



From Static Assessment to Adaptive Environmental Regulation: Digital Twins in Environmental Impact Assessment (EIA) Law in Nigeria and South Africa

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Abstract

Environmental digital twins are increasingly proposed as instruments of anticipatory environmental governance, yet their legal place within Environmental Impact Assessment (EIA) remains unsettled. The difficulty is chiefly institutional, not merely technical: EIA regimes in Nigeria and South Africa are organised around discrete reports and one-off authorisation decisions, whereas digital twins produce iterative, probabilistic, and continuously updated outputs. This article examines the conditions under which such outputs may be incorporated into EIA without compromising legality, procedural fairness, or accountability. It argues that the key distinction is between admissibility and evidentiary weight: model outputs may properly enter the administrative record yet remain too uncertain, opaque, or insufficiently validated to justify significant regulatory consequences. Using Nigeria and South Africa as comparative case studies, and drawing on examples from the Limpopo basin, Nigerian coastal pollution, and municipal waste-routing in Tshwane, the article develops a framework for disciplined integration. Digital twins, it contends, should enter EIA through certified simulation reports, auditable provenance, structured disclosure obligations, and proportionate trigger-based responses, rather than through assertions of technological authority. Properly constrained, they may enable more adaptive regulation; unconstrained, they risk importing technical opacity into already fragile administrative systems.

Keywords: digital twin; Environmental Impact Assessment; administrative law; electronic evidence; model governance; data justice; adaptive regulation; Nigeria; South Africa.

Introduction: EIA, Environmental Uncertainty, and the Appeal of Digital Twins

EIA has long functioned as a legal technique for managing environmental uncertainty.¹ Well before contemporary debates on algorithmic governance and predictive systems, it rested on a normatively ambitious premise: public authorities should confront probable environmental consequences before authorising environmentally significant activities.² EIA therefore belongs to a broader family of preventive public-law instruments that seek to move decision-making forward in time. Ideally, it allows harms to be anticipated, alternatives compared, mitigation specified, and objections heard before ecological change becomes irreversible.³

Yet the procedural form through which EIA performs this anticipatory function remains strikingly static.⁴ In jurisdictions such as Nigeria and South Africa, the process still follows a familiar sequence: screening, baseline description, specialist reporting, impact prediction, time-bounded public comment, and administrative decision on a record expected to remain sufficiently stable for a once-

¹AL Balogun and others, 'Digitalization for Transformative Urbanization, Climate Change Adaptation, and Sustainable Farming in Africa: Trend, Opportunities, and Challenges' (2022) 19(1) *J Integr Environ Sci* 17.

²AL Balogun and others, 'Assessing the Potentials of Digitalization as a Tool for Climate Change Adaptation and Sustainable Development in Urban Centres' (2020) 53 *Sustain Cities Soc* 101888.

³FO Ajagunna and OA Gbadegesin. "Do Laws Serve or Oppose Us?? Reinventing Environmental Sanitation Laws in Nigeria". (2023) *Administrative and Environmental Law Review* 4 (2):83-96. <https://doi.org/10.25041/aclr.v4i2.2972>.

⁴A Devis, 'The Renewable Energy Directive III and the streamlining of environmental procedures: a paradigm shift in EU environmental policy?' (2025) 37(3) *Journal of Environmental Law* 443.

off authorisation to be lawful. This architecture assumes that environmental evidence can be assembled, closed, and judged in documentary form.⁵ It also assumes that the tempo of environmental change is compatible with the tempo of administrative review.

That assumption is increasingly untenable. Environmental systems do not pause for the closure of an administrative file. River basins respond to shifting hydrological conditions; urban systems generate variable pollution and waste flows; coastal environments are reshaped by tides, storms, sediment transport, industrial discharges, informal settlements, and infrastructure interventions that do not respect procedural timelines.⁶ Climate change intensifies this mismatch between static legal evidence and dynamic environmental conditions.⁷ In settings marked by weak baseline data, fragmented institutions, and uneven compliance systems, the difficulty is not that EIA's preventive aspiration is misguided, but that its evidentiary architecture is often too episodic for the environments it seeks to govern.

⁵ C Malcolm, 'Witness, Evidence, and the Environmental Archive' in *Survey Practices and Landscape Photography Across the Globe* (Routledge 2022) 280–98.

⁶ Z Yang, Y Cai and W J Mitsch, 'Ecological and hydrological responses to changing environmental conditions in China's river basins' (2015) 76 *Ecological Engineering* 1; T Z Oo, U W Humphries and M K Mone, 'Remote sensing-derived land use land cover for hydrological modelling of flood hydrographs in the Mun River Basin, Thailand' (2026) 41(1) *Geocarto International* 2620189.

⁷ K Abbass and others, 'Does financial inclusion enable low-carbon transitions? Nonlinear and threshold evidence for climate change mitigation in emerging economies' (2026) *International Journal of Sustainable Development & World Ecology* 1–24.

The practical consequences of this episodic architecture are visible in several African environmental settings. In the Niger Delta, for example, oil pollution has not presented itself as a single, closed event capable of being fully captured at the moment of project approval.⁸ Contamination of land, groundwater, creeks and mangrove ecosystems has evolved across time, often requiring repeated assessment, remediation and monitoring long after initial regulatory decisions were made. The Ogoniland assessment illustrates this difficulty: the problem was not merely the occurrence of pollution, but the persistence, spread and delayed recognition of environmental and public-health harm.⁹ This shows the limitation of an assessment model that treats environmental knowledge as if it can be finalised at one procedural moment.

Similar difficulties arise in relation to flooding, coastal erosion and urban environmental stress.¹⁰ Nigeria's recurrent flood disasters demonstrate that environmental risks are often cumulative, seasonal and responsive to changing hydrological conditions rather than fixed at the date of approval.¹¹ These examples do not render EIA obsolete;

⁸Gbadegesin OA, Adeniran HA and Ojogbo UE, 'Towards Holistic Environmental Governance: Embedding Biodiversity in Nigeria's Climate Change Frameworks' (2026) 15 Climate Law 487 <https://doi.org/10.1163/18786561-bja10077> accessed 25 May 2026.

⁹United Nations Environment Programme, *Environmental Assessment of Ogoniland* (UNEP, 17 January 2011) <https://www.unep.org/resources/report/environmental-assessment-ogoniland> accessed 25 May 2026.

¹⁰ Ayodele-Olajire D, Oluwaleye J, Gbadegesin O and Gbadegesin A, 'Climate Change and Megacities: Flooding along the Urbanising Atlantic Coastline of Lagos, Nigeria' (2026) 5(4) *Journal of Inclusive Cities and Built Environment* 31 <https://doi.org/10.54030/2788-564X/2025/spi4v5a4> accessed 25 May 2026.

¹¹ Ayodele-Olajire and others (n 10) 33.

rather, they expose the need for assessment systems capable of treating environmental evidence as dynamic. The static nature of EIA therefore has concrete consequences: it may understate cumulative harm, delay regulatory response, and weaken the connection between predicted impact and actual environmental change.

Environmental digital twins have emerged in this context as an attractive, though often over-celebrated, innovation.¹² Broadly understood, a digital twin is a data-driven virtual representation of a physical system that updates as new information becomes available.¹³

In environmental settings, such systems are used or proposed for river basins, coastlines, floodplains, urban transport, waste infrastructures, energy systems, and industrial pollution pathways.¹⁴ Their attraction is obvious: they seem to offer what static EIA often cannot—continuous monitoring, iterative scenario testing, dynamic representations of uncertainty, and a closer link between prediction and operational response. That appeal is especially strong in relation to SDGs 9 and 11, where resilient infrastructure and adaptive urban

¹²Y Sahu and VK Upadhyay, ‘Environmental Application of Digital Twins: A Review’ in *Environmental Risk and Resilience in the Changing World: Integrated Geospatial AI and Multidimensional Approach* (2024).

