RESEARCH PROGRAM ON Dryland Systems

CGIAR

Food security and better livelihoods for rural dryland communities

Review of integrated systems modelling methods and selection guide

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CRP-DS
Agricultural Livelihood Systems

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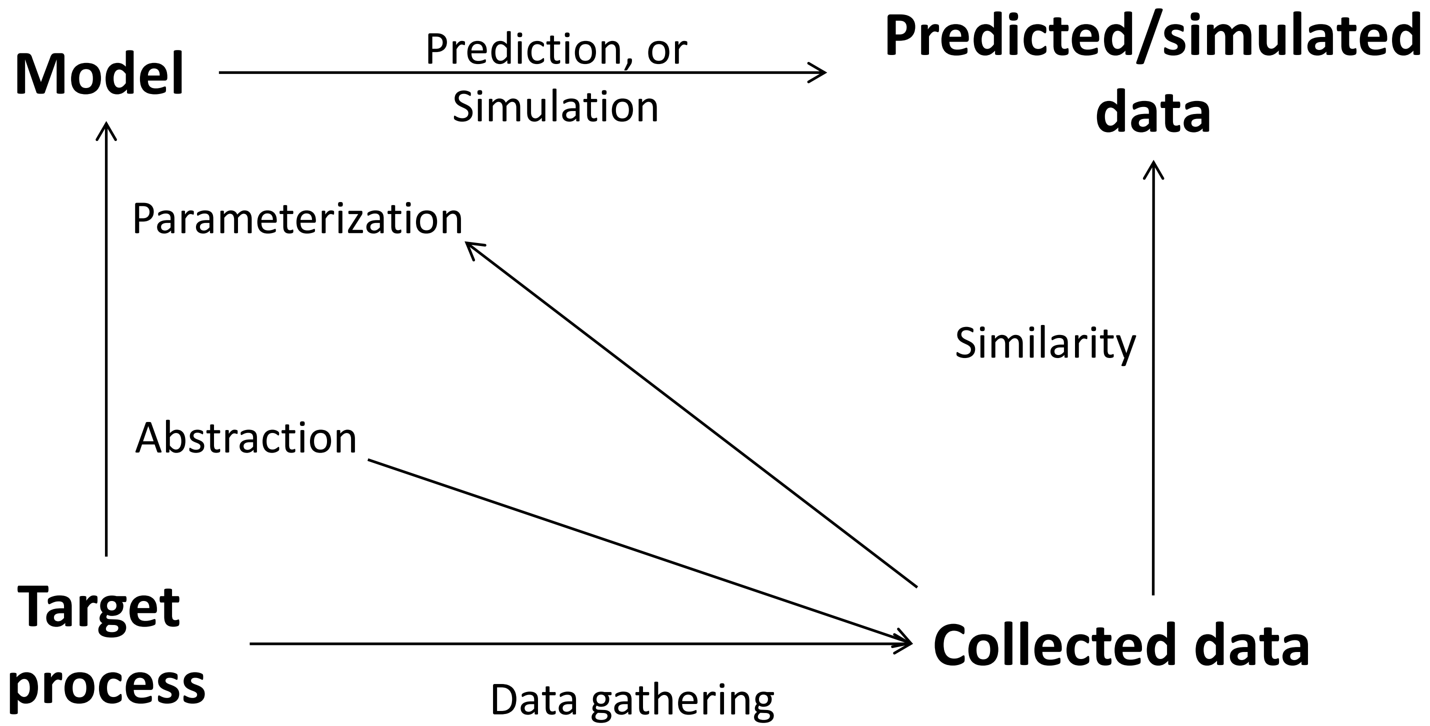
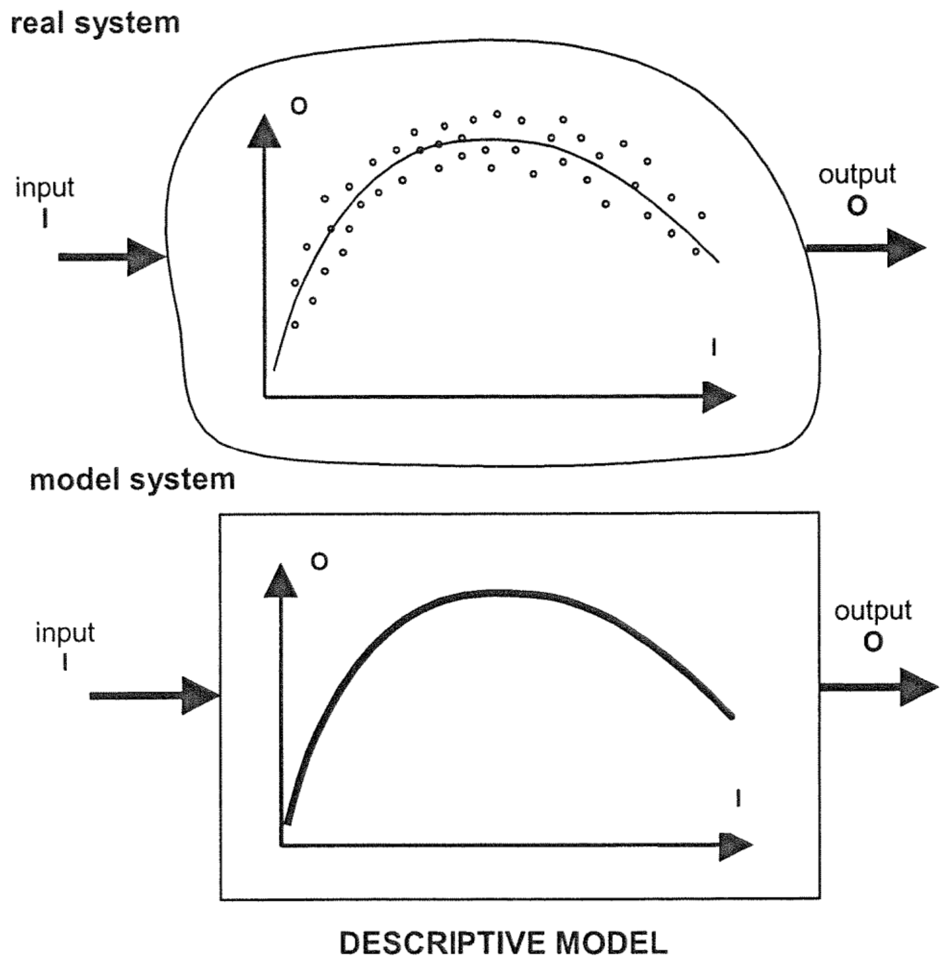
www.drylandsystems.cgiar.org

