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REVIEW

Challenges and Pathways for Sustainable Development in Global Land Use Systems: A Narrative Review

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ABSTRACT

Land is essential for the flourishing of human civilizations. It is a complex interplay of natural processes, socio-economic dynamics, and environmental sustainability. Hence, it influences policy, research, and practice. This study critically reviews the literature about the challenges and issues currently explored for sustainable development in global land use systems based on an extensive bibliographic database from the Web of Science. It explores the complex world of global land use system development, examining research trends, tools, and future directions. This study's findings indicate that current research trends emphasize the use of emerging digital

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technologies, including geospatial and informatics techniques, Geo-detectors, regression models, artificial intelligence, and socio-economic models. These tools are instrumental in addressing the challenges posed by land use change at various scales. They enable us to effectively identify, track, and enhance our understanding of the sustainability, science, and management of land use systems. The studies reviewed offer valuable support for initiatives aimed at adopting innovative theories, methods, instruments, and procedures to tackle land use and sustainability issues related to natural resources globally. Furthermore, new fields within land use systems are increasingly recognized for their potential to transform traditional practices, strengthen urban-rural linkages, and contribute to the realization of the 17 UN Sustainable Development Goals. This recognition stems from the multidisciplinary nature of the discipline.

Keywords: Current Issues; Global; Land Cover; Land Management; Land Use; Sustainable Development

1. Introduction

The canvas of human history bears the marks of humans' relationship with the land. Over the centuries, agricultural practices, settlements, and use of resources have shaped landscapes and societies. The agrarian roots of civilization laid the groundwork for evolving land use systems that responded to the needs of growing populations [1]. From the agricultural revolution to the industrial age, these systems evolved and encountered challenges, leading to the complex mosaic of land use observed today. A major turning point came with the introduction of mechanization and rapid urbanization in the 19th and 20th centuries. Technological advancements and the rise of industrial economies spurred changes in land use patterns [2,3]. Expansive agricultural fields coexisted with sprawling urban landscapes, each competing for their share of this limited resource in most developing countries. Concurrently, concerns about environmental sustainability began to emerge, leading to a shift towards sustainable land use.

The evolution of sustainable land use systems worldwide has attracted interest from various academic and industrial circles. As a result, there have been increasing calls for more research and scientific progress in Land System Science (LSS) discipline. This has influenced global discourse, policy directives, and state-of-the-art initiatives. Worldwide socio-political, economic, and environmental investments and development have led to transformations of previous environments into various land use forms. However, these desired changes have had unintended consequences, including land degradation, air pollution, concerns about food and water scarcity, infiltration of cultural systems, climate stressors, and disturbances. **Figure 1** depicts the changes in global land use systems between 1993 and 2023. The spatial distribution shown in the figure was derived from Landsat datasets stored in Google Earth Engine (GEE) (https://code.earthengine.google.com/) and analyzed using ArcGIS 10.8 software.

The global LULCC (**Figure 1**) spatial distribution based on the change detection analysis performed in this study illustrates the increasing areas of grasslands, built environments, and water bodies over the past 30 years (1993–2023) (**Supplementary Table S1**). Specifically, cultivated lands, built environments, grasslands and water bodies have expanded globally at annual rates of 0.38%, 0.16%, 0.41% and 0.001%, respectively. On the other hand, unused land and natural vegetation have seen a decrease in their areas at annual rates of 0.02% and 0.36%, respectively, over the same period. These changes based on the spatial distribution of land use systems between 1993 and 2023, largely driven by human-induced and biophysical factors across different eras, underscore the relevance of studying and understanding shifts in global land use systems. Additonal information related to accuracy assessment results are captured in Supplementary Figure S1. According to Sarfo et al., the Global Land Project (GLP) that began in 2006, through a group of land system scientists from various academic and research institutes worldwide, has played a significant role in shaping discussions on LSS [4]. Combining the efforts of the International Geosphere-Biosphere Programme (IGBP) and the Inter-