¹³S Nativi, P Mazzetti and M Craglia, ‘Digital Ecosystems for Developing Digital Twins of the Earth: The Destination Earth Case’ (2021) 13(11) *Remote Sens* 2119.

¹⁴S R Moon and others, ‘Water Resources and Environmental Sustainability: Current Challenges and Future Perspectives’ (2026) 15(2) *Resources* 31.

management appear to depend on systems capable of integrating real-time data with scenario modelling.¹⁵

The legal significance of that promise, however, is not self-evident. The issue is not whether digital twins are technically impressive, but whether law can use their outputs without abandoning the disciplines that make environmental decision-making legitimate. Continuous forecasts are not, by themselves, lawful grounds for public action. Environmental law still demands intelligibility, procedural fairness, institutional responsibility, and reviewable reasons. The deeper problem is therefore not simply that law has failed to “catch up” with environmental data science, but that digital twins sit uneasily within the evidentiary and institutional assumptions on which EIA has traditionally relied.

Nigeria and South Africa provide useful comparative sites for testing this difficulty.¹⁶ Both operate formal EIA systems and face acute governance pressures linked to urbanisation, pollution, extraction, and climate variability. Yet the legal frameworks differ in ways that matter. Nigeria’s regime is shaped by the Environmental Impact Assessment Act and a federal administrative structure in which the

¹⁵ SE Bibri, *Artificial Intelligence of Things for Smarter Eco-Cities: Pioneering the Environmental Synergies of Urban Brain, Digital Twin, Metabolic Circularity, and Platform* (CRC Press 2024).

¹⁶ TA Olorundami, *Environmental Impact Assessment (EIA) Effectiveness and “Local Context”: The Case of Nigeria* (dissertation, Newcastle University 2022); T Rabakali, *An Evaluation of the Strategic Environmental Assessment (SEA) as a Tool for Promoting Sustainable Development in South Africa* (dissertation, Stellenbosch University 2022).

evidentiary form of submissions is central.¹⁷ South Africa's framework is embedded in section 24 of the Constitution, NEMA, the EIA Regulations, and the administrative-law standards of Promotion of Administrative Justice Act (PAJA).¹⁸ The pathway for integrating digital twin outputs is therefore unlikely to be identical across the two systems.

This article makes a deliberately limited claim. It does not assume that digital twins have already improved EIA outcomes in any generalisable sense. It argues instead that they may support a more adaptive form of EIA-informed regulation in Nigeria and South Africa, but only if legal frameworks are redesigned around four points of friction: evidentiary admissibility, evidentiary weight, institutional ownership and coordination, and accountability for error and misuse. These are not secondary implementation details. They are the legal conditions under which predictive systems remain informative background tools or become decision-shaping infrastructures.

The article proceeds in five stages. Section II frames digital twins as predictive evidence and distinguishes admissibility from evidentiary weight. Section III uses three case studies as legal stress tests. Section IV examines doctrinal integration in Nigerian and South African EIA

¹⁷I A Adedokun, 'ENvIronmental, Social, And Governance (Esg) Metrics And Nigeria'S Energy Transition: Towards Legal Integration In The Oil And Gas Sector' (2026) 17(1) *Journal for Sustainable Development Law & Policy*

¹⁸TJ Rantlo, 'The Practical Application of Section 24G of the NEMA: A Critical and Quantitative Empirical Analysis' (2025) 28(1) *Potchefstroom Electronic Law Journal* 1–38 https://doi.org/10.17159/1727-3781/2025/v28i0a14505

law. Section V addresses governance and accountability. Section VI sets out the minimum legal architecture for adaptive use.

1. Predictive Environmental Models and the Law of Administrative Evidence

EIA is a preventive legal and administrative process through which the likely environmental consequences of a proposed activity are identified, evaluated and considered before authorisation is granted.¹⁹

Its value lies not only in technical prediction, but also in public participation, reasoned decision-making and accountability. In this sense, EIA is both an evidentiary process and a governance process: it gathers information, tests alternatives, discloses risks and creates a record upon which the legality of public action may later depend.

Digital twins, by contrast, are not merely reports or static models. They are virtual representations of physical systems that can be updated through data inputs and used to simulate possible future conditions.²⁰ In environmental governance, this may include river-basin behaviour, coastal pollution movement, flood risk, waste flows or infrastructure stress. Their significance for EIA lies in their ability to connect prediction with continuous monitoring. However, this same quality creates legal difficulty because a continuously updated model does not fit easily into a process traditionally organised around a fixed report, a closed record and a one-off authorisation decision.

¹⁹ AL Balogun and others, (n 1)

²⁰ Sahu and Upadhyay (n 12).

The legal challenge posed by environmental digital twins is often described in overly general terms.²¹ One frequently encounters the claim that the technology has advanced, whereas law remains behind. This description is not wholly false, but it is inadequate. It obscures the precise problem. The relevant difficulty is not simply that digital twins are new. It is that they produce a type of evidentiary material that does not sit neatly within the categories through which administrative decision-making usually organises environmental knowledge.²²

Traditional EIA evidence is heterogeneous but recognisable.²³ It includes baseline field studies, laboratory results, expert opinions, consultations, maps, project descriptions, and predictive assessments generated through discrete modelling exercises. These materials are assembled into a record that an authority can review, weigh, and rely upon. Digital twins complicate this picture because they are neither raw observational data nor conventional expert reports.²⁴ They are computational systems that integrate multiple data streams, produce outputs through iteratively updated modelling, and often generate

²¹ X Li and others, 'Big Data in Earth System Science and Progress towards a Digital Twin' (2023) 4(5) *Nat Rev Earth Environ* 319.

²² W Hazeleger and others, 'Digital Twins of the Earth with and for Humans' (2024) 5(1) *Commun Earth Environ* 463.

²³ O Ogunwale and others, 'Modernizing Legacy Systems: A Scalable Approach to Next-Generation Data Architectures and Seamless Integration' (2023) 4(1) *Int J Multidiscip Res Growth Eval* 901.

²⁴ S Yoon and J Koo, 'In Situ Model Fusion for Building Digital Twinning' (2023) 243 *Build Environ* 110652.

probabilistic predictions rather than definitive statements of fact.²⁵

They are thus hybrid evidentiary objects: part dataset, part model, part scenario engine, part interface.

The first analytical move required is therefore to distinguish admissibility from evidentiary weight.²⁶ This distinction is familiar in evidence law but insufficiently developed in discussions of environmental digital governance. Admissibility concerns whether a piece of material may properly enter the record at all.²⁷ Evidentiary weight concerns how much reliance a decision-maker may lawfully place on that material.²⁸ These are separate questions. A simulation output may be admitted, documented, and disclosed, yet still deserve only modest weight because its assumptions remain contestable, because the underlying data are sparse or uneven, because local calibration is weak, or because the relationship between the forecast and the proposed regulatory consequence is too uncertain.

This distinction matters because much of the policy literature effectively assumes that once a model is validated or certified, the

²⁵ M Magnani and A Provenzale, 'Models, Digital Twins and Virtual Research Environments' in *Critical Zone and Ecosystem Dynamics* (Springer 2024).

²⁶ A Kusiak, 'Open Manufacturing: A Design-for-Resilience Approach' (2020) 58(15) *Int J Prod Res* 4647.

²⁷ M I Al Zobi and R M M Qomum, 'A Comparative Study of the Admissibility and Invalidity of Electronic Evidence' in *Artificial Intelligence for Sustainable Innovation Management and Risk Management: A Systems (and Network) Perspective* (Springer Nature Switzerland 2026) 1339–1353.

