Science for resilient livelihoods in dry areas

Frameworks, tools, and approaches for the assessment of rangeland governance

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Acronyms

BBN	Bayesian Belief Network
CBO	Community-Based Organization
CPT	Conditional probability table
CRP-PIM	CGIAR Research Program on Policies, Institutions, and Market
GDA	Groupement de Développement Agricole
GIS	Geographical information system
ICARDA	International Center for Agricultural Research in the Dry Areas
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
IRA	Institut des Régions Arides
LMC	Land Management Council
PRODESUD	Programme de développement agro-pastoral et de promotion des initiatives locales pour le sud-est
SES	Socio-Ecological System

Key messages

Like other common natural resources, rangelands require infrastructural, national-level support from institutions and organizations to ensure their effective sustainable management and use. National-level frameworks empower stakeholders to develop, implement, and control rangeland management and restoration strategies; however, appropriate rangeland management may fail in the absence of such support that ensures financial viability, sustainability, and equitable access as core outcomes. It is commonly recognized that the economic and environmental performances of rangelands rely on the effectiveness of their governance.

This document aims to contribute to the empirical development of effective approaches for the assessment of rangeland governance at local levels, and provide insights about major governance drivers through the quantitative assessment of their effects. Our focus is an application of the Bayesian Belief Network (BBN) methodology to assess key variables that affect the probability of good rangeland governance under contrasting contexts of land tenure in Southern Tunisia.

We present a general framework for the assessment of rangeland governance as a first step in the evaluation of the effectiveness of rangeland institutions. This should contribute to clearer understanding of institutional gaps; thus, pathways to enhance rangeland governance may be identified and governance strategies to address the challenges facing rangeland management and sustainability may be explored. A second section of the document presents the BBN methodology and requirements for its application in the study of local-level rangeland governance. The BBN offers scope to characterize complex causalities and attribute realistic weights to identified causal linkages that are relevant for the study of natural resource governance. The final section of this document presents requirements for empirical data and methods for data collection through focus groups and farmer interviews. We demonstrate how to determine a set of socioeconomic and environmental variables that influences the success of rangeland management, and its use in the construction of a BBN. The document ends with some conclusions, lessons learned, and recommendations for users.

Highlights

- We present a framework for the analysis and assessment of institutional performance and rangeland governance. The framework accounts for the dimensions, components, and levels of rangeland governance.
- The framework describes practical steps for the implementation of rangeland governance assessment at a local level, and a set of governance indicators for use in Bayesian modeling of determinants of states of governance.
- The BBN methodology provides a framework for combining knowledge and data derived from a range of sources with variable accuracy, including the capacity to integrate social, economic, and environmental variables within a single model.
- The framework used is based on multi-stakeholders' participatory discussions and focus groups to reveal actors' perceptions and knowledge about local rangeland governance.
- The consideration of rangeland governance as a final outcome of a given Bayesian network allows for the identification of key drivers of good governance.

Section 1. A general framework for rangeland governance assessment

1.1 Background and rationale

Rangelands are widespread areas of pastorally grazed, native vegetation; thus, ensuring the sustainable management and maintenance of these natural resources is complex, requiring consensus and cooperation among rangeland stakeholders. It is also well known that the economic and environmental importance of rangelands is mostly compromised by the weakness of its land governance (Davies et al. 2016).

The objective of this document is to provide a comprehensive framework and operational guidelines for participatory assessment of rangeland governance. Provision of such a framework by institutions and organizations, within which various stakeholders could work, would ensure consistent and appropriate management activities; however, the lack of effective governance and focus on the financial viability of rangelands, sustainability, and equitable access threaten the long-term future of these important natural and cultural resources.

With their individual and different perspectives and definitions of governance, rangeland stakeholders tend to have conflicting interests, often have only a partial understanding of regulatory, administrative, or policy aspects of governance, and are driven by natural self-interest. While it is important to consider the opinions of individual stakeholders, a broader, multi-level framework that accounts for the perspectives of multiple stakeholders should be considered in an assessment of governance. This report aims to contribute to the development of such a generic framework.

Collections of good practices and analytical tools that exist in the literature may be used to develop and implement an overarching protocol for good governance to achieve effective management of natural resources. Here, we borrow from the groundwater governance framework, developed by Wijnen et al. (2012), to define the organizational levels at which rangeland governance may be embedded: (1) national level for setting policies and overseeing governance; (2) strategic level, also known as the level of "governance functions"; and (3) local level at which stakeholders and local institutions operate, and where governance outcomes are generated and assessed.

In addition to presenting a qualitative assessment of rangeland governance, this document aims to provide a comprehensive quantitative approach based on indicators of local rangeland governance that cover the scope of influence of environmental, institutional, and economic variables on the state of rangeland governance in a given context. We developed this quantitative approach based on BBN models that generate conditional probability distributions of contrasting management scenarios to identify optimal rangeland governance.

This document is divided into four sections: in this first section, we present an institutional framework for rangeland governance assessment and analysis; in the second and third, we present the BBN approach and its empirical data requirements; and in the final, concluding section, we provide general guidelines and recommendations for the effective implementation of our proposed methodology.

1.2 Levels of rangeland governance assessment

Dimensions, components, and levels of rangeland governance

Three **levels** of rangeland governance assessment can be considered (Figure 1). The first refers to the national level **governance framework**, where rangeland policies and management instruments are determined within a livelihood and environmental policies arena[1], and where policy makers and central administrations (directly or indirectly) devise and harmonize rangeland development agendas. Effective coordination among senior staff in central administrations and institutions is essential at