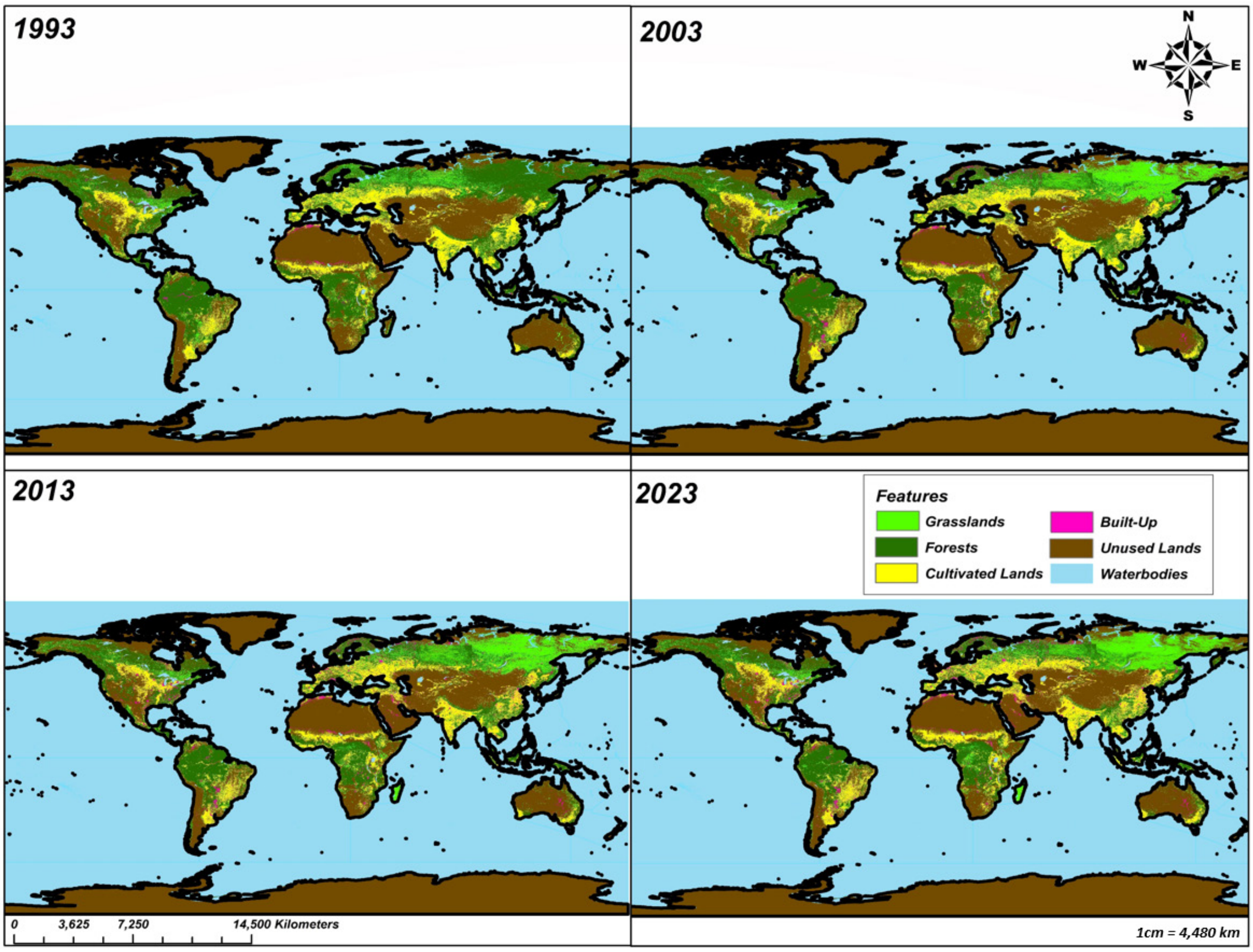

Figure 1. Spatial Distribution of Land Use and Land Cover Change (LULCC) Across the Globe (1993–2023).

national Human Dimensions Programme on Global Environmental Change (IHDP), GLP serves as an essential platform for synthesizing information, methodologies, and knowledge within the LSS community. Subsequent to the 1994–2005 LULCC project and the Global Change and Terrestrial Ecosystems project, GLP tackles the evolving challenges of understanding and managing land use systems worldwide. In line with the objectives of the GLP, this narrative review sought to identify key issues that engulf the tools and practices used in facilitating land management, informatization, and sustainability of land use systems worldwide using recent studies spanning from 2004 to 2023.

Land Use Management (LUM) innovations are essential for tackling the contemporary challenges in LSS and LULCC [5]. Technological advancements, including Geographic Information Systems (GIS), remote sensing, and drone technology, have transformed planning and monitoring of the subject. According to Kumar et al., these innovations allow for more precise and efficient management of land resources [6]. By providing detailed, real-time data on land use patterns, environmental conditions, and resource availability, these technologies support improved decision-making [7]. According to Dinesha et al., sustainable farming techniques such as permaculture, agroforestry, and organic farming are currently utlized to enhance farming outputs while maintaining ecological balance [8]. In cities, urban greenery and architecture, urban agriculture, and vertical farming are presently being institutionalized to promote urban resilience and transform cities [9]. For further details, please refer to **Supplementary Table S2**, which details the research progress in relation to the subject worldwide. Over the years, there have been significant advancements at various levels—global, regional, national, and local—that have enhanced scientific productivity and improved the identification, monitoring, and response of land use systems to environmental challenges. This narrative review aims to enrich existing literature and explore various concepts related to land use systems, land management, and sustainability worldwide that influence policy, research, and practice. Specifically, the present study will analyze current trends, smart tools, and practices in the sustainability of LSS land use systems worldwide.

2. Methodology

Source of Data, Search, Screening and Analysis Procedures

This narrative review examined land use studies conducted worldwide. Data from the core database collection of Web of Science (WoS) between 2004 and 2023 were used. The WoS is renowned for its standardized and widely recognized bibliographic and citation database, which is organized in a well-structured format. This study specifically focused on significant studies published between 2004 and 2023 because they offer valid and reliable information on advancements, tools, and scientific production in the field of land use [10]. Overall, four stages were utilized in generating and screening the datasets used for the analysis. In the initial stage marks data search in WoS (**Figure 2**), based on the search terms "global land use system*" (Topic) or "land use management" (Topic) or "land use science" (Topic) or "land use" (Topic) and " land cover change" (Topic) and "sustainable development" or "global sustainability" (Topic) were utilized. The first step generated an overall output of 2,221 documents. The overall output was further refined to constitute book chapters, reviews and original research articles during the second stage of the screening process. This resulted in the overall output, being reduced to 2,204 documents. The third stage included limiting the search to some disciplines interlinked to the study's rationale, based on WoS database core collection, as well as some specific indexing. This further shrunk the total output to 1,829 documents. The final step further limited the resultant outcome by excluding papers not published in English medium. This brought the total to 1,814 documents, which were utilized for the comprehensive analysis conducted in this study.

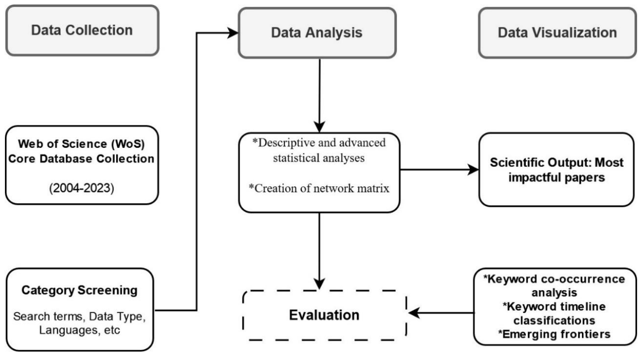

Figure 2. Search, Screening and Analysis Procedures Utilized in This Study.