The logic of modeling as a research method



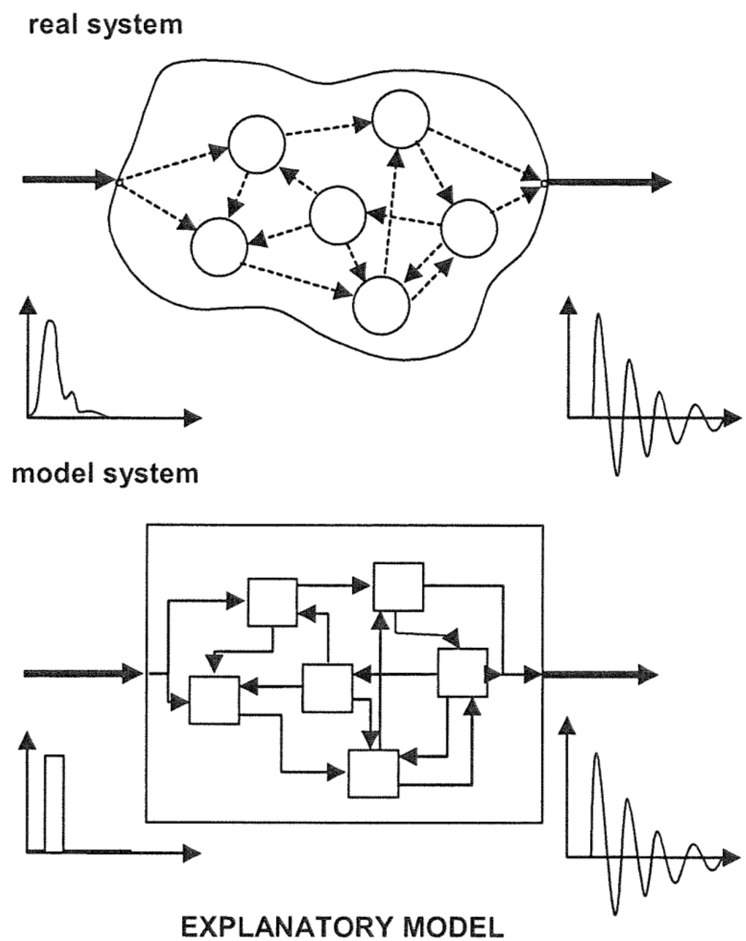
Source: modified from Gilbert, H., Troitzsch (2005*). Simulation for the Social Scientist.* Philadelphia: Open University Press

Descriptive Models



Source: Bossel, H., 2007. Systems and Models: Complexity, Dynamics, Evolution and Sustainability. Demand GmbH, Norderstedt, Germany.

Explanatory/Process-based Models



Bossel (2007), p.21

Source: Bossel, H., 2007. Systems and Models: Complexity, Dynamics, Evolution and Sustainability. Demand GmbH, Norderstedt, Germany.

Why model?

- … scientific understanding: scientific reasoning of things
- … system development in technology
- … system management
- … development planning

Simulation as a particular type of modeling

- **Analytic modeling:** formulate theoretical and complete mathematical representation of the study phenomenon ***based on axioms***. Thus, it is a ***deductive reasoning.***

- **Statistical modeling**: infer patterns and/or general hidden laws regarding the study phenomenon ***based on empirical data***. It is an ***inductive reasoning***.

- **Simulation modeling**: design system representation that ***mimics the real*** behavior of individual entities in the study system and their interrelationships. It can be either ***deductive*** or ***inductive reasoning***.

Why simulation model?

- Explain (complex) causalities (very distinct from predict)
- Reveal core factors and processes
- Suggest dynamical analogies
- Anticipate or predict the phenomenon in space and/or time
- Discover new research questions
- Illuminate core uncertainties
- Demonstrate tradeoffs / suggest efficiencies
- Reveal the apparently simple (complex) to be complex (simple)
- Support decisions dealing with complex problems
- ...

Epstein, J. M. (2008). Why Model? *Journal of Artificial Societies and Social Simulation*, 11(4), 12.

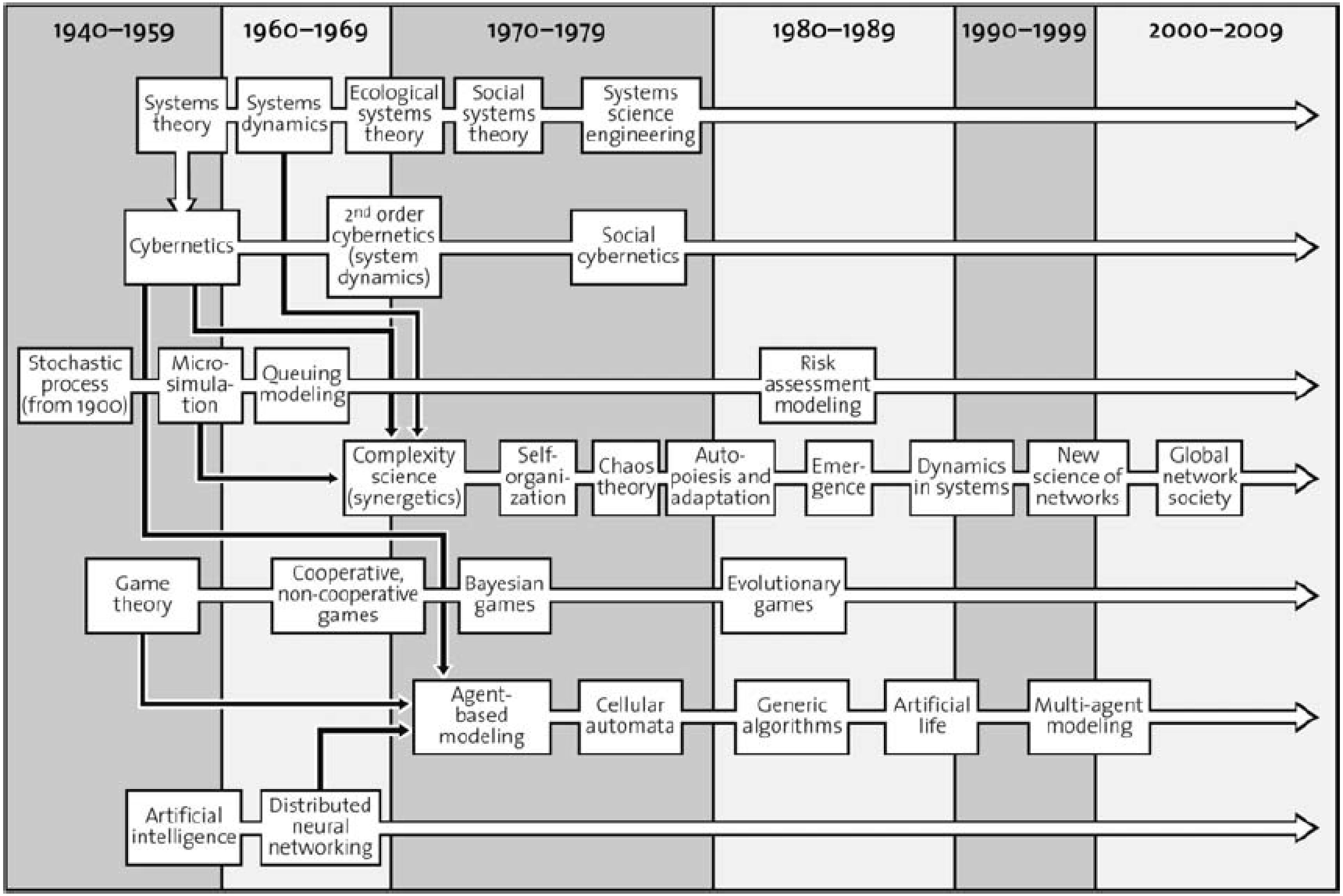
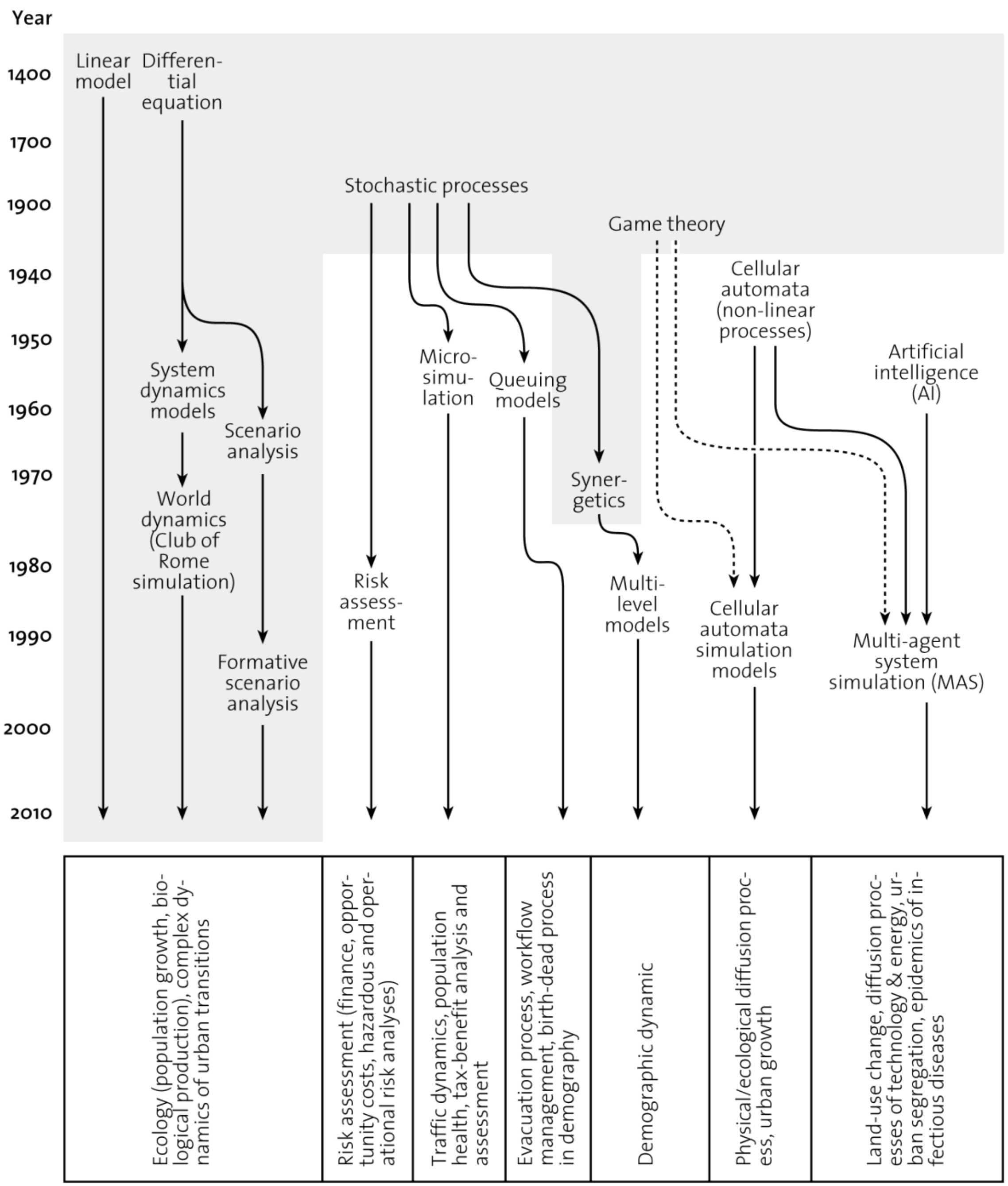


