# Systems Thinking for Sustainable National Land-Use Data Governance: Practitioner Insights from CATWOE Analysis and Causal Loop Diagramming in South Africa

**Bulelwa SEMOLI, South Africa**

**Key words**: Land-use data governance, Systems thinking, CATWOE analysis, Causal Loop Diagramming, Spatial Data Infrastructure

## 1. SUMMARY

The development of authoritative national land-use data in South Africa remains an unresolved challenge despite enabling legislation, established geospatial standards, and demonstrated technical capacity. This paper argues that the gap reflects a governance and institutional learning challenge rather than a purely technical deficiency. Adopting a systems thinking perspective, the study applies Customers, Actors, Transformation, Worldview, Owner, and Environmental constraints (CATWOE) analysis and causal loop diagramming (CLD) to examine institutional worldviews, governance dynamics, and feedback mechanisms shaping land-use data governance within South Africa's spatial information system. Drawing on qualitative evidence from practitioner experience, policy analysis, and institutional mapping, the study identifies the absence of a shared transformation logic linking land cover to land use as a central constraint. CATWOE reveals divergent interpretations across planning and geospatial institutions, resulting in contested ownership, weak accountability, and fragmented responsibility. The CLD shows that strengthening reinforcing feedback can build institutional demand and stimulate sustained investment in standards and capability, enabling a shift away from fragmented governance patterns.

The paper further highlights the role of national and international standards SANS 1877-2:2025, SANS 19144-2:2014 (LCML) and ISO/TS 19144-3:2024 (LUML) as boundary spanning governance mechanisms that can align land-cover observation with policy-relevant land-use interpretation within SPLUMA and the Spatial Data Infrastructure framework. The findings indicate that standards based, systems aware integration of land cover and land use is essential for coherent spatial planning and credible reporting on Sustainable Development Goal (SDG) indicators, including SDG 11.3.1, SDG 15.3.1, and SDG 13, and offer transferable insights for strengthening land-use data governance in complex multilevel environments.

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## 2. INTRODUCTION

Effective spatial planning and sustainable development depend on access to authoritative, consistent, policy relevant national land-use information to support development control, infrastructure investment, environmental management, climate adaptation, and reporting obligations. Yet many countries with complex, multilevel governance arrangements struggle to develop and sustain coherent national land-use datasets. In South Africa, this challenge persists despite advanced geospatial capability and a relatively mature Spatial Data Infrastructure (SDI): national land cover data is standardised and institutionalised, but land-use information remains fragmented, inconsistently interpreted, and weakly integrated into planning and governance. This gap reflects systemic governance issues overlapping mandates, contested meanings, and misalignment between planning and geospatial frameworks. Therefore, this study uses qualitative evidence from practitioner experience, policy analysis, and institutional mapping to examine the underlying dynamics.

To visualise this complexity, the study first developed a rich picture (figure 1). In Soft Systems Methodology (SSM), Rich Pictures are diagnostic devices used to explore complex, ill-structured problem situations (Checkland, 2000). It offers a non-linear, intuitive representation of the situation of concern, emphasizing interactions, perspectives, and systemic dynamics. The illustration reveals a fragmented institutional landscape in which multiple government spheres, national custodians, provincial actors, and local planners operate with divergent assumptions, disconnected processes, and limited feedback mechanisms. It depicts parallel data production efforts, blurred ownership, inconsistent standards, and uncoordinated reporting responsibilities within South Africa's land-use data governance landscape. This diagnostic exercise suggests that technical coordination alone is insufficient without addressing systemic misalignments and institutional worldviews.