²⁸ J Donnelly, 'National interest, present tense: A case for a statutory contemporaneity duty in s 501 decisions' (2026) *Alternative Law Journal* (advance online publication) <1037969X261419845>.

question of legal use is largely solved.²⁹ That assumption is untenable. Certification may demonstrate that certain technical or procedural standards have been followed. It may improve trust in the provenance and handling of the system. It does not extinguish uncertainty. A twin may be meticulously documented and still produce results that are too contingent, too assumption-sensitive, or too context-dependent to justify strong regulatory consequences. In law, the problem is not whether one can certify a model. The problem is what public authorities may do, lawfully, with the outputs of that model.

This becomes especially important in environmental governance, where uncertainty is not an exceptional feature but a constitutive one. EIA has always involved predictions. Air dispersion models, hydrological forecasts, traffic assessments, and ecological impact projections are familiar tools.³⁰ But digital twins differ in at least three ways. First, they are designed for continuity rather than bounded use.³¹ Second, they are often linked to operational feedback loops

²⁹ Martin García-Vaquero, Antonio Sánchez-Bayón and Frank Daumann, 'From Static Welfare Optimization to Dynamic Efficiency in Energy Policy: A Governance Framework for Complex and Uncertain Energy Systems' (2026) 19(6) *Energies* 1460; Frieder Bögnér, 'The Lock-and-Key Model of Technosolutionism: the Case of AI and Sustainability Challenges' (2026) 39(1) *Philosophy & Technology* 22

³⁰ AM Lawal, IF Vincent-Akpu and GN Woke, 'Evaluation of Stakeholder Perceptions and Applicability of Artificial Intelligence Integration into Environmental Impact Assessment Processes in Nigeria' (2024) 28(10) *J Appl Sci Environ Manage* 3165.

³¹ M Magnani and A Provenza, 'Models, Digital Twins and Virtual Research Environments' in *Critical Zone and Ecosystem Dynamics* (Springer 2024)

rather than one-off submissions.³² Third, they can produce outputs with varying degrees of uncertainty over time, meaning that their evidentiary condition is not fixed at the moment of submission.³³ These differences alter the legal stakes. A conventional model run once for a report is easier to stabilise within a procedural record than a continuously updating twin whose outputs evolve as new data arrive.³⁴

The proper legal response is not to exclude predictive systems from environmental assessment. That would be artificial and self-defeating. Nor is it to treat them as a superior form of evidence simply because they are dynamic. The more defensible response is to adopt a principle of proportional reliance. Under such an approach, the level of legal reliance placed upon a digital twin output should be calibrated to the significance of the regulatory consequence that follows from it.³⁵ A twin used informationally—for example, to identify where further sampling or specialist inquiry is needed—need not satisfy the same demands as a twin whose output is used to trigger restrictive permit conditions, compliance escalations, or suspensions of activity. As the burden imposed on regulated actors increases, so too should the demands of validation, transparency, and opportunity for challenge.

³² SA Argyroudis and others, ‘Digital Technologies Can Enhance Climate Resilience of Critical Infrastructure’ (2022) 35 *Clim Risk Manag* 100387.

³³ MW Ahmed and MJ Uddin, ‘Digital Twins and Legal Liability: Navigating Accountability in Simulated Realities’ (2025) 7(8) *Int J Law Polit Stud* 19.

³⁴ *Ibid*

³⁵ MAK Akhtar, M Kumar and A Nayyar, ‘Transparency and Accountability in Explainable AI: Best Practices’ in *Towards Ethical and Socially Responsible Explainable AI: Challenges and Opportunities* (Springer 2024).

This proportionality is not merely prudential. It is the means by which administrative law can remain coherent when confronted with probabilistic evidence. Environmental law often invokes precaution, but precaution cannot mean that any uncertain forecast automatically justifies any chosen intervention. The authority must still explain why the evidence is sufficient for the step taken. A model predicting a possible pollutant exceedance may justify closer monitoring or conditional mitigation.³⁶ It does not, without more, justify categorical assumptions of breach or irreversible harm. The legal relationship between uncertainty and consequence must therefore be articulated, not assumed.

There is a second reason why digital twins must be handled carefully: they are not neutral reflectors of reality.³⁷ They are selective and normative infrastructures. Every twin embodies choices about what to model, what data to privilege, what thresholds matter, how uncertainty is represented, and what counts as acceptable performance.³⁸ A river-basin twin, for example, might foreground flow levels, drought risk, and reservoir operations, while leaving social vulnerability or informal water access largely outside the model

³⁶ AV Chukwuka, AD Adegboyegun and AO Adeogun, 'GIS-Based Pollution Mapping for Net-Zero Planning: Enhancing Blue Economy Sustainability in Coastal West Africa' in *Handbook of Sustainable Blue Economy* (Springer 2025).

³⁷ C Davey, 'Digital Twin Cities: An Instrument for Pedagogical Change' in *Teaching Architecture(s) in the Post-Covid Era* (Routledge 2024).

³⁸ D Appelbaum, 'Securing Big Data Provenance for Auditors: The Big Data Provenance Black Box as Reliable Evidence' (2016) 13(1) *J Emerg Technol Account* 17

frame.³⁹ A coastal pollution twin may produce elegant plume maps without adequately representing local patterns of exposure or livelihood dependence.⁴⁰ A waste-routing twin may optimise collection efficiency while embedding assumptions about service priorities that have distributive consequences across neighbourhoods.⁴¹ These are not merely technical matters. They are governance choices. Once a public authority relies on them, they become legal choices as well.

This is why the literature on socio-technical governance is useful, but only up to a point.⁴² That literature is correct to insist that technology adoption depends on institutions, trust, and co-production.⁴³ Yet for public-law purposes, one must go further. The issue is not simply that communities and regulators should be involved in twin design. It is that questions of power, access, and responsibility must be formalised if the twin is to function within a lawful regulatory system. Who controls the model? Who can inspect its assumptions? Who determines when an output becomes a trigger? Who bears the burden

³⁹ A Afham and others, *Limpopo River Basin Digital Twin Open Data Cube Catalog* (CGIAR Initiative on Digital Innovation, International Water Management Institute (IWMI) 2024).

⁴⁰ K Akpoti and others, 'State of Continental Discharge Estimation and Modelling: Challenges and Opportunities for Africa' (2024) 69(15) *Hydrol Sci J* 2124.

⁴¹ Qazi Salman Khalid, Shahid Maqsood, Jabir Mumtaz and Sheheryar Mohsin Qureshi, 'An Emission-Capacitated Vehicle Routing Model for Sustainable Urban Waste Collection Using Hybrid Guided Local Search' (2026) 16 *Scientific Reports* 7691

⁴² S Borrás and J Edler, 'The Roles of the State in the Governance of Socio-Technical Systems' Transformation' (2020) 49(5) *Res Policy* 103971.

⁴³ Anna Uster, 'Governmental Implementation of Information and Communication Technology at the Local Level: Digital Co-Production during a Crisis' (2025) 84(1) *Australian Journal of Public Administration* 69

when it is wrong? Unless these questions are answered in legal form, digital twins risk becoming opaque infrastructures of decision support that are difficult for affected communities, courts, or even regulators themselves to interrogate.

The conclusion of this section is therefore twofold. First, digital twins should be understood as forms of predictive and contestable expert evidence rather than as self-validating decision systems. Second, their regulatory use must be organised around pathways of disciplined reliance. This means not only creating routes through which outputs may enter the administrative record, but also specifying how uncertainty, disclosure, validation, and review relate to the consequences authorities wish to attach to those outputs. Without that architecture, the introduction of digital twins into EIA is likely to produce more legal instability than regulatory intelligence.

