Integrated management of land use systems under systemic risks and food-energy-water-environmental security targets: a stochastic Global Biosphere Management Model

Tatiana Ermolieva, Yuri Ermoliev, Petr Havlík, Aline Mosnier, Michael Obersteiner, Dadid Leclere, Nikolay Khabarov, Hugo Valin, Wolf Reuter

Global changes, increasing interdependencies, vulnerability, and systemic risks in land use systems

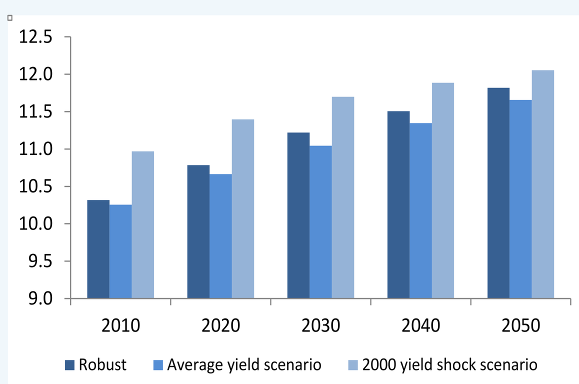
- Land use systems (LUS) resemble a complex network connected through demand–supply relations such that the disruption of one—perhaps due to a yield shock in one region—may catalyze systemic risks affecting LUS worldwide and thus threaten food-energy-water-environmental (FEWE) security.
- Systemic risks are characterized by the structure of the interdependencies in/between LUS, as well as by the distribution of risks (natural and shaped by decisions of intelligent agents), by targets and security constraints, e.g. emissions, biofuels, food requirements, water availability and quality, land pollution, etc.

Stochastic GLOBIOM and FEWE security management

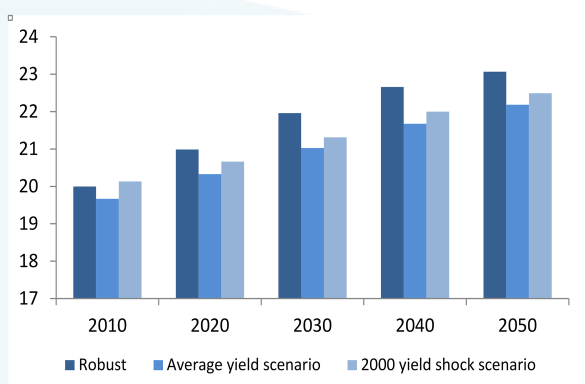
- Stochastic GLOBIOM is a stochastic partial equilibrium price-endogenous model; main land uses distinguish crop land, grass land, forest (managed and non-managed) land, fast-rotation forest plantations, and natural land.
- Stochasticity is represented by random yield shock scenarios. The model can include stochastic costs, other threats.
- Production from LUS has to cover respective demand in all scenarios: Food security constraint ensures that the energy intake from food cannot be lower than minimum amount of kilocalories needed to satisfy dietary requirements; Feeds produced for livestock cannot be lower than the minimum livestock dietary requirements; First-generation biofuels from crops and second-generation biofuels from lignocellulosic biomass (woody crops) and agricultural residues have to fulfill biofuel production targets, etc.
- Food, feed, and biofuel security targets introduce competition for limited natural resources (land and water) among different land uses.
- Global interdependencies between demand, prices, international trade flows, and environmental constraints are analyzed in an endogenous manner for 30 world regions (Havlík et al. 2011), while decisions on production and land use allocation are taken at a 50 x 50 km grid cell resolution.
- Robust solutions make systems and regions better-off in all scenarios.