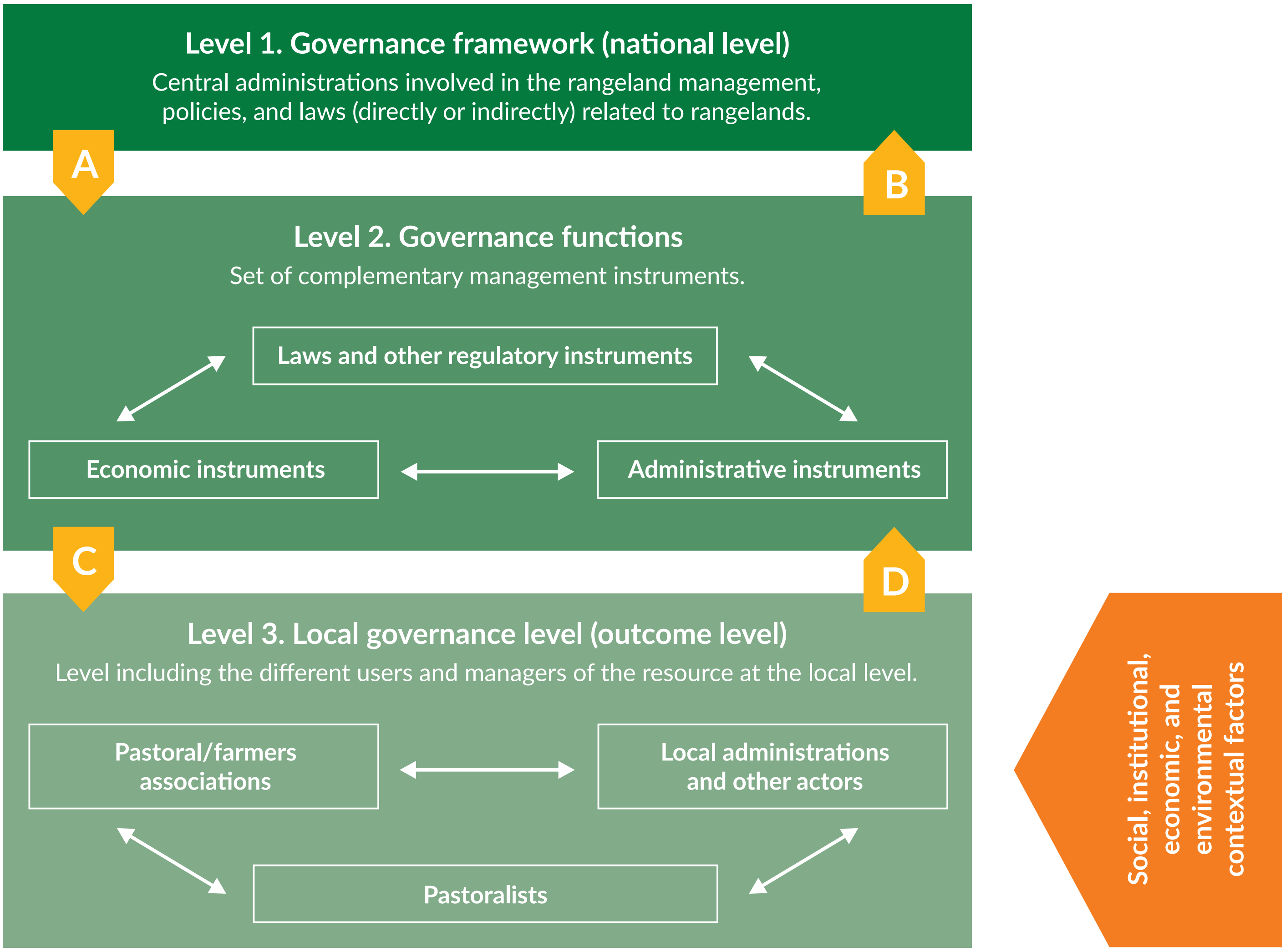
[1] For example, investments in road infrastructure in a given area may affect pastoralist mobility, and thus indirectly influence rangeland sustainability; or farmers who receive subsidies for the purchase of feed may change their patterns of rangeland use.

this level to ensure coherence and positive impact of their respective interventions and policies on pastoral rangelands.

Defined and designed operational instruments are part of the second level and aim to facilitate meeting the objectives set within the national-level governance framework. These strategic level instruments constitute **governance functions**, which operate at institutions to align stakeholder behavior with national-level policy objectives, comprise regulatory (e.g. right of access to and use of rangeland goods and services) and economic policy (e.g. subsidies, grazing fees) instruments. Both formal and informal (or customary) instruments should be described, with their implementation realistically assessed; for example, some rangeland laws exist, but are inadequately enforced. The set of instruments must be coherent and avoid the creation of conflict scenarios. Rangeland laws, rights, regulatory instruments, incentives, and other economic instruments designed to support local rangeland management are components of this strategic level.

The **local governance level** corresponds to pastoralists (in addition to any other end users), organizations, and institutions that control outcomes of the governance framework, through their responses to strategic governance level rules and incentives. This level may include public agencies (administrations) that are expected to implement national policies at the local level using instruments; local collective management and social organizations (Groupements de Développement

Figure 1. Rangeland governance levels and components.



[2] Similar to the Community-Based Organization (CBO) concept.

Agricole [GDAs][2], and other types of users' associations); individual pastoralists, whose behavior should reflect and affect the final outcome of the rangeland governance structure in a given area, for a given time; and other stakeholders directly or indirectly involved in the use and management of rangelands. In contrast to national and strategic levels, which are consistent across contexts within a country, local-level strategies tend to be related to variable contextual characteristics. For example, factors such as land tenure system, social capital, and organizational capacity of local pastoralists are important in determining the outcome of rangeland governance, and other factors, such as performance of local organizations and pastoralist networks, may vary with socio-ecological context. Therefore, it is essential that these types of factor should be accounted for at the local governance level using empirical tools and methodologies to quantify their effect on pastoralism and rangeland sustainability. The following are possible, local-level factors:

- Pastoral and herd mobility and associated impacts;
- Use of technology, such as mobile water points, Geographical Information System interactive maps, and drones that re-defines mobility patterns of pastoralists;
- The level of trust and coordination between GDA and other public administrations, as well as the existence and clarity of their functional boundaries that define their rights and obligations;
- Levels of community participation and engagement, including formal and informal instruments that motivate voluntary action or behavioral changes, without use of direct financial instruments; and
- Land tenure system as one of the most influential local contextual factors on rangeland management.

Interactions among the different governance levels.

Governance assessment should not only include a review of institutional components and levels, but also consider the way stakeholders interact to achieve anticipated, desirable outcomes. Interactions may occur within or across strategic levels, and are essential to achieve the governance framework objectives and facilitate dynamic feedback mechanisms that enhance adaptation capacity and performance of rangeland institutions. These types of interaction, which are illustrated in Figure 1 using different arrows linking governance levels to each other, should be integral to a comprehensive assessment of rangeland governance.

Performance indicators to assess rangeland governance

In the previous sections, we stated that governance structures and arrangements for rangeland management vary with context, as a result of differences in stakeholder characteristics and interactions within and between strategic levels. Implicitly, this indicates that outcomes of rangeland governance vary with socio-ecological context. A set of key performance indicators should be developed to evaluate and compare outcomes of contrasting governance strategies against given or known benchmarks. Indicators may include presence and success of funded rangeland restoration programs, livestock density, presence and nature of conflicts in the CBOs, and local pastoralist perceptions of the state of their rangeland.

