Survey Review

ISSN: 0039-6265 (Print) 1752-2706 (Online) Journal homepage: www.tandfonline.com/journals/ysre20

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To cite this article: Mengying Chen, Abdullah Kara, Peter van Oosterom, Regina Orvañanos Murguía, John Gitau & Christiaan Lemmen (20 Aug 2025): Analyzing and formalising land indicators of LGAF, GLII and SDGs through LADM, Survey Review, DOI: 10.1080/00396265.2025.2544400

To link to this article: https://doi.org/10.1080/00396265.2025.2544400

Published online: 20 Aug 2025.

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Analyzing and formalising land indicators of LGAF, GLII and SDGs through LADM

Mengying Chen*[1], Abdullah Kara[1,2], Peter van Oosterom[1], Regina Orvañanos Murguía[3], John Gitau[3] and Christiaan Lemmen[4]

Over the past fifteen years, LGAF, GLII, and SDGs frameworks have jointly shaped a complementary global land governance monitoring system. However, challenges remain in data fragmentation and standardised indicator computation. This study explores how ISO 19152 LADM provides a unified technical foundation to model and monitor global land indicators. It develops a standardised conceptual model with UML-based implementation and proposes a modular indicator computation architecture based on interface classes and reusable logic components. The proposed approach supports scalable reporting, enhances indicator operationalisation, and bridges the gap between global policy frameworks and practical land administration systems at the national level.

Keywords: Land administration, Land Administration Domain Model, ISO19152 LADM, Land Governance Assessment Framework, Global Land Indicators Initiative, Sustainable Development Goals Indicator Formalization

Introduction

The evaluation of the performance of a land administration system (LAS) is an important task, as it can provide the input for the improvement of the performance of the system. An assessment may identify the strengths and weaknesses of the existing system and provide the basis for improving it.

The evaluation of LASs is a complex task. Since 2010, a number of representative international frameworks have been released, building a basic toolbox for global LASs (Williamson and Ting 2001, Steudler *et al*. 2004). The World Bank launched the Land Governance Assessment Framework (LGAF) in 2010, providing a comprehensive diagnostic tool for assessing land governance at the national level. In 2012, the Global Land Indicators Initiative (GLII) was established under the Global Land Tool Network (GLTN), hosted by UN-Habitat, as a collaborative platform to develop a set of harmonised land indicators and advocate for their inclusion in global monitoring agendas. Subsequently, the United Nations adopted the Sustainable Development Goals (SDGs) in 2015, which include several land-related targets and indicators to support global monitoring efforts. 2019, the Framework for Effective Land Administration (FELA) was published by the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM), providing further guidance for developing and integrating land administration systems within the context of the SDGs and other international frameworks.

This study focuses on three key international indicator frameworks: the World Bank's LGAF, the GLII developed under GLTN and UN-Habitat, and the UN's SDGs, examining their relationships and how they can be integrated and monitored through LADM.

As the earliest established framework, LGAF, introduced in 2010, primarily serves as a diagnostic tool for assessing the current status of land governance at the national level, supporting countries in identifying institutional bottlenecks and policy reform priorities. GLII, launched in 2012, was initially created to promote the standardisation of global land governance indicators and to foster international consensus. Notably, several core indicators proposed by GLII – such as those addressing tenure security and gender equality – were successfully integrated into the SDGs adopted in 2015. Moreover, GLII does not collect data directly; rather, it has served as a normative platform for defining indicators and promoting methodological guidance. The SDGs, as the UN-led global monitoring framework, focus on providing standardised indicators and statistical methods to support the monitoring of land tenure security, governance conditions, and spatial development across all UN Member States. Countries are responsible for collecting and reporting data based on their national data resources and following the agreed methodologies.

However, despite the complementary roles and collaborative development of these three frameworks, significant challenges persist in the practical monitoring and implementation of land governance indicators at both global and national levels. In particular, the monitoring

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© 2025 Survey Review Ltd
Received 15 April 2025; accepted 31 July 2025
DOI 10.1080/00396265.2025.2544400

of SDG land-related indicators is hindered by the lack of reliable and standardised administrative data, fragmented land information spread across multiple government agencies, and the technical complexity of integrating data from heterogeneous Land Information System. In the absence of well-functioning land administration systems, many countries rely on household surveys or other statistical sources for reporting. Yet this approach is often constrained by limited technical capacity, inadequate financial and human resources, and discrepancies between existing survey tools and the standardised SDG methodologies. Furthermore, such survey-based data often lacks disaggregation at sub-national levels, making it difficult to assess land tenure indicators at local or project scales. These challenges highlight the urgent need for a standardised and technically implementable framework that can bridge the gap between global policy indicators and operational land information systems.

In this context, the Land Administration Domain Model (LADM), published as ISO 19152, provides a possible solution. LADM offers a standardised data modelling framework that enables the integration of heterogeneous land information, supports the consistent computation of indicators, and facilitates cross-jurisdictional comparison. It can therefore be applied not only to monitor global land indicators but also to evaluate the performance of LADM-based LASs. To operationalise this potential, interface classes can be designed within the LADM structure to support indicator generation, data management, and reporting processes in a standardised and repeatable manner.

This study is guided by the following research questions:

- What are the complementary functions of LGAF, GLII, and SDGs? How do they differ in terms of objectives, application scope, and data requirements?
- Are countries around the world adopting and using these indicators in practice, and to what extent?
- How can the LADM be used to support the monitoring of these indicators in a standardised and technically implementable way?

The objective of this study is to explore the extent to which LADM can be used to monitor the indicators of LGAF, SDGs and GLII. To this end, the indicators are categorised according to their degree of association with LADM (i.e. full computational association, partial computational association, indirect association, association with other standards and non-association) as proposed by Chen *et al.* (2024), and interface classes are created for the computational associations.

In particular, this paper contributes to the understanding of how land indicators can transition from high-level policy agendas into practical implementation within LASs. By introducing UML-based workflows and pseudocode examples grounded in the ISO 19152 LADM standard, the study demonstrates how indicators from LGAF, SDGs and GLII can be translated into standardised, automatable processes – effectively bridging the gap between global frameworks and operational systems. Beyond technical implementation, the use of LADM supports the formalisation of indicator definitions, enabling precise, unambiguous specification of key concepts, attributes, and computation methods. This contributes not only to consistent monitoring across spatial and institutional contexts, but also facilitates comparability over time, improved data quality, and the potential for automation. Thus, the LADM serves not only as a data model but also as a foundational tool for standardising and operationalising land governance indicators.

The remainder of this paper is organised as follows: Section 2 introduces the key international frameworks – LADM Edition II, LGAF, GLII, and the SDGs – and explains the methodology used to assess the association between indicators and LADM components. It also outlines the implementation workflow for transforming conceptual indicators into computable models. Section 3 presents the results, including the classification of LGAF and SDG, GLII indicators by their degree of association with LADM, a unified conceptual visualisation of the tenure security theme across the three frameworks, and a UML-based implementation case that demonstrates how tenure-related indicators can be monitored through a shared data model. Section 4 discusses the complementarities among the indicator frameworks, the strengths and limitations of LADM as a monitoring tool, key findings of the study, and future research directions.

Materials and methods

To evaluate the extent to which the LADM can support the monitoring of international land governance indicators, this study adopts a structured methodology combining conceptual analysis, model-based mapping, and computational design. The selected indicator frameworks – LGAF, GLII, and the SDGs – are examined in relation to LADM Edition II to determine their technical compatibility and the feasibility of implementation within a unified modelling environment. This section outlines the key data sources, the mapping and classification methodology, and the standardised workflow for indicator computation.

Sources

This section presents the primary sources that form the foundation for the conceptual and technical components of this study. These include the LADM as the core data standard, and three international indicator frameworks – LGAF, GLII, and the SDGs – that serve as reference systems for evaluating LA. The following subsections provide a brief overview of each source and explain their relevance to the implementation and analysis presented in this paper.

LADM Edition II

The Land Administration Domain Model (LADM), published as ISO 19152 in 2012, defines a standardised conceptual model for land administration, covering rights, restrictions, responsibilities, parties, spatial units, and sources (ISO 2012, Lemmen *et al.* 2015). The first edition focused primarily on tenure and geometry, while external classes suggested pathways for integrating valuation (*ExtValuation*) and land use (*ExtLandUse*) (Lemmen 2012).