Robust solutions: strategic and adaptive decisions

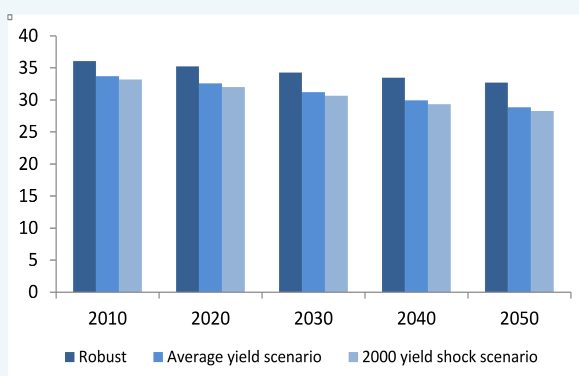
- Stochastic GLOBIOM is formulated as a two-stage stochastic optimization model deriving robust interdependent decisions: ex ante strategic decisions (production allocation, storage capacities) and ex post adaptive (demand, trading, storage control, prices) decisions.
- Strategic decisions can be viewed as decisions in the face of uncertainties (before the exact state of nature is learned). Adaptive (operational) decisions are executed when additional information on uncertainties is revealed (after learning), allowing the policies to be adjusted. The model embeds quantile-based security constraints, which are central for ensuring security, managing systemic risks, maladaptation and irreversibility.
- The model recommends strategic solutions: natural ecosystems should be preserved, the conversion of natural forests into managed should slow down, grass land should be protected as an important feed source for livestock, etc. Robust strategic solutions are supplemented with adaptive scenario-specific trade and storage decisions.



