LAND DEGRADATION NEUTRALITY (LDN): A CRITICAL REVIEW OF CONCEPTUAL GAPS AND CHALLENGES IN IMPLEMENTATION AND MONITORING

NEUTRALIDADE DA DEGRADAÇÃO DA TERRA (LDN): UMA REVISÃO CRÍTICA DAS LACUNAS CONCEITUAIS E DESAFIOS DE IMPLEMENTAÇÃO E MONITORAMENTO

NEUTRALIDAD DE LA DEGRADACIÓN DE LA TIERRA (LDT): UNA REVISIÓN CRÍTICA DE LAS LAGUNAS CONCEPTUALES Y LOS RETOS DE IMPLEMENTACIÓN Y MONITOREO

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ABSTRACT

Land Degradation Neutrality (LDN) was proposed by the United Nations Convention to Combat Desertification (UNCCD) to curb productivity loss and socio-environmental impacts caused by terrestrial ecosystem degradation. As a recent goal, LDN remains debated regarding its conceptual clarity, methodological consistency, and applicability across regional contexts. This study, covering the period 1997–2019, aims to analyze the LDN implementation process by identifying conceptual gaps and challenges related to the use of biophysical indicators for monitoring and assessment at multiple scales. The selected timeframe encompasses the consolidation of the UN Convention to Combat Desertification and the formal inclusion of LDN within the 2030 Agenda, enabling an understanding of its conceptual and institutional evolution. The integrative and bibliometric research analyzed 54 scientific articles and 8 institutional reports from indexed databases and grey literature. Results show that although LDN has advanced as a key component of SDG 15 in the 2030 Agenda, uncertainties persist concerning baseline definition, indicator comparability, and policy effectiveness in countries with limited technical capacity. Strengthening the scientific and institutional framework of LDN requires conceptual harmonization and integration among science, governance, and sustainable financing to ensure a balanced future between land degradation and restoration.

Keywords: Land Degradation. Desertification. Land Degradation Neutrality.

RESUMO

A Neutralidade da Degradação da Terra (LDN) foi proposta pela Convenção das Nações Unidas de Combate à Desertificação (UNCCD) com o propósito de conter a perda de

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produtividade e os impactos socioambientais decorrentes da degradação dos ecossistemas terrestres. Como conceito e meta recente, a LDN ainda suscita debates quanto à sua clareza conceitual, coerência metodológica e aplicabilidade em diferentes contextos regionais. Este estudo, desenvolvido no período de 1997 a 2019, tem como objetivo analisar o processo de implementação da LDN, identificando as principais lacunas conceituais e os desafios relacionados à utilização de indicadores biofísicos no monitoramento e na avaliação da meta em distintas escalas. O recorte temporal adotado justifica-se por abranger desde a consolidação da Convenção das Nações Unidas de Combate à Desertificação até a incorporação formal da LDN na Agenda 2030, permitindo observar sua evolução conceitual e institucional. A pesquisa, de natureza integrativa e caráter bibliométrico, abrangeu 54 artigos científicos e 8 relatórios institucionais, obtidos em bases indexadas e documentos da literatura cinzenta. Os resultados evidenciam que, apesar do avanço no estabelecimento da LDN como componente do ODS 15 da Agenda 2030, persistem incertezas quanto à definição de linhas de base, à comparabilidade dos indicadores e à efetividade das políticas públicas em países com limitada capacidade técnica. Conclui-se que o fortalecimento científico e institucional da LDN depende da harmonização conceitual e da integração entre ciência, governança e financiamento sustentável, de modo a assegurar um futuro com equilíbrio entre degradação e restauração das terras.

Palavras-chave: Degradação da Terra. Desertificação. Neutralidade da Degradação da Terra.

RESUMEN

La Neutralidad en la Degradación de la Tierra (LDT) fue propuesta por la Convención de las Naciones Unidas de Lucha contra la Desertificación (UNCCD) con el objetivo de frenar la pérdida de productividad y los impactos socioambientales derivados de la degradación de los ecosistemas terrestres. Como meta reciente, la LDT sigue siendo objeto de debate respecto a su claridad conceptual, coherencia metodológica y aplicabilidad en distintos contextos regionales. Este estudio, desarrollado en el período 1997–2019, tiene como propósito analizar el proceso de implementación de la LDT, identificando las principales lagunas conceptuales y los desafíos vinculados al uso de indicadores biofísicos para su monitoreo y evaluación en diversas escalas. El período elegido abarca desde la consolidación de la Convención de las Naciones Unidas de Lucha contra la Desertificación hasta la inclusión formal de la LDT en la Agenda 2030, lo que permite observar su evolución conceptual e institucional. La investigación, de carácter integrador y enfoque bibliométrico, abarcó 54 artículos científicos y 8 informes institucionales procedentes de bases indexadas y literatura gris. Los resultados muestran que, aunque la LDT se ha consolidado como un componente esencial del ODS 15 de la Agenda 2030, persisten incertidumbres sobre la definición de líneas de base, la comparabilidad de los indicadores y la eficacia de las políticas públicas en países con limitada capacidad técnica. Se concluye que el fortalecimiento científico e institucional de la LDT depende de la armonización conceptual y de la integración entre ciencia, gobernanza y financiamiento sostenible, a fin de garantizar un futuro equilibrado entre la degradación y la restauración de las tierras.

