Sustaining GNSS CORS Networks through Structured Partnership and Governance Frameworks

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1. SUMMARY

Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) constitute foundational national geodetic and digital infrastructure. They underpin land administration, infrastructure development, agriculture, disaster risk reduction, climate monitoring, and a growing range of location-based public and private services. Despite their strategic importance, many GNSS CORS networks in low- and middle-income countries fail to achieve long-term sustainability. Repeated donor investments have often resulted in technically sound installations that deteriorate over time due to fragmented institutional ownership, insufficient operational funding, and weak integration into national policy and governance frameworks.

This paper argues that the sustainability challenge of GNSS CORS networks is systemic rather than technical. Drawing on case experience from Africa, Southeast Asia, and Latin America, it demonstrates that durable outcomes require the deliberate alignment of three interdependent elements: the layout of the CORS infrastructure, the governance arrangements that allocate responsibility and risk across the lifecycle, and the environment being political, institutional, economic, and human within which the system operates.

From an investment perspective, infrastructure layout defines the physical and digital architecture of national positioning capability, including station typology, standards compliance, redundancy, and integration with spatial data infrastructure. Governance determines whether this layout can be sustained over time through clear ownership, operational responsibility, quality assurance, and financing mechanisms. These arrangements must be adapted to the national environment, reflecting policy priorities, regulatory maturity, market demand for positioning services, workforce capacity, and geographic scale.

The paper examines a range of public, public–private, and hybrid partnership models, highlighting how cooperative and blended approaches can reduce donor risk while strengthening national ownership. A CORS Sustainability Matrix is introduced as a practical decision-support tool for structuring investments across the CORS lifecycle. Aligned with the UN-GGIM Integrated Geospatial Information Framework (IGIF) and the Global Geodetic Reference Frame (GGRF), the paper positions GNSS CORS as shared national infrastructure and calls for a shift from project-based funding toward long-term stewardship.

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2. INTRODUCTION: WHY CORS MATTER TO DEVELOPMENT FINANCE

Global Navigation Satellite System Continuously Operating Reference Stations form the geodetic backbone of national positioning capability. They underpin land administration, infrastructure development, agriculture, disaster risk reduction, climate monitoring, and an expanding range of digital public services that depend on accurate and reliable location information. As such, GNSS CORS networks function as enabling national infrastructure rather than as specialist technical assets confined to surveying or scientific communities.

Over the past two decades, governments, development banks, and international donors have invested significantly in the establishment of GNSS CORS networks in low- and middle-income countries. These investments have frequently succeeded in delivering technically sound installations that comply with international standards and, in some cases, contribute to regional or global reference frames. However, the long-term sustainability of many of these networks remains fragile. Operational performance often declines after initial project funding ends, services become intermittent, and institutional responsibility for ongoing operation weakens.

This recurring pattern indicates a structural problem in how GNSS CORS investments are conceived and financed. Too often, CORS initiatives are treated as discrete technology projects focused on equipment procurement and installation for one specific application. In doing so, insufficient attention is given to the institutional arrangements, financing mechanisms, and operating conditions required to sustain these systems over decades. As a result, countries remain dependent on repeated external interventions, while the underlying national positioning capability remains vulnerable.

This paper argues that the sustainability challenge facing GNSS CORS networks is systemic rather than technical. Drawing on international experience and selected country cases, it applies a three-part analytical lens focusing on i) (infrastructure) **layout**, ii) **governance** (arrangements), and iii) the (operating) **environment**. The purpose of this approach is to support investment decisions that align technical design with institutional responsibility and national context.

This perspective is consistent with international guidance given in the Integrated Geospatial Information Framework (IGIF) developed under the auspices of UN-GGIM. Particularly its emphasis on geodetic reference systems as foundational elements of national geospatial capability, the importance of clear institutional stewardship, and the alignment of geospatial investments with broader policy and development objectives. However rather than requiring engagement with the full framework, this paper draws selectively on these principles to frame GNSS CORS as long-lived national infrastructure requiring proactive stewardship beyond the lifecycle of individual projects.

3. GNSS CORS AS NATIONAL GEOSPATIAL (INFRASTRUCTURE) LAYOUT

From an investment perspective, the layout of a GNSS CORS network defines how national positioning capability is realised in practice. Layout encompasses the physical distribution of stations, their technical specifications, the communications and data processing infrastructure that supports them, and the integration of positioning services into national spatial data infrastructure (NSDI) and downstream applications. These elements together influence technical performance, operational complexity, and long-term viability.

