Artificial Intelligence implementation process into ESIA permitting system: Case Study from Nigeria (RAAMP Project)

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ABSTRACT: This study investigates the integration of Human-Centric AI approach with Dynamic Computational GIS within Environmental and Social Impact Assessment (ESIA) permitting framework, focusing on governance and implementation advancements. Building on previous Digital EIA Applications in Nigeria. The research examines the application of a DCGIS permitting platform that merges AI-driven tools and blockchain security with smart contracts for real-time data acquisition and environmental monitoring. Applications extend to livestock management and circular economy facilities, where smart contracts enhance operational transparency and support sustainable practices in waste management and resource cycles. Through 307 semi-structured questionnaires, stakeholder perceptions were evaluated across government officials, environmental practitioners, and community activists, showing high AI awareness (93.2%) and general confidence (61.9%) in EIA decisions, despite challenges in demographic inclusivity and engagement. This research underscores the transformative potential of integrating AI, DCGIS, and blockchain within ESIA and CSR. A human-centric approach based on stakeholder input promotes acceptance and operational efficiency, contributing to a growing body of knowledge on AI in environmental governance and permitting. The study offers insights into implementing solutions that prioritize human needs, accountability, and sustainability within circular economy and livestock management applications.

SUMMARY STATEMENT: *This study explores AI-DCGIS and blockchain integration in ESIA, enhancing real-time environmental monitoring, transparency, and sustainable practices in Nigeria's circular economy and livestock management.*

KEY WORDS: DCGIS, EIA process, RAAMP, blockchain, MBCA

Introduction

Environmental and Social Impact Assessments (ESIAs) constitute a fundamental tool for ensuring sustainability in the implementation of development projects. Nevertheless, traditional permitting systems are often hindered by fragmented data flows, limited transparency, and inadequate stakeholder engagement—challenges that are particularly pronounced in the context of rural infrastructure development.

Following the global conference *IAIA15: "Impact Assessment in the Digital Era"*, IAIA Italy—together with the Italian Ministry of the Environment, regional authorities, and international IAIA partners—initiated the development of an institutional Artificial Intelligence-based permitting platform for ESIA and SEA processes. This platform serves as an integrated framework for impact assessment evaluation and supports stakeholders—including regulatory agencies, consultants, and project proponents—through all key phases of project governance: scoping, screening, assessment, monitoring, and adaptive corrective action.

The system leverages Dynamic Computational Geographic Information Systems (DCGIS) to integrate ESIA/SEA standards with ground-truth data across multiple spatial scales. Furthermore, it incorporates AI-based uncertainty modeling and predictive analytics to improve impact forecasting and optimize mitigation and compensation strategies.

In parallel, the Federal Government of Nigeria, with financial backing from the World Bank and the French Development Agency (AFD), launched the Rural Access and Agricultural Marketing Project (RAAMP). The project targets the rehabilitation of rural roads, the enhancement of agro-logistical networks, and the institutional strengthening of rural infrastructure governance across 19 states.

The convergence of AI, DCGIS-based permitting tools, and blockchain technologies marks a paradigm shift in environmental governance—one that prioritizes real-time data integration, adaptive decision-making, and human-centric regulatory systems.

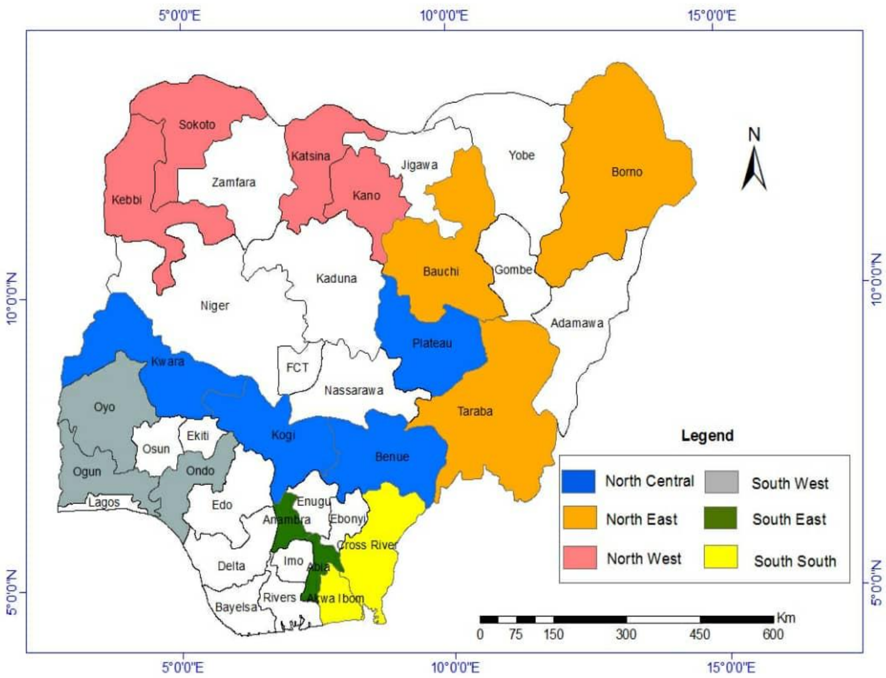
This paper presents the deployment of the AI4IA (Artificial Intelligence for Impact Assessment) framework within the RAAMP initiative, positioning it as a large-scale field test of a next-generation digital permitting platform. The AI4IA system has been developed to improve a data driven project management system based on a Monitoring Based Corrective Actions (MBCA) framework to measure Impacts improving AI in the governance process.