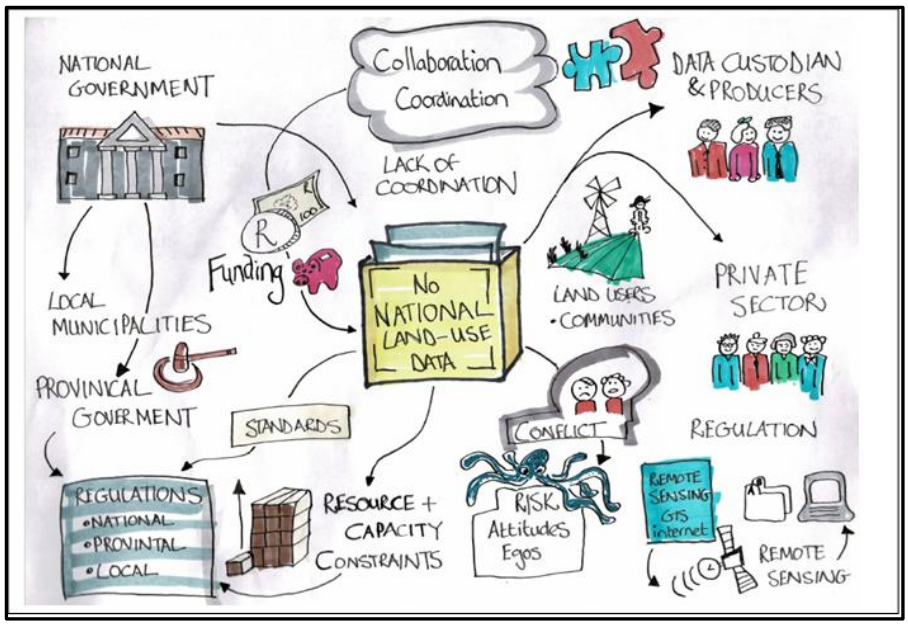


Figure1: Rich Picture of South Africa's land-use data Governance landscape

Building on this diagnostic baseline, CATWOE is then applied to surface how different stakeholders interpret the purpose, ownership, and value of national land-use data, clarifying the competing worldviews that shape governance choices. The CLD translates these interpretive differences into system behaviour by mapping causal relationships and feedback loops that explain why fragmentation persists and where reinforcing pathways could be strengthened to generate demand and improvement over time.

## 3. NATIONAL LAND-USE DATA GOVERNANCE IN SOUTH AFRICA

The national land-use data governance in South Africa is embedded within a complex, multi-level legislative and institutional framework, primarily shaped by the Spatial Planning and Land-Use Management Act (SPLUMA) and the Spatial Data Infrastructure (SDI) Act. Collectively, these statutes establish the formal architecture through which land-use information is generated, managed, and applied across national, provincial, and local government spheres. However, while both frameworks are integral to spatial planning and development, they operate according to distinct logic and priorities, creating structural tensions in the governance of national land-use data.

SPLUMA provides a national framework for integrated spatial planning, land-use management, and development control, positioning local government as the primary implementing authority for land-use decisions. Municipalities are tasked with preparing Spatial Development Frameworks (SDFs), managing land-use schemes, and administering zoning and development approvals, all of which require reliable, consistent, and up-to-date land-use information. Within SPLUMA's logic, land-use data functions as a decision-support and regulatory instrument, supporting objectives such as spatial justice, sustainability, efficiency, and spatial transformation. Yet, despite this reliance, SPLUMA does not explicitly designate responsibility

for producing authoritative national land-use datasets. This omission has resulted in uneven practices across municipalities, variable interpretation of land-use categories, and limited aggregation of local data into a coherent national perspective.

Conversely, the SDI Act establishes the governance framework for coordinating, standardising, and disseminating spatial information within South Africa's national geospatial system. It has been particularly effective in structuring the production and governance of national land cover datasets through clear custodianship arrangements, adoption of standards, and interoperability mechanisms. However, its emphasis on technical coherence and data management has not been fully reconciled with the interpretive and regulatory nature of land-use data required by spatial planning practice.

In the systems perspective, SPLUMA and the SDI Acts function as interdependent yet weakly coupled subsystems. SPLUMA generates demand for land-use information particularly at the local government level, while the SDI Act structures the supply of spatial data. Limited alignment between these frameworks perpetuates ambiguity regarding ownership, accountability, and transformation logic for national land-use data. In this study, both Acts are treated as structural elements shaping institutional behaviour, incentives, and learning, examined through CATWOE and CLD to explain persistence and identify demand-generating leverage points.