This narrative review study focused on recent years considering the ever-evolving landscape of land use science. As new information is constantly being generated, it is crucial to stay current with latest advancements; hence, this study focuses on recent years. Also, focusing on recent years facilitated the identification of knowledge gaps, trends and developments that require further investigation to drive innovation in the field. The data gathered through this study shows that as we go back in time, scientific studies in relation to land use science become increasingly sparse. Additionally, there is a scarcity or absence of comprehensive review studies on global land use systems. This study includes recent developments in the field that may have been ignored/overlooked in earlier reviews. It is important to note that this study only utilized articles published in English to maintain consistency and prevent any over- or under-representation of studies published in other languages. The following parameters, were used for the selection process [10,11] :

The primary goal was to review papers that primarily focused on providing in-depth information about 'land use', 'land cover change', 'land management', and sustainable development.

Papers that had 'land use' and 'land cover' in their title or keywords but were published in languages other than English were excluded.

Furthermore, studies conducted multiple times in the same area that employed similar techniques or approaches and had nearly identical viewpoints or contributions, were also excluded.

The 'Analysis and Discussions' section primarily includes representative works from the 1814 articles obtained from the said database. It is worth mentioning that the study's discussions were not solely subjected to content analysis of the 5 most cited papers among the 1814 articles generated from the WoS core database collection, but also included other relevant studies, information about policy frameworks, and sectoral reports that demonstrate LSS's impact on development practices and science.

Indicatively, this research employed R's biblioshiny package to conduct its analysis. Aria and Cuccurullo assert that this software integrates bibliometrix package functions and facilitates the creation of web-based applications [12]. This narrative review identified and quantified the co-occurrence of keywords based on the articles generated in line with the search terms and information titles, abstracts, and years that the given output or papers were published using R's biblioshiny. **Figure 2** presents a flowchart of data search, screening and analysis procedures based on this standardized approach.

3. Analysis and Discussions

This section presents findings on the current trends, smart tools, and practices associated with the challenges and pathways of promoting sustainable land use systems worldwide. **Table 1** includes the 5 most influential papers from 2004 to 2023, as determined by the WoS core database collection, which has substantially contributed to the progress of the field worldwide [13–17].

3.1. Analysis of Keyword Co-Occurrence and Classification of Trending Topics (2004–2023)

The analysis of keyword co-occurrence in the sustenance of the subject demonstrates the strong and

Table 1. The Most Cited Studies Given the Search Terms or Scope (2004–2023).

No.	Paper	Author/Publication Year/ Journal	DOI	Total citations	Annual total citations
1	Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management	[13] ECOL LETT	10.1111/j.1461-0248.2005. 00782.x	2829	141.45
2	Soil structure and management: a review	[14] GEODERMA	10.1016/j.geoderma.2004.03.005	2611	130.55
3	China and India lead in greening of the world through land-use management	[15] NAT SUSTAIN	10.1038/s41893-019-0220-7	1391	231.83
4	Defining place attachment: A tripartite organizing framework	[16] J ENVIRON PSYCHOL	10.1016/j.jenvp.2009.09.006	1278	85.20
5	Effects of landscape structure and land-use intensity on similarity of plant and animal communities	[17] GLOBAL ECOL BIOGEOGR	10.1111/j.1466-8238.2007. 00344.x	1104	61.33

interdependent relationship between the keywords used in the study sample (i.e., 1814 articles used). In **Figure 3**, the width of the connecting lines indicates the degree of co-occurrence based on the study sample. **Figure 3** shows the top ten concept/keyword pairs in the field, which include *'Land Use – Land Cover', 'Land Use – Climate Change', 'Land Use – Ecosystem Services', 'GIS – Spatial Planning', 'GIS – Remote Sensing', 'Land Use – Remote Sensing', 'Land Use – Urbanization', 'Land Use – Water Quality', 'Ecosystem Services – Sustainable Development',* and *'Land Use – Land Use Management'.* These pairs analyze a range of environmental, political, cultural, social, technological, and economic parameters that drive progress in the field. Furthermore, they emphasize the intricate and dynamic characteristics of land use systems.

A wide range of topics have garnered noticeable attention over time. Based on the results presented in **Figure 4**, the classification of keywords provides a timeline view of trending topics and emerging areas of focus in this field. In **Figure 3**, the node sizes indicate the number of times the trending topics appeared in various studies. The lines embedded with the nodes mark the density and centrality of each given term over a given period. When examining the scientific research productivity relevant to this study, it is clear that the importance of land use topics has significantly increased since the late 2000s, especially in 2010. From 2010 to 2020, several topics have gained prominence. These topics include *'Sustainability', 'Biodiversity', 'Land Use Management', 'Watershed Management', 'Land Use Planning', 'Modelling', 'Soil Organic Carbon', 'Impact Assessments', 'Sensitivity Analysis', 'Land Use Change', 'Global Change', 'Landscape Ecology', and many others. In the post-2020 era, topics such as 'Land use', 'Ecological Services', 'Climate Change', 'Ecological Service Value (ESV)',*

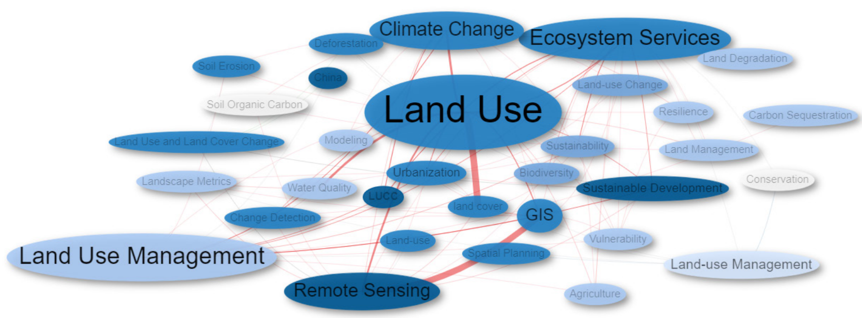

Figure 3. Keyword Co-Occurrence Analysis in Land Use Systems and Sustainability Studies Wordwide (2004–2023).

