



(RESEARCH ARTICLE)



SYSTEM FOR LAND-BASED EMISSIONS ESTIMATION IN KENYA(SLEEK) AND LAND-SECTOR CARBON ACCOUNTING IN KENYA: EVIDENCE FROM EMISSIONS AND REMOVALS ACCOUNTING, 1990-2015

Ali Mwanzei Mweu ^{1,*}, James Mwangi Kinyanjui ², George K. Tarus ³ and Elizabeth Adobi Okwuosa ⁴

¹ Independent climate-transparency Researcher, Kenya.

² School of Natural resources and Environmental Studies, Karatina University, Kenya.

³ Ministry of Environment, Climate Change and Forestry, Kenya.

⁴ Environment and Natural Resources, Kenya Agricultural and Livestock Research Organization (KARLO), Kenya.

* Corresponding Author

ORCID Details

James Mwangi Kinyanjui: <https://orcid.org/0000-0002-7177-5458>

Elizabeth Okwuosa: <https://orcid.org/0000-0001-5941-7423>

International Journal of Science and Research Archive, 2026, 21(01), 067–075

Publication history: Received on 26 August 2026; revised on 01 October 2026; accepted on 03 October 2026

Article DOI: <https://doi.org/10.30574/ijrsra.2026.21.1.1858>

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

Developing countries face persistent constraints in producing transparent, consistent and nationally owned greenhouse-gas inventories for the land sector. Kenya responded through the System for Land-based Emissions Estimation in Kenya (SLEEK), a national programme designed to integrate activity data, country-specific parameters, spatial modelling, reporting tools and institutional capacity. This paper examines SLEEK's contribution to emissions and removals accounting from Kenya's land sector using documentary analysis of programme records, technical manuals, national reporting material and carbon-accounting spreadsheets for 1990-2015. The evidence shows that SLEEK supported complete land representation across six IPCC land-use classes, generated wall-to-wall land-cover and land-use change datasets for 17 epochs, enabled emission-factor development for forest strata and supplied land-sector activity data used in FOLU accounting. The accounting spreadsheets estimate cumulative net CO₂ emissions of 858.66 Mt CO₂ over 1990-2015, equivalent to an average of 34.35 Mt CO₂ yr⁻¹. Montane and Western rainforest strata accounted for 72.83% of cumulative forest-stratum emissions, while land converted to grassland and cropland were the dominant source categories. SLEEK's major contribution was therefore both technical and institutional: it converted fragmented datasets into an auditable national accounting chain while building domestic expertise for transparency reporting.

Keywords: SLEEK; Kenya; Land-sector carbon accounting; FOLU; FLINT; MRV

1 INTRODUCTION

National greenhouse-gas (GHG) inventories are a core instrument of international climate governance because they provide the evidence base for mitigation planning, nationally determined contributions and transparency reporting. Under the Paris Agreement's Enhanced Transparency Framework, countries require recurring institutional capacity to prepare inventories that are transparent, accurate, complete, comparable and consistent [1,2]. These requirements are especially demanding in the land sector, where emissions and removals are spatially heterogeneous and depend on land cover, land-use change, biomass stocks, climate, soils, management regimes and disturbance.

Kenya's land sector illustrates this challenge. The national land inventory needs to represent forests, croplands, grasslands, wetlands, settlements and other lands across a country with large ecological gradients and rapidly changing land-use pressures. Land-based emissions arise from deforestation, forest degradation, conversion among non-forest land categories and biomass burning, while removals occur through afforestation, enhancement of forest carbon stocks and regrowth after land-use change. Without a consistent spatial accounting system, these flows are difficult to estimate, verify and improve.

The System for Land-based Emissions Estimation in Kenya (SLEEK) was developed to address this technical and institutional problem. Its purpose was not only to generate a single inventory estimate, but to create a national system capable of estimating emissions and removals from all land uses and supporting decision-making, REDD+ processes and UNFCCC reporting [3-6].

The objective is to assess how SLEEK contributed to land-sector emissions and removals accounting in Kenya. The paper asks three questions: first, what accounting chain did SLEEK help establish from land representation to emissions estimates; second, what do the 1990-2015 spreadsheets show about the categories and strata driving net land-sector emissions; and third, what lessons does SLEEK offer for countries seeking to move from consultant-dependent inventories to nationally owned climate-transparency systems?