AI4IA enables real-time data acquisition, predictive modelling of environmental and social impacts, and continuous performance management—setting a new standard for ESIA implementation in complex, multi-stakeholder infrastructure programs.

Materials and Methods

Project Background

The Rural Access and Agricultural Marketing Project (RAAMP) is structured around four strategic components, each designed to address critical gaps in rural infrastructure, governance, and sustainability in Nigeria. The project is implemented across 19 participating states, with the objective of improving rural connectivity and agricultural value chain efficiency through both physical infrastructure and institutional reform.



Nigeria Highlighting Participating States

Component A – Improvement of Rural Access and Trading Infrastructure

This component targets the physical upgrading of the rural transport network and the development of agro-logistics infrastructure. Specifically, it includes:

- Rehabilitation of rural roads, with targets of up to 160 km per state, and construction of short-span cross-drainage structures (e.g., culverts and small bridges up to 15 meters).
- Upgrading of agro-logistics centers, aiming to improve rural market infrastructure with 5–10 facilities per state depending on need and context.

Component B – Asset Management, Agro-Logistics Performance Enhancement, and Sector Reform

This component introduces performance-based maintenance mechanisms and strengthens the agricultural logistics chain. Activities include:

- Routine and backlog maintenance of rural roads (up to 700 km of routine maintenance and 250 km of rehabilitation per state annually).
- Support for small and medium agro-enterprises (SMEs) to reduce post-harvest losses and improve logistics performance.

- Special emphasis on inclusion, particularly of women entrepreneurs and marginalized groups, with prior studies identifying access barriers to markets.

Component C – Institutional Development, Project Management, and Risk Mitigation

A key innovation of RAAMP lies in its focus on governance and institutional capacity building, both at federal and state levels. Sub-components include:

- C.1: Strengthening institutions through training, project monitoring tools, and the establishment of Rural Access Roads Agencies (RARA) and State Road Funds (SRF), as required by legal covenants.
- C.2: Addressing social and environmental risks, particularly Gender-Based Violence (GBV), Sexual Exploitation and Abuse (SEA), and climate resilience. AI4IA modules are deployed here to support real-time monitoring, automated alerts, and corrective action recommendations, ensuring adaptive risk governance.

Component D – Contingent Emergency Response

Although budgeted at zero in the current phase, this component is structured to allow rapid reallocation of project funds in the event of natural disasters or unforeseen infrastructure emergencies. It serves as a risk buffer and enhances the project's resilience to external shocks.

Data Collection Protocol

Data sources include:

- Semi-structured surveys (N=307) across three target groups: regulatory officials, ESIA practitioners, and civil society actors.
- Project performance data collected through digital monitoring of RAAMP infrastructure and logistics components.
- Environmental and Social Baseline Data derived from remote sensing, community feedback loops, and state-level ESMF (Environmental and Social Management Frameworks).

Stakeholder perception metrics were analyzed using a mixed-methods approach, combining descriptive statistics and grounded coding of qualitative responses.

Results and Discussion: ***AI4IA System Architecture***

The project aims to develop a shared framework for an economic incentive system that supports companies in making informed managerial and structural decisions, based on the level of materiality and effectiveness of those decisions in relation to the actual needs of the local territorial context.