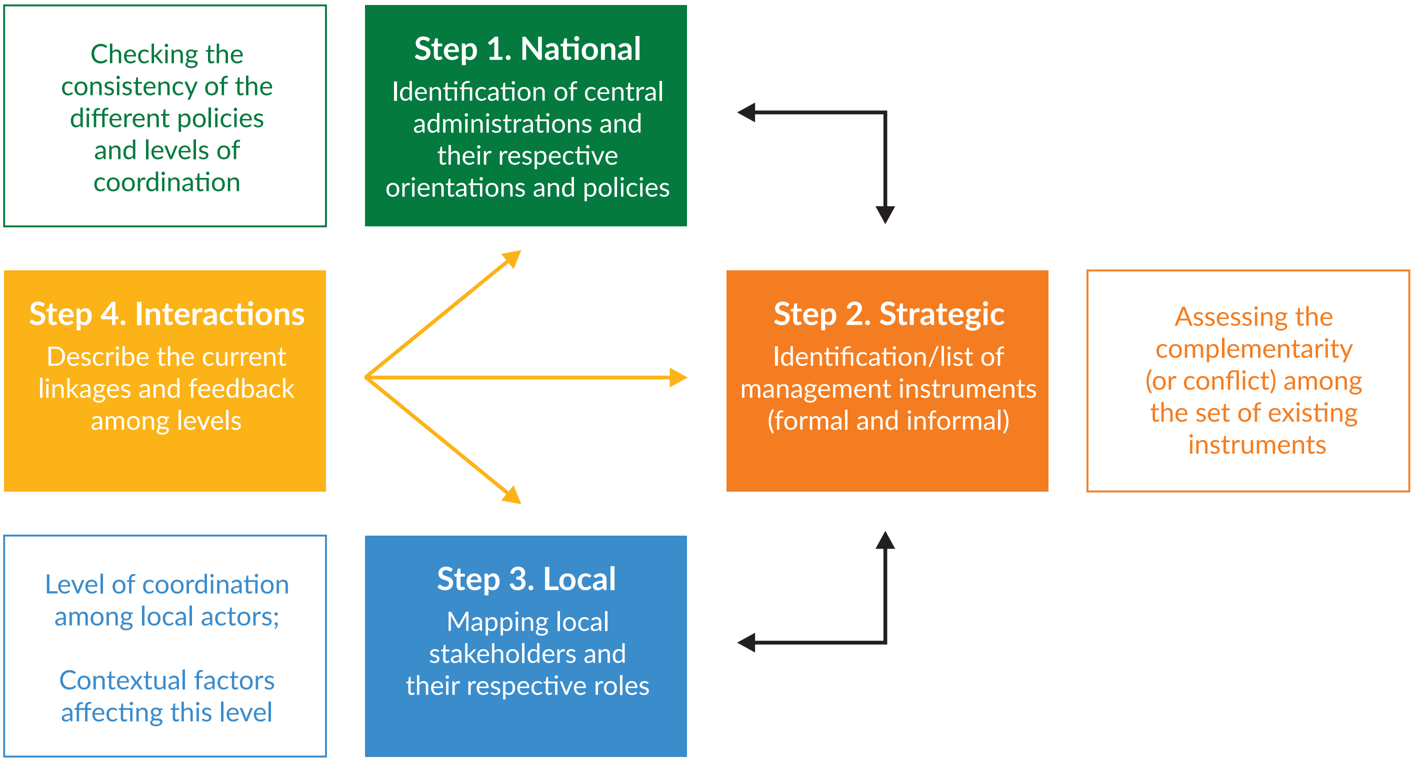
Practical steps for the implementation of the rangeland governance assessment framework

Three practical implementation steps for the rangeland governance assessment framework (Figure 2) are related to the characterization of the three levels of governance, while the final step is related to the description of their respective interactions.

The four steps and their respective tasks are defined as:

1. Identification of central administrations, and their respective objectives, including agendas and plans, and policies. In this first step, we aim to check consistency and coherence of policies that are directly and indirectly related to rangelands and developed by national-level stakeholders, and define the current level of coordination. The information for this assessment can be found in gray literature, official reports and, if necessary, completed from interviews.
2. Enumeration and assessment of an inventory of all rangeland management instruments currently in use, and provision of an initial assessment of the level of complementarity (or substitution). It will be important to report the historical development and implementation of these instruments, including details on when and under what circumstances they were devised, and it may be useful to cite relevant strategic studies on the effectiveness of the instruments. Information for conducting this assessment can primarily be found in official reports and other publications.
3. Mapping of all stakeholders directly and indirectly involved at the local level in the use and

Figure 2. Practical steps for the implementation of rangeland governance assessments.



management of the rangeland, along with the definition and illustration of a list of the key influential contextual factors that may affect implementation of the rangeland management instruments (Step 2). Stakeholder mapping can be done based on available documents in addition to semi-structured interviews with key local rangeland managers.

4. An overall assessment of the nature and magnitude of the different interactions and feedbacks among the three defined governance levels. This assessment will allow understanding of the scope and speed, and possibly direction, of change in governance and identify the optimal strategy for successful sustainable rangeland management. This analytical step requires qualitative data collection from multi-stakeholder focus groups and discussions.

Once implemented, this governance assessment framework will help identify governance failures, provide recommendations about achievements, and highlight institutional capacity challenges that must be addressed. By comparing contrasting scenarios, this assessment should allow benchmarks to be set and identify pathways for improvement to optimize specific rangeland governance requirements.

The development and implementation of this guide for rangeland governance assessment should be considered as a first step in the evaluation of the function and effectiveness of rangeland institutions, and should deliver a clear understanding of institutional gaps and strategic pathways to improved governance for the sustainable management of rangelands. However, a move beyond qualitative assessments and descriptive frameworks requires quantitative methodologies to describe and simulate scenarios of governance improvement, particularly at the local level. The next section of this document presents a methodology that has been designed and tested by the International Center for Agricultural Research in the Dry Areas (ICARDA) and the Institut des Régions Arides (IRA) Médenine within the CGIAR Research Program on Policies, Institutions, and Markets framework to evaluate alternative pathways for the improvement of local rangeland governance.

Section 2. From concepts to applications: the use of Bayesian Belief Networks to evaluate local rangeland governance systems

The task of developing and implementing appropriate methodologies and approaches that integrate interdisciplinary knowledge into a holistic integrated framework to understand the effects of socioeconomic, environmental, and institutional factors on local rangeland governance remains a challenge. Given the complexity of influencing factors and their association with governance, we developed a Bayesian approach to generate conditional probability distributions[3] that allow sensitivity testing of rangeland governance under different scenarios[4].

We present our approach in this section, and show how socioeconomic and environmental data may be integrated and analyzed using Bayesian Belief Networks (BBNs). We adapt and use this approach to assess, and then validate using empirical data, the effect and weight of key contextual variables on good rangeland governance in a case study from Southern Tunisia.

