INTERNATIONAL JOURNAL OF ARTS MANAGEMENT AND PROFESSIONAL STUDIES
E-ISSN: 2814-0389, ISSN: 2814-0370
VOL. 5, ISSUE 2, 2025
AVAILABLE ONLINE: www.ijamps.com

AI GOVERNANCE IN NIGERIA'S RENEWABLE ENERGY TRANSITION: ADDRESSING ETHICAL AND LEGAL CHALLENGES FOR SUSTAINABLE DEVELOPMENT

Eze Chidi Nwauba
Professor of Intrapreneurship
Department of Public Administration,
Prowess University, Delaware-USA
E-mail: dparlay@gmail.com
dr.prince@pu-edu.us
+2349124673109
+22996547204

And

Dr. Bassey Moses Ogar
Senior Lecturer,
Department of International Relations
Institute of Arts Management & Professional Studies, Nigeria
basseymoses2k24@gmail.com

Abstract

This research investigates the ethical and legal considerations governing artificial intelligence (AI) technologies in Nigeria's renewable energy sector transition, addressing a critical gap in emerging technology governance within developing economies. As Nigeria pursues its ambitious target of achieving 30% renewable energy by 2030, the integration of AI technologies presents both unprecedented opportunities for sustainable development and complex regulatory challenges requiring urgent attention.The study employs a comprehensive doctrinal legal research methodology, incorporating systematic comparative analyses of international regulatory frameworks from the European Union, United States, China, Singapore, and the United Arab Emirates to identify best practices and contextual adaptations suitable for Nigeria's unique socio-economic landscape. Through extensive examination of existing legislation, policy documents, and regulatory initiatives, the research maps the current governance ecosystem and identifies critical implementation barriers.Key findings reveal significant structural gaps in Nigeria's legal framework concerning AI deployment in renewable energy systems, particularly regarding algorithmic transparency requirements, comprehensive data governance protocols, clear liability allocation mechanisms, robust environmental stewardship provisions, and enforceable social equity safeguards. These deficiencies create regulatory uncertainty that potentially undermines investor confidence, limits innovation adoption, and risks perpetuating existing energy inequalities across Nigeria's diverse geographic and demographic populations.The research proposes an innovative hybrid regulatory model strategically combining risk-based regulatory approaches, comprehensive principles-based standards, collaborative co-regulatory mechanisms, and controlled regulatory sandboxes to enhance AI governance effectiveness in Nigeria's renewable energy sector. This multifaceted framework aims to foster sustainable, ethical, and accountable AI integration while actively supporting Nigeria's 2030 renewable energy targets and broader sustainable development objectives.

Keywords: Artificial intelligence governance, renewable energy transition, regulatory frameworks, Nigeria, sustainable development, energy justice

Introduction

The convergence of artificial intelligence (AI) and renewable energy technologies represents a transformative opportunity for Nigeria's sustainable development trajectory. In 2023, Nigeria committed to achieving 30% renewable energy in its energy mix by 2030, identifying AI technologies as critical enablers for this ambitious transition (Shao et al., 2025). This commitment aligns with Nigeria's pledge at COP27 to reduce carbon emissions by 47% by 2030, reflecting the country's growing commitment to climate action (Okafor et al., 2025).

The global market dynamics underscore the economic significance of this technological convergence. The AI market in renewable energy is projected to grow from $8.5 billion in 2022 to $72.8 billion by 2032, representing substantial opportunities for developing economies like Nigeria (Allied Analytics LLP, 2024). This growth trajectory reflects the increasing recognition of AI's potential to enhance efficiency, reduce costs, and accelerate renewable energy deployment across various applications (Adewoyin et al., 2025).

For Nigeria, where approximately 85 million people lack access to electricity and 54% of urban populations face unreliable power supply, the potential benefits of AI-driven renewable energy solutions are particularly compelling (Sunday et al., 2024). AI applications span various domains including predictive maintenance of solar installations, grid optimization, energy trading, and consumption forecasting, promising enhanced system performance and broader energy access.

However, this technological convergence introduces complex ethical and legal challenges requiring careful consideration. The deployment of AI in Nigeria's renewable energy sector raises concerns about data privacy protection, algorithmic bias and fairness, accountability and transparency, intellectual property rights, cybersecurity, and environmental justice (Ncube et al., 2024). These concerns are particularly pronounced in the Nigerian context, where regulatory frameworks for both AI and renewable energy are still evolving.

Nigeria's current legal framework, comprising the National Information Technology Development Agency (NITDA) Act of 2007, the Nigerian Data Protection Regulation

(NDPR) of 2019, the Electric Power Sector Reform Act of 2005, and the Nigeria Data Protection Act of 2023, provides limited guidance for addressing the unique challenges posed by AI deployment in renewable energy systems. This regulatory gap creates uncertainty for investors, developers, and consumers, potentially hampering sector growth.

This paper examines the intersecting ethical and legal challenges in regulating AI within Nigeria's renewable energy sector. It adopts a doctrinal legal research methodology to analyze existing regulatory frameworks, identify gaps, and propose a hybrid regulatory model that balances innovation with public interest protection.

2. Theoretical Framework

2.1 AI Ethics Theory

The deployment of AI in Nigeria's renewable energy sector necessitates a robust ethical framework to guide development, implementation, and governance. AI ethics theory provides a foundation for understanding and addressing the moral implications of AI systems, ensuring they respect human dignity, promote well-being, and uphold fundamental rights (Mienye et al., 2024).

Contemporary approaches to AI ethics include consequentialist perspectives that evaluate systems based on outcomes, focusing on maximizing benefits while minimizing harms (Lottu et al., 2024). Deontological approaches emphasize respecting rights, dignity, and autonomy regardless of outcomes, insisting that AI systems must respect human agency and privacy even if this reduces efficiency gains (Machado et al., 2024).