## 4. METHODOLOGY: APPLICATION OF CATWOE AND CAUSAL LOOP DIAGRAMMING

The persistent absence of authoritative national land-use data in South Africa constitutes a complex socio-institutional governance challenge rather than a purely technical problem. From a systems theory perspective, such challenges are characterised by multiple interacting actors, overlapping mandates, contested meanings, and feedback driven behaviours that reinforce existing patterns over time (Sterman, 2000). Systems thinking provides an analytical lens that foregrounds interaction, feedback, and learning, enabling examination of how governance arrangements themselves generate persistent outcomes (Meadows, 2008). Within this framing, the study employs CATWOE analysis and causal loop diagramming (CLD) as complementary practitioner oriented tools. CATWOE is used to surface differences in meaning and purpose by making institutional assumptions explicit; CLD is used to map feedback structures that shape system behaviour over time, indicating both persistence mechanisms and pathways for improvement.

### 4.1 The Use of CATWOE: Divergent Worldviews and Meaning

CATWOE, developed within Soft Systems Methodology (SSM), is a structured framework for analysing complex, ill-defined problem situations (Checkland, 1999). It supports formulation of a root definition by clarifying the system's purpose, boundaries, and key actors. A central premise of CATWOE is that different actors interpret the same system through distinct worldviews shaped by institutional mandates, professional norms, and policy priorities.

CATWOE structures analysis around six interrelated elements:

- Customers (C): beneficiaries or those affected by the system.
- Actors (A): those who perform activities within the system.
- Transformation (T): the core changes the system seeks to achieve.
- Worldview (W): underlying assumptions that give meaning to the transformation.
- Owners (O): those with authority to change or terminate the system.
- Environmental constraints (E): external factors shaping or limiting system operation.

Its analytical strength lies in making implicit assumptions explicit and enabling multiple perspectives to be examined without privileging a single institutional position. In South Africa, the absence of authoritative national land-use data reflects precisely these dynamics. Spatial planning institutions often conceptualize land-use data as a decision-support instrument essential for development control and spatial transformation, whereas geospatial custodians frame it as a technical derivative of land cover mapping, prioritizing classification consistency over regulatory interpretation. These divergent assumptions influence decisions about responsibility, prioritization, and investment, often without being reconciled.
CATWOE is therefore appropriate for this study because it:

- Expose implicit institutional assumptions,
- Facilitates comparison of multiple perspectives, and
- Shifts analysis from blame ("who is responsible") to understanding ("how the system is conceived").

In this study, CATWOE clarifies:

- Who the perceived beneficiaries (Customers) of national land-use data are,
- Who is considered responsible (Actors and Owners) for its development,
- What transformation is assumed (e.g., land cover to land-use, or data to planning decision), and
- Which worldviews dominate decision-making within the national geospatial and planning system.

### 4.2 The Causal Loop Diagramming: Dynamics and Feedback

While CATWOE surfaces divergent interpretations of purpose and responsibility, it does not explain how these interpretations interact over time to produce persistent outcomes. To address this limitation, the study employs Causal Loop Diagramming (CLD), a core tool within system dynamics for analysing feedback-driven behaviour in complex systems (Sterman, 2000).

CLDs represent causal relationships among key variables and distinguish between reinforcing loops (R), which amplify change, and balancing loops (B), which counteract change. Link polarity is indicated in the CLD as same-direction (S) or inverse (O) relationships. Rather than predicting outcomes quantitatively, CLDs provide qualitative insight into why systems persist in particular states despite interventions and where leverage may exist to shift behaviour.

## 5. FINDINGS

The findings have direct implications for spatial planning and development practice in institutional settings characterised by fragmented mandates, multi-level governance, and

competing interpretations of land-use information. The combined application of CATWOE and causal loop diagramming indicates that the continuing absence of authoritative national land-use data in South Africa is attributable less to technical limitations than to governance dynamics, institutional learning processes, and the management of divergent worldviews.

### 5.1 CATWOE Findings: Divergent Worldviews and the Absence of a Shared Transformation Logic

The CATWOE analysis, summarised in table 1, reveals significant divergence in how key institutions conceptualise the purpose, ownership, and value of national land-use data. While spatial planning actors predominantly frame national land-use data as a decision-support resource essential for development control, spatial transformation, and policy implementation, geospatial data custodians often conceptualise land-use data as a technical derivative of land cover mapping, emphasising classification consistency and data production over regulatory interpretation.

