Mountain Sentinels Network
Participatory Modeling of Mountain Social-Ecological Systems Workshop
Preparation guidelines
23 April – 27 April 2017 at Rock Springs Resort, Bend, Oregon

Background and model purpose

In preparation for the upcoming workshop, we are asking participants to develop cognitive models based on your understanding of how your mountain system operates. This is an important first step towards model synthesis and for identifying the key factors for maintaining the flow of critical ecosystem services, for improving or sustaining the resilience of current livelihoods, and for supporting adaptive transformation in the face of global change. We can then assess how these factors vary across different land uses. To this end, we will develop cognitive models (sometimes referred to as causal models or mental models) of our respective study systems that can then be used to develop Bayesian Network (BN) models. BN models are statistical models that represent key parts of a system and connections between them, and can incorporate uncertainties in both input data and model construction. A BN model can be used to anticipate the likelihood of a local actor's (i.e. decision-maker's) choices for resource use and livelihoods. Results can provide insights into trajectories of change in mountain social-ecological systems in response to global change (both long-term presses and episodic pulses), and assess how different adaptation pathways affect the system at local (e.g. mobility along elevation gradients), regional (e.g., watershed management) or national levels (e.g. change in ecosystem stewardship subsidies). Results may be used to further inform decision making in agent-based models (ABMs), depending on the workshop outcomes. This document outlines the suggested steps in developing the cognitive model, associated scenarios, and key definitions (refer to glossary), with examples.

Suggested basic components of the model

We suggest that the model will represent a key actor's decision-making process on one land use type during a particular season. Drivers of change (defined as node set categories in Bayesian networks) include **climate presses/pulses** (e.g. climatic changes in precipitation and temperature), **policy presses/pulses** (e.g. changes in the extent of openness of the national agricultural market), **demographic presses/pulses** (e.g. in/out migration, population change), **governance arrangements** (e.g. provision of public funding or aid to incentivize ecosystem service stewardship), **biophysical characteristics** (e.g. slope, elevation, farm size), **built infrastructure** (e.g. irrigation or road infrastructure), and **economic income/costs** (e.g. production costs, on/off-farm income). These factors then influence a local actor's decision-making, land use, and arising livelihoods associated with ecosystem service provision on that land use. Land use and how this changes under different scenarios can be spatially mapped, depending on the available data and livelihood outcomes quantified (e.g. in terms of kg/ha or income in terms of USD).

Land-use groups we have identified

Pastoral:	Tibet, Switzerland
Agro-pastoral:	Peru, China and Ethiopia
Tourism/Logging:	Cascades Oregon
Tourism/Residential:	Rockies Colorado, Slovenia
Crop/NTFPs:	Honduras, Kenya, Morocco, Nepal

Thank you for your contribution of your time and expertise! Jessica Thorn is open to discussing this further on email or Skype: Jessica.thorn9.

Please complete and send to jessica.thorn@colostate.edu by 20 April 2017:

Step 1. Provide basic site information.

1) Summary title of study (<7 words)
2) Study site name, country, region
3) Mountain range
4) Primary current land use type (Select 1: pastoral; agro-pastoral; tourism/logging; tourism/residential; crops)
5) Approx. study area (km^2)
6) Latitude / longitude (decimal degrees) (choose central point)
7) Explain how the study has been defined (e.g. biophysical, political, administrative, watersheds , however you have been defined it)
8) Elevation range (min, max - masl)
9) Long-term (e.g. 20 year) mean annual precipitation (mm)
10) Long-term (e.g. 20 year) mean annual temperature (°C)
11) Period of empirical data collection (months, season, year)
12) Collaborators for current and past work
13) Cognitive model developer(s) (see step 3 and 4)
14) Funders
15) Typology of actors' decision-making rationality (e.g. bounded rationality) (see Table 1)
16) Who are the potential end users of the model?
17) What planning processes might the model inform, i.e. the decision making context?
18) The most important actor (agents) in your system, whose decisions effects land or resource use.
19) Please specify if you have historical land use maps for model validation, specifying the year.
20) Describe, if any, previous socio-ecological models you have already developed.