2 LITERATURE REVIEW

The IPCC Guidelines provide the methodological foundation for national land-sector accounting. They require a consistent representation of land, transparent selection of activity data and emission factors, and application of methods that reflect national circumstances and available data [1]. The guidelines recognise alternative approaches and tiers. Approach 1 relies on aggregate land-use areas, Approach 2 tracks land-use changes between categories, and Approach 3 provides spatially explicit land-use conversion information. Tier 1 applies default methods and factors, while higher tiers incorporate country-specific data, repeated observations and models.

Land-sector inventories therefore need more than a spreadsheet calculation. They need institutions that generate activity data, ecological stratification, emission factors, quality assurance and quality control (QA/QC), data archives, expert judgement procedures and recurrent reporting calendars. The FOLU inventory material reviewed for this paper explicitly applied the 2006 IPCC Guidelines to land-use representation, activity data, emission factors and gain-loss calculations, with country-specific data used where available and IPCC default values applied where national data were unavailable [1,3].

International experience shows why spatially explicit modelling is important. Australia's Full Carbon Accounting Model (FullCAM) is used in its national greenhouse accounts to model emissions from the land sector and produce annual totals for National Inventory Reports; the Australian Government notes that direct measurement alone is impractical across a national land sector of approximately 769 million hectares [7]. The Kenyan SLEEK design drew from this tradition of national land-sector carbon accounting while adapting it to Kenyan institutional mandates and data conditions.

The Full Lands Integration Tool (FLINT) provides a related open-source architecture for integrating multiple data streams and models for AFOLU emissions and removals. Moja global describes FLINT as a modular software framework for MRV and forecasting that combines remote sensing, models and ground data and allows users to move from simple implementations towards continuous improvement [8]. Documentation on FLINT further presents it as an open-source platform for estimating land-sector emissions and removals using modules that analyse carbon flows [9].

SLEEK's importance in the literature therefore lies in its attempt to combine three strands of inventory development: IPCC-consistent land representation, spatially explicit modelling and institutional capacity building. The SLEEK design documents emphasised nationally consistent, fine-scale time-series land-cover information, transparency, auditability, minimum UNFCCC standards and tools to enable government use of land-sector information for decisions [4-6]. ACIAR later commissioned the Mullion Group to expand SLEEK's operational capacity and explore integration of forest,

agriculture and livestock GHG estimation, demonstrating the wider relevance of the Kenyan platform for integrated land-sector accounting [10].

3 MATERIALS AND METHODS

Table 1: Documentary evidence base used in the analysis.

Evidence source	Contribution to analysis
FOLU National Inventory Report section	Provided land-sector methodology, activity-data description, land classes, emission factors and reported emission patterns.
Carbon-accounting spreadsheets	Provided epoch-level CO ₂ estimates by forest stratum and IPCC land category for 1990-2015.
SLEEK design and handbook documents	Explained programme objectives, Tier/higher-tier approach, FLINT architecture, data management and governance.
SLEEK progress and status reports	Documented implementation achievements, training, QA/QC requirements, data gaps and computing constraints.
International sources	Situated SLEEK in relation to IPCC methods, FLINT, FullCAM and broader land-sector MRV practice.

This paper uses a documentary case-study method. The evidence base comprises SLEEK programme design material, implementation status reports, technical manuals, the SLEEK Handbook and set-up guides, Reporting Tool documentation, the FOLU National Inventory Report section and carbon-accounting spreadsheets covering five epochs: 1990-1995, 1995-2000, 2000-2005, 2005-2010 and 2010-2015 [3-6,11-14]. The spreadsheets include combined summaries by forest stratum, separate epoch workbooks and an IPCC category CO₂ emissions summary table.

The analysis focused on the contribution of SLEEK to the land-sector accounting chain. Documentary material was reviewed to identify how SLEEK supported land representation, activity data generation, ecological stratification, emission factors, QA/QC, model integration and reporting. Spreadsheet values were extracted from the summary worksheets and checked against the FOLU report tables. The paper reports positive values as net emissions and negative values as removals or sinks, following the sign convention used in the spreadsheets.