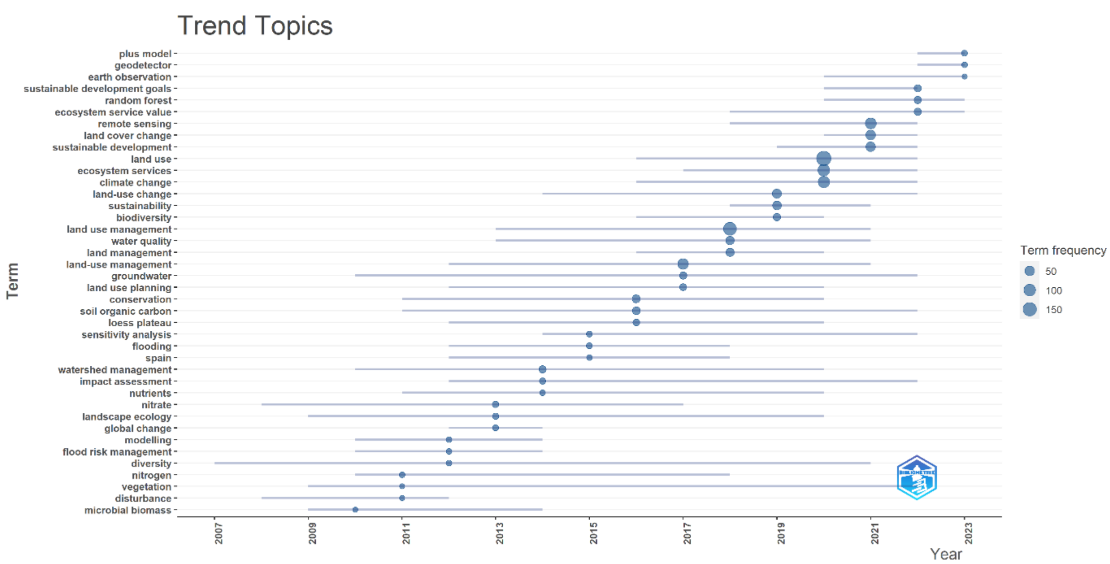

Figure 4. Timeline Classification of Keywords Related to the Scope of This Study (2004–2023).

'Remote Sensing', 'Sustainable Development Goals (SDGs)', 'Land Cover Change (LCC)', 'Random Forest (RF)', 'Earth observation', 'Geodetector', and 'PLUS Model' have become more popular. It is worth noting that the periods (i.e., between 2004–2007) were not captured in **Figure 4** mainly as a result of their frequencies of occurrence being less than 50, coupled with scientific studies in the field becoming increasingly sparse as we go back to these years.

3.2. Evaluating Major Studies and Trends in Land Use Systems Development

Given the findings presented in **Table 1**, it is evident that the top five most cited papers have had a significant impact on diverse studies in different disciplines, nations, and sectors. This underscores the complexity and comprehensive nature of land use systems. A detailed analysis of the top five influential papers, based on their citation count and influence in the field, further emphasizes the multidisciplinary nature of the subject in scope. In their 2005 study, Tscharntke et al. emphasized the importance of understanding the bottlenecks and principles of agricultural land use to maintain biodiversity, ecosystem functions, and endpoints [13]. They highlighted how agriculture influences land management and identified research gaps and opportunities across various scales. Moreover, they stressed the need for further investigation into the relative significance of local versus landscape management concerning biodiversity and ecosystem services. Their calls for research have inspired numerous studies exploring the interplay between different land use systems and ecosystem services, as illustrated in **Figures 3** and **4**. Bronick and Lal in their review study examined how management practices and environmental changes can modify soil structure [14]. They highlighted its importance for sustainable food production and societal well-being. In their conclusion, they advocated for a holistic approach to LUM to address the various practices that place pressure on soil resources. Given the significant impact of soil structure on multiple fronts, pedology is crucial for the sustenance and effective management of land use systems.

Currently, many industrialized nations in both the Global North and Global South are actively working towards regenerating and greening urban and peri-urban areas within their territories. These efforts, which involve significant investments, political commitment, and scientific productivity, aim to transform landscapes and bring various direct and indirect benefits. These benefits include enhancing urban resilience, improving air quality, preventing land degradation, and supporting mitigation and adaptation measures. In a study conducted by Dormann et al. investigated land management strategies for nature conservation in Europe using ecological models to analyze the composition, configuration, and intensity of land use, along with their effects on plant and animal species and communities [15]. Their research demonstrated how these parameters influence ecological processes and contribute to overall diversification and productivity. Several researchers have reported some progress and observations in China and India [16,17]. By analyzing satellite data, these researchers identified significant greening patterns in both countries. As the largest developing country, China has made substantial efforts to preserve and expand its forests and croplands in alignment with the SDGs. These initiatives address key issues related to poverty (SDG 1), hunger (SDG 2), child health (SDG 3), safe cities (SDG 11), climate action (SDG 13), and preserving life on land and biodiversity (SDG 15) [17]. The authors concluded by emphasizing the importance of accurately representing human land use practices through advanced observation models.

3.3. Theories, Tools, Practices, and the Future of Land Use Science

3.3.1. Land Cover Transition Theory (LCTT)

According to Coral et al., the LCTT originated from observations in agriculture and rural development in the late nineteenth and early twentieth centuries [18]. Unlike being associated with a specific individual, this theory represents a conceptual framework that researchers in the geography, environmental science, and land-use planning disciplines have collectively developed. Noteworthy contributions to this theory were made by Halford Mackinder, who enhanced our understanding of how geographical factors, such as land utilization, can significantly shape the fate of nations and societies [19]. Pulver et al., on the other hand, laid the foundation for comprehending the dynamics of societies within their landscapes by emphasizing the impact of geographical factors on human behavior [20]. The LCTT examines the progression of land use patterns over a specific timeframe, largely dwelling on the transition from traditional agricultural practices to more diverse and multifunctional land uses [21]. It analyzes the socio-economic, technological, and policy-driven factors that contribute to these shifts and investigates their global impact [22]. For instance, the timeline classification of key land use terms (**Figure 4**) captured in the 1814 articles show the encompassing nature of land use science, the transitions and management approaches involved.