2.1 Socio-ecological rangeland systems

Farming systems that combine the use and management of natural ecological resources are known as socio-ecological systems (SESs), in which institutions mediate between biophysical interdependencies of stakeholders through trade-offs in resource-related ecosystem goods and services within a defined landscape. Recent research has focused on characterizing these interdependencies and showing how some of the environmental and resource characteristics shape the effectiveness of policies and institutional arrangements (Thiel 2014), leading to different governance structures. Appropriate institutions (both formal and informal) should be appropriately and intricately embedded with the identities and mental models that structure the way local populations are thinking and perceiving their environment. Thus, institutional and behavioral change is a multi-faceted, often unpredictable process that may be accompanied by unintended consequences (Thiel 2014). To stimulate institutional change and generate appropriate forms of governance, incentives may be restructured, additional information be made available, and/or mental models may be altered through, for example, initiating processes of social learning (Pahl-Wostl et al. 2008). The use of participatory modeling techniques, such as BBNs, generates valuable information about specific directions, requirements, and incentives needed to generate institutional change and enhance governance structures. It is important to consider contextual specificities, because **institutional guiding behavior must be well-adapted to the specific context** in which they operate. For example, instruments for rangeland restoration, such as relieving grazing pressure and temporary fencing of land, will be more readily accepted by pastoralists if they are based on robust field data, a consensus of agreement from participatory discussions, and social acceptance among local stakeholders.

Against this background, we analyzed the socio-ecological context into which rangelands are embedded, with the objective of enacting and evaluating requirements for possible change in rangeland governance. This analysis relied on expert opinion through system thinking, where a rangeland SES and its dynamics, challenges, and components (socioeconomic, ecological, and institutional) are described based on the knowledge of local experts[5] to effectively represent local understanding and context; additional empirical field data was collected to fully develop the model. These steps are described in more detail in the following sections.

[3] Probability of having good governance under fixed conditions.
[4] Represented by given states of discrete variables supposed to be linked to governance state.
[5] The profile of these experts will be a combination of scientific and technical/field leaders with intensive knowledge about local rangeland management and function.

2.2 BBN for rangeland governance assessment

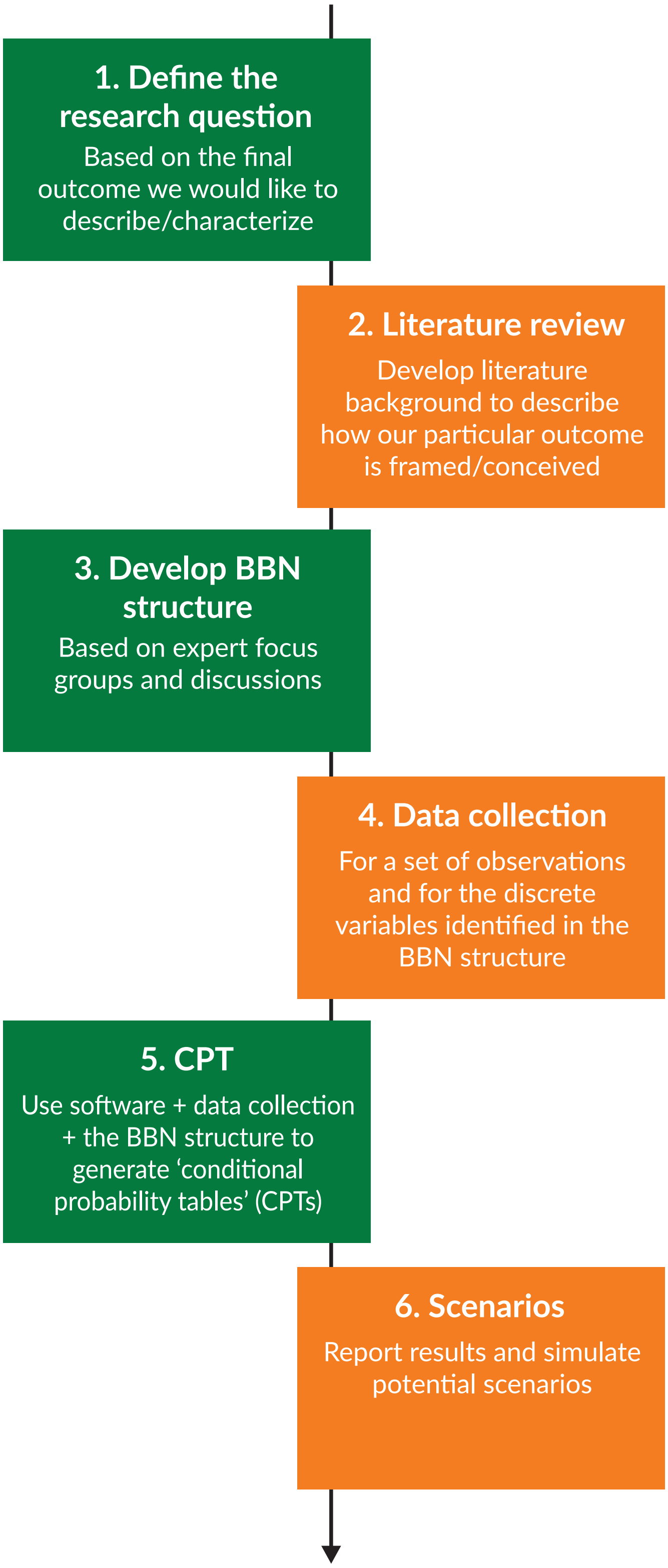
BBN modeling is well-suited to representing causal relationships of a system in the context of variability, uncertainty, and subjectivity, as it elicits subjective expert opinion, deals competently with missing or sparse data, facilitates participatory model-development, and provides a framework for model improvement (updating) as new data and knowledge become available (Richards et al. 2013).

This type of modeling provides a framework to combine knowledge and data from different sources and with varying accuracy (Uusitalo 2007), including the capacity to integrate social, economic, and environmental variables within a single model. The utility of BBNs for eliciting expert opinion through the development of a descriptive network structure of complex causality dynamics and populating conditional probability tables (CPTs) through empirical data collection is well-established (Richards et al. 2013).

Steps for the application of the BBN

Application of the BBN requires clear definition of the causality linkages, so the first step is definition of the research question to identify data, expertise, and local knowledge requirements. Typically, research questions should be defined as: "what is the effect (weight) of variables *A*, *B*, and *C* on creating a desirable state of an outcome event *D*". Mathematically, this research question is interpreted as "how a prior probability of given variables *A*, *B* and *C* would affect the probability of having a state '*D1*' in outcome *D*". Here, our research question is related to the effect of a set of environmental, social, and economic variables on the state of rangeland governance as an outcome event. Given it is preferable that variables used in a BBN are discrete[6], it is necessary to develop quantitative governance indicators in response to the research question; this discretized process results in different states of governance. Once a research question has been identified, the remaining steps for the implementation of the BBN are described in Figure 3.