The "principled approach" to AI ethics has gained significant global traction, articulated through principles such as transparency, fairness, non-maleficence, responsibility, and privacy (Morley et al., 2020). These principles have been embedded in numerous ethical guidelines developed by international organizations, governments, and industry groups (Papagiannidis et al., 2025).

In the Nigerian context, AI ethics must contend with local values, cultural considerations, and development priorities. Scholars note that dominant Western ethical frameworks may not fully account for communal values, Ubuntu ethics, or development imperatives central to African ethical traditions (Kiemde & Kora, 2021). This necessitates a contextualized approach to AI ethics in Nigeria's renewable energy sector that balances universal principles with local values and development objectives.

2.2 Regulatory Theory for Emerging Technologies

Regulatory theory provides crucial insights into how governance frameworks can respond to emerging technologies like AI in the renewable energy sector. Traditional command-and-control regulation faces significant challenges when applied to rapidly evolving technologies, including information asymmetries between regulators and industry, technological change outpacing regulatory processes, and risks of stifling innovation through premature rules (Jørgensen & Ma, 2025).

Alternative regulatory approaches have emerged in response to these challenges. Risk-based regulation advocates for calibrating interventions according to risk levels posed by different activities (Cajueiro & Celestino, 2024). Responsive regulation proposes dynamic approaches that escalate from persuasion to penalties based on regulated entities' behavior (Bolton et al., 2020). Meta-regulation involves the state overseeing private regulatory systems rather than directly regulating primary conduct (Buhler, 2024).

Regulatory sandboxes have emerged as particularly valuable tools for regulating emerging technologies, providing controlled environments where innovative products can be tested under regulatory supervision without immediately incurring all normal regulatory consequences (Guio, 2024). In developing country contexts like Nigeria, regulatory approaches must contend with resource constraints, institutional capacity challenges, and technology adoption imperatives (Nwaimo et al., 2024; Ullah et al., 2024).

3. Comparative Analysis of Global and Nigerian AI Regulations

3.1 Global Approaches to AI Regulation

The global regulatory landscape for AI is evolving rapidly as jurisdictions balance innovation with fundamental rights protection. Table 1 presents a comparative overview of major regulatory approaches.

Table 1: Comparative Analysis of Global AI Regulatory Approaches

Jurisdiction	Regulatory Approach	Key Features	Energy Sector Provisions
European Union	Risk-based comprehensive regulation	AI Act with four risk categories; strict requirements for high-risk systems	Critical infrastructure (electricity) classified as high-risk
United States	Sector-specific, largely non-binding	Executive Order on AI; agency-specific guidelines	Department of Energy AI strategies; critical infrastructure focus
China	Centralized comprehensive approach	Algorithmic recommendation regulations; national strategic alignment	AI as key enabler for renewable energy transition
Singapore	Voluntary principles-based framework	Model AI Governance Framework; regulatory sandboxes	Emphasis on regulatory enablers for innovation
UAE	National program approach	Sector-specific strategies; regulatory enablers focus	Specific renewable energy AI applications

The European Union has emerged as a frontrunner with its Artificial Intelligence Act, adopting a risk-based approach categorizing AI systems into unacceptable risk (prohibited), high risk (strict requirements), limited risk (transparency obligations), and minimal risk (minimal regulation) (European Parliament, 2023). For energy applications, the EU identifies AI systems in critical infrastructure management as high-risk applications subject to stringent requirements (Montagnani et al., 2024).

The United States favors a sector-specific approach, with the 2023 Executive Order on Safe, Secure, and Trustworthy Artificial Intelligence establishing safety standards for AI systems and addressing critical infrastructure risks, including energy (Davtyan, 2024). China has adopted a more centralized approach emphasizing alignment with national strategic objectives, including AI as a key enabler for renewable energy transition (AnJie Broad Law Firm, 2025).

Smaller jurisdictions offer innovative approaches potentially relevant for Nigeria. Singapore's Model AI Governance Framework provides a voluntary, principles-based approach complemented by regulatory sandboxes (Allen et al., 2024). The UAE's National Program for Artificial Intelligence includes sector-specific energy strategies focusing on regulatory enablers (UAE Government, 2025).

International organizations have contributed to global AI governance through initiatives like the OECD Principles on AI and IEEE standards for ethically aligned design (Kijewski et al., 2024; IEEE Standards Association, 2025).

3.2 Nigeria's Current Regulatory Landscape

Nigeria's regulatory framework for AI remains nascent, particularly concerning renewable energy applications. The current landscape consists of fragmented laws and policies addressing aspects of digital technologies and energy systems without comprehensive AI governance.

The National Information Technology Development Agency (NITDA) serves as the primary digital technology regulator, empowered by the NITDA Act of 2007 to develop guidelines for electronic governance and monitor information technology use (National Information Technology Development Agency Act, 2007). The 2020 National Digital Economy Policy identifies AI as a key driver for digital economic growth, including in energy (Federal Ministry of Communication, Innovation and Digital Economy, 2024).

In January 2023, NITDA released the National Policy on the Nigerian Artificial Intelligence Strategy, representing Nigeria's first comprehensive AI policy document (National Information Technology Development Agency, 2025). However, the policy remains primarily aspirational, lacking specific regulatory mechanisms for AI applications in renewable energy.

Data protection regulations constitute another important framework component. The Nigerian Data Protection Regulation (NDPR) of 2019 and the Nigeria Data Protection Act of 2023 establish requirements for personal data processing, including provisions for automated processing relevant to AI applications (Mondaq, 2024).