The theory has been criticized by Petroni et al. for oversimplifying the complex processes of land-use change [23]. Similarly, Long et al. pointed out that the theory fails to adequately consider the political and power dynamics that affect land-use decisions [24]. However, despite these limitations, the theory has several strengths that contribute to its prominence in exploring land-use dynamics. It provides a historical framework for understanding changes in land utilization [25]. The theory emphasizes the importance of societal transitions and recognizes that changes in land use are often linked to broader economic, demographic, and cultural trends [26]. Moreover, it provides valuable insights into the relationship between cultures and land use by examining historical transitions. This approach helps us understand how socio-economic, technological, and cultural changes influence global patterns of land utilization. By utilizing this theory, understanding the complex dynamics that shape modern land-use systems and guide sustainable development and resource management policies worldwide is enhanced.

3.3.2. Land Use and Sustainable Development

The term "sustainable development" was introduced in the 1987 report by the World Commission on Environment and Development (WCED), also known as the Brundtland Commission [27]. Abera significantly contributed to this theory by highlighting the necessity of integrating social, economic, and environmental factors to achieve sustainable outcomes [28]. Sustainable development advocates for the responsible and equitable use of resources to ensure both long-term environmental sustainability and societal well-being [29]. However, the theory has often been criticized for its broad scope and lack of a precise, actionable definition [30]. Striking a balance between economic growth and environmental preservation within sustainable development can also present challenges [31]. Despite these criticisms, sustainable development remains a vital component in the evolution of land use systems [32].

Sustainable development is globally relevant because it helps to address common challenges, promote global collaborations, and emphasizes the importance of addressing issues such as LULCC, climate change, biodiversity loss, and poverty [33]. There have been numerous calls for sustainable land use through the Sustainable Development Goals (SDGs) 11 and 15, considering that all activities take place on land. SDG 11 focuses on sustainable cities and the quality of life, while SDG 15 addresses land use issues. By prioritizing resilience and equity, this approach encourages the exploration of emerging areas (see **Figures 3** and **4**) such as *'land metrics and transitions', 'land use dynamics degree (LUDD)', 'causality/spatial and temporal inference causality', 'land and habitat fragmentation', 'ecological security patterns (ESP) and ecosystem services value (ESV)', and 'urban-rural linkages/transformations.'* This ensures the adoption of sustainable practices that meet current needs while safeguarding the well-being of future generations in the ever-evolving field of land use systems. Hence, there is a need to support calls for 'adaptation justice', 'social justice', *and 'empathy'* among key players who influence or are influenced by policies/decision-making processes.

3.3.3. Urbanization and Land Use Change

Urbanization is extensively influenced by rural-to-urban migration, presence of economic opportunities, and the process of industrialization [34]. As populations increase, urban areas need to develop infrastructure, services, and facilities, resulting in the construction of residential, commercial, and industrial buildings. This, in turn, has an impact on consumerism and social structures through population fluctuations, cultural dynamics, and lifestyle changes [26]. The rapid pace of urbanization also leads to LULCC, environmental degradation, resource depletion, and social inequalities. To ensure sustainable urban development, it is essential to create inclusive and resilient cities for future generations. This requires effective urban planning, infrastructure development, and governance mechanisms [35].

LULCC and land management techniques vary over time because of natural and human-induced factors [36]. These changes affect agricultural land, forests, grasslands, wetlands, urban areas, and infrastructure development. Agricultural growth, urbanization, industrialization, and infrastructure projects all have an impact on land use and geographical distribution [37,38]. Changes in land use have significant effects on the environment, biodiversity, socio-economic systems, habitat suitability, ecosystem services, and livelihoods. In a rapidly changing world, it is crucial to have land use regulations, sustainable management methods, and integrated approaches to balance conflicting land use demands, conserve natural resources, and promote resilient socio-ecological systems [39].

3.3.4. Land Use, Carbon Neutrality and Climate Mitigation/Adaptation

Climate adaptation involves actively modifying societal structures and ecosystems to limit harm and increase advantages [40]. It encompasses various approaches aimed at reducing vulnerability, enhancing resilience, and promoting sustainable development in the face of changing conditions. These approaches range from small community-based adaptations to major infrastructure and policy changes. The goals of climate adaptation include protecting human health, livelihoods, ecosystems, and vulnerable sectors from extreme weather conditions, sea-level rise in coastal regions, variations in precipitation patterns and temperature [41]. To achieve these goals, adaptation strategies encompass a wide range of measures such as digital or critical infrastructure, sustainable land and water management, early warning systems using Digital Technologies (DTs), livelihood diversification, adaptation justice and social capital, social safety nets, and incorporating climatic concerns into development planning and decision-making processes. Despite resource constraints, uncertainties, and socio-political barriers, successful climate adaptation requires collaborative governance, stakeholder engagement, capacity building, and the utilization of local knowledge and skills [42].

Climate mitigation and adaptation involve various strategies aimed at reducing greenhouse gas emissions, managing the Earth's energy balance, and tackling the core and potential drivers driving global warming to lessen its impacts [43]. These efforts include implementing carbon capture and storage techniques (carbon sequestration), transitioning to renewable energy sources, enhancing energy efficiency, reducing deforestation, and promoting sustainable land management. To achieve the objectives of mitigation and adaptation, Saraji and Streimikiene opines that concerted efforts, international exchanges, and robust policy actions are essential for accelerating the transition to a low-carbon economy and meeting climate targets [44].

3.4. Tools: Utilization of Artificial Intelligence and Digital Technologies in Land Use Management

Innovative approaches or tools are needed for monitoring, managing, and utilizing land resources [45]. Digital technologies such as remote sensing and GIS offer precise mapping of land cover changes, aiding in planning and decision-making (**Figure 3**). In precision agriculture, for example, sensors and data analytics using machine and deep learning techniques can enhance crop management, resource efficiency, and production while minimizing environmental impact [46]. Land information systems integrate various datasets to facilitate land management, ensure land tenure, and enhance government transparency. Blockchain technology can enhance the credibility and efficiency of the land tenure system by ensuring secure and transparent land transactions. Digital soil mapping can contribute to conservation and restoration efforts by providing information on soil health and characteristics. Internet of Things

(IoT) applications can improve farming resilience and sustainability by enabling real-time monitoring and management of operations [47]. Lastly, land restoration technologies based on ecological principles and innovative approaches can restore ecosystem services, biodiversity, and promote sustainable land use. These technological advancements have the potential to address complex land issues, support sustainable development, and enhance global land management [48].