Palabras clave: Degradación de la Tierra. Desertificación. Neutralidad en la Degradación de la Tierra.

1 INTRODUCTION

Land degradation has a profound impact on societies and nature, compromising natural resources across the planet, and is the most challenging environmental problem in drylands (MEA, 2005b). This happens because such a process affects livelihoods, biodiversity, and ecosystem services, while exacerbating climate change and ultimately affecting the well-being of 1.5 billion people worldwide (LAL et al., 2012; ELD, 2015).

The impacts of land degradation are perceived very unevenly in different regions of the planet, and may be more serious in the poorest countries, where about 40% of all land degradation is concentrated (UNCCD, 2015b). In addition, because the impacts of land degradation have direct effects on climate change and biodiversity loss (LAL et al., 2012), they can also influence the ability of nations to achieve the targets set by the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (UNCBD) (LAL et al., 2012).

As defined by the United Nations Convention to Combat Desertification (UNCCD), land degradation is characterized by the reduction or loss of biological or economic productivity and complexity of agricultural land, pastures, or forest areas in arid, semi-arid, and dry sub-humid zones (UNCCD, 2015c). This process results from a combination of factors, including unsustainable land-use systems and the aggravating effect of climate change, which reduce the land's ability to provide vital services, especially under water scarcity (CHASEK et al., 2017).

Given the urgency of reversing this trend, the concept of Land Degradation Neutrality (LDN) was introduced into the global dialogue during the United Nations Conference on Sustainable Development (Rio+20) in 2012. Member States have recognised the need for urgent action to reverse degradation, proposing to achieve a land degradation-neutral world (UNCCD, 2012). This commitment was formally established in the framework of the Sustainable Development Goals (SDGs) in 2015.

Target 15.3 of SDG 15 sets the priority target of achieving the LDN by 2030, which proposes that the global rate of land degradation should not exceed its capacity to recover, keeping the extent of degraded land stable or with minimal increase (UN, 2014; UNCCD, 2015).

Although the LDN is a globally recognized goal and fundamental for sustainable development, its implementation and practical monitoring present significant complexities, especially with regard to its conceptual basis and the biophysical indicators used. This explains the fact that the concept and, in particular, its biophysical monitoring indicators have been the target of criticism by the scientific community in relation to its conceptual clarity, methodological consistency and effective applicability in different regional contexts.

Given this scenario and the need to guide progress towards SDG Target 15.3, the following research question arises: What are the main conceptual gaps, uncertainties, and challenges related to the LDN implementation process and the use of its biophysical indicators for monitoring and evaluating this goal in different regions of the planet?

The relevance of this study lies in its contribution to critically addressing a central theme of the global sustainability agenda. The deepening of the analysis of the LDN implementation process and the identification of limitations in the conceptual basis and biophysical indicators are crucial to guide future methodological and scientific improvements. In practical terms, this debate is indispensable to subsidize public policies that are truly effective in combating degradation and desertification. By highlighting gaps and uncertainties, this research provides an essential knowledge base for countries to adapt and strengthen their strategies, contributing more effectively to achieving the goal of a land degradation-neutral world.

In this sense, the present study aims to analyze the process of implementation of Land Degradation Neutrality, identifying the main gaps related to the conceptual basis and biophysical indicators, as well as the uncertainties and challenges found in related research to monitor and evaluate LDN in various regions of the planet.

2 THEORETICAL FRAMEWORK

Land degradation has been configured, over the last decades, as one of the most serious environmental and social challenges faced by humanity. This phenomenon compromises livelihoods, biodiversity, and ecosystem systems, intensifying climate change and affecting the well-being of an estimated 1.5 billion people worldwide (NACHTERGAELE et al., 2010; LAL et al., 2012; ELD, 2015). It is a complex and multidimensional problem, whose causes and effects transcend geographical borders and demand an integrated approach, articulating ecological, social and economic dimensions.

The conceptual discussion on land degradation is marked by the breadth and polysemy of the term "degradation", often used generically to encompass different environmental processes — such as desertification, salinization, erosion, compaction, and loss of soil fertility. This semantic generalization, although common in the literature, makes it difficult to accurately measure the phenomenon and compare it between studies (GIBBS; SALMON, 2015).

According to the United Nations Convention to Combat Desertification (UNCCD), land degradation corresponds to the reduction or loss of biological or economic productivity, as well as the ecological complexity of agricultural land, pastures, woodlands, and areas of native vegetation in arid, semi-arid, and dry sub-humid zones. At its core, this process results from unsustainable human practices and the inappropriate use of natural resources (UNCCD, 2015c; AYNEKULU et al., 2017).