Responding to international LA community's request, LADM Edition II was launched (ISO 2024a) to expand support for integration of valuation information (Part 4) (ISO 2025b), spatial plan information (Part 5), 3D

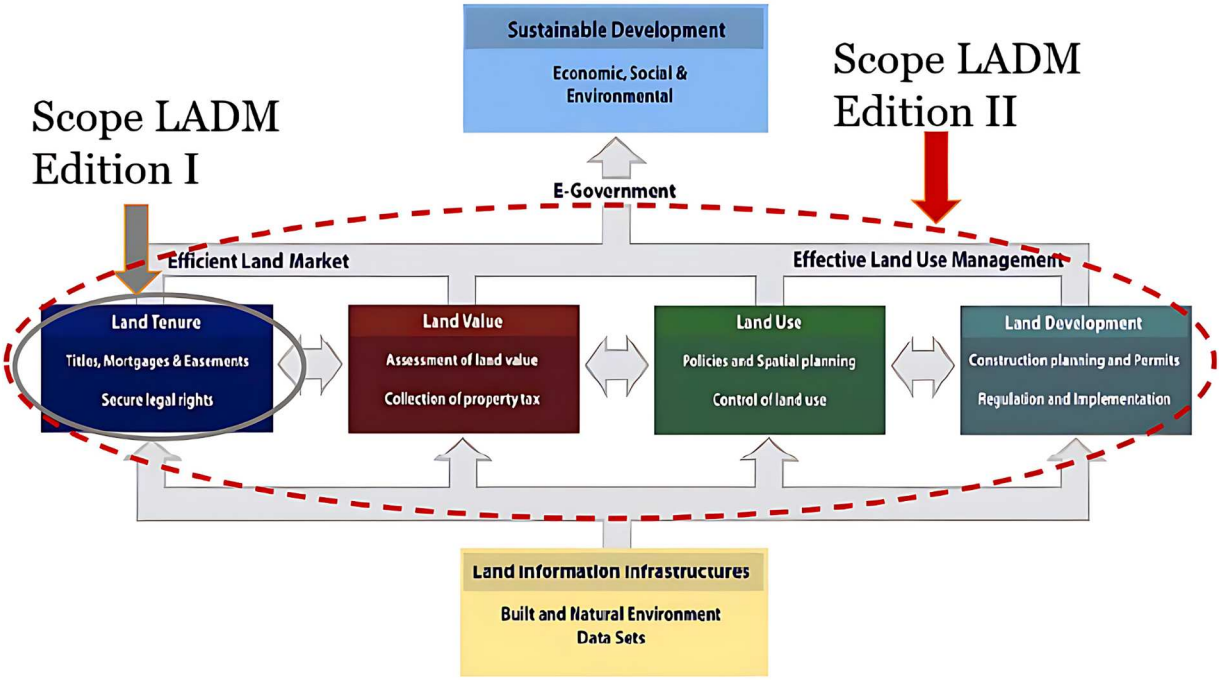

Figure 1. The extended scope of LADM (adapted from Enemark 2006).

(below, on and above the surface of the earth) on land (Part 2) (ISO 2025a) and Marine land administration (Parts 3) (ISO 2024b). In addition, the need for further, refinement of rights, restrictions and responsibilities (RRRs), refined survey model, new subclasses for spatial units, a set of possible representations of spatial units in 2D, 3D or mixed dimension (Kara *et al.* 2024), identifying legal spaces in buildings, refined legal profiles have been considered (Lemmen *et al.* 2020). Figure 1 shows the extended scope of LADM Edition II. Since the conceptual models of the mentioned parts are at a mature stage, they can be used to develop interface classes, for example, to monitor the efficiency of LASs in different contexts, including land tenure, value, and use.

World Bank's LGAF

The World Bank launched the Land Governance Assessment Framework (LGAF) in 2010 to systematically assess national land governance. The framework evaluates 27 core indicators and 108 dimensions through expert panels, covering nine thematic areas such as land tenure recognition, public land management, urban planning, and land valuation and taxation (World Bank 2013, 2024). The assessment process includes information collection, expert scoring, report drafting, policy recommendations, and follow-up planning. Each panel consists of 3–8 experts from legal, academic, governmental, and non-governmental sectors. Emphasising participation and policy orientation, LGAF has been applied in 39 countries worldwide, mostly in Africa (World Bank 2024). See Table A1 for details on LGAF indicators.

GLII's Global Land Indicators

To strengthen the monitoring of land governance, the Global Land Indicators Initiative (GLII) was launched in 2012 by the Millennium Challenge Corporation, the World Bank, and UN-Habitat, and is coordinated by the GLTN platform (GLTN 2024). Bringing together over 50 international institutions, GLII aims to develop nationally applicable and globally comparable land indicators and data protocols. It proposed 15 indicators covering four key areas: land tenure security, land and conflict, land administration services, and sustainable land use. Several of these were integrated into the SDG framework, resulting in core indicators such as 1.4.2, 5.a.1, 5.a.2, 11.3, and 15.3.1. The indicators are reported at three levels: nationally led, internationally assisted, and global monitoring (UN-Habitat/GLTN 2017). Among them, the five indicators on tenure security (1.1–1.5) are the most widely used (UN-Habitat/GLTN 2021; UN Habitat/GLTN/GLII 2022), and are closely aligned with the SDG goals. See Table A2 for details on GLII indicators.

SDGs

The Sustainable Development Goals (SDGs), adopted by the United Nations in 2015, provide a global framework for development across social, economic, and environmental dimensions. While land administration is not a standalone goal, key elements – such as tenure security, land use, and spatial planning – are embedded across multiple targets. According to GLTN (2024), land-related issues are reflected in 12 indicators under 8 goals, including 1.4.2, 2.3.1–2.3.2, 5.a.1–5.a.2, 11.3.1, and 15.3.1. With the expansion of international standards such as LADM Edition II and FELA, marine spaces have also been incorporated into the definition of 'land'. For instance, SDG Indicator 14.5.1 on marine protected areas has been included under LADM Part 3 (Chen *et al.* 2024).

These indicators are managed by the UN Statistics Division and the Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs), and are classified into three tiers (Tier 1–3) based on the maturity of their

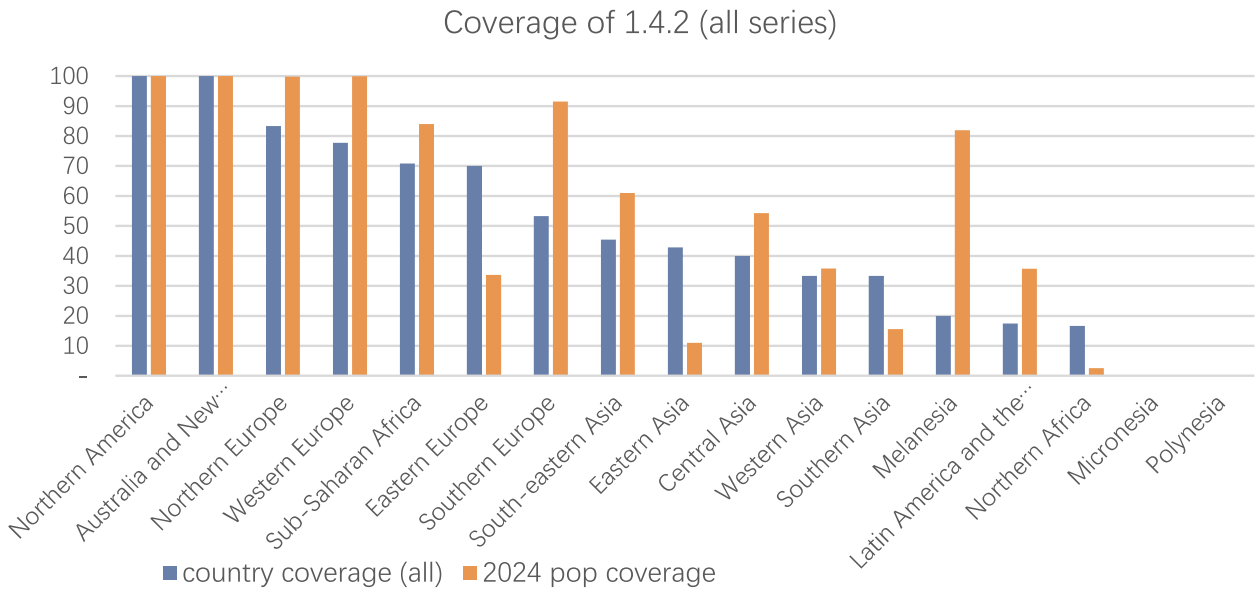

Figure 2. Global coverage of SDG Indicator 1.4.2 (as of 2024).

methodology and data availability. Each indicator is accompanied by detailed metadata and is coordinated by a designated UN custodian agency. Despite the presence of a standardised framework, data collection and implementation at the national level remain uneven. For example, only 98 countries reported on Indicator 1.4.2 by late 2024, covering 46% of UN member states. Sub-Saharan Africa performed relatively well, while other regions lagged behind (Figure 2).

These data gaps demonstrate that global land governance monitoring still lacks a unified and structured data foundation, highlighting the urgent need for a technically implementable and comparable framework to enhance the efficiency and effectiveness of land-related indicator monitoring.

Indicator mapping and association methodology

This study aims to explore how three major international indicator frameworks – LGAF, GLII, and the SDGs – can be systematically linked to the LADM at the conceptual level, ultimately enabling a unified and operable UML-based representation.

The first step involves a systematic review of the content and structure of the three frameworks to identify thematic overlaps in their indicator definitions. For example, the concept of tenure security is a shared priority: it appears under the dimension of 'land tenure recognition' in LGAF, is covered by the first five indicators in GLII, and is directly addressed in SDG indicators 1.4.2 and 5.a.1. Although the formulations and technical methodologies differ across frameworks, they share core conceptual elements such as legal recognition, registration status, perceived security, and gender disaggregation.

