. Research shows that the coastal countries of the

Caspian Sea, including Russia, Iran, Azerbaijan, Kazakhstan and Turkmenistan, together dump approximately 10 kilotons (1 Kt = 1000 tons) of plastic waste into the sea annually (Figure 7).

**Figure 7: Amount of plastic waste dumped into the Caspian Sea by country (in tons)**



*Source: Ghayebzadeh et al., 2020*

All these oil, gas, and industrial activities negatively impact the Caspian Sea's ecosystem. Pollution by chemicals and heavy metals is among the most significant of these impacts. Water pollution in the Caspian Sea leads to the disruption of the sea's ecology, harming marine organisms, particularly fish, mollusks and other aquatic life. Toxic substances accumulate in the bodies of marine organisms, leading to bioaccumulation and biomagnification processes. As shown in Table 1, 161 of the Caspian Sea's 1,860 species are already listed in the Red Book, highlighting the alarming impact of pollution on biodiversity, including critical losses among fish, mammals, and birds.

**Table 1: Biodiversity of the Caspian Sea**

Bio Groups	Total Species	Endemic Species	Alien Species	Species in Red Book
Phytoplankton	441	17	6	-
Zooplankton	315	64	7	10
Zoobenthos	380	190	12	20
Fishes	133	54	17	27
Mammals	125	1	3	41
Birds	486	-	-	63

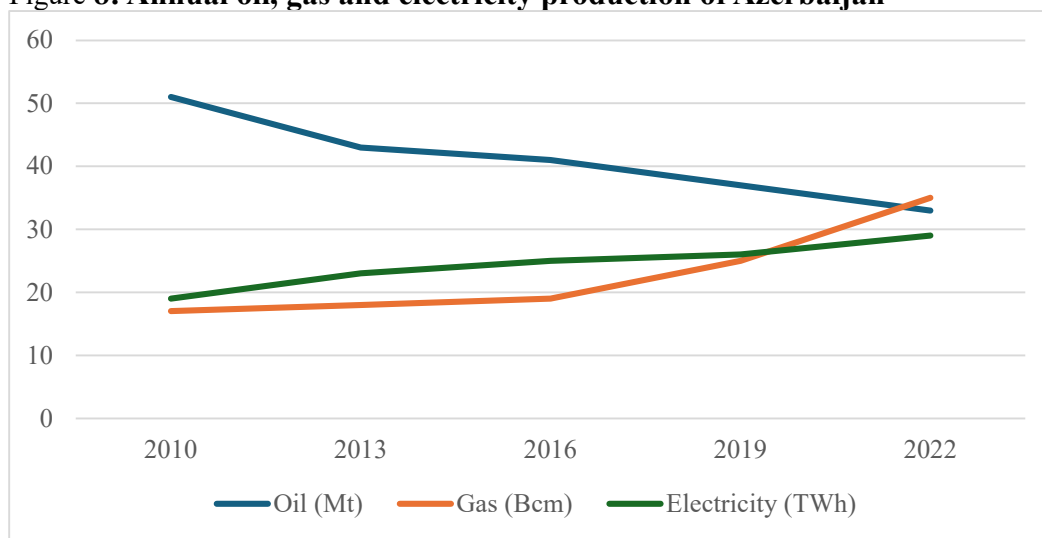
*Source: GRID-Arendal*

Industrial and oil waste pose a grave threat to the Caspian Sea’s ecosystem, contributing to water pollution, biodiversity loss, and disruptions in ecological functions. As seen in the rising number of endangered species and the persistence of oil and plastic pollutants, immediate action is required. Coordinated international efforts, stricter environmental regulations, and the promotion of green technologies are essential to mitigate these impacts. By prioritizing a sustainable approach to economic development, the Caspian region can protect its natural resources while contributing to global environmental goals.