The energy sector is regulated primarily through the Electric Power Sector Reform Act of 2005, establishing the Nigerian Electricity Regulatory Commission (NERC) as the primary electricity industry regulator (Nigerian Electricity Regulatory Commission, 2025). However, this framework has not specifically addressed AI technology integration or associated regulatory challenges.

4. AI Applications in Nigeria's Renewable Energy Sector

4.1 Current Implementations

AI integration in Nigeria's renewable energy sector shows promising developments across several applications. Table 2 summarizes current implementations and their impacts.

Table 2: Current AI Applications in Nigeria's Renewable Energy Sector

Application Area	Companies/Projects	AI Technology Used	Impact/Benefits	Challenges
Solar Resource Assessment	Ambition Solar, Resource Energy	Machine learning for satellite imagery analysis	Optimized site selection; 20,000 households served in Kaduna/Plateau	Data quality limitations
Predictive Maintenance	Lagos/Abuja commercial installations	Sensor data analysis with ML algorithms	15-30% cost reduction; improved uptime	Limited connectivity in rural areas

Application Area	Companies/Projects	AI Technology Used	Impact/Benefits	Challenges
Grid Integration	Transmission Company of Nigeria (TCN)	Forecasting algorithms for demand/supply	Enhanced grid stability	Integration complexity
Off-grid Solutions	Arnergy, Lumos	AI-powered energy management	Improved energy access in rural areas	Limited technical expertise
Smart Energy Systems	Lagos Smart Energy Initiative	IoT-AI convergence	Enhanced system responsiveness	Cybersecurity concerns

Solar resource assessment and forecasting represent significant applications, with companies like Ambition Solar and Resource Energy deploying AI-powered systems analyzing satellite imagery and historical weather data to identify optimal solar installation locations (Ukoba et al., 2024). These systems use machine learning algorithms to predict solar radiation patterns with greater accuracy than traditional methods, supporting mini-grid deployment in rural communities (Addeh, 2025).

Predictive maintenance and performance optimization utilize AI to analyze performance data and predict potential failures before occurrence (Onwusinkwue et al., 2024). Commercial solar installations in Lagos and Abuja have implemented monitoring systems using AI to identify patterns indicating potential issues, reportedly reducing maintenance costs by 15-30% and improving system uptime (Ledmaoui et al., 2025).

Grid integration and management applications include TCN piloting AI technologies to improve renewable energy integration into the national grid (TCN News, 2024). These systems use machine learning to forecast renewable energy generation and electricity demand, helping operators balance supply and demand more effectively.

Energy access and off-grid solutions represent another important domain, with startups like Arnergy and Lumos deploying AI-powered systems for managing decentralized renewable energy solutions in rural and peri-urban areas (Ahmed et al., 2025).

4.2 Emerging Trends and Future Applications

Several emerging trends indicate future directions for AI applications in Nigeria's renewable energy sector. The convergence of AI with Internet of Things (IoT) technologies enables more sophisticated renewable energy systems with enhanced sensing, communication, and autonomous decision-making capabilities (Wang et al., 2025). Projects like the Lagos Smart Energy initiative explore interconnected, AI-powered devices for more responsive and efficient energy systems (Clegg, 2025).

Digital twins—virtual replicas of physical renewable energy systems—represent another emerging application. Companies like Sterling Bank's Imperium Africa explore digital twin use for simulating and optimizing renewable energy infrastructure before physical deployment (Sharma et al., 2024).

Blockchain-AI integration emerges as a promising approach for creating transparent, secure, and efficient renewable energy trading platforms. The OneWattTime project in Lagos develops a blockchain-based platform enhanced with AI for peer-to-peer renewable energy trading (Taherdoost, 2024).

5. Ethical Challenges in AI Governance for Renewable Energy

5.1 Privacy and Data Protection

AI deployment in Nigeria's renewable energy sector raises significant privacy and data protection concerns. Smart grids, energy management systems, and predictive maintenance platforms collect granular data about energy consumption patterns that can reveal intimate details about individuals' lifestyles, behaviors, and financial status (Shahverdi et al., 2025). Smart meter data analyzed by AI systems can indicate when people are home, what appliances they use, and sleep patterns—information that could compromise personal security if misused (You et al., 2024).

Nigeria's data protection framework through the NDPR and NDPA establishes some safeguards for personal data processing. However, several challenges persist in the renewable energy context (Aloamaka, 2023). First, obtaining meaningful informed consent becomes complex in systems where data collection is continuous and often invisible to consumers. Second, the principle of purpose limitation faces challenges in AI systems that employ data for multiple purposes or where purposes may evolve as algorithms identify new patterns (Hassan, 2024). Third, data minimization principles conflict with AI systems' data requirements, where more comprehensive data can lead to better optimization but increases privacy risks (King & Meinhardt, 2024).

Energy data inequity can emerge when certain communities, particularly marginalized or rural populations, have their data extensively harvested without receiving commensurate benefits from AI-powered energy solutions (Joshi, 2024).

5.2 Algorithmic Bias and Fairness

Algorithmic bias represents a significant ethical challenge in AI-powered renewable energy systems. AI algorithms trained on historical data can perpetuate or amplify existing biases and inequalities in energy access and distribution (Shittu et al., 2024). In Nigeria, where historical energy access has been uneven across geographic, socioeconomic, and demographic lines, this risk is particularly acute.

Distributional fairness concerns arise when AI systems for planning renewable energy infrastructure may inadvertently prioritize already privileged areas if trained on historical investment patterns (Dibie, 2024). Algorithms optimizing locations for solar mini-grid deployment might favor communities with existing infrastructure, higher income levels, or better data representation, potentially reinforcing rather than alleviating energy inequality. A 2022 study found that AI-based planning tools for renewable energy in Nigeria consistently underserved communities in the North-East region due to underrepresentation in training data (Muraina et al., 2025).

