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INDUSTRIAL POLLUTION CONTROL IN THE CASPIAN SEA OIL AND GAS SECTOR: LEGAL FRAMEWORKS AND TECHNOLOGICAL SOLUTIONS

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Abstract. The Caspian Sea, which is endowed with hydrocarbons and biodiversity, is subjected to cumulative pollution by offshore and coastal oil and gas exploitation. Discharges of produced water, routine flaring and venting and contaminated sediments preserve the ecosystem and endanger fisheries and coastal populations. Some of them use sophisticated technologies - closed-loop drilling, gas recovery units, fibre-optic leak detection, bioremediation pilots - although these are ad hoc, mostly voluntary and poorly enshrined in legislation. This paper examines the environmental effects of oil and gas production in the Caspian, taking Azerbaijan and Kazakhstan as examples. It explores the national laws, regional policies like the Tehran Convention and provisions of the global instruments, pinpointing loopholes in enforcement potential, technological requirements and international cooperation. The article then characterizes important pollution control technologies that have already been tried in the basin and evaluates the impediments to broader implementation. It holds that the sustainable development of the Caspian demands greater integration of law and engineering through explicit technology-enforcing standards, stronger institutions and a regional agreement on environmental technologies that will make fragmented innovations a long-term, comprehensive strategy for ecological restoration.

Keywords: *Caspian Sea, oil and gas, pollution control, environmental law, technological innovation.*

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1. Introduction

The Caspian Sea, the largest closed inland sea in the world, is located at the environmental extremes and is affected by industrial activities. As one of the largest oil and gas reserves, it has been the hub of the region of the oil and gas development of Eurasia and the practice of strategy to the wars in the region and the neighboring countries, namely, Azerbaijan, Kazakhstan, Turkmenistan, Iran and Russia (Effimoff, 2000). It is discovered that with the development of offshore oil and gas in the Caspian, the economic growth of these nations has improved and is currently a very significant source of revenue to Azerbaijan and Kazakhstan, in particular, but it has also over-strained the weak marine life of the Caspian (Mityagina *et al*., 2019).

Over the past 30 years, such industrial processes as deep-water drilling, pipeline construction, coastal refining and terminal operations have experienced a surge in activity. The activities constitute a number of stressors, including the operational releases, flaring emissions and spillage and aspects of the contamination of the sediment (Bodini *et al*., 2024). An internationally established fisheries regime attempted to develop a permit system, but this faded quickly as nations agreed to this, but the actuality is 25 percent less since the 1990s in their fish stocks, which is mainly attributed to pollution

and habitat loss (Bastami *et al*., 2015). Hydrocarbons in the waters offshore the regions of Azerbaijan and Kazakhstan now frequently exceeded the national norms and the norms established by the World Health Organization (WHO) and the composition of the sediments on these sites contains a significantly high amount of toxic substances, like polycyclic aromatic hydrocarbons, mercury, cadmium and others (Tolosa *et al*., 2004).

The overall regulatory environment with regard to environmental protection is not fully harmonized: whereas the policies adopted by the likes of TotalEnergies and BP Multinational corporations to combat the adverse environmental impacts of oil drilling are consistent with global standards (zero-discharge, satellite-assisted leak detection systems), the markets they operate in still lack the consistency found in the policies of individual companies. Local companies, especially state-owned or smaller/contractors, have commenced operations with minimal monitoring or technology. The upshot of this is that environmental degradation persists in most regions despite the advancement in technology in some regions (World Bank, 2023a). As an example, routine flaring and uncontrolled discharge of the produced water continue in some areas of the Mangistau region of Kazakhstan, which poses substantial environmental and health risks (Bayramov, 2020).

The urgency of the Caspian pollution crisis is related not only to the extent of damage but to the lack of cohesion in the legal and technological response to the crisis. National legislation is frequently out of date and ineffectively implemented and there is poor regional collaboration despite the signing of many of the significant treaties, among them the Tehran Convention (2003). Current legal systems are not keeping up with the rapidly changing rates of technological development and they also do not enforce the adoption of technologies of pollution controls that already exist and have been tested (Rahbar *et al*., 2016).