### AZERBAIJAN'S GREEN TECHNOLOGIES AND OIL, GAS INDUSTRY.

Since gaining independence in 1991, Azerbaijan has undergone significant economic transformation, driven largely by its substantial oil and gas reserves. These resources fueled rapid economic growth during the 1990s and 2000s, with oil and gas exports accounting for over 90% of Azerbaijan’s total exports during this period, according to the International Energy Agency (IEA). The discovery of the Shah Deniz gas field in the early 2000s further boosted production, which peaked in 2010 (see Figure 8).

Figure 8: Annual oil, gas and electricity production of Azerbaijan



Energy type	Unit	2010	2013	2016	2019	2022
Oil	Mt	50.9	43.5	41.1	37.5	32.7
Gas	Bcm	16.7	18.3	18.7	24.5	35
Electric	TW h	18.7	23.4	25	26.1	29

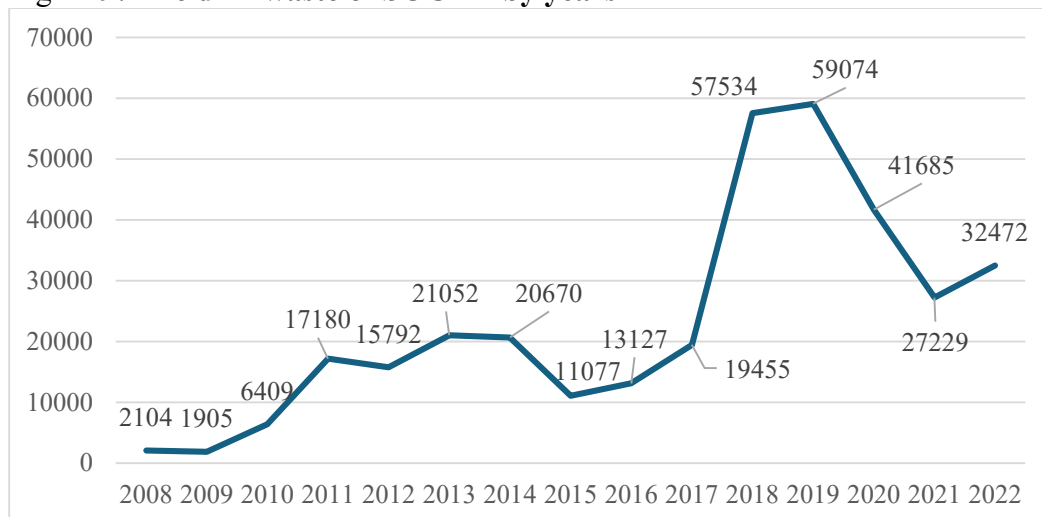
**Note:** Mt = million tons, bcm = billion cubic meters, TWh = terawatt hour.

**Source:** International Energy Agency (IEA)

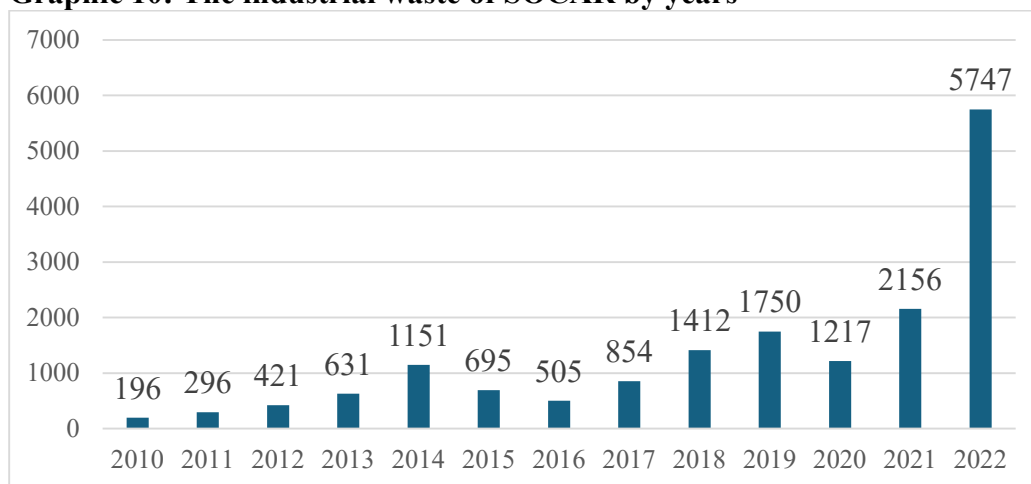
Recognizing the ecological challenges associated with industrial activities, Azerbaijan has increasingly focused on green technologies and sustainable practices. A cornerstone of these efforts has been the accurate identification and management of ecological problems and waste statistics. The State Oil Company of Azerbaijan Republic (SOCAR) has taken a leading role by establishing the Waste Management Center (WMC), which monitors waste from both marine and land-based activities. In 2022, SOCAR reported managing 32,472.9 tons of drilling waste (Figure 9) and 2,510.3 tons of industrial waste (Figure 10).