Representational harms occur when AI systems fail to adequately represent or consider certain groups' needs (Hall et al., 2025). In Nigeria's diverse socio-cultural landscape, algorithms trained primarily on urban or wealthier community data may fail to account for unique energy needs and usage patterns of rural, low-income, or culturally distinct communities.

Performance disparities constitute another bias dimension, where AI systems might perform with different accuracy levels for different groups or regions (Ferrara, 2024). Energy forecasting algorithms might be less accurate for communities with non-standard usage patterns or limited historical data, potentially leading to less reliable service (Babayeju et al., 2024).

5.3 Accountability and Transparency

Accountability and transparency present distinct challenges in AI deployment within Nigeria's renewable energy sector. The "black box" nature of many AI systems, particularly those using complex deep learning approaches, creates difficulties in understanding decision-making processes and responsibility allocation (Oyeyemi et al., 2025).

Explainability challenges arise when AI systems cannot provide understandable explanations for decisions or recommendations (Grover & Dogra, 2024). In renewable energy applications, this might involve systems making decisions about energy allocation, infrastructure planning, or maintenance prioritization without clear reasoning accessible to affected communities or system operators.

Accountability gaps emerge in complex socio-technical systems with multiple stakeholders. Determining responsibility among technology developers, energy providers, regulatory bodies, and other actors becomes challenging when AI-powered renewable energy systems make harmful decisions or fail to perform as expected (Novelli et al., 2024).

Transparency limitations affect various AI system aspects in renewable energy. Technical transparency concerns whether algorithm functioning is open to stakeholder scrutiny (Cheong, 2024). In Nigeria, proprietary algorithms used in renewable energy planning are often protected as trade secrets, limiting regulatory or independent oversight. Operational transparency involves clarity about when and how AI is being used in energy systems (Adedeji, 2025).

Meaningful human oversight presents additional challenges. While often proposed as an AI system safeguard, implementing effective oversight requires both technical understanding of complex systems and authority to intervene when necessary (Akinrinola et al., 2024).

6. Legal Challenges in AI Governance

6.1 Regulatory Gaps and Jurisdictional Issues

Nigeria's current legal framework exhibits significant gaps in addressing unique challenges posed by AI in the renewable energy sector. These gaps stem from AI technology novelty and Nigeria's fragmented legal and institutional landscape.

The foremost regulatory gap concerns the absence of AI-specific legislation in Nigeria. While general laws like the NITDA Act, NDPR, and Electric Power Sector Reform Act may apply to certain AI system aspects, they were not designed with AI's unique characteristics in mind (Adedeji, 2025). This creates legal uncertainty regarding how existing provisions apply to novel AI applications in renewable energy.

Jurisdictional ambiguities further complicate the regulatory landscape. Multiple agencies including NITDA, NERC, NEMSA, and the Standards Organisation of Nigeria may claim jurisdiction over different AI aspects in renewable energy, creating potential for regulatory overlap, conflict, or gaps (Akinrinola et al., 2024).

Enforcement capacity represents another significant challenge. Even where applicable regulations exist, Nigerian regulatory agencies often lack technical expertise, resources, and institutional capacity to effectively monitor and enforce compliance for sophisticated AI systems (Okosu, 2025). The pace of technological change creates additional regulatory challenges, with AI technologies evolving faster than traditional regulatory processes can adapt (Mennella et al., 2024).

6.2 Liability and Responsibility Allocation

Liability and responsibility allocation for AI systems in Nigeria's renewable energy sector presents complex legal challenges that current frameworks cannot adequately address. Traditional liability regimes assume clear causal relationships and human decision-makers, assumptions that may not hold for AI systems characterized by autonomy, opacity, and distributed development (Alliance Law Firm, 2024).

Product liability frameworks in Nigeria, primarily governed by the Federal Competition and Consumer Protection Act of 2018, may be difficult to apply to AI systems in renewable energy (Federal Competition and Consumer Protection Act, 2018). These frameworks typically require establishing product defects, but determining what constitutes a "defect" in an AI system is conceptually challenging.

Contractual liability frameworks also face challenges in the AI context. Contracts between renewable energy providers and consumers, or between different AI supply chain stakeholders, may not adequately address AI system complexity and unpredictability (Wang et al., 2025). Negligence frameworks require establishing duty of care, breach, causation, and damages, with each element becoming challenging in AI systems (Fraser & Suzor, 2025).

The distributed nature of AI development and deployment further complicates liability allocation. AI systems in renewable energy typically involve multiple actors including algorithm developers, data providers, hardware manufacturers, system integrators, operators, and users (Rashid & Kausik, 2024).

6.3 Intellectual Property and Access Concerns

The intellectual property regime governing AI technologies in Nigeria's renewable energy sector creates tensions between innovation protection and equitable access to essential technologies. These tensions are particularly significant where technologies have implications for basic human needs, sustainable development, and climate change mitigation.

Table 3: Intellectual Property Challenges in AI for Renewable Energy

IP Type	Current Legal Framework	Challenges	Potential Solutions
Patents	Patents and Designs Act (outdated)	Uncertainty about AI invention patentability; patent thickets	Update patent law; compulsory licensing provisions
Copyright	Copyright Act	AI-generated works status	Modernize copyright

IP Type	Current Legal Framework	Challenges	Potential Solutions
	1999 (pre-AI)	unclear; training data protection	framework
Trade Secrets	Common law protection	Conflicts with transparency requirements	Balance protection with accountability
Technology Transfer	TRIPS Agreement constraints	Limited policy space for local adaptation	Explore TRIPS flexibilities

Patent protection for AI innovations in renewable energy raises several legal challenges. Nigeria's Patents and Designs Act does not explicitly address AI-related invention patentability, creating uncertainty about protection for algorithms, training methodologies, or AI-enabled renewable energy systems (Mondaq, 2025). Patent thickets may emerge around AI technologies in renewable energy, potentially impeding innovation by creating legal and financial barriers (Ajuzieogu, 2025).

