

AI-Driven Compliance Monitoring in the Oil and Gas Industry: Governance Frameworks for
Environmental Accountability and Regulatory Oversight

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Abstract

Artificial Intelligence (AI) is increasingly being deployed across the oil and gas industry to support environmental monitoring, predictive risk analysis, spill detection, and automated regulatory reporting. While these technologies present opportunities to significantly improve operational transparency and regulatory compliance, they also introduce new governance challenges, particularly in jurisdictions where environmental accountability and data transparency remain ongoing concerns. Building on earlier research examining the ethical implications of AI in extractive industries, this paper explores the governance structures required to ensure responsible AI deployment within oil and gas regulatory ecosystems. Using Nigeria's petroleum regulatory framework as a case study, the study examines how AI-enabled systems—including natural language processing models for regulatory document analysis and machine learning tools for environmental incident monitoring—can strengthen compliance oversight and improve the detection of environmental violations such as oil spills and reporting inconsistencies. However, the integration of AI into regulatory processes also raises concerns regarding algorithmic bias, data governance integrity, explainability of automated decision systems, and institutional dependence on opaque technological infrastructures. This paper proposes a governance-centered framework for AI adoption in extractive industries that integrates legal oversight, transparent algorithmic auditing, and responsible data management practices. By situating AI deployment within broader regulatory and governance structures, this research highlights the critical role of law and policy in shaping accountable and trustworthy AI systems capable of enhancing environmental stewardship, regulatory compliance, and public trust in resource-dependent economies.

Keywords: *Artificial Intelligence Governance, Regulatory Technology (RegTech), Oil and Gas Compliance, Environmental Monitoring, Data Governance, Responsible AI.*

1. Introduction

The global oil and gas industry is navigating an era of unprecedented dual transformation. On one side, public and institutional demand for rigorous environmental accountability has intensified; on the other, rapid digitization is reshaping historical modes of regulatory oversight. Central to this integration is Regulatory Technology (RegTech) driven by Artificial Intelligence (AI). Advanced technologies such as machine learning algorithms, satellite imaging analytics, and natural language processing (NLP) models are transitioning from pilot projects into structural components of environmental governance.

In highly complex petroleum ecosystems, AI holds massive potential. Automated tracking algorithms can parse vast fields of remote sensing data to pinpoint pipeline micro-fractures before catastrophic spills occur, while language models read statutory submissions to catch compliance anomalies. However, technical sophistication does not automatically ensure legal, transparent, or equitable enforcement. In resource-dependent nations, deploying opaque, third-party technology within state regulatory apparatuses risks introducing systemic vectors of institutional opacity and computational bias.

Building directly on the author's previous scholarship, *"The Ethics of Artificial Intelligence in the Oil and Gas Industry: Navigating Environmental Impact, Spill Response, and Data Governance in Nigeria,"* this paper shifts the academic focus from purely normative ethical codes to statutory and administrative governance structures. Using the legal baseline established by Nigeria's landmark Petroleum Industry Act (PIA) 2021, we examine how advanced automated mechanisms can be securely anchored. Ultimately, this study articulates a comprehensive, three-tiered framework capable of enforcing algorithmic accountability while preserving public trust and legal integrity.

2. Literature Review & Theoretical Context

2.1 The Rise of RegTech in Extractive Industries

RegTech originally emerged within the financial sector as an automated mechanism to prevent fraud and manage capital risk. Recently, its application has expanded deeply into heavy extractive sectors. Traditionally, environmental compliance monitoring in oil exploration has operated under a retrospective self-reporting model. Corporations maintain data logs and file periodic disclosures, while resource-constrained state regulatory inspectors perform occasional field-level physical audits. This dynamic often leaves regulatory bodies chronically dependent on operator-supplied narratives, leading to enforcement delays and reporting friction.

2.2 The Intersection of AI and Environmental Accountability

Modern AI applications break this structural bottleneck by replacing retroactive audits with real-time, objective data capture. Computer vision algorithms continuously audit spectral images from satellites to flag unauthorized gas flaring or detect surface-level hydrocarbon leaks. Concurrently, NLP frameworks ingest compliance documentation to verify internal cross-system consistency. Despite these efficiencies, legal theorists emphasize the "black box" crisis: if a system operates with deep multi-layered neural networks whose intermediate processing steps are unmapped, the outputs lack the clear procedural transparency necessary to meet stringent administrative evidentiary standards.