2. Three Illustrative Contexts and Their Legal Significance

The available case materials on environmental digital twins in Africa do not justify strong empirical claims about maturity or effectiveness. They do, however, illuminate the legal and institutional frictions that emerge when predictive systems begin to intersect with environmental regulation. Their value lies less in what they prove than in what they expose. Three contexts are particularly instructive.

2.1. The Limpopo Basin Twin and the Translation Problem in Transboundary Governance

The Limpopo basin provides a useful setting because it combines hydrological uncertainty, multiple legal orders, shared infrastructure, and strong incentives for anticipatory coordination.⁴⁴ A basin-scale digital twin drawing on hydrological modelling, rainfall data, reservoir information, environmental flow measurements, and satellite-derived observations can generate scenarios of drought stress, flood propagation, and abstraction consequences.⁴⁵ Such a system is attractive from a management standpoint because it allows authorities to compare outcomes before interventions occur. It can enhance common situational awareness and support basin planning under uncertain conditions.

The legal relevance of the Limpopo example, however, lies in the relationship between model outputs and jurisdiction.⁴⁶ A basin twin coordinated by or associated with an institution such as LIMCOM (the four-country Limpopo Watercourse Commission) may exist within a transboundary governance framework.⁴⁷ But environmental authorisations, dam operations, abstraction decisions, and project-specific EIAs remain embedded in domestic legal systems. This raises a translation problem. A forecast generated within a shared regional

⁴⁴ S Ghosh and others, 'Recent Drought Prevalence in the Limpopo River Basin: Insights from the Digital Twin Platform' (2025) *J Indian Soc Remote Sens* 1.

⁴⁵ Op cit Afham et al., 2024

⁴⁶ M Garcia Andarcia and others, *Digital Twin for Management of Water Resources in the Limpopo River Basin: A Concept* (CGIAR Initiative on Digital Innovation, International Water Management Institute (IWMI) 2024)

⁴⁷ *ibid*

system does not automatically become a lawful basis for national administrative action. For that to occur, there must be a route through which the model output can be received, authenticated, and weighed within domestic procedure.⁴⁸

This problem is not merely formal. It has several dimensions.⁴⁹ One is provenance. Data contributing to the model may originate in multiple states, be processed through external technical platforms, and then return as outputs relevant to a particular national decision. Another is authority. A basin body may coordinate information-sharing and planning, but it may not possess direct power to impose legal consequences on domestic permitting authorities. A third is responsibility. If a national authority relies on a transboundary forecast that later proves materially defective, it becomes necessary to ask where responsibility for model design, calibration, and disclosure resides.

The most interesting legal lesson here is that transboundary digital twins make visible a problem already latent in many forms of environmental coordination: the disjunction between shared knowledge and fragmented authority. A twin may improve information without clarifying who is entitled to act on that information. Yet in environmental law, the threshold at which information becomes action is precisely where legality begins to

⁴⁸ Ibid

⁴⁹ FC Prinsloo, *A Geo-Informatics Approach to Sustainability Assessments of Floatovoltaic Technology in South African Agricultural Applications* (dissertation, University of South Africa 2022).

matter most. A forecast, however sophisticated, does not determine its own legal consequence.

This is why the Limpopo context is best understood not as proof that transboundary twins are ready for regulatory use, but as a reminder that any such use requires formal institutional design. Domestic environmental laws would need to specify whether basin-generated model outputs may be submitted as specialist evidence, how their provenance is to be established, what weight may be assigned to them, and how conflicting domestic evidence is to be resolved. Cross-border data-sharing arrangements would need to move beyond technical cooperation into questions of evidentiary custody, quality control, and responsibility for updates. Without those moves, the twin remains a sophisticated planning aid rather than a legally meaningful component of EIA.

2.2. The Nigerian Coastal Pollution Twin and the Instability of Dynamic Evidence

The Nigerian coastal example reveals a different problem: the procedural instability introduced by dynamic evidence into a report-based assessment system.⁵⁰ A coastal twin combining hydrodynamic modelling, satellite remote sensing, drone imagery, sensor feeds, and local coastal observations can generate pollution forecasts, hotspot maps, and scenario-based projections of dispersal under different

⁵⁰ United Nations Decade of Ocean Science for Sustainable Development, 'Pilot Digital Twins for Water Pollution in Africa' (2023) https://oceandecade.org/actions/pilot-digital-twins-for-water-pollution-in-africa/#weglot_switcher accessed 30 December 2025

discharge or tidal conditions.⁵¹ For coastal management, this is attractive because it promises a more realistic representation of highly variable marine and shoreline environments.⁵²

Yet the legal significance of this promise lies in the structure of the EIA process into which the twin would be inserted.⁵³ Nigeria's EIA system assumes a staged submission and review model. Information is collected, set out in reports, submitted for review, and exposed to public comment within a determinate window.⁵⁴ The process presupposes a sufficiently stable evidentiary basis on which a decision can be reached. A digital twin unsettles this assumption because its outputs can change after submission. The more dynamic the system becomes, the less clear it is what constitutes the relevant record.

This matters in several concrete ways. If a coastal pollution twin is used during assessment to identify likely contamination pathways, and subsequent incoming data materially alter those projections before authorisation is granted, what is the legal status of the earlier submission? Must the proponent update the record? Does the authority have a duty to revisit the evaluation? Are affected

⁵¹ M Palmer and others, 'Establishing Community Interfaces to Optimise Outcomes and Maximise Impacts from Digital Twins of the Ocean' (One Ocean Science Congress OOS2025-972, 2025) <https://doi.org/10.5194/oos2025-972>.

⁵² Ibid

⁵³ Op cit Chukwuka et al., 2025

⁵⁴ I Mugudamani, SA Oke and H Ikrema, 'Detecting Plastic Pollution in Aquatic Environment Using Remote Sensing Technology: Cost-Saving Method in Pollution and Risk Management for Developing Countries' (2025) 7(6) *J Environ Earth Sci*.

communities entitled to comment on the changed output? The current EIA architecture does not expressly answer these questions. That silence is significant because it means that the legally operative value of dynamic modelling is uncertain even before one reaches the deeper questions of admissibility and weight.

The coastal context also foregrounds data politics.⁵⁵ Publicly described initiatives often emphasise stakeholder co-design, community participation, and localisation of interfaces.⁵⁶ These features are normatively attractive, but they should not be mistaken for legal safeguards. A community may contribute local observations, host sensors, or assist in identifying discharge points, yet still have no enforceable right to inspect the data pipeline, challenge modelling assumptions, or access the outputs in a form that affects regulatory decisions. The result is a familiar asymmetry: communities provide informational value to the system without gaining corresponding control over how that value is translated into public authority.⁵⁷

The interaction with freedom-of-information and public participation norms is particularly important in Nigeria.⁵⁸ Environmental data that remain institutionally or contractually closed can undermine the reality of public participation even where formal notice and comment requirements are observed. If the legal basis of a decision depends

⁵⁵United Nations Decade of Ocean Science for Sustainable Development, 'Digital Twins of the Ocean (DITTO)' (n.d.) <https://oceandecade.org/actions/digital-twins-of-the-ocean-ditto/> accessed 30 December 2025.

⁵⁶Op cit Lawal et al., 2024

⁵⁷Op cit Ajagunna and Gbadegesin 2023)

⁵⁸Gbadegesin O. A., 'Lost in Transplantation: Revisiting Indigenous Principles as a Panacea to Natural Resource Sustainability in Nigeria' (2024) 68(1) *Journal of African Law* 41, 41–57 <https://doi.org/10.1017/S0021855323000256>

materially on a twin's forecasts, then affected parties require more than a general statement that "the model shows" a risk or safe condition. They need access to enough of the underlying logic to make challenge possible. Otherwise, digital sophistication becomes a new mode of opacity.