Figure 14.6 Development lines of human literacy in system complexity (modified from Wikipedia http://en.wikipedia.org/wiki/Complexity).



Development paths of different modeling approaches. Legend: grey shaded area: equation-based models; white area: object-, event-, or agent-based models

Source: adapted from Gilbert & Troitzsch (2005), see Scholz, Gallati, Le, & Seidl. (2011). Integrated systems modeling of complex human–environment systems. In R. W. Scholz (Ed.), *Environmental Literacy in Science and Society* (pp. 341-372). Cambridge: Cambridge University Press.

Common integrated modeling methods

- Econometrics (regression-based, most of you knew!)

- Optimization (Yigezu)
- General equilibrium (Yigezu)

- Bayesian (belief) network (BBN)

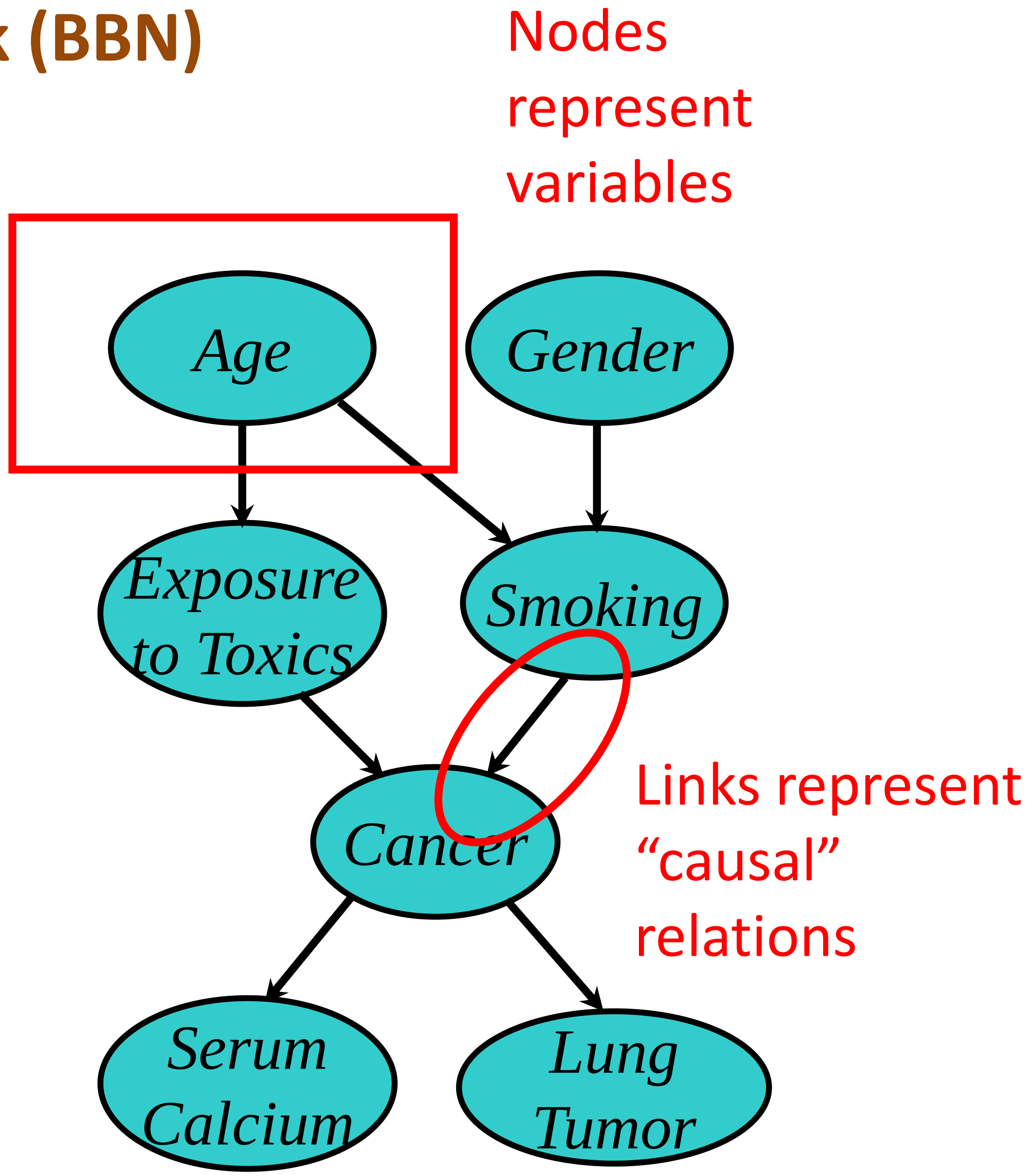
- Material flow analysis (MFA)
- System dynamics (SD)

- Component-based or model chains systems

- Agent-based model/ multi-agent system (ABM / MAS)

Bayesian Belief Network (BBN)

- Bayesian Belief Networks (BBN) can reason with networks of propositions and associated probabilities
- As probabilities (conditional and joint) used, it is well-suited for capture imperfect information, e.g. social norms, expert-opinions, etc.