The FOLU report states that emissions and removals were estimated using two main activity types: land remaining in the same use and land converted to another use. Activity data consisted of hectares of land-use transitions, which were multiplied by emission factors to estimate CO₂ emissions. The report identifies the principal datasets as land-use representation, land-use change matrices, carbon stocks, roundwood harvesting and areas affected by wildfire, with key land-sector data made available through SLEEK, Kenya Forest Service and FAO statistics where necessary [3].

The land representation system adopted six IPCC land categories and ten mappable Kenyan classes: dense forest, moderate forest, open forest, wooded grassland, open grassland, perennial cropland, annual cropland, vegetated wetland, open water and other lands/settlements. The FOLU report states that wall-to-wall land-cover and land-use maps were generated for 17 epochs between 1990 and 2015 using Landsat imagery and pixel-based supervised classification with a Random Forest algorithm [3]. Five-year interval change maps were then used to generate activity data for emissions calculations.

Emission factors were generated using a combination of country-specific and default values. Pilot National Forest Inventory data were used for above-ground biomass for forest cover categories in each forest stratum; below-ground biomass was calculated using IPCC root-shoot ratios; biomass was converted to carbon and then to CO₂ using IPCC default conversion factors. Research data were used for perennial cropland biomass, while IPCC defaults were used for other classes where country-specific data were unavailable [1,3].

4 RESULTS

Table 2: SLEEK-supported elements in the land-sector accounting chain.

Accounting element	SLEEK-supported contribution	Accounting significance
Land representation	Six IPCC land categories translated into Kenyan mappable classes.	Enabled complete and consistent national land accounting.
Activity data	Wall-to-wall land-cover and land-use change maps for 17 epochs from 1990 to 2015.	Enabled transition matrices for land remaining and land converted categories.
Emission factors	Forest strata, pilot NFI biomass data, IPCC defaults and country-specific data where available.	Allowed stock-change estimates to reflect ecological differences.
Integration	FLINT and associated data-preparation workflows.	Provided architecture for spatially explicit calculations and continuous improvement.
Reporting	Reporting Tool and IPCC category summaries.	Linked scientific estimation outputs to UNFCCC-compatible reporting categories.
Capacity	Working groups, training, QA/QC and documentation.	Shifted inventory capability towards national institutions.

4.1 SLEEK's contribution to the accounting chain.

The uploaded FOLU report explicitly identifies SLEEK as a source of land-use maps, land-use change maps and land-use change matrices for forest land, cropland, grassland, wetlands and other land categories. It also identifies SLEEK-supported ecological zones and forest stratification as part of the data chain used to generate land-sector emission estimates [3]. This evidence shows that SLEEK supplied the activity-data foundation for national FOLU accounting rather than merely serving as a stand-alone modelling experiment.

4.2 Land representation and activity data.

Kenya adopted a complete representation of lands approach and mapped land-use areas for forest land, grassland, cropland, wetland and other lands/settlements from 1990 to 2015. The FOLU report shows average mapped areas of 3.56 million ha forest land, 42.15 million ha grassland, 5.53 million ha cropland, 1.25 million ha wetland and 6.72 million ha other lands/settlements. Grassland was the dominant land category, averaging approximately 70% of national land area, while the long-term trend showed cropland increasing and forest land and grassland generally decreasing [3].

4.3 Emission-factor stratification

SLEEK supported a forest stratification approach that separated dryland forest, montane and western rainforest, coastal and mangrove forest and plantation forest. This allowed emission factors to reflect ecological differences in carbon stocks. The FOLU report explains that montane and western rainforest had high carbon stocks and therefore higher emission factors than dryland forest, making it possible to distinguish emissions significance from land-area extent [3].

Table 3: Net CO₂ emissions by monitoring epoch from the uploaded accounting spreadsheets.

Epoch	5-year net emissions (tCO ₂)	Average annual emissions (tCO ₂ yr ⁻¹)
1990-1995	135,191,965	27,038,393
1995-2000	271,077,510	54,215,502
2000-2005	130,887,927	26,177,585
2005-2010	145,133,698	29,026,740
2010-2015	176,370,533	35,274,107

4.4 Net emissions by monitoring epoch

The carbon-accounting spreadsheets estimate cumulative net CO₂ emissions of 858.66 Mt CO₂ over 1990-2015, equivalent to 34.35 Mt CO₂ yr⁻¹. The highest annual average occurred in 1995-2000 at 54.22 Mt CO₂ yr⁻¹, followed by

35.27 Mt CO₂ yr⁻¹ in 2010-2015. The lowest annual average occurred in 2000-2005 at 26.18 Mt CO₂ yr⁻¹. These patterns are consistent with the FOLU narrative that emissions peaked in 1995-2000 and declined in 2000-2005 following policy action to halt forest destruction and enactment of the Forest Act 2005 [3].

