A Framework for Measuring African Ecosystem Services Impacts from Land-Related Policies

GTAP: 28th Annual Conference on Global Economic Analysis

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Building on GTAP-InVEST

From Global to Local

Johnson et al.'s GTAP-InVEST framework (Johnson et al. 2023) established global-scale integration of economic and ecosystem service modeling

GTAP-InVEST (Global)

- Global CGE model
- Broad ecosystem service impacts
- Country-AEZ level aggregation

Our Framework (National→Local)

- National CGE model for Kenya
- Economic-environmental shocks at Kenya AEZ level
- Fine resolution LULC and ecosystem service maps
- Subnational policy assessment

Motivation

Sub-Saharan Africa faces trade-offs between economic development and environmental sustainability.

Current modeling gaps:

- **CGE models**: Miss spatial ecology
- **Ecosystem models**: No economic feedbacks
- **Global models**: Lack policy-relevant resolution

Case Study: Kenya

- Need to bridge economic modeling with environmental valuation for sustainable development planning
- Representative of broader African development challenges

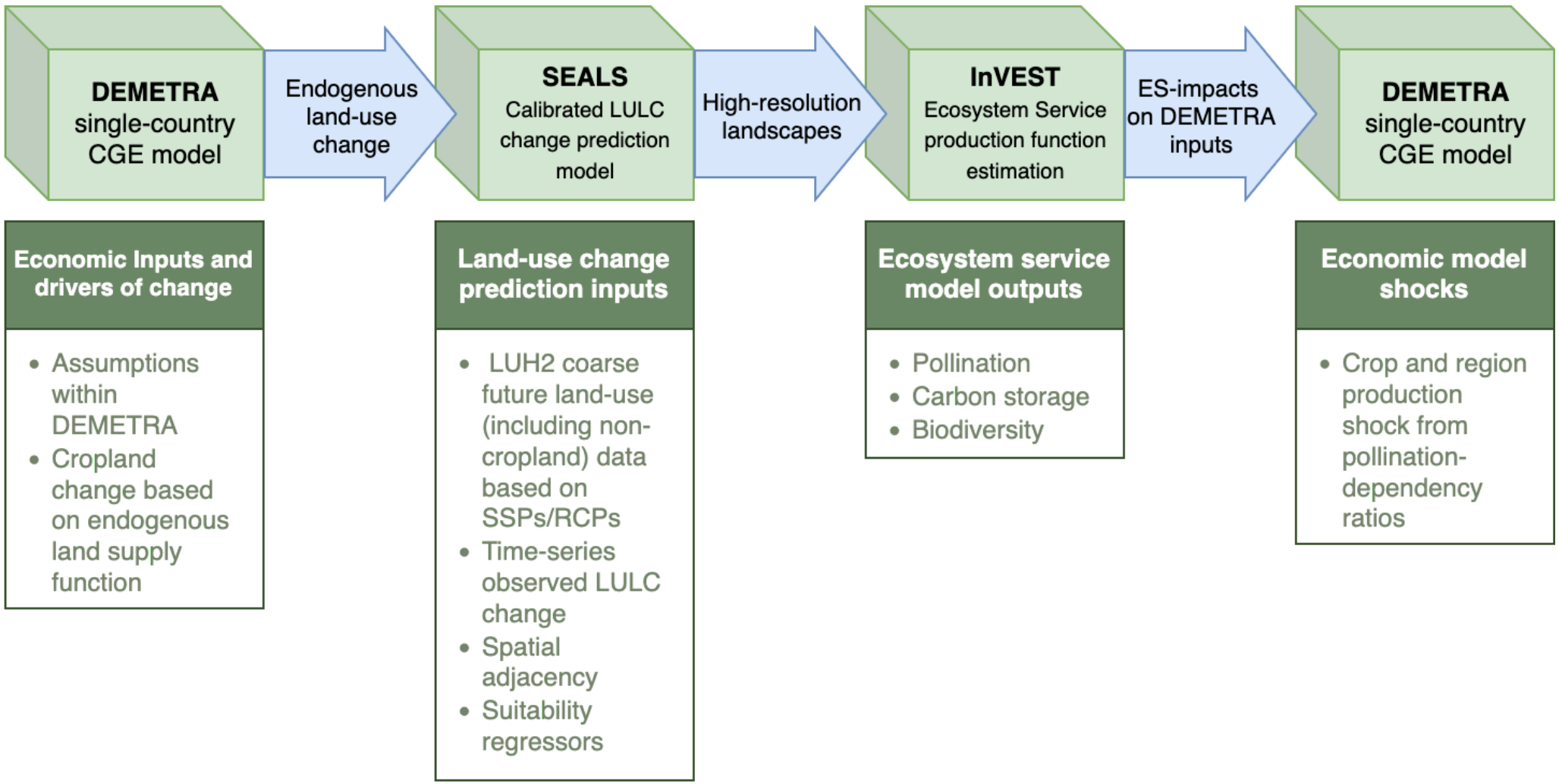
Contributions

1. **Scale bridging**
    - Global GTAP-InVEST methodology → National CGE → Subnational environmental impacts
2. **Technical innovations**
    - Endogenous land supply, Alternative basemaps, Kenya AEZ-level spatial units, integrated biodiversity metrics
3. **Policy-relevant resolution**
    - Economic-environmental feedbacks at subnational level (pollination shocks affecting agricultural productivity)
4. **Extensible framework**
    - Replicable approach for other African countries with globally available geospatial data