These contrasting worldviews result in:

- Fragmented responsibility for data production and governance,
- Misaligned priorities between planning and geospatial communities, and
- Limited institutional incentives to invest in authoritative national datasets.

The absence of a shared transformation logic whether national land-use data is primarily a regulatory instrument or a technical product emerges as a critical barrier to systemic alignment.

| CATWOE Element | Perspective 1: Data Governance / Technical Coherence | Perspective 2: Planning & Regulatory Use / Decision-Readiness | Explicit Link to CLD Variables |
|---|---|---|---|
| Root Definition | A system **TO** ensure land-use data integrity and interoperability BY applying custodianship, governance standards, and quality controls **IN ORDER TO** support aggregation and national reporting. | A system **TO** enable consistent, policy-aligned land-use interpretation **BY** applying shared standards, rules, and meanings **IN ORDER TO** strengthen planning and regulatory decision-making. | Frames demand, Standards adoption, quality assurance, and accountability as system purpose. |
| Customers (C) | National departments, SDI stakeholders, reporting bodies, research institutions. | Municipal planning authorities, regulators, communities, development actors. | Customers influence perceived value which drives institutional demand. |
| Actors (A) | SDI custodians, technical units, standards bodies, data managers. | Planners, municipal land-use regulators, policy implementers, sector departments. | Actor roles affect coordination, quality assurance consistency, and stakeholder engagement. |

| CATWOE Element | Perspective 1: Data Governance / Technical Coherence | Perspective 2: Planning & Regulatory Use / Decision-Readiness | Explicit Link to CLD Variables |
|---|---|---|---|
| Transformation (T) | Transform fragmented and inconsistently managed land-use datasets into an authoritative national dataset that is governed, standardized, interoperable, and quality-assured. | Transform fragmented and inconsistent land-use interpretations into authoritative, policy-aligned information that is standardized and integrated into spatial planning and regulatory decision-making processes. | Captures the missing transformation logic linking land cover to land-use; influences demand and investment loops. |
| Worldview (W) | Land-use data is an information asset whose value depends on consistency, interoperability, and compliance. | Land-use data is a planning instrument whose value depends on regulatory meaning, spatial transformation, and decision impact. | Divergent worldviews drive weak alignment, weak accountability, and low demand in reinforcing loops. |
| Owners (O) | National geospatial authorities with custodianship mandates under SDI governance. | Planning authorities under SPLUMA with authority over land-use regulation and implementation. | Ownership ambiguity reduces accountability, weakening demand and investment (core CLD mechanism). |
| Environmental Constraints (E) | Institutional silos; uneven technical capacity; weak enforcement of governance mandates. | Legislative overlap; political sensitivity; uneven municipal planning capacity; contested definitions. | Constraints feed resistance to change, weaken coordination, and reduce policy enforcement leverage. |

Table 1: CATWOE Summary for National Land-Use Data Governance in South Africa

The CATWOE analysis (table 1) shows substantial divergence in how key institutions conceptualise the purpose, ownership, and value of national land-use data. Spatial planning actors predominantly frame land-use data as a decision-support resource required for development control, spatial transformation, and policy implementation. By contrast, geospatial custodians often frame land-use as a technical derivative of land-cover mapping, emphasising classification consistency and production workflows over regulatory interpretation.

These divergent worldviews contribute to fragmented responsibility, misaligned priorities between planning and geospatial communities, and weak incentives to invest in authoritative national land-use information. The absence of a shared transformation logic specifically, how land-cover observation should be translated into policy-relevant land-use interpretation emerges as a central governance constraint. Environmental constraints such as legislative overlap, uneven institutional capacity, and unclear ownership of a national land-use mandate

further reinforce ambiguity and dampen demand formation. The CLD in figure 2 explains how this governance condition interacts through feedback to change the current status quo over time.

### 5.2 Causal Loop Findings: Governance Dynamics and Demand Formation

CATWOE clarifies how actors frame land-use data governance in terms of purpose, ownership, and worldview; the CLD (figure 2) explains how these framings translate into system behaviour through feedback. Figure 2 maps causal relationships among variables shaping demand for national land-use data and identifies four reinforcing loops (R1–R4) that describe both persistence under weak governance coupling and opportunities for cumulative improvement when the loops are strengthened.