The third edition of the *World Atlas of Desertification* (CHERLET et al., 2018) shows that it is not possible to deterministically map the global extent of degradation, given the complexity of the interactions between social, economic, and environmental systems. This finding reinforces the need for multiscale methodologies and integrated approaches that consider both the biophysical factors and the socioeconomic dynamics that aggravate the process.

According to the *Global Assessment of Soil Degradation* (GLASOD), about 20% of soils in dry areas of the planet are degraded, 17% have mild or moderate degradation and more than 2.5% are heavily degraded (GIBBS; SALMON, 2015). The most affected regions are Asia, with approximately 370 million hectares degraded; Africa, with about 319 million; and the American continent, with 279 million hectares. In this context, the *Food and Agriculture Organization* (FAO, 2011) warns that, if current patterns of use and occupation are maintained, by 2025 about 25% of the planet's arable land could be degraded. In arid and semi-arid regions, the picture is even more alarming, with about 69% of potentially agricultural areas suffering erosion and loss of fertility (SALVATI et al., 2009). In these fragile environments, degradation intensified by human action reaches critical levels, configuring itself as desertification (BRASIL, 2004).

The UNCCD defines desertification as the process of land degradation in arid, semi-arid and dry sub-humid regions, resulting from the interaction between climatic factors and human activities (UNCCD, 2015; MAPBIOMAS, 2018). This definition broadens the understanding of the phenomenon by including, in addition to the soil, the loss of biodiversity and the compromise of water resources. Although there are natural causes — such as climatic variations and geomorphological processes (MEADOWS; HOFFMAN, 2003; EU, 2011; WEBB et al., 2017; DHARUMARAJAN et al., 2019) —, degradation is often aggravated by inadequate anthropogenic land use and management practices (CUNHA et al., 2013; SPALEVIC et al., 2014; MATANO et al., 2015; WANJALA; KINYANJUI, 2016).

The phenomenon of desertification manifests itself in various parts of the world, especially in North and South Africa (Sahel region), south-central Eurasia (especially China), the western portion of the Americas and Australia (ROSÁRIO, 2004). In Brazil, the most vulnerable areas are predominantly located in the Northeast region, although recent studies point to the expansion of these climatic zones to other regions of the country (MAPBIOMAS, 2018). Such evidence highlights the urgency of environmental mitigation and restoration policies adjusted to local specificities.

The conceptual breadth of the terms *land degradation* and *desertification* (ZUCCA, 2012) amplifies the controversies and makes it difficult to make precise estimates at multiple scales. The absence of a standardized global monitoring system is, therefore, one of the main obstacles to the formulation of effective public policies and to the international comparability of data (GIBBS; SALMON, 2015).

In view of the socio-environmental impacts of land degradation, the theme was incorporated into the global goals of the United Nations (UN), in 2015, in the document *Transforming our World: The Sustainable Development Agenda for 2030*. This document defined 17 Sustainable Development Goals (SDGs), divided into 169 integrated and indivisible goals, respecting the specificities and priorities of each State.

In the context of SDG 15, which deals with "protecting, restoring and promoting the sustainable use of terrestrial ecosystems, sustainably managing forests, combating desertification, halting and reversing land degradation and halting biodiversity loss", target 15.3 was approved, which determines, "by 2030, to combat desertification, restore land and degraded soil, including land affected by desertification, droughts and floods, and striving to achieve a land degradation-neutral world" (CGEE, 2016).

The concept of *Land Degradation Neutrality* (LDN) emerged in 2015, in the context of the UNCCD, defined as "a state in which the amount of healthy and productive land resources, necessary to support ecosystem services, remains stable or increases within specific temporal and spatial scales" (UNCCD, 2015). In practical terms, the LDN implies that the degradation that occurred in a given locality must be compensated by the recovery or rehabilitation of previously degraded areas.

In Brazil, research on land degradation and LDN has intensified since 2013, especially in semi-arid regions. Studies by SALGADO and OLIVEIRA (2018) and CUNHA et al. (2013) highlight the importance of integrating biophysical indicators, remote sensing, and public policies in improving environmental monitoring. Despite the advances and the country's adherence to the goals of the UNCCD, challenges related to methodological standardization and institutional articulation persist (BAPTISTA; SILVA, 2019). Such efforts, however, constitute an essential theoretical and methodological basis for strengthening the LDN agenda in the national and regional context.

The literature on Land Degradation Neutrality (LDN) reveals the coexistence of different theoretical currents that express different conceptions about its foundations and forms of implementation. These approaches reflect tensions between ecological, technical, and institutional perspectives, demonstrating the complexity of the concept and its multiple interpretations in the field of environmental sciences.