GNSS CORS networks typically include stations designed for different functional purposes. High stability stations support national and regional reference frames and scientific applications, while other stations prioritise real time access for surveying, construction, agriculture, and infrastructure development. This tiered approach allows countries to balance scientific integrity with service accessibility when expectations and responsibilities are defined clearly at the design stage.

Beyond the stations themselves, CORS layout includes a broader technical ecosystem. Reliable power supply, communications connectivity, data processing platforms, quality control procedures, and metadata management are essential components of national positioning capability. Increasingly, these elements are complemented by cloud-based services and application interfaces that support integration with digital government platforms and private sector solutions. In this sense, GNSS CORS operate as enabling platforms rather than isolated installations within individual agencies.

Experience from donor-funded deployments shows that technical adequacy at commissioning does not guarantee sustained performance. Equipment lifecycles, software maintenance, calibration requirements, and cybersecurity obligations impose ongoing demands that extend beyond initial capital investment. Networks designed without explicit consideration of these lifecycle requirements often become operationally fragile over time, even when they meet international standards.

Understanding GNSS CORS as national infrastructure therefore requires a shift from project-oriented design toward lifecycle-oriented layout decisions. Choices related to station density, redundancy, interoperability, and standards compliance directly influence operational burden and long-term cost structures. These choices also constrain or enable different governance and financing models, shaping who can realistically operate, maintain, and evolve the network over time.

4. THE SUSTAINABILITY CHALLENGE: WHY CORS NETWORKS DEGRADE OVER TIME

Despite their recognised importance, GNSS CORS networks in many low- and middle-income countries exhibit a recurring pattern of decline after initial deployment. Stations that function reliably during project implementation often experience reduced availability, declining data quality, or complete service interruption within a few years. This outcome is widely documented across regions and persists despite repeated donor investment (UN-GGIM, 2020).

A primary contributor to this pattern is the imbalance between capital investment and long-term operational commitment. Installation costs and equipment procurement are typically well defined and funded, while ongoing expenses related to power, communications, software maintenance, calibration, and skilled personnel are underestimated or left unfunded beyond the project horizon. When operational funding competes with other public sector priorities, CORS networks are frequently deprioritised due to their enabling and indirect nature and often their perceived technical complexity.

Institutional fragmentation further compounds these challenges. Responsibility for GNSS CORS infrastructure is often distributed across multiple agencies, including national mapping organisations, land authorities, scientific institutions, and ministries responsible for infrastructure or digital transformation. In the absence of a clearly designated steward with authority and resources, coordination weakens and accountability for long-term performance erodes.

Human capacity constraints represent another persistent vulnerability. GNSS CORS networks require sustained expertise in geodesy, information technology, quality assurance, and systems management. In many countries, these skills are scarce and concentrated in a small number of individuals. Without structured approaches to training and knowledge retention, operational capability diminishes over time.

Regulatory and policy conditions also influence sustainability outcomes. Unclear data access policies, absence of licensing frameworks for value added services, and weak integration with national spatial strategies can limit demand for positioning services and constrain opportunities for cost recovery. Where GNSS CORS are not recognised as shared national infrastructure, their potential contribution across sectors remains underutilised.

Taken together, these factors show that sustainability challenges arise from misalignment between infrastructure design, governance arrangements, and the operating context rather than from technical inadequacy alone.

5. GOVERNANCE MODELS FOR SUSTAINABLE CORS INVESTMENT

Governance determines whether GNSS CORS networks function as durable national infrastructure or remain dependent on repeated external intervention. While infrastructure layout defines what is built, governance defines who is responsible for continued operation, how decisions are made, and how long-term obligations are recognised and met. For development banks and national governments, governance therefore represents one of the primary sources of both investment risk and institutional resilience.

In many GNSS CORS initiatives, governance has been addressed implicitly rather than designed deliberately. Responsibilities for ownership, operation, quality control, and financing are frequently distributed across institutions without a shared understanding of authority or accountability. This fragmentation weakens decision making and increases vulnerability to changes in funding priorities or institutional leadership. Over time, the absence of clear governance arrangements undermines system performance even when technical design is sound.