Table 1. Assumptions of actor rationality. Adapted from Schluter et al (2017)

Theory	Description
Rational choice theory	Self-interest, maximize income or utility. Perfect knowledge
Bounded rationality	Imperfect knowledge, but otherwise similar to rational choice
Theory of planned behavior	Normative values and perceived impacts of behavior affect decision to do it
Habitual or reinforcement learning	Satisfaction from behavior reinforces it; a threshold will determine when it's time to change the behavior
Descriptive norm	Observations of neighbors impact decisions of individuals
Prospect theory	Risk aversion biases decision making; avoiding loss > chancing gain

Step 2. Formulate 2-3 research questions and hypotheses Questions may be those most relevant in your study system for decision-making, tie into the broader questions of Mountain Sentinels, build on existing models or be new avenues of inquiry.

The following questions have been previously identified by Mt Sentinels as potentially guiding questions across mountain sites. They may be adapted and specified to your system:

1. In the face of climate and socio-political change, what impact factors emerge as critical for maintaining the flow of critical ES and the resilience of current livelihoods?
2. What factors emerge as critical for transformative adaptation toward desired outcomes in mountains?
3. How do these factors vary by land use; market-orientation; and local-regional challenges and contexts?

Our hypothesized factors could relate to the mountain characteristics and incongruities, e.g.:

1. 'Policies by outsiders'. Innovative, cross-scale governance is more successful than when policy is made by those living beyond the Mountain socio-ecological system.
2. 'Data required, but lacking'. Shared knowledge of ecosystem processes that combines scientific and local knowledge improves capacity to identify approaches for resilient and transformative ecosystem services and livelihoods undergoing change.

Step 3. Take the diagram in figure 1 which represents the working conceptual model to shape the selection of your variables. List nodes excluded. Impact factors may be prioritized on the basis of (a) how strongly the factor influences the land use decision, b) data availability and reliability, and (c) comparability of the model to other systems. Prioritized factors will then be broken down as shown in figure 2 within a causal diagram (e.g. if there is extreme snowstorm, then what will happens) (step 4).

Step 4. Develop a cognitive model, or directed acyclic graph (DAG) composed of nodes (variables) and theoretical causal links (relationships) representing your system understanding of how land use decision-making operates in your mountain region or local site. Please draw this by hand or use a digital program (e.g. PowerPoint, Venism or Netica to facilitate the manipulation and adjustment of the DAG).

In your land use category**, please identify the key drivers and factors that are likely to influence a key local actors' decisions of interest**. These decisions lead to particular outcomes of land use, livelihood resilience, ecosystem service provision and/or food security. For example, in the Swiss Valais pastoral case study, potential decisions are to intensity, extensify (including diversify), or abandon their agricultural livelihood and move to urban centers or shift to non-agricultural livelihoods.)Here, we employ a broad definition of agricultural livelihoods including rangelands, crops, mixed crop livestock, NTFPs, and timber production. The glossary provides definitions of how we synthesizing variables within broad node set categories (See Figure 1 and 2).
In developing a clear and detailed model of your system understanding, consider:

- The model must be directed, or acyclic, which means there are no feedbacks within an individual time step. Arrows must therefore be unidirectional.
- Indicate the likely influence of drivers / factors by indicating a positive, neutral or negative influence on the node it feeds into.
- Please limit the model to 20-30 nodes. When drawing linkages, attempt to minimize the number of parent nodes connected to the child nodes, as we will calculate the conditional probability of each node given its relationship to previous nodes. Incorporating more combinations introduces greater complexity and uncertainty.
- The scale of each variable will vary according to its category. Processes operate across spatial scales from plot, landscape, district,canton, regional, national, to international (specified in step 5).
- The reference season (e.g. summer livestock grazing). We would prefer to work with data that has been collected in the last decade and is comparable to other systems (e.g. on Switzerland and Tibet the data was collected in 2011-12).
- Assumptions of the actors' rationality. For this please specify the typology of actor rationality, based on the work of Schlüter, et al 2017.
- Consider biophysical limitations that might go beyond the capacity of a local actor to make a decision (e.g. slope, soil quality, elevation). In Figure 2 this is described as "marginal plot gain".