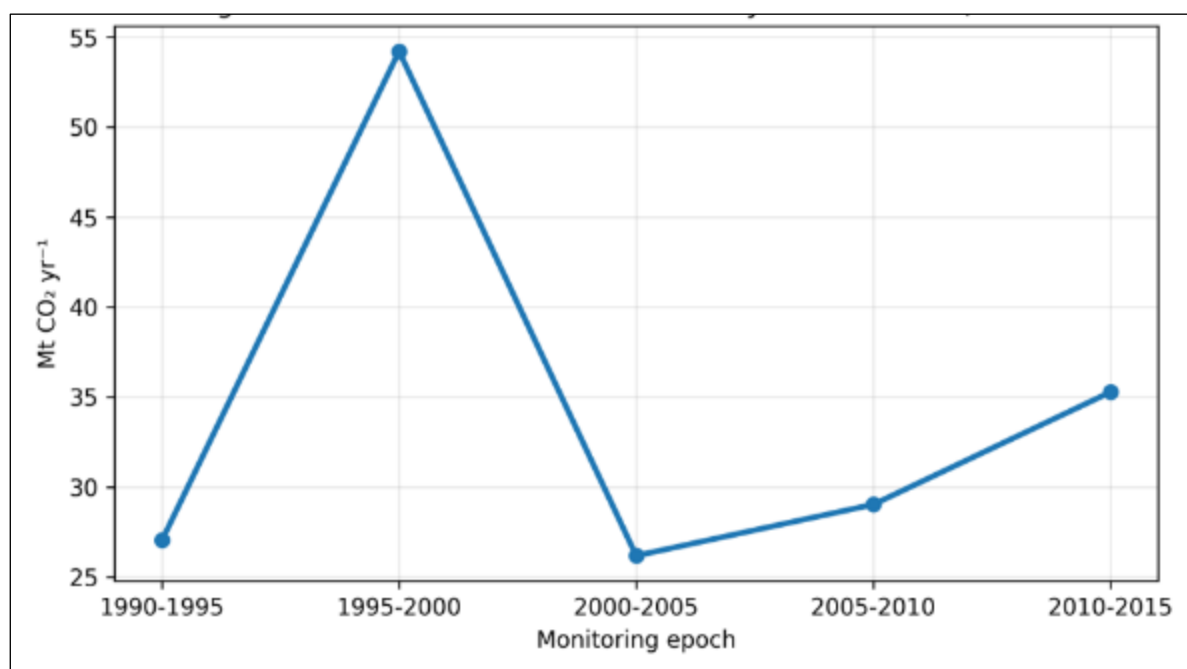


Figure 1: Average annual net CO₂ emissions from Kenya's land sector, 1990-2015.

4.5 Forest-stratum contributions

Across the five monitoring epochs, montane and western rainforest accounted for 625.39 Mt CO₂, or 72.83% of cumulative forest-stratum emissions. Coastal and mangrove forest accounted for 125.41 Mt CO₂ (14.60%), dryland forest for 68.31 Mt CO₂ (7.96%) and plantation forest for 39.55 Mt CO₂ (4.61%). This confirms that areas with higher carbon stocks can dominate national emissions even when their converted area is smaller than dryland forest.

Table 4: Cumulative emissions by forest stratum, 1990-2015.