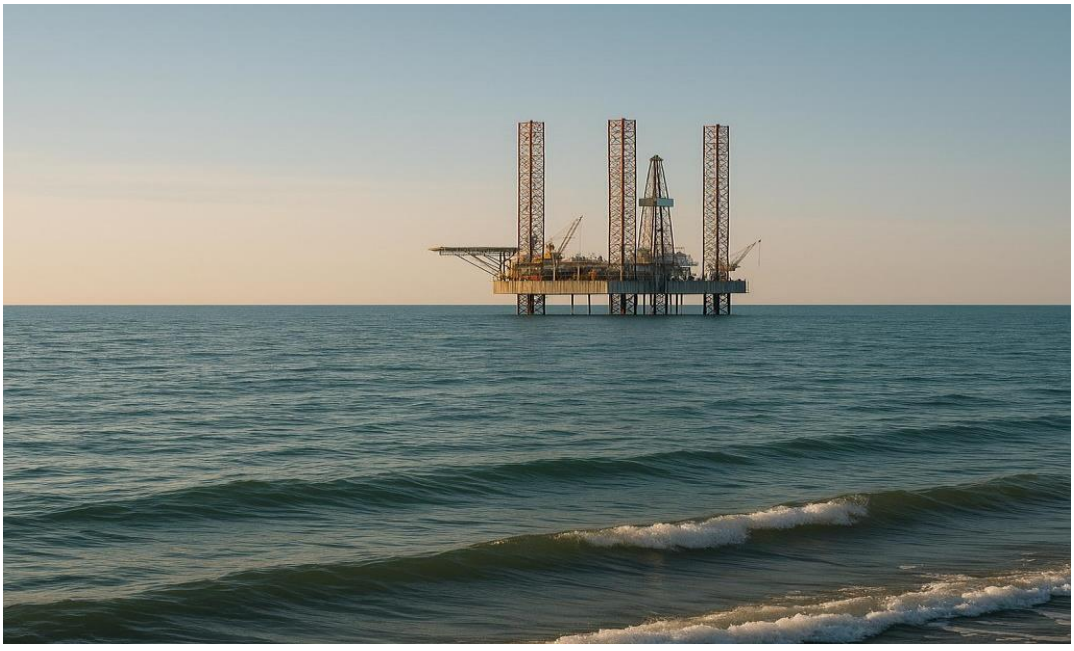

Figure 1. The picture depicts an oil platform at sea in the Caspian Sea, which shows the sensitivity of the region to hydrocarbon production

The paper is a response to the necessity of an effective and consistent framework that will combine technology and legal problems. It commences by reporting the environmental implications of human activity surrounding oil and gas use in the Caspian Sea, based on empirical case examples. It also evaluates the framework of national and international laws as they are now applied in controlling pollution and highlights how the system is structurally weak or has loopholes in its implementation. The third section summarizes technological solutions that cannot be mitigated, offering potential mitigation opportunities, including those already implemented in the region. The paper concludes by addressing the challenges that make it hard to appropriately match legal instruments to technological possibilities. The paper concludes by proposing a multidisciplinary examination of issues relating to pollution control that seeks to understand the interconnected nature of law, governance and engineering as they play a role in overseeing one of the most threatened inland seas in the world.

2. Environmental impact of oil and gas activities in the Caspian Sea

The implications of hydrocarbon exploitation on the Caspian coastline are far-reaching, cumulative as well and getting nearer and nearer impossible to repair. Oil and gas mining, both offshore and onshore, has a pollution element at every point in the extraction process, in operations and transportation and storage of the products. The partially closed geography of the sea also intensifies the retention of pollution as the pollutants accumulate over time in the absence of any natural dispersion (Nasrollahzadeh, 2010).

The outputting of produced water, the oily, oil-contaminated water yielded to the surface during the course of oil production, is one of the most outstanding causes of marine pollution in the region. The volume of water produced has sometimes surpassed the oil volume by 10 times or even more, although some operators are diverting into reinjection or even treatment technology, many facilities still discharge their produced water into the sea. These effluents contain such hazardous compounds as benzene, toluene, xylene, heavy metals and naturally occurring radioactive materials (NORMs), which pose a hazard to aquatic ecosystems (Kharaka & Hanor, 2014).

The coastal areas of Azerbaijan around the Baku Bay have suffered recurrent pollution incidents, with the worst one being the pipeline break in the year 2001 by SOCAR that spilled in excess of 4,000 barrels of crude oil in the waters. Its resulting pollution resulted in direct drops in local fish stocks estimated at 30% as well as the adverse effects on migratory bird species that relied on coastal wetlands. Although emergency enforcement cleaning up took place, long-term observation revealed the presence of residual hydrocarbons in the location decades later and the title effects are measurable ecologically (Kebria *et al*., 2020).

In the Kashagan oil field in Kazakhstan, another high-impact extraction in a sensitive environment can be noted. The region has experienced a raft of infrastructure breakdowns and a number of untapped methane spills since the field went commercial in 2013. According to the environmental officials of Kazakhstan, the Kashagan field is known to release an amount of about 300,000 tonnes of methane every year, which is equivalent to about 8 million tonnes of carbon dioxide in terms of climatic feasibility indicators. This not only adds hugely to greenhouse gases in the region but also poses safety hazards to the workers and communities in the surroundings because of high levels of hydrogen sulfide contained in the extracted gas (Schwab, 2024).

Another old location of concern is the oil field of Azeri-Chirag-Gunashli (ACG), where decades of active operations have led to an established accumulation of pollutants in sea floor sediments. Independent environmental monitoring has documented PAH concentrations up to 50 percent above safety levels and a 40 percent collapse in the diversity of the benthic fauna- organisms vital to the health of the marine food web. All these alterations impair the robustness of the ecosystem and endanger the commercial fisheries that directly provide thousands of households along the coastline of Azerbaijan (Tolosa *et al*., 2004).

In the Mangistau region, Kazakhstan, onshore oil processing has contaminated both groundwater and the coastal water. In 2023, there will be an increase of 2030 percent in mercury and cadmium, superior to the limits of safety in WHO data. There is a direct human health impact reflected in local studies that indicate higher concentrations of heavy metals in the blood of the populations, as well as an increase in cases of respiratory and gastrointestinal disease (Bastami *et al*., 2015).

All in all, these case studies indicate that pollution in the Caspian Sea is not confined to incidental pollution but is sustained through exposure and ineffective policing. Depending on vague responses and largely confined to small projects existing responses are largely reactive and underfunded. There is still a lack of a regional system of risk assessment, exposure mapping and impact tracking and so many incidents are not registered. The sections below reflect on the potential of using legal and technological instruments to fill this gap and help restore the ecology (Bayramov, 2020).