Step 5. Each of the nodes we define in the model has a prior probability distribution, based on empirical and secondary data. **Should you be willing, populate a data table with the following headings.** See examples below**.** Standard procedures for data protection will be adhered to. States of the node (column 8) should usually be 2 or 3, not more than 5. For comparability, we suggest the use of USD and metric indicators.

Table 2. Data table

Node name	Node set category	Year/ season of collection	Data source (s)	Scale of data	Spatially explicit?(Y/N) If Y, specify resolution	Sample size	Node states Including the unit of measurement	Definition of node	Level of uncertainty of data
Slope	Biophysical	2005, ONDJF (Summer)	Digital Elevation Model DHM 25 Swisstopo	Parcel (plot)	Yes, 1m resolution	13689	Below 18°masl/btw 18-35° masl/ above 35°masl	Determined using slope categories	Very certain
On farm revenue	Economic	2012	Interviews by Brändle (2011)	Agent	No	111	Below or above 19008 USD per annum	Revenue from cash crops per annum or season	Certain
Part-time business	Local actor characteristic	2012	Interviews by Brändle (2015)	Farm	No	111	Below or above 50% of income in agriculture	If farmers earn <50% of their tot. income from farming (acc. federal rules)*	Certain

*Part time businesses include tourism, chemical industry, forestry, conservation, urban investment or renewable energy.

Table 3. Level of uncertainty of data. Adapted from Mastrandrea, et al (2010)

Degree of confidence in the data	Level of uncertainty
Very certain	90-100%
Certain	66-100%
About as certain as not	33-66% probability
Uncertain	0-33% probability
Very uncertain	0-10% probability

Step 6. Specify four plausible scenarios, including time steps. Within each scenario, it may be helpful to think about the potential adaptation pathways or maladaptation that could be tested. When specifying time steps which to apply, account for the degree in uncertainty that you are confident about (defined in Table 3). In each time step, an actor makes a land use decision. The output of each time step serves as the input to the next step of the model.

Table 4. Scenarios

Scenarios	**Time step 1:** e.g. 2035	**Time step 2:** e.g. 2050
Climate press or pulse	e.g. Return rate extreme snowstorms (Moderate/high incr, in frequency)	
Emission scenario	e.g. RCP4.5 and RCP 8.5 IPCC 2007	
Policy intervention	e.g. Restriction of mobility (moderate / high increase)	
Market intervention	e.g. Increase in livestock prices (High, Low)	
Spatial planning intervention	e.g. Urban expansion (10%, 20%)	
Demographic change	e.g. Outmigration (</>350 000)	

The scenario approach has been employed to BN and ABM requirements. In specifying the scenarios, we prefer the use of local/regional scenarios that have been developed with stakeholders in a participatory manner, if available. Alternatively, scenarios could include regionalized or downscaled narratives from the Millennium Ecosystem Assessment (2005) scenarios (e.g. global orchestration, order from strength, adapting mosaic, techno-garden), IPBES (2017) or IPCC (2007) scenarios (e.g., in some models we are using temperature and precipitation projected data under the RCP 4.5. and 8.5 IPCC 2007 emissions scenarios). In the quantitative model the scenarios trajectories are represented either by a change of state at one node (e.g. a biophysical parameters like rainfall), or by consistent state changes at different nodes (e.g. precipitation and part-time business), in both cases determining a cascade effect on child (or "downhill") nodes.

Consider these main characteristics of scenarios (JRC Scenario building EU commission, 2014):

- *Plausibility:* A scenario must be plausible. This means that it must fall within the limits of what might conceivably happen.
- *Consistency:* A scenario must be internally consistent; meaning the combination of logics in a scenario must not have any built-in inconsistency that could undermine the credibility of the scenario.
- *Decision-making utility:* Each scenario, and all scenarios if they constitute a set, should contribute specific insights into the future that will lead to the decision of the local actor. For this consider the potential "adaptation pathways" that could be tested.
- *Differentiation:* Each scenario should be structurally different, meaning they should not be so close to one another that they become simply variations of a base case.
- *Challenge:* The scenarios should challenge one's conventional wisdom about the future

Step 7. Develop a story line to explain the cognitive model for the current and future trajectories. Flesh out the model, developing internally consistent description which projects how you understand the system, representing the "current situation" or base year for scenarios. Then scenario storylines represent a future evolution of this. The scenarios storylines may represent the qualitative description of the main expected changes in the "drivers" and "decision context" nodes of the conceptual model deriving from specific shocks at the presses or pulses level, in other words a "conceptual model for the future". Please come prepared to share you storyline with other participants at the workshop.

