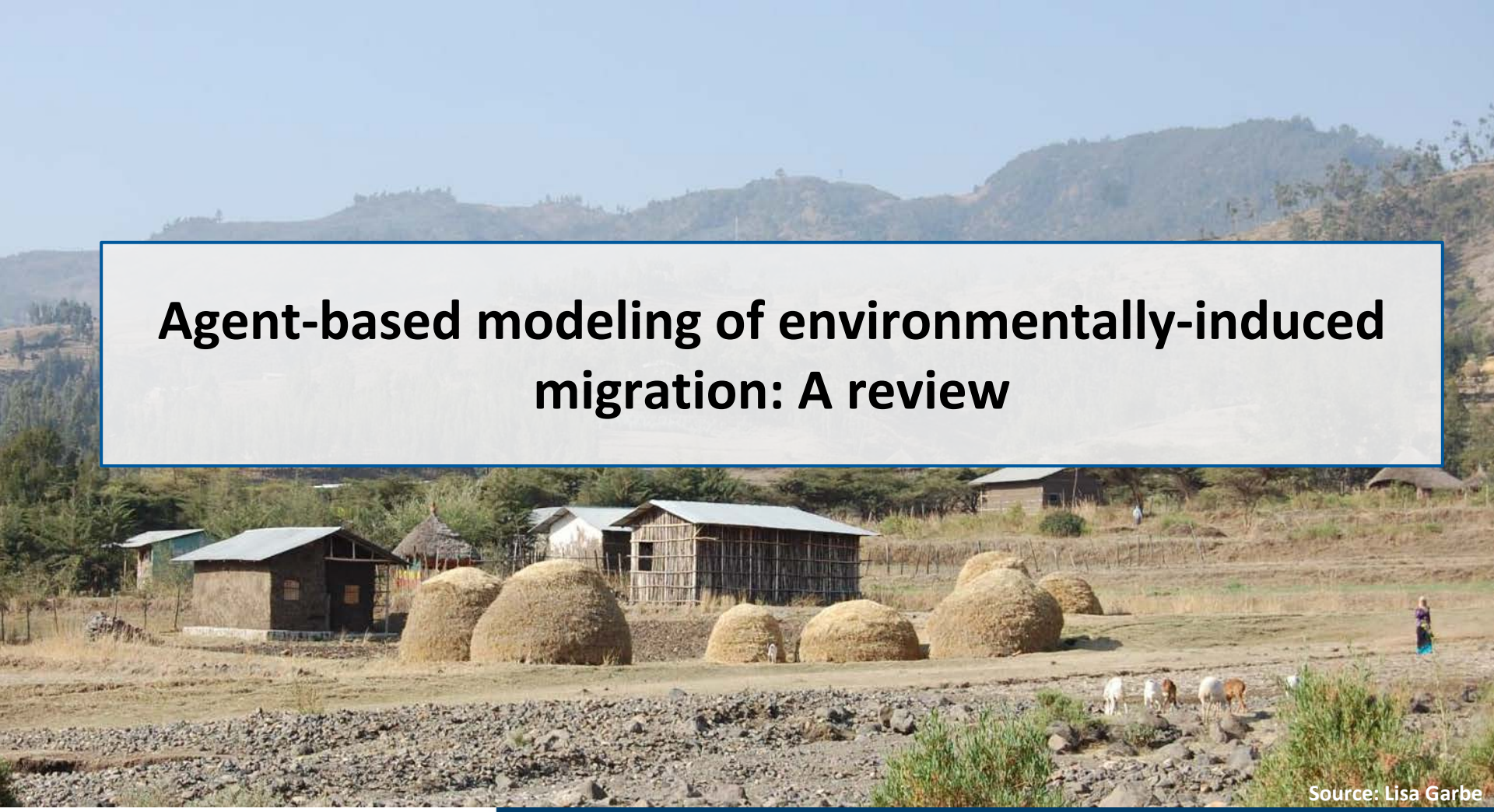
Agent-based modeling of environmentally-induced migration: A review