Figure 3. Steps required to develop and apply a BBN for the study of rangeland management.



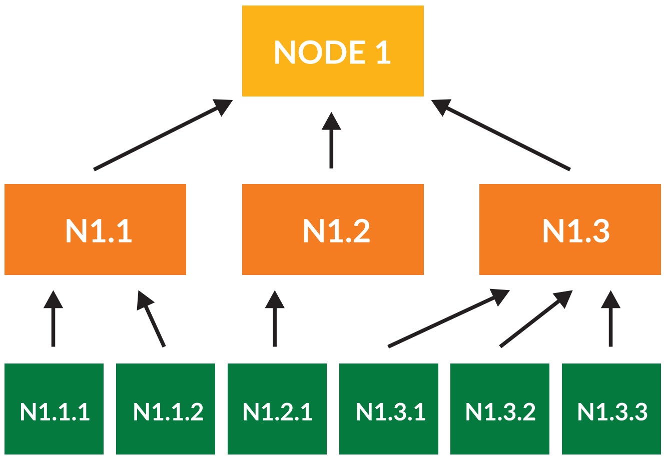
[6] In some cases, we may also use continuous variables.

It is important to conduct a literature review (Step 2) of the outcome event to be investigated to provide a theoretical basis upon which the participative design of the BBN structure, such as primary and secondary nodes and their links, and links to the outcome event, may be constructed. Although it is preferable for the BBN structure to be described through multi-stakeholder discussions (Step 3), a literature review is nevertheless useful to frame and organize focus group discussions and questionnaires. Once a clear BBN structure, with defined types of primary and secondary node and associated discrete levels elucidated by focus group participants, has been created, a survey should be designed (Step 4). It is important that the survey includes one closed question relating to each defined node, where respondents should choose a single response reflecting a given, predefined state of each node variable. BBN training with empirical data (Step 5) generates CPTs and weights of each of the node variables on the final, studied outcome, using the generated CPTs for scenario simulations.

Developing the core network structure through expert opinion

The core of the network structure[7] must be developed first, where the construction of graphical network (causality) linkages, which is often the crucial initial step in the structuring of relationships in the SES (Janssen et al. 2006), serves as a basis for the BBN model (McCann et al. 2006). The network structure may be described as a logical suite of nodes that describe causality between drivers and their logical consequences (Figure 4). Expert knowledge, which is essential to develop this structure, may be gathered from multidisciplinary focus groups. A first step is to define and present to the group the target issue that is to be modeled (Node 1); this usually reflects the final causal link. Node 1 (also called a child node) must comprise a discrete variable that reflects the outcome of different socioeconomic and environmental interventions. For example, the variable *"A GDA[8] is successful in managing the rangeland"* has two condition states: yes/no. Once Node 1 has been defined, the experts should be asked to agree on three (or more) primary variables, called parent nodes (N1.1, N1.2, and N1.3), that directly influence the desirable (and/or undesirable) state of Node 1, and provide their respective desirable and undesirable states. Example parent nodes include rainfall anomalies, land tenure system (existence of a successful management council), and existence of a rangeland restoration program in the GDA mandate area. A final iteration in the development of a third hierarchical layer in the network structure involves asking the expert panel to identify variables N1.1.1, N1.1.2, N1.2.1, N1.3.1, N1.3.2, and N1.3.3 that directly influence the primary variables N1.1, N1.2, and N1.3, respectively. Once this task has been achieved, the first step of defining the BBN structure is complete.

Figure 4. Conceptualization of a two-level BBN structure diagram developed around a selected priority issue (Node 1).



Collecting data for the conditional probability tables

Following the participatory development of the BBN structure, the next step is to collect data for the calculation of CPTs, where the initial prior probability of an event *A* may be updated by collecting appropriate information about its driver event *B*. Field data collection for a large set of observations is usually required to accomplish this second step to train the BBN model. For each observation, data may be limited to collecting information about the condition state (either desirable or undesirable) of the nodes defined in the BBN structure (Figure 4). If we consider the example mentioned in the previous section, then the survey should be conducted at the level of a set of GDAs, where information about the condition state of the second and third layer nodes is gathered. Then, the collected data should be mapped into the developed

[7] Which can also be defined as a representation of nodes/linkages, as described in Figure 4.
[8] GDA: Groupement de Développement Agricoles; similar to farmers' associations (or also Community-Based Organizations).

BBN structure and computer software may be used to calculate CPTs to define the probability weight of each node on the outcome (Node 1). CPTs may also be used for the third and final steps to simulate different framework options and scenarios using sensitivity analyses. A prior probability in a specific context for given factors is fixed during scenario simulation in the BBN to identify other factors that may enhance the probability of good rangeland governance.

Section 3. Multi-stakeholder focus groups for BBN design and data collection on rangeland governance: an illustration from a case study in Southern Tunisia

3.1 Introduction

While some researchers use available literature to predefine a Bayesian Belief Network (BBN) structure, others prefer to consult stakeholders to develop a wider and more comprehensive understanding of the causal linkages in the studied outcome events. In our case study, we preferred to benefit from local knowledge and expertise, so we organized a multi-stakeholder workshop to co-design our Bayesian (causality) network. The objective of the workshop was twofold: (1) to co-define an appropriate and relevant research question in relation to rangeland governance; and (2) to use the research question to develop a network and node structure with the help of local partners and experts through focus group discussions. The workshop was attended by 28 participants in total. These included 19 participants from different professional backgrounds from the region of Tataouine, and nine participants representing support structures such as research institutions (IRA, ICARDA) and donors (International Fund for Agricultural Development [IFAD]). Participants at the workshop represented 10 institutions and rangeland end users and manager groups (Table 1). The region of Tataouine is dominated by pastoral and agro-pastoral production systems with high degrees of livestock activity and traditional pastoral mobility. Rangelands in the area are directly managed by farmer associations known as Groupements de Développement Agricole (GDAs) that decide the day-to-day management of biomass resources. The region is also characterized by the existence of collective land tenure systems, where rangelands tend to be communal or tribal property. Land Management Councils (LMCs), comprising land owner representatives, are established by local communities to coordinate access to rangelands with the GDA, based on customary laws and agreements.