BBN: Methodological chance for including social traits

P. Poppenborg, T. Koellner / Land Use Policy 31 (2013) 422–429

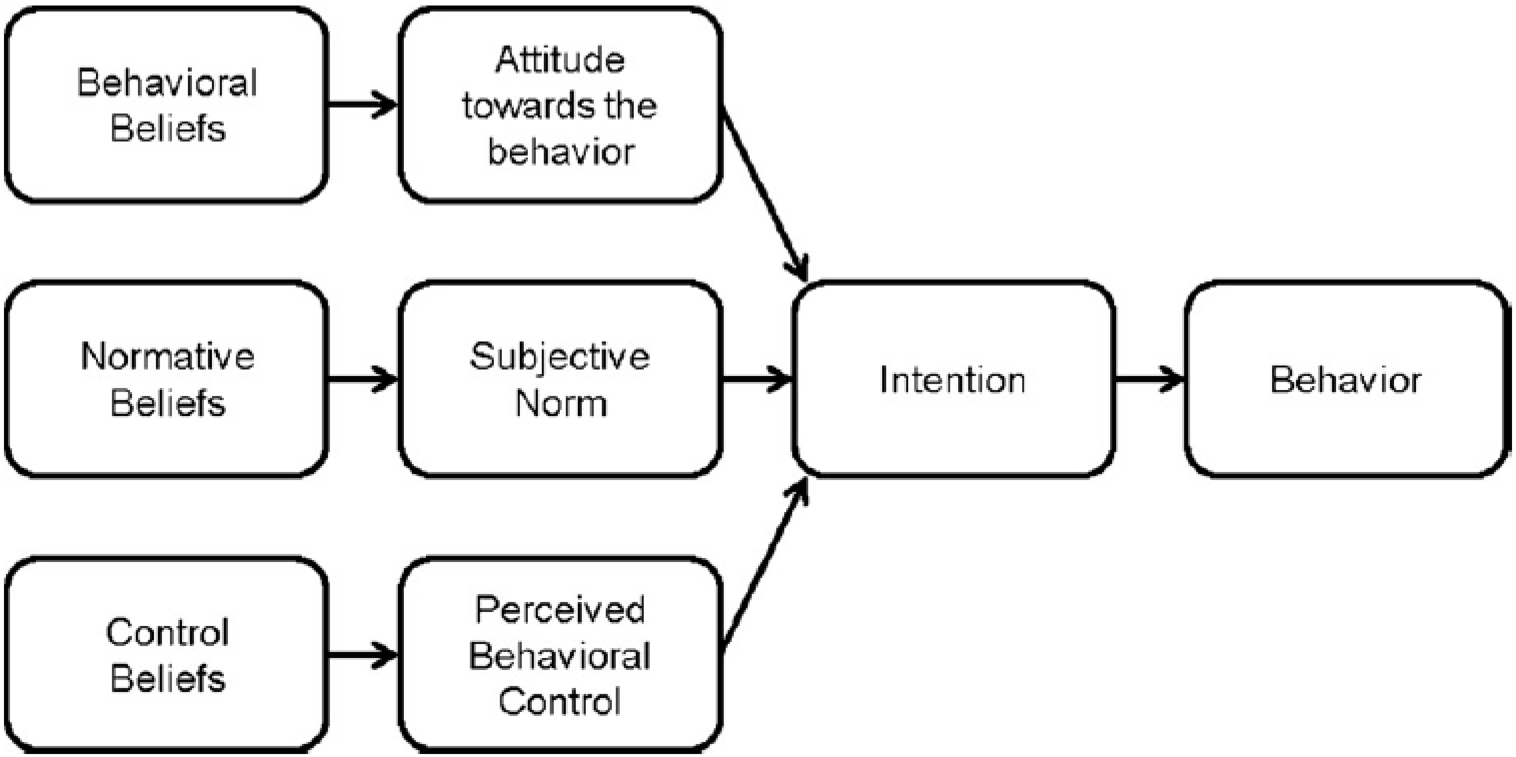


Fig. 1. Components of the theory of planned behavior (adapted from Ajzen, 2006).

Poppenborg, P., Koellner, T., 2013. Do attitudes toward ecosystem services determine agricultural land use practices? An analysis of farmers’ decision-making in a South Korean watershed. Land Use Policy 31, 422-429.

BBN: Methodological chance for including social traits

Table 1
Total number of datasets for each crop type and percentage share of answers about cultivation method.

	Rice ($n = 125$)	Annuals ($n = 143$)	Perennials ($n = 87$)	All crops ($n = 355$)
Cultivation method (%)				
Conventional	65	70	23	56
Organic	16	21	21	19
Both	5	3	0	3
No answer	14	6	56	22

Table 2
Means and standard deviations of behavioral scores separated by cultivated crop type and cultivation method.

	Rice	Annual crops	Perennial crops	Organic farming	Conventional farming
Attitudes toward behavior					
Biomass production	2.5 (1.04)	2.79 (1.11)	3.63 (1.11)	2.69 (1.11)	2.86 (1.12)
Soil loss reduction	2.81 (1.3)	1.9 (1.17)	3.32 (1.38)	2.41 (1.47)	2.42 (1.36)
Water quality improvement	2.71 (1.14)	1.87 (1.03)	3.01 (1.31)	2.46 (1.32)	2.35 (1.19)
Plant and animal conservation	1.74 (1.14)	1.62 (1.05)	2.06 (1.43)	1.82 (1.3)	1.68 (1.09)
Perceived behavioral control					
Money availability	3.26 (1.57)	3.87 (1.34)	4.09 (1.16)	4.04 (1.29)	3.54 (1.5)
Skills and knowledge	1.5 (1.02)	1.78 (1.2)	3.24 (1.45)	1.88 (1.33)	1.82 (1.28)
Plot characteristics	2.34 (1.37)	2.45 (1.47)	2.9 (1.44)	2.35 (1.5)	2.41 (1.38)
Given legislation	2.06 (1.52)	1.98 (1.48)	2.14 (1.46)	2.07 (1.44)	2.02 (1.52)
Social norms					
Household members	3.04 (1.48)	2.87 (1.45)	3.01 (1.48)	2.99 (1.54)	3.02 (1.42)
Fellow farmers	2.22 (1.18)	2.24 (1.31)	2.1 (1.15)	2.18 (1.3)	2.27 (1.23)
Downstream people	1.3 (0.61)	1.21 (0.49)	1.51 (0.99)	1.31 (0.63)	1.31 (0.64)
Environmental protection agencies	1.28 (0.66)	1.26 (0.61)	1.59 (1.01)	1.35 (0.82)	1.31 (0.67)

Poppenborg, P., Koellner, T., 2013. Do attitudes toward ecosystem services determine agricultural land use practices? An analysis of farmers’ decision-making in a South Korean watershed. Land Use Policy 31, 422-429.