Table 1. Major environmental incidents and chronic pollution sources in the Caspian region

Incident/Area	Impact
Baku Oil Spill (2001)	4,000 barrels spilled; fish populations ↓ 30% in affected zone
Kashagan (Kazakhstan, 2013–)	300,000 tonnes methane annually ≈ 8 Mt CO_2 equivalent
ACG Oil Field (Azerbaijan)	PAHs exceed limits by 50%; benthic fauna diversity ↓ 40%
Mangistau Region (Kazakhstan)	Mercury & cadmium exceed WHO thresholds by 20-30%

3. Legal frameworks governing pollution control

Environmental protection functioning in the Caspian Sea region will largely rely on the efficacy of regulations and legal provisions, domestically and internationally established and known to manage pollution in the oil and gas industry. Although individual littoral states all have adopted environmental legislation and are signatories to international conventions, their application is patchy, uneven and frequently out of step with the realities of technology. This part reviews the legislation of major states at the national level, analyzes the relevance of the regional and international legal tools and determines the primary gaps that conspire to block integrated and efficient pollution control.

3.1. National legislation: Azerbaijan and Kazakhstan

Azerbaijan and Kazakhstan are two of the largest producers of hydrocarbons in the Caspian and have domestic legal systems that underpin their pollution regulation, but both systems have difficulties in implementation and coherence.

The main environmental law in Azerbaijan is the Law on Environmental Protection (Republic of Azerbaijan, 1999b), according to which the general principles of ecological safety, the use of natural resources and the avoidance of pollution are established (Republic of Azerbaijan, 1999b). It mandates Environmental Impact Assessments (EIAs) of industrial activities and bestows upon the Ministry of Ecology and Natural Resources permits and powers to grant and enforce such permits (Republic of Azerbaijan, 1999b, arts. 50-55). Other laws, such as the Law on Environmental Safety and the Law on Ecological Expertise, support commitments to reduce damage and introduce monitoring (Republic of Azerbaijan, 1999c). But it is not followed and especially in the state-owned enterprises, as well as politically cushioned ventures. Transparency Azerbaijan reports that corruption and incompetence within institutions limit wholesale adoption of legal protection, particularly in extractive sectors (Transparency International, n.d.).

Kazakhstan is not idle in its attempt to implement its updated Environmental Code in 2021, as new progressive ideas include the principle of paying the polluter, environmental auditing and varying environmental permits, depending on the risk category of operations (Republic of Kazakhstan, 2021). It obliges environmental oversight and reporting and introduces norms with regard to emissions and effluents and introduces winner-takes-all in instances of harm (Republic of Kazakhstan, 2021, arts. 38-45). However, the activities are poorly controlled, particularly in the remote areas like Mangistau and Atyrau, where the oil and gas production is concentrated. The NGO Crude Accountability has reported investigations to indicate that fines levied on environmental offences are small enough to induce non-cooperation and there is no public involvement in the management of the environment (Crude Accountability, 2021).

3.2. Regional and international legal instruments

Parallel to the national activities are the commitments of the Caspian states to a number of regional and international legal aspects that strive to control pollution and ensure the safety of the marine environment.

The most crucial one among them is the Tehran Convention (2003), officially called the Framework Convention on the Protection of the Marine Environment of the Caspian Sea, which was adopted in 2003. It became the first legally binding regional environmental agreement signed by all five littoral states and binds the parties to prevent, reduce and control land-based and offshore pollution. Several protocols have been developed under the Convention, such as those on biodiversity protection, oil spill preparedness and pollution monitoring. Ratification and implementation of these protocols have not been even, however. An example is the Protocol Concerning Regional Preparedness, response and cooperation in combating oil pollution incidents, which Azerbaijan and Russia ratified, but is not yet operational because the infrastructure is absent and the countries are not engaged in joint training exercises (United Nations Environment Programme, 2019).

The other applicable international tool is the United Nations Convention on the Law of the Sea (UNCLOS), which extends state liability to curb sea pollution by seabed activities, shipping and on land (United Nations, 1982). Though not all Caspian states

have ratified UNCLOS, some of them, such as Kazakhstan, have (United Nations Treaty Collection, 2016). In addition, the special legal status of the Caspian as a closed sea has made the actual application of the UNCLOS provisions more difficult, especially concerning the Exclusive Economic Zone (EEZ) provisions, maritime boundary and seabed jurisdiction (Hatamzade, 2019).

The Espoo Convention (1991) is also of potential importance (United Nations Treaty Collection, 1991). It also commits parties to conduct transboundary EIAs of projects that are likely to produce an environmental impact across national boundaries. Although both Azerbaijan and Kazakhstan are signatories to Espoo, the lack of cross-border consultation as regards oil and gas projects is quite evident. Transboundary activities, including the development of new deep-sea wells or increased flaring activity, begin with offshore activities often unannounced to adjacent states (UNECE, 2019a).