The workshop was conducted on 3 and 4 October 2017 in Tataouine, Tunisia. The BBN was developed through focus group discussion, and following presentation of the context, objective, and expected outcome from the project, along with the methodological framework to assess determinants of good rangeland governance, stakeholders were provided with a simplified framework to develop the BBN structure, and the rules that underpin BBN discretization of its node variables. The purpose of the discussion was to gain responses from participants on five questions:

1. A general introductory discussion on context analysis, focusing on the most important advantages and weaknesses of rangelands in Southern Tunisia.
2. The definition of good rangeland governance.
3. The four most important indicators of good rangeland governance in the participant's region.
4. As a focus statement, workshop participants were asked to identify primary variables that directly influence local capacity to have good rangeland governance in their region. Consequently, the attendees provided a set of primary variables, from which they selected the three most important for inclusion in the BBN structure by scoring from 0 to 10 according to the level of influence[9]. The first level of causality in the diagram was then developed using this process.
5. A follow-up focus statement, which emphasized direct causality, was posed to the workshop stakeholders to elicit additional hierarchical layers in the BBN (Richards et al. 2013), where participants in each focus group were asked to identify the variables that directly influence the selection of the primary variables that had been listed in the previous question (question 4, above). This question applied to the four most significant primary-level variables in the first BBN layer.

Questions 3 and 4 discretize the level of the outcome event in our case study, which was defined as good governance of rangeland (see Table 2), while questions 3 and 4 identified the set of relevant primary and secondary-layer variables that affect rangeland governance. Results of these discussions, in addition to the BBNs created for the study area in Tataouine, are presented in the following sections.

Table 1. List of participants in the BBN design workshop.

Professional background	Tataouine	Others
GDA, including farmers and managers	7	-
LMC	2	-
UTAP (Farmers Union) representatives	3	-
Staff from local and regional agricultural administrations	7	-
Research (Institut des Régions Arides de Médenine)	-	6
Research (ICARDA)	-	2
Donors (IFAD)	-	1
Sub total	19	9
Total	**28**	

GDA = Groupement de Développement Agricole; LMC = Land Management Council; ICARDA = International Center for Agricultural Research in the Dry Areas; IFAD = International Fund for Agricultural Development

[9] Results of this scoring is not presented here, but was used in the refinement of the final BBN structure used for the remainder of the study.

3.2 Outcome event: good governance of rangelands

Here, the aim of modeling the outcome event (or priority issue) using the BBN approach is to estimate the probability of good local rangeland governance in a given community area. However, such an outcome event is difficult to confirm by surveyed rangeland users, because of its subjective nature. For this reason, we preferred to ask rangeland users about indicators of good governance and use these to deduce the state of good governance. According to the BBN approach (McCann et al 2006; Richards et al. 2013; Drees and Liehr 2015), the outcome event and its primary and secondary-level determinant variables need to be easily discretized by assigning different states to each, where the states should be consistent, comprehensive, and mutually exclusive.

A predefined discretization of the good governance event based on the responses (indicators) of the focus group participants is shown in Table 2. It is important to note that only easily discretized indicators of good governance have been considered as proxies for this governance classification, and some of the redundant indicators mentioned by participants have been merged to create the final and accurate list.

3.3 BBN structures

The most important primary factors suggested by participants as affecting local governance structure in the study area are shown in dark orange boxes in Figure 5. Importance scores for these factors are presented above each box, and secondary variables are shown by category in different colored boxes (yellow, green, blue, and light orange). It was clear from discussions that rangeland governance in Tataouine is primarily affected by land ownership status, existence and level of local infrastructure, and performance of local GDAs responsible for rangeland management.

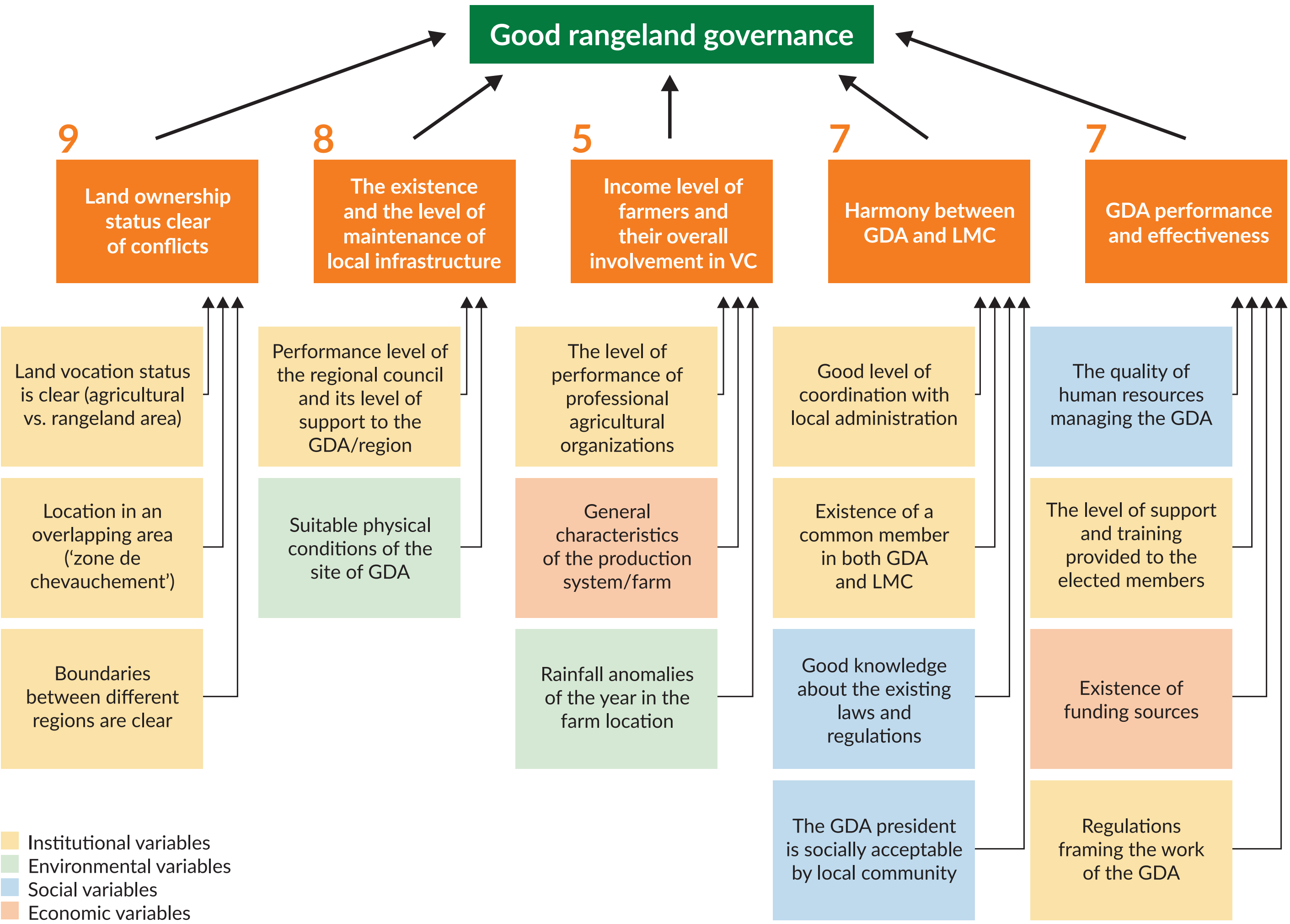
The BBN of Tataouine shows that land tenure system is a major determinant of good governance of rangelands in the area. According to the participants, rangelands in overlapping tenure areas, with no clear boundaries between different group ownerships, may be adversely affected and have weak levels of governance. Another land status issue relates to the official declaration of land as agricultural or rangeland; status of rangeland is easier to clarify, because it falls under the responsibility of local government agencies. Figure 5 shows that institutional factors (in yellow boxes) tend to be cited as drivers of good governance in the Tataouine region.