On the one hand, authors linked to the **ecosystem and restorative** approach (ARONSON; ALEXANDER, 2013; COWIE et al., 2018) understand the LDN as a strategy for **reconciling conservation and development**, emphasizing the need to integrate mitigation and ecological restoration policies. From this perspective, neutrality represents a dynamic balance between the land's capacity to sustain ecosystem services and human demands for productivity and land use.

On the other hand, currents of **a technocratic and quantitative** nature (KUST et al., 2016; DALLIMER; STRINGER, 2018) prioritize the improvement of **biophysical indicators** and the search for standardized methodologies that ensure global comparability. This strand attributes a central role to the measurement of degradation, defending the need for universalizable models for monitoring LDN, although this standardization does not always contemplate regional and socioeconomic specificities.

There is also a **critical-institutional** aspect (CHASEK et al., 2019; GICHENJE; PINTO-CORREIA, 2019), which problematizes the political-structural limitations and inequalities of technical capacity between countries. This perspective questions the feasibility of achieving neutrality in asymmetric contexts, especially where there is institutional fragility, scarcity of resources, and dependence on international funding agendas.

This diversity of interpretations reinforces that the **conceptual gaps and methodological uncertainties** discussed in this research do not stem only from technical limitations, but reflect **epistemological tensions** between different ways of conceiving degradation, restoration, and sustainability. Understanding these theoretical divergences is essential to consolidate a **more cohesive conceptual framework**, capable of guiding comparable methodologies and consistent interpretations of the LDN within the scope of global sustainability goals.

Several factors accentuate environmental vulnerability in the face of degradation: irregular rainfall, shallow soils susceptible to erosion, fragmentation of vegetation, poverty, unemployment and lack of social infrastructure. However, there is still no scientific consensus on which biophysical indicators are most appropriate to measure degradation or to assess progress towards neutrality.

The use of environmental indicators represents a fundamental tool to assess the state of the landscape and understand the responses to anthropogenic pressures. According to NIEMEIJER and DE GROOT (2008), environmental indicators are variables capable of describing the state of the environment, its pressures, impacts and systemic responses. For MATTALO JR. (2001), a good indicator must be meaningful, measurable, clear and sensitive to changes, reflecting future trends. Given the complexity of ecological processes, no single indicator is able to fully represent land degradation; therefore, it is recommended to use combined indicators, forming composite indices that allow comparisons between different spatial contexts (SALVATI; ZITTI, 2009).

Achieving target 15.3 of the Sustainable Development Goals (SDGs), aimed at combating desertification and restoring degraded land by 2030, requires the development of more accurate analytical models capable of identifying and measuring affected areas. This advance depends on overcoming the current limitations in the definition and operationalization of biophysical indicators, which are fundamental for the effective monitoring of land degradation.

Understanding the interrelationships between degradation processes and biophysical systems is an essential condition for the scientific and institutional strengthening of the LDN agenda. This integrated approach — which articulates science, technique, and policy — broadens the debate on sustainability, territorial planning, and rational management of natural resources, favoring the improvement of conservation and environmental governance strategies at different scales.

3 METHODOLOGY

The present research is characterized as an integrative bibliographic review associated with an exploratory bibliometric analysis, based on the principles of BOTELHO, CUNHA and MACEDO (2011). This methodological combination allowed the integration of conceptual, technical, and political dimensions of Land Degradation Neutrality (LDN), enabling a comprehensive understanding of international scientific production on the subject.

The time frame in the period 1997–2019 was defined as corresponding to the period of consolidation of the United Nations Convention to Combat Desertification (UNCCD) and the formalization of the LDN in the 2030 Agenda for Sustainable Development, which marks the conceptual maturation and institutionalization of global policies for sustainable land management.