The coastal example thus clarifies that the integration of twins into Nigerian EIA is not simply a matter of accepting simulation outputs as evidence. It is a matter of rethinking when the record is open or closed, how material updates are handled, and what disclosure obligations arise when continuously evolving evidence is brought into a process designed around documentary stability.

3.3 The Tshwane Waste-Routing Twin and the Expansion of Environmental Governance Beyond the Permit File

The Tshwane context is useful because it expands the analysis beyond the conventional boundaries of project assessment.⁵⁹ A waste-routing twin typically integrates sensor data from waste infrastructure, GIS mapping, routing algorithms, and sometimes citizen-generated reports.⁶⁰ Its immediate purpose is operational: to improve route efficiency, reduce collection failures, and optimise use of municipal resources.⁶¹ In environmental terms, such systems may also lower

⁵⁹C Paredes-Riera, J Paredes-Riera and MC Guerra, 'Philosophy, Complexity, and Environment: Epistemological Framework on Contemporary Issues' (2025) *J Cult Anal Soc Change* 3677.

⁶⁰T Mokebe, *Implementation of Waste Management Policy in the City of Tshwane* (dissertation, University of South Africa 2018).

⁶¹*Ibid*

fuel use, reduce emissions associated with collection logistics, and improve cleanliness or service reliability.⁶²

The legal relevance of this example is not that it resembles a standard EIA model. It is that it shows how digital systems can become environmentally consequential without first appearing as formal evidence in an environmental authorisation process.⁶³ A routing twin can shape municipal service expectations, define performance metrics, influence contracts, and indirectly affect the environmental obligations of developments or large generators linked to local infrastructure systems.⁶⁴ In that sense, it is a reminder that the governance footprint of digital twins may exceed the narrow domain of specialist reports.

This has two implications. First, legal analysis must look beyond evidence law. Procurement law, municipal by-laws, contract design, and public access to operational data become central. If a municipality deploys a routing twin through a vendor-controlled platform without interoperability guarantees, audit rights, or data portability, it may later discover that core environmental intelligence sits behind proprietary interfaces it does not fully control. A technically successful system can thus produce a legally problematic dependence.

⁶²SJ Ramson and others, 'A LoRaWAN IoT-Enabled Trash Bin Level Monitoring System' (2021) 18(2) *IEEE Trans Ind Inform* 786.

⁶³IL Cárdenas-León, *From Trash to Digital Treasure: Urban Digital Twinning for Solid Waste Management* (Master's thesis, University of Twente 2023).

⁶⁴I Cárdenas-León and others, 'Urban Digital Twin-Based Solution Using Geospatial Information for Solid Waste Management' (2024) 115 *Cities Soc* 105798.

Second, this example warns against equating measurable efficiency with regulatory readiness. The fact that a twin may reduce total route distance or improve collection times does not by itself establish that it is fit to play a role in environmental governance. Efficiency is not legality. A city may obtain operational benefits from a black-box system that remains opaque, difficult to audit, and poorly aligned with participatory or accountability norms. For public law, these concerns are not secondary. They are central to whether the system can legitimately inform regulatory expectations or compliance judgments. What the Tshwane example therefore contributes is a broader understanding of the legal field in which environmental twins operate. If digital twins are to matter in EIA or environmental regulation more generally, the relevant legal architecture must include not only evidentiary rules and permitting procedures, but also procurement safeguards, public-sector control over operational data, and mechanisms for scrutinising algorithmically mediated environmental decision-support at local level.

2.3. What the contexts support

Read together, these contexts support a restrained but valuable conclusion. They do not prove that environmental digital twins are ready to transform EIA. They do show that different environmental domains generate different legal stress points. In transboundary water governance, the problem is shared authority. In dynamic coastal modelling, it is the instability of the evidentiary record. In municipal

systems, it is infrastructural dependency and procurement discipline. Across all three, the same deeper issues recur: how model outputs become legally cognisable, how uncertainty is managed, how thresholds are defined, how data are governed, and how responsibility is allocated. That is the level at which reform must be pitched.

3. Doctrinal Integration into EIA Law in Nigeria and South Africa

If digital twin outputs are to matter in EIA, they must be translated into legally recognisable forms. That translation requires more than general statutory definitions. It requires attention to how evidence enters the record, how procedures accommodate or resist dynamic updates, how public participation operates when the relevant material is highly technical, and how post-authorisation monitoring relates back to the evidentiary basis of the initial decision.

Comparative experience shows that digital environmental modelling has begun to operate as institutionalised decision-support infrastructure in some jurisdictions, although this should not be mistaken for full integration into EIA law or environmental authorisation frameworks.⁶⁵ The European Union's Destination Earth initiative, for instance, is designed to develop a digital twin of the Earth capable of monitoring, modelling and simulating natural phenomena, hazards and human activity in support of adaptation and

⁶⁵ Stefano Nativi, Paolo Mazzetti and Max Craglia, 'Digital Ecosystems for Developing Digital Twins of the Earth: The Destination Earth Case' (2021) 13(11) *Remote Sensing* 2119

mitigation planning.⁶⁶ Its relevance for Nigeria and South Africa is therefore not that it provides a directly transferable legal model, but that it illustrates how digital twins may support public decision-making where they are connected to institutional responsibility, data governance and defined procedures for use.⁶⁷

Singapore's Virtual Singapore provides a second useful example, not as an EIA-law model in itself, but as an illustration of how a high-resolution digital representation of a city may support urban planning, infrastructure analysis and environmental simulation.⁶⁸ The lesson is that legal systems seeking to use digital twins must address questions of access, institutional control, data reliability and inter-agency use from the beginning.⁶⁹ Likewise, operational water-management systems such as Delft Flood Forecasting and Early Warning System (Delft-FEWS) show that predictive environmental systems can be embedded in decision-making where forecasting, quality control, reporting and expert interpretation are structured around institutional

⁶⁶Francisco J Doblas-Reyes and others, 'The Destination Earth Digital Twin for Climate Change Adaptation' (2025) *EGUsphere* 1

⁶⁷Hans Jørgen Henriksen and others, 'A New Digital Twin for Climate Change Adaptation, Water Management, and Disaster Risk Reduction (HIP Digital Twin)' (2023) 15(1) *Water* 25

⁶⁸Hanzhang Zhan, Bon-Gang Hwang and Pramesh Krishnankutty, 'Embracing Digital Transformation for Sustainable Development: Barriers to Adopting Digital Twin in Asset Management within Singapore's Energy and Chemicals Industry' (2025) 33(2) *Sustainable Development* 2864

⁶⁹Hao-Qing Yang, Jian Chu, Shifan Wu, Xing Zhu, Xiaohui Qi and Kiefer Chiam, 'Advancing Geological Modelling and Geodata Management: A Web-Based System with AI Assessment in Singapore' (2025) 19(1) *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards* 218

procedures.⁷⁰ These examples therefore do not provide ready-made legal templates for Nigeria and South Africa; rather, they show how digital systems may support forecasting, planning and environmental decision-making where institutional responsibility, data governance and review procedures are clearly defined.