3.3. Gaps in implementation and enforcement

Despite the national laws and regional agreements, some systematic loopholes still exist that restrict the effectiveness of pollution control activities in the Caspian region:

- Ambiguity of marine jurisdiction: Decades of disagreement about the legal nature of the Caspian Sea (e.g., lake or sea) have postponed explicit regulation of offshore limits, jurisdiction over sea resources and common environmental ownership. Despite the resolution of these problems, to a degree, in the 2018 Convention on the Legal Status of the Caspian Sea, important areas of the agreement, such as environmental cooperation and enforcement, remain ambiguous or optional (Tehran Convention, 2018).
- Weak regulatory ability and capability: In most cases, the regulatory bodies do not have sufficient budgetary resources, technical necessities or political autonomy to oversee the activities or impose penalties on industries. Regulatory capture, particularly in oil-rich provinces, is a long-time challenge (Bayramov, 2020).
- Weak relationship with technology: The use of modern pollution control technologies is not clearly spelled out or even obligatory in the current legal frameworks. Consequently, firms are sometimes able to fulfil the bare minimalistic legal requirements without installing more efficient systems, e.g., real-time leak sensors, re-injection of discharged water or gas recovery plants (OECD, 2019a).
- Weak civil and public society control: The availability of environmental information is limited in most cases and the process of consultation is weak or not present. This negatively affects accountability and transparency, especially the marginalized coastal communities that are impacted by the pollution (Crude Accountability, 2021b).

3.4. Need for legal harmonization and innovation

The lack of coherence in environmental governance in the Caspian area can be seen not just through institutional constraints, but also through a more generalized lack of success in aligning environmental protection with technological capacities and across borders. Though reforms have been proposed by individual states, like the tiered system of environmental permits in Kazakhstan, there is no single regional standard on limits to emissions or spill response or even standardized technological levels (OECD, 2019a).

This incoherence of the law allows a race to the bottom to occur, where an investor and operator will choose to move into a jurisdiction with weaker environmental regulations or enforcement (Nejat *et al*., 2018). In addition to this, the lack of legal requirements on the implementation of advanced technologies is a lost chance to

modernize the region and reform the industry in an environmentally friendly way (Nejat *et al*., 2018).

Any plausible plan to protect the Caspian environment should not confine itself to action-reactive compliance, as this article subsequently argues. It should encourage flexible law systems that not only enforce outcomes, but also processes, connecting legal tools to changing technological benchmarks and creating new joint institutions across boundaries. In the absence of this integration, legal reform will remain trailing in respect of environmental risk (Nejat *et al*., 2018).

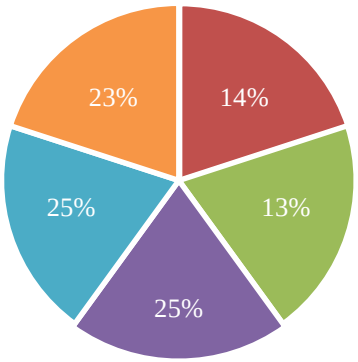

Diagram 1. Comparative efficiency of national, regional and international legal instruments that govern pollution control in the Caspian Sea
Note: Blue - Azerbaijan - Law on Environmental Protection (1999);
Green - Kazakhstan - Environmental Code (2021) ; Grey - Tehran Convention (2006);
Orange - UNCLOS (1982); Yellow - Espoo Convention (1991)

4. Superior pollution prevention techniques

To counter the threats to the environment that oil and gas processes within the Caspian Sea recreation may cause, a warmer legislative framework is needed, but what is more important is that the technology is to be highly sophisticated and location-specific. Some of the operators in the region, who are multinationals and other national firms, have implemented creative forms of abatement of pollution. Nevertheless, these technologies have questionable effectiveness because, in their practical application, they are very different, conditioned by the scale of application, legal support and support of institutional forces.

This section explores pollution control technologies applied in the Caspian region that have the best application in regard to control of pollution, effectiveness and case studies to depict their usage in real-life situations.

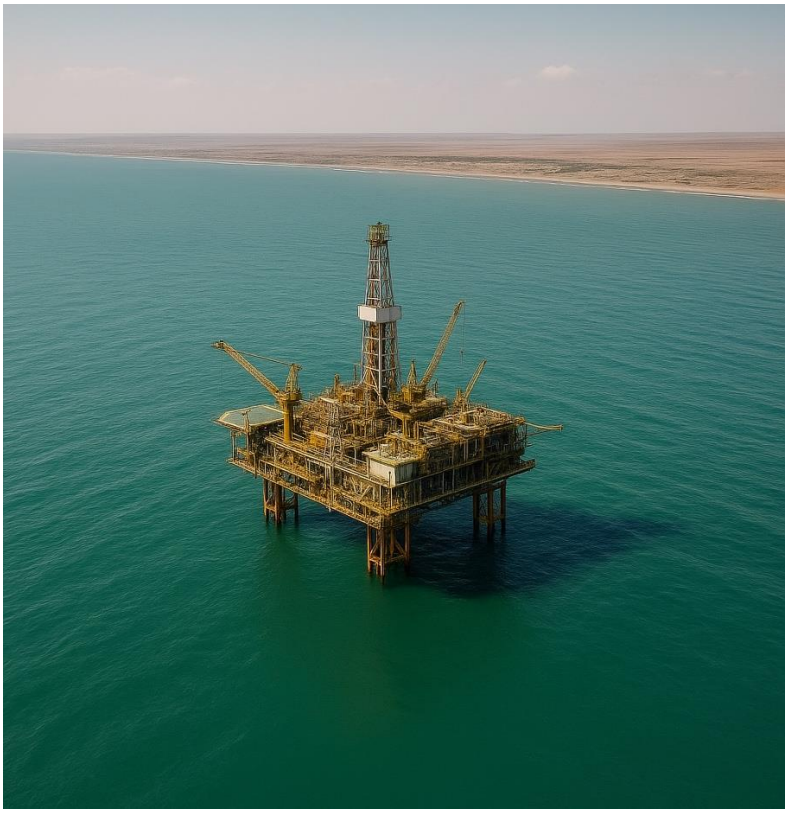

Figure 2. Offshore oil platform in the Caspian Sea, which symbolizes the technological infrastructure that is key in pollution mitigation

4.1. Produced water treatment and closed-loop drilling systems

The most significant marine pollution source of offshore oil platforms has remained to be produced water, which is sometimes laden with hydrocarbon content, heavy metals and naturally occurring radioactive materials (Kharaka & Hanor, 2014). Effective treatment or reinjection is paramount in order to prevent the leaching of toxic waste into the sea.