The second step draws on the classification method proposed by Chen *et al.* (2024), which systematically matches the identified indicator elements with classes and attributes in LADM Edition II. This method assesses the conceptual and technical compatibility of each indicator with the LADM structure. Given that all indicators selected from LGAF and GLII are directly related to land administration, preliminary filtering was deemed unnecessary.

Five types of associations are defined to describe the relationship between indicators and LADM:

(1) **Full computational association**, where the indicator can be entirely computed based on LADM classes and attributes;
(2) **Partial association**, where certain components are computable using LADM, while others require external input or assumptions;
(3) Indirect association, where the indicator involves LADM classes or attributes conceptually, but lacks direct representation or computability within the structure of the model. This includes two subtypes: **(a) indicators that reference elements modelled in LADM but are assessed through external, non-structured methods (e.g. surveys, expert scoring); (b) indicators that contain components loosely related to LADM concepts, without producing outputs that can be directly derived from the model;**
(4) **Association with other standards**, indicators categorised as such are fundamentally linked with other (international) standards to be computed and potentially may partly rely on the LADM;
(5) Non-association, where the indicator falls outside the scope of representation in LADM, which does not exist in GLII and GLAF.

This classification system provides a standardised foundation for assessing the operational compatibility of global indicators with LADM-based land information systems.

In this study, a unified conceptual model is constructed for a representative cross-cutting theme – tenure security. This model is based on core LADM classes (such as *LA_Party*, *LA_RRR*, and *LA_BAUnit*), and integrates data requirements from all three frameworks. Through the design of interface classes and logical filtering conditions, the model enables the

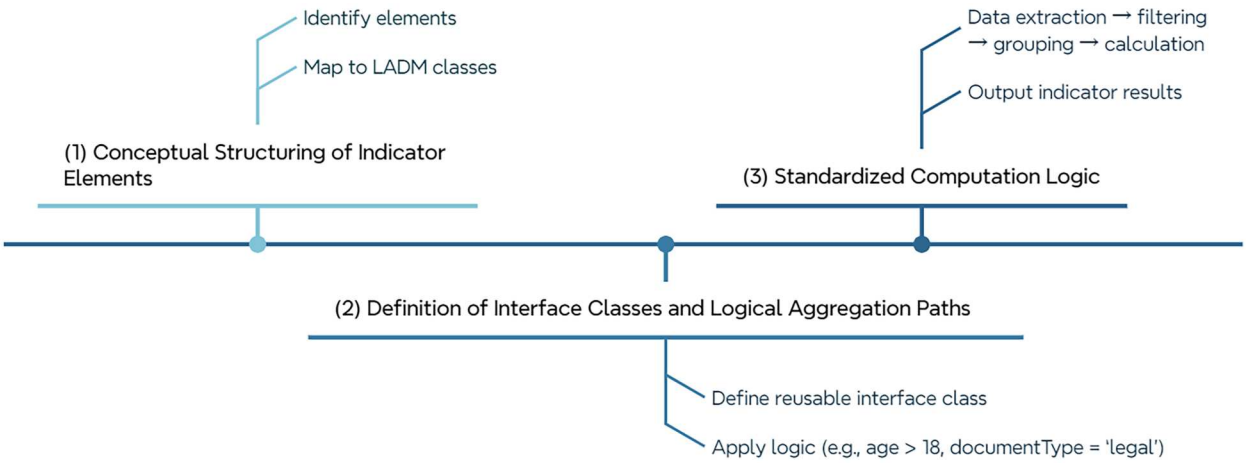

Figure 3. Implementation Workflow for Computing Land Indicators Using LADM.

standardised aggregation and representation of indicator components. This UML-based approach offers both theoretical and technical support for the future integration and automated computation of multi-framework land indicators.

Implementation workflow

Following the conceptual mapping of indicators to LADM structures, a generalised implementation workflow (as shown in Figure 3) has been developed to support the generation and monitoring of land governance indicators across multiple international frameworks. This workflow provides a standardised technical pathway that facilitates indicator computation, reporting, and comparative analysis across different spatial and institutional contexts.

The implementation process consists of three main stages:

(1) Conceptual Structuring of Indicator Elements

In the first step, core elements from selected indicators – such as tenure type, documentation status, rights holders, spatial units, and demographic attributes – are identified and mapped to corresponding LADM classes and attributes. This involves translating the logical content of each indicator into formal model components (e.g. *LA_Party.gender*, *LA_RRR.rightType*, *LA_SpatialUnit.geometry*). Where indicators require information not explicitly modelled in LADM, extension classes (e.g. *ExtPartyPerception*) are proposed. This structuring ensures that all indicator-relevant data elements are represented in a consistent and interpretable way.

(2) Definition of Interface Classes and Logical Aggregation Paths

Once indicator components are mapped, interface classes are defined to abstract the required combinations of LADM elements for each indicator or indicator group. These interface classes act as intermediary views, aggregating multiple attributes into logically coherent structures. For instance, a class for tenure security indicators may include links to *LA_RRR, LA_Party* (with gender attribute), and documentation status. Each interface class also encodes logical conditions or filters (e.g. *age* > *18*, *source.documentType* = *'legal'*) to support standardisation of computation criteria. Indicators with similar structures across different frameworks (e.g. GLII 1.1 and SDG 1.4.2) can share interface designs, facilitating cross-framework consistency.

(3) Standardised Computation Logic

Based on the defined interface classes, a standardised computational logic is developed. This includes a sequence of operations such as data extraction from LADM-compliant databases, application of filtering conditions, grouping by classification variables (e.g. sex, tenure type), and calculation of ratios or counts. These steps can be implemented through database queries (e.g. SQL), scripted routines (e.g. Python), or logic templates encoded in UML activity diagrams. The output of each computation process is aligned with the structure and disaggregation requirements of the original indicator. Furthermore, the approach supports temporal versions (via LADM's *VersionedObject* structure), allowing for change analysis and time-series reporting.

Overall, the workflow enables the unified modelling and logical integration of thematically aligned indicators across multiple international frameworks. This allows indicators from different sources to be computed and interpreted using a consistent data structure, enhancing the applicability of LADM in global land governance monitoring.

Results

This section presents the results of applying the proposed methodology to evaluate how LGAF, GLII, and SDGs can be conceptually and structurally linked to the LADM. The mapping between LGAF and GLII indicators and LADM Edition II is analyzed in detail, while the correspondence between LADM and SDG land-related indicators is covered in Chen *et al.* (2024).

To demonstrate the feasibility of integrated indicator modelling, the shared theme of tenure security is selected as a representative case. A conceptual comparison is conducted across the three frameworks, revealing a consistent focus on legal documentation, perceived security, and equity in land rights. Based on this, in Section 3.2, a UML model is developed using the LADM core classes and interface structures, following the methodology described in Section 2.2. This unified conceptual model is further implemented through a modular indicator computation workflow as detailed in Section 3.3.

Finally, Section 3.4 presents an overview of the current global uptake of these indicator frameworks, highlighting both their growing adoption and the challenges related to data fragmentation and methodological inconsistency.

Applicability of LADM in LGAF and GLII

This section summarises the mapping results between two major global land governance frameworks – LGAF and GLII – and the LADM Edition II conceptual model. Based on the association classification methodology described in Section 2.2, each indicator or dimension was assessed for its conceptual and technical alignment with LADM classes and attributes. The full classification results are provided in the Appendix (Tables A1 and A2).

LGAF – LADM mapping results

The LGAF framework consists of 9 thematic areas, 27 core indicators, and 106 dimensions. The analysis shows that the majority of LGAF dimensions exhibit indirect association with LADM. This is primarily due to LGAF's diagnostic nature, which focuses on policy-level assessments through expert panels, and lacks formalised, computation-ready definitions. Only a small number of dimensions show full or partial computational association. The remainder are heavily dependent on national legal frameworks, institutional practices, or stakeholder consultations, making them less directly suitable for automatic evaluation using LADM-based systems.

However, several dimensions that assess legal recognition of different types of tenure – such as 'Individual rural land tenure rights are legally recognized' or 'Urban land tenure rights are legally recognized' – demonstrate potential for transformation into computable indicators. Although these dimensions are originally qualitative, they can be operationalised using a combination of existing and extended LADM structures. For instance, *LA_Right.rightType* and *LA_SpatialUnit.registerType* can be used to identify relevant tenure types and spatial contexts, while LA_AdministrativeSource or an extension such as LA_Governance can reflect the existence of legal instruments or national-level recognition. This enables the calculation of, for example, the percentage of land parcels or individuals whose rural tenure rights are formally recognised under existing law. Although such modelling requires national customisation and legal interpretation, it significantly improves the computability and consistency of LGAF-based assessments.

