Towards a new generation of Integrated Land-System Models – A review of modelling approaches

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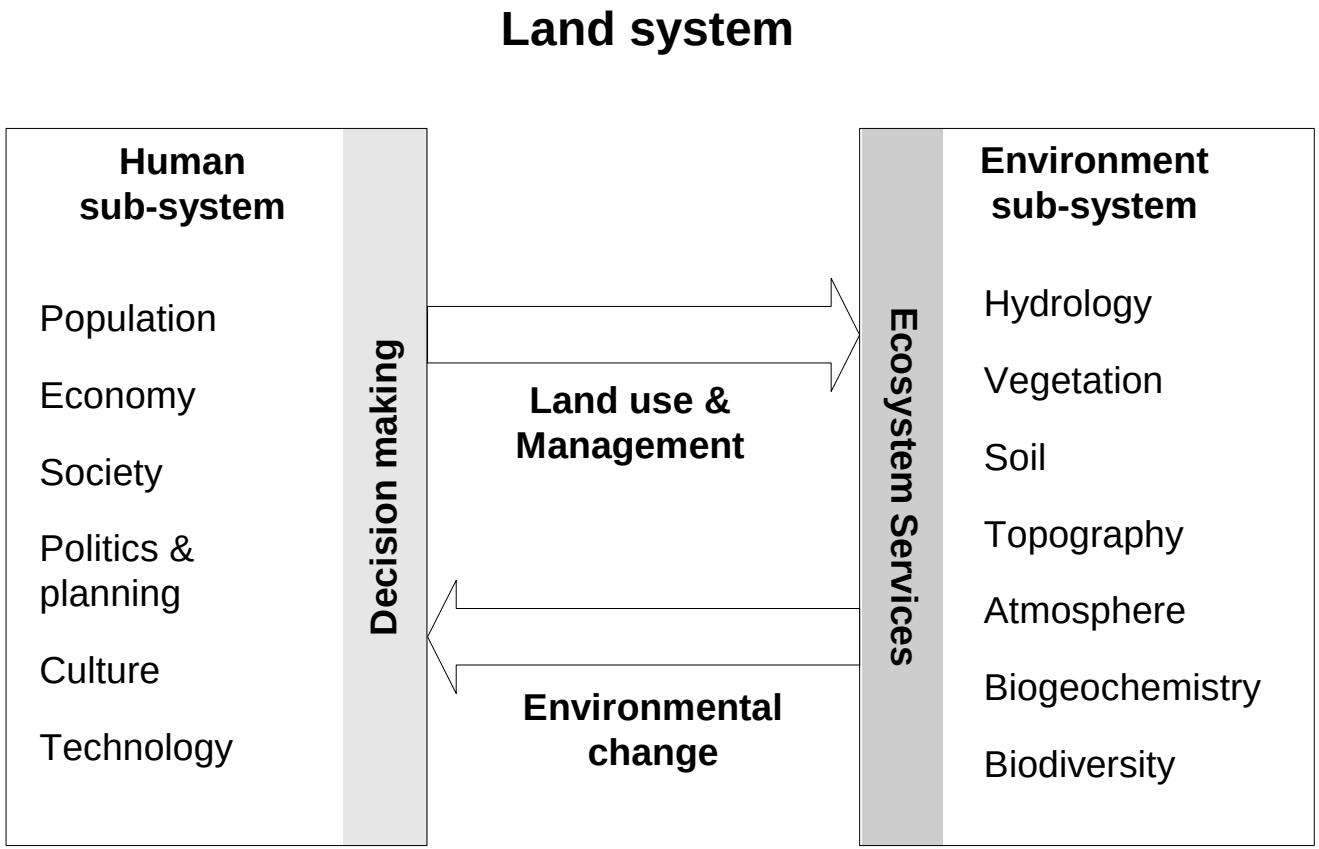
Outline

- Analytical framework and scope of the review
- Model concepts on the regional and global scale
  - Human sub-system
  - Environment sub-system
  - Human-environment interactions
- Summary and Outlook

Conceptual model of Land Systems



Based on GLP (2005)

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What defines an Integrated Model?