Methodology

DEMETRA + SEALS + InVEST

Overall Modeling Framework

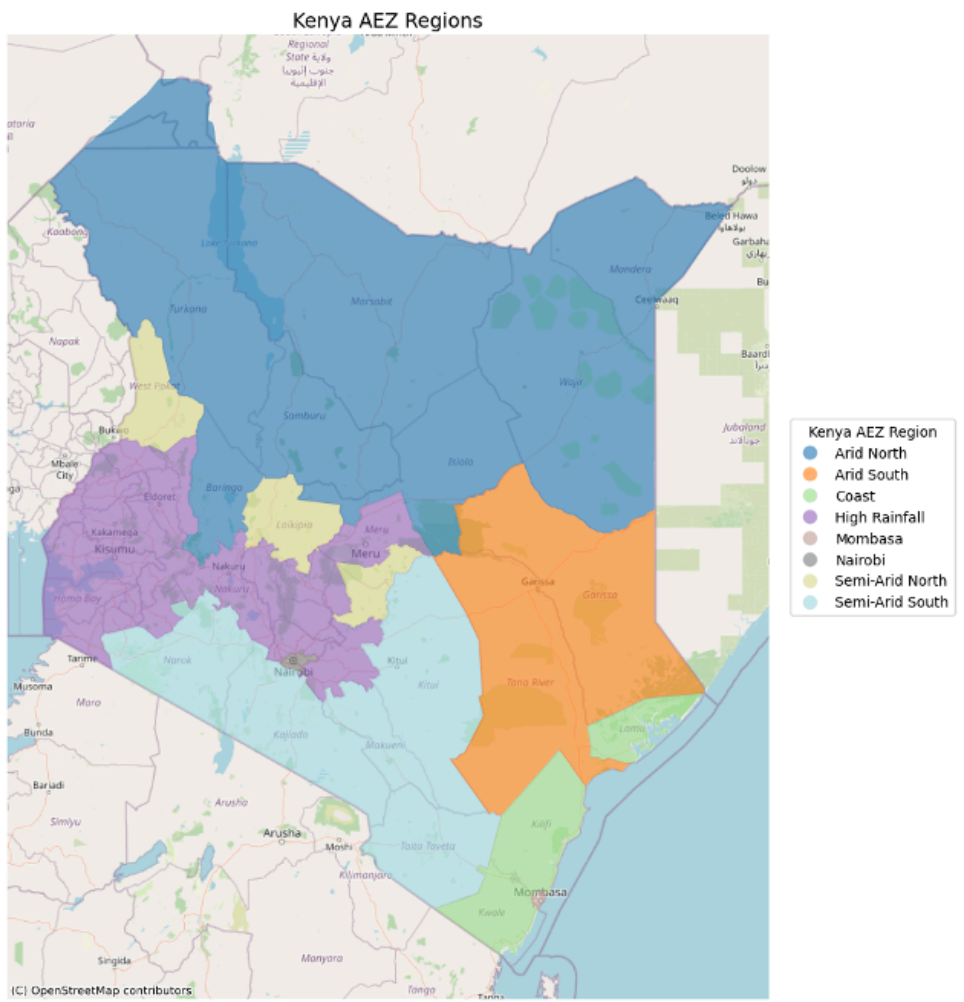


DEMETRA

Dynamic CGE Model for Economic Development, Resources and Agriculture

Model Framework:

- Recursive dynamic CGE for single-country applications
- Built on STAGE_DEV framework (Aragie et al. 2017)
- Focus on developing countries
  - → Dual role of semi-subsistence agricultural households
- 2017 Kenya Social Accounting Matrix (Mainar Causapé et al. 2018)
- Spatial units: 8 Kenya AEZ regions
  - → 6 aggregated county regions and 2 urban areas (Mombasa, Nairobi)



SEALS

Spatial Economic Allocation Landscape Simulator

Purpose: Downscale land-use change predictions to fine resolution (300m)

- Coarse LUH2 data aligned with SSP-RCP scenarios
- Regional change from CGE

Methodology (Suh et al. 2020; Johnson et al. 2020):

- Spatial allocation based on observed relationships in timeseries data
- Iterative Gaussian L1-loss function minimization
- Calibrated on ESA CCI Land Cover dataset (1992-2015) (ESA 2017)

InVEST

Integrated Valuation of Ecosystem Services and Tradeoffs

Carbon Storage:

- Four pools: above/belowground biomass, soil, dead matter
- Carbon storage estimation from land-use maps (Sharp et al. 2020)
- Data has global coverage

Pollination:

- Natural habitat as pollinator source
- Distance decay to crops (ESA CCI classes)
- Globally flexible approach (Chaplin-Kramer et al. 2019)

Biodiversity Extension:

- More flexible than habitat suitability model
- Gridded biodiversity index

Ecosystem-Economy Feedback Loop

Pollination Feedback with DEMETRA

Feedback Mechanism (Johnson et al. 2023):

- InVEST pollination output feeds back to DEMETRA as agricultural productivity shock
- Factor-neutral approach modifies efficiency coefficients in production functions
- Spatially detailed data identifies areas losing pollinator habitat
- Pollination sufficiency threshold: 0.3 (below this triggers linear productivity loss)
- Crop dependence data: pollination dependency coefficients by crop type (Garibaldi et al. 2013)