BBN: Methodological chance for including social traits

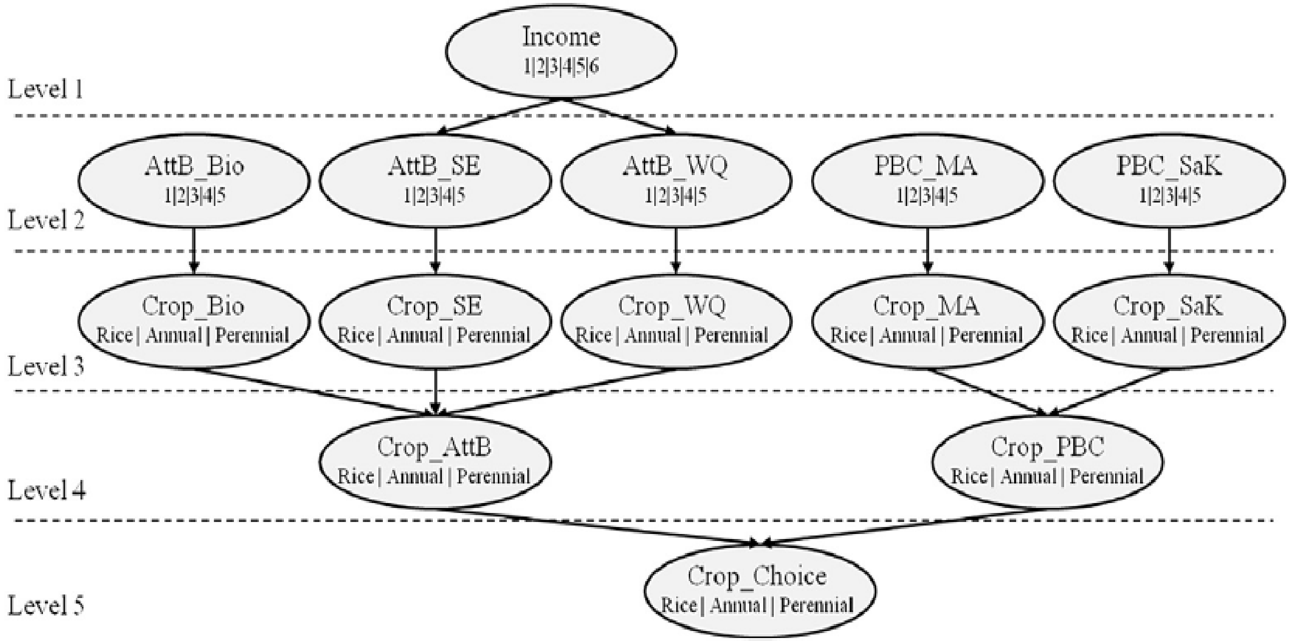
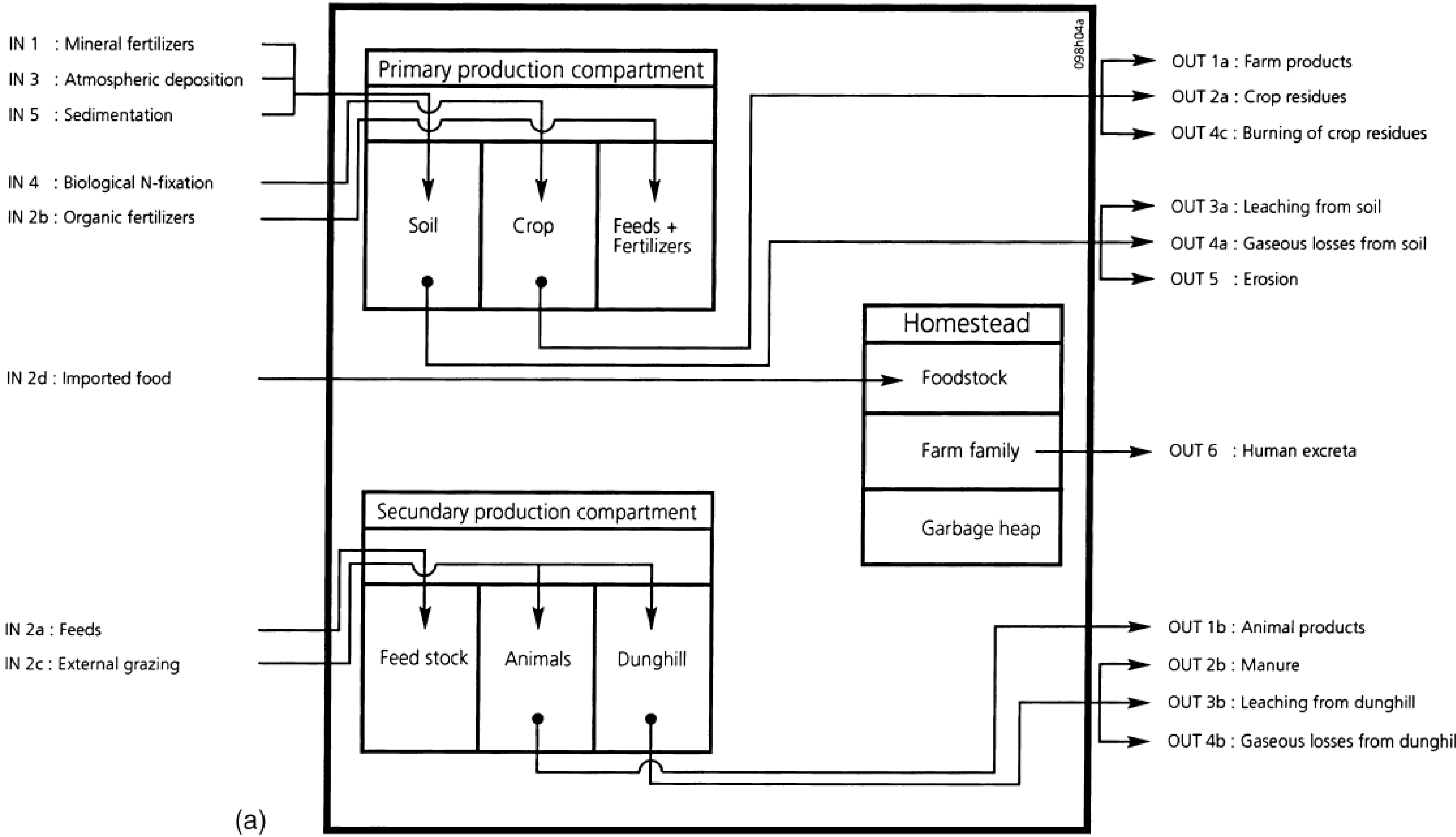


Fig. 1. Graphical structure of the BN showing probabilistic dependencies between variables. Nodes contain the name of the variable they represent, as well as all states the variable can take on. Abbreviations stand for farmers' attitudes toward the behavior (AttB) with respect to the ES biomass production (Bio), soil erosion reduction (SE), and water quality (WQ), as well as farmers' perceived behavioral control (PBC) over money availability (MA), and skills and knowledge (SaK). Horizontal stratification into levels only serves to ease the verbal description of the network.

Poppenborg, P., Koellner, T., 2014. A Bayesian network approach to model farmers' crop choice using socio-psychological measurements of expected benefits of ecosystem services. Environmental Modelling & Software 57, 227-234.