Spangler et al. analyzed agricultural land use and policy data comprehensively [5]. They visualized land modifications like farmland transformation, crop production, and crop composition throughout the United States in recent decades. They further identified significant policy changes in the U.S. Farm Bills between 1933 and 2018, which are linked to the understudied land use trends. They reported that the agricultural sector in the United States has progressively shifted into a highly regulated and specialized structure. Agricultural cultivation is predominantly focused on specific regions, with the expansion of larger farms and a decline in the number of smaller ones resulting in a reduction in crop variety. Simultaneously, the scope and influence of federal agriculture policy are expanding. These data-driven findings indicate that both gradual and radical approaches to change are essential for promoting alternative production techniques, encouraging diverse landscapes, and fostering innovation in sustainable agricultural systems at all levels.

The study by Mohamed and Worku modeled changes in LULC and created future scenarios of LULC based on induced trends/activities [49]. Land use predictions are essential for promoting sustainable growth planning and management in both rural and urban areas of Addis Ababa and its surroundings. This study utilized Cellular Automata, Markov Chain (CA-Markov), and Multi-criteria Analytical Hierarchy Process (AHP) modeling methods. The findings indicate a consistent increase in built-up areas, often at the expense of ecologically beneficial land features. Quantitative landscape measurements demonstrate that the Ecologically Sensitive Scenario (ESS) modeling offers significant advantages over the Business-as-Usual Scenario (BAUS), particularly in ensuring the long-term sustainability of urban spaces. ESS modeling aids in enhancing urban systems by limiting built-up expansion and managing the loss of water bodies, forests, and agricultural land. Additionally, scenario-based simulations of LULC dynamics provide valuable decision-making alternatives for long-term urban growth planning and management, applicable not only to the study region but also to other similar cities and regions.

3.5. Optimization of LULC Analysis Within the Context of Geo-Visualization

LULCC analysis is essential for understanding the dynamics of land use changes over time, particularly in the context of rapid urbanization and environmental degradation. As shown in **Figure 3**, geo-visualization methods have become increasingly important for optimizing LULCC analysis. These methods serve as powerful tools for visualizing spatial data and analyzing patterns and trends in land use changes [47]. The optimization of LULCC analysis through geo-visualization provides key insights, highlighting the integration of advanced visualization techniques in this field.

By employing geo-visualization techniques, we can significantly enhance our understanding and interpretation of complex land use change patterns. Tools such as maps, 3D models, and interactive visualizations allow researchers to gain valuable insights into the drivers of LULCC and identify areas at high risk for environmental degradation or resource depletion [49]. Advanced techniques like remote sensing and GIS enable the analysis of large datasets, revealing patterns that may not be apparent through traditional analytical methods. This approach facilitates the clear and intuitive communication of complex spatial information. By presenting data visually, researchers can effectively share their findings with diverse stakeholders, including policymakers, land managers, and the general public [50,51]. Ultimately, this can promote informed decision-making and raise awareness about the impacts of land use changes on the environment and society.

Optimizing LULCC analysis through geo-visualization enhances the accuracy and reliability of research findings. By integrating spatial data from various sources and presenting it in a coherent and interactive format, researchers can achieve a deeper understanding of the dynamics of land use changes and their implications for environmental sustainability. This improved understanding can inform more effective conservation and land management strategies based on data-driven insights across different sectors of the economy.

3.5.1. Validating and Estimating the Accuracy of Global Land Use/Land Cover (LULC) Over the Years

The validation of LULC data and the estimation of accuracy are crucial for ensuring the reliability and credibility of land cover change detection studies. Advancements in remote sensing technology and spatial analysis techniques have enhanced the accuracy of these detections over the years. However, challenges remain in accurately validating LULC data and estimating the accuracy of change detection algorithms. These challenges arise from issues such as class definitions, spatial heterogeneity, temporal consistency, and scale mismatches. Variations in classification schemes, spatial resolution, and validation methods also contribute to these difficulties. Validation methods include ground truthing data from field surveys and photo interpretation, cross-validation with other datasets, confusion matrices, error metrics, and independent benchmark datasets [52–56]. **Table 2** presents an overview of accuracy trends for widely used global LULC products, along with their validation approaches.

Table 2 illustrates the estimated accuracy rates of global LULC trends over time. Early datasets from the pre-2000 era, such as IGBP and UMD, had accuracy rates of around 65–75%. These limitations were primarily due to their coarse resolution of 1 km and a smaller number of validation samples. In the 2000s, the MODIS and GlobCover datasets improved their accuracy to 75–85%, although they still exhibited some regional inconsistencies. By 2010, datasets like FROM-GLC and CCI achieved higher resolutions (75–85%), but this came with trade-offs between resolution and global consistency. In the 2020 era, the ESA WorldCover (10 m) and Dynamic World (AI-based) datasets surpassed 80% accuracy, benefiting from advancements in Sentinel-2 technology and deep learning techniques.

Table 2. Overview of Global Land Use and Land Cover Accuracy Trends and Validation Efforts.