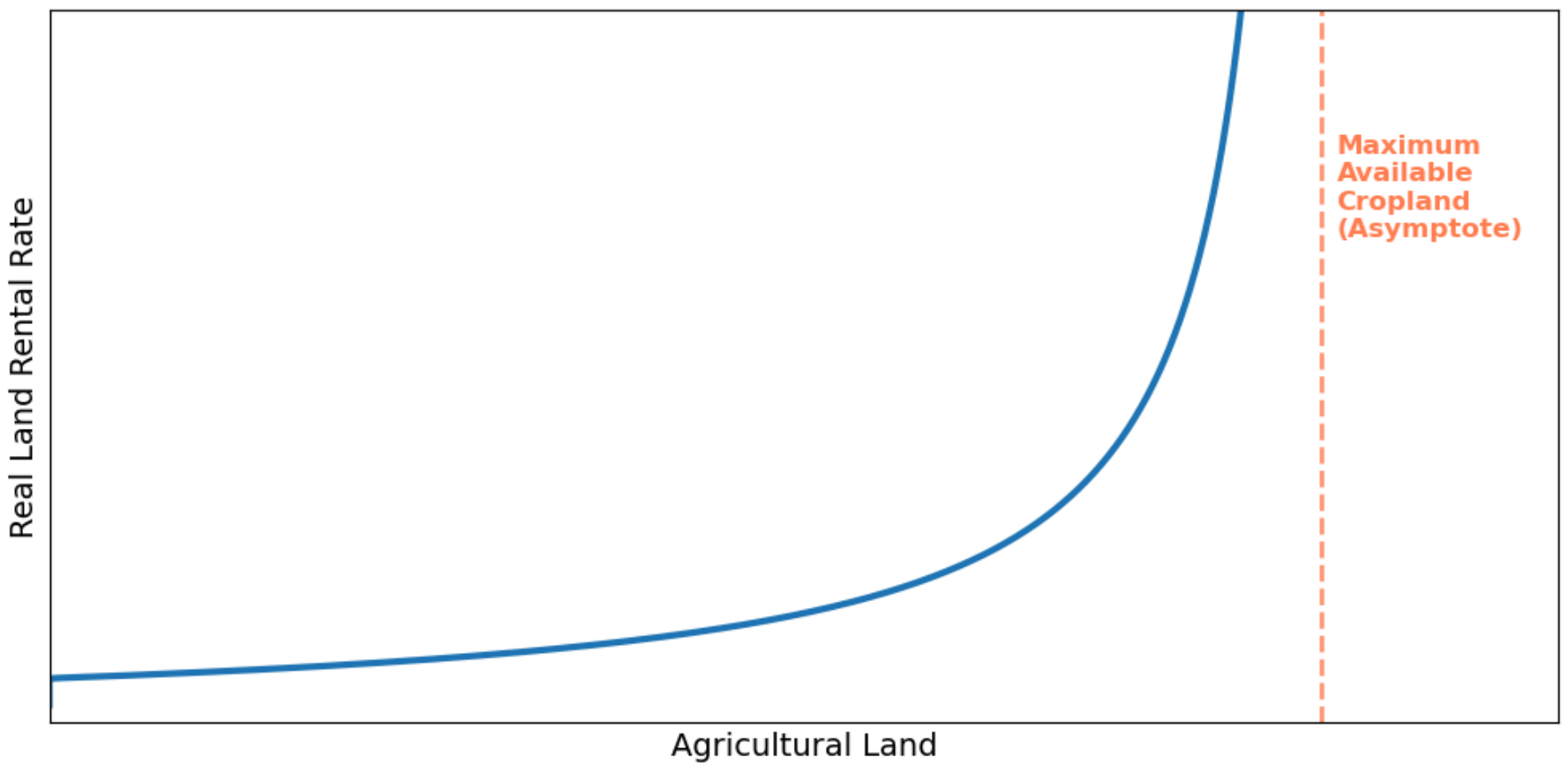
Spatially explicit coupling captures heterogeneous landscape effects on agricultural productivity, improving on static approaches that assume uniform pollination impacts (Appendix).

Methodological Advances

Endogenous Land Supply

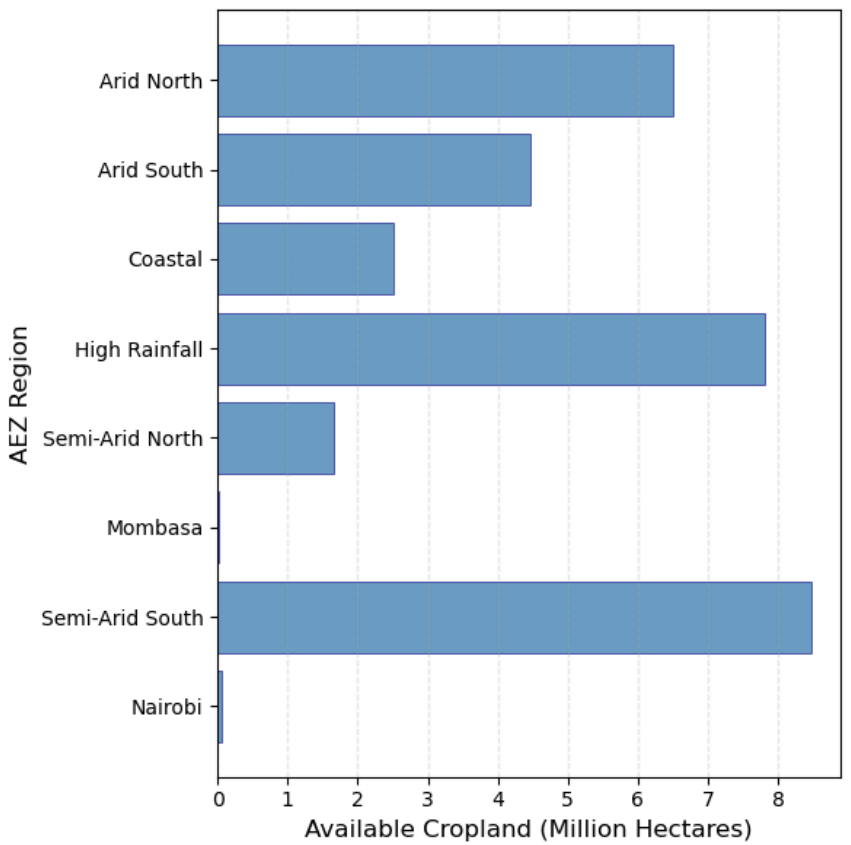
DEMETRA

Follow MAGNET (Woltjer et al. 2014) and GTAP-InVEST (Johnson et al. 2023) approaches