GLII – LADM mapping results

The GLII framework defines 15 globally comparable land indicators across four thematic categories. As summarised in Table A2 (Appendix), three indicators were found to have full computational association with LADM, one indicator showed partial computational association, and three were classified as indirectly associated. The remaining eight indicators were considered to have no association, as they depend primarily on country-specific legal frameworks or qualitative policy evaluations rather than structured land administration data.

Compared to LGAF, GLII presents a more structured and data-centric indicator framework. Several of its indicators (e.g. on documented rights, perceived tenure security, and gender disaggregation) are directly aligned with LADM components such as LA_Party, LA_RRR, and LA_BAUnit. Nonetheless, some indicators still rely on subjective or external inputs – such as household surveys or perception-based scoring – which limits full computational implementation. In these cases, extensions like ExtPartyPerception may serve as a modelling bridge between the subjective components of the indicator and the technical representation in LADM.

In summary, the classification of LGAF and GLII indicators highlights both the opportunities and constraints of using LADM as a unifying data model for global land indicator frameworks. While most LGAF indicators are not natively computable, structured modelling combined with legal metadata can significantly improve their formalisation. GLII indicators show greater alignment with data models, and several can be directly calculated using LADM-compliant systems. These findings provide the basis for identifying shared conceptual themes – most notably tenure security – and for constructing a unified conceptual visualisation, which is addressed in the next section.

Unified conceptual visualisation

To further clarify the structural commonalities and potential integration pathways among the three international frameworks – LGAF, GLII, and the SDGs – this section presents a unified conceptual visualisation model centred on the theme of tenure security (see Figure 4). This theme is consistently emphasised across all three frameworks. Although their formulations differ, the underlying policy objectives and data requirements show a high degree of consistency, making it an ideal example for cross-framework indicator integration.

The diagram consists of three components: SDG indicators (blue), GLII indicators (yellow), and LGAF dimensions (green). At the centre of the diagram is SDG Indicator 1.4.2, which focuses on two dimensions simultaneously: land rights with legal documentation (legal documentation) and subjective perceptions of security of tenure (perceived security). This objective can be seen as the core element at the intersection of the three frameworks. This dual focus is reflected and further expanded upon in both the GLII and LGAF frameworks.

Within GLII, a cluster of indicators directly aligns with this SDG target:

- **GLII 1.1 (Documented Land Rights)** corresponds to **SDG 1.4.2(a)**, measuring the proportion of men and women with legally recognised documentation of land rights.
- **GLII 1.2 (Perceived Tenure Security)** corresponds to **SDG 1.4.2(b)**, capturing individuals' perception of tenure security against dispossession.
- **GLII 1.4 (Equal Rights of Women)** complements **SDG 5.a.1** by addressing gender equity in access to land and resources.
- **GLII 1.5 (Indigenous Land Rights)** highlights the recognition of collective and indigenous land rights, which is not directly covered in SDG but can be calculated through LADM and remains a critical priority

within the international development agenda, particularly in relation to biodiversity conservation frameworks.

In the LGAF framework, relevant dimensions are spread across two main themes:

- **Theme 1: Recognition of a Continuum of Rights**, which addresses the Legitimate recognition of rural, urban, customary, and indigenous land rights.
- **Theme 2: Respect for and Enforcement of Rights**, which evaluates the actual registration, enforcement, and gender balance in recognised land rights.

While these frameworks differ in structure – SDGs focusing on global monitoring, GLII providing a complementary normative framework, and LGAF emphasising institutional diagnostics – their thematic focus remains remarkably consistent. All three underscore the importance of legal documentation, equitable access, registration coverage, recognition of vulnerable groups, and perceived tenure security.

These elements can be comprehensively modelled using LADM:

- ***LA_Party*** supports disaggregation by gender (Unger *et al.* 2023), legal entity, or social category;
- ***LA_RRR*** accommodates various types of rights, restrictions, and responsibilities, including customary and shared tenure;
- ***LA_SpatialUnit*** defines the land or spatial extent to which rights apply;
- ***LA_BAUnit*** links rights to legal objects and documentation;
- Subjective components such as perceived tenure security can be modelled through **extension classes** (e.g. *ExtPartyPerception*).

As the figure demonstrates, even when indicators are framed differently across institutional agendas, the underlying data requirements are structurally aligned. The LADM provides a neutral and standardised model that enables integrated monitoring, allowing multiple indicator systems to be supported through a single, coherent LA infrastructure.

The unified concept map is not only a visualisation tool, but also a platform for structured comparative analysis, helping to identify potential synergistic pathways between the various frameworks and supports the move from a 'multi-source indicator system' to the integration of a 'single data model'. As will be shown in subsequent chapters, this integration path is not only conceptually feasible, but also has a clear logic and path of operation at the technical implementation level, thanks to the modelling capabilities provided by LADM.

Implementation cases

UML-based conceptual modelling

To monitor indicators through the LADM, this subsection presents a detailed conceptual modelling process for the domain of land tenure security. This theme is addressed across all three frameworks – SDG, GLII, and LGAF – through various indicators that focus on legal documentation, perceived tenure security, gender equality, and group-based rights. A comparative decomposition of these indicators reveals a set of recurring data elements that form the foundation for unified modelling.

(1) Indicator Element Mapping and Class Structure

Based on the comparative analysis of relevant indicators, a set of core data elements was identified, including demographic attributes (e.g. sex, group), tenure attributes (e.g. right type, registration status), spatial dimensions (e.g. urban/rural), and perceived tenure security. Table 1 summarises the mapping between indicator components, the corresponding frameworks and indicator codes, and the LADM classes and attributes used for representation. Where necessary, extension classes have been introduced to accommodate information not natively supported in LADM Edition II.

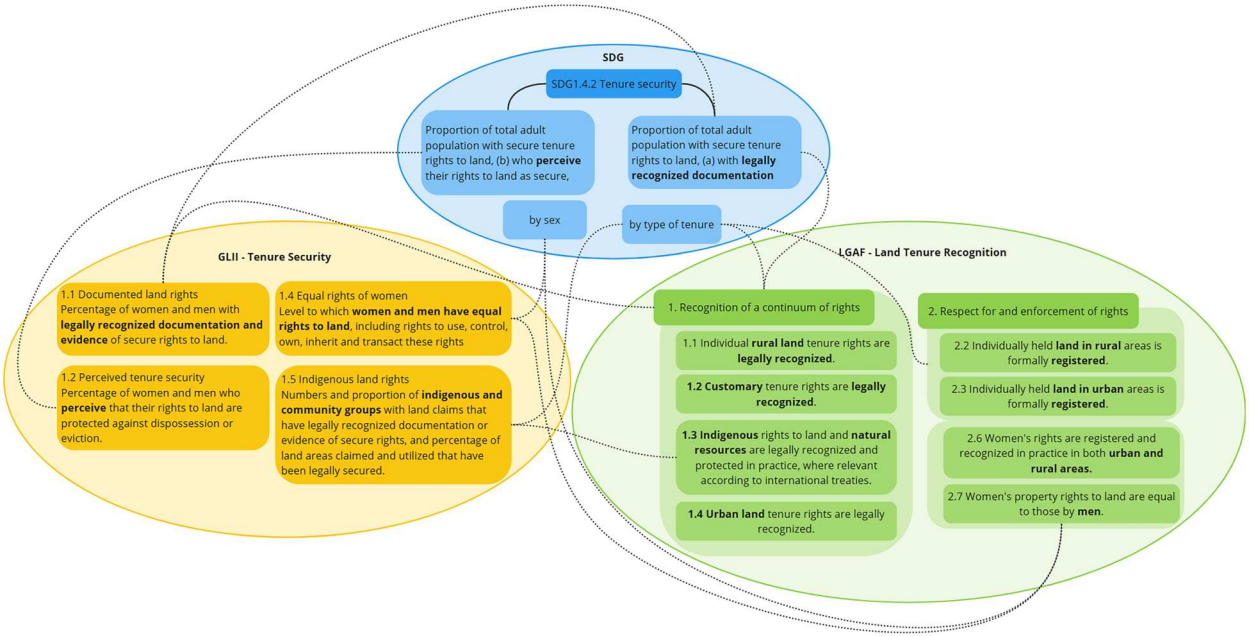

Figure 4. Conceptual relationship between LGAF, GLII, and SDG indicators on tenure security.

This structured mapping serves as a bridge between policy-defined indicators and technically defined data schemas. It also ensures that multiple indicators – despite coming from distinct frameworks – can rely on a common set of model elements when implemented in LADM-compliant systems.

(2) Mapping of Core Elements and Extension Classes

In the second step, these elements are mapped to LADM feature types. Standard components are represented using existing LADM classes (e.g. *LA_Party, LA_Right, LA_SpatialUnit*), while subjective or group-based attributes are handled through extension classes such as *ExtParty* and *ExtSecureLandRights*. This structure supports both objective and perception-based indicators in a unified modelling environment.

(3) Unified Interface Class Design

To support indicator calculation across multiple frameworks, a unified interface – *TenureSecurityIndicatorInterface* – is designed to serve as a flexible and reusable component for different indicator types. Instead of hardcoding logic for each indicator, the interface delegates configuration and execution rules to an external definition class, *IndicatorDefinition*.