Material Flow Analysis (MFA)



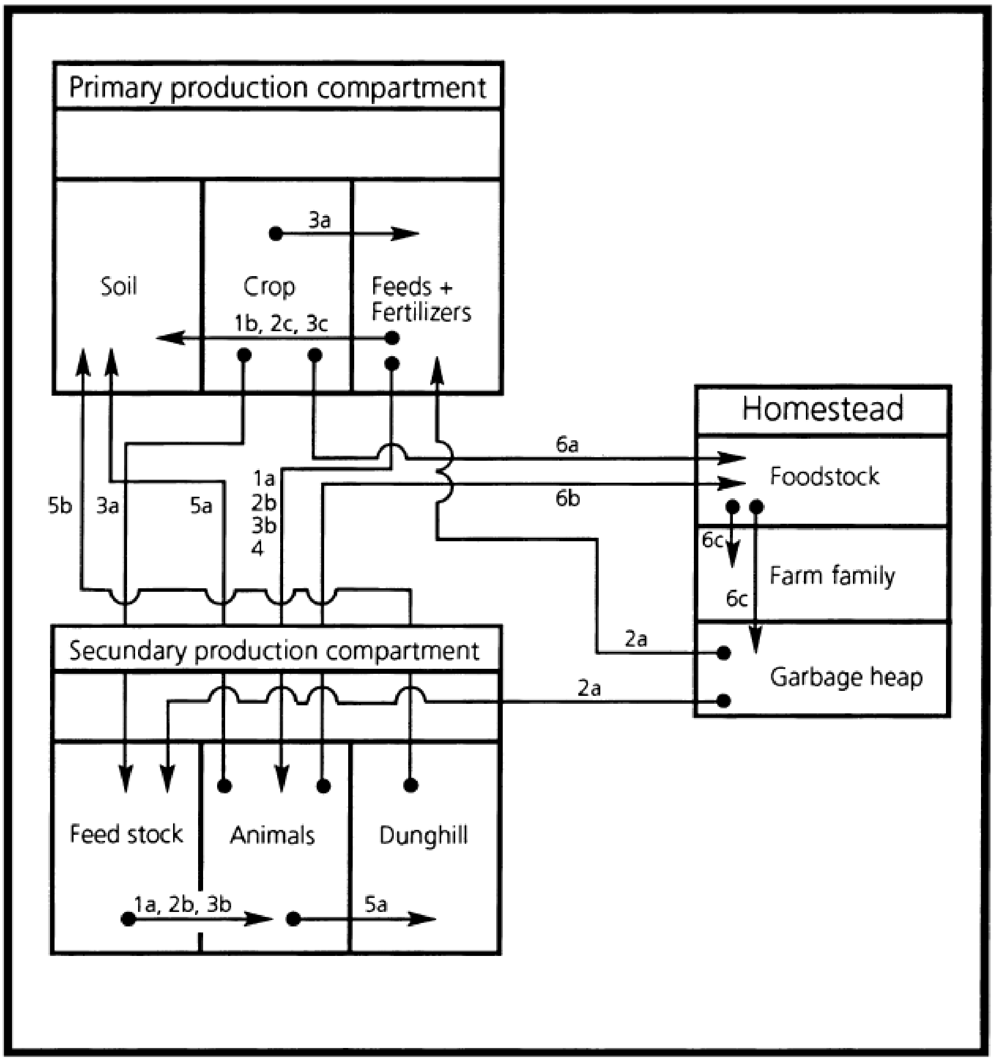
Nutrient flows across farming systems

Den Bosch, H.V., De Jager, A., Vlaming, J., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) II. Tool development. AGEE 71, 49-62.

Material Flow Analysis (MFA)

Good basis for:

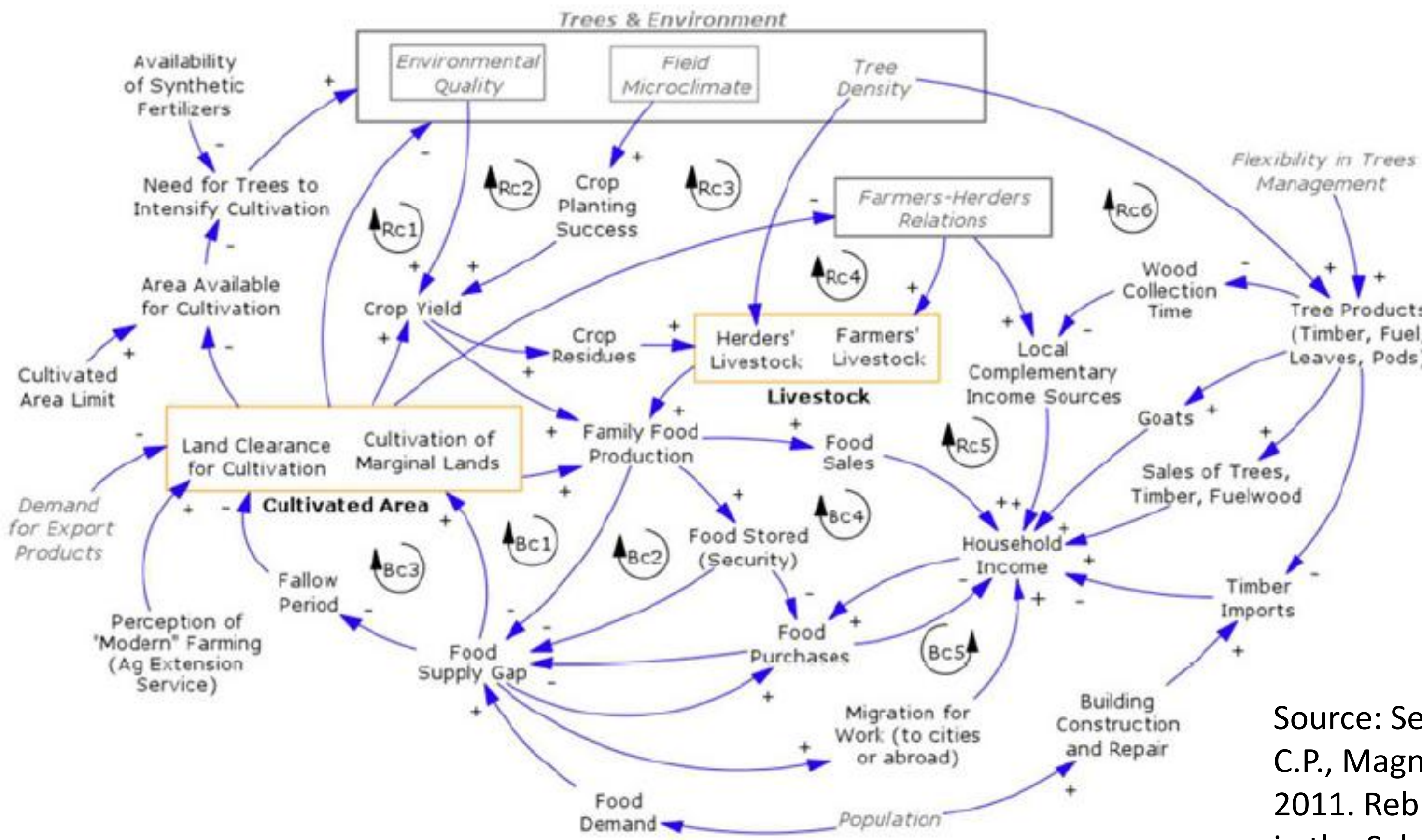
- Calculating different kinds of efficiencies (dimension, scale)
- Basic skeleton for develop further comprehensive model types



(b)

Nutrient flows among components of farming systems

System Dynamics (SD)