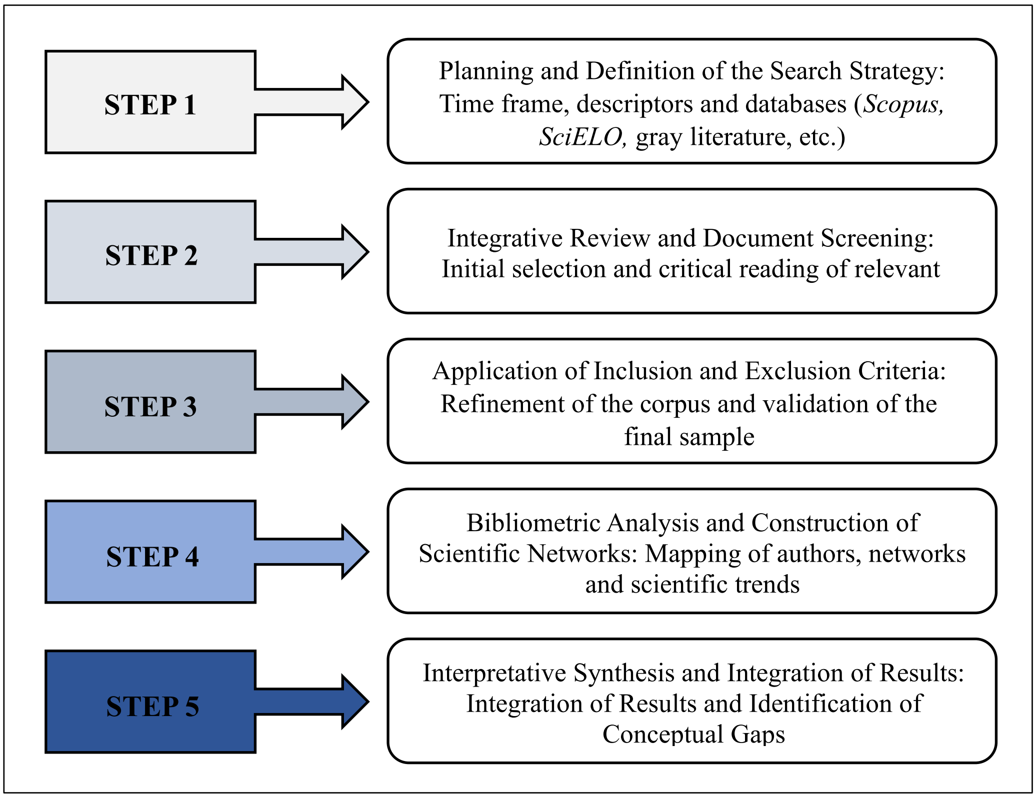
3.1 METHODOLOGICAL STRUCTURE AND STAGES OF THE RESEARCH

The methodology was structured in five sequential and interdependent stages, represented in the Methodological Diagram (Figure 1). The flowchart illustrates the iterative nature of the process, evidencing the integration between the literature review, the selection criteria and the bibliometric analysis, which supported the final interpretation of the results.

To ensure greater transparency, the exact number of documents analyzed was recorded at each stage of the methodological funnel: initially 312 records identified, reduced to 156 after the screening of titles and abstracts, of which 62 were selected in the complete reading, resulting in the final corpus of 54 scientific articles and 8 institutional reports used in qualitative and bibliometric analyses.

Figure 1

Methodological Flowchart



Source: Prepared by the authors, 2020.

3.2 STEP 1 – PLANNING AND DEFINING THE SEARCH STRATEGY

The time frame (1997–2019), the scientific bases, and the main descriptors used in the searches were established. The search was carried out in *the Scopus*, SciELO, *ResearchGate* and *Google Scholar databases*, complemented by consultations with the gray literature (reports from UNCCD, FAO, EEA and MMA).

The search expressions were structured with the TITLE-ABS-KEY command, using Boolean operators (AND, OR, NOT) to combine terms and refine the accuracy of the results. The main descriptors included: *"land degradation neutrality", "desertification*", "*dryland degradation",* "*biophysical indicators"* and *"sustainable land management".* The search was structured using the *TITLE-ABS-KEY* command, using Boolean operators (*AND, OR, NOT*) to refine the accuracy of the results.

This stage aimed to identify relevant scientific publications and institutional documents that addressed the conceptual development and evaluation mechanisms of the LDN in different regional contexts.

3.3 STEP 2 – INTEGRATIVE REVIEW AND SCREENING OF DOCUMENTS

The integrative review consisted of a systematic process of **critical reading and thematic categorization**, guided by the criteria of relevance, originality, and adherence to the scope of the LDN. Initially, **312 documents were identified**, of which **156** were kept after reading titles and abstracts. The data were organized according to the baseline variables (author, year, country, descriptors, thematic area, and type of publication).

Table 1 presents the synthesis of the databases consulted, the search parameters and the inclusion criteria used in this stage.

Table 1

Database Synthesis and Search Parameters

Database	Publication Type	Period	Search Fields	Examples of Descriptors	Inclusion Criteria
Scopus	Indexed articles	1997–2019	Title, Abstract, Keywords	*"land degradation neutrality", "LDN indicators", "desertification"*	Articles with ≥10 citations
SCIELO	Reviewed Articles	2000–2019	Title, Abstract	"Sustainable land	Thematic relevance

				management", "biophysical indicators"	
Google Scholar / Grey Literature	Reports and technical documents	1997–2019	Full text	"UNCCD", "2030 Agenda", "SDG 15.3"	Recognized institutional sources

Source: Prepared by the authors, 2020.

3.4 STEP 3 – APPLICATION OF INCLUSION AND EXCLUSION CRITERIA

At this stage, the documents were filtered to ensure coherence and scientific representativeness.

The inclusion criteria included:

- Publications between 1997 and 2019;
- Texts in English, Spanish or Portuguese;
- Studies on biophysical indicators, evaluation methodologies or public policies related to LDN;
- Institutional documents of international organizations.

Opinion articles with no empirical basis, studies without explicit mention of LDN or focused exclusively on agricultural degradation were excluded. Opinion articles without empirical basis, studies without explicit mention of the LDN, duplicate studies and studies focused exclusively on agricultural degradation were excluded. After applying the filters, 62 documents were analyzed in full text, resulting in the final corpus of 54 scientific articles and 08 institutional reports.