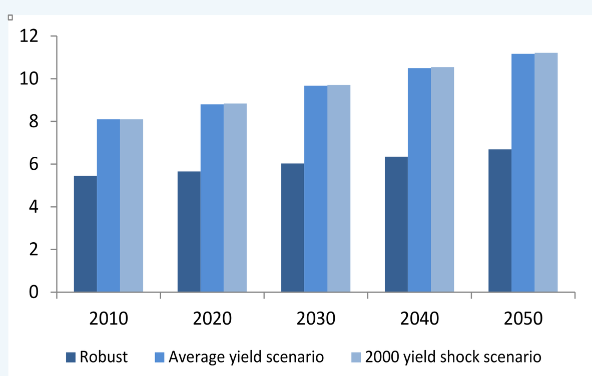
Crop land



Grass land

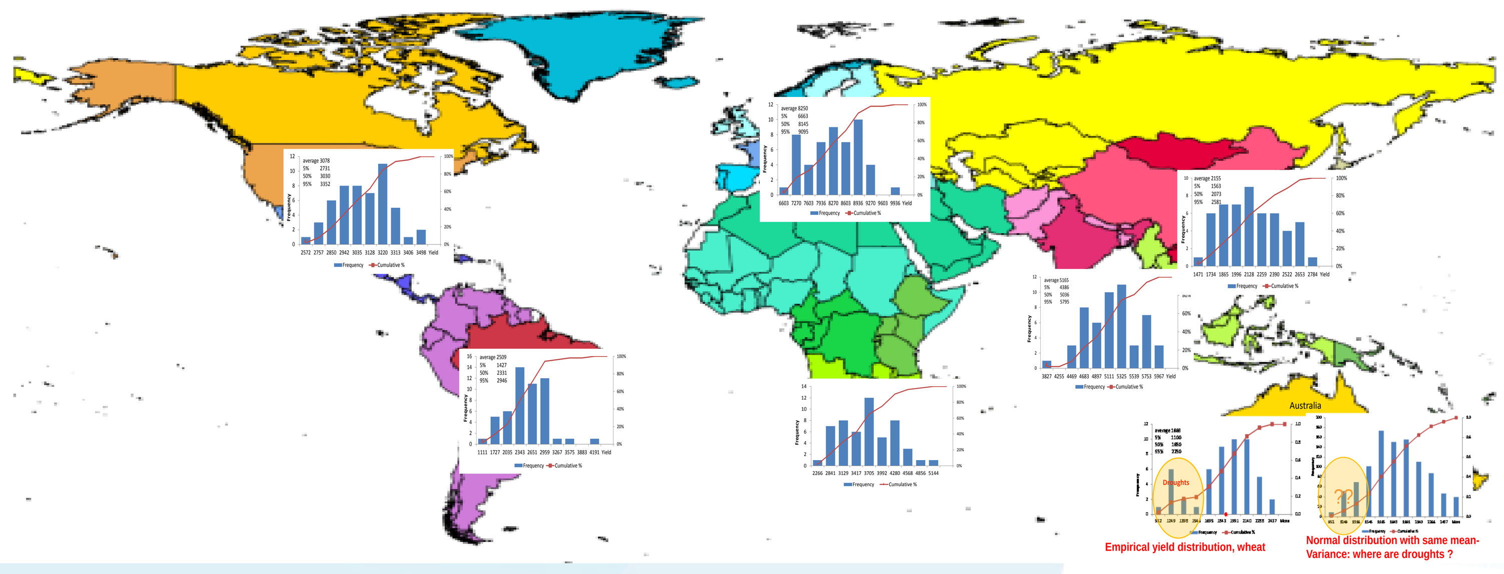


Natural forest



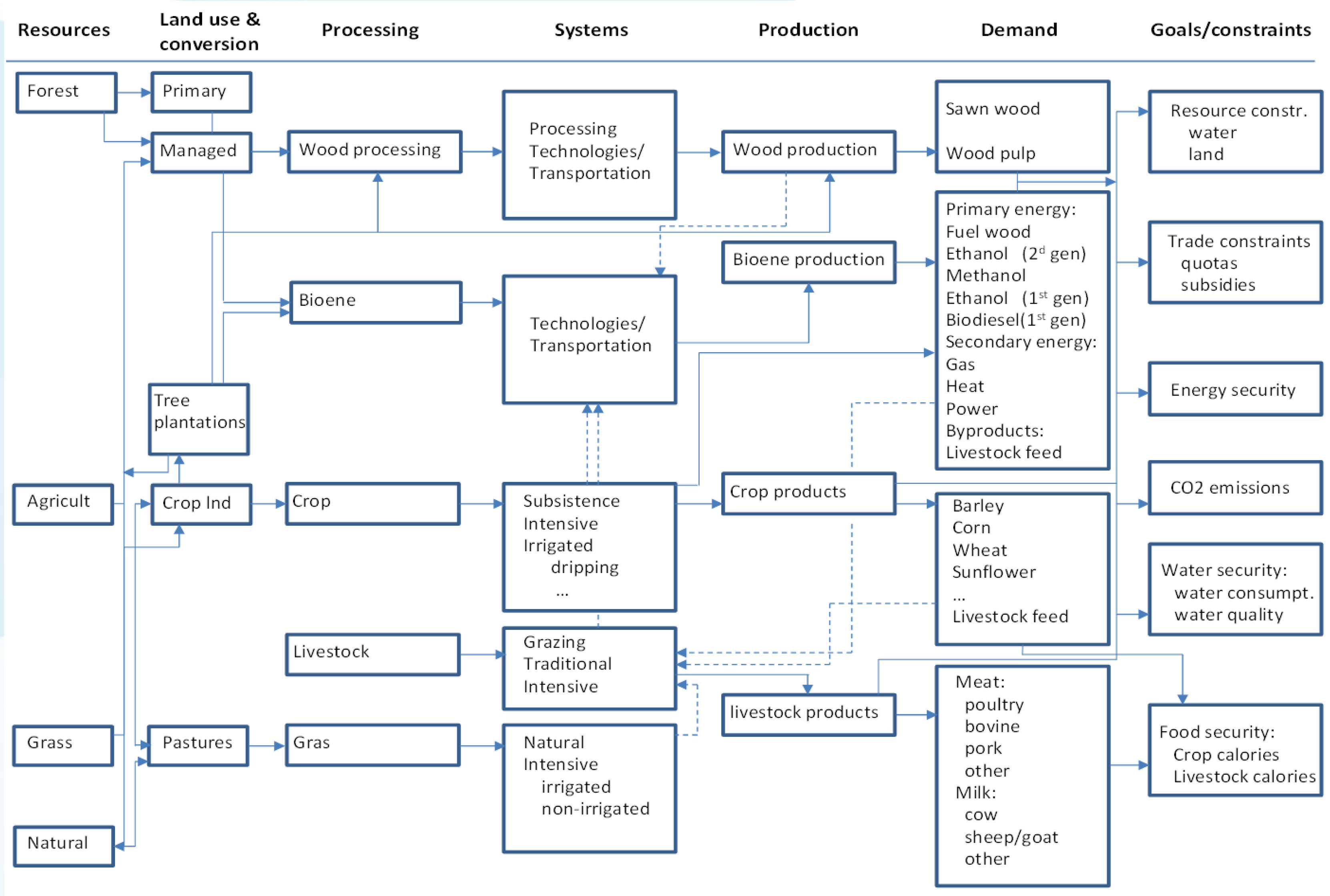
Managed forest

Stochastic yield shocks



- Location-specific yield-shock distributions are multimodal, analytically intractable. Rare-low values representing e.g. droughts in Australia, cannot be captured by normal distribution (mean-variance), what precludes the use of mean-variance approaches, requires quantile-based systemic risks and security indicators, constraints and goals.