Effective governance for GNSS CORS networks must achieve several functions across the full lifecycle of the infrastructure, in particular they must:

- establish a clear institutional mandate that recognises positioning infrastructure as a national responsibility rather than as a discretionary technical service;
- ensure continuity of operations through predictable arrangements for funding, staffing, and maintenance;
- protect standards and data integrity in order to sustain trust and interoperability across sectors; and
- provide mechanisms for coordination among public institutions and for engagement with private operators where appropriate.

Experience across countries suggests that these functions are rarely performed by a single organisation. Instead, sustainable governance typically emerges through the interaction of multiple institutional roles. At the national level, legal and policy frameworks provide authority and legitimacy by embedding GNSS CORS within broader spatial or digital strategies. Strategic coordination bodies translate this mandate into priorities for investment, standards, and cross sector alignment. Operational entities carry responsibility for network performance, quality assurance, and service continuity. Users across government and the private sector generate demand and provide feedback that link infrastructure performance to wider societal value.

Public private partnerships (PPP) are often introduced as a means of strengthening governance and operational capacity. Their effectiveness depends on how well they are aligned with these institutional roles. Public ownership models can safeguard standards and public interest objectives, but they often struggle to secure stable long term operational funding. Fully commercial models can deliver efficiency and innovation, but they may prioritise profitable markets over national coverage or public services for citizens. Hybrid arrangements that combine public stewardship with private operational capability can offer greater resilience when roles and responsibilities are clearly defined and aligned with lifecycle obligations.

Partnerships alone do not compensate for weak institutional foundations. Where mandates are unclear or regulatory frameworks incomplete, the introduction of private actors can increase complexity rather than reduce risk. Governance arrangements must therefore precede partnership design and provide a stable framework within which different delivery models can operate.

From a development finance perspective, governance maturity is a stronger predictor of long-term sustainability than ownership structure. Investments that embed clear stewardship roles, stable operational responsibility, and mechanisms for accountability are more likely to endure beyond the initial funding period. This understanding is consistent with international guidance on geospatial infrastructure, including the emphasis placed by UN-GGIM on institutional clarity and cross sector coordination as foundations for sustainable national geospatial capability.

In this sense, governance should be understood as an enabling system rather than as a contractual arrangement. It creates the conditions under which infrastructure layout can be sustained and adapted, and within which the broader operating environment can be engaged productively. Recognising governance in this way is essential for governments and donors seeking to move from project delivery toward long term stewardship of national positioning infrastructure.

6. THE (ENABLING) ENVIRONMENT FOR SUSTAINABLE CORS NETWORKS

Infrastructure layout and governance arrangements do not operate in isolation. They function within a wider set of conditions that shape what is feasible, affordable, and sustainable over time. For GNSS CORS networks, these conditions form an enabling environment that influences how infrastructure is valued, how institutions behave, and how services evolve. Development banks and national governments therefore need to assess not only what is built and who is responsible, but also whether the surrounding environment can support long term operation and adaptation.

The enabling environment encompasses policy and institutional settings, economic conditions, technical operating realities, human capacity, and geographic context. These elements do not merely form a backdrop to infrastructure investment. They actively shape how governance arrangements perform and whether infrastructure layouts can deliver sustained public value. Where these conditions are misaligned with governance and layout choices, sustainability risks are transferred downstream into operations and renewal, where corrective action is more difficult and costly.

Policy and institutional alignment provide an essential foundation for durability. Where GNSS CORS are explicitly embedded within national geospatial strategies, land administration reform programmes, or digital government agendas, their role as shared infrastructure is more readily recognised. This recognition strengthens political legitimacy and supports continuity across budget cycles and institutional change. International guidance developed under the auspices of UN-GGIM reinforces this perspective by positioning geodetic reference systems as foundational components of national geospatial capability rather than as stand-alone technical systems. In contrast, where such alignment is absent, CORS networks are more vulnerable to marginalisation and institutional restructuring.

Economic conditions shape both the cost burden of GNSS CORS networks and the range of sustainability options available. While core geodetic functions serve the public interest, many downstream applications such as surveying, construction, agriculture, and infrastructure monitoring generate demand for real time positioning services. In contexts where these sectors are active and well regulated, this demand can support partial cost recovery or private sector participation. Where demand is weak or poorly understood, networks remain dependent on public or donor funding, increasing long term fiscal exposure. Assessing the economic environment therefore requires attention to both current market conditions and the potential for future uptake as positioning services become embedded in national workflows through effective donor coordination and adoption by cross-sector applications.