Endogenous Land Supply

Base Year Maximum Available Cropland



Spatial Input Conditions:

- Nutrient indices (retention, availability)
- Oxygen availability index
- Rooting conditions index
- Soil toxicity index
- Excess salts index
- Land workability index
- Topographic roughness index
- Local caloric yields
- Land use/land cover

SEALS Enhancements

Subnational Units & Alternative Basemaps

1. Alternative Basemaps

- Flexible initialization with range of land-use datasets
- Adaptable to different regional contexts

2. Sub-national Administrative Boundaries

- Integration of detailed administrative units
- Granular modeling within countries
- Alignment with single-country CGE analyses

Biodiversity Index

Additional Measure of Ecosystem Services

Not currently included in the InVEST suite of models

- Habitat Quality model requires detailed data on threats to habitat
- New biodiversity index captures aggregate impacts based on changes in land-use

Components:

- Species habitat suitability mapping (IUCN Red List)
- Key biodiversity areas (The World Database of Key Biodiversity Areas)
- Ecoregion mapping (WWF)
- Land-use land-cover classifications (ESA CCI)

Baseline Results

Baseline Scenario

SSP2-4.5 LUH2 Data

SSP2-4.5 MESSAGE derived from IIASA Integrated Assessment Modelling (IAM) framework

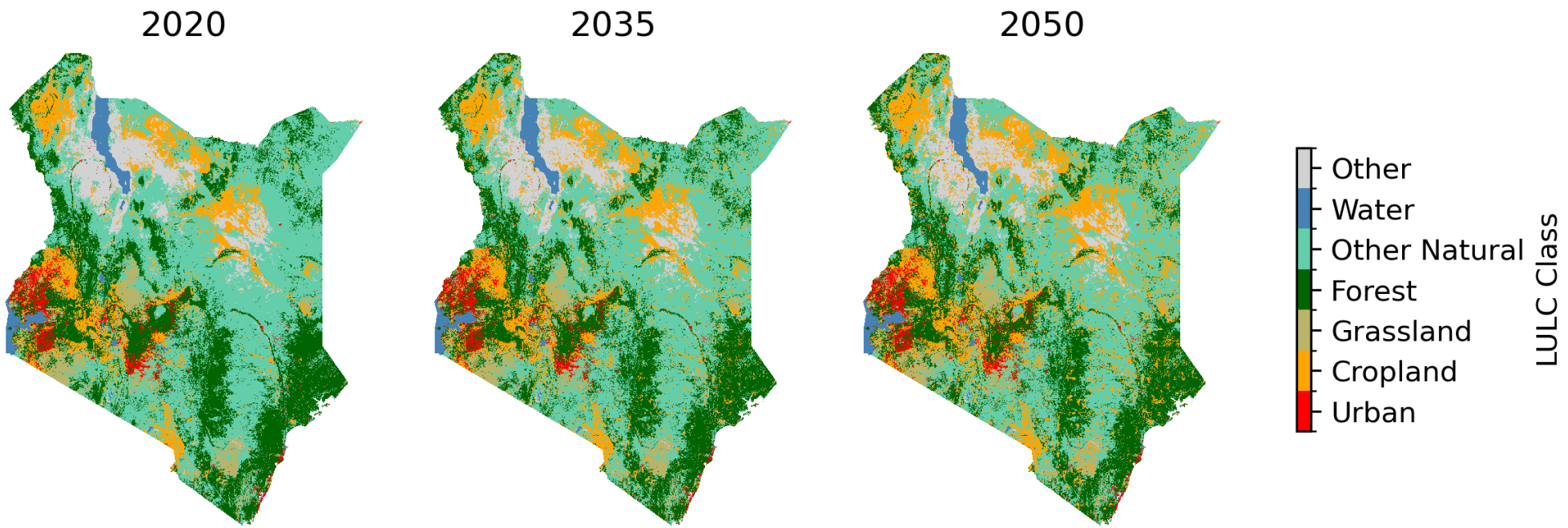
Projected Land Use Trends

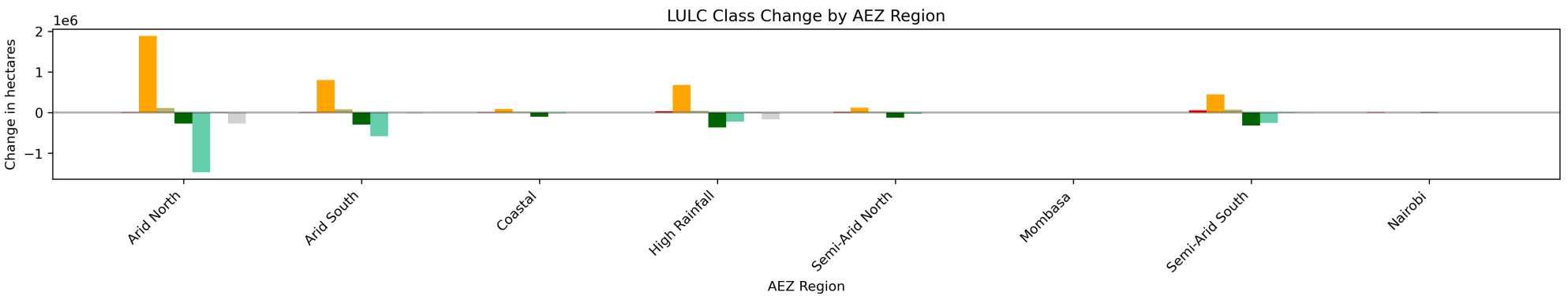
- *Cropland*: Moderate expansion, especially in Sub-Saharan Africa and South Asia
- *Pasture*: Slight growth or stabilization; concentrated in Latin America and Africa
- *Forest*: Net loss of ~43 million ha by 2050
- *Urban*: Steady expansion near growing cities, especially in developing regions