Forest stratum	Cumulative emissions 1990-2015 (tCO ₂)	Share of forest-stratum total (%)
Dryland forest	68,313,566	7.96
Coastal and Mangrove forest	125,406,004	14.60
Montane forest/Western Rainforest	625,387,690	72.83
Plantation	39,554,373	4.61

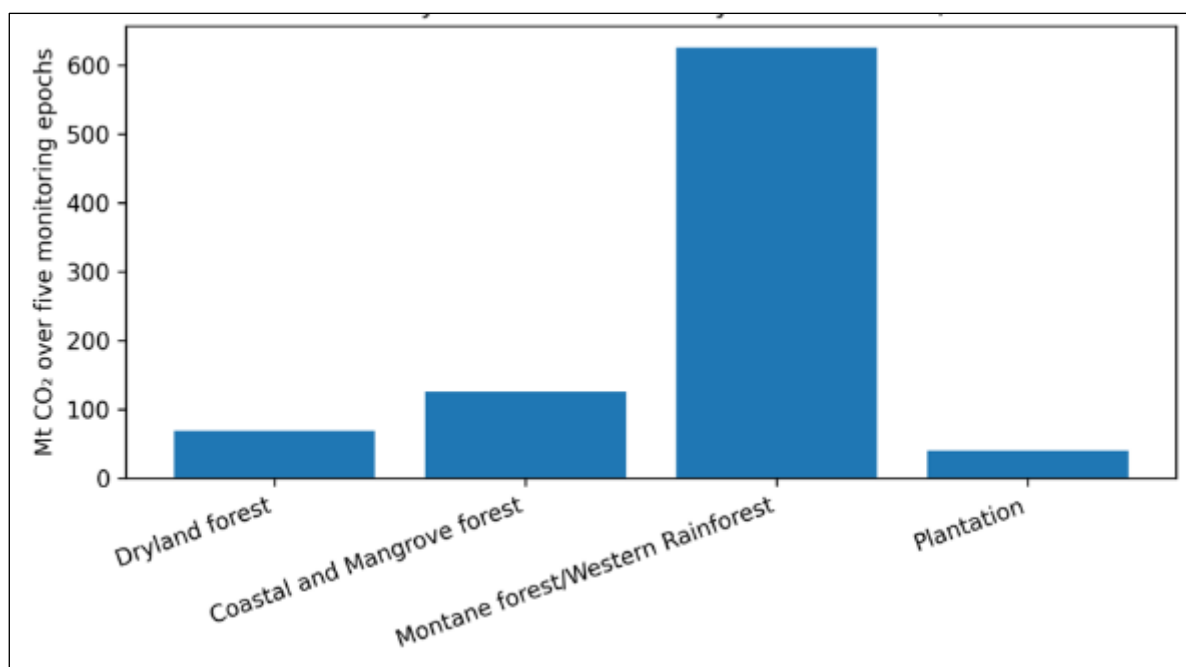


Figure 2: Cumulative emissions by forest stratum, 1990-2015.

4.6 Source and sink categories

The IPCC category spreadsheet shows that land converted to grassland was the largest cumulative source at 598.65 Mt CO₂, followed by land converted to cropland at 351.22 Mt CO₂ and forest land remaining forest land at 213.31 Mt CO₂. Land converted to forest land was the largest sink at -450.69 Mt CO₂. This pattern demonstrates why SLEEK's land-transition matrices matter: the main accounting insight comes from tracking conversions, not simply reporting total areas in each land class.

5 DISCUSSION

Table 5: Cumulative CO₂ sources and sinks by IPCC land category, 1990-2015.

IPCC category	Cumulative 1990-2015 (tCO ₂)	Interpretation
FL remaining FL	213,305,347	Source
Land converted to FL	-450,685,394	Sink/removal
GL remaining GL	12,144,592	Source
Land converted to GL	598,654,711	Source
CL remaining CL	2,142,460	Source
Land converted to CL	351,215,172	Source
Land converted to WL	7,667,876	Source
Land converted to OL	124,216,868	Source