2.3 Transition from Ethics to Governance Frameworks

Ethical principles, while valuable, lack the statutory force needed to drive public-sector enforcement. While ethical parameters outline what a fair algorithm *ought* to perform, a robust governance framework establishes the institutional structures, judicial recourse, and data validation techniques required to operationalize those ideals within a living administrative law framework. This paper provides that operational link.

3. Case Study: Nigeria's Petroleum Regulatory Framework

Nigeria represents a premier geopolitical space to observe the introduction of RegTech, due to the comprehensive regulatory overhaul initiated by the Petroleum Industry Act (PIA) 2021. The PIA restructured the institutional architecture, creating distinct entities for separate industry streams: the Nigerian Upstream Petroleum Regulatory Commission (NUPRC) and the Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA).

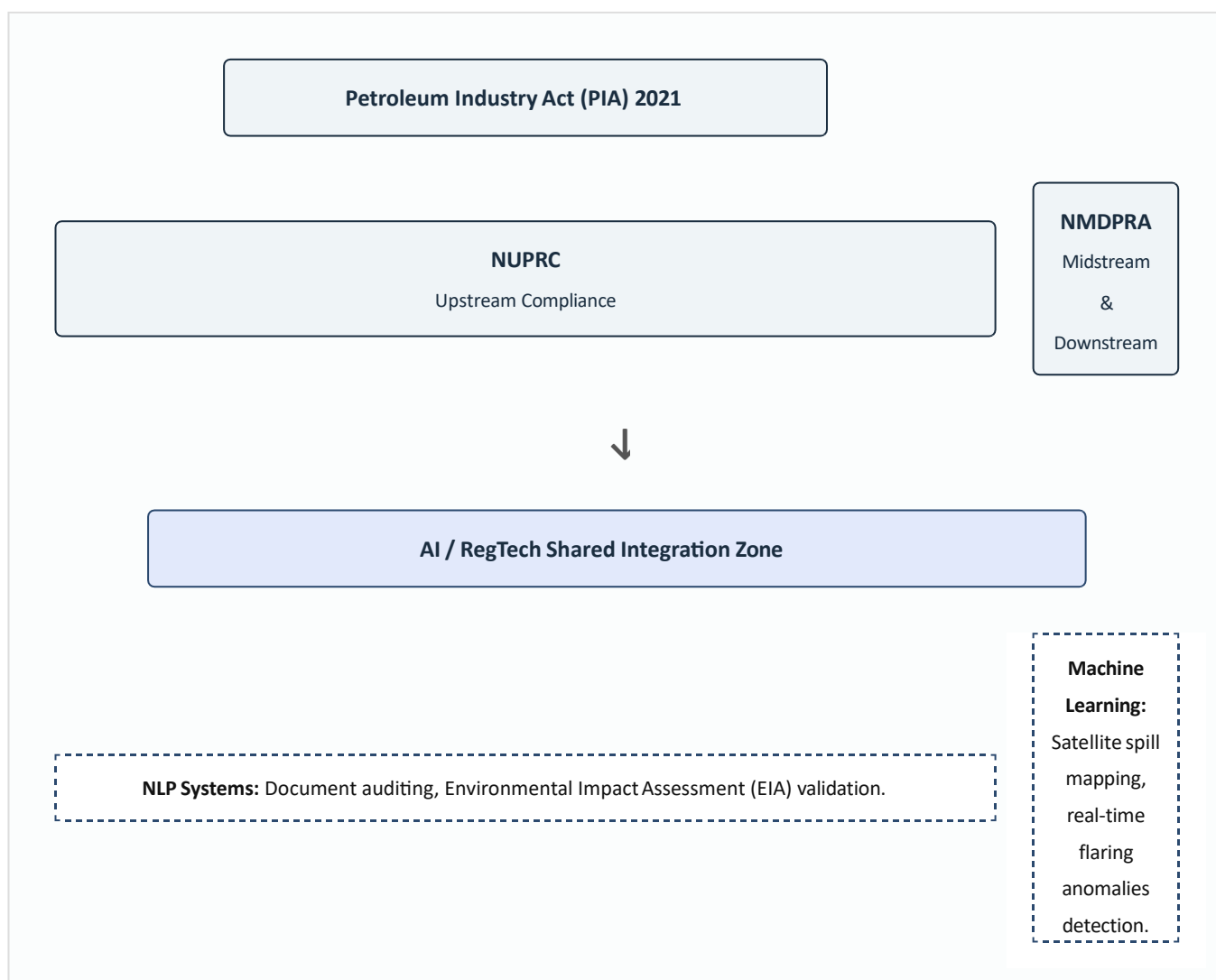


Figure 1: Nigeria Petroleum Regulator Framework

3.1 Technological Infrastructure and Implementation

Under the auspices of the NUPRC and NMDPRA, deploying automated tools offers a distinct opportunity to tackle legacy regulatory inefficiencies. Machine learning tools can analyze sensory feeds directly across the Niger Delta pipeline network to automatically flag drops in operating pressure, enabling instant remote detection. Similarly, NLP engines can instantly screen Environmental Impact Assessments (EIAs), cross-referencing historical parameters to immediately identify anomalies or plagiarized metrics.