Copyright protection for AI algorithms, training data, and outputs presents another complexity area. Nigeria's Copyright Act, last substantially revised in 1999, does not specifically address AI-generated works or training data status (Adegoke, 2025).

Trade secret protection often serves as an alternative to patent or copyright protection but creates tensions with transparency and accountability goals (Raza, 2024). Technology transfer and localization face legal barriers under current IP regimes, with international agreements like TRIPS establishing minimum standards that may constrain Nigeria's policy options (Birkbeck, 2009).

7. Proposed Regulatory Framework and Recommendations

7.1 A Hybrid Model for AI Regulation in Nigeria's Renewable Energy Sector

Based on the analysis of ethical and legal challenges and comparative review of regulatory approaches, this paper proposes a hybrid regulatory model for governing AI in Nigeria's renewable energy sector. This model aims to balance innovation with fundamental rights and public interest protection while accounting for Nigeria's specific context and development priorities.

The proposed hybrid model combines risk-based regulation, principles-based standards, co-regulatory mechanisms, and regulatory sandboxes to create a flexible yet effective framework. At its core, the model adopts a risk-tiered approach calibrating regulatory requirements according to risk levels posed by different AI applications.

Risk Categorization Framework:

Critical Risk AI Systems: Applications controlling critical energy infrastructure, such as national grid management systems or large-scale power distribution algorithms, subject to strictest regulatory requirements including prior conformity assessments, continuous monitoring, and mandatory human oversight.

High Risk AI Systems: Applications with potential significant impact on people or society, such as systems determining energy access and pricing, predictive maintenance for critical infrastructure, or automated decision systems serving large consumer populations, requiring impact assessments and transparency/auditing measures.

Medium Risk AI Systems: Applications including customer service AI, energy efficiency recommendation engines, and supervised optimization tools, regulated primarily through self-regulation, codes of practice, standards, and self-certification procedures.

Low Risk AI Systems: Applications such as basic analytical tools and simple optimization algorithms with low harm potential, subject only to voluntary guidelines and general principles.

The hybrid model includes several key components:

Principles-Based Standards: Establish overarching principles for all AI applications in renewable energy emphasizing fairness, transparency, accountability, privacy, security, and sustainability. These would draw from international frameworks but be tailored to Nigeria's socio-economic and cultural context.

Co-Regulatory Approach: Develop sectoral codes of practice through multi-stakeholder engagement involving government, industry, academia, civil society, and community representatives. These codes would specify how core principles should be implemented across different applications and risk levels.

Regulatory Sandboxes: Enable testing of innovative AI-powered renewable energy solutions within controlled environments that waive certain regulatory compliance requirements. These environments would provide learning opportunities for both innovators and regulators while managing risks carefully.

Governance Institutions: Establish an AI Advisory Council with representation from relevant regulatory bodies (NITDA, NERC, NEMSA), industry, academia, civil society, and community organizations. This council would coordinate guidance, advice, and regulatory action on complex cross-jurisdictional issues.

This hybrid model is particularly advantageous for Nigeria's context as it balances the need to keep pace with rapidly evolving AI technologies while providing meaningful protection for critical public interests. It focuses limited regulatory resources where most needed by concentrating strictest oversight on highest-risk systems while enabling innovation and experimentation through regulatory sandboxes and multi-stakeholder processes.

7.2 Specific Recommendations

Building on the proposed hybrid regulatory model, this paper offers specific recommendations to address ethical and legal challenges surrounding AI in Nigeria's renewable energy sector:

Establish Risk-Based Regulatory Framework: Enact comprehensive legislation establishing a risk-based regulatory framework for AI in renewable energy with graduated requirements for higher-risk applications such as grid management systems, while clearly delineating regulatory boundaries between agencies.

Create Inter-Agency Coordination Mechanism: Establish a joint regulatory working group comprising NITDA, NERC, NEMSA, and other relevant bodies to harmonize regulatory approaches, address jurisdictional gaps, and coordinate oversight of AI in critical energy infrastructure.

Implement Regulatory Sandboxes: Develop controlled testing environments where innovative AI applications in renewable energy can be piloted under relaxed regulatory requirements while ensuring community participation and stakeholder engagement in the design and evaluation process.

Clarify Liability Allocation: Develop comprehensive liability frameworks that address responsibility distribution among multiple stakeholders in AI systems through clear guidelines, mandatory insurance requirements, and victim compensation mechanisms.

Mandate Algorithmic Impact Assessments: Require developers to conduct and publicly disclose assessments of potential impacts on safety, privacy, equity, and environment before deploying AI systems in renewable energy applications, with particular attention to vulnerable populations.

Strengthen Data Protection: Enhance data protection frameworks specifically for AI applications in renewable energy, including requirements for meaningful consent, data minimization, purpose limitation, and community data sovereignty provisions.

Promote Transparency and Explainability: Establish requirements for algorithmic transparency in high-risk applications, including public disclosure of AI system capabilities, limitations, and decision-making processes affecting energy access and pricing.

Support Capacity Building: Invest in technical capacity building for regulatory agencies, including training programs, technology assessment capabilities, and partnerships with academic institutions and international organizations.

Enable Technology Transfer: Develop intellectual property frameworks that balance innovation incentives with technology access needs, including provisions for compulsory licensing, technology sharing requirements, and support for local innovation capacity.