Source: Lisa Garbe

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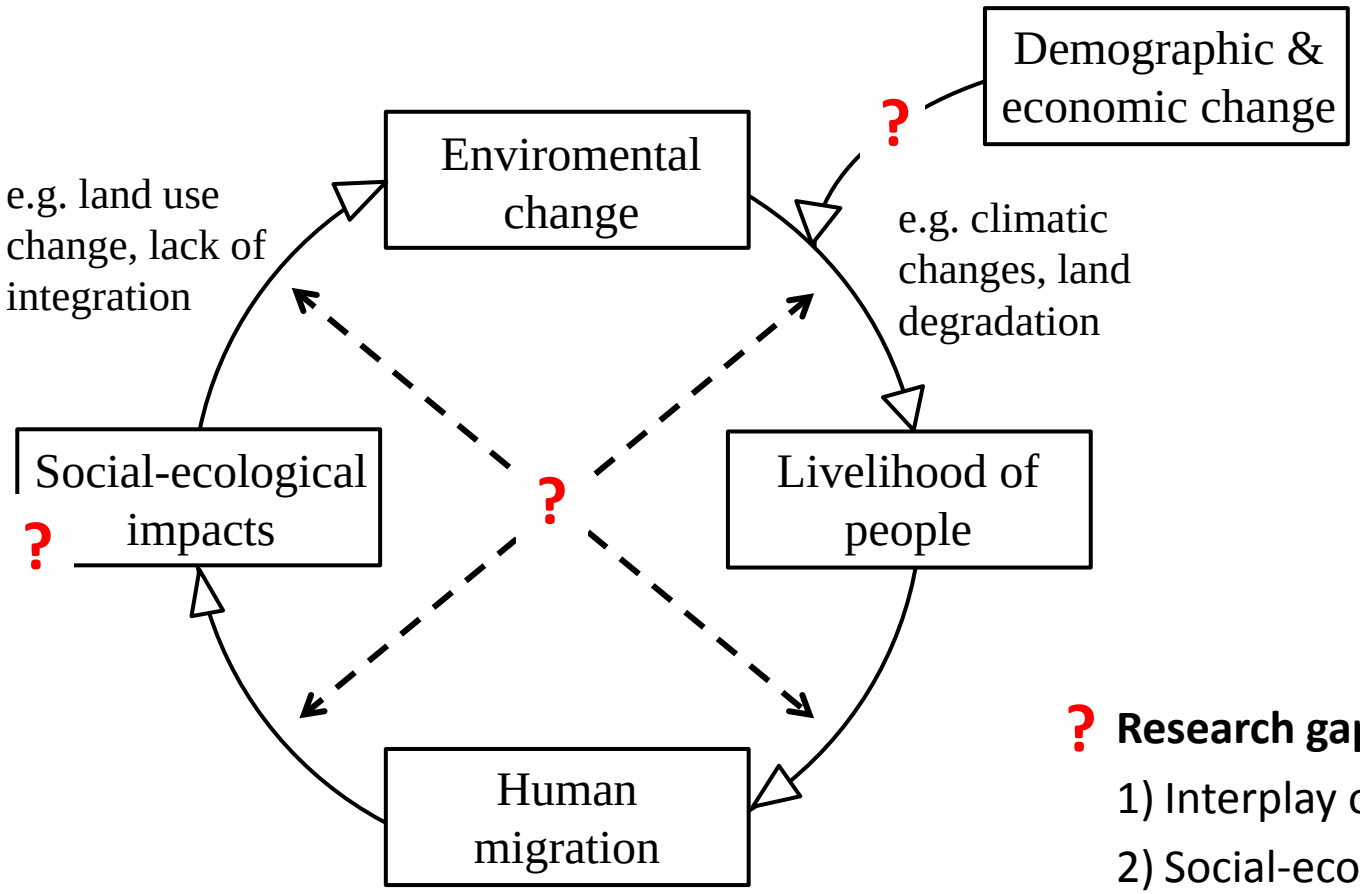
THE ENVIRONMENT-MIGRATION NEXUS



? **Research gaps:**

1) Interplay of influence factors
2) Social-ecological impacts
3) Circular relationship

POTENTIAL OF SIMULATION MODELS

Simulation models:

- Ability to study feedbacks between social and ecological systems & future trajectories under different scenarios
- Some aggregated modeling approaches exist[1]
- **But:** based on "regional-level assumptions regarding migration decisions"[2]
  → ignoring that migration emerges from individual decision-making

→ Agent-based modeling

- Ability to depict individual behavior & social-ecological feedbacks[3]
- Recently increasing number of agent-based models (ABMs) that consider the role of the natural environment in rural migration processes[4]

[1]Döll & Krol 2002; Krol & Bronstert 2007; Barbieri et al. 2010; Feng et al. 2010; Marchiori & Schumacher 2011