3.2 Systemic Vulnerabilities and Operational Challenges

However, deploying advanced analytical technology in this ecosystem exposes structural challenges. If the primary environmental baseline datasets are fragmented, poorly digitized, or corrupted by historical collection disparities, the algorithmic output will inherit these flaws. Furthermore, a serious

regulatory gap arises if these state institutions lack internal data engineering capacity, rendering them heavily reliant on proprietary software managed by foreign contractors or the oil operators themselves.

4. Governance Risks and Algorithmic Challenges

4.1 Algorithmic Bias and Data Imbalances

Artificial intelligence models are fundamentally constrained by their training data. If historical compliance reporting in certain regions has been systematically distorted due to conflict, lack of physical access, or underreporting, an algorithm trained on those skewed logs will codify those gaps. The system will interpret an absence of recorded incidents as a lack of environmental risk, misallocating enforcement resources and further marginalizing vulnerable ecological zones.

4.2 The Problem of Opaque Infrastructure and Explainability

In administrative law, any regulatory enforcement action—such as imposing an environmental penalty or suspending an operating license—must satisfy rigorous standards of proof and administrative fairness. If an AI system flags a company for an environmental violation through an unexplainable "black box" calculation, that flag cannot legally serve as sole evidence in a contested proceeding. Without clear algorithmic audit trails, the state's regulatory decisions become vulnerable to aggressive judicial challenges by operators.

5. The Proposed Governance-Centered AI Framework

To bridge these technological and legal challenges, this paper presents a governance-centered framework structured into three core operational pillars, presented in Table 1.

Table 1: Governance-centered AI Framework

1. LEGAL & POLICY OVERSIGHT	2. ALGORITHMIC AUDITING	3. RESPONSIBLE DATA MANAGEMENT
• Statutory Alignment: Formally incorporate AI data validation into NUPRC & NMDPRA operational guidelines under the PIA. • Human-in-the-Loop: Restrict automated flags to an investigative advisory status; final sanctions require human sign-off. • Administrative Redress: Establish transparent appeal procedures for affected operators or host communities.	• Third-Party Reviews: Enforce independent, biannual technical code audits of compliance software. • Mandated Explainability: Prioritize "White-Box" algorithms or explicit XAI wrappers over opaque deep-learning models. • Bias Testing: Continuously stress-test predictive models against historical data imbalances.	• Data Sovereignty: Store national environmental data assets inside secure, sovereign state cloud repositories. • Standardized baselines: Mandate peer-reviewed, independent empirical data collection for training inputs. • Integrity Protocols: Secure telemetry logs using immutable, tamper-evident digital ledgers.

This structural arrangement ensures that advanced tech serves to enhance, rather than subvert, the rule of law. By keeping human inspectors at the center of the decision-making loop, it guarantees that administrative actions remain constitutionally sound and procedurally fair.

6. Conclusion and Policy Recommendations

The deployment of Artificial Intelligence within oil and gas compliance frameworks offers a profound upgrade for global environmental stewardship and regulatory efficiency. However, implementing these advanced tools without structural legal guardrails creates profound compliance risks, technological vulnerabilities, and institutional blind spots. For resource-dependent states like Nigeria, law and public policy must actively shape and guide technological integration, rather than simply responding to corporate ad-hoc deployments.

Key Recommendations for Action:

- **Regulatory Amendments:** NUPRC and NMDPRA should immediately promulgate specific subsidiary regulations under the PIA to govern data validation, algorithmic evidence standards, and automated risk scoring.
- **Domestic Technical Capacity:** Launch dedicated technical training initiatives to upskill public sector inspectors in digital forensics, data engineering, and algorithmic oversight, thereby reducing institutional dependency on external software providers.
- **Public Data Commons:** Mandate the publication of anonymized, AI-driven environmental monitoring outputs—such as satellite spill logs and flaring maps—on a public dashboard to build civil accountability and restore community trust.

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