In the Kashagan oil field, Kazakhstan, the drilling fluid and related drilling fluid and produced water are not discharged directly to the environment but have been replaced by closed-loop drilling systems since 2016 (OECD, 2019b). These systems have since caused chemical waste discharges offshore to be reduced by about 70 percent (Ministry of Ecology, Geology and Natural Resources of Kazakhstan, 2021). The strength of this technology is that it traps and manages the waste form before it can go to the marine environment, thus being able to manage the waste disposal most efficiently and with reduced contamination.

Nevertheless, facilities in the Caspian region are still holding on to older open discharge techniques because of the prohibitive cost of fitting new ones and the lack of incentive to upgrade due to the low regulatory incentive. Lack of legal requirements that compel the use of a closed-loop system throughout has helped in slowing adoption.

4.2. Emission control: The minimization of flaring/venting

Gas flaring and venting create major amounts of greenhouse gas emissions and localized air pollution, particularly in regions where infrastructure to collect and process the gas is undeveloped (World Bank, 2023b).

The Azeri-Chirag-Gunashli (ACG) consortium, under which BP has a leading role, has installed gas reinjection technologies so that the associated gas is captured and compressed to be reinserted into the reservoir, maximizing the recovery rates and reducing flaring (BP, 2019). A similar case concerns the field of ACG, where this strategy allegedly cut flaring by more than 60 percent between 2015 and 2022 (BP, 2022). Moreover, gas recovery units (GRU) already in use in the terminal stations, close to Sangachal, enable to reuse of the gas already vented, directed in the supply chain (BP, 2022).

Conversely, in parts of Turkmenistan and Iran, where monitoring systems are less developed, flaring remains widespread and largely unregulated. A 2022 satellite analysis conducted by the Earth Observation Group at NOAA identified persistent high-temperature flaring sites along Turkmenistan's coast, suggesting that modern flaring-reduction technologies are not yet widely implemented outside of select projects (National Centers for Environmental Information, 2022).

4.3. Subsea acoustic leak detection system and subsea gas monitoring systems

Real-time leakage detection and underwater surveillance are important tools of timely intervention and prevention of spills (Eisler & Lanan, 2012). These technologies have been found to be a cost-effective risk mitigation strategy in a region where the offshore infrastructure is aging and the pipelines are more susceptible to corrosion.

In 2019, the ACG consortium installed a fiber-optic leak detection system along its subsea pipelines (BP, 2019b). On integration with satellite imaging and acoustic sensors, this system has been able to do something no other subsea monitoring system could: detect a minor leak within a few hours and indicate the necessity of shutdown and containment (BP, 2019b). The case reveals how much the integration of multi-sensors played a role in pollution prevention and has since then been referred to in similar types of offshore fields.

In the Shah Deniz gas field, a different consortium has used AUVs to achieve high-resolution seabed mapping and pipeline inspection (SOCAR, 2020). The advantages of these vehicles are that they are easier to cover larger areas with no diver necessarily required, which makes them safer and economical. In 2020, the early detection of corrosion on a pipeline that was possible with the help of the AUV encouraged the implementation of timely repairs and eliminated the possible damage to the environment (SOCAR, 2020).

4.4. Oil spill response/sludge service

With its technological developments, the danger of oil leakages and purges is very imminent in the Caspian. The region has no universal mechanism of spill response and remediation technologies are applied irregularly (Taylor, 2018).

To a certain degree, some innovation has happened to establish an element of bioremediation pilot projects, as is evident in the case of Kashagan. These projects utilize native microorganisms to break down hydrocarbon contaminants in soil and shoreline sediment (Mamedov *et al*., 2019). The initial results show that the process of the

contaminated areas is fast and hydrocarbon concentrations decrease by more than 50 percent within three months (Mamedov *et al*., 2019). Although encouraging, such projects are small-scale and may need bigger support from the regulators, along with long-term investments.

The problem of sludge and sediment pollution, especially by old onshore refineries, is mostly unresolved. Some terminals near Baku have advanced sludge processing units, such as thermal desorption systems, although technically this is not required throughout the region (SOCAR, 2020).

4.5. Data, environmental monitoring

Environmental monitoring should be accurate, transparent and continuous so as to ensure compliance and trust of the masses (OECD, 2021). New technology may enable monitoring of emissions in the air, the quality of water and sediment conditions using the Internet of Things (IoT) (Ullo & Sinha, 2020).

Recently, SOCAR has started piloting an environmental data analytics platform powered by artificial intelligence, collecting the data received by the sensors in real-time, calculating the risk of leakages and visualizing the impact of pollution in internal decision-making (SOCAR, 2022). But it is not publicly available at the moment and its regulatory recognition is still awaited.

In addition, the bulk of Caspian states do not have a centralized database or open-access reporting system on pollution cases (UNECE, 2019). The fragmentation of data has been a major obstacle to the integrated management of the environment and accountability to citizens.