[2]Neumann & Hilderink 2015

[3]Schlüter et al. 2012; [4]McLeman 2013; Klabunde & Willekens 2016

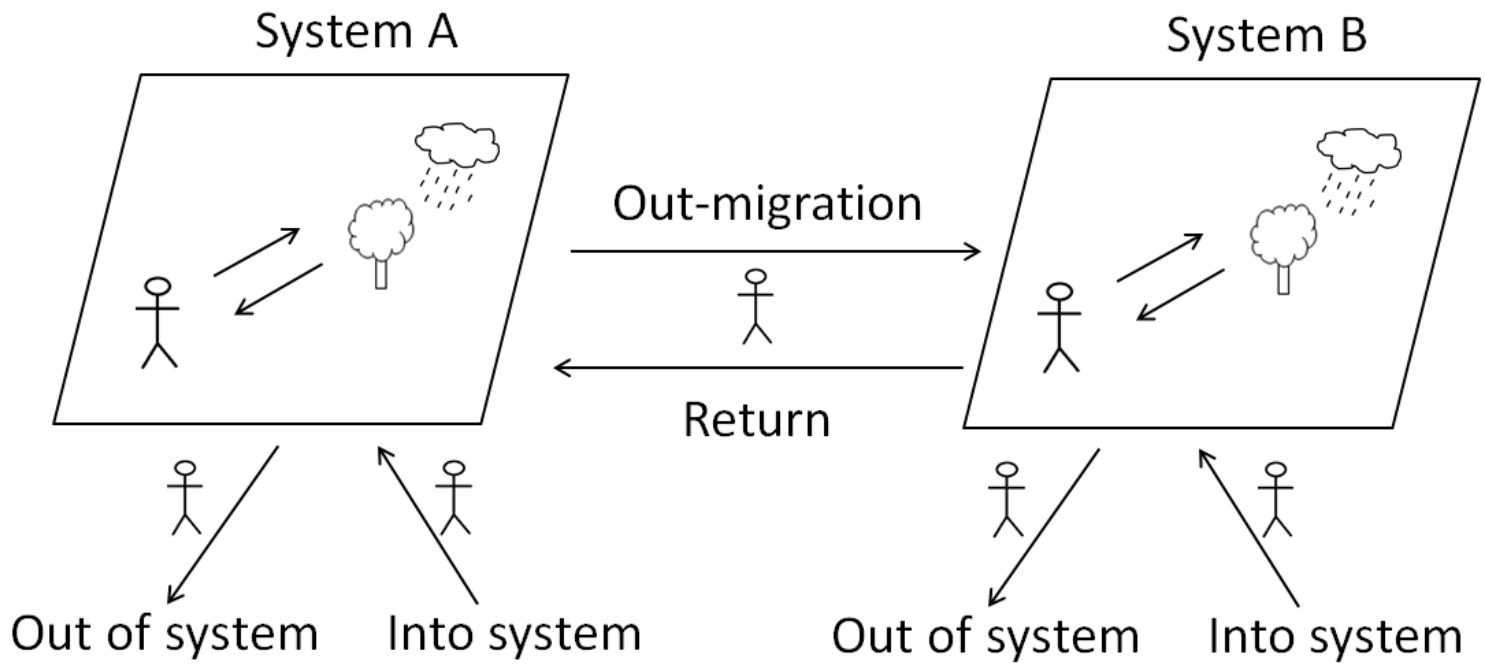
STUDY AIM & RESEARCH QUESTIONS

Review of existing **ABMs of environment-migration linkages** to advance further model development in the field

Research questions:

- Which migration flows have been studied with ABMs (e.g. in- and/or out-migration, return)?
- Which environmental, economic and social influence factors of migration decisions are considered and how?
- How are social and ecological systems coupled in ABMs of environmentally-induced migration? In particular, have environmental consequences of migration been studied with ABMs?
- Do conceptual gaps of modeling environment-migration linkages exist, and if so, what are reasons for their existence?

CONCEPTUAL FRAMEWORK



PAPER SELECTION & EVALUATION

Selection:

- *Agent based models* and *migration*
- Focus on ABMs of environmentally-induced migration in rural contexts of natural resource use
- Exclusion of urban-urban migration & constantly moving societies (e.g. pastoral systems, hunter-gatherer-systems)

→ **15 Agent-based models**

Systematic evaluation:

- Each ABM was classified by two of us
- Cross-check by developers of the ABM (response rate was 87%)
- According to conceptual framework and standardized protocol

STANDARDIZED PROTOCOL
CATEGORIES

General aspects:
- Model purpose (understanding, decision support, theory development …)
- Case study
- Spatial & temporal scale