Integrated (Assessment) Models: Computer simulation frameworks that try to describe quantitatively as much as possible of the cause-effect relationships of a specific issue, and of the interlinkages and interactions among different issues. (Rotmans, 1998)

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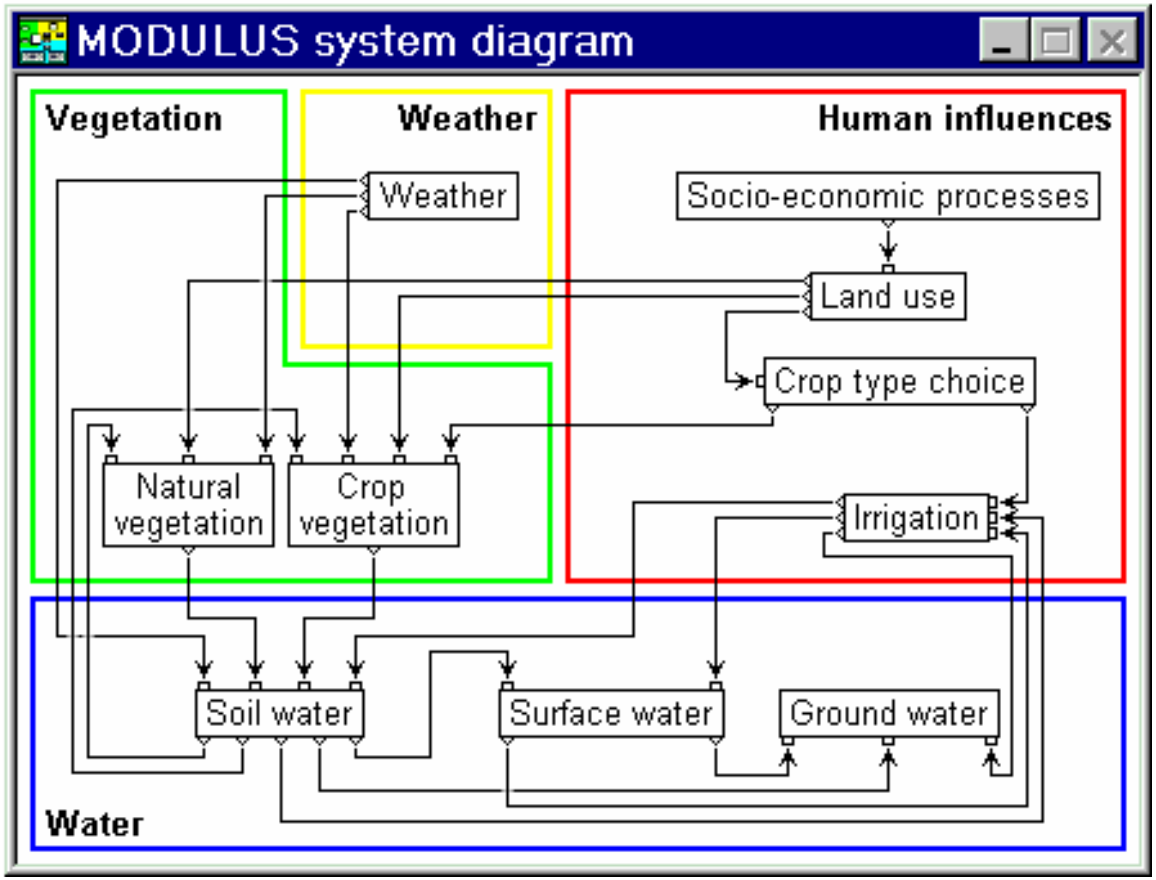
Land Systems: Elements and interactions



Engelen et al. (2000)

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Integrated Land-System Models on the regional and global level

Selection criteria:

1. Models that include processes of both the human and environment sub-systems to simulate the dynamics of the coupled human-environment system.
2. Models that focus on the interplay and competition between multiple land-use related human activities and their environmental consequences.
3. Geographically explicit models that are designed for the regional and watershed level (>1000 km^2) up to the global level.