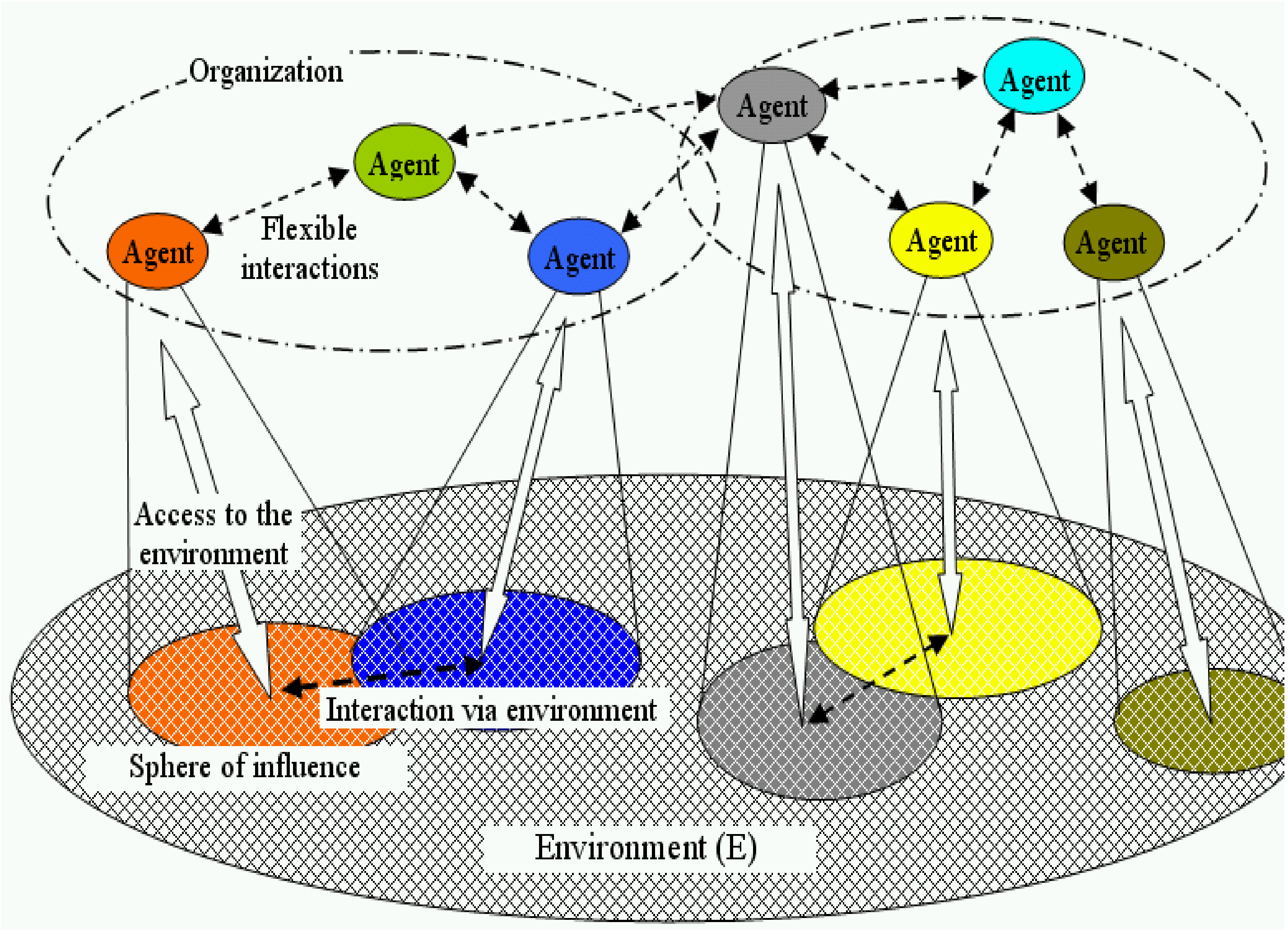


Source: Sendzimir, J., Reij, C.P., Magnuszewski, P., 2011. Rebuilding resilience in the Sahel: Regreening in the Maradi and Zinder regions of Niger. Ecology and Society 16, 1

Differences from MFA:

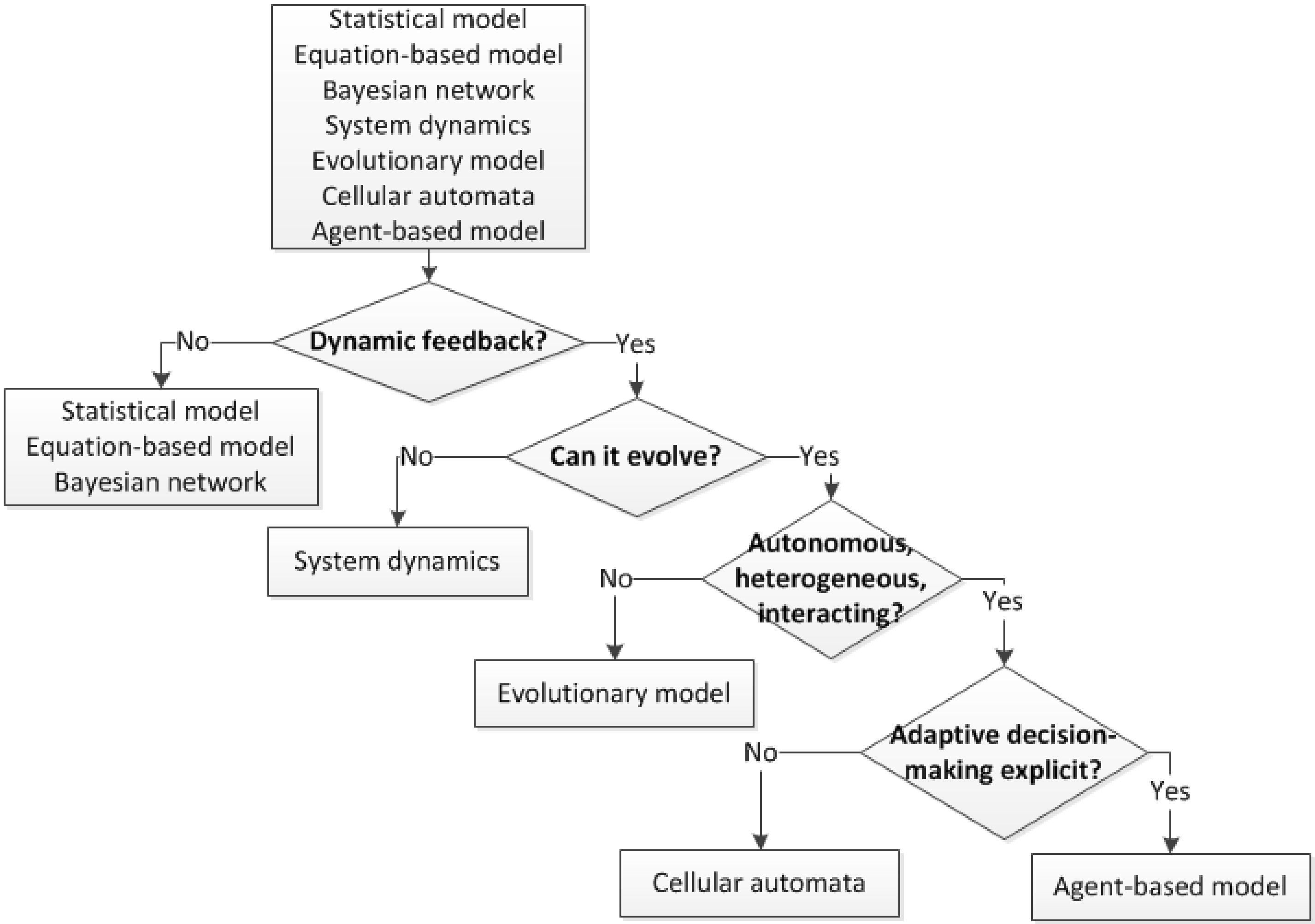
- Time
- “Soft” factors/variables
- Means of causal-effect relation = material /energy or information flows

Multi-agent System (MAS) / Agent-based Model (ABM)



Source: Le, Q.B., 2005. Multi-Agent System for Simulation of Land-use and Land-cover Change: A Theoretical Framework and Its First Implementation for An Upland Watershed in the Central Coast of Vietnam. Cuvillier Verlag, Göttingen, Germany.