4.6. Assessment: Strengths, weaknesses and gaps

The commitment to the installation of the latest pollution control technology in the Caspian Sea illustrates positive developments; nevertheless, there still exist some fundamental issues:

• Fragmented adoption: Expensive technology is focused on a few bright spot projects with little diffusion to national companies or fringe applications (OECD, 2019).

• Absence of mandates: Mandates: Most of the technologies are adopted on a voluntary basis or a reputation-based point of view rather than legalities (Bayramov, 2020).

• Poor scalability: Smaller operators cannot afford and at times do not have the technical know-how to use such innovations (Crude Accountability, 2021).

• Lack of satisfactory integration with law: National laws often fail to recognise and/or mandate new technologies, thereby lacking incentives to upgrade (OECD & UNECE, 2016).

All in all, the balance in the technological front of the Caspian region remains imbalanced and it has a lot of possibilities. Innovative monitoring, risk assessment and pollution control techniques are available, but their implementation is highly disparate and takes the form of donor-driven or short-term programs instead of coordinated regional efforts (United Nations Environment Programme, 2019). Such uneven implementation of them hinders their proper efficiency and precludes a consistent reaction to transnational environmental threats. The following section explains why these potentially transformative technologies have fallen short of realizing their optimistic applications on a region-wide scale and argues that more robust legal frameworks and forms of

coordinated governance are the only means by which this gap can ultimately be filled and credible ecological recovery can be realized.

Table 2. Comparative efficiency of some technological solutions used in oil and gas production in the Caspian Sea

Technology/Project	Effectiveness/Result	Pollution Reduction (%)
Closed-loop Drilling (Kashagan, 2016-)	Offshore chemical waste discharges reduced	70
Gas Reinjection & Recovery (ACG, 2015-22)	Flaring reduced by more than 60%	60+
Fiber-optic Leak Detection (ACG, 2019)	Detected subsea leak within hours; rapid containment	60
AUV Pipeline Inspections (Shah Deniz, 2020)	Early corrosion detection → timely repairs, avoided spill	50
Bioremediation (Kashagan pilot projects)	Hydrocarbon reduction in sediments by >50% within 3 months	50+

5. The disparities of legal and technological responses to integration

Many technological solutions that can be employed to reduce pollution caused in the oil and gas industry in the Caspian Sea exist, but their implementation in the regulatory frameworks is quite modest (OECD, 2019c). Such disconnect is not caused by technological impracticability but rather by a single web of legal, institutional and political places (Zebardast, 2018). In some instances, operators come up with promising innovations that go untapped because their introduction lacks required regulatory support or because institutional adaptation is slow (United Nations Environment Programme, 2019). This section discusses the key impediments to matching the legal frameworks with environmental technologies in the Caspian region (UNECE, 2017).

5.1. Legal-technical mismatch

The major issue is that the regional legal systems are unresponsive to technological advancement and use vague general standards rather than precise criteria (Zebardast, 2018). In Kazakhstan, its Environmental Code mandates permits and monitoring but not closed-loop drilling or fiber-optic leak detection, whereas Azerbaijan specifically allows discharges without defining or specifically requiring best available technologies (BAT) (Republic of Kazakhstan, 2021).

Table 3. The gap between technological availability and weak enforcement in the Caspian region

Category	Problem	Effectiveness (%)
Technology Available	Advanced systems exist (closed-loop, sensors, AUVs, bioremediation)	~80
Legal Enforcement	Weak mandates, low fines, fragmented institutions	~40
Political/Regional Cooperation	Tehran Convention weak enforcement; fragmented regional governance	~30

This technical-legal loophole provides operators with an opportunity to comply at a low threshold without an infrastructure upgrade (OECD, 2019a). Even when more advanced measures such as satellite monitoring or artificial intelligence-assisted leakage detection are in place, they frequently lack regulatory authority and as such, rarely present an enforcement option or do not carry legal standing (Tehran Convention & UNEP, 2020).

5.2. Institutional/regulatory limits

The other hurdle is institutional design/ability of the environmental regulatory apparatus. One of the major problems facing the regulators is the limited budget, shortage of personnel and lack of technical expertise, especially in remote areas that are not located near national capitals (OECD, 2019). In other situations, environmental inspectors either receive no access to independent monitoring data or have no equipment with which to check whether or not the claims placed on oil and gas operators by these operators are actually accurate (UNECE, 2019).

There are even cases of the lack of strong enforcement mechanisms, even where the violations have been traced (UNECE, 2019). Fines are usually sparse compared to the size of profit taken by oil activity and are not enforced in case of politically powerful companies involved in a joint venture with the national governments (Caspian Policy Center, 2025). In Azerbaijan, as an example, reports indicate that sometimes the inspections are preannounced, cutting down on their effectiveness as deterrents (Republic of Azerbaijan, 2015). In Kazakhstan, the complaints that the communities raise against flaring or discharge violations will be lost in the administrative procedures, with insufficient information about the final decision (UNECE, 2017).

Further, regulatory overlap and interministerial rivalries, particularly between the environmental and energy ministries and the investment ministry, hinder the decision-making process and expose loopholes in regulatory enforcement (UNECE, 2011). Such is especially concerning cross-sector technologies like IoT-based emission sensors, which must be legalized not only in environmental law but in industrial law as well (OECD, 2018).

5.3. Political will and regional fracture

Between the intention of greater commitment to environmental leadership in a part of the world where the economic interest remains paramount lies a greater still barrier to integration, the political level of commitment. There are weak binding mechanisms designed to guarantee compliance with environmental obligations despite the signing of the Tehran Convention and other regional declarations. Monitoring and enforcement have largely remained at the discretion of individual countries and with energy exports and other short-term economic priorities seen by many littoral countries to take precedence over longer-term environmental protection (Tehran Convention, 2011).