Technical operating conditions exert a strong influence on sustainability outcomes. Reliable power supply, communications connectivity, data management capability, station security and cybersecurity arrangements vary widely across countries and regions. These conditions directly affect operational complexity and cost. Networks designed without regard for these realities often experience service instability and escalating maintenance burdens over time. Practical experience from national operators highlights the importance of aligning technical design choices with operating conditions rather than assuming ideal infrastructure environments.

Human capacity represents another critical component of the enabling environment. GNSS CORS networks require sustained expertise in geodesy, information technology, quality assurance, and systems management. In many countries, this expertise is scarce and concentrated in a small number of individuals. Without structured approaches to training, career development, and institutional knowledge retention, operational capability erodes gradually. Reliance on external consultants may address short term gaps but rarely builds durable national capacity. Case experience from national geodetic programmes underscore the importance of embedding capacity development within operational models rather than treating it as a temporary project activity.

Geographic scale and spatial context further shape sustainability considerations. Large or geographically diverse countries face different coverage, redundancy, and cost challenges than smaller or more compact nations. Exposure to natural hazards such as seismic activity or extreme weather also influences infrastructure design and operational resilience. Recognising these spatial realities allows governance and layout decisions to be tailored appropriately rather than applied uniformly across contexts.

Taken together, these environmental conditions determine whether governance arrangements can function as intended and whether infrastructure layouts can be sustained over time. Ignoring them does not remove risk but displaces it into later stages of the lifecycle. Explicit consideration of the enabling environment is therefore essential for development banks and governments seeking to design GNSS CORS investments that remain viable beyond the initial funding period and capable of adaptation as national needs evolve.

7. INTEGRATING LAYOUT, GOVERNANCE, AND ENVIRONMENT ACROSS THE CORS LIFECYCLE

Sustainable GNSS CORS outcomes depend not only on the quality of individual design decisions, but on how infrastructure layout, governance arrangements, and the enabling environment are considered together across the full investment lifecycle. Many CORS initiatives struggle because early decisions are made in isolation, with technical design, institutional responsibility, and contextual conditions addressed sequentially rather than as interdependent concerns. When these dimensions are misaligned at the outset, sustainability risks are embedded into the system and become increasingly difficult to correct over time.

At the initial diagnostic stage, the purpose of GNSS CORS investment must be situated within national development priorities rather than defined narrowly in technical terms. Layout considerations at this stage concern the role that positioning infrastructure is expected to play in land administration, infrastructure delivery, disaster risk reduction, climate services, or digital government. Governance assessment should identify existing institutional mandates related to geodesy and positioning, the degree of coordination between responsible bodies, and the extent to which stewardship responsibility is clearly assigned. Environmental analysis should consider policy alignment, market demand, technical operating constraints, human capacity, and geographic scale. Diagnostic work that neglects any of these dimensions often leads to technically ambitious designs that exceed institutional or operational capacity.

During feasibility and investment design, the interaction between layout, governance, and environment becomes more explicit. Decisions regarding station density, redundancy, communications architecture, and data processing platforms directly influence lifecycle cost and operational complexity. These choices must be assessed alongside governance arrangements that define ownership, operational responsibility, quality assurance authority, and funding mechanisms. Partnership options, including public private and cooperative models, are most effective when selected at this stage based on functional requirements and risk allocation rather than as default policy instruments. Environmental conditions should inform both technical and institutional design choices, shaping realistic expectations for performance, cost recovery, and capacity development.

Procurement and deployment translate design intent into operational reality. Technical specifications that prioritise interoperability, standards compliance, and adaptability support long term sustainability more effectively than solutions optimised solely for initial performance. Governance arrangements are operationalised through procurement by embedding accountability for maintenance, data integrity, and service continuity into contractual and institutional agreements. Where private operators are involved, clear distinction between public interest functions such as reference frame integrity and commercial service delivery responsibilities reduces ambiguity and conflict.

The operational phase reveals the cumulative consequences of earlier decisions. Layout choices determine maintenance burden, upgrade requirements, and resilience to disruption. Governance effectiveness becomes visible through the stability of operational funding, clarity of authority, and consistency of quality assurance. The enabling environment continues to evolve, influencing staffing stability, policy priorities, and user demand. Networks designed without capacity for adaptation often experience gradual service degradation as conditions change and institutional attention shifts.