**Figure 9: The drill waste of SOCAR by years**



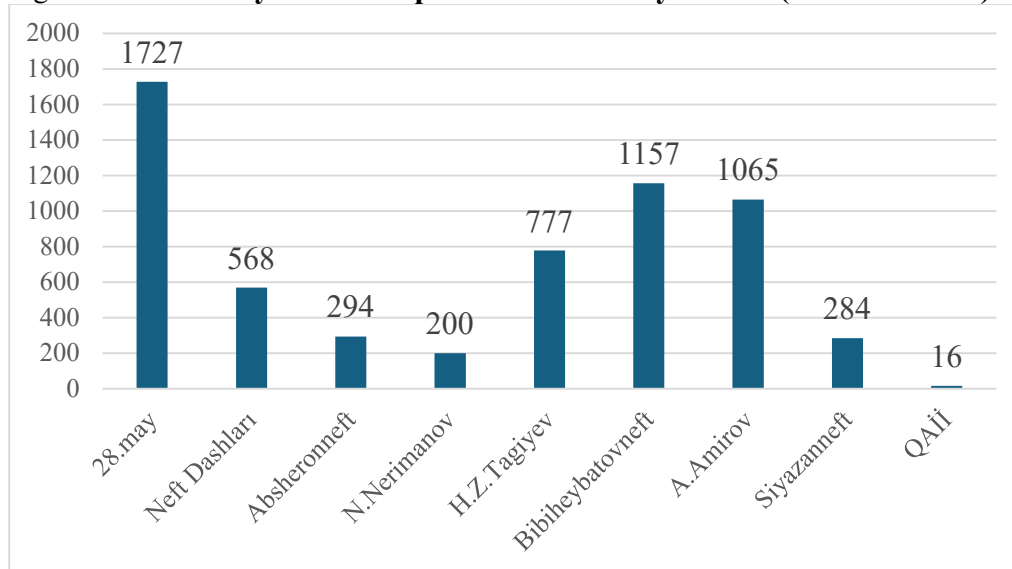
**Graphic 10: The industrial waste of SOCAR by years**



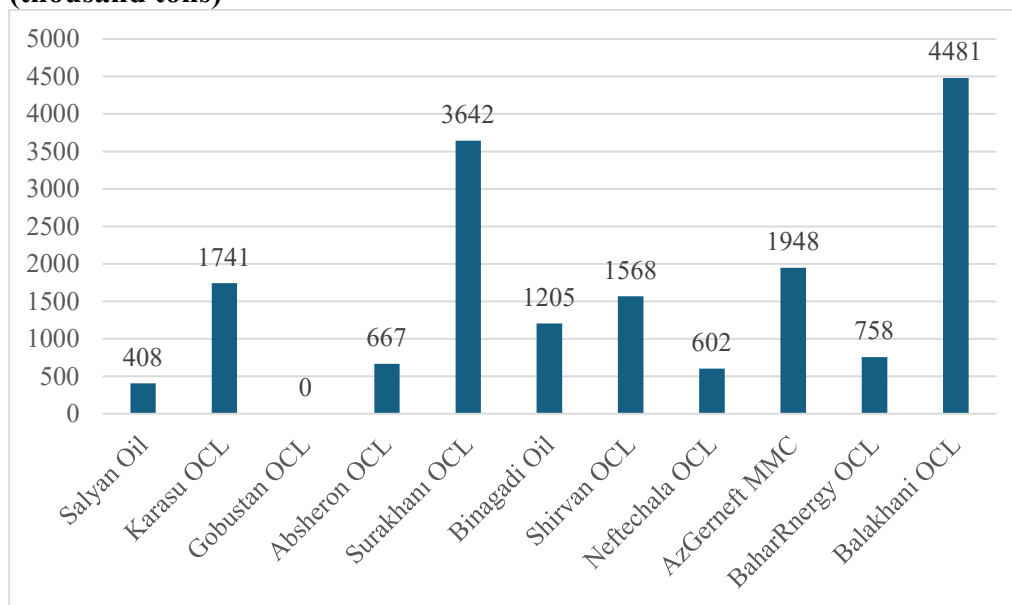
*Source: SOCAR, sustainable development report 2022*