3.1. Nigeria: admissibility, authentication, and the structure of the EIA record

Nigeria's EIA Act is built around a preventive approval structure. Section 2 prohibits projects likely to significantly affect the environment from proceeding without prior assessment. Section 3 establishes the evaluative logic of environmental study and review, while sections addressing notice, consultation, and review assume the existence of an identifiable documentary record. This statutory logic matters because digital twins challenge the assumption that relevant environmental evidence can be packaged in a relatively stable form.⁷¹ The first doctrinal issue is admissibility. If a digital twin output is to be used in a contested administrative or judicial setting, the Evidence Act 2011 becomes highly relevant. Section 84 is the key provision. It governs statements contained in documents produced by computers and requires that certain conditions be met before such documents are admissible. Section 84(4), in particular, requires a certificate identifying the document and describing the manner in which it was

⁷⁰ Elda Cina, Ersin Elbasi, Gremina Elmazi and Zakwan AlArnaout, 'The Role of AI in Predictive Modelling for Sustainable Urban Development: Challenges and Opportunities' (2025) 17(11) *Sustainability* 5148

⁷¹ C DeVries, 'Governance Framework for Citizen Digital Twins in Smart Cities' (2025) 1(1) *Intell Hum Futures*.

produced. Nigerian case law has emphasised the importance of such requirements. *Kubor v Dickson*⁷² underscored the strict treatment of electronically generated material, and *Brila Energy v FRN*⁷³ clarified that although a section 84 certificate is not the only conceivable route, it remains a principal means of grounding admissibility.

For digital twins, this has immediate practical implications.⁷⁴ A forecast map, animated visualisation, or dashboard cannot be assumed to carry legal weight in its native form. It must be translated into a documentary artefact capable of satisfying the demands of electronic evidence law. This means that a model output should ordinarily be accompanied by a structured report stating, at minimum, the model used, version information, data sources, the system through which the output was produced, relevant assumptions, calibration status, and the nature of the output being tendered. In other words, the twin must be rendered into evidence through documentation, not merely displayed through interface.

Yet admissibility is only the beginning. The deeper issue is what follows once the material is in the record. Here the distinction between admissibility and weight becomes central. A Nigerian authority may lawfully receive a digital twin output and still be obliged to assign it limited significance. A probabilistic flood

⁷²*Kubor & Anor v. Dickson & Ors* (2013) 4 NWLR (Pt. 1345) 534 SC.

⁷³*Brila Energy Ltd v. Federal Republic of Nigeria* (2018) LPELR-43926(CA)

⁷⁴Gbadegesin, O A, 'Leveraging Artificial Intelligence (AI) in Strengthening the Legal Framework for Regulation of Wildlife and Forest Crimes in Nigeria' (2023) 53(4) Environmental Policy and Law 259. <https://doi.org/10.3233/EPL-230011>

projection, pollution plume, or traffic-emissions forecast remains open to challenge on grounds of model choice, data sufficiency, calibration, sensitivity, and scenario selection. If an authority simply cites the output without explaining why it relied on it, the decision risks appearing unreasoned. The more intrusive the consequence attached to the model output, the stronger the obligation to explain how uncertainty was evaluated.

This problem becomes particularly acute at the scoping stage. EIA in Nigeria is supposed to identify the issues that require investigation.⁷⁵ If a proponent wishes to rely on a digital twin as part of impact analysis, that intention should be disclosed at scoping in more than generic terms. A proper modelling plan should identify the environmental variables to be modelled, the intended scenarios, the sources of data, the proposed update logic, the approach to validation, and the form in which outputs will be disclosed. Without that level of specificity, the authority and the public cannot meaningfully assess whether the twin is an appropriate methodology or merely a rhetorical marker of innovation.

During substantive assessment, the twin output should be treated as the equivalent of a specialist study rather than as an informal supplement. This does not mean it must displace conventional specialist evidence. On the contrary, one of the more serious analytical mistakes would be to present the twin as a replacement for

⁷⁵ S Nandmehar and T S Marah, 'The Effectiveness of Environmental Impact Assessment (EIA) Laws in Developing Countries: Case Studies from Sierra Leone, Nigeria, and Indonesia' (2025) 7(2) *Jurnal Rechten: Riset Hukum dan Hak Asasi Manusia* 35

baseline and field-specific expertise. In most cases, it should sit alongside and be tested against more conventional forms of environmental assessment. A hydrological twin, for example, may refine understanding of flow scenarios, but it does not make site-specific ecological observations redundant. A coastal dispersion model may illuminate pollutant pathways, but it does not substitute for direct measurement or sediment sampling.⁷⁶ Authorities should be alert to this complementarity rather than allowing the symbolic authority of digital systems to crowd out other evidence.

Public participation presents a further difficulty. Nigerian EIA procedure assumes that the public can be informed of the contents of the assessment and afforded an opportunity to comment. But the meaningfulness of that opportunity depends on the intelligibility of the material. A twin output that appears only as a highly technical simulation without explanatory disclosure risks undermining the reality of participation. This suggests that twin-supported assessments should include a non-technical explanation of the model's purpose, assumptions, limitations, and uncertainty range. That explanation should not be a mere publicity summary. It should be designed to support actual challenge. If affected communities cannot understand the basis of the simulation, participation becomes formal rather than substantive.

⁷⁶ I B Ayoub, S Ara and S A Lone, 'Microplastics in the Himalayan Environment: A Review of Sources, Atmospheric Inputs, and Subsurface Pathways' (2025) 197(9) *Environmental Monitoring and Assessment* 1020

The most difficult Nigerian issue arises at the post-authorisation stage. Digital twins are most attractive when they continue to operate after approval and inform adaptive management. Yet Nigeria's EIA framework is not presently designed around a continuously shifting evidentiary environment. If permit conditions are to depend on updated outputs, then there must be express legal authority for such reliance, clear disclosure duties, and procedures for review where updated outputs materially alter the regulatory posture. Otherwise, post-authorisation twin use may erode the procedural safeguards of the original assessment by introducing moving evidentiary targets outside the original participatory framework.

3.2. South Africa: constitutional environmentalism, NEMA, and model-dependent administrative judgment

South Africa's doctrinal terrain is both more receptive and more demanding. Section 24 of the Constitution creates a rights-based background for environmental regulation. NEMA and the EIA Regulations 2014 structure environmental authorisation through principles of sustainable development, integrated environmental management, public participation, and specialist input. Administrative action under this framework is further disciplined by the Promotion of Administrative Justice Act,⁷⁷ which requires lawful, reasonable, and procedurally fair decisions.

⁷⁷ Promotion of Administrative Justice Act 3 Of 2000. https://www.saflii.org/za/legis/consol_act/poaja2000396.pdf

In this environment, the obstacle to digital twins is less likely to be basic admissibility. Section 15 of the Electronic Communications and Transactions Act⁷⁸ allows data messages and similar electronic records into evidence, subject to reliability considerations. The more difficult issue is whether reliance on such material can satisfy the standards of rationality, reasonableness, and fairness demanded by administrative law. That is a more exacting question than it first appears. A digital twin output may be technically impressive and still be legally insufficient if the authority cannot show why the model was trusted, how uncertainty was understood, and how affected parties were enabled to respond.

The EIA Regulations provide an obvious route for twin-related material to enter the process.⁷⁹ Scoping reports and environmental impact reports routinely include specialist studies and assessments of alternatives, cumulative effects, and mitigation options. There is no conceptual barrier to a proponent saying that hydrological, coastal, atmospheric, or waste-related scenarios have been modelled through a digital twin architecture. The challenge lies in the detail. If such modelling is to influence the authorisation decision, the report must disclose enough about the system to make scrutiny meaningful. Merely invoking a “digital twin” would be legally empty.

⁷⁸South Africa. 2002. Electronic Communications and Transactions Act 25 of 2002. Government Gazette, 446(23708), Aug. 30

⁷⁹See Regulation 6 and Regulation 25 of the Environmental Impact Assessment (EIA) Regulations, 2014 (as amended)

The participatory implications are significant. South African environmental law takes public participation seriously.⁸⁰ Interested and affected parties must be able to inspect and respond to the evidentiary basis of the decision.⁸¹ A twin output that is materially relied upon therefore requires layered disclosure. Technical documentation is necessary for specialist interrogation; non-technical explanation is necessary for broader participatory fairness. It may also be necessary, in cases of substantial reliance, to facilitate independent expert review so that the public's ability to contest the model does not depend entirely on its own technical resources.