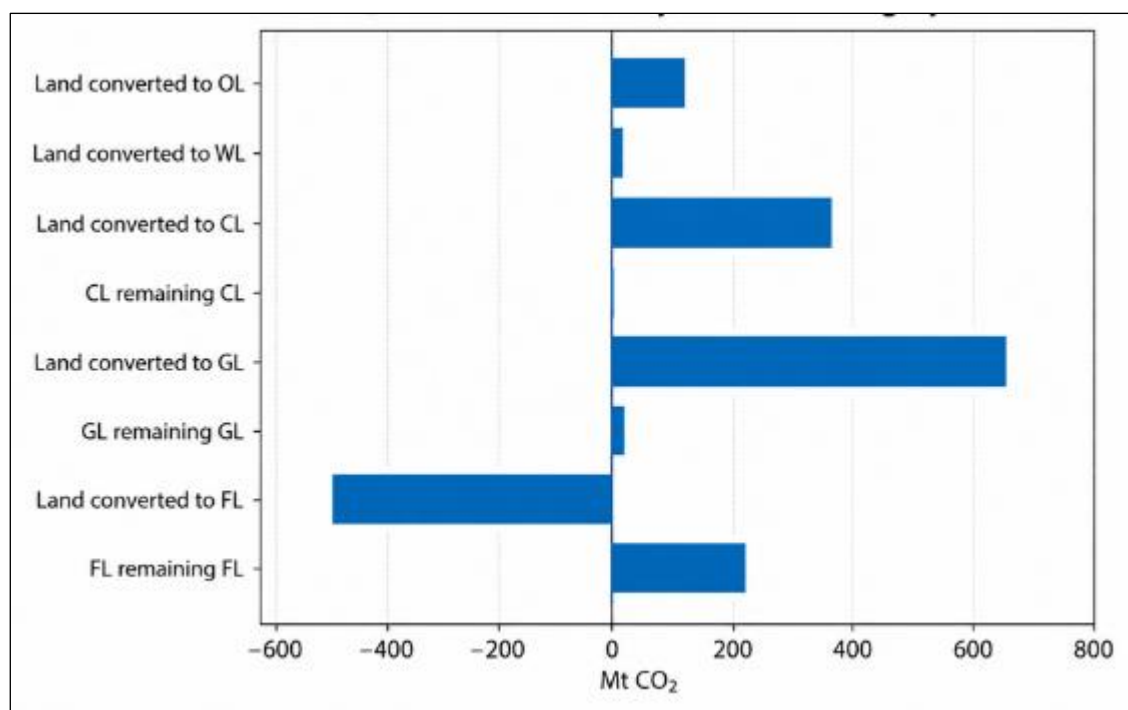


Figure 3: Cumulative CO₂ sources and sinks by IPCC land category, 1990-2015.

5.1 Technical contribution

SLEEK's first contribution was to convert land-sector accounting from a fragmented data exercise into a spatially explicit and methodologically documented accounting chain. The chain links Landsat-derived land-cover maps, classification of Kenyan land classes into IPCC categories, five-year transition matrices, forest-stratum emission factors, gain-loss calculations and reporting tables. Without SLEEK-supported activity data and stratification, Kenya would have had to rely more heavily on aggregate land-area assumptions and default factors.

5.2 Institutional contribution

SLEEK's second contribution was institutional. The programme brought together mandated data-producing institutions, universities and technical experts into working groups responsible for climate parameters, land cover, forest biomass, soil carbon, crops and modelling. Implementation records show that Kenyan technical teams were trained to prepare FLINT-ready data, update input datasets, run the system, merge outputs and apply QA/QC procedures [6,11-14]. This changed the role of national experts from external data suppliers to co-producers of the inventory system.

5.3 Relationship to national reporting

The evidence supports a careful claim. SLEEK contributed data, methods, expertise and institutional arrangements that strengthened land-sector accounting capability. However, it should not be asserted without further verification that SLEEK-FLINT generated every land-sector number in Kenya's later UNFCCC submissions. Kenya's 2024 National Inventory Document is a separate official submission to the UNFCCC [15]. The defensible conclusion is that SLEEK helped build the land-sector data and capacity infrastructure and foundation on which national inventory development could draw.

5.4 Contribution to transparency and auditability

The FOLU report and spreadsheets show an auditable path from land-use maps to activity data, emission factors and emissions estimates. This is important because the Enhanced Transparency Framework requires not only numbers but also explanations of methods, data sources, assumptions and improvements. The spreadsheet architecture shows how source categories can be disaggregated by land transition and forest stratum, enabling reviewers and national experts to identify the drivers of emissions and priorities for improvement.

5.5 Relevance of FLINT and open-source MRV

FLINT's modular design is relevant because developing countries often need systems that can begin with available data and improve over time. Moja global presents FLINT as a framework capable of combining remote sensing, models and

ground data and producing outputs such as maps, tables and reports [8,9]. Kenya's experience confirms the practical importance of this architecture, but also shows that software alone is insufficient. Sustainable operation requires staff, recurrent budgets, computing infrastructure, institutional mandates, data-sharing protocols and continuous QA/QC.