Key Land Use Drivers

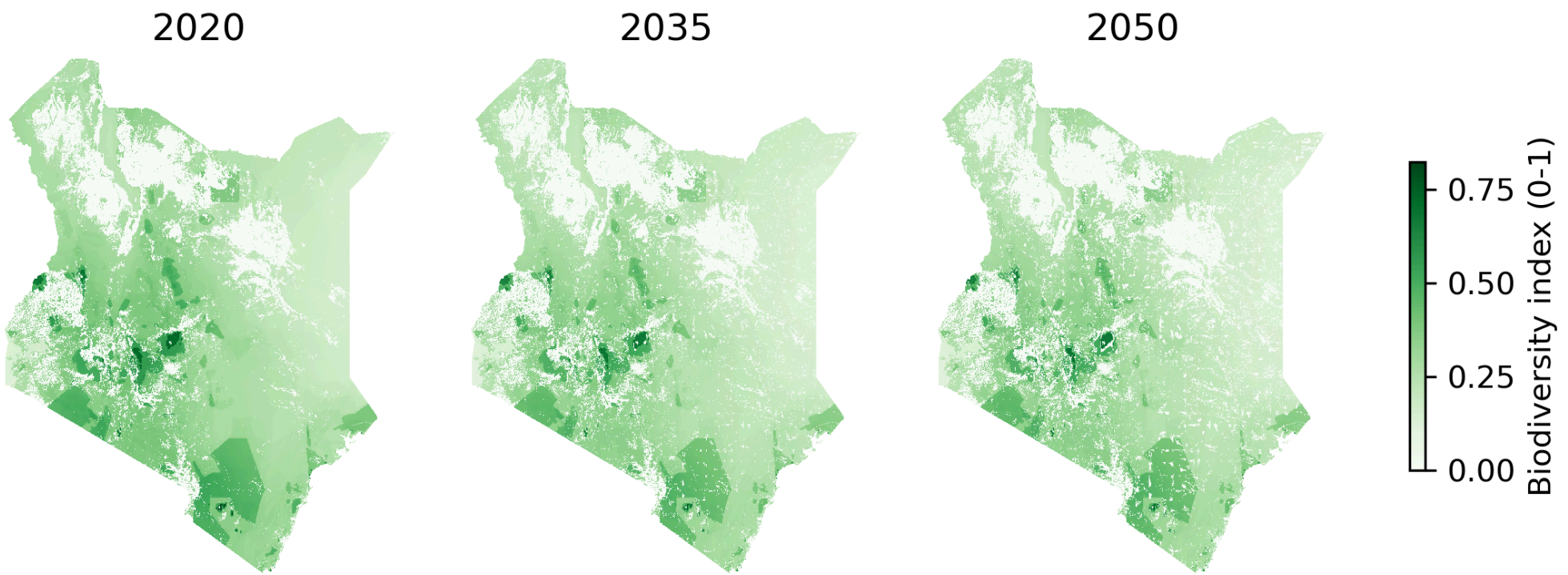
- *Population growth*: Increases land and food demand
- *Agricultural productivity*: Moderate gains; not enough to offset land expansion fully
- *Consumption patterns*: No major dietary shift; livestock demand remains high
- *Land-use regulation*: Weak enforcement; limited protection of natural areas