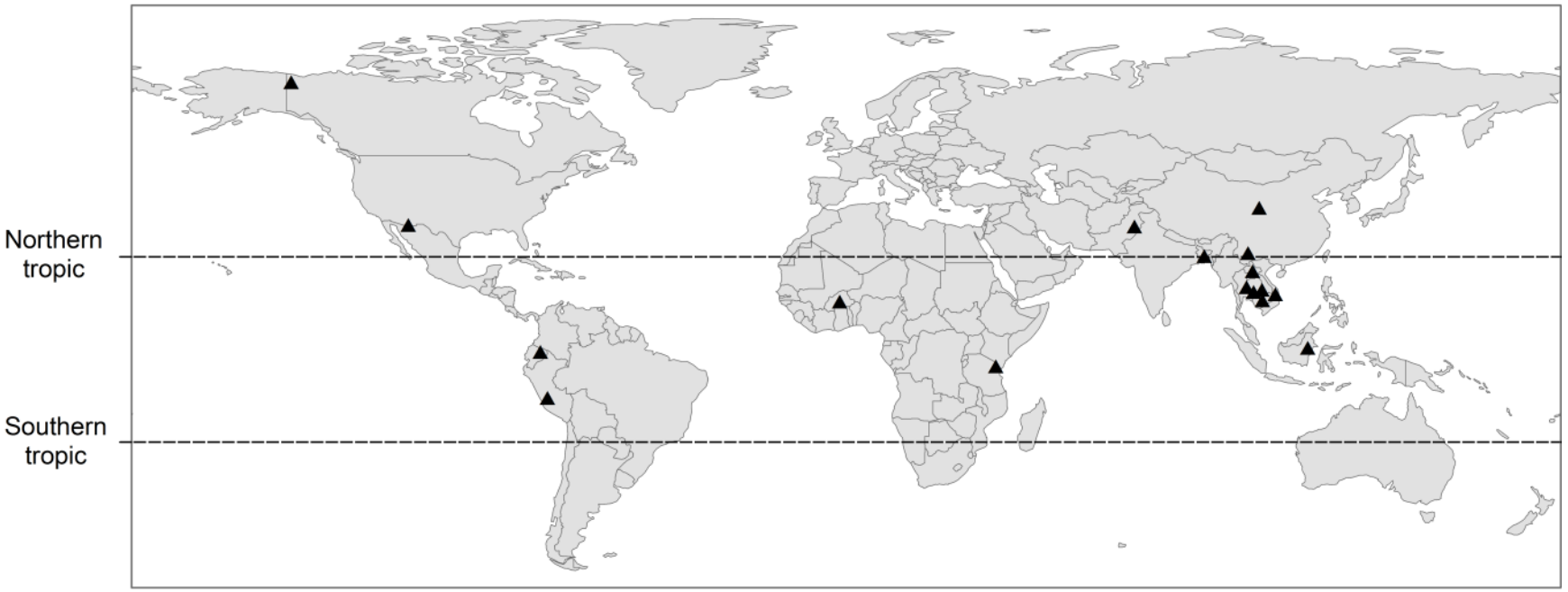
Migration processes:
- Migration flow (out-migration, return, out of system, into system)
- Duration

Influence factors:
- Environmental influence factors (number, type, direct/indirect)
- Economic & social influence factors

Decision-making:
- Methodology (probability function, decision theory, heuristics, optimization)

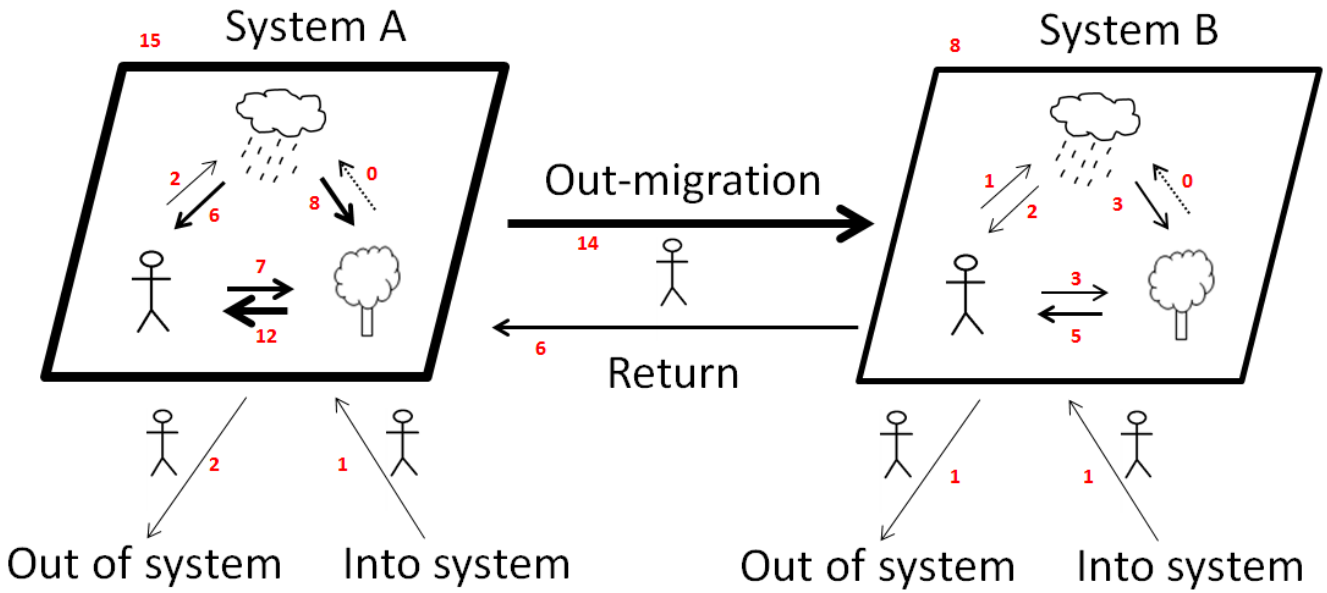
Social-ecological feedback:
- Type of coupling (one-way linkage, partly integrated, fully integrated)