Foster Community Engagement: Establish mechanisms for meaningful community participation in AI governance processes, including community representation in regulatory bodies, public consultation requirements, and community oversight mechanisms.

8. Conclusion

The integration of artificial intelligence with renewable energy technologies offers profound opportunities and challenges for sustainable development in Nigeria. As demonstrated throughout this analysis, AI applications across Nigeria's renewable energy value chain—from resource assessment and infrastructure planning to system optimization and energy access solutions—promise significant improvements in efficiency, reliability, cost-effectiveness, and environmental sustainability. However, realizing these benefits while mitigating risks requires thoughtful governance approaches that address the multifaceted ethical and legal challenges these technologies present.

The ethical challenges examined—privacy and data protection, algorithmic bias and fairness, and accountability and transparency—highlight how AI technologies could either exacerbate or help resolve inequities in Nigeria's energy systems. Without appropriate safeguards, AI-enabled renewable energy technologies could create new forms of exclusion, exploitation, or harm, particularly for vulnerable populations. Conversely, if guided by robust frameworks centered on human rights, equity, and inclusion, these technologies have the potential to democratize energy access and accelerate Nigeria's transition toward sustainability and justice.

The legal challenges regarding regulatory gaps and jurisdictional issues, liability and responsibility allocation, and intellectual property and access concerns demonstrate that Nigeria's current legal frameworks are inadequately equipped to address these emerging technologies. The fragmented regulatory landscape, limited enforcement capacity, and outdated legal frameworks create risks for all stakeholders in the AI-enabled renewable energy ecosystem. Addressing these challenges requires not only legal reforms but also institutional innovations that enhance coordination, technical capacity, and adaptive governance capabilities.

The hybrid regulatory model proposed in this study represents an attempt to balance innovation promotion with public interest protection by combining risk-based regulation, principles-based standards, co-regulatory mechanisms, and regulatory sandboxes. This model recognizes both the transformative potential and inherent risks of AI in Nigeria's renewable energy transition, seeking to navigate between over-regulation that stifles innovation and under-regulation that fails to address potential harms. The specific recommendations provide actionable guidance for policymakers, regulators, industry stakeholders, and civil society organizations seeking to implement this framework.

As Nigeria navigates the intersection of rapid technological change and energy transition, the governance decisions made today will shape not only the technical architecture of future energy systems but also their social implications and alignment with development goals. By adopting appropriate responses to the ethical and legal challenges of AI in renewable energy outlined in this paper, Nigeria can harness these technologies to accelerate renewable energy deployment while ensuring that the benefits are broadly and equitably shared. This balanced approach to AI governance in renewable energy represents a pathway toward sustainable development, energy security, and human flourishing in Nigeria.

References

Addeh, E. (2025, May 16). FG launches 990kW electricity mini-grid for 3,900 households. *ThisDay Live*.

Adedeji, K. (2025). Addressing data privacy concerns in artificial intelligence systems: Regulatory mechanisms in Nigeria. *Business Africa Online*.

Adedeji, K. (2025). Addressing data privacy concerns in artificial intelligence systems: Regulatory mechanisms in Nigeria. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.5222866

Adegoke, P. (2025). Implications of the Copyright Act 2022 on generative AI and fair dealing. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.5010517

Adewoyin, M. A., Adediwin, O., & Audu, A. J. (2025). Artificial intelligence and sustainable energy development: A review of applications, challenges, and future directions. *International Journal of Multidisciplinary Research and Growth Evaluation*, 6(2), 196-203. https://doi.org/10.54660/.IJMRGE.2025.6.2.196-203

Ahmed, F., et al. (2025). AI-driven microgrid solutions for enhancing energy access and reliability in rural and remote areas: A comprehensive review. *Control Systems and Optimization Letters*, 3(1). https://doi.org/10.59247/csol.v3i1.183

Akinrinola, O., et al. (2024). Navigating and reviewing ethical dilemmas in AI development: Strategies for transparency, fairness, and accountability. *GSC Advanced Research and Reviews*, 18(3), 050. https://doi.org/10.30574/gscarr.2024.18.3.0088

Ajuzieogu, U. (2025). Intellectual property regimes for AI: Optimal design for innovation and growth. https://doi.org/10.13140/RG.2.2.22525.88806

Allen, J. G., Loo, J., & Luna, J. (2024). Governing intelligence: Singapore's evolving AI governance framework. *SMU Centre for Digital Law Research Paper No. 4/2025*. https://ssrn.com/abstract=5097834

Alliance Law Firm. (2024, May 20). Artificial intelligence and the energy sector: A legal perspective. *Mondaq*.

Allied Analytics LLP. (2024, November 18). AI (artificial intelligence) in renewable energy market worth $4.6 billion by 2032. *EIN Presswire*.

Aloamaka, P. (2023). Data protection and privacy challenges in Nigeria: Lessons from other jurisdictions. *UCC Law Journal*, 3(1), 281. https://doi.org/10.47963/ucclj.v3i1.1259

AnJie Broad Law Firm. (2025, April 14). China and the U.S. - different approaches to regulating AI. *Mondaq*.