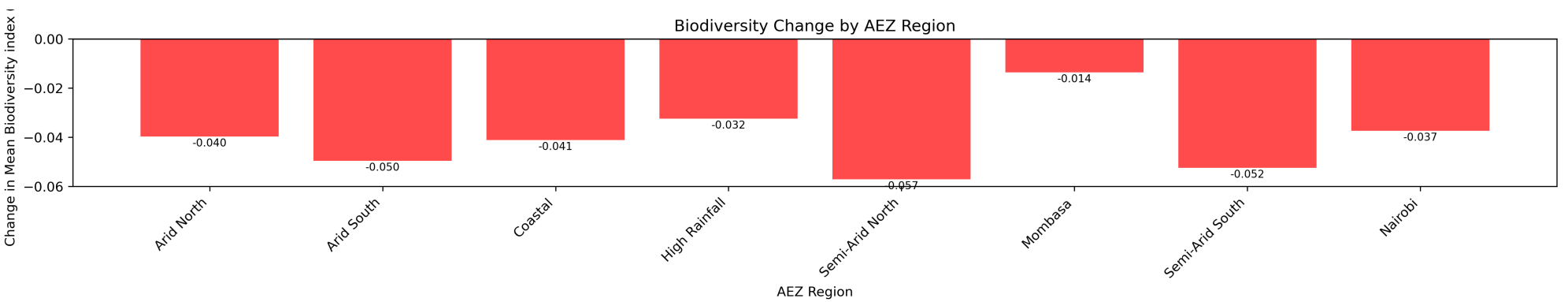
Land Use Change



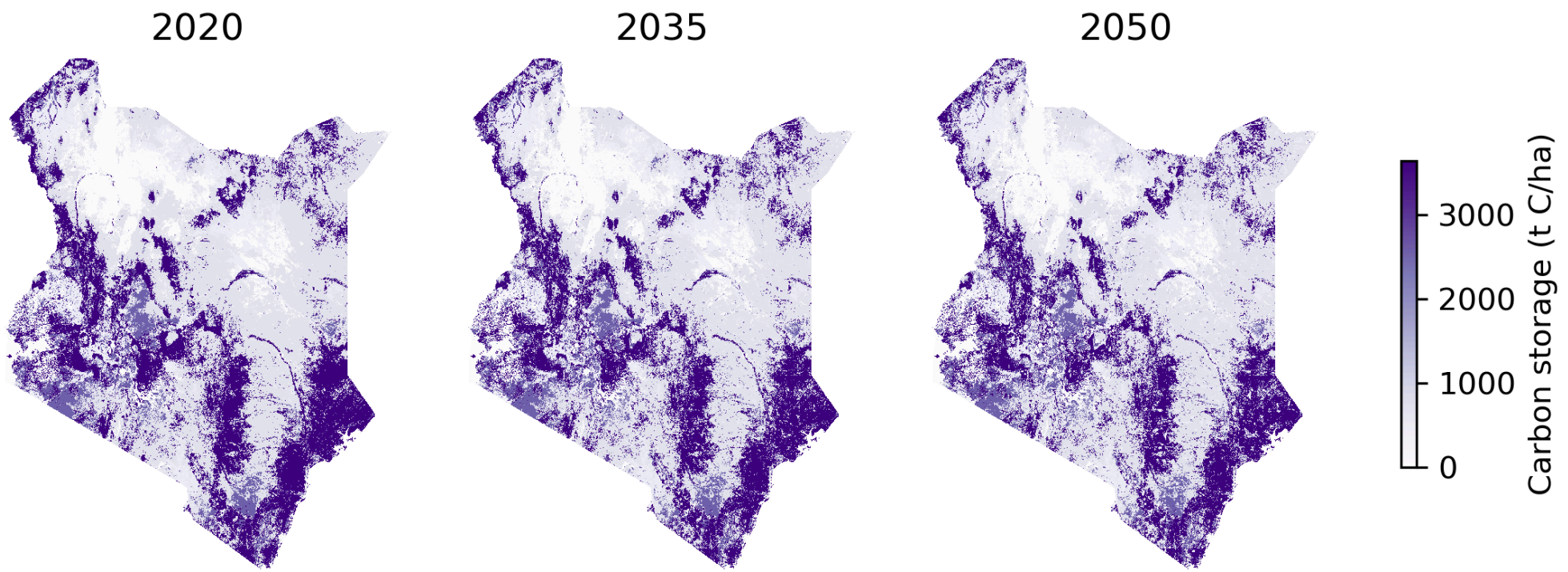


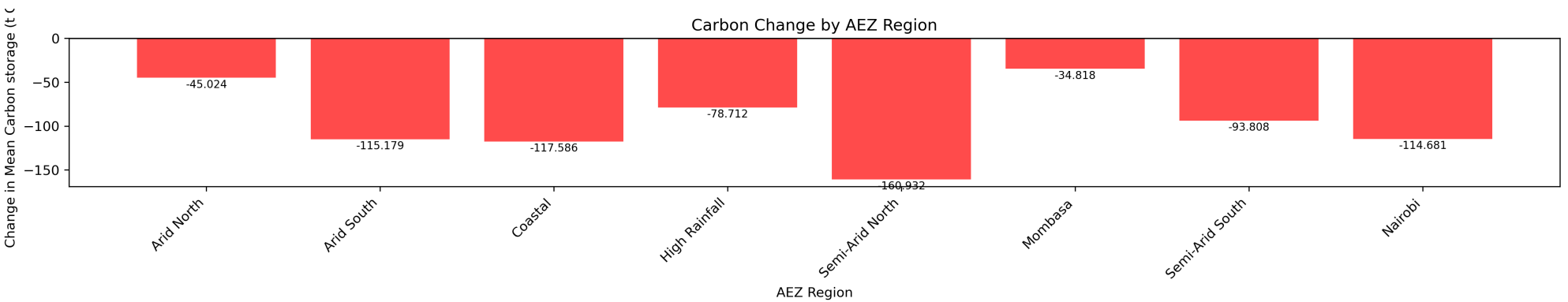
Biodiversity



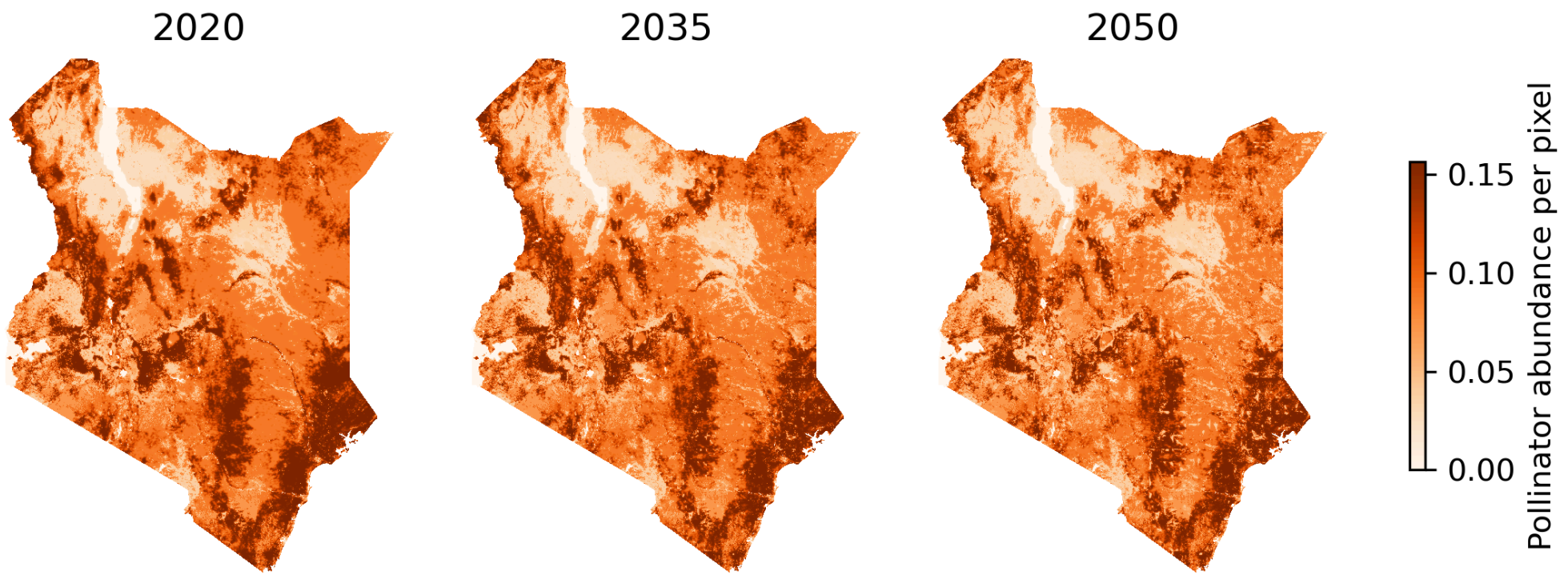


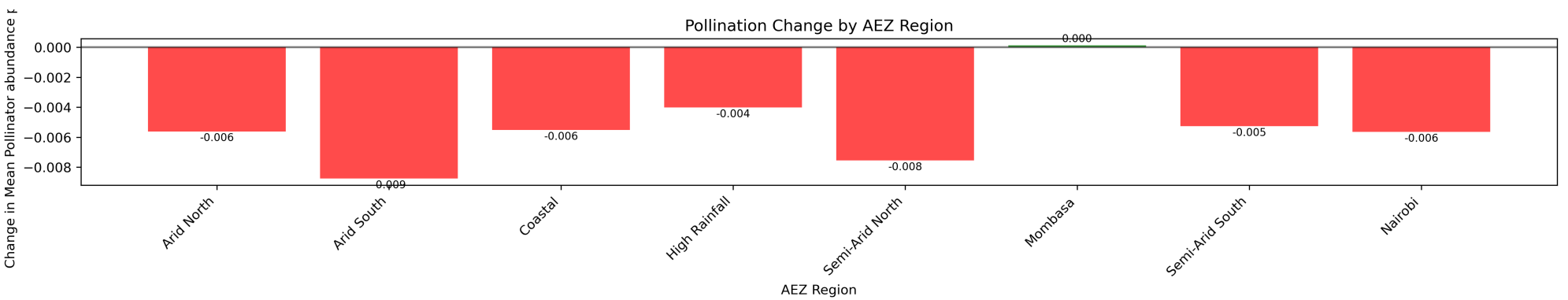
Carbon Storage



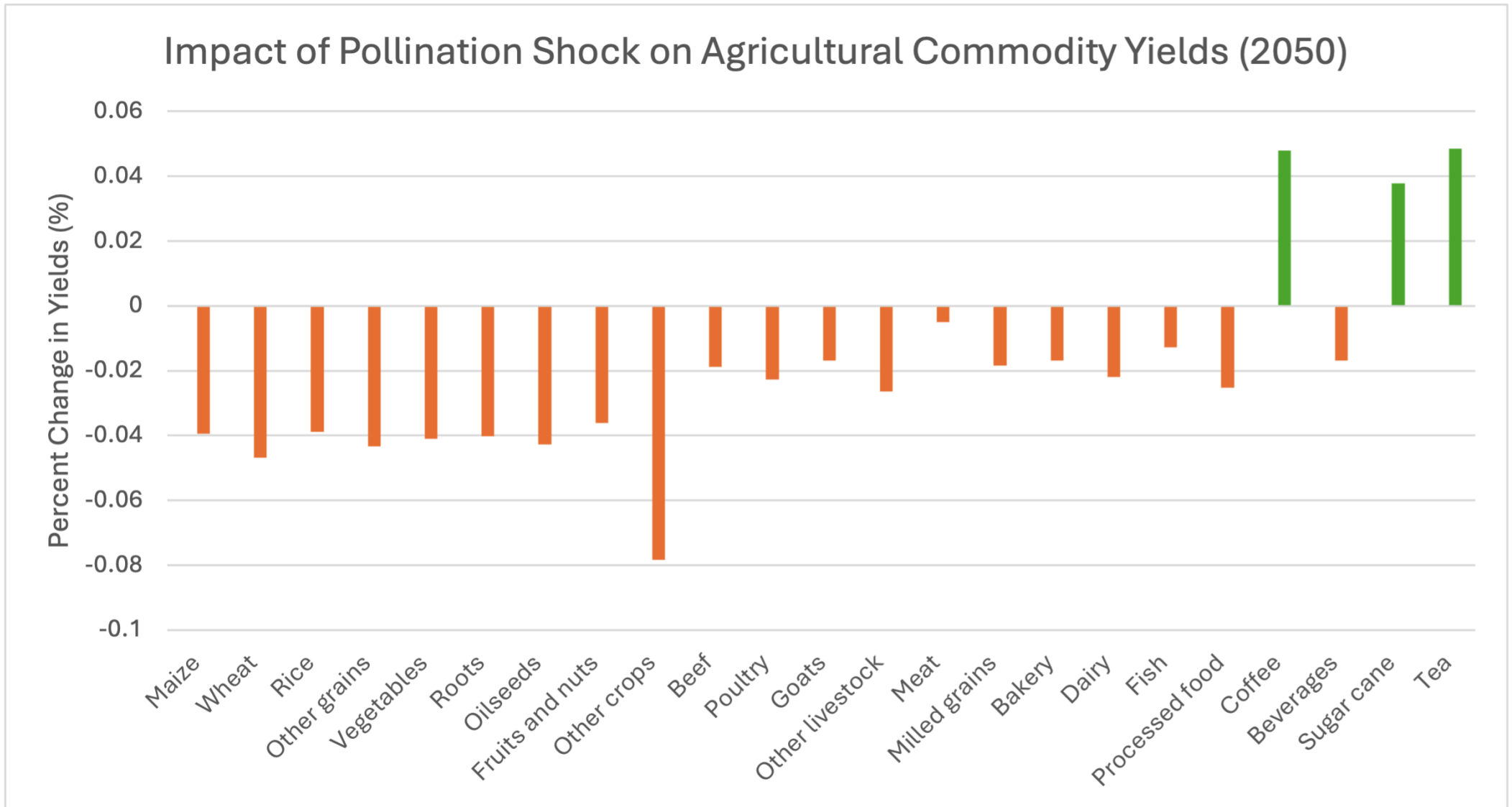


Pollination

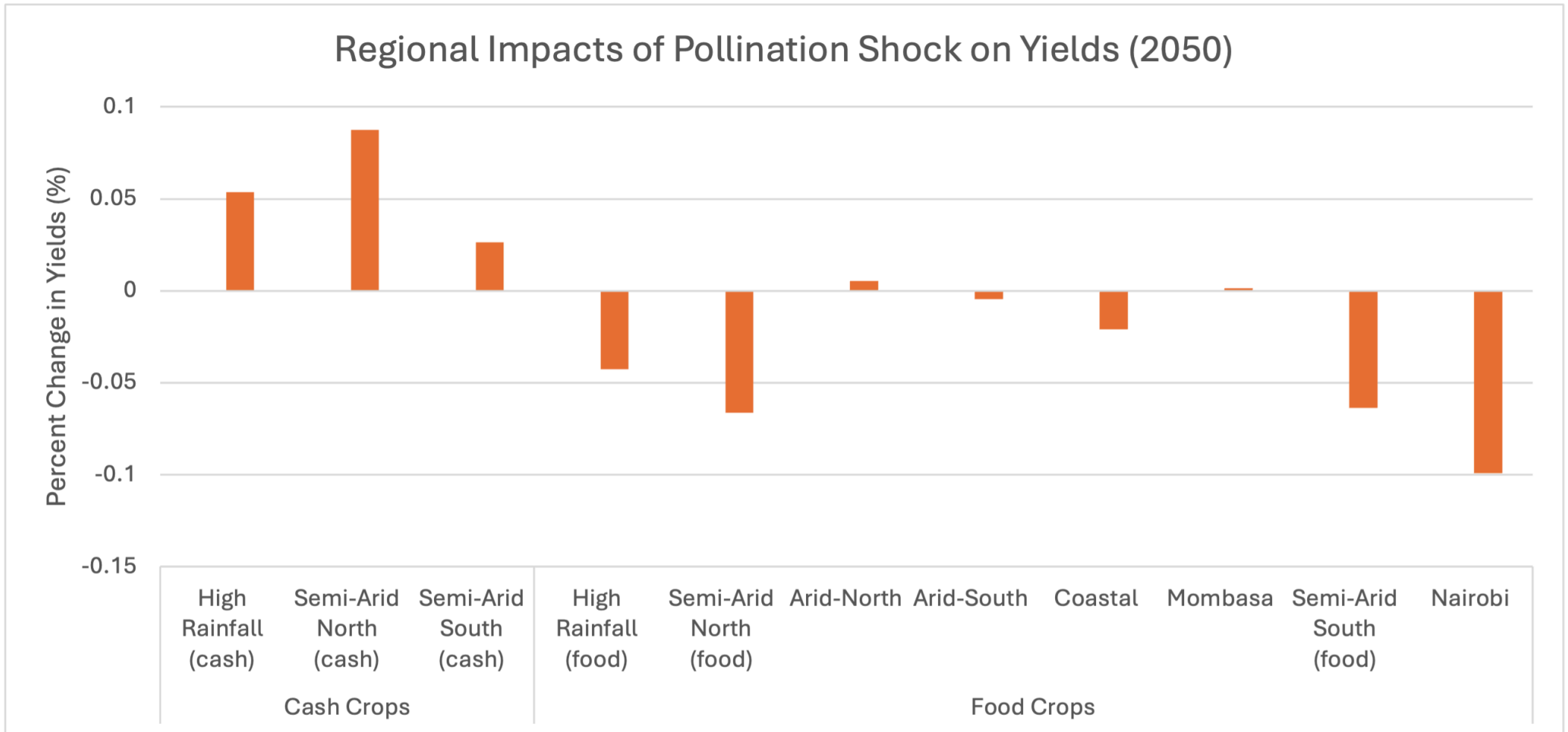




DEMETRA Pollination Shock



DEMETRA Pollination Shock



Conclusion

Policy Applications & Framework Flexibility

Flexible Framework Design:

- Compatible with multiple SSP-RCP-LUH2 scenario combination
- Data with global coverage means analysis is adaptable to different African countries and policy contexts
- Multiple experiment types supported

Potential Applications:

- **Economic shocks**: Land productivity impacts via DEMETRA
- **Spatial policies**: Protected area management and forest conservation
- **Pathway scenarios**: SSP2-RCP4.5, SSP3-RCP7.0

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[1] Presentation theme by Grant R. McDermott

Appendix

Complexity of landscape configuration in the context of pollination