The repeated stalling of efforts to create a regional platform to deploy common environmental technologies by geopolitical conflicts, disparate legal systems and competition in resource access must be addressed. Absence of the common ecological data-exchange data bank, as well as the united sets of the measures of the technology performance of oil and gas sectors, leaves the states in a state of functioning in a legal vacuum, despite the presence of international risks (United Nations Environment Programme, 2018).

As recently as 2022, in the example of satellite data that showed evidence of more flaring near the Caspian coast of Turkmenistan, no collective efforts were made to respond through the Tehran Convention (Carrington, 2023). Similarly, the pilot bioremediation project implemented in Kazakhstan was not implemented in Azerbaijan and Turkmenistan, even though both countries have a degradation pattern similar to that of coastlines (Funtikova *et al*., 2023).

5.4. Recommendations, lost opportunities

The inability to synchronize legal instruments with existing technologies can be regarded as one of the wasted opportunities to modernize in a sustainable manner the Caspian hydrocarbon industry (United Nations Environment Programme, 2011). Substantial systems, which include gas recovery equipment, automated monitoring systems and seabed mapping devices, are no longer a novelty but are truly capable, scalable and eventually cost-efficient to operate (World Bank, 2023c). However, the adoption of these practices is skewed and in part, this is because codes do not come with any form of incentive or legislation (OECD, 2019).

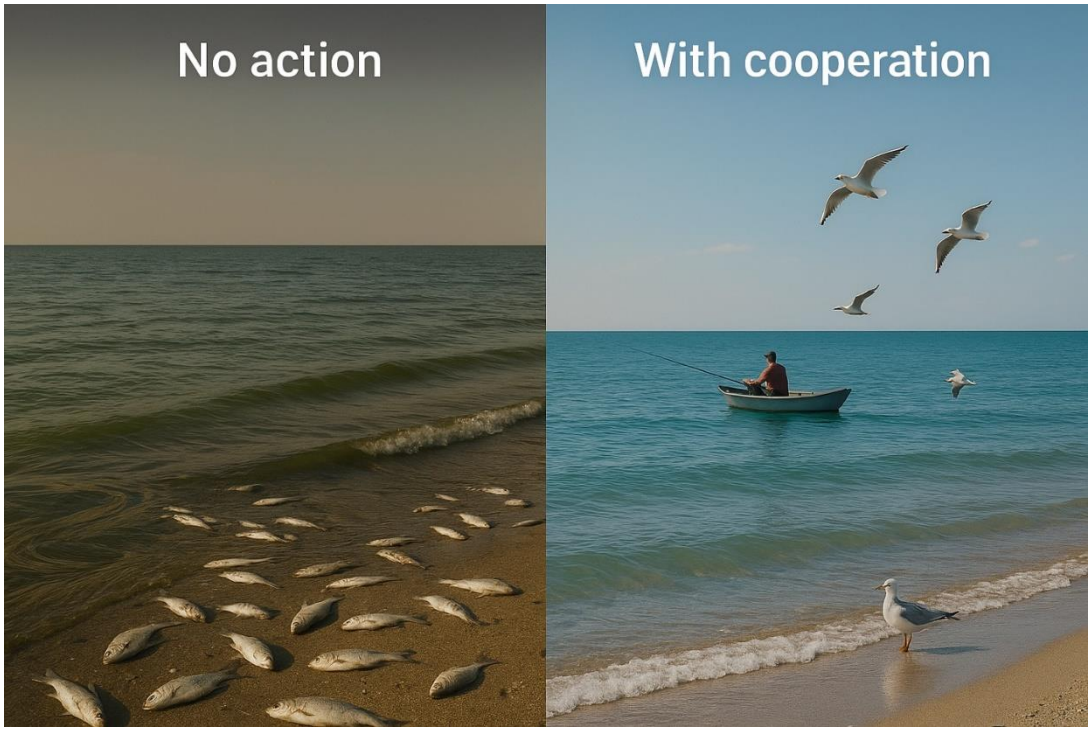

Figure 3. The future of the Caspian Sea according to poor enforcement (left) and to regional understanding and integration (right)

To bridge the above-discussed gap, the following is recommended:

- **Enforce mandate technology at law:** national legal frameworks need to shift from vague environmental requirements to explicit mandates to adopt a defined set of technologies, closed-loop systems, real-time monitoring and remote sensing (Republic of Kazakhstan, 2021).
- **Formalising novel data saturations:** The new regulatory frameworks ought to recognise the novelty of digital monitoring outputs as manifested through AI and IoT-

based systems as acceptable evidence in the context of inspection and enforcement (OECD, 2018).

• **Strengthen Institutional Capabilities:** Invest in environmental agencies through selected training, technical support and digital infrastructure to enable the verification and enforcement of technology-based compliance (UNECE, 2011).

• **Establish a transboundary regulatory regime:** Establish a Caspian Regional Environmental Technology Forum in the Caspian Environment Programme to harmonize on technology sharing and standards, as well as develop joint guiding implementation.

These suggestions prepare the basis of a more implementable and proactive governance of the environment. They also set up the stage for the final section of the article, which presents an original and scalable policy proposition to aid long-term integration of law and engineering in the situation in the Caspian Sea. Collectively, they are indicators of a transition from ad-hoc to a coordinated framework that is able to handle both domestic and cross-border ecological risks.