Dataset	Period (s)	Reported Accuracy	Resolution	Remarks
IGBP DISCover – 17-class land cover dataset	1992–1993	~65–75%	1 km	*Early global product, moderate accuracy
University of Maryland (UMD) Land Cover	1992–1993	~70–75%	1 km	*Improved over IGBP
MODIS Land Cover (MCD12Q1)	2001–2020	~75–85% (with variations in features/classes)	500 m	*Yearly updates, commonly used
GlobCover (ESA)	2005, 2009	~70–80%	300 m	*MERIS sensor, regional variations
Climate Change Initiative (CCI) Land Cover (ESA)	1992–2020	~75–85%	300 m	*Merges MERIS and PROBA-V
FROM-GLC (Tsinghua)	2010, 2015, 2017	~65–80%	10–20 m	*Higher resolution but lower global consistency
WorldCover (ESA)	2020	~75–85%	10 m	*Sentinel-1/2, high-resolution
Dynamic World (Google)	2015–2023	~80–90% (near-real-time)	10 m	*AI-based, frequent updates

3.6. Policy-Regulatory Frameworks, Stakeholder Involvement and Public-Private Partnerships

Monkkonen et al. used novel data to investigate the relationship between urban land policy, urban form, and greenhouse gas emissions from transportation [57]. The study used property registration administration as a substitute measure to examine the correlation across 431 metropolitan areas in approximately 40 countries. The results of the study validate that highly populated metropolitan regions, characterized by concentrated city centers and shorter road sections, exhibit reduced carbon emissions per person. Regions with more laborious property administration have higher population density and lower levels of emissions. This discovery diverges from the typical correlation between rules and urban expansion, emphasizing the need for a more refined awareness of the effect of laws on urban structure and sustainability.

Spangler et al. also examined previous and present U.S. agricultural landscapes using national open-source datasets from various decades in the National Research Council's (NRC) Sustainable Agricultural Systems Framework [5,58]. Their study analyzed policy data as well as agricultural land use and cover datasets. Their study sought to (1) record and visualize changes in cropland conversion, agricultural productivity, and crop mix throughout the United States during recent decades and (2) identify general policy changes in the 1933–2018 Farm Bills related to these land use patterns. The study demonstrates that United States agriculture has become highly regulated and specialized. Larger farms are growing, smaller farms are shrinking, and agricultural variety is dwindling. These data-driven insights provide incremental and revolutionary change routes to encourage different production techniques, incentivize varied landscapes, and encourage innovation toward more sustainable agricultural systems at various scales.

Hasnat and Hossain argue that studying international land use policies, changes, and conflicts provides the latest research on LULCC worldwide [59]. This research can help develop land use policies aimed at protecting the Earth for both present and future generations. The study investigates land tenure systems in various nations and the causes behind policy changes. It provides guidance on sustaining land management, using landscape models to predict future land use, implementing best architectural practices, and utilizing urban forestry to enhance environmental management and climate adaptation. Studies of this nature relevant stakeholders or proponents to optimizefuture land use systems. To this end, it is worth noting that several planning models or approaches that draw on the tenets of 'bottom-up,' 'transformative governance' and 'top-down' paradigms could be utilized to examine land use systems at all levels.

In line with SDG 17, community-based land use planning and public-private partnerships are two widely used approaches for managing and developing land. Both methods involve collaboration between various stakeholders to ensure a sustainable and equitable use of land resources. According to Li et al., community-based land use planning involves engaging key project proponents to circumvent or make informed decisions regarding land use [60]. This approach allows for greater participation and input from those who will be directly impacted by development projects. By engaging the community in the planning process, it ensures that their needs and preferences are taken into account, leading to more sustainable and socially responsible development outcomes. In the United States, these approaches are often conducted at the local level, with cities and counties responsible for zoning regulations and development decisions [61]. Here, one common approach is the use of comprehensive land use plans, which outline long-term goals and strategies for land use within a community. These plans are typically developed with input from residents, businesses, and other stakeholders to ensure that they reflect the collective vision for the community's future. In addition, tools such as community workshops, surveys, and public hearings are used to gather input from a diverse range of stakeholders, helping to ensure that the planning process is inclusive and transparent.

In developing countries like Kenya, community-based land use planning is essential for promoting sustainable development and addressing land tenure issues [62]. With a majority of the population relying on agriculture for their livelihoods, proper land use planning is crucial for ensuring food security, reducing conflicts over land, and promoting economic development. One example of successful community-based land use planning initiatives in Kenya is the establishment of community conservancies, where local communities manage and conserve their natural resources in a sustainable manner. By involving communities in the management of their natural resources, these conservancies have helped to protect biodiversity, promote sustainable land use practices, and improve livelihoods for local residents [63].

In Australia, community-based land use planning is often integrated with indigenous land management practices, recognizing the long-standing connection between indigenous peoples and the land. Indigenous land use planning involves engaging indigenous communities in decisions about how their traditional lands are managed and developed, ensuring that their cultural practices and environmental knowledge are taken into account [64]. One successful scenario of indigenous land use planning in Australia is the Working on Country program, which provides funding and support for indigenous land management initiatives. By involving indigenous communities in land use planning, Australia is able to promote sustainable development while respecting the rights and traditions of indigenous peoples [65].

3.7. Economic Viability of Emerging Land Use Practices

Bibri et al. explored the implementation and rationale of the compact city model in urban planning and development, with a focus on its three dimensions of sustainability and an evaluation of progress [66]. They employed a descriptive case study as a qualitative research method to investigate this urban phenomenon. The empirical foundation of the study included official plans and documents from two Swedish cities, Gothenburg and Helsingborg, along with qualitative interviews and secondary data.

In their study, they identified key design strategies for creating compact cities, which encompass compactness, density, diversity, mixed land use, sustainable transportation, and green spaces. It also highlighted the concept of green structure, an institutional framework that governs the operations of both cities and is closely linked to the notion of green space. Furthermore, the compact city model relies on strong collaboration among its underlying strategies, which work together to produce synergistic effects greater than the sum of their individual impacts. This collaboration aims to maximize the sustainability benefits of the model, which consists of three interconnected components. Moreso, the study demonstrated that the compact city model, as implemented by the governments of the two cities, was effective in contributing to the economic, environmental, and social objectives of sustainability. However, it noted that economic objectives tend to take precedence over environmental and social ones, despite the theoretical assertion that all three components of sustainability hold equal significance.

Xie et al. examined the patterns, distribution of research influence, focal areas, popular research topics, and global collaboration in sustainable land use research in recent years [67]. The work employed the Bibliometrix and Biblioshiny software packages to conduct a comprehensive bibliometric analysis and visually present the research papers on sustainable land use (1990–2019). The results indicated that the impact of industrialized nations in the domain of sustainable land utilization is considerably higher than that of emerging nations. The concepts that engulf sustainable land use have undergone significant transformations throughout different periods (**Figure 4**); however, a strong sense of continuity can be observed in some key themes (**Figure 4**). Their study further suggests that to advance the progress of sustainable land use, it is crucial to incorporate robust sustainability, landscape ecological theories, and geographical design principles into LSS.