Interdependencies in GLOBIOM induce systemic risks



Robust storages

- The model is applied to the case of increased storage facilities, which can be viewed as catastrophe pools to buffer production shortfalls and fulfill regional and global FEWES requirements when extreme events occur.
- Expected shortfalls and storage capacities have a close relation with Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR) risk measures.
- Calculated Value of Stochastic Solutions of about 25% demonstrates the importance of applying the stochastic model. Distribution of storage withdrawals, in thousand tons, at the global level.
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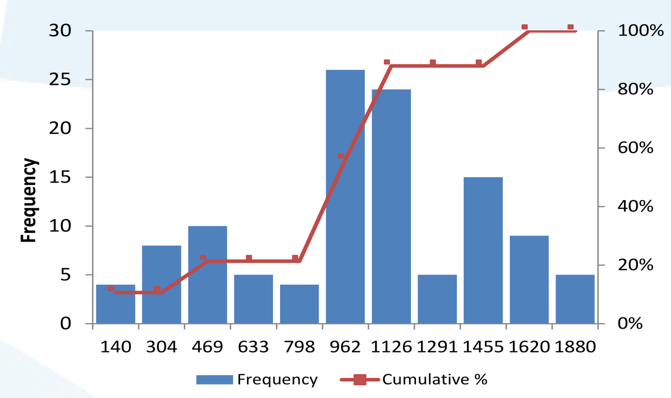
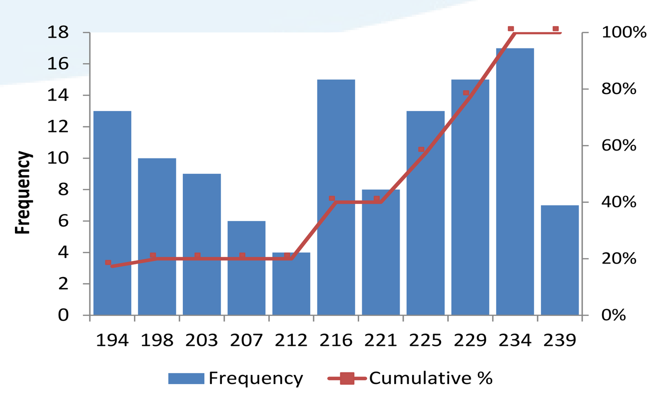
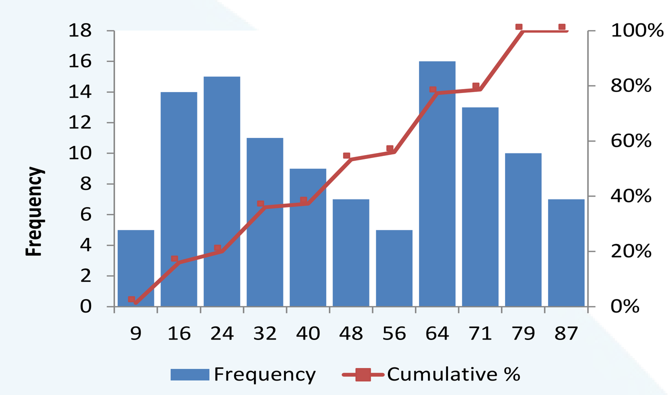


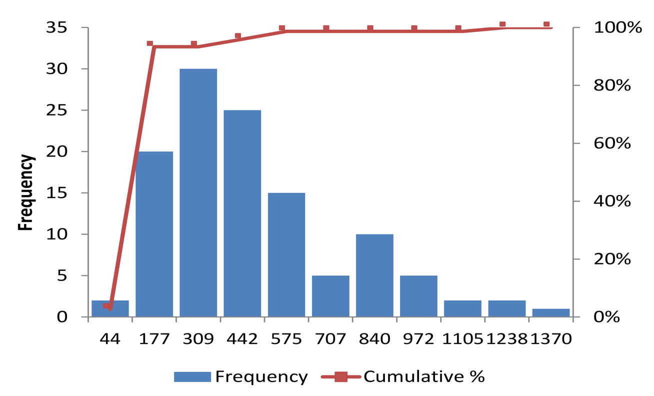
Rice.



Wheat.



Rape.



Sunflower.

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