Table 2. Indicators used to discretize different governance levels.

Indicators	Good Governance	Acceptable Governance	Weak Governance
Case study of Tataouine			
Local population satisfaction about the GDA management of community rangeland	If all indicators are highly ranked	If at least one of these indicators is not highly ranked	If more than one indicator is not highly ranked
Perception about the state of biomass dynamics and existence of successful rangeland restoration programs			
Perception about the existence and quality of appropriate grazing infrastructure–water points, rest shelters, etc.			
Perception about decision-making coherence between GDA and LMC* administrator groups			

GDA = Groupement de Développement Agricole; LMC = Land Management Council

Figure 5. BBN structure for Tataouine drawn from focus group discussions.



VC = Value chain; GDA = Groupement de Développement Agricole; LMC = Land Management Council

3.4 Survey and data collection process

Following the workshop, we fine-tuned the established networks in a desk study, where we eliminated and/or reformulated the list of primary and secondary variables so they were easily integrated into a questionnaire and clearly discretized (Annex 1), with care taken to ensure the initial idea and rationale of stakeholders were not lost. We designed a short and clear questionnaire based on the final list of variables (Annex 1) to allow the collection of empirical data from local rangeland users in the region. With the exception of a brief section about structural characteristics of the surveyed farms, the remainder of the questions were closed and focused directly on asking for specific states of primary and secondary variables. In May 2017, we surveyed a stratified sample of about 60 rangeland pastoralists from a range of land tenure systems in the region.

Section 4. Empirical results

4.1 Model structure and resulting conditional probabilities

Building, training, and applying the Bayesian Belief Network (BBN) were carried out using NETICA software (Norsys 2017). The first output from the BBN approach is a trained network comprising the complete dataset, using the entropy maximization algorithm. At this point, underlying conditional probability tables were completed and relations among the primary and secondary variables and the outcome event were identified (Figure 6). The complexity and importance of many interacting variables for defining final rangeland governance patterns are clearly illustrated in the estimated BBN (Figure 6), where histograms illustrate the probability of the defined states of a given variable. For example, good rangeland governance perceptions were uncommon in Tataouine (only a probability of 18.9%) and there was a high probability of weak governance (about 40%). Grazing on combined collective and private ownership was the most likely type of land ownership system in the region (about 68%), and the probability of a moderate or poor performance Groupement de Développement Agricole (GDA) was about 92.3%.

Sensitivity analyses generated entropy reduction values for the primary and secondary variables (Figure 7) that indicate their weight and influence on the probability of the target or query node (governance). Entropy reduction values express how a change in the probability of a state of a given node or variable would impact the probability of the target variable (governance). The performance of the local farmers' association (GDA) and its good relationship with the Land Management Council (LMC) were the greatest influence on the state of rangeland governance; land tenure and investment in infrastructure were also highly important.

Once trained, BBNs may simulate simple scenarios that are then used to inform and improve desired states of governance. The posterior and prior probabilities of the outcome event after changing the state of a given node were estimated: the percentage change in estimated probability of having different states of governance depending on prior conditions of land tenure and GDA Performance is shown in Table 3, where the three upper rows show the change in probability of rangeland governance under different GDA Performance levels (good/medium/weak), and shaded rows show changes in probability of states of governance under different land tenure regimes.

Figure 6. BBN for assessment of rangeland governance in Tataouine.