Each *IndicatorDefinition* specifies key metadata such as the indicator code, framework, target object (e.g. person or parcel), required disaggregation (e.g. sex, group, region), output type (e.g. count, percentage), and whether subjective dimensions like perceived tenure security are involved. By passing the indicator code to the interface, the appropriate logic is selected, and relevant filters and calculations are applied accordingly. This allows a single interface structure to compute various indicators from

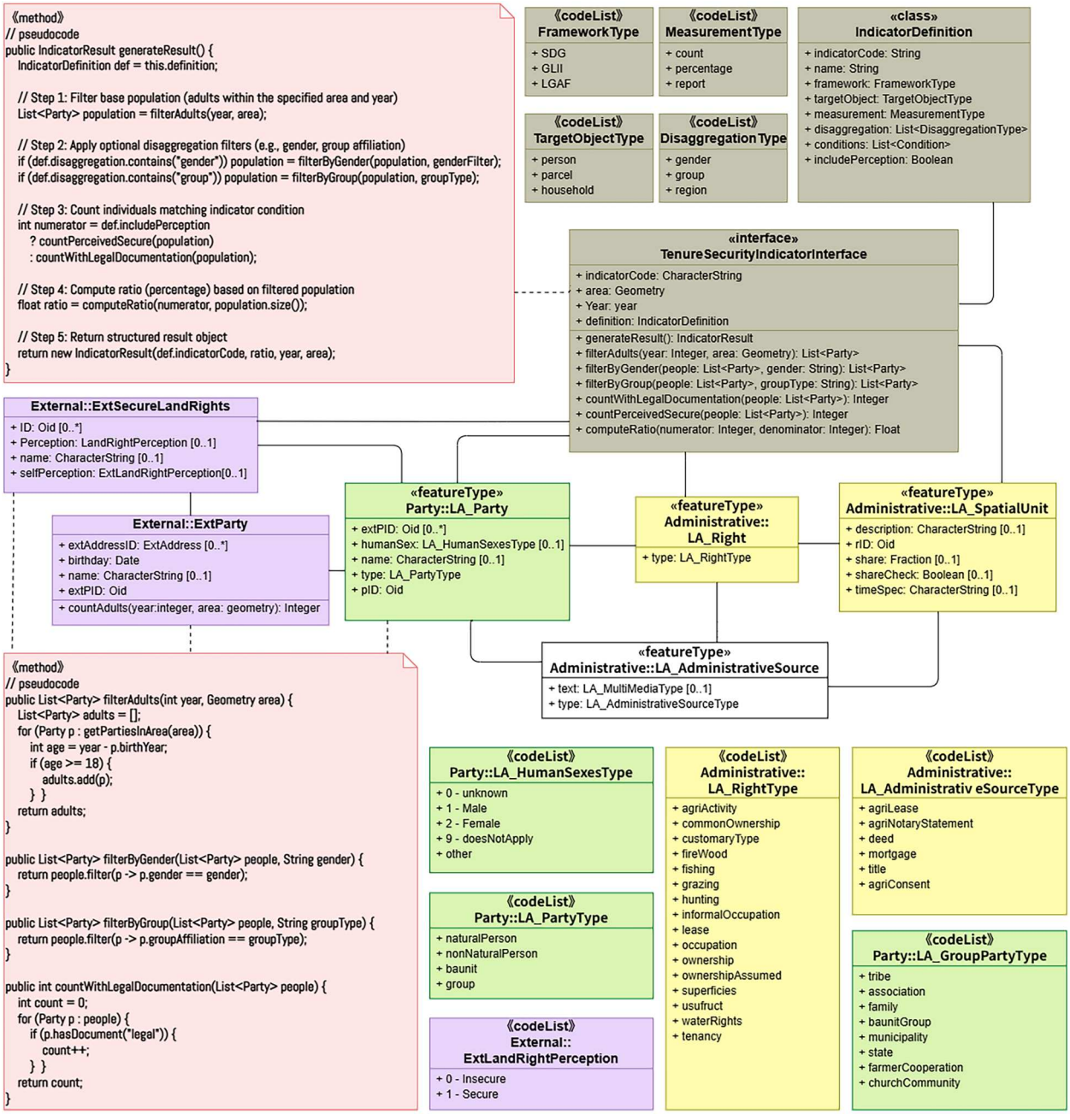

Figure 5. Tenure Security Indicator Computation Framework Based on LADM (Chen *et al*. 2024).

Table 1. Element mapping and corresponding LADM representation.

Element	Indicators	Description	LADM Class/Attribute
Sex (women/men)	GLII 1.1, 1.2, 1.4; LGAF 2.6, 2.7; SDG 1.4.2	Disaggregation by gender	*LA_Party. humanSex*
Right type	LGAF 1.2, 1.3, GLII 1.1, 1.4; SDG 1.4.2	Type of right held (ownership, use, customary)	*LA_Right. LA_RightType*
Region (rural/urban)	LGAF 1.1, 1.3, 2.2, 2.3, 2.6, SDG 1.4.2	Spatial disaggregation of land tenure	*LA_SpatialUnit. LA_RegisterType*
Legally recognised	SDG 1.4.2(a), GLII 1.1, 1.5, LGAF 1	Indicates if the right is formally documented	*LA_Administrative. SourceType*
Registration status	LGAF 2.2, 2.3	Whether the land right is officially registered in the system	*VersionedObject. beginLifespanVersion*
Group affiliation (indigenous)	GLII 1.2, SDG 1.4.2(b); LGAF 1.3	Affiliation to indigenous/ community groups	*LA_GroupParty*
Perceived tenure security	GLII 1.2, SDG 1.4.2(b)	Subjective interpretation of being secure in land rights	*ExtPartyPerception. selfPerception*
Age (adults)	GLII 1.1, SDG 1.4.2	Age of person to filter adults	*ExtParty.birthday*
Area	LGAF 2.1; GLII 1.1	Spatial unit for aggregation	*LA_SpatialUnit.area*

SDG, GLII, and LGAF frameworks without modifying its internal structure.

Figure 5 illustrates the complete UML class structure, including interface classes, associated LADM classes and extensions, base methods, control logic, and configuration parameters. This model ensures consistency, scalability, and extensibility, as new indicators can be integrated through configuration rather than code changes.

Query logic and calculation implementation

Building on the conceptual model presented in the previous section, this subsection outlines the implementation of indicator computation based on the defined interface architecture. The computation process is grounded in a modular and logic-driven workflow, in which reusable query components are dynamically assembled according to the structure of each indicator.

The core method *generateIndicatorResult(indicatorCode)* acts as the entry point for indicator execution. Once invoked, the system retrieves the corresponding *IndicatorDefinition*, interprets the required filters and computation logic, and activates a sequence of predefined functions such as *filterAdults()*, *filterByGender()*, *countWithLegalDocumentation()*, or *computeRatio()* depending on the indicator's design.

For instance, an indicator measuring the proportion of adult women with legally documented land rights would involve the following steps:

1. Filter the population by area and age (18+);
2. Apply gender filter (female);

```
SELECT
  COUNT(*) FILTER (WHERE gender = 'female'
                   AND documentType = 'legal') AS women_with_docs,
  COUNT(*) FILTER (WHERE gender = 'female') AS total_women,
  ROUND(
    COUNT(*) FILTER (WHERE gender = 'female'
                     AND documentType = 'legal') * 1.0 /
    NULLIF(COUNT(*) FILTER (WHERE gender = 'female'), 0), 2
  ) AS proportion
FROM
  LA_Party p
JOIN
  LA_RRR r ON p.id = r.partyID
JOIN
  LA_BAUnit b ON r.baunitID = b.id
JOIN
  AdministrativeSource s ON r.sourceID = s.id;
```

3. Count individuals with legal documentation;
4. Compute the percentage by dividing the count by the total number of women in the target area.

This logic can be implemented through standard SQL or any query language supported by the database hosting the LADM-compliant data. Below is a simplified SQL-like pseudocode representing this process:

The flexibility of this model lies in its abstraction. Similar queries can be composed of other indicators, such as those involving perceived tenure security (*perceivedSecure = true*), group-based disaggregation, or spatial filtering (e.g. by urban/rural region). Because the interface methods are designed to be composable, they can be reused across multiple indicator definitions with minimal adjustment. Moreover, this structure supports integration with geospatial platforms (e.g. PostGIS), allowing for spatial unit-based aggregation and region-specific reporting. It also lays the foundation for web-based dashboards or automated reporting pipelines, where indicators are regularly generated based on updated datasets. For more technical details, refer to Chen (2024).

Global application of land indicators

Globally, the adoption and application of land governance indicators exhibit a diverse and evolving landscape.

According to data from the World Bank, 40 countries or regions – primarily in Africa, Asia, and Latin America – have implemented the LGAF. As the earliest proposed framework for land governance assessment, LGAF has been used since its launch in 2010 to diagnose national land governance systems and support policy analysis. While the framework is primarily based on expert scoring and qualitative assessments, several dimensions still require quantitative data to calculate percentage-based scores in practice.