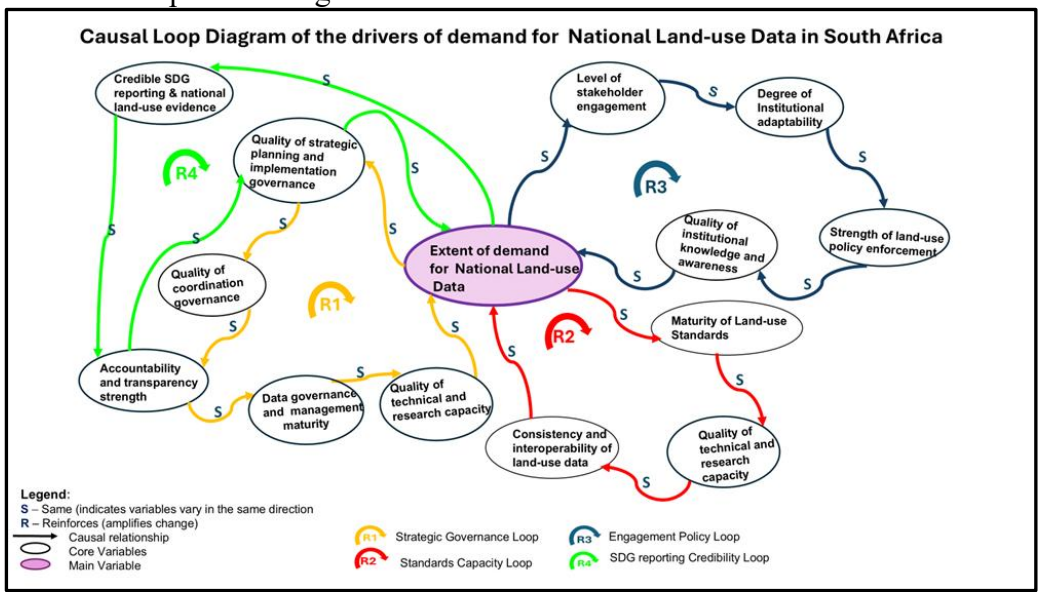


Figure 2: Causal Loop Diagram of governance dynamics influencing demand national land-use data

Figure 2 illustrates the feedback dynamics shaping demand for national land-use data in South Africa and explains why governance conditions can persist despite periodic interventions.

- R1: Strategic governance links strategic planning and implementation to stronger coordination, which enhances accountability and transparency, improves data management, and supports technical and research capacity. As reliability and perceived value increase, institutional demand can rise, strengthening incentives for further strategic action and coordination.
- R2: Standards capacity interoperability shows that demand and technical performance can co-evolve through standards uptake. Higher demand can justify investment in standards adoption, which strengthens capability and improves consistency and interoperability, making land-use information more usable and further stimulating uptake and demand.
- R3: Engagement policy learning) captures how growing demand can deepen stakeholder engagement and strengthen institutional adaptability, enabling more

consistent policy enforcement and increasing knowledge and awareness of land-use value. These learning effects can reinforce routine use and support further demand growth.

- R4: Reporting credibility accountability legitimacy) links improved evidence to more credible reporting outputs, including SDG relevant indicators. Credible outputs strengthen accountability and legitimacy, reinforcing demand by making public value visible and tightening expectations for consistent land-use evidence.

Taken together, the CLD indicates that demand can be generated and sustained when reinforcing feedback among coordination, accountability, standards uptake, capability development, and reporting credibility is consistently activated. Where enabling conditions remain weak, these reinforcing pathways are dampened; where they are strengthened, incremental gains can accumulate into a higher-demand trajectory and more integrated land-use data governance.