Over time, GNSS CORS networks require renewal, expansion, and integration with emerging digital infrastructure and applications. At this stage, layout considerations relate to scalability, interoperability, and the ability to support new use cases without undermining core geodetic functions. Governance arrangements must support reinvestment, institutional learning, and continuity beyond individual projects or leadership cycles. Improvements in the enabling environment, including growth in demand and skills, can then be leveraged to strengthen sustainability and reduce reliance on external support. This progression aligns with international guidance that emphasises long term stewardship of geodetic infrastructure as a core component of national geospatial capability.

Integrating layout, governance, and environment across the GNSS CORS lifecycle therefore shifts investment practice from episodic project delivery toward coherent infrastructure development. For development banks and national governments, this integrated perspective provides a practical basis for aligning technical ambition with institutional reality and for maximising long term public value from positioning infrastructure investments.

8. CASE STUDIES: EVIDENCE FROM PRACTICE

Experience across countries demonstrates that the long-term performance of GNSS CORS networks is shaped less by technical sophistication than by the alignment of infrastructure layout, governance arrangements, and the enabling environment. While national contexts differ, recurring patterns emerge that are directly relevant to development bank investment decisions. The cases discussed here are not presented as exhaustive national profiles, rather they are used to illustrate how different configurations perform over time and where sustainability risks tend to concentrate.

Ghana provides an example of strong public sector leadership combined with a gradual search for sustainable operational models. National investment supported the deployment of a GNSS CORS layout aligned with land administration and surveying needs, establishing credibility and technical legitimacy. Governance responsibility has remained largely within public institutions, supporting standards compliance and national coordination. Over time, however, operational funding pressures and increasing demand for real time positioning services have prompted interest in partnership arrangements that can diversify revenue sources and strengthen service delivery. This experience illustrates how public ownership can establish authority while still requiring adaptive governance to sustain operations as demand and expectations grow.

Uganda reflects a pattern common to many donor supported deployments. Investment focused on establishing foundational geodetic capability through technically sound infrastructure, often with strong external technical assistance. While this approach improved national positioning capability, governance responsibility for ongoing operation and maintenance has been distributed across institutions with limited coordination. Human capacity constraints and reliance on project-based funding have increased vulnerability once external support diminishes. This case highlights how sustainability risks persist when governance design and capacity development are not integrated into investment planning from the outset.

Indonesia illustrates the potential of hybrid governance arrangements in a large and diverse operating environment. Public institutions retain authority over reference frames, standards, and data integrity, safeguarding national and international obligations. At the same time, private and sector specific actors contribute to service delivery and innovation in response to user demand. Infrastructure layout differentiates between reference grade stations and service-oriented networks, allowing investment and operational effort to be matched to function. A broad user base across construction, infrastructure, and agriculture has supported demand for positioning services and enabled partial cost recovery. This configuration demonstrates how deliberate separation of public interest and service delivery functions can support scalability when governance roles are clearly articulated.

Kenya represents a transition from project driven deployment toward institutional consolidation. Initial GNSS CORS investments were closely linked to specific land and infrastructure initiatives, with layout decisions driven by immediate project requirements. Over time, attention has shifted toward integrating positioning infrastructure into national spatial strategies and clarifying stewardship responsibilities. This transition illustrates the importance of revisiting governance and environmental assumptions as GNSS CORS move from pilot installations toward permanent national services.

Brazil provides contrast through a relatively mature geospatial ecosystem. GNSS CORS infrastructure is embedded within established technical institutions and supported by a large professional user community. Governance arrangements benefit from recognised standards, professional bodies, and coordination mechanisms across agencies. While regional variation and operational challenges remain, the broader enabling environment supports sustained operation and incremental evolution. This case illustrates how favourable environmental conditions can compensate for governance complexity, although such conditions cannot be assumed in lower capacity contexts.

Across these cases, several consistent observations emerge.

- Technically robust infrastructure layout is necessary but does not ensure sustainability.
- Early emphasis on installation without parallel attention to governance and the enabling environment increases long term risk.
- Hybrid governance models tend to perform better where public interest functions and service delivery roles are clearly distinguished.
- Market demand and human capacity strongly influence the feasibility of cost recovery and private participation.
- Countries that treat GNSS CORS as permanent national infrastructure demonstrate greater resilience than those that approach them as time-bound projects.

In summary, these observations reinforce the central argument of this paper. Sustainable GNSS CORS outcomes depend on deliberate alignment of layout, governance, and environment across the investment lifecycle. Case experience shows that where this alignment is achieved, GNSS CORS networks are more likely to evolve from project funded installations into resilient components of national geospatial ecosystems.