RESULTS
GLOBAL DISTRIBUTION OF MODELS



Number of models: 15 ABMs; 13 focus on a specific case study
Model purpose: system understanding, (participatory contexts, decision support, prediction)
Spatial scale: local – national extent
Temporal scale: small (3 years in daily steps) – large (10.000 years in yearly time steps)

RESULTS
MIGRATION FLOWS



- Two types of environmental factors
- Most reviewed ABMs consider out-migration from one system & the option to return
- Underrepresentation of migration out of and into the system

RESULTS
ENVIRONMENTAL INFLUENCE FACTORS (EFs)

In general:

- ABMs include between **1 to 5 EFs**
- Majority of ABMs consider <= 2 EFs
- Most often as **indirect factors**

Influencing environmental factors		**Availability of natural resources**	
	Number of ABMs		Number of ABMs
Rainfall	7	Crop yield	4
Climate shock (e.g. flood)	4	Food resource availability	4
Soil quality	2	Wildlife availability	3
Temperature	2	Water availability	2
Increasing weather variability	1	Timber	1
Sunlight luminosity	1	Livestock stock	1
Glacier albedo	1		
Glacier melt	1		
Slope	1		
Brackish water	1		

RESULTS
ECONOMIC & SOCIAL INFLUENCE FACTORS

- Most of the 15 ABMs consider economic & social factors
- Only four ABMs explicitly model social networks
- **Most frequently considered economic influence:** distance to nearest road, market or to the destination system, assets, income
- **Most frequently considered social influence factors:** age, influence by peers, gender, population size, migration experience, social ties and education

→ **In general, these correspond with identified influence factors in empirical studies of human migration**

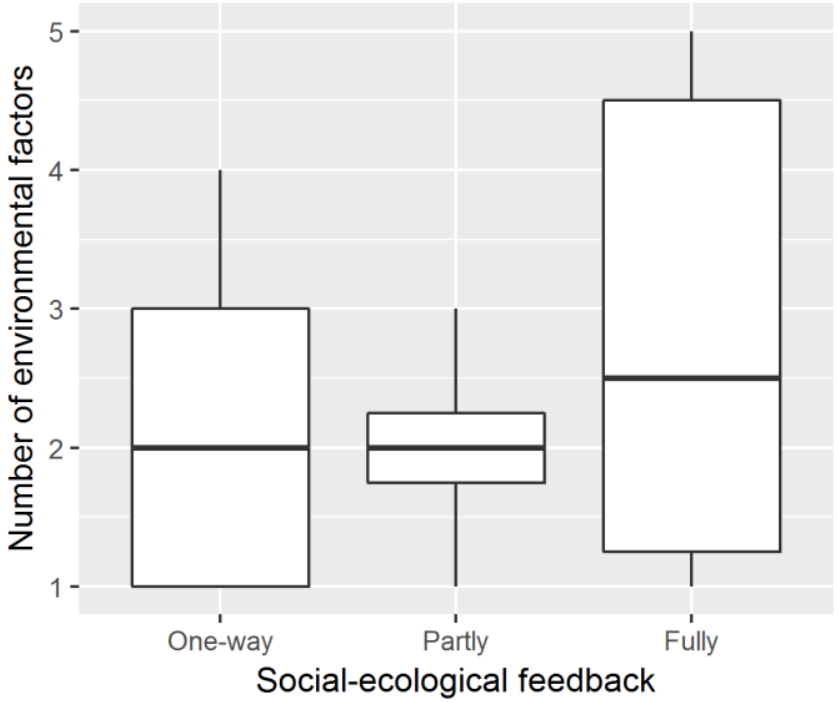
→ **But:** class of political influence factors is underrepresented in ABMs