## 6. LAND COVER, LAND-USE INTERRELATIONSHIP AND STANDARDS

Land Cover (LC) and Land-Use (LU) represent distinct yet interdependent dimensions of spatial information that underpin spatial planning, land governance, and sustainable development. LC describes the observable biophysical state of the Earth's surface (e.g., vegetation, water, built-up areas), whereas LU captures the socio-economic functions, regulatory intent, and human purposes associated with those areas (Di Gregorio & Jansen, 1998; FAO, 2000). From a systems perspective, LC functions as a comparatively stable, observation-driven subsystem that records physical characteristics at a given time, while LU is a dynamic subsystem shaped by evolving human activities, socio-economic change, and policy frameworks. Their interaction is reciprocal: LC conditions the opportunities and constraints for LU, and LU decisions and practices, in turn, transform LC through land management and development (FAO, UoS, & STIIMA-CNR, 2024).

In South Africa, national land-cover initiatives supported by standards such as SANS 1877-2:2025 and SANS 19144-2:2014 (LCML) demonstrate the value of standardised, coordinated spatial evidence. By contrast, there is currently no integrated, standardised national land-use dataset; land-use information remains fragmented across institutions and sectors, shaped by contested mandates and the interpretive complexity inherent in attribution. Integrating LC and LU through meta-language frameworks such as the Land Characterization Meta-Language (LCHML) and ISO/TS 19144-3:2024 (LUML) strengthens analytical coherence by linking biophysical patterns to policy-relevant interpretation. This standards-based linkage enables LC and LU to function as a connected information value chain, improving semantic interoperability and supporting more robust assessment of land dynamics. When embedded within SPLUMA and SDI governance frameworks, LC and LU integration strengthens decision-making and supports credible reporting for indicators that depend on comparable evidence (e.g., SDG 11.3.1 and SDG 15.3.1).

## 7. DISCUSSION

This study reinforces the argument that national land-use data governance should be understood as a complex socio-technical system rather than a linear production process. While South Africa has achieved notable success in producing standardised national land-cover datasets, translating these datasets into authoritative, policy-relevant land-use information remains constrained by institutional fragmentation, contested meanings, and weak systemic alignment.

CATWOE highlights the absence of a shared transformation logic linking land cover to land use as a central governance challenge. Without consensus on whether transformation involves technical reclassification, institutional interpretation, or regulatory application, responsibility for land-use data development remains ambiguous, weakening accountability and dampening demand signals.

The CLD complements this interpretation by showing how strengthening reinforcing governance dynamics particularly coordination, accountability, standards uptake, and sustained engagement can generate demand and support institutional learning. Rather than treating land-use data as a standalone product, the findings position it as an emergent outcome of aligned governance, shared meaning, and feedback-aware planning practice.

National and international standards SANS 1877-2:2025, SANS 19144-2:2014 (LCML) and ISO/TS 19144-3:2024 (LUML) are therefore best understood as boundary-spanning governance mechanisms that provide shared semantics and structure to align SPLUMA-driven planning needs with SDI-governed geospatial coordination, enabling consistent interpretation and comparability across institutions and scales.

## 8. CONCLUSION

This paper examined why the development of authoritative national land-use data in South Africa remains unresolved despite enabling legislation, established geospatial standards, and demonstrated technical capacity. Using a systems thinking perspective supported by CATWOE analysis and CLD, the study shows that the primary constraints are governance and institutional learning dynamics rather than technical failure. Misaligned worldviews, the absence of a shared transformation logic linking land cover to land use, and weak coupling between accountability, capability and legitimacy explain why technical interventions alone have not produced a sustained national land-use dataset.

The study reframes national land-use data as a governance and accountability instrument central to spatial planning coherence and credible SDG reporting. Integrating land cover and land use through SANS 1877-2:2025, SANS 19144-2:2014 (LCML) and ISO/TS 19144-3:2024 (LUML) enables empirical spatial evidence to be transformed into policy-relevant knowledge, supporting indicators such as SDG 11.3.1, SDG 15.3.1, and SDG 13. The findings demonstrate the practical value of systems thinking tools for identifying leverage points, aligning mandates, and embedding standards based workflows within multilevel planning systems, offering a viable pathway toward more coherent and sustainable national land-use data governance.

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## BIOGRAPHICAL NOTES

Ms Bulelwa Semoli is a South African geospatial and Earth Observation executive with 22+ years' experience spanning private and public service, intergovernmental collaboration, and applied research. She is a senior manager leading national Earth Observation delivery, including

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