How do the modelling methods differ from each other ?



Source: modified from Heckbert et al. (2010). Ann. N.Y. Acad. Sci. 1185: 39–53

Methodological problems and requirements in modeling for studying sustainability-based issues

Problem	Method requirement
Complex human-environment interactions	Interdisciplinary approach
Uncertainties	Uncertainty management
Externalities and trade-offs - vs. time - vs. space - vs. social group - vs. goal	Long-term perspective Micro-macro links Stakeholder participation Distributed outputs vs. space, time, and actor groups Multi-dimensional outputs

Source: Boulanger, P.M., Brechet, T., 2005. Models for policy-making in sustainable development: The state of the art and perspectives for research. Ecol. Econ. 55, 337-350.

Methodological problems and requirements

Problem

- Flexible (not fixed) feedback loops genetated by actors‘ decisions
- Actors‘ decisions changable along learning
- Heterogeneity as important source of buffering, adaptive capacities
- Framing drivers

Method requirement

- Actors' behavior explained
- Relevant learning process captured
- Within- and between- farm heterogeneities represented
- Sensitive to key drivers

Source: Le et al. (in prep). Methodological Abilities of Integrated Models to Support Agricultural Landscape Resilience: Current Status and Research Perspectives. Manuscript in preparation.

What systems modeling methods?

P.-M. Boulanger, T. Bréchet / Ecological Economics 55 (2005) 337–350 343

Table 4
Relative strengths and weaknesses of various modelling approaches with respect to criteria for sustainable development policy-making

	Interdisciplinary potential	Long-term, intergenerational	Uncertainty management	Local–global	Participation	Ranking
Multi-agents	0.29	0.27	0.30	0.34	0.40	
System dynamics	0.29	0.27	0.08	0.11	0.20	
Bayesian networks	0.17	0.07	0.39	0.17	0.13	
Optimization	0.05	0.07	0.06	0.17	0.08	
General equilibrium	0.10	0.21	0.08	0.11	0.08	
Macro-econometric	0.10	0.10	0.10	0.09	0.10	

Based on this table, one can realize the potentials/limitations of common systems modeling methods in meeting criteria required in his/her research-in-development project.

What systems modelling methods are suitable to your project context?

Based on this method decision tree, one can select a few relevant systems modeling methods given their project context (questions and scientific interested, team capacity, resources, etc.)

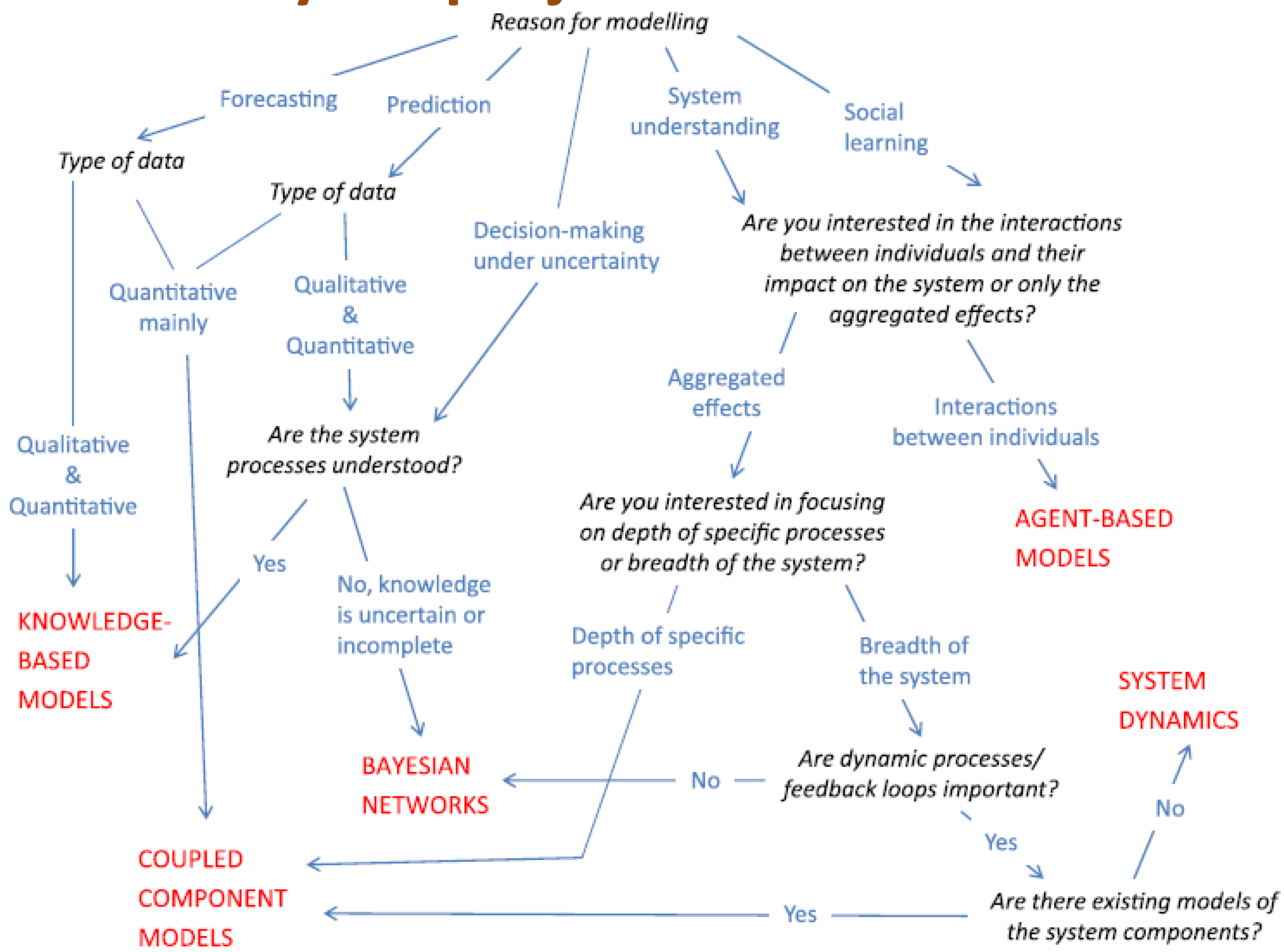


Fig. 1. Decision tree for selecting the most appropriate integrated modelling approach under standard application.

Source: Kelly, R.A. et al. 2013. Selecting among five common modelling approaches for integrated environmental assessment and management. Environmental Modelling & Software 47, 159-181.

Group discussion

Let exchange with your friends about integrated modelling/assessment methods you experienced.

Some suggesting points to share:

1. What methods have you experienced? (not necessarily limited to the methods discussed so far)

2. Level of your experience? E.g. Practiced via courses. Or Applied to for own research, or Developed new tools?

3. Your reflections on the method *pros*, *cons* and relevant usages?