Liu et al. devised a novel framework for measuring Land Use Efficiency (LUE) that takes into account the anticipated land use outcomes and the interplay between three key aspects: production of food, economic viability, and environmental sustainability [68]. They employed the coupling coordination degree model to assess the spatial variations and coordination relationships among these sub-categories. The evaluation focused on Jiangsu Province in eastern China, utilizing multivariable linear regression and geographical detectors. A total of ten indicators were considered, including cultivated land quality, grain output, multiple cropping index, average Gross Domestic Product (GDP) per km^2, population density, proportion of industry and service sector, vegetation cover index, water conservation index, soil retention index, and carbon concentration. Jiangsu's LUE for food production, economic development, and environmental conservation was estimated at 54.15%, 85.56%, and 54.95%, respectively, exceeding expectations. This suggests that Jiangsu province has high prospects for the sustenance of its land use systems. The degree of coupling typically corresponds to the level of coordination between land use activities, which accounts for 65.34% of the province's land area.

3.8. Future Scenarios and Uncertainties

The future of land use science and systems development is uncertain due to factors such as population growth, urbanization, climate hazards, technological advances, governmental interventions, and global market dynamics [69]. Urban growth, climate hazards, technological adoption, regulatory frameworks, governance frameworks, global demand for land-based commodities, and conservation objectives all have elements of uncertainty [70]. Therefore, it is necessary to utilize multiple tools to comprehensively model or simulate trends. This can be achieved by using big data platforms and machine and deep learning techniques to provide more information on environmental and sustainability challenges. Integrated methods/models, evidence-based decision-making, stakeholder involvement, and transformative governance are also essential to address these challenges. Scenario planning, risk assessments, and participatory procedures can be used to develop alternative futures that provide effective solutions to uncertainties, build resilience, and achieve sustainable land use outcomes in a rapidly changing world [71]. It is also important to empower youth through innovative schemes that allow them to contribute to global discussions and debates, as well as to promote scientific research collaborations and investments between industrialized nations with high scientific productivity and emerging or less productive nations.

3.9. Limitations and Future Research Perspectives

In spite of these developments, the current study is not devoid of some limitations and opportunities that could drive further studies. To begin with, one of the main limitations of this narrative review is linked to the potential for bias as this study may unconsiciously select studies that align with the authors' beliefs. This may result in skewed representation of existing literature and failure to cover the full range of perspectives and findings on a particular topic. Hence, further studies could be conducted to cover each theme or subject presented in the analysis and discussion section. Another limitation of this narrative review is linked to the lack of systematic methodology. Unlike systematic reviews that adhere to strict protocols for selecting and analyzing studies, this research acknowledges the element of subjectivity and inconsistencies that may occur during data extraction and analysis processes, further making it challenging to make evidence-based recommendations for policy and practice.

Furthermore, this review may also be limited by the quality of the studies included. In land use studies, where research methods and data sources can vary widely, it can be difficult to assess the reliability and validity of the findings in each study. This can undermine the credibility of the review and its utility for informing decision-making in the field of land use planning and management. In addition, while this narrative review may serve as a valuable tool for synthesizing existing studies in this field, it may not always reflect the most current research on this topic as land use studies/land system science is constantly evolving. New studies published regularly may contradict or build upon existing studies. Future studies could investigate automated validation methods using crowdsourcing, multi-sensor fusion, and machine learning to achieve scalable validation. Additionally, employing standardized protocols like CEOS Land Product Validation (LPV) could improve consistency in the validation process.

4. Conclusions

Global land use systems have changed significantly over time due to technological advancements, socioeconomic transformations, and environmental challenges. To manage modern land use effectively, a multidisciplinary approach that integrates technology, policy, and economics is essential. As technology advances, the need for sustainable and equitable land management practices grows. It is crucial to adapt to these changes to strike a balance between competing demands on land resources in order to secure a sustainable future for both human societies and the environment. In this study, we critically reviewed existing literature on the development and sustainability of global land use systems. Using an extensive bibliographic database from Web of Science, we explored the complex realm of global land use systems, including their historical trajectories, contemporary issues, and future outlook.

Evidence shows that current research trends in land use science, management, and sustainability involve the use of emerging DTs such as geoinformatics, Geo-detectors, regression models, artificial intelligence (including machine and deep learning models), as well as social and economic models. The integration of remote sensing and geospatial techniques with transformative governance models that incorporate economic, social, and environmental factors is crucial for addressing land use issues and promoting sustainability. This review study emphasizes the importance of thoroughly examining the different aspects of this subject to establish a comprehensive understanding of the historical, current, and future developments in global land use systems. Therefore, this study's outcome suggest fostering strong collaborations among researchers, government agencies, private organizations, international donors, policy-makers, and other stakeholders to collectively advance knowledge in this field. Enhancing the theoretical and practical foundations of land use sustainability requires the combination of various techniques and models, the integration of policy approaches, and the utilization of big data platforms.

Supplementary Materials

The following supporting information can be downloaded at https://journals.nasspublishing.com/files/lmu-1836_Supplementary-Materials.docx

Author Contributions

Conceptualization, I.S. and N.A.A.E.; methodology, I.S., N.A.A.E., E.Y., and D.B.A.; validation, I.S., N.A.A.E., M.A.D., M.K.A., E.Y., D.B.A., A.B., P.A.D., and G.H.X.; formal analysis, I.S., N.A.A.E., M.A.D., M.K.A., D.B.A., M.B., A.B., P.A.D., and G.H.X.; resources, N.A.A.E.; data curation, I.S., N.A.A.E., and E.Y.; writing—original draft preparation, I.S.; writing—review and editing, N.A.A.E., M.A.D., M.K.A., D.B.A., M.B., A.B., P.A.D., and G.H.X.; visualization, N.A.A.E. and E.Y. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interests

The authors declare no conflict of interest.

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