3.5 STEP 4 – BIBLIOMETRIC ANALYSIS AND CONSTRUCTION OF SCIENTIFIC NETWORKS

This stage aimed to identify patterns of production, collaboration and thematic convergence on the LDN in the delimited period, articulating quantitative data and qualitative interpretations. The metadata was previously organized, with standardization of authors, institutions, countries and keywords, ensuring the consistency and comparability of the information.

The final database was exported to *the VOSviewer 1.6.20* software, applying the *"association strength"* normalization model, as proposed by VAN ECK AND WALTMAN (2014), together with the modularity algorithm for the detection of conceptual clusters. This approach allowed the identification of co-authorship networks, institutional collaboration nuclei and emerging research trends.

The results of this stage enabled the formation of three *main interpretative* clusters:

(1) Conceptualization and definition of the LDN;
(2) Biophysical indicators and evaluation methodologies;
(3) Uncertainties and challenges related to implementation, including governance issues, scales of analysis, and integration with environmental policies.

From these networks, it was possible to establish the empirical and conceptual basis that guided the integrated thematic analysis, developed in the next stage.

3.6 STEP 5 – INTEGRATED THEMATIC ANALYSIS AND SYNTHESIS OF RESULTS

In this stage, the correlation between the bibliometric results and the qualitative evidence extracted from the literature was carried out, in order to understand the conceptual, technical and methodological foundations of the LDN. The analytical reading of the full texts allowed the identification of excerpts that addressed the conceptual dimensions, the biophysical indicators and the operational challenges of the implementation of the LDN in different contexts.

The information was classified into three analytical macrogroups:

1) Conceptualization and definitions of the LDN;
2) Biophysical indicators and methodological integration;
3) Uncertainties and gaps, associated with baseline, measurement scales, governance, and financing.

Based on this categorization, an analytical triangulation was carried out between the bibliometric clusters and the thematic categories, which allowed the construction of a convergence matrix between the main conceptual trends and the empirical evidence in the literature. This matrix evidenced gaps and recurrent challenges, later systematized in **Table 2 (Results and Discussion),** coherently integrating the quantitative and qualitative results of the research.

As a limitation, the possibility of linguistic bias is recognized, due to the predominance of publications in English, which may have restricted the inclusion of relevant studies in other languages. In addition, there is a time restriction, as the cut up to 2019 does not cover more recent methodological and institutional advances, still under development after the consolidation of the 2030 Agenda.

4 RESULTS AND DISCUSSIONS

4.1 CONCEPTUAL FOUNDATIONS OF LAND DEGRADATION NEUTRALITY (LDN)

The concept of Land Degradation Neutrality (LDN), as defined by the UNCCD (2015), represents the state in which the quantity and quality of terrestrial resources remain stable or increase over time, ensuring the maintenance of ecosystem functions and food security. This proposal aims to balance degraded and non-degraded areas, applying to all ecosystems and territorial scales (KUST, ANDREEVA and COWIE, 2017).

The main innovation of LDN lies in the requirement to restore and sustainably manage the earth's resources, so that any inevitable losses are compensated by the rehabilitation of previously degraded areas (GNACADJA and WIESE, 2016; WUNDER, 2018). This logic implies a transformation in global environmental governance, in which neutrality results from the sum of local and national goals (KUST et al., 2016; 2018).

However, conceptual and operational challenges remain. The definition of "quantity" and "quality" of land requires the use of physical and qualitative indicators, the application of which still presents methodological complexities (AKHTAR-SCHUSTER et al., 2016; 2017). The absence of standardized baselines and clearly defined spatial and temporal scales hinders international monitoring and comparability (SAFRIEL, 2017; DALLIMER and STRINGER, 2018).

In response to these limitations, the UNCCD recognizes the need to strengthen the scientific foundation and harmonize methodologies, reducing divergent interpretations. Three axes structure this guideline: maintenance of ecosystem services; integration between environmental and socioeconomic goals; and inclusive and participatory governance (UNCCD, 2015).

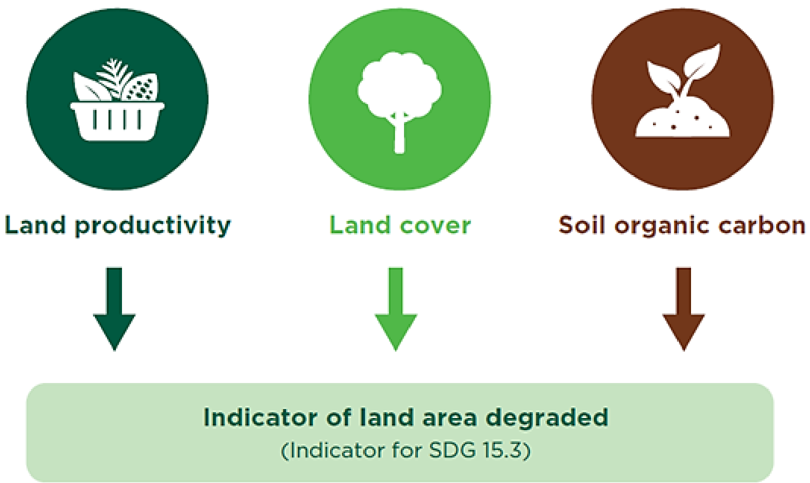
In summary, the LDN represents an integrative approach that articulates ecological, social and economic dimensions, guiding policies for restoration and sustainable management of soils. Its effectiveness depends on methodological standardization and international cooperation, ensuring comparability between countries and strengthening local actions to mitigate degradation.