The AI4IA permitting platform is structured into five sequential implementation phases, each designed to address specific regulatory, operational, and territorial challenges associated with Environmental and Social Impact Assessments (ESIAs) in large-scale infrastructure projects such as RAAMP. The approach merges institutional capacity building, participatory governance, and advanced digital instrumentation (AI, DCGIS, and blockchain), enabling a progressive calibration of the permitting process aligned with real-world complexity.

Phase A1 – Institutional Training and Agreement Framework

This phase focuses on capacity development and regulatory alignment through a structured sequence of institutional engagements:

- Identification and mapping of all institutional actors involved in RAAMP's permitting chain, from federal ministries to state-level authorities and technical consultants.
- Delivery of targeted training sessions on the use of AI within ESIA, oriented both to internal (project staff) and external (stakeholder) audiences.
- Drafting, validation, and formal adoption of an Agreement Document outlining project objectives, regulatory baselines, stakeholder responsibilities, and governance procedures for AI4IA implementation.

Outcomes include the formalization of a multilevel governance framework and the creation of a shared reference for the operational deployment of the system.

Phase A2 – Characterization of the territory and Sustainability mapping

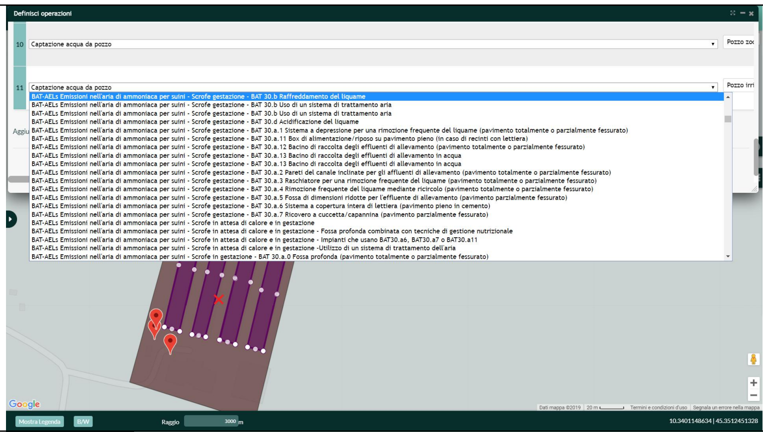
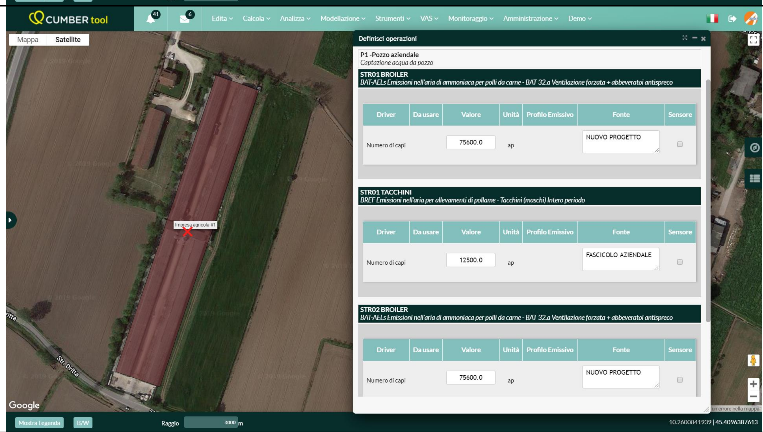
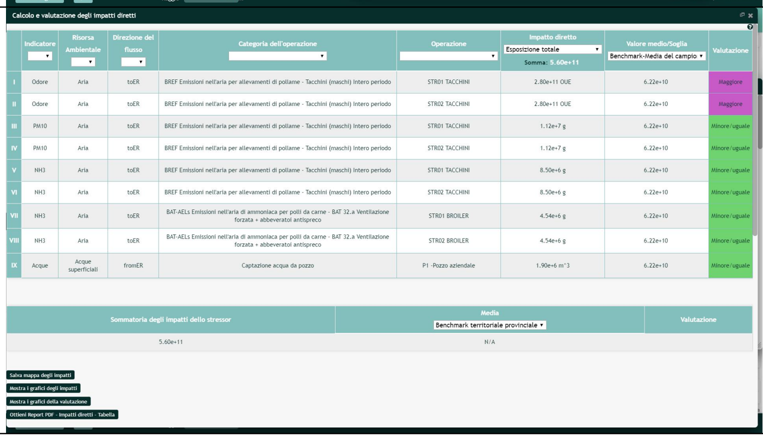
This technical phase involves the preparation of the descriptive technical documentation of the Environmental Impacts/Risks system of the territory affected by the RAAMP Project. The function of the documentation is to provide the project team with strategic information relating to the preparation of the information frameworks necessary for the implementation of the system, defined on the basis of the site-specific needs of the territory.