This leads to a subtle but important point. In South Africa, digital twins should not be seen as reducing the procedural burden of environmental assessment by delivering "better information." They are more likely to increase that burden, because using them lawfully requires greater attention to explanation, transparency, and reviewability. The price of technically richer evidence is procedurally richer justification.

⁸⁰ See Constitution of the Republic of South Africa, 1996, ss 24, 33, 59, 118; National Environmental Management Act 107 of 1998, ss 2(2), 2(4)(f), 24(4)(a)(v), 32; EIA Regulations 2014 (GN R982 GG 38282), regs 39–44; Promotion of Administrative Justice Act 3 of 2000, ss 3–4; National Environmental Management: Protected Areas Act 57 of 2003, ss 31, 33

⁸¹ See *Fuel Retailers Association of Southern Africa v Director-General: Environmental Management, Department of Agriculture, Conservation and Environment, Mpumalanga Province and Others* 2007 (6) SA 4 (CC); *Earthlife Africa (Cape Town) v Director-General: Department of Environmental Affairs and Tourism and Another* 2005 (3) SA 156 (C); *Sustaining the Wild Coast NPC and Others v Minister of Mineral Resources and Energy and Others* 2022 (6) SA 589 (ECP).

The post-authorisation domain is where the South African framework offers the greatest conceptual space for twin integration. Environmental management programmes, audit duties, and compliance monitoring already create a setting in which iterative information can matter. A digital twin could, in principle, support adaptive permit conditions, periodic review triggers, or escalated monitoring obligations. But again the legal challenge is not simply technical feasibility. It is how updated outputs become part of a lawful compliance architecture. If model results continue to evolve, the regulated party and affected public must know when those results are treated as informational, when they become trigger-relevant, and what rights of challenge remain available. Continuous modelling cannot become a route to continuous but opaque regulatory drift.

3.3. Why both systems need a certified simulation report

Despite their doctrinal differences, both jurisdictions would benefit from a common evidentiary bridge: the certified simulation report.⁸² This is not because their laws are identical, but because both operate through administrative records and reason-giving. A certified simulation report would convert dynamic modelling outputs into a stable legal artefact.⁸³ It should identify the model, record its version,

⁸² T Akther and F Xu, 'An Investigation of the Credibility of and Confidence in Audit Value: Evidence from a Developing Country' (2021) 34(5) *Account Res J* 488.

⁸³ B Batidzirai and others, 'Towards People-Private-Public Partnerships: An Integrated Community Engagement Model for Capturing Energy Access Needs' (2021) 74 *Energy Res Soc Sci* 101975.

specify inputs and provenance, summarise validation and calibration, define scenarios, state uncertainty, and include a clear explanation of limitations.⁸⁴ In higher-stakes contexts, it should also contain an independent audit or review statement.

The certified simulation report proposed here is not without comparative analogues. Environmental assessment systems already rely on documentary mechanisms that translate technical knowledge into legally reviewable form. Independent review of EIA quality, expert verification, audit statements and environmental compliance reports all perform a similar function: they do not eliminate uncertainty, but they make the basis of expert reliance visible. For example, the Netherlands Commission for Environmental Assessment provides independent advice on the scope and quality of environmental assessment reports and processes,⁸⁵ illustrating how external review can strengthen the credibility and completeness of environmental decision-making.⁸⁶ A certified simulation report would adapt this logic to digital twin outputs by requiring the modelling process, assumptions, uncertainty range and validation status to be placed in a form capable of legal scrutiny.

⁸⁴ A Goudge, 'Administrative Law, Artificial Intelligence, and Procedural Rights' (2021) 42 *Windsor Rev Legal Soc Issues* 17.

⁸⁵ Junati Ria Claudia Sibuea, 'Continuous Public Participation in Environmental Impact Assessment: A Comparative Study of Port Infrastructure Projects in the Netherlands and Indonesia' (PhD thesis, University of Iceland 2025) <https://tinyurl.com/8tmj48av> accessed 25 May 2026.

⁸⁶ Z El Haouat and Others, 'Development of a Global Framework for an Integrated Life Cycle Assessment (LCA) Model in Quality, Safety and Environmental (QSE) Management Systems: Improving Environmental, Social and Economic Sustainability Performance' (2025) 17(8) *Sustainability* 352

This is why certification should be understood as procedural certification, not a guarantee of scientific truth. The report should certify that the model output has been generated, documented and disclosed according to defined standards. It should not certify that the predicted environmental outcome will necessarily occur. This distinction is important because it preserves the legal separation between admissibility and evidentiary weight. The report brings the digital twin output into the administrative record, but the regulator must still decide how much reliance the output deserves in light of uncertainty, contestation and the seriousness of the regulatory consequence.

The key point is conceptual. The report does not certify that the model is correct. It certifies that the system and output have been documented in a way that permits legal scrutiny. In Nigeria, that helps satisfy the evidentiary formalities associated with computer-generated material and creates a reviewable record. In South Africa, it supports intelligibility, participation, and reasoned reliance. In both contexts, it supplies the documentary focal point through which contestability can be organised.

4. Governance, Data Rights, Validation, and Administrative Accountability

A digital twin is not merely a method; it is an ongoing system of environmental governance. That fact carries important legal consequences. A static model run for a single assessment can be

judged primarily by reference to its assumptions, method, and output. A twin, by contrast, depends on continuous data ingestion, periodic recalibration, institutional maintenance, quality control, access management, and threshold governance. It is therefore not enough to ask whether a twin output is admissible. One must ask who is responsible for the integrity of the system from which that output emerges.

4.1. Institutional custody and the problem of ownership

The first governance question is deceptively simple: who owns the twin? The answer is rarely straightforward. A digital twin may be co-developed by regulators, universities, private vendors, international organisations, and community actors.⁸⁷ It may sit technically on one platform and institutionally within another. It may rely on datasets controlled by multiple public bodies. In legal terms, “ownership” is often less important than custody and authority. Who is answerable for maintaining the twin, setting standards, approving updates, disclosing changes, and coordinating its use in decision-making?

Absent a clear answer, digital twins are likely to generate two opposite pathologies. One is institutional abandonment: the system is launched, perhaps through a pilot, but no public body has the sustained authority or budgetary responsibility to maintain it. The other is infrastructural capture: the system becomes operationally indispensable but is effectively controlled by private vendors or narrowly specialised technical actors whose incentives do not map

⁸⁷ Ibid.

cleanly onto public accountability. Both are inimical to lawful environmental governance.

The appropriate response is to create a custody structure rather than merely a project. This need not always take the form of a new institution. It could be a defined function within an existing environmental ministry, basin commission, municipal authority, or inter-agency platform. What matters is that there be a legally recognisable body responsible for standards, registry, audit coordination, disclosure protocols, and inter-agency data governance. Without that, no one is responsible for the integrity of the system when its outputs begin to shape decisions.

4.2. Data governance and the public character of environmental intelligence

Digital twins depend on data, but the legal meaning of that dependency is often misunderstood.⁸⁸ The relevant issue is not simply whether data are available. It is whether the legal framework governing access, control, and use is compatible with public decision-making. Environmental intelligence used in permitting or compliance cannot be governed entirely as if it were an ordinary private asset. Once it enters the justificatory structure of a public decision, transparency and review concerns are engaged.