RESULTS
SOCIAL-ECOLOGICAL FEEDBACKS

Type of coupling	**Number of ABMs**	**Examples of causal chain**
One-way linkage	5	Rainfall -> *Migration decision* (Kniveton et al. 2011, 2012)
		Climate warming -> Caribou numbers -> Hunting success -> *Migration decisions* (Berman et al. 2004)
Partly integrated	4	Rainfall + *Rice planting* -> Rice growth -> Income -> *Migration decision* (Naivinit et al. 2010)
		Slope -> *Land use selection* -> Assets -> *Migration decision* (Mena et al. 2011)
Fully integrated	6	Soil quality + Rainfall -> Harvest level -> *Migration decision* -> Population density -> Soil quality (Janssen 2010)
		Resource availability -> *Migration decision* -> Resource availability (Rogers et al. 2011)

→ Potential of ABMs for studying environmentally-induced migration is not fully exploited

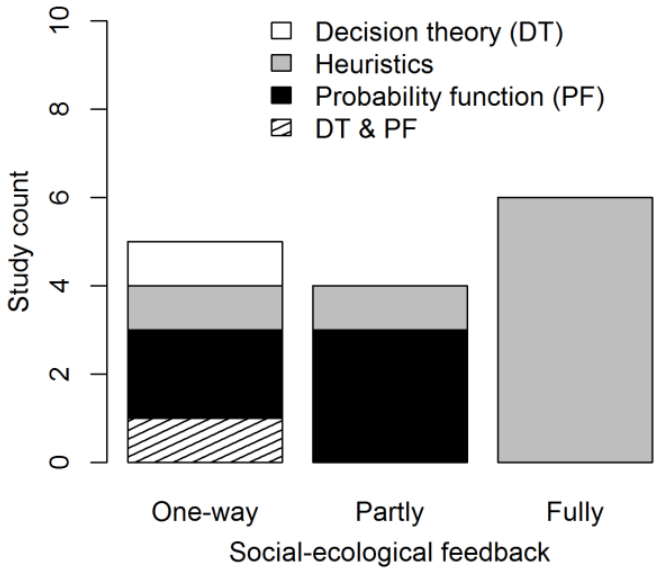
RESULTS
THE CHALLENGE OF MATCHING THE FRAMEWORK

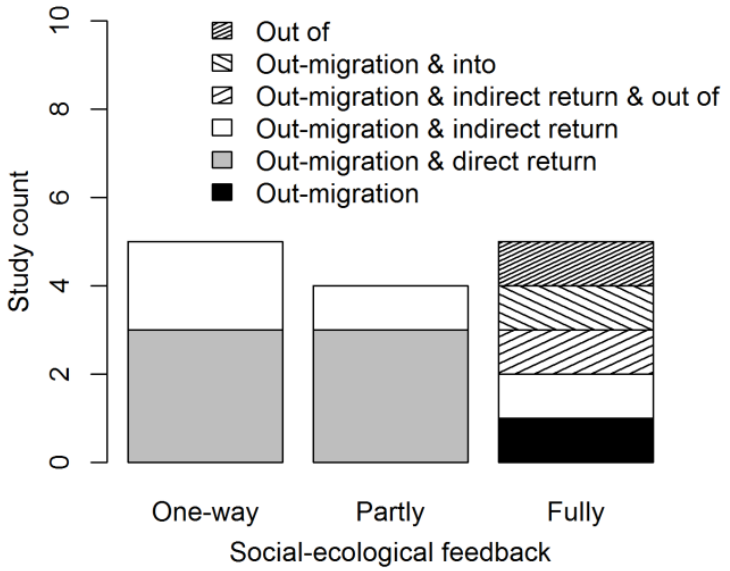


- number of EFs is slightly higher for ABMs with fully integrated linkages
- higher number of EFs is needed in order to represent fully integrated linkages

→ Hindrance of considering fully integrated feedbacks due to a lack of knowledge or data on environmental influence factors?