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Overview of Integrated Models

Model	Scale level	Case study regions	First description
CLUE	Regional – Continental	Several case studies	Veldkamp and Frasco (1996)
GEONAMICA	Regional	Several case studies	Engelen et al. (2000)
IMAGE	Global	Global assessments	Alcamo et al. (1998) Bouwman et al. (2006)
ITE²M	Regional	Lahn-Dill region, Germany	Frede et al. (2002)
LANDSHIFT	Country – Global	Africa and India	Alcamo and Schaldach (2006) Schaldach et al. (2006)
PLM	Regional	Patuxent watershed, USA	Costanza et al. (2002)
SITE	Regional	Sulawesi, Indonesia	Priess et al. (2007a, b)
SYPRIA	Regional	Southern Yucatan, Mexico	Manson (2006)

Schaldach and Priess (under review) Integrated Models of the Land System: A review of modelling approaches on the regional to global scale, Living reviews in Landscape Research

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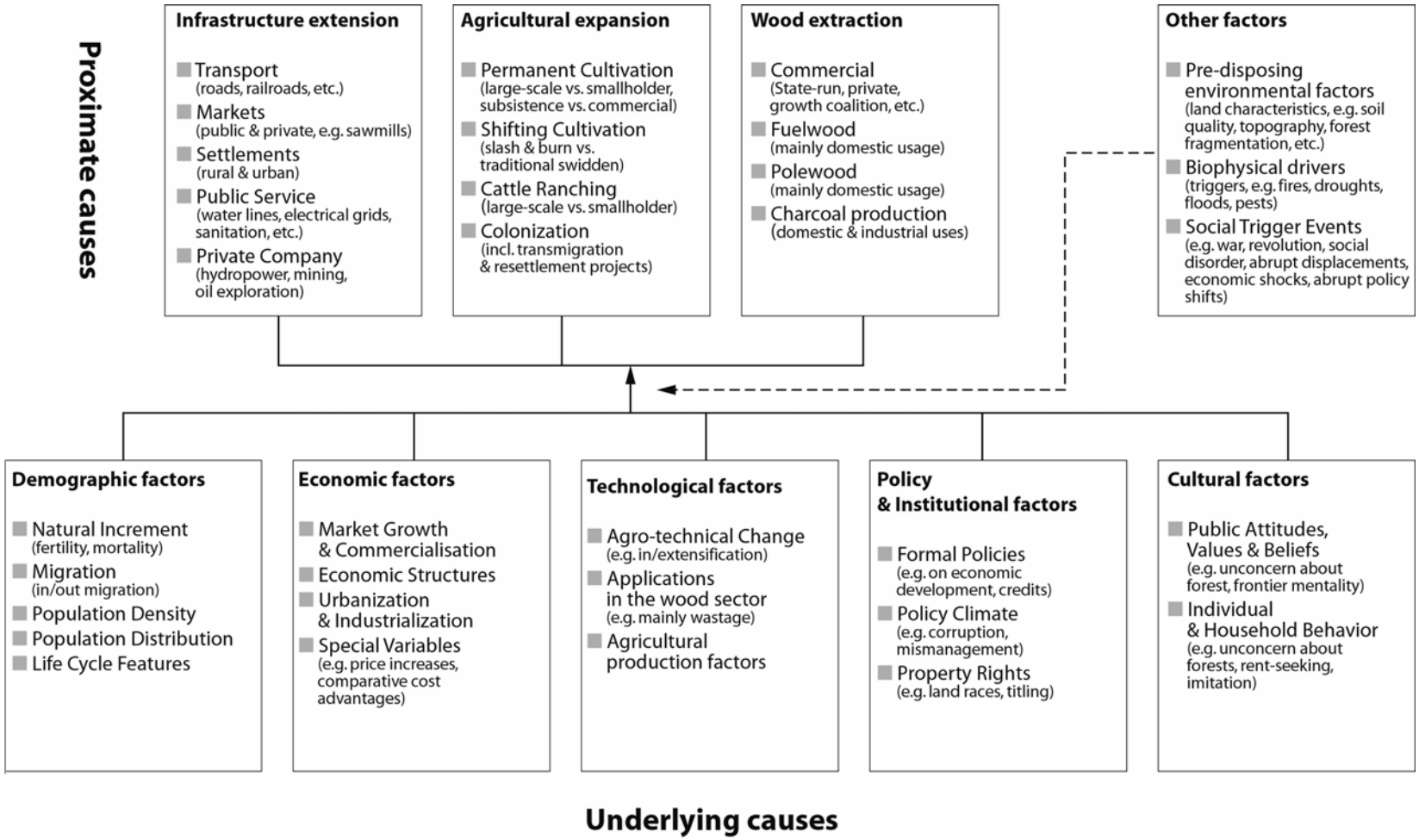
The Human sub-system