Glossary of drivers and node set categories

Drivers that influence land use, ecosystem service provision, and livelihood outcomes include climate, markets, policy, and demographic changes and can be exogenous or endogenous. Drivers operate at different time scales - episodic ('pulse') and sustained ('press'). Presses are gradual or cumulative pressures on a system, such as temperature and precipitation change, population growth, urban expansion, growing water demand, migration, or change in land use or market policy. Pulses are sudden or abrupt events of a SES, such as natural disturbance (e.g. extreme drought, forest fires, extreme snow storms, hurricane, land slides) and socio-economic disruptions (e.g. economic crisis, civil war).

Scenarios are "plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships" (MEA 2005). Scenarios can help people conceptualize the future (Polasky et al., 2011) and provide insight into the range and uncertainty of future ES changes (Rounsevell et al., 2012; Grêt-Regamey et al., 2013). Scenarios can include desired futures and push back scenarios leading to unwanted outcomes. Scenarios can be normative, explorative, as well as qualitative (e.g. storylines or narratives) (Alcamo, 2008) or quantitative (Brunner, Huber and Grêt-Regamey, 2016) or a mixed combination.

Biophysical characteristics and processes includes biotic and abiotic factors that can be measured using chemical indicators (e.g. dissolved oxygen in water), physical indicators (e.g. soil texture), and biological indicators (e.g. pest and natural enemy abundance that can be assessed in terms of functional traits (Swartz et al 2000, de Bello et al 2010, Mace, Norris and Fitter 2012). Examples include slope, elevation, farm size, grassland biomass, agricultural productivity, water availability, livestock units and type, vegetation type and traits, soil quality, and wildlife type and traits.

Built environment is the human-constructed feature of a landscape and settlements, such as fences, property boundaries, road and irrigation infrastructure, buildings, transportation, communications networks and structures, infrastructure for energy production and consumption, waste management, renewable energy power plants, or dams, etc.

Economic factors might on-farm/off-farm income, costs, economic subsidies for ecosystem service stewardship, part-time businesses, property values, non-agricultural product demand and the extent of international market liberalism or protectionism

Local actor characteristics include gender, age, ethnicity, education, ethnicity or origin, social capital, membership to farmers cooperative, household size, degree of innovative technology adoption, cultural value, succession rate, education, food source, labor availability, political orientation or land tenure, length of time farming on a property, access to early warning systems, etc.

Actors include organizations, governments, informal groups and individuals, such as part-time or full time farmers, rangeland managers, private business, elected government officials, household dependents, etc. For our purpose we are considering an actor within a single land parcel.

Governance is broadly defined as the exercise of authority (often through multiple actors/entities interacting within and across levels) that shapes decisions, behaviors and outcomes in a given realm (e.g., forests, cities) (Tucker 2010). Governance arrangements are the structure/type of constitutional, collective choice and operational levels in a governance system; interactions and patterns within and across these levels, and the institutions (rules-in-use) and entities/actors with authority that compose the governance system. Governance and policy considerations might include decisions on spatial planning, mobility arrangements and land use policy, government support for restocking, decisions on irrigation frequency, participation in local decision making, land and water tenure, access to protected areas and grazing or water rights.

Actor's land-use decisions determine land use types. Mountain Sentinels delineates between five main land use types: pastoral, agro-pastoral, tourism/logging, tourism/residential, and crops.

Ecosystem services are aspects of ecosystems utilized (actively or passively) to produce human well-being (Fisher, Turner and Morling 2009 in Lamarque, Meyfroidt, Nettier and Lavorel 2013). ES can be turned directly into benefits ('final ecosystem services'), and those that support other services (called 'intermediate ecosystem service'). Before being used, consumed or enjoyed by human beneficiaries, ES should only be considered as potential ES'' (Lamarque, Quetier, Lavorel, 2011). Ecosystem goods and services that include both material (e.g. medicinal and aromatic plants) and non-material benefits (e.g. spiritual value of harvesting the crop) (UKNEA 2011), or marketable and non-marketable. Ecosystem services include provisioning, supporting, regulating and cultural services.