⁸⁸OA Gbadegesin and S Akintola, 'Bridging the Governance Gap: A Case for an Indigenous Jurisprudential Framework for Genomic and Biobanking Research in Nigeria' (2025) Bioethical Inquiry <https://doi.org/10.1007/s11673-025-10463-2>

This does not mean that all environmental data should be fully open at all times. Some data may be commercially sensitive, security-sensitive, or linked to identifiable persons or communities. But it does mean that the law must distinguish between secrecy justified by legitimate protection and opacity that merely conceals the evidentiary basis of public action. At minimum, the public logic, threshold criteria, general assumptions, and explanatory basis of regulatory reliance must be disclosed in a meaningful way.

The issue becomes even more complicated where local knowledge, citizen observations, or community-generated data are involved.⁸⁹ These forms of input may improve the twin's responsiveness, but they also raise issues of consent, benefit-sharing, and data sovereignty. It is not enough to celebrate participatory sensing if the result is a system that uses local knowledge to support state or project decisions without giving affected communities meaningful control over how that knowledge is represented and deployed. This is particularly sensitive in contexts where environmental governance already suffers from legitimacy deficits.

4.3. Validation, auditing, and the temporality of trust

A static certification model is ill-suited to environmental twins. Continuous systems change, drift, and fail in ways that are often difficult to detect from the outside. Sensors degrade; weather patterns change; land-use conditions alter the relevance of earlier calibration; software interventions affect system outputs. For these reasons, trust

⁸⁹ Ibid

in a digital twin must be temporal rather than one-off. It must be earned and renewed.

The most workable approach is a tiered validation regime. Where a twin is used only to guide further inquiry or support low-stakes monitoring, a lighter form of validation may suffice: clear provenance, baseline testing, and disclosure of uncertainty. Where the twin is used to justify conditional permit obligations, the system should be periodically benchmarked against observed conditions, and those results should be reported. Where the twin is tied to regulatory triggers or enforcement-linked consequences, stronger requirements become necessary: external audit, incident reporting, change logs, and explicit rules for downgrading or suspending the model's trigger function when performance falls below threshold.

This is important because one of the greatest risks of digital governance is silent degradation. A model may continue to operate and even to produce visually persuasive outputs while gradually losing evidentiary reliability. Administrative law should not assume that operational continuity equals legal trustworthiness. Continuous reliance requires continuous governance.

Comparative practice also shows that successful use of digital environmental systems depends less on technological sophistication alone than on governance arrangements surrounding the technology. Destination Earth,⁹⁰ Virtual Singapore⁹¹ and Delft-FEWS⁹² each

⁹⁰Nativi, Mazzetti and Craglia (n 65).

illustrate, in different ways, that digital systems require institutional ownership, defined user access, maintenance responsibilities and procedures for updating information. Their usefulness depends on whether public authorities can understand, interrogate and explain the system's outputs. For Nigeria and South Africa, this means that digital twins should not be procured or adopted merely as software platforms. They should be governed as public decision-support infrastructures with clear rules on data custody, model updating, audit rights, public disclosure and institutional accountability.

This point is especially important where digital twins are supplied by private vendors or developed through donor-funded pilots. If the public authority lacks access to source data, change logs, validation records or model assumptions, it may become dependent on a system it cannot adequately explain. Such dependence is legally dangerous because environmental decisions must remain reviewable even when they are technically assisted. Procurement contracts and inter-agency agreements should therefore require interoperability, data portability, audit access and disclosure protocols. Without these safeguards, a digital twin may improve operational efficiency while weakening the legal transparency of environmental governance.

⁹¹Zhan, Hwang and Krishnankutty (n 68).

⁹²Cina and others (n 70).

4.4. Liability, duty of care, and review

The distribution of responsibility in digital twin systems is complex.⁹³ Permit holders remain responsible for compliance with environmental obligations. They cannot evade liability by blaming a model. But consultants, certifiers, system operators, and vendors may also be responsible in different ways. A consultant who negligently certifies a model, a vendor who conceals relevant system limitations, or an operator who fails to maintain calibration may all contribute to regulatory failure.

At the same time, regulators remain subject to public-law review. The presence of a sophisticated model does not relax the duty of reasoning. If anything, it intensifies it. A regulator that relies heavily on a twin output without explaining why that reliance was proportionate, how uncertainty was evaluated, or how affected parties could challenge the model is vulnerable to the charge that it has substituted technical opacity for legal justification.⁹⁴

This means that liability and accountability should be understood as layered rather than singular. Environmental responsibility remains with the regulated actor; professional responsibility may attach to those who design or certify the system; contractual responsibility may govern relationships with vendors and operators; and public-law accountability remains with the authority that uses the system to

⁹³ P Ghorbani Bam and others, 'Digital Twin Applications in the Water Sector: A Review' (2025) 17(20) *Water* 2957.

⁹⁴ W He, W Li and P Deng, 'Legal Governance in the Smart Cities of China: Functions, Problems, and Solutions' (2022) 14 *Sustainability* 9738

justify regulatory consequences. A robust framework makes each layer explicit rather than assuming that responsibility will sort itself out through practice.

4.5. Failure modes as design criteria

The most credible legal frameworks are built around predictable failure, not optimistic assumptions.⁹⁵ Digital twins in environmental governance are susceptible to a number of recurrent problems: incomplete datasets, geographically uneven measurement, false positives, false negatives, model drift, vendor dependence, weak public-sector capacity, and the translation of technical outputs into regulatory action without adequate scrutiny. These are not reasons to reject digital twins altogether. They are reasons to build legal safeguards before reliance deepens.

Such safeguards include interoperability requirements, audit rights, data portability, mandatory disclosure of model changes, plain-language explanations, rights of technical challenge, and explicit differentiation between informational and trigger-based uses. The more a legal framework internalises these risks, the less likely it is that digital twins will become sources of opaque administrative power.

⁹⁵ M Janssen and others, 'Data Governance: Organizing Data for Trustworthy Artificial Intelligence' (2020) 37(3) *Gov Inf Q* 101493.

5. Conclusion

Environmental digital twins are not legally valuable simply because they generate more data, richer visualisations, or more granular scenarios than conventional assessment tools. Their legal significance depends on whether environmental law can accommodate predictive, continuously updating, and probabilistic outputs without compromising the principles that make EIA legitimate: intelligibility, participation, accountability, and reviewability. The central claim of this article is therefore not that law must choose between innovation and regulation, but that it must distinguish between admissibility and evidentiary weight. A digital twin output may properly form part of the administrative record while remaining too uncertain, assumption-dependent, or weakly validated to support substantial regulatory reliance. The legal question is not whether such systems should be used at all, but under what conditions their use is justified.

The comparison between Nigeria and South Africa clarifies this point. In Nigeria, the main difficulties concern record formation, authentication, and the fit between dynamic model outputs and a report-based EIA framework. In South Africa, the more demanding issues lie in public justification, participatory fairness, and reasoned administrative reliance within a constitutional and administrative-law setting. The case studies further show that the legal issues are domain-specific, extending from shared authority in transboundary

basins to the incorporation of digital-twin logic through municipal procurement and operational infrastructures.

The appropriate legal response is therefore incremental but exacting. Digital twins should be mediated through certified simulation reports, differentiated validation standards, and explicit rules for post-authorisation use. The comparative examples also suggest that Nigeria and South Africa should approach digital twins incrementally. Existing international practice supports the use of digital systems for forecasting, planning and environmental decision-support, but it also shows that their legal value depends on institutional design. The central reform task is therefore not to import digital twins wholesale, but to create domestic legal pathways through which their outputs can be documented, challenged, reviewed and proportionately relied upon. Unless law disciplines their use tightly through requirements of auditability, institutional responsibility, liability, and reason-giving, they will merely reproduce familiar governance weaknesses in more technically complex form.