5.5. Toward a Caspian Regional Environmental Technology Accord (CRETA)

To mend the gap between the rules and the available pollution control devices, this paper suggests the formation of a Caspian Regional Environmental Technology Accord (CRETA) - a multilateral agreement aimed at pooling the control technology in use, reconciling the regulatory frameworks used by the Caspian littoral states and ensuring cross-border liability and responsibility (Convention on the Legal Status of the Caspian Sea, 2018).

Compared to the existing frameworks, like the Tehran Convention, which centers on the generic principles of cooperation (Tehran Convention, 2003). CRETA would allow parties to offer binding obligations on concrete types of adoption of technology. These can include:

• Environmental real-time monitoring systems
• Closed-loop drilling and flaring controls system
• Bioremediation of the reshaping of coastlines
• Openly available sources of information on emissions and discharges to the environment

The signatory states would undertake not only to incorporate these technologies into the domestic environmental law on a certain timeline, but would also be required to present annual reports verified with the help of an independent technical entity established under the Caspian Environment Programme (CEP) (UNEP & Tehran Convention, 2018).

To promote adoption, CRETA ought to implement a step-by-step implementation strategy:

• **Tier 1:** Incremental adoption of minimum core technologies (e.g., leak detection, basic reporting);
• **Tier 2:** Connection to digital compliance systems (e.g., IoT and AI);
• **Tier 3:** Total harmonization, data-sharing and trans-border enforcement.

A tech fund, backed by license collections and external donors (e.g., EBRD, UNEP or the World Bank), would help less-resourced operators apply the required upgrades (EBRD, 2021).

By designing a legally binding framework and relying on technological reality, CRETA would transform the disjointed innovation in coordinated regional development. It is also a direct response to a governance vacuum that has enabled the continued existence of pollution despite it being possible to implement cost-effective, scalable

solutions (UNECE, 2019). In addition to bridging this gap, CRETA would serve as a shared means of sharing data, being held mutually accountable to each other and having unified standards, such that environmental protection in the Caspian shifts away from scattered efforts and toward a sustainable, region-wide culture of compliance and innovation (UNEP, 2018).

6. Conclusion

In the Caspian, the environmental impact of oil and gas activities is in direct sight, not theoretical anymore and usually cannot be reversed. Produced water, flaring and industrial pollution have harmed marine biodiversity and polluted the coastal zone as well as the ecological health of the largest inland body of water on earth. In some projects, modern pollution control technologies exist; however, the impact remains local and scattered since institutions are weak.

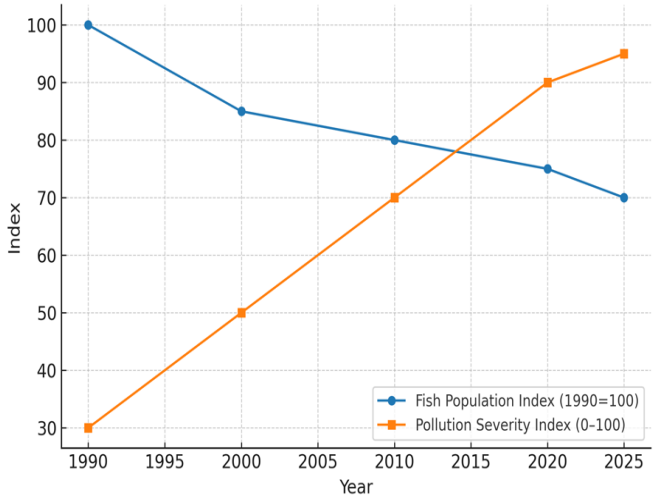

Chart 1. Long-term ecological trends in the Caspian Sea: Fish stocks declining while pollution rises

Azerbaijan and Kazakhstan have national legislation providing the minimum foundation in the field of environmental protection and both systems also have problems with the ages of regulatory acts, insufficient institutional capabilities and compliance with innovative best practices. The regional legal instruments do not work and especially Tehran Convention could not generate binding obligations and uniform standards. At the same time, the use of technology remains voluntary and its progress is motivated by reputational or business reasons and not government accountability or even lawfulness.

To fulfill this governance-related vacuum, this paper has introduced the idea of a Caspian Regional Environmental Technology Accord (CRETA), a binding, tiered agreement on the standardization of the implementation of pollution control technologies across the shoreline states in the Caspian Sea. CRETA would facilitate regulatory integration as well as technological integration by creating a minimum level of legal obligations, minimum shared monitoring procedures and a regional source of financing. It was proposed that, instead of other initiatives, it would give legal obligations directly to the realistic installations of the tools, like the real-time leak detection, flaring mitigation systems and the installation of data transparency platforms.

The aim of RTA is not to supersede, but to serve to buttress and to operationalise legal regimes by inscribing engineering solutions in enforceable norms. This would only succeed basically by the political determination of the member states and the expertise of an independent body of experts and the endorsement of international agencies that were already operating in the region. Most importantly, it would symbolize a move beyond aspirational cooperation to a quantifiable and science-driven environmental governance.

Figure 4. A striking imagery that is presented as an opposition between actual reality and the beauty of a new man-made future

The safeguarding of the Caspian Sea can no longer remain rhetoric. It must seek workable models bringing law into operation and novelty into obligations. The benefit of filling the gap between law and technology to overcome the current existing gap is that the region will no longer be associated with a pollution control response, but instead will be characterized as a proactive, sustainable governance. RTA has just such a course, one that is at once technically possible and obligatory in morality.

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