Adaptation services are benefits that people derive from the capacity of ecosystems to mitigate and adapt to climate change impacts. Adaptation services differ from ecosystem services in the recognition of ecosystems' intrinsic ability to provide valuable services for societal adaptation by: (a) buffering risks, (b) providing options and (c) transforming. For instance, maintenance of forests on steep slopes buffers risks from increasingly extreme precipitation events; functional diversity provides response diversity to novel disturbances (e.g. fire in previously wetter regions); and recolonization of glacial margins provides new resources for summer grazing, especially during drought years.

For our purposes, livelihoods are the economic and productive activities that provide sustenance for a household or people and are derived from ecosystems service benefits (See Tanner et al 2015).

Mountain characteristics *(From Klein et al, forthcoming)*
A unique combination of mountain characteristics (MC) explain why mountain systems are fundamentally different from other regions, even while being closely connected to them.
MC1: Mountains are biophysically and culturally complex systems, characterized by steep vertical gradients, compressed ecosystems, and climatic, hydrologic, and topographic complexity.
MC2: Mountains supply essential ES at local to global scales.
MC3: Mountains are dynamic and have long been exposed to high-energy disturbance regimes.
MC4: Physical remoteness and isolation form barriers and borders, creating fragmented landscapes.
MC5: Physical isolation and distance from centers of power and decision-making contribute to social, economic, and political isolation and marginalization.

Paradoxes or incongruities *(From Klein et al, forthcoming)*
P1: MtSES are resource-rich, but income poor.
P2: Policies affecting mountain systems are often made by outsiders, with little understanding of local dynamics.
P3: MtSES are remote, but exposed to global change.
P4: MtSES are experiencing destabilizing demographic fluxes due to in- and outmigration.
P5: Mountains can be remote and difficult to access, but a range of diverse actors are nonetheless drawn to them, creating challenges for equitable decision-making and resource management.
P6: Mountains require fine-scale data, which are lacking.

Assumptions in the model development
For our purpose, we assume that the models represent the views of local stakeholders as they are set up in an expert-based process with researchers who have long-term experience and expertise with stakeholders in the case study regions. The model does not consider environmental histories. A stated limitation is only one actor (or agent type) is included in the model, meaning we cannot assess the distribution of benefits or differentiation of access to resources, or how the resilience of some peoples' livelihoods may results in the increased vulnerability of others (e.g. through downstream impacts of flood protection measures) (Tanner et al 2014). However, we do account for the varied value systems influencing an actor's intention to behave (e.g. economic optimization, or cultural value).

Suggested further reading

1. Alcamo, J. (2008). The Practice of Environmental Scenario Analysis. *Elsevier Science*.
2. Capitani, et al. (2016). From local scenarios to national maps: a participatory framework for envisioning the future of Tanzania. *Ecology and Society,* 21 (3): 4.
3. Celio and Gret-Regamey (2016). Understanding farmers' influence on land-use change using a participatory Bayesian network approach in a pre-Alpine region in Switzerland. *Journal of Environmental Planning and Management,* 59 (11): 2079-2101.
4. Netica provides useful tutorials in working with belief networks and influence diagrams: https://www.norsys.com/netica.html. A free version is downloadable for up to 20 nodes.
5. Schlüter, et al (2017). A framework for mapping and comparing behavioral theories in models of social-ecological systems, *Ecological Economics*, 131: 21-35.
6. Seidl, R. (2015). A functional-dynamic reflection on participatory processes in modeling projects. *Ambio*, 44 (8), 750-765.
7. Smajgl, A., and Barreteau, O. (2017). Framing options for characterizing and parameterizing human agents in empirical ABM. *Environmental Modeling & Software, 93*, 29-41
8. Tanner, et al (2015). Livelihood resilience in the face of climate change. *Nature Climate Change*, 5, 23-26.
9. Mastrandrea, et al., 2010: Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. IPCC. Available at <http://www.ipcc.ch>.