9. THE CORS SUSTAINABILITY MATRIX: A DONOR DECISION TOOL

As GNSS CORS investments move from diagnosis toward design and implementation, decision makers require a way to integrate technical, institutional, and contextual considerations into a coherent view. The CORS Sustainability Matrix introduced here responds to this need by bringing together infrastructure layout, governance arrangements, and the enabling environment within a single analytical framework. The matrix does not function as a scoring tool or maturity model. Its purpose is to make alignment and misalignment visible and to support informed judgment across the investment lifecycle.

The matrix is structured around three interdependent dimensions. The layout dimension captures the configuration of physical and digital infrastructure, including station typology, network density, redundancy, standards compliance, communications architecture, and integration with national spatial data infrastructure. These choices shape technical performance, operational burden, and lifecycle cost. The governance dimension focuses on institutional responsibility across ownership, stewardship, operations, quality assurance, and financing. It considers how authority is distributed, how accountability is maintained, and how continuity is secured over time. The environment dimension reflects the broader conditions within which layout and governance operate, including policy alignment, regulatory maturity, market demand, human capacity, and geographic scale.

Individually, each of these dimensions is familiar to practitioners and donors. What the matrix adds is an explicit focus on their interaction. Sustainability challenges rarely originate from weakness in a single dimension alone. More commonly, they arise when strength in one area masks fragility in another. Robust technical layouts can obscure weak governance. Strong individual expertise can compensate temporarily for missing institutional arrangements. Favourable market conditions can conceal deficiencies in policy or regulation. The matrix provides a structured way to surface these compensations and to assess whether they can be relied upon over time.

Applied at the diagnostic stage, the matrix supports realistic assessment of national readiness. It helps identify situations where technical ambition exceeds institutional capacity or where governance expectations are misaligned with the operating environment. In such cases, the matrix encourages adjustment of scope, sequencing, or investment focus before commitments are locked in. This early use is particularly relevant for development banks seeking to balance development impact with fiduciary responsibility.

During feasibility and investment design, the matrix supports comparison of alternative configurations. Different combinations of layout and governance can be examined against environmental conditions to understand how risk and responsibility are distributed. For example, higher density networks with sophisticated service offerings may be viable where market demand and capacity are strong, but they may be inappropriate in contexts with limited operational skills or unstable funding. The matrix allows these trade-offs to be explored explicitly rather than implicitly assumed.

During implementation and operation, the matrix functions as a reference point for monitoring alignment over time. Changes in policy priorities, institutional leadership, staffing, or market demand can be assessed against the original assumptions that informed the design. Where misalignment emerges, the matrix provides a basis for targeted adjustment rather than reactive intervention. This use recognises that sustainability is not achieved at commissioning but maintained through continuous attention to institutional and environmental change.

Repeated application of the matrix across countries and projects reveals a limited number of recurring sustainability trajectories. Some configurations remain donor dependent, characterised by technically sound layouts combined with weak governance and constrained environments. These systems tend to rely on repeated external support and experience declining performance once projects close. Other configurations evolve toward blended arrangements, where public institutions retain stewardship of core geodetic functions while private or cooperative actors contribute to service delivery. Where governance roles are clear and demand exists, such arrangements can stabilise operations and reduce fiscal pressure. A smaller number of cases demonstrate consolidation toward self-sustaining operation, supported by mature governance and favourable environments that enable reinvestment and adaptation over time.

For development banks, the value of the matrix lies in its ability to link technical design choices to institutional and contextual risk. It supports due diligence that extends beyond capital expenditure to consider stewardship, capacity development, and long-term viability. For national governments, it provides a shared language for coordination across ministries, regulators, and service providers. This approach aligns with international guidance that emphasises institutional clarity, cross sector coordination, and long-term stewardship as foundations for national geospatial capability, including principles articulated through UN-GGIM.

By making sustainability conditions explicit, the CORS Sustainability Matrix (as in Table 1) shifts attention from short term delivery toward long term stewardship. It enables GNSS CORS investments to be conceived, designed, and managed as durable national infrastructure capable of evolving with changing technologies, policy priorities, and user needs.