To address these challenges, SOCAR introduced the **"Zero Waste" program** at the 2023 Baku Energy Forum. This program focuses on waste prevention, reuse, and recycling to mitigate the ecological crisis facing the Caspian Sea. A major ecological issue involves "produced water"—a byproduct of oil and gas extraction containing chemicals, salts, heavy metals, and organic compounds. Since 2017, SOCAR has implemented **"Zero Discharge" technology**, which eliminates the release of produced water into the environment by purifying and reusing it or injecting it into underground formations. In 2022, SOCAR managed a total of 23,120 thousand tons of produced water, with 6,122 thousand tons handled by Azneft (Figure 11) and 17,028 thousand tons managed by other partner companies (Figure 12).

**Figure 11: Annually extracted produced water by Azneft (thousand tons)**



**Figure 12: Annual extraction of produced water by operating companies and joint ventures (thousand tons)**



**Source:** SOCAR, sustainable development report 2022

Azerbaijan has also made strides in wastewater management. The Hovsan Aeration Station in Baku, the largest treatment facility in the South Caucasus, is a critical initiative. Designed to treat and safely dispose of wastewater collected from Baku, the facility utilizes advanced green technologies for biological purification. This process minimizes ecological harm, with a portion of the treated water discharged into the Caspian Sea. Residual sludge from the treatment process is managed in 36 sludge fields, each with a capacity of 17,500 cubic meters, where it is dewatered and treated to prevent further environmental impact.

The Caspian Sea region holds significant potential for green energy development, emphasizing its importance as a key area for sustainable initiatives. As noted by Gasimli, Huseyn, and Huseynov (2024), highlighting the opportunity for harnessing renewable resources in the region. This aligns with broader strategies for transitioning oil-rich countries like Azerbaijan toward a greener energy future.

Azerbaijan's efforts to balance its reliance on oil and gas with the adoption of green technologies highlight a forward-thinking approach to sustainability. Initiatives like the "Zero Waste" and "Zero Discharge" programs, along with cutting-edge wastewater treatment facilities, underscore the country's commitment to addressing ecological challenges. By integrating green technologies into its oil and gas industry, Azerbaijan is setting a precedent for sustainable development in the Caspian region.

## EXPERIENCES OF REGIONAL COUNTRIES IN THIS FIELD

The Caspian Sea region holds immense economic and ecological significance, making its protection a shared responsibility for all neighboring countries. This section highlights innovative green technologies implemented by other regional countries to safeguard the Caspian Sea and their respective outcomes.

In **Kazakhstan**, significant strides have been made in the field of bioremediation to address ecological issues in the Caspian Sea. This technology utilizes bacteria and other microorganisms to break down pollutants. Field experiments conducted on soil contaminated with 10% crude oil at the K-Kurylys site demonstrated its effectiveness. Over a six-month trial, the population of oil-degrading microorganisms reached  $10^7$  CFU/g, resulting in the degradation of 70% of the crude oil. Such results underscore the potential of bioremediation as a sustainable method for managing oil pollution.