The baseline impact framework is structured around the following steps:

- Identification of the spatial reference domain (R)
- Identification of the temporal reference domain (T)
- Identification of the system elements (stressor elements / vulnerability elements/projects)
- Definition of the attributes (u/w/v) of the elements
- Identification of the relationships between elements/attributes (impact **analysis**, including both diagnostic assessments (identifying causes) and correlational evaluations (understanding effects)
- Identification of the states
- Identification of the problems
- Identification of the solutions: recommendation of actions for: (a) enhancing site-specific knowledge of individual production facilities through targeted measurements;

  (b) mitigating risks and impacts associated with specific operational and environmental factors using dedicated indicators and processes;

  (c) compensating for environmental, economic, and social impacts, potentially through the development of financially oriented instruments.
- Adaptive monitoring

Elements: operations	
Attributes: drivers	
Evaluation of the impacts	

This phase ensures that permitting logic is anchored in site-specific sustainability demands, enabling predictive modeling to be context-aware.

Phase A3 – Stakeholder Co-Design of Functional Specifications

Building on the territorial diagnostics of Phase A2, this phase adopts participatory design methodologies to shape the functional architecture of the platform:

- Organization of co-design meetings and feedback loops with key stakeholders (state authorities, community representatives, ESIA consultants, NGOs);
- Elicitation of user needs, information gaps, and procedural pain points, leading to the technical specification of system functions, including data input protocols, dashboard structures, alert triggers, and reporting workflows;
- Mapping of interoperability needs with existing systems such as NiRTIMS or local road inventory platforms.

The result is a tailored permitting interface, adapted to local institutional realities and community expectations.

Phase A4 – System Implementation and Beta Calibration

This phase marks the operational deployment of the AI4IA system in a controlled, iterative environment:

- Rollout of the back-end dashboard for regulatory institutions and the data-entry interface for project proponents.
- Execution of real-time data simulations and test scenarios, allowing the system to calibrate functions such as AI-driven screening, cumulative impact modeling, and scenario-based recommendations.
- Feedback collection and refinement based on field-level performance and user interaction logs.
- Integration of blockchain features and Regulatory Compliance.
- Employment of Smart contract modules to certify the issuance and renewal of permitting titles (via NFTs); timestamp environmental datasets; automate alerts for non-compliance or expired authorizations; guarantee auditable traceability of project actions and data modifications.

This beta deployment is essential for stress-testing the AI algorithms under operational constraints and for refining system outputs prior to full-scale rollout.