The application of the GLII framework is primarily reflected in the incorporation of its indicators into the global monitoring system of the SDGs. Since its establishment in 2012 under the leadership of UN-Habitat, GLII has played a vital role in the standardisation of land governance indicators. Several core GLII indicators – particularly GLII 1.1–1.4 – were adopted during the formulation of the SDGs in 2015 and have since evolved into key components of the SDG indicator framework, including 1.4.2, 5.a.1, and 5.a.2. GLII itself does not collect data directly; instead, it acts as a platform for defining land indicators and providing methodological guidance, continuously supporting SDG monitoring and national land governance practices (UN-Habitat 2021).

Within the SDG framework, land tenure – related indicators such as 1.4.2, 5.a.1, and 5.a.2 have become central to global land governance monitoring. As of 2024, according to the UN Statistics Division's SDG Indicator Database, 86 countries have reported data for 1.4.2(a) (the proportion of people with legally recognised documentation of rights), and 27 countries have reported data for 1.4.2(b) (perceived tenure security). The indicator 5.a.1 (gender-equitable control over agricultural land) is covered in 49 countries, 5.a.2 (legal frameworks supporting women's land rights) in 68 countries, and indicator 15.3 (land degradation) in 121 countries.

Despite this increasing uptake, several technical and structural challenges remain. Countries differ widely in their approaches to data collection – some relying on national land administration systems, others on household or community-level surveys. While the SDG methodology provides a standardised approach for indicator calculation, countries often depend on available data sources, and existing surveys may not specifically address the questions required by the SDG methodology. Furthermore, the lack of standardised and integrated LAS in many countries makes it difficult to aggregate data from multiple LIS at the national level for SDG reporting. Additional challenges include uncertainty regarding the coverage, completeness, and timeliness of available administrative data, which affects the reliability of the data for statistical reporting and international comparison.

The LADM-based unified modelling and computation framework proposed in this study provides a potential solution to these challenges. Through its interface-based design and decoupled indicator configuration, the model facilitates standardised representation of indicator logic and promotes structural consistency across national implementations. This offers a technical foundation for more coherent and scalable land governance monitoring, supporting international efforts in policy evaluation and sustainable development planning.

Discussion

Why is more than one indicator framework needed?

The LGAF, GLII, and SDG indicator frameworks have evolved at different stages of global land governance through complementary and interconnected processes. The SDG framework, as a unified global monitoring system, has adopted and standardised early contributions from GLII; GLII continues to provide technical support by advancing indicator definitions and methodological guidance; and LGAF focuses on institutional diagnostics and policy evaluation. While their objectives differ, all three share a common conceptual foundation in indicator design and data requirements.

Among them, many of LGAF's qualitative indicators do not have direct computational methods but can be translated into quantifiable forms through the LADM. For example, 'formally registered rural land rights' can be represented using *LA_BAUnit* in LADM; alternatively, the legal basis for dimensions such as 'recognition of urban land tenure rights' could be modelled via the *LA_Governance* class – which, although currently implemented mainly in the marine georegulation domain, provides a potential extension path for future standardisation in land modules. The expanded capabilities of LADM Edition II also support the modelling of other LGAF dimensions – for instance, building permits (LGAF 8) can be represented using spatial planning classes from *Part 5*, and land valuation and transactions (LGAF 13) can be modelled through the valuation information structures in *Part 4*.

The value of LADM in land administration monitoring

As an international standard, the LADM Model provides a clear conceptual structure, defining standardised classes, attributes, and relationships for modelling land tenure, use, value, and restrictions. This makes it well-suited to support

indicator monitoring, particularly in scenarios where structural consistency, interoperability, and repeatability are required. Its modular design also allows for extensions to represent non-traditional elements such as perception-based data and group-specific classifications.

However, the application of LADM is not without limitations. Its implementation depends on the availability and maturity of LADM-compliant land administration systems, which remain limited globally. For indicators involving subjective dimensions or governance-related outcomes – such as institutional recognition or legal coverage – LADM cannot always represent the full logic directly. In such cases, additional data models or external integrations may be required.

More critically, beyond its technical modelling capabilities, a key challenge for using LADM in SDG reporting lies in establishing effective information flows from different LADM-compliant LIS into national statistical systems (NSO) and subsequently into the global SDG reporting mechanisms. This requires not only standardised data models but also robust governance of information sharing, data integration, and cross-institutional coordination. Therefore, while LADM provides a strong technical foundation for standardised monitoring of land indicators, its practical effectiveness will ultimately depend on institutional uptake, data readiness, and the governance of information flows across systems and administrative levels.

In addition to LADM (ISO 19152) providing technical support for land-related SDG indicators, ISO has recently developed a complementary management standard – the 'Management Systems for UN Sustainable Development Goals' (ISO/UNDP WD 53001.2 2024) under (ISO/PC 343 2023). This standard offers a systematic framework for organisations to improve performance, fulfil compliance obligations, and achieve SDG objectives. Together, LADM and this emerging management system standard provide both technical and governance-level support for SDG monitoring, facilitating more integrated, standardised, and accountable implementation of land governance indicators worldwide.

Main results and limitations

This study provides a unified technical framework for monitoring global land governance indicators using the LADM. By analyzing and comparing the structure of LGAF, GLII, and SDG indicators, the research demonstrates that a shared set of core elements – such as tenure type, gender, documentation status, and spatial unit – can be abstracted and modelled within LADM.

The paper proposes a modular implementation architecture based on a reusable interface class (*TenureSecurityIndicatorInterface*) and a configurable indicator definition structure. This design enables flexible computation across different frameworks and indicator types without modifying the core system structure. The workflow was illustrated through UML diagrams and pseudocode, showing how administrative and perception-based data can be used to generate consistent, standardised outputs. The approach not only validates LADM's extensibility but also contributes to a scalable method for integrating diverse indicator systems into one interoperable model.

However, the scope of this study is primarily focused on tenure security indicators. While the framework is theoretically extensible, its applicability to other domains – such as land use planning, valuation, or dispute resolution – requires further modelling and validation. Additionally, the implementation logic assumes access to structured, LADM-compliant datasets, which may not be available in many national contexts. Therefore, while the results demonstrate conceptual feasibility, their practical application will depend on broader data and system readiness.

Future research directions

The LADM-based monitoring framework offers a new technical pathway for standardising land administration data and integrating global indicator systems. Future research can extend its application beyond tenure security to other governance topics such as conflict resolution, compensation, spatial planning, and valuation. Reducing technical barriers – e.g. through user-friendly configuration tools – will be crucial for broader adoption.

Integrating administrative data with household surveys is another priority. Aligning LADM attributes with survey design and using survey results to refine data models would promote co-evolution of technical standards and governance practices. Emerging technologies such as AI, GIS, and blockchain may further enhance automation, spatial disaggregation, and traceability.

Finally, improving the LADM standard itself is essential – particularly for modelling governance elements, collective rights, and land use dynamics, and for enabling data flow across LIS and NSO systems. Deep integration of LADM into global indicator frameworks is not only a technical necessity but also vital for achieving sustainable land governance.

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Appendix

The table below classifies each indicator by its level of association with the LADM:

(1) **Full** computational association;
(2) **Partial** association;
(3) **Indirect** association: **(a)** indicators that reference elements modelled in LADM but are assessed through external, non-structured methods (e.g. surveys, expert scoring); **(b)** indicators that contain components loosely related to LADM concepts, without producing outputs that can be directly derived from the model;
(4) Association with **other standards**;
(5) **Non**-association, where the indicator falls outside the scope of representation in LADM, which does not exist in GLII and GLAF.

Table A1. LGAF indicators and their relationships with LADM

Land Governance Indicator	LGAF Dimension	LADM	Level of Association
Land Tenure Recognition			
1. Recognition of a continuum of rights	Individual rural land tenure rights are legally recognised.	This dimension is related to the national legislation of a country and to the implementation of the legislation. LADM supports representing individual tenure rights in rural and urban areas (see LA_Party, LA_RRR, LA_SpatialUnit and LA_Level) as well as customary and Indigenous rights (see also Social Tenure Domain Model (STDM), specialisation of LADM).	Indirect(a)
	Customary tenure rights are legally recognised.		Indirect(a)
	Indigenous rights to land and natural resources are legally recognised and protected in practice, where relevant according to international treaties.		Indirect(a)
	Urban land tenure rights are legally recognised.		Indirect(a)
2. Respect for and enforcement of rights	Accessible opportunities for tenure individualisation exist.	A LADM based LAS can enable analyses to check whether tenure individualisation exists. Information from different registries (e.g. population, company etc.) can be required to make such analysis.	Partial
	Individually held land in rural areas is formally registered.	A LADM based LAS can be used to monitor these dimensions with LA_Party, LA_SpatialUnit, LA_BAUnit and LA_Level, see Section 5.	Full
	Individually held land in urban areas is formally registered.		Full
	The number of illegal land sales is low.	A LADM based LAS can provide total number of transactions, but extra information is required to monitor these dimensions.	Partial
	The number of illegal lease transactions is low.		Partial
	Women's rights are registered and recognised in practice in both urban and rural areas.	A LADM based LAS can keep track of these dimensions, see Section 5 (LA_Level, LA_Party)	Full
	Women's property rights to land are equal to those by men.		Full
Rights To Forest and Common Lands & Rural Land Use Regulations			
3. Rights to forest and common lands	Rural group rights are formally recognised.	This dimension is related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	Even where ownership is with the state, arrangements to ensure users' rights to key natural resources (incl. fisheries) on land are legally recognised and protected in practice.		Indirect(a)
	Multiple rights over the same common land and natural resources on these lands can legally coexist.		Indirect(a)
	Most communal and/or indigenous land is mapped (demarcated and surveyed) and rights are registered.	A LADM (or STDM) based LAS can help to check how many land parcels are mapped; which rights on that parcel are registered, and who owns the right. Information from different registries (e.g. population etc.) can be required to make such analysis.	Partial

(*Continued*)

Table A1. Continued.