RESULTS
THE CHALLENGE OF MATCHING THE FRAMEWORK



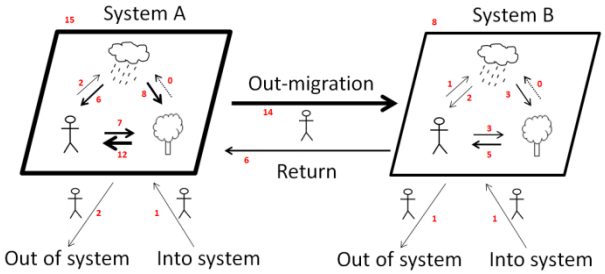


→ Focus either on representing human decision-making or on representing fully integrated social-ecological feedbacks and all relevant migration flows

KEY FINDINGS AND A WAY AHEAD

Key findings from review

1. No ABM exists that considers all components of the conceptual framework
2. Fully integrated ABMs are not the majority
3. Focus either on decision-making or on migration flows and fully integrated social-ecological feedbacks



Ways ahead

1. Potential of ABMs should be exploited by implementing more fully integrated systems
2. Into and out of the system should be incorporated

→ Model developers could check all of the framework's components and evaluate for each component whether it is needed in the model

AN ABM OF HUMAN MIGRATION IN ETHIOPIA

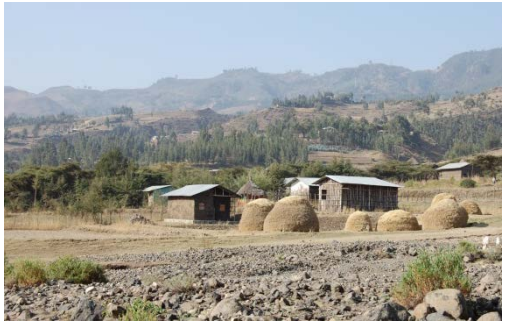
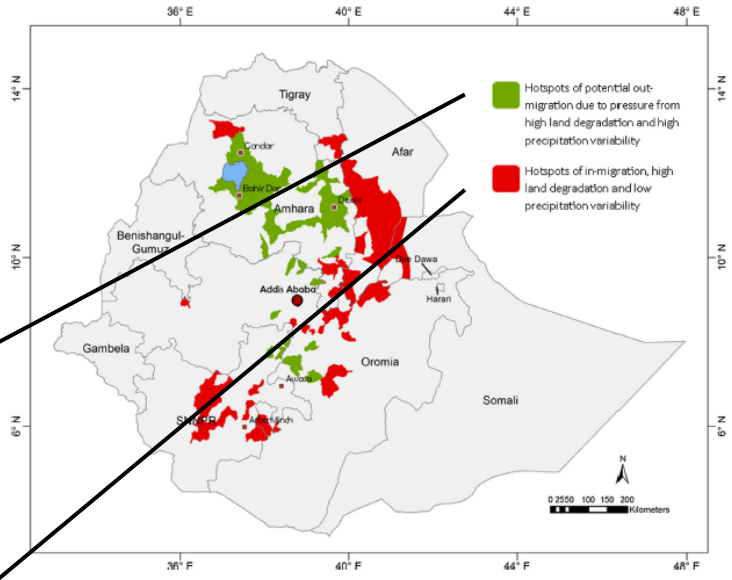


Photo: Lisa Garbe

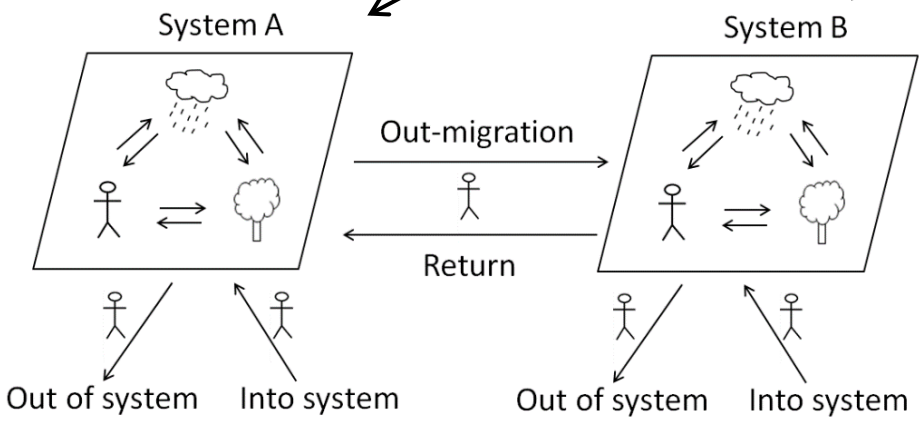
- Precipitation: -20%
- Droughts
- Population increase
- Land degradation