Babayeju, O. A., et al. (2024). Advancements in predictive maintenance for aging oil and gas infrastructure. *World Journal of Advanced Research and Reviews*, 22(3), 252. https://doi.org/10.30574/wjarr.2024.22.3.1669

Birkbeck, C. D. (2009). *The implementation game: The TRIPS agreement & the global politics of intellectual property reform in developing countries*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199550616.001.0001

Bolton, D., Landells, T., & Roberts, B. (2020). Sustainable governance and responsive regulation: The higher education sector and maritime industry in Australia. *Journal of Sustainable Research*, 2(3), e200023. https://doi.org/10.20900/jsr20200023

Buhler, P. A. (2024). What prospects in Canadian waters? In *Shipping in Inuit Nunangat* (pp. 297). Brill. https://doi.org/10.1163/9789004508576_014

Cajueiro, D. O., & Celestino, V. R. R. (2024, September 9). A comprehensive review of artificial intelligence regulation: Weighing ethical principles and innovation. *SSRN*. http://dx.doi.org/10.2139/ssrn.4950727

Cheong, B. C. (2024). Transparency and accountability in AI systems: Safeguarding wellbeing in the age of algorithmic decision-making. *Frontiers in Human Dynamics*, 6. https://doi.org/10.3389/fhumd.2024.1421273

Clegg, T. (2025, May 16). Oyeniyi Ajao explores AI's potential to address energy crises – learnings for developing nations. *ThisDay Live*.

Davtyan, T. (2024, September 9). The U.S. approach to AI regulation: Federal laws, policies, and strategies explained. *SSRN*. http://dx.doi.org/10.2139/ssrn.4954290

Dibie, E. U. (2024). The future of renewable energy: Ethical implications of AI and cloud technology in data security and environmental impact. *Journal of Advances in Mathematics and Computer Science*, 39(10). https://doi.org/10.9734/jamcs/2024/v39i101935

Electric Power Sector Reform Act. (2005). Nigeria.

European Parliament. (2023, June 8). EU AI Act: First regulation on artificial intelligence. *Press Release*.

Federal Competition and Consumer Protection Act. (2018). Nigeria. *Federal Republic of Nigeria Official Gazette No. 18*.

Federal Ministry of Communication, Innovation and Digital Economy. (2024, August). National artificial intelligence strategy [Draft].

Ferrara, E. (2024). The butterfly effect in artificial intelligence systems: Implications for AI bias and fairness. *Machine Learning with Applications*, 15, 100525. https://doi.org/10.1016/j.mlwa.2024.100525

Fraser, H. L., & Suzor, N. P. (2025). Locating fault for AI harms: A systems theory of foreseeability, reasonable care and causal responsibility in the AI value chain. *Law, Innovation and Technology*, 17(1), 103. https://doi.org/10.1080/17579961.2025.2469345

Grover, V., & Dogra, M. (2024). Challenges and limitations of explainable AI in healthcare. In *Analyzing explainable AI in healthcare and the pharmaceutical industry* (pp. 72-85). IGI Global. https://doi.org/10.4018/979-8-3693-5468-1.ch005

Guio, A. (2024). *Regulatory sandboxes in developing economies: An innovative governance approach*. Economic Commission for Latin America and the Caribbean. LC/TS.2024/59.

Hall, S. M., et al. (2025). The human labour of data work: Capturing cultural diversity through world wide dishes. *arXiv preprint*. https://arxiv.org/abs/2502.05961v2

Hassan, A. (2024, May 13). The legal, ethical issues and impact of artificial intelligence on legal profession: Which way Nigeria? *LawPavilion*.

IEEE Standards Association. (2025). The IEEE Global Initiative 2.0 on ethics of autonomous and intelligent systems. *IEEE Standards Association*.

Joshi, N. (2024). Emerging challenges in privacy protection with advancements in artificial intelligence. *International Journal of Law and Policy*, 2(4), 55. https://doi.org/10.59022/ijlp.171

Jørgensen, B. N., & Ma, Z. G. (2025). Regulating AI in the energy sector: A scoping review of EU laws, challenges, and global perspectives. *Energies*, 18(9), 2359. https://doi.org/10.3390/en18092359

Kiemde, S. M. A., & Kora, A. D. (2021). Towards an ethics of AI in Africa: Rule of education. *AI and Ethics*, 2(1), 35. https://doi.org/10.1007/s43681-021-00106-8

Kijewski, S., Ronchi, E., & Vayena, E. (2024). International organisations and the global governance of AI in health. In *[Editor(s)]* (Eds.), (pp. 254-272). Edward Elgar Publishing. https://doi.org/10.4337/9781802205657.ch15

King, J., & Meinhardt, C. (2024, February). Rethinking privacy in the AI era: Policy provocations for a data-centric world. *Stanford University Institute for Human-Centered Artificial Intelligence*.

Ledmaoui, Y., et al. (2025). Review of recent advances in predictive maintenance and cybersecurity for solar plants. *Sensors*, 25(1), 206. https://doi.org/10.3390/s25010206

Lottu, O., Jacks, B. S., Ajala, O. A., & Okafor, E. S. (2024). Towards a conceptual framework for ethical AI development in IT systems. *World Journal of Advanced Research and Reviews*, 21(3), 408. https://doi.org/10.30574/wjarr.2024.21.3.0735

Machado, J., Sousa, R., Peixoto, H., & Abelha, A. (2024). Ethical decision-making in artificial intelligence: A logic programming approach. *AI*, 5(4), 2707. https://doi.org/10.3390/ai5040130

Mennella, C., et al. (2024). Ethical and regulatory challenges of AI technologies in healthcare: A narrative review. *Heliyon*, 10(5), e26297. https://doi.org/10.1016/j.heliyon.2024.e26297

Mienye, I. D., Sun, Y., & Ileberi, E. (2024). Artificial intelligence and sustainable development in Africa: A comprehensive review. *Machine Learning with Applications*, 18, 100591. https://doi.org/10.1016/j.mlwa.2024.100591

Mondaq. (2024, February 29). Understanding the Nigeria Data Protection Act 2023: Obligations of digital platforms and businesses. *Mondaq*.

Mondaq. (2025, March 25). Artificial intelligence and patent law: Navigating ownership, innovation, and protection in the AI era. *Mondaq*.