Figure 1. Working conceptual framework of factors to consider in the cognitive model of your system.

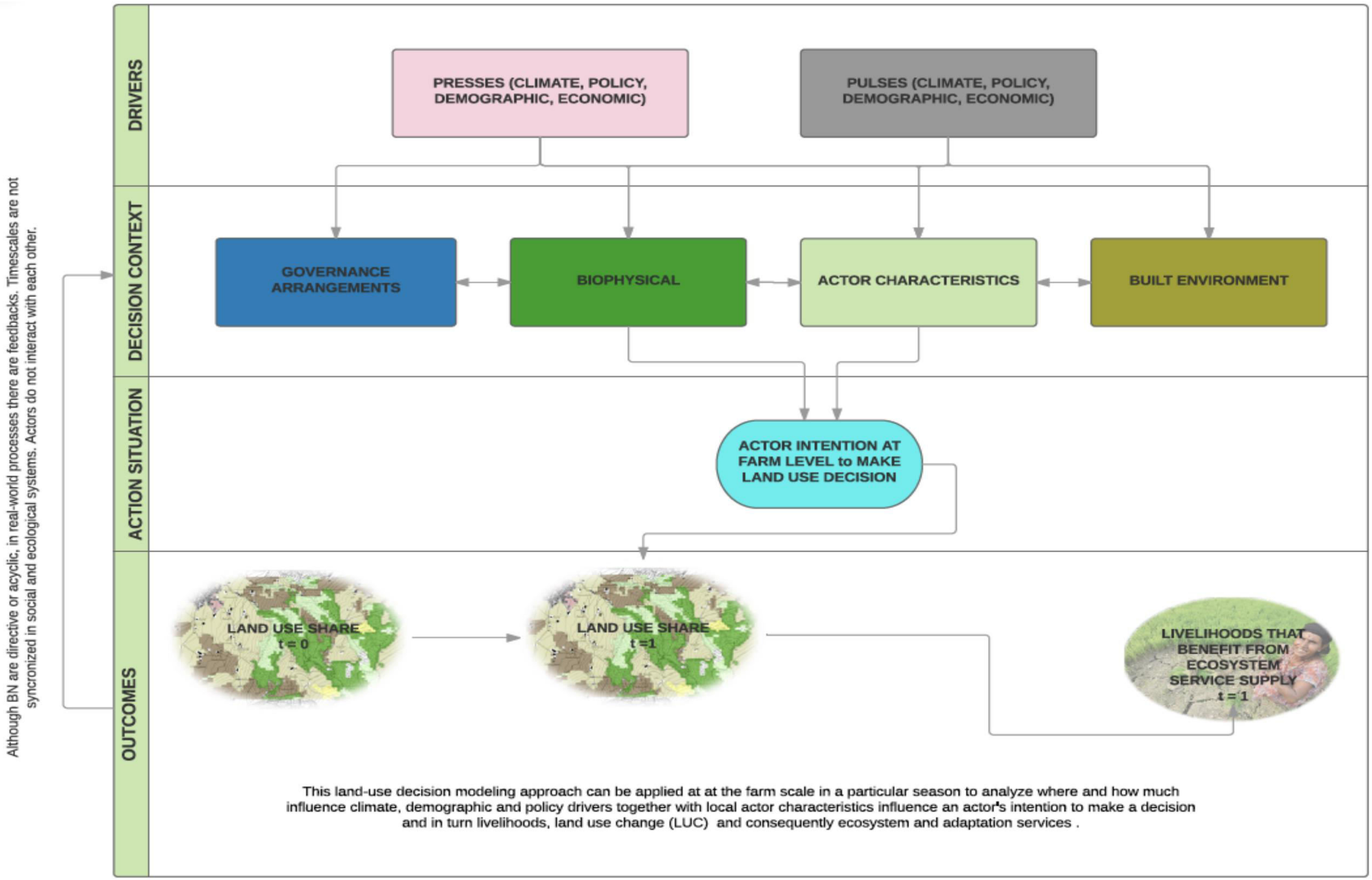

Figure 2. Example of a Bayesian network of a priori states of pastoral livelihoods in Valais in the French Alps of Switzerland (Work in progress Thorn et al 2017)