→ Food insecurity & migration



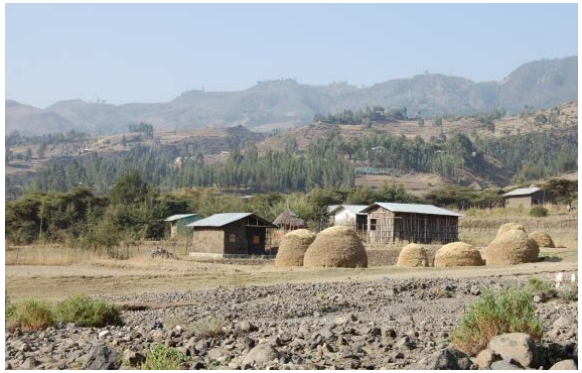
Source: Hermans-Neumann et al. (2017)

Model design:



- stylized & a case-study specific model version
- based on project results from meta-analysis & focus group interviews

THANK YOU FOR YOUR ATTENTION!



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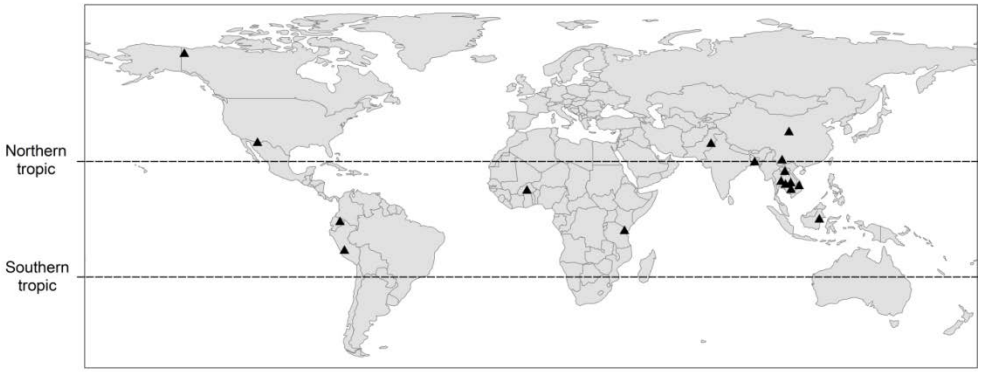

This study has been conducted in the frame of the BMBF- and UFZ-funded junior research group MigSoKo (https://www.ufz.de/index.php?en=41462).

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APPENDIX
DEFINITIONS

Duration of migration (seasonal/permanent): Migration is defined as "being absent from the place of origin for more than three months" (Liehr et al. 2016, page 153). Additionally, we differentiate between seasonal and permanent migration. Seasonal migration is characterized by short-term absence (i.e. less than a year) from the place of origin whereby the return is already planned at the time of migration. In the context of natural resource use, this type of migration is often aligned to harvest cycles. In the case of permanent migration, migrants leave with the intention to stay abroad for long-term periods. However, it is not precluded that they move on or return after a short-term due to changing conditions.

Direct/indirect environmental influence factors: Regarding the environmental factors we analyzed whether these are conceptualized as direct (e.g. agents consider amount of precipitation when deciding to migrate or not) or indirect drivers (e.g. rainfall affects income which agents consider when deciding whether to migrate or not).

Social network: Social networks are explicitly modeled social linkages (e.g. remittance, information exchange, dependents). Just considering the situation of others without an explicit network is not yet a social network effect (e.g. comparing your own situation with that of others or considering the impact a decision has on others).

APPENDIX
DEFINITIONS

Social-ecological feedbacks (one-way linkages/partly integrated linkages/fully integrated linkages): For one-way linkages, agents are influenced by the environment but do not influence the ecosystem. In the case of partly integrated linkages, agents can alter for example land use and are in turn influenced by harvest success. Finally, for fully integrated linkages also environmental consequences of natural resource use and migration decisions are considered within the model (e.g. resource depletion or soil degradation).

Migration decision (probability function/decision theory/heuristics/optimization): Here, we classify according to the techniques used in the decision model. "Probability function" can be any function that includes a stochastic factor to determine the migration decision (e.g. random destination, logistic regression function). Based on "decision theory" are those decision models that are based on an existing decision theory from economics, psychology or other fields (e.g. Theory of Planned Behavior). "Heuristics" are simple decision rules or rules of thumb (e.g. if-then rule). "Optimization" includes any form of maximization of a certain indicator (e.g. income, fitness, happiness).

Migration flows: We differentiate between out-migration of a system and return migration: systems can be characterized by out-migration from system A to system B and return-migration from system B to system A. Here, agents can move directly back (direct return) to the origin or do so via multiple stops (indirect return). Furthermore, humans can in-migrate from outside the two systems into system A and/or B and humans can out-migrate from system A and/or B to somewhere outside the overall system.