5.6 Limitations

The accounting evidence reviewed here has limitations. Some spreadsheets contain spelling inconsistencies in category labels, and the FOLU report is an edited draft with editorial notes still visible in figures. Several modules envisaged under SLEEK, including soil carbon and crop components, depended on input datasets that were not always complete. The analysis is therefore best interpreted as evidence of SLEEK's contribution to FOLU activity data, forest-stratum emissions accounting and national capacity, rather than as a final verification of all land-sector emissions estimates.

6 CONCLUSION

SLEEK made a substantial contribution to Kenya's ability to account for emissions and removals from the land sector. The evidence reviewed in this paper shows that SLEEK supported complete land representation, time-series land-cover mapping, land-use change matrices, forest stratification, emission-factor development, QA/QC processes, FLINT-based integration and reporting-tool development. These contributions are visible in the 1990-2015 FOLU accounting chain and associated spreadsheets, which estimate cumulative net emissions of 858.66 Mt CO₂ and identify land conversion to grassland and cropland as dominant sources, land conversion to forest land as the main sink and montane/western rainforest as the largest forest-stratum contributor.

The principal lesson is that sustainable land-sector transparency cannot be created through periodic consultancy reports alone. It requires national datasets, national experts, auditable methods, working institutions and systems that can improve as data improve. SLEEK should therefore be understood as both a technical carbon-accounting platform and a national capacity-building model for implementation of the Paris Agreement's Enhanced Transparency Framework.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

The authors acknowledge the Government of Australia for its financial support during the implementation of the System for Land-based Emissions Estimation in Kenya (SLEEK) programme. The authors also acknowledge Kenya's Ministry of Environment, Climate Change and Forestry for its role as the programme's policy owner.

Funding Source

The implementation of the SLEEK programme, which provides the basis for this study, received financial support from the Government of Australia.

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript

REFERENCES

- [1] IPCC. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Hayama: Institute for Global Environmental Strategies; 2006.
- [2] UNFCCC. Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement. Decision 18/CMA.1. Bonn: UNFCCC; 2018.
- [3] Government of Kenya. FOLU National Inventory Report section: Land sector emissions and removals accounting, 1990-2015. Draft report, 2019.
- [4] Government of Kenya. SLEEK: System for Land-based Emissions Estimation in Kenya - Program Design Document. Nairobi: Ministry responsible for Environment; 2013.
- [5] Government of Kenya. SLEEK: Key Decisions and Design. Nairobi: Ministry responsible for Environment; 2016.
- [6] Government of Kenya. SLEEK Status Report, August 2016. Nairobi: Ministry responsible for Environment; 2016.

- [7] Australian Government Department of Climate Change, Energy, the Environment and Water. Full Carbon Accounting Model (FullCAM). Canberra: DCCEEW; 2026. Available from: <https://www.dcceew.gov.au/climate-change/publications/full-carbon-accounting-model-fullcam>
- [8] Moja global. FLINT. Available from: <https://moja.global/flint/>
- [9] Moja global. Understanding FLINT. Moja global technical guide documentation. Available from: <https://docs.moja.global/en/master/FLINT/UnderstandingFLINT/index.html>
- [10] Australian Centre for International Agricultural Research. Integrating approaches for estimating greenhouse gas emissions from forests and livestock in Kenya. Project LS/2018/202. Canberra: ACIAR; 2021. Available from: <https://www.aciar.gov.au/project/ls-2018-202>
- [11] Government of Kenya. SLEEK Progress Report to the Office of the Auditor-General. Nairobi: Ministry responsible for Environment; 2019.
- [12] Government of Kenya. Guide to Setting up and Running SLEEK-FLINT. Version 1.0. Nairobi: Ministry of Environment and Forestry; 2019.
- [13] Government of Kenya. SLEEK Reporting Tool: User Guide. Version 2.0b. Nairobi: Ministry of Environment and Forestry; 2019.
- [14] Government of Kenya. SLEEK Reporting Tool: System Installation Guide. Version 2.0b. Nairobi: Ministry of Environment and Forestry; 2019.
- [15] Government of Kenya. Kenya 2024 National Inventory Document. Bonn: UNFCCC; 2024. Available from: <https://unfccc.int/documents/645092>