4.2 BIOPHYSICAL INDICATORS OF THE LDN

To monitor progress towards Land Degradation Neutrality, the UNCCD has established a minimum set of three global biophysical indicators, which are key to monitoring SDG Target 15.3 (UNCCD, 2013; 2016a; GLII, 2015). These indicators are: (1) land cover and cover changes, (2) land productivity, and (3) soil organic carbon stock (SOC). Figure 2 summarizes the model proposed by the Convention, which guides the measurement of soil degradation and restoration on a global scale.

Figure 2

The UNCCD indicators to assess trends in land degradation and achieve the LDN SDG



Source: UNCCD, 2015.

Land cover is the most sensitive indicator of anthropogenic and natural transformations, and can be monitored by remote sensing. Changes in vegetation cover indicate both degradation processes, such as deforestation and fragmentation, and recovery (CUNHA et al., 2013; EASDALE et al., 2019). Therefore, the spatial analysis of the cover must be complemented by local validation, in order to distinguish sustainable from unsustainable variations (WUNDER, 2018).

Land productivity, associated with Net Primary Productivity (NPP), reflects the capacity of vegetation to accumulate biomass and regulate energy and matter exchanges between surface and atmosphere (LIETH, 1975; BAO et al., 2017). Significant changes in NPP can indicate anthropogenic pressure or climatic disturbances, and are therefore a useful indicator to assess the balance between degradation and restoration.

Soil organic carbon stock (SOC) is one of the most robust indicators of the health of terrestrial ecosystems, reflecting the soil's capacity to store carbon and sustain ecosystem services (UNCCD, 2016a; CHAPPELL et al., 2019). Despite its relevance, the lack of standardized data and consistent monitoring systems in various regions of the world limits the comparability of results (JONES and FALLOON, 2009).

The integration of the three indicators constitutes a relevant methodological advance, as it allows us to understand together the structural, functional and temporal dimensions of land degradation. Its effectiveness depends on robust time series, regional calibration, and articulation between scientific research and territorial management (KUST et al., 2016; GICHENJE and GODINHO, 2018). Thus, understanding the interdependence between indicators is essential for diagnosing trends and strengthening public policies aimed at sustainable land governance.

4.3 UNCERTAINTIES AND CHALLENGES FOR THE IMPLEMENTATION OF THE LDN

Table 2 summarizes the main uncertainties and challenges identified in the scientific literature on the operationalization of Land Degradation Neutrality (LDN) in different global contexts.

Table 2

The main uncertainties and challenges identified in the reference articles on LDN

UNCERTAINTIES / CHALLENGES	AUTHOR(S) / YEAR
Need for a methodology adapted to regional realities to define the baseline of the LDN (different causes and trends of land degradation, natural and socioeconomic characteristics of the territory);	UNCCD (2012, 2014a); CASPARI et al. (2015); CHASEK et al. (2015); GRAINGER (2015); STAVI & LAL (2015); KUST et al. (2018)
Consideration of environmental, economic, social, political and cultural particularities, as well as the diversity of determinant factors and processes of land degradation, among countries, which need to be considered in the formulation of LDN goals;	O'CONNELL et al. (2013); FAO (2011); NKONYA et al. (2015); KUST et al. (2018)
Balanced integration between prevention and reversal of degradation (ecosystem approach): (i) address current and	ARONSON & ALEXANDER (2013); GIROT et al. (2013);