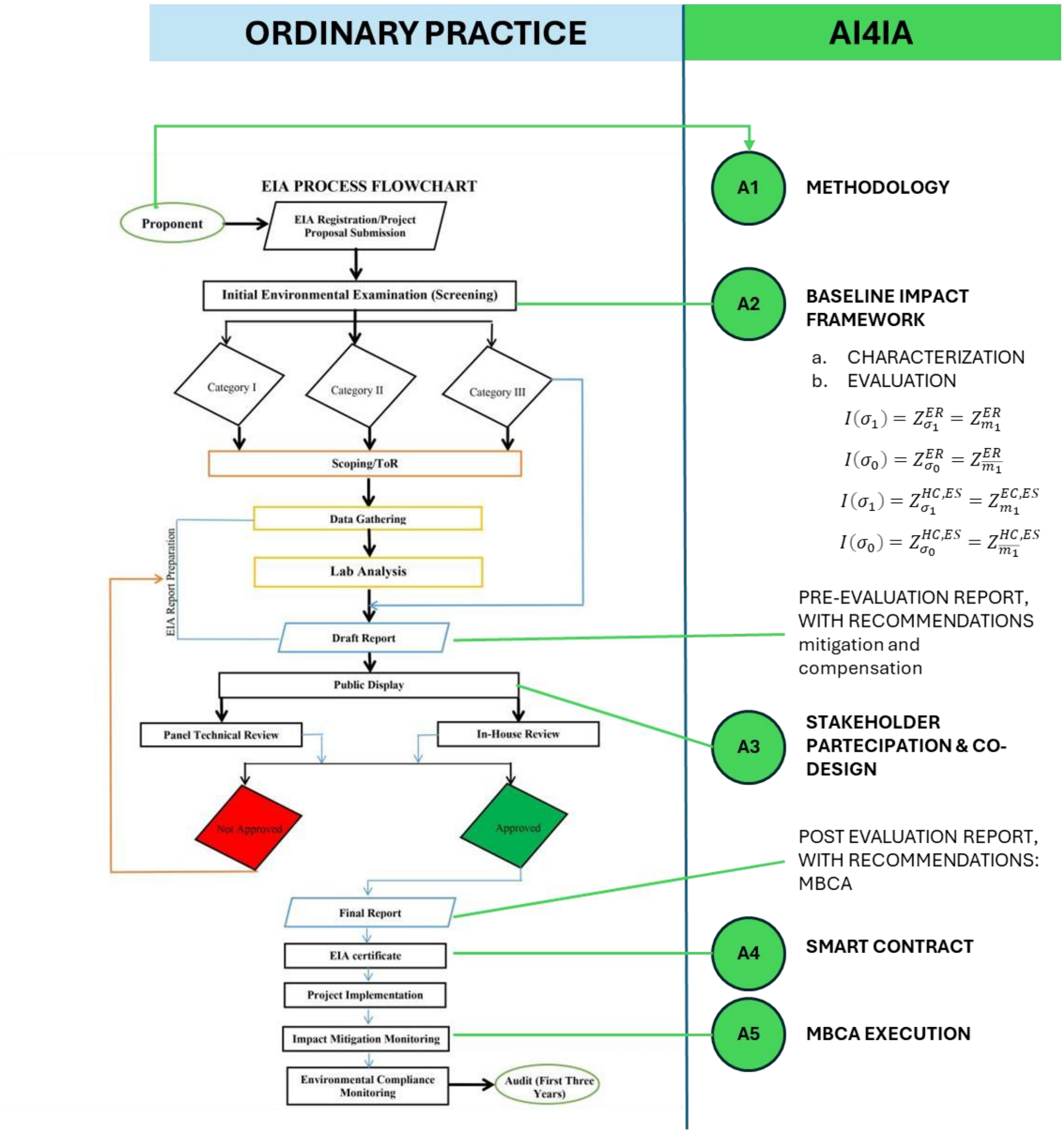
Phase A5 – Adaptive Monitoring and Performance Analytics

The final phase introduces a dynamic performance management layer, integrating AI and blockchain to support continuous environmental and social compliance:

- Monitoring of live project data, automatically analysed through AI algorithms to detect threshold exceedances or non-conformities;
- Generation of recommendation alerts for corrective actions, remediation, or stakeholder re-engagement;

This ensure alignment with Nigerian national ESIA regulations and international frameworks such as the IFC Performance Standards and World Bank ESS.

The following image illustrates the implementation framework of AI, Dynamic Computational GIS (DCGIS), and blockchain integration within ESIA practices in Nigeria, as applied to the Rural Access and Agricultural Marketing Project (RAAMP).



Results and Discussion: ***Institutional Readiness and Stakeholder Feedback***

- **AI Awareness** among stakeholders reached 93.2%, with 61.9% expressing **confidence in AI-enabled permitting systems**.
- **Perceived Limitations** includes digital literacy gaps, data privacy concerns, and inconsistent access to IT infrastructure at local levels.
- The methods used for data collection and storage must comply with data protection regulations, such as the Nigerian Data Protection Regulation (NDPR).

- The co-design process enhanced stakeholder trust, particularly among rural community leaders and women's cooperatives impacted by Component B interventions.

Conclusion

The integration of Human-Centric AI, DCGIS, and Blockchain technologies within the RAAMP permitting process demonstrates significant potential for transforming environmental governance in infrastructure development. The AI4IA platform effectively supported multi-level decision-making, predictive impact mitigation, and stakeholder participation, offering a robust digital backbone for ESIA implementation.

Future development should focus on:

- Enhancing interoperability with national information systems (e.g., NiRTIMS, NBS, NiMET);
- Scaling the permitting model to other sectors such as renewable energy and extractive industries;
- Institutionalizing the approach through national policy frameworks and capacity-building programs.

The RAAMP pilot validates the hypothesis that AI-driven permitting platforms can enhance transparency, accountability, and sustainability in large-scale infrastructure projects, particularly in low- and middle-income countries.