In **Russia**, electrocoagulation technology has been deployed to mitigate the environmental impact of the oil and gas industry. This method treats wastewater by aggregating and removing contaminants through electrical currents. Research shows that electrocoagulation is particularly effective in eliminating heavy metals and oil components from wastewater, reducing water pollution levels by over 90%. These achievements exemplify the technological advancements within the region aimed at ecological restoration.

## CONCLUSION

The Caspian Sea is a unique and ecologically sensitive region that has been significantly impacted by industrial waste, oil extraction, and climate change. These challenges have disrupted its biodiversity, water quality, and overall ecosystem stability. As this paper highlights, green technologies offer a pathway to addressing these issues effectively and sustainably.

The experiences of regional countries such as Kazakhstan and Russia demonstrate the potential of innovative approaches like bioremediation and electrocoagulation in mitigating the ecological impact of industrial activities. Azerbaijan, with its ongoing efforts in adopting green technologies like the "Zero Waste" and "Zero Discharge" programs, has shown that such solutions can be integrated into existing industries to minimize environmental damage while maintaining economic growth.

To ensure the long-term ecological balance of the Caspian Sea, a comprehensive, multi-stakeholder approach is necessary. This requires active collaboration among governments, the private sector, and international organizations to:

- Expand the use of renewable energy sources to reduce dependency on fossil fuels.
- Invest in advanced water purification systems to tackle industrial and oil-related pollution.
- Foster cross-border initiatives to share successful technologies and best practices.

Moreover, strengthening international environmental agreements and policies tailored to the Caspian region will create a robust framework for ecological protection. These measures not only address current environmental challenges but also align with global sustainability goals, such as the Paris Agreement and the United Nations' Sustainable Development Goals (SDGs).

Green technologies are not just a means of addressing today's environmental crises; they represent a forward-looking strategy for securing a sustainable future for the Caspian Sea. By integrating such technologies, the region can transition towards a more resilient and sustainable ecological framework. This will not only restore the ecological balance but also provide a healthy and livable environment for future generations, ensuring that the Caspian Sea continues to be a vital resource for economic and environmental stability.

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# XƏZƏR DƏNİZİNİN EKOLOJİ PROBLEMLƏRİNİN HƏLLİNDƏ YAŞIL TEXNOLOGİYALARIN ROLU

**Günay Quliyeva,  
Fəqan Qənbərli**

## XÜLASƏ

Bu məqalə Xəzər dənizinin ekoloji problemlərini və bu problemlərin həlli istiqamətində yaşıl texnologiyaların transformativ potensialını tədqiq edir. Dünyanın ən böyük qapalı su hövzəsi olan Xəzər dənizi, neft hasilatı, sənaye tullantıları və iqlim dəyişikliyinə təsirləri nəticəsində ekosistemini ciddi şəkildə pozan ekoloji təhdidlərə qarşı yüksək həssaslıq nümayiş etdirir. Tədqiqatın əsas məqsədi bu ekoloji problemləri ətraflı şəkildə təhlil etmək və yaşıl iqtisadiyyat texnologiyalarının dənizin ətraf mühitinin qorunmasına töhfəsini müəyyən etməkdir. Xüsusilə, məqalədə ekoloji cəhətdən dayanıqlı su təmizləmə texnologiyalarının, bioloji innovasiyaların və regionun ekoloji balansını bərpa etməkdə digər davamlı təcrübələrin effektivliyi analiz edilir. Eyni zamanda, bu problemlərin həllinə yönəlmiş mövcud layihə və təşəbbüslər qiymətləndirilərək, onların təsir dairəsi və genişlənmə potensialı ilə bağlı nəticələr təqdim olunur. Həll yollarını araşdırmaqla, məqalə yaşıl texnologiyaların Xəzər dənizinin ekoloji davamlılığını təmin etməkdə oynadığı strateji və mühüm rolunu vurğulayır.

Açar sözlər: İqlim dəyişikliyi, Xəzər dənizi, "Sıfır Tullantı" proqramı, Bioremediasiya, Elektrokoagulyasiya

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