The CORS Sustainability Matrix integrates infrastructure layout governance arrangements and enabling environment to support assessment and design of sustainable GNSS CORS investments. It highlights how technical design institutional responsibility and contextual conditions interact to shape long term outcomes across the CORS lifecycle. The matrix is intended as a decision support tool for development banks and governments rather than a scoring instrument.

ANALYTICAL LENS	LAYOUT	GOVERNANCE	ENVIRONMENT
Primary focus	Infrastructure design and technical architecture that enable national positioning capability	Institutional responsibility for stewardship coordination and long-term operation	Conditions that shape feasibility durability and adaptation over time
Key design levers	Station typology and density Standards compliance and interoperability Redundancy and resilience Integration with national spatial data infrastructure	Ownership and stewardship mandate Operations and maintenance responsibility Quality assurance authority Financing mechanisms including partnerships	Policy alignment and legal recognition Regulatory maturity Market demand for positioning services Human capacity and skills availability Geographic scale and exposure
Typical risks	Over specification relative to capacity Under investment in lifecycle support Vendor dependence High operational burden	Fragmented institutional mandates Unfunded operations and maintenance Weak accountability mechanisms Short term budgeting cycles	Political volatility Limited skills pipelines Weak or uncertain demand Connectivity and power constraints
Common failure patterns	Technically sound networks that become operationally fragile over time	Absence of a clear steward able to sustain the system	Infrastructure exists but cannot scale or adapt to changing needs
Mitigation approaches	Tiered network design matched to function Lifecycle cost modelling Standards based and modular architecture	Hybrid governance arrangements Ring fenced operational funding Performance based accountability Cross sector coordination	Capacity development embedded in operations Policy embedding within national strategies Market stimulation and user engagement Regional cooperation
Sustainability trajectory	Transition from project-based installation toward scalable national infrastructure	Transition from informal control toward institutional stewardship	Transition from constraining conditions toward an enabling operating context

Table 1. CORS Sustainability Matrix

10. INVESTMENT PATHWAYS AND STRATEGIC RECOMMENDATIONS

The preceding analysis shows that sustainable GNSS CORS outcomes do not emerge randomly. They follow a limited number of recurring investment pathways shaped by how infrastructure layout, governance arrangements, and the enabling environment are aligned over time. Recognising these pathways allows development banks and national governments to design interventions that reduce long term risk and increase the durability of public value created through geodetic investment.

A first pathway – **Project-based Deployment** – is characterised by donor-led deployment with limited institutional consolidation. In this configuration, investment focuses on establishing technically robust CORS infrastructure to meet immediate project or programme objectives, often linked to land administration reform or infrastructure delivery. Governance responsibility remains fragmented or weakly defined, and long-term operational funding is uncertain. While this pathway can deliver short term development outcomes and may be appropriate in low-capacity contexts, experience shows that it carries high sustainability risk unless accompanied by deliberate measures to strengthen stewardship, coordination, and operational capability. Without such measures, networks tend to deteriorate once project support ends, leading to repeated cycles of reinvestment rather than cumulative capability building.

A second pathway – **Blended Stewardship** – reflects the emergence of blended investment approaches. Here, public institutions retain stewardship of core geodetic functions, including reference frame integrity, standards, and regulatory oversight, while operational roles or service delivery functions are shared with private or cooperative actors. This configuration can stabilise operations and introduce performance incentives when market demand exists and governance roles are clearly articulated. Evidence from multiple national contexts suggests that blended arrangements can reduce fiscal pressure and improve service reliability when they are grounded in realistic assessments of demand, capacity, and risk allocation. Where these conditions are absent, however, blended models can amplify governance complexity rather than resolve it.

A third pathway – **Fully Institutional** – represents longer term consolidation toward self-sustaining operation. In this configuration, GNSS CORS infrastructure is embedded within national spatial strategies and supported by mature governance arrangements and a favourable enabling environment. Layout decisions support scalable service delivery and interoperability. Governance arrangements are institutionalised and resilient to leadership change. Demand for positioning services across sectors contributes to ongoing operation, renewal, and incremental expansion. While this pathway is not immediately attainable in many contexts, it provides a strategic direction against which progress can be measured and toward which incremental investments can be oriented.

For development banks, these pathways carry several strategic implications.