Causes of land-use change



Geist and Lambin (2002)

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Underlying causes

Endogenously modelled

- Agricultural demand modelled by General Equilibrium Model GTAP and energy demand modelled by TIMER (IMAGE)
- System Dynamics approach to model regional demands for land-use classes from demographic development and the agricultural and non-agricultural parts of the economy (GEONAMICA)
- Institutions that define boundary conditions for land use (SYPRIA)

Exogenous input variables (driving factors)

- Demography and population growth → Area demands for housing
- Agricultural production → Area demands or product demands
- Technological Change → Crop yields, water use efficiency
- Policy and planning → Subsidy payments, land-use constraints

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Proximate causes

Decision making related to land-use change

- Cellular automata
- Rule based approaches
- Statistical regression
- Markov chain approach
- Land-rent based decision making
- Agent based modelling

→ The reviewed models implement top-down approaches

- Assessment of cell suitability
- Allocation of land or production

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The Environment sub-system

Land

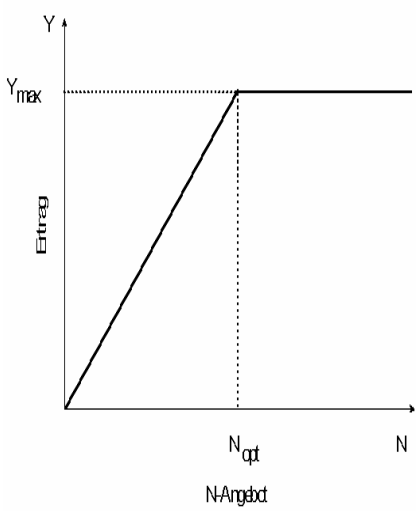
- Vegetation growth (e.g. yields, NPP)
- Vegetation cover and succession
- Soil nutrient dynamics
- Soil erosion
- Biodiversity (species number and richness, pollinators)

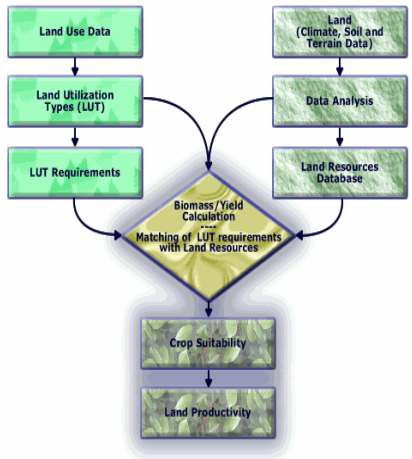
Water

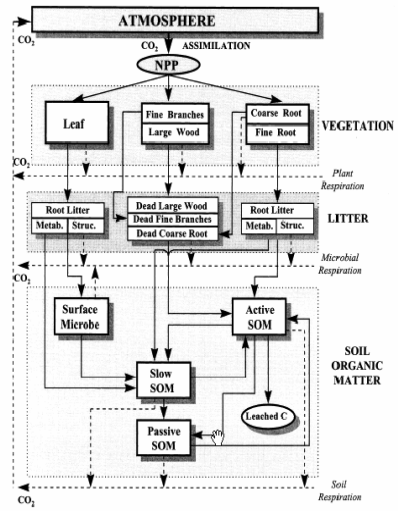
- Vertical water balance (e.g. ET, run-off)
- Horizontal water fluxes (river discharge)
- Water quality (nutrient levels)

Model complexity

Example: Modelling of crop yields:







Level of complexity

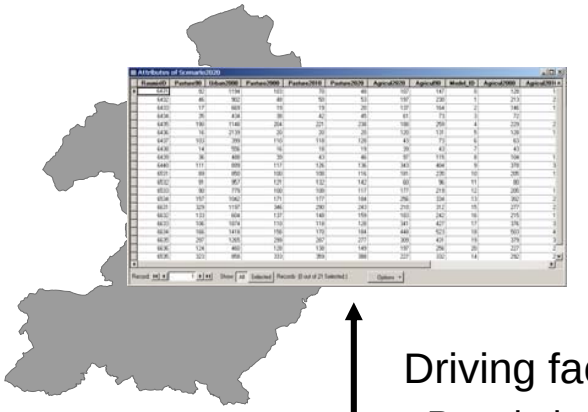
Empirical models (Liebig function)