Montagnani, M. L., Najjar, M. C., & Davola, A. (2024). The EU regulatory approach(es) to AI liability, and its application to the financial services market. *Computer Law & Security Review*, 53, 105984. https://doi.org/10.1016/j.clsr.2024.105984

Morley, J., Floridi, L., Kinsey, L., & Elhalal, A. (2020). From what to how: An initial review of publicly available AI ethics tools, methods and research to translate principles into practices. *Science and Engineering Ethics*, 26(3), 1473. https://doi.org/10.1007/s11948-019-00165-5

Muraina, S. A., et al. (2025). Artificial intelligence-driven renewable energy solutions for rural electrification in Africa. *International Journal of Engineering and Modern Technology*, 11(3), 81. https://doi.org/10.56201/ijemt.vol.11.no3.2025.pg81.102

National Information Technology Development Agency. (2025). Home. *NITDA*. https://nitda.gov.ng

National Information Technology Development Agency Act. (2007). Nigeria. No. 28.

Ncube, C., et al. (2024). *Artificial intelligence and the law in Africa*. LexisNexis.

Nigeria Data Protection Act. (2023). Nigeria.

Nigerian Data Protection Regulation. (2019). Nigeria.

Nigerian Electricity Regulatory Commission. (2025). The Commission. *NERC*. https://nerc.gov.ng/about

Novelli, C., Taddeo, M., & Floridi, L. (2024). Accountability in artificial intelligence: What it is and how it works. *AI & Society*, 39(4), 1871. https://doi.org/10.1007/s00146-023-01635-y

Nwaimo, C. E., et al. (2024). Overcoming barriers to technology adoption in Nigerian government institutions. *Academy of Entrepreneurship Journal*, 30(4), 1-12.

Okafor, C. C., et al. (2025). Research on climate change initiatives in Nigeria: Identifying trends, themes and future directions. *Sustainability*, 17(9), 3995. https://doi.org/10.3390/su17093995

Okosu, N. D. (2025, April 29). States' regulatory autonomy in Nigeria's electricity sector: Unveiling hidden dimensions. *BusinessDay*.

Onwusinkwue, S., et al. (2024). Artificial intelligence (AI) in renewable energy: A review of predictive maintenance and energy optimization. *World Journal of Advanced Research and Reviews*, 21(1), 2487. https://doi.org/10.30574/wjarr.2024.21.1.0347

Oyeyemi, B., Ifedayo, A. M., & Awodola, M. (2025). Ethical challenges in AI-powered supply chains: A U.S.-Nigeria policy perspective. *International Journal of Applied Research in Social Sciences*, 7(5), 367. https://doi.org/10.51594/ijarss.v7i5.1911

Papagiannidis, E., Mikalef, P., & Conboy, K. (2025). Responsible artificial intelligence governance: A review and research framework. *Journal of Strategic Information Systems*, 34(2), 101885. https://doi.org/10.1016/j.jsis.2024.101885

Rashid, A. B., & Kausik, M. A. K. (2024). AI revolutionizing industries worldwide: A comprehensive overview of its diverse applications. *Hybrid Advances*, 7, 100277. https://doi.org/10.1016/j.hybadv.2024.100277

Raza, A. (2024). Trade secrets as a substitute for AI protection: A critical investigation into different dimensions of trade secrets. *The International Journal of Social Sciences and Business*, 2(12), 2506. https://doi.org/10.5281/zenodo.15108933

Shahverdi, N., Saffari, A., & Amiri, B. (2025). A systematic review of artificial intelligence and machine learning in energy sustainability: Research topics and trends. *Energy Reports*, 13, 5551. https://doi.org/10.1016/j.egyr.2025.05.021

Shao, Y., et al. (2025). Navigating Nigeria's path to sustainable energy: Challenges, opportunities, and global insight. *Energy Strategy Reviews*, 59, 101707. https://doi.org/10.1016/j.esr.2025.101707

Sharma, P., et al. (2024, April). Overview of digital twins in renewable energy. *2024 1st International Conference on Trends in Engineering Systems and Technologies*. https://doi.org/10.1109/ICTEST60614.2024.10576156

Shittu, R. A., et al. (2024). Ethics in technology: Developing ethical guidelines for AI and digital transformation in Nigeria. *International Journal of Multidisciplinary Research and Growth Evaluation*, 5(6), 1260. https://doi.org/10.54660/.IJMRGE.2021.2.1-401-412

Sunday, I., et al. (2024). Sustainable energy solutions: Opportunities and challenges in Nigeria.

Taherdoost, H. (2024). Blockchain integration and its impact on renewable energy. *Computers*, 13(4), 107. https://doi.org/10.3390/computers13040107

TCN News. (2024, March 3). TCN holds workshop on integration of renewable energy to national grid for stakeholders.

UAE Government. (2025). Artificial intelligence in government policies. *UAE Government*. https://u.ae/en/about-the-uae/digital-uae/artificial-intelligence/artificial-intelligence-in-government-policies

Ukoba, K., et al. (2024). Optimizing renewable energy systems through artificial intelligence: Review and future prospects. *Energy & Environment*, 35(7). https://doi.org/10.1177/0958305X241256293

Ullah, W., Zubir, A. S. M., & Ariff, A. M. (2024). Exploring the moderating effect of regulatory quality on the relationship between financial development and economic growth/economic volatility for developed and developing countries. *Business and Investment Review*. https://doi.org/10.1016/j.bir.2024.04.015

Wang, Q., Li, Y., & Li, R. (2025). Integrating artificial intelligence in energy transition: A comprehensive review. *Energy Strategy Reviews*, 57, 101600. https://doi.org/10.1016/j.esr.2024.101600

You, L., et al. (2024). AI ethics in smart homes: Progress, user requirements and challenges. *arXiv preprint*. https://arxiv.org/html/2412.09813v1