- First, GNSS CORS should be treated as long-lived national infrastructure rather than as discrete technology projects. Investment appraisal should therefore extend beyond installation costs to include stewardship arrangements, lifecycle funding, and institutional continuity.
- Second, governance design should be addressed explicitly at early stages, alongside technical feasibility. Clear stewardship mandates and accountability mechanisms reduce downstream risk more effectively than retrofitted solutions.
- Third, partnership models should be selected as instruments to support governance and service delivery rather than as objectives in themselves. Their suitability depends on alignment with national capacity, regulatory maturity, and market conditions.
- Fourth, capacity development should be integrated into operational models to reduce long term dependence on external expertise and to support institutional learning.

Alignment with national geospatial strategies and international guidance strengthens both legitimacy and sustainability. Principles promoted through UN-GGIM emphasise the importance of institutional clarity, cross sector coordination, and stewardship of foundational geospatial infrastructure. When GNSS CORS investments are framed within this broader context, they are more likely to attract sustained political support and to deliver value beyond the lifespan of individual projects.

For national governments, these pathways highlight the importance of positioning GNSS CORS as shared infrastructure serving multiple sectors. Clear assignment of responsibility, coordination across institutions, and recognition of long-term public value are essential for translating donor support into durable national capability. Where these conditions are present, GNSS CORS networks are more likely to evolve from project driven installations into resilient components of national geospatial ecosystems.

11. CONCLUSION: FROM PROJECTS TO STEWARDSHIP

GNSS CORS networks underpin national positioning capability and enable a wide range of public and private sector activities that depend on reliable location information. Their importance extends well beyond surveying and geodesy to include land administration, infrastructure development, agriculture, disaster risk reduction, and climate related services. Despite sustained investment by governments and development partners, the long-term sustainability of many GNSS CORS networks in low- and middle-income countries remains fragile. This paper has shown that this fragility cannot be understood or addressed through technical considerations alone.

By examining GNSS CORS through the combined lenses of infrastructure layout, governance arrangements, and the enabling environment, the paper has reframed sustainability as a systemic and institutional challenge.

- **Infrastructure** layout establishes the technical configuration of positioning capability and shapes lifecycle cost and operational complexity.
- **Governance** arrangements determine whether this capability can be stewarded over time through clear mandates, accountability, and financing.
- The enabling **environment** influences how governance and layout perform in practice through policy alignment, economic conditions, technical realities, human capacity, and geographic context.

Where these elements are misaligned, sustainability risks are embedded into the system and become increasingly difficult to correct once infrastructure is in place.

Evidence from international experience and country cases demonstrates that investments focused primarily on installation and equipment procurement are unlikely to deliver durable outcomes. Networks delivered through such approaches often experience declining performance once project funding concludes, leading to renewed dependence on external support and repeated cycles of reinvestment. In contrast, investments that integrate governance design, capacity development, and contextual awareness from the outset show greater resilience and a stronger ability to adapt as national needs evolve.

For development banks and international financing institutions, these findings carry important implications. Supporting GNSS CORS as shared national infrastructure requires a shift from project-oriented delivery toward stewardship-oriented investment. This shift involves embedding lifecycle thinking into appraisal and design, recognising operational capability as a core investment requirement, and aligning geodetic infrastructure with broader national spatial strategies. Such an approach strengthens fiduciary assurance while increasing the likelihood that positioning infrastructure will continue to deliver public value beyond the lifespan of individual projects.

For national governments, the analysis reinforces the importance of clear institutional responsibility and sustained coordination across sectors. Treating GNSS CORS as permanent national infrastructure rather than as time bound initiatives strengthens the case for predictable funding, institutional learning, and long-term planning. Where governance arrangements support continuity and adaptation, and where the operating environment enables demand and capacity to grow, GNSS CORS networks are more likely to evolve into resilient components of national geospatial ecosystems.

The CORS Sustainability Matrix introduced in this paper provides a practical means of translating these insights into decision making. By making alignment and misalignment across layout, governance, and environment explicit, it supports more informed investment design, risk assessment, and adaptive management. Its value lies not in prescribing a single model, but in helping governments and donors understand the conditions under which different configurations are likely to succeed or fail.

Ultimately, the success of GNSS CORS investments should be judged not by the number of stations deployed or the sophistication of the technology installed, but by the continued ability of national positioning infrastructure to deliver reliable services over decades. Achieving this outcome requires deliberate alignment between technical design, institutional stewardship, and operating context. Development banks, governments, and the geospatial community are well positioned to advance this shift in practice and, in doing so, to strengthen the long-term public value of foundational geodetic infrastructure in support of sustainable development, consistent with principles articulated through UN-GGIM.

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