Hybrid models (AEZ)

Process based models (DayCent, GEM)

Spatial model integration

Regional level

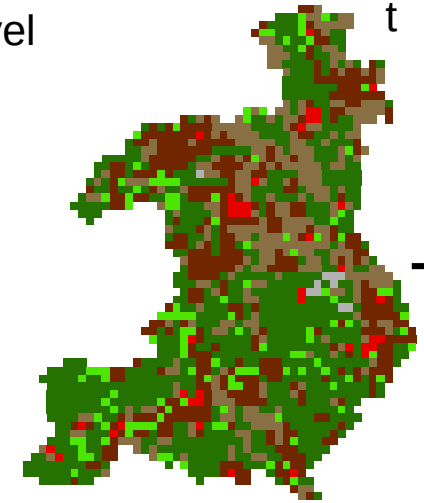


Driving factors

- Population growth
- Change in crop production etc.

Grid level

t



Land-use change

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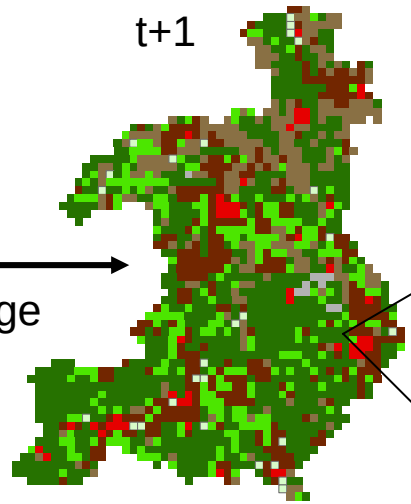
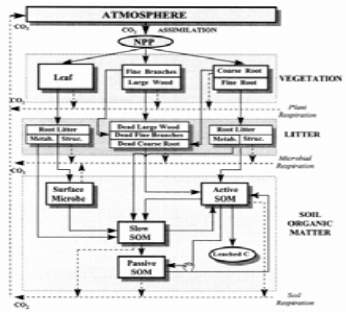


Ecosystem and hydrological processes



Human-Environment interactions: Land-use and management

Land-use and management	Ecosystem services / functions
Change of spatial land-use pattern	Vegetation cover, carbon and water balance, biodiversity
Settlement development	
- Sewage disposal	Water quality
- Soil sealing	Hydrological cycle (run-off)
Agricultural management	
- Fertilizer input	Crop yield, soil quality, water quality
- Practice (fallow, tillage)	Crop yield, soil quality
- Irrigation water use	Water availability
- Livestock	Climate (greenhouse gas emissions)

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Human-Environment interactions
Environmental Change

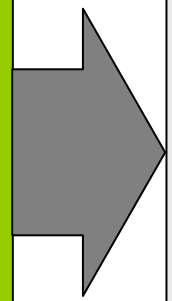
Environmental Change

Change of biomass productivity

- Crop yields
- NPP
- Soil fertility
- Soil depth (erosion)

Change of water availability

Change of land availability



Land-use decisions

Location of cropland and grazing land, crop choice

Location of irrigated area and crop choice

Agriculture economy

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Summary

- Integrated approaches for global and regional level are relatively scarce in literature
- Wide range of model approaches, complexity and level of integration
- Most models put their focus on one sub-system which is modelled with higher level of detail
- Linkages between the human and the environment sub-system still relatively limited
- Examples for redundant definition of environmental processes
- In most of the models, underlying causes of land-use change are not explicitly simulated and therefore cannot be influenced by Environmental Change feedback

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Outlook: Towards a new generation of Land-System Models

Modelling of the human and environment sub-systems

- What level of detail is necessary (key processes)?
- Should both parts have a similar level of complexity?
- How important is a unique definition of processes within the integrated model?

Linkages between the human and environment System

- Which linkages are needed to achieve a more realistic model behaviour?
- How can the human influence on the environment be modelled more explicitly?
- How can feedback of environmental change on the underlying causes of land-use change be modelled?
- How can these complex models be tested and validated?