Land Governance Indicator	LGAF Dimension	LADM	Level of Association
4. Transparency of land use rezoning in rural areas	Restrictions regarding rural land ownership are justified.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	Restrictions regarding rural land transferability are justified		Indirect(a)
	Rural land use plans and changes in these plans (incl. rezoning) are based on public input and burden sharing.		Indirect(a)
	Rural land use changes to the assigned land use in a timely manner. use plans/rezoning for specific rural land classes (forest, pastures, wetlands, national parks etc.) are in line with actual use		Indirect(a)
	There is a clear public process for rezoning of land use classes that result in changes regarding to environmental protection.		Indirect(a)
	Use plans for specific rural land classes (forest, pastures, wetlands, national parks etc.) are in line with actual use.	ISO 19152–5 Spatial plan information is capable of representing land use types originated from zoning plans. Land use types in zoning plans (ISO 19152-5) and cadastral maps (ISO 19152-2) can be overlaid and the result map can be used to check differences. However, land use maps are required for actual use. Therefore, information from ISO 19144–3 Land Use Meta Language (LUML) is required (or other land use standards)	Partial + Other Standard
Urban Land Use, Planning, and Development			
5. Restrictions on rights: land rights are not conditional on adherence to unrealistic standards	Restrictions regarding urban land ownership and transferability are justified.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	Restrictions regarding urban land use are justified and enforced (including risk prone and protected areas).		Indirect(a)
6. Transparency of land use restrictions	There is a clear decision making process for expansion of urban land and associated land use change that respects existing rights and information on change is publicly available.	These dimensions are related to the national legislation of a country and to the implementation of the legislation. Note that ISO 19152–5 Spatial plan information is capable of representing land use types originated from zoning plans. Land use types can be obtained from ISO 19144–3 Land Use Meta Language.	Indirect(a)
	In urban areas, land use plans and changes in these plans are based on public input.		Indirect(a)
	Urban land use changes to the assigned land use in a timely manner.		Indirect(a)
7. Efficiency in the urban land use planning process	A policy is in place and progress is being made to ensure delivery of low-cost housing and associated services to those in need.	These dimensions are related to the national legislation of a country and to the implementation of the legislation. If all land use plans are represented in LADM Part 5 then spatial expansion can be traced by means of temporal characteristics of LADM.	Indirect(a)
	Land use planning effectively controls urban spatial expansion in the largest city in the country.		Indirect(a)
	Land use planning effectively controls urban development in the four largest cities in the country, excluding the largest city.		Indirect(a)
	Planning processes are able to cope with urban growth.		Indirect(a)
8. Speed and predictability of enforcement of restricted land uses	Applications for building permits for residential dwellings are affordable and effectively processed.	This dimension is related to the national regulations and pricing.	Indirect(a)
	The time required to obtain a building permit for a residential dwelling is short.	A LADM based LAS can keep track of this dimension with SP_Permit and VersionedObject classes, see Section 5.	Full

(*Continued*)

Table A1. Continued.

Land Governance Indicator	LGAF Dimension	LADM	Level of Association
9. Tenure regularisation schemes in urban areas	Formalisation of urban residential housing is feasible and affordable.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	In cities with high levels of informal tenure, a clear, well-documented process to address tenure security, infrastructure and housing, exists.		Indirect(a)
	A condominium regime provides for appropriate management of common property (rules for common property for management of driveways, parking, gardens, stairways, etc.)		Indirect(a)
Public Land Management			
10. Identification of public land and clear management	Public land ownership is justified and managed at the appropriate level of government.	These dimensions are related to the national legislation of a country, to the implementation of the legislation. Note that a LADM based LAS can keep track of this dimension (if all public land is receorded) with LA_Party, LA_BAUnit and LA_SpatialUnit.	Indirect(a)
	There is a complete recording of publicly held land.		Indirect(a)
	The inventory of public land is accessible to the public.		Indirect(a)
	The management responsibility for public land is unambiguously assigned.		Indirect(a)
	Sufficient resources are available to fulfil land management responsibilities.		Indirect(a)
	The key information on public land allocations to private interests is accessible to the public.		Indirect(a)
11. Justification and time-efficiency of expropriation processes	There is minimal transfer of expropriated land to private interests.	Expropriation can be recorded as a source in LA_Source but since it is not explicitly modelled in LADM these dimensions are not considered as monitorable by LADM. By analyzing source documents, the number of transfer amount from expropriated land to private interests and elapsed time for destined use can be detected.	Indirect(b)
	Expropriated land is transferred to destined use in a timely manner.		Indirect(b)
12. Transparency and fairness of expropriation procedures	Compensation is paid for the expropriation of all rights regardless of the registration status.	LADM can be extended with a country profile to cover expropriation information (e.g. compensation, appeal, etc.).	Indirect(a)
	There is compensation for loss of rights due to land use changes.		Indirect(a)
	Expropriated owners are compensated promptly.		Indirect(a)
	There are independent and accessible avenues for appeal against expropriation.		Indirect(a)
	Timely decisions are made regarding complaints about expropriation.		Indirect(a)
13. Transparent process and economic benefit	Public land transactions are conducted in an open transparent manner.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	Payments for public leases are collected.		Indirect(a)
	Public land is leased and/or sold at market prices.	The leased and sold land public lands and their prices can be represented with LADM (LA_Party, LA_BAUnit, VM_TransactionPrice and VM_Valuation), however expert opinion may be required to detect whether land is sold/leased at market price.	Partial
	The public captures benefits arising from changes in permitted land use.	A LADM based LAS can enable to detect changes in permitted land use through Part 5 (SP_PlanUnit), Part 2 (LA_BAUnit, LA_SpatialUnit) and their values with Part 4 (VM_Valuation). However, extra information and analyses are required to monitor these dimensions.	Indirect(b)

(*Continued*)

Table A1. Continued.

Land Governance Indicator	LGAF Dimension	LADM	Level of Association
Transfer of Large Tracts of Land to Private Investors			
14. Private investment strategy	Policy and regulations are in place to unambiguously and publicly identify public/ communal land that can be made available to investors, in agreement with legitimate land rights holders.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	A policy process is in place to identify and select economically, environmentally, and socially beneficial investments and implement these effectively.		Indirect(a)
	Public institutions involved in transfer of large tracts of land to private investors are clearly identified; without institutional and administrative overlap.		Indirect(a)
	Public institutions involved in transfer of large tracts of land to private investors share land information and effective inter-ministerial coordination mechanisms are in place to timely identify and solve competing land use assignment (incl. sub-soil).		Indirect(a)
	Investors' compliance with business plans is regularly monitored and remedial action is taken if needed.		Indirect(a)
	Safeguards are established and applied to prevent that investments involving large tracts of land infringe on or extinguish existing legitimate tenure rights.		Indirect(a)
	Cases where resettlement is possible are clearly circumscribed and procedures to carry it out are in place.		Indirect(a)
15. Policy implementation is effective consistent and transparent and involves local stakeholders	Sufficient information is required from investors for government to assess the cost-benefits of the proposed investments.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	A clearly identified process is in place for approval of investment plans and the time required is reasonable and adhered to.		Indirect(a)
	There are free, direct and transparent negotiations between right holders and investors; legitimate rights holders have always access to information.		Indirect(a)
	Contractual provisions are publicly available and include benefit sharing mechanisms with legitimate right holders.		Indirect(a)
16. Contracts are made public, and agreements are monitored and enforced	Accurate information on spatial extent and duration of approved concessions is publicly available so as to minimise overlap and facilitate transfers.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	Compliance with safeguards is monitored and enforced effectively.		Indirect(a)
	Avenues exist for legitimate right holders to air complaints if investors do not meet contractual obligations and decisions are timely and fair.		Indirect(a)

(*Continued*)

Table A1. Continued.