future land degradation by avoiding/preventing/minimizing land degradation processes; and (ii) reverse past land degradation;	UNCCD (2014b, 2014c); CHASEK et al. (2015); COWIE et al. (2018)
Limits in the measurement of degradation in terms of the quantity and quality of available land: severity of degradation and area of land involved;	UNCCD (2012, 2014a); EC JRC (2014); SOLOMUN et al. (2018)
Lack of consensus on the optimal scales of application and monitoring of the status and trends of the LDN;	NKONYA et al. (2015); CROSSLAND et al. (2018); SOLOMUN et al. (2018)
Difficulty in measuring large areas due to the need for technical assistance and scientific research, especially in poorer countries;	GRAINGER (2015); COWIE et al. (2018)
Definition and standardization of national LDN LDN indicators;	KUST et al. (2018); DALLIMER & STRINGER (2018)
The need for simple, comparable indicators based on common principles;	O'CONNELL et al. (2013); CASPARI et al. (2015); CHASEK et al. (2015); GRAINGER, 2015; TAL (2015); STAVI and LAL (2015);
Integration of LDN with biodiversity, climate (climate change), poverty, and food security	KUST et al. (2018); ARONSON AND ALEXANDER, 2013; LIU et al., 2013; IPCC, 2014; REID, 2015); OKPARA et al., 2108;
Management of *trade-offs* and synergies between different land uses for multiple benefits;	LIU et al. (2013); EC JRC (2014)
Application of the socio-ecological approach (SES) in the implementation: human beings as part of nature in the search for LDN;	OKPARA et al. (2108);
Creation of national policies and partnerships between the State (national and local governance) and the scientific community;	KUST et al. (2018); CROSSLAND et al. (2018)
Involvement and effective commitment of all stakeholders;	UNCCD (2012, 2014a); GRAINGER, 2015; GICHENJE, MUÑOZ-ROJAS & PINTO-CORREIA (2019)

High costs of implementation, evaluation and monitoring of the LDN,	DALLIMER & STRINGER (2018); DARADUR et al. (2018); CHASEK et al. (2019) CHASEK et al. (2019); GICHENJE, MUÑOZ-ROJAS and PINTO-CORREIA, (2019)

Source: the Author, 2025.

The scientific literature shows that the implementation of the LDN faces a significant set of uncertainties and conceptual, methodological and institutional challenges, which compromise its consolidation as a global sustainability goal. The most critical point refers to the definition of baselines, which should reflect the environmental, social and economic particularities of each territory (UNCCD, 2012; CASPARI et al., 2015; KUST et al., 2018).

Another recurrent limitation is the selection of analysis scales and biophysical indicators used to measure degradation. The adoption of inappropriate scales can distort results and make comparisons between countries and biomes difficult (CROSSLAND et al., 2018; SOLOMUN et al., 2018). In addition, the lack of reliable data and the low technical-scientific support in countries with limited institutional capacity represent obstacles to the measurement and monitoring of large areas (GRAINGER, 2015).

The lack of international consensus on the standardization of LDN indicators is also a significant weakness. These indicators must be simple, measurable, and based on integrative ecosystem principles, but the multiplicity of definitions and the absence of universal parameters make comparability difficult (O'CONNELL et al., 2013; STAVI and LAL, 2015).

From a strategic point of view, the literature reinforces the need for integrated ecosystem approaches, which reconcile preventive and restorative actions, combining the mitigation of current degradation and the recovery of areas already affected (ARONSON and ALEXANDER, 2013; LIU et al., 2013; IPCC, 2014). This perspective should incorporate dimensions such as biodiversity, climate change, and food security, maximizing synergies between public policies (KUST et al., 2018; OKPARA et al., 2018).

Finally, the effectiveness of the LDN depends on favorable institutional environments and participatory governance mechanisms, with cooperation between governments, the scientific community, and civil society. The absence of robust national policies, the fragmentation of inter-institutional actions, and the high costs of implementation continue to limit progress (DALLIMER and STRINGER, 2018; GICHENJE, MUÑOZ-ROJAS and PINTO-CORREIA, 2019).

5 CONCLUSION

The results of this research confirm the relevance of Land Degradation Neutrality (LDN) as one of the central goals of the 2030 Agenda, established by the UN. The analysis demonstrates that, although the concept represents an important advance in the integration between science, policy and environmental management, its definition remains incomplete, which limits methodological clarity and hinders the effective monitoring of degradation processes on a global scale.

It was found that the consolidation of the LDN requires the improvement of its conceptual bases and the standardization of biophysical indicators, in order to ensure comparability and effectiveness in public policies aimed at sustainable land governance. In this sense, it is essential that governments incorporate the LDN into their environmental governance agendas, establishing stable financing mechanisms and integrated institutional structures, with active participation of the scientific community and civil society in the restoration and rehabilitation of degraded lands.

From an academic point of view, this study offers a significant theoretical contribution by systematizing and critically discussing the conceptual and methodological foundations of the LDN, highlighting gaps, uncertainties, and opportunities for future research. Such a contribution reinforces the importance of interdisciplinary and multi-scalar approaches in the formulation of more precise and equitable environmental policies.

It is therefore recommended that further investigations deepen the empirical validation of the three minimum indicators proposed by the UNCCD, considering different biophysical and socioeconomic contexts. In addition, it is suggested the development of complementary indicators that are more sensitive to local dynamics, capable of strengthening the monitoring and effective implementation of the global goal of a neutral world in land degradation.

Finally, it is important that future versions of this research integrate post-2019 analyses, in order to reflect the most recent conceptual, institutional, and methodological evolution of the LDN, considering the scientific and political advances that occurred after the consolidation of the 2030 Agenda and the maturation of global neutrality strategies.

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