Land Governance Indicator	LGAF Dimension	LADM	Level of Association
Public Provision of Land Informatin: Registry and Cadastre			
17. Mechanisms for recognition of rights	There is an efficient and transparent process to formalise possession that is in line with local practice and understanding.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	Non-documentary evidence is effectively used to help establish rights.		Indirect(a)
	Long-term unchallenged possession is formally recognised.		Indirect(a)
	First-time registration on demand includes proper safeguards and access is not restricted by high formal fees.		Indirect(a)
	First-time registration does not entail significant informal fees.		Indirect(a)
18. Completeness of the land registry	The cost of registering a property transfer is low.	This dimension is related to the national legislation of a country.	Indirect(a)
	The mapping or charting of registry records is complete.	A LADM based LAS can help to check whether the mapping of registry records is complete via LA_SpatialUnit, LA_BAUnit, LA_RRR and LA_Level, see Section 5.	Full
	Economically relevant private encumbrances are recorded.	A LADM based LAS enables recording private encumbrances via LA_RRR and LA_Party, see Section 5	Full
	Socially and economically relevant public restrictions or charges are recorded.	It is possible to record public restriction in LADM via LA_RRR, see ISO 19152–2 Annex E for details.	Full
	There is a timely response to requests for accessing registry records.	Depending on the Land Registry and Cadastre regulations and their implementation, it may change.	Indirect(a)
	The registry is searchable.	A LADM based LAS enables all kind of search (e.g. geometrical, temporal, textual and so no)	Full
	Records in the registry are easily accessed.	Depending on the land registry and cadastre regulations and their implementation, it may change.	Indirect(a)
19. Reliability: registry information is updated and sufficient to make meaningful inferences on ownership	Information regarding land rights maintained in different registries is routinely synchronised so as to reduce transaction cost for users and ensure integrity of information.	Depending on the land registry and cadastre regulations and their implementation, it may change.	Indirect(a)
	Registry/cadastre information is up-to-date.	A LADM based LAS can enable to search whether registry/cadastre information is up to date via comparing date of source data (LA_Source, VersionedObject) and registration date (real world time, database time, etc).	Full
20. Cost-effectiveness and sustainability	The registry is financially sustainable through fee collection.	It depends on the financial regulation of national land registry and cadastre	Indirect(a)
	Investment is sufficient cope with demand and provide high quality services.		Indirect(a)
21. Fees are determined transparently to cover the cost of service provision	The schedule of fees is publicly accessible.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	Informal payments are discouraged.		Indirect(a)
	Service standards are published and monitored.		Indirect(a)
Land Valuation And Taxation			
22. Transparency of valuations	There is a clear process of property valuation.	A LADM based LAS enables to record all input and output data used and produced in valuation processes, see ISO 19152–4 Valuation information. However, this dimension is related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)

(*Continued*)

Table A1. Continued.

Land Governance Indicator	LGAF Dimension	LADM	Level of Association
	Valuation rolls are publicly accessible.	This dimension is related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
23. Collection efficiency	Exemptions from property taxes are justified and transparent.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	Property holders liable to pay property tax are listed on the tax roll.		Indirect(a)
	Assessed property taxes are collected.		Indirect(a)
	Receipts from property taxes exceed the cost of collection.		Indirect(a)
Dispute Resolution			
24. Assignment of responsibility	There is clear assignment of responsibility for conflict resolution.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	Conflict resolution mechanisms are accessible to the public.		Indirect(a)
	Decisions made by informal or community based dispute resolution systems are recognised.		Indirect(a)
	There is a process for appealing dispute rulings.		Indirect(a)
25. The share of land affected by pending conflicts is low and decreasing	Land disputes constitute a small proportion of cases in the formal legal system.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
	Conflicts in the formal system are resolved in a timely manner.		Indirect(a)
	There are few long-standing land conflicts (greater than 5 years).		Indirect(a)
Review of Institutional Arrangements and Policies			
26. Clarity of mandates and practice	Policy formulation, implementation, and arbitration are properly separated.	These dimensions are related to the national legislation of a country and to the implementation of the legislation. Also, organisational structure affects the evaluation of these dimensions.	Indirect(a)
	The responsibilities of the ministries and agencies dealing with land do not overlap (horizontal overlap).		Indirect(a)
	Administrative (vertical) overlap is avoided.		Indirect(a)
	Information on land ownership and use is shared among responsible institutions and relevant parts are freely accessible to the public.		Indirect(a)
	Overlaps of rights (based on tenure typology) are minimial and do not cause friction.		Indirect(a)
	Ambiguety in institutional mandates (based on institutional map) does not cause problems.		Indirect(a)
27. Equity and non-discrimination in the decision-making process	Land policies and regulations exist and are developed in a participatory manner.	These dimensions are related to the national legislation of a country and to the implementation of the legislation. Also, organisational structure affects the evaluation of these dimensions.	Indirect(a)
	There is meaningful incorporation and monitoring of equity goals in land policy.		Indirect(a)
	The implementation of land policy is costed, matched with benefits and adequately resourced.		Indirect(a)
	There is regular and public reporting indicating progress in policy implementation.		Indirect(a)

(*Continued*)

Table A2. GLII indicators and their relationships with LADM.

GLII Indicator		LADM	Level of Association
Tenure Security			
Indicator 1.1 Documented land rights	Percentage of women and men with legally recognised documentation and evidence of secure rights to land.	A LADM based LAS enable to specify this indicator using LA_Party, LA_RRR, LA_Source,	Full
Indicator 1.2 Perceived tenure security	Percentage of women and men who perceive that their rights to land are protected against dispossession or eviction.	This indicator is related to the evaluation of right holders.	Indirect(a)
Indicator 1.3 Tenure security under a plurality of tenure regimes	Level of legal recognition and protection of land rights and uses derived through either statutory or customary regimes	This dimension is related to the national legislation of a country and to the implementation of the legislation. LADM supports representing individual tenure rights in rural and urban areas (see LA_Party, LA_RRR, LA_SpatialUnit and LA_Level) as well as customary and Indigenous rights (see also Social Tenure Domain Model (STDM), specialisation of LADM). Historical source document and current status of land right can be recorded in different levels (LA_Level) in LADM.	Indirect(b)
Indicator 1.4 Equal rights of women	Level to which women and men have equal rights to land, including rights to use, control, own, inherit and transact these rights	A LADM based LAS can keep track of this dimension, see Section 5 (LA_Level, LA_Party)	Full
Indicator 1.5 Indigenous land rights	Numbers and proportion of indigenous and community groups with land claims that have legally recognised documentation or evidence of secure rights, and percentage of land areas claimed and utilised that have been legally secured.	A LADM based LAS can partially keep track of this dimension, see Section 5 (LA_Party, LA_GroupParty, LA_Source, LA_BAUnit, LA_SpatialUnit).	Partial
Land Disputes and Land Conflicts			
Indicator 2.1 Frequency of land disputes and conflicts	Percentage of women and men, Indigenous Peoples and local communities who have experienced land, housing or property disputes or conflicts of different types in the past X years	A LADM based LAS may support the calculations for this indicator. For example, both historic ownership (Level 1), current ownership (Level 2) can be stored in LADM	Indirect(a)
Indicator 2.2 Availability of dispute-resolution mechanisms	Percentage of women and men, indigenous and local communities that have access to effective dispute resolution mechanisms	This indicator is related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
Indicator 2.3 Land dispute-resolution effectiveness	Percentage of women and men, indigenous and local communities who reported a conflict or dispute in the past X years that have had the conflict or dispute resolved.	This indicator is related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
Land Administration Services			
Indicator 3.1 Land administration efficiency	Range of times and costs to conduct land transactions	This indicator is related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
Indicator 3.2 Transparency of land information	Level to which land information is available for public access	This indicator is related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
Indicator 3.3 Land administration availability	Level to which all users, including women and vulnerable groups, have equal access to land administration services	This indicator is related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)
Indicator 3.4 Mobilisation of land-based taxes	Government tax derived from land-based sources as a percentage of total government revenue.	This indicator is related to the national legislation of a country and to the implementation of the legislation. LADM can support taxation via providing information on land (LA_SpatialUnit, LA_BAUnit) and their values (VM_Valuation).	Indirect(b)
Indicator 3.5 Land area mapped	Proportion of national land areas with rights holders and tenure status identified that are incorporated into cadastral maps / land information systems.	A LADM based LAS enable to calculate the proportion defined in this indicator using LA_Party, LA_SpatialUnit and total national land area.	Full

(*Continued*)

Table A2. Continued.

GLII Indicator		LADM	Level of Association
Sustainable Land Use			
Indicator 4.1 Aggregate national changes in land-use sustainability	Changes in the geographical extent of sustainable land use, measured by: i) land cover/land use change; ii) land productivity change; and iii) soil organic carbon change.	This indicator is related to the national legislation of a country and to the implementation of the legislation. If LADM Part 5 is fully implemented, then changes in planned land use can be specified.	Indirect(b)
Indicator 4.2 Progress in sustainable land-use planning	Proportions of rural and urban administrative districts or units in which land-use change and land development are governed by sustainable land-use plans that take account of the rights and interests of the local land users and landowners.	This indicator is related to the national legislation of a country and to the implementation of the legislation.	Indirect(a)