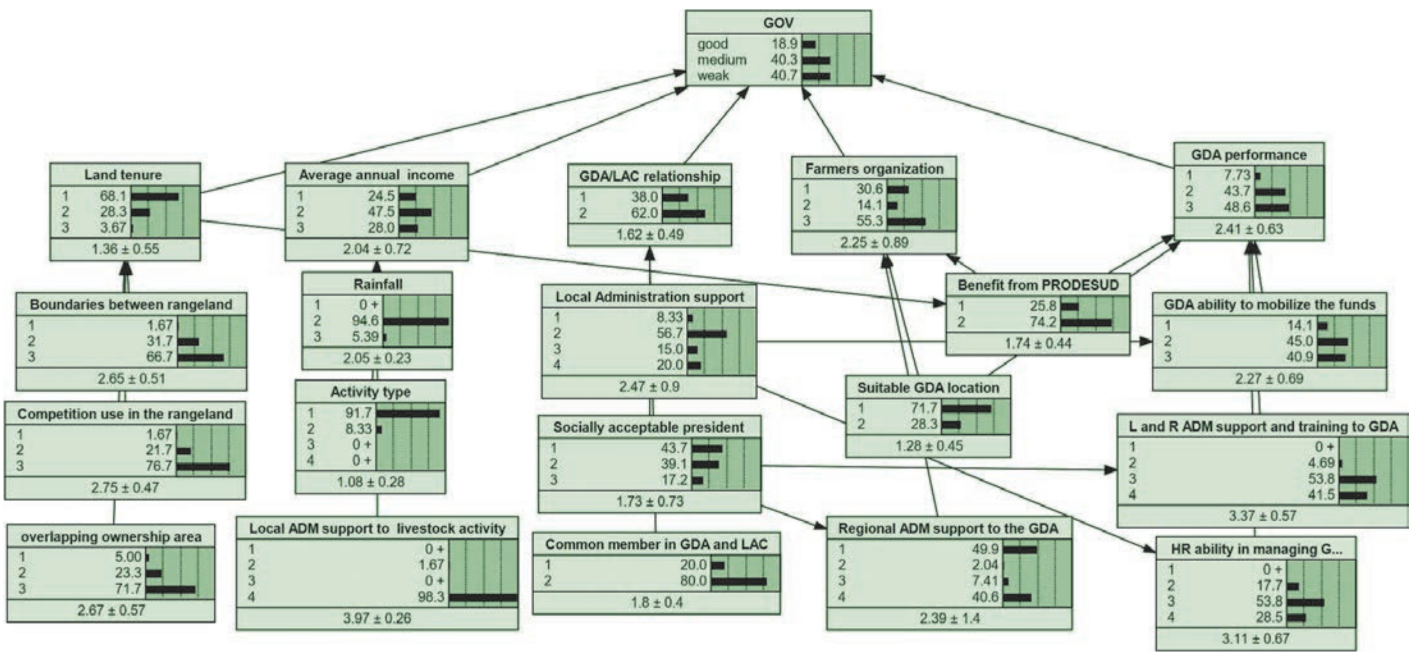
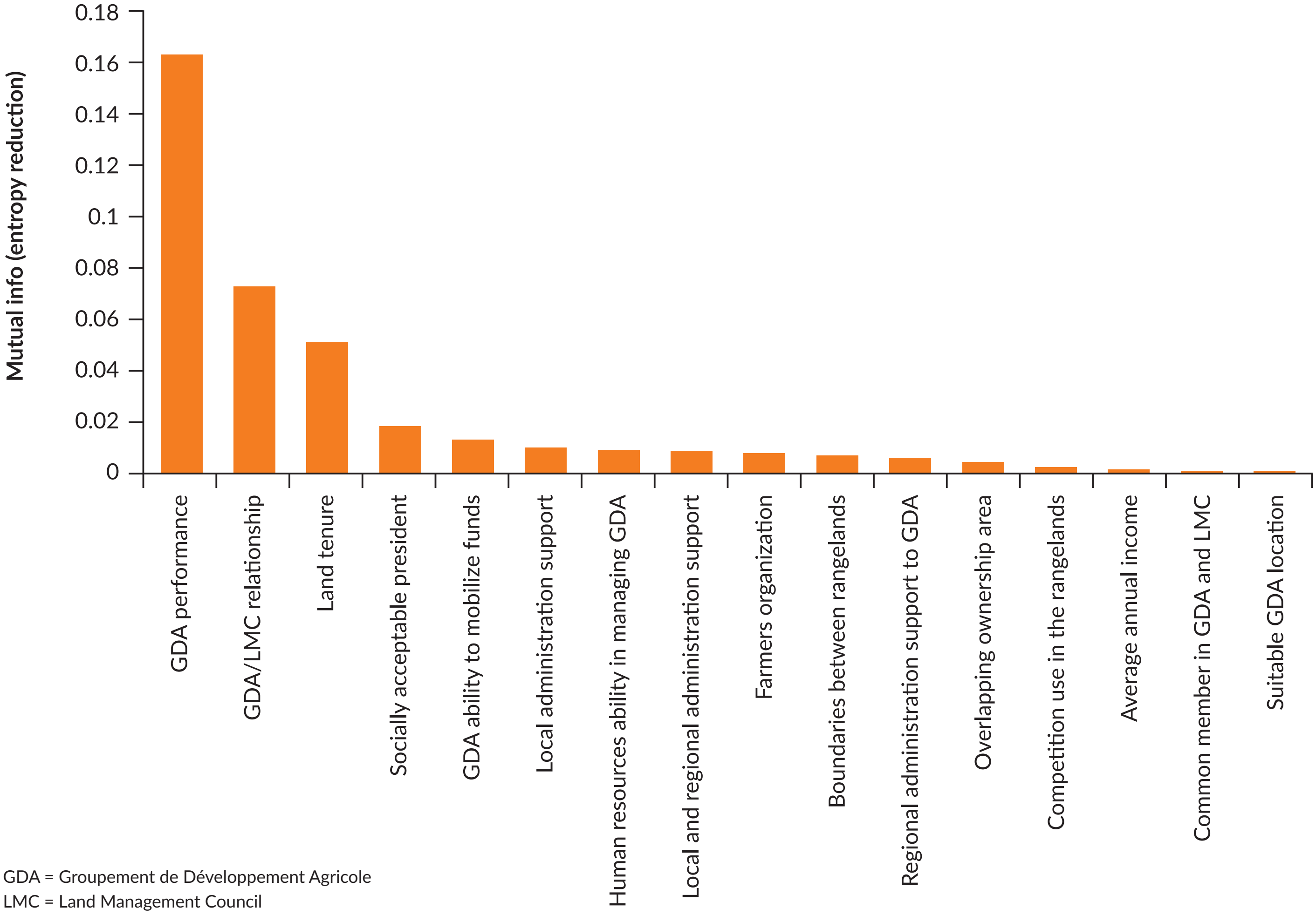


Figure 7. Sensitivity analysis showing the weight of different causality nodes affecting the state of rangeland governance in Tataouine.



GDA = Groupement de Développement Agricole
LMC = Land Management Council

4.2 Using Bayesian Belief Networks as an analytical and diagnostic tool

BBN may be used to analyze prior conditions of having good rangeland governance. In the example below, we defined probabilities for pre-existing conditions on the two nodes that represent “GDA performance” and “land tenure system”. For the land tenure scenarios, we predefined that 100% of the surveyed farmers are operating under collective land tenure regimes (P (Governance/Collective) = 100%), and then we tested for changes in the probability of having good rangeland governance, given this pre-existing condition, using:

Change of governance state = Posterior probability – Prior probability

As a result, the probability of having good governance increased in communities where the GDA is highly performing, while combined collective and private land ownership[10] status was the least favorable to good governance, because the probability of having good rangeland governance decreased under this condition (Table 3).

[10] These are farmers who are grazing on both private lands and collective communal rangelands.

Table 3. Percentage change in conditional probability of the state of governance under single prior conditions of land tenure system and GDA performance.

Indicators	P (Good Governance)	P (Medium Governance)	P (Weak Governance)
P (Governance/GDA Performance)			
P (Governance/Good GDA Performance)	109.8	50.8	-62.8
P (Governance/Medium GDA Performance)	-28.7	29.8	-21.9
P (Governance/Weak GDA Performance)	-19.7	-57.5	54.9
P (Governance/Land Tenure)			
P (Governance/Collective + Private)	-32.2	98.9	52.4
P (Governance/Collective)	12.2	-39.1	-4.3
P (Governance/Private)	1.8	-3.1	-19.7

GDA = Groupement de Développement Agricole

Overall, the application of the BBN in this case study showed that rangeland governance was relatively problematic in the Tataouine region of Tunisia, because the probability of having weak governance was about 40%, and we found that GDA performances in addition to the type of relationship between land owners (LMC) and land users (GDA) were among the highest determinants of rangeland governance. Land tenure was also among the five variables that had the greatest influence on the state of rangeland governance. Finally, it was shown that the BBN approach provides significant insights to the importance of causality relationships in complex socio-ecological systems, with minimum availability of data.

4.3 Feedback and results validation with stakeholders

Participation was a key element of this study on local rangeland governance. At the end of our analysis, we were also able to share our results with local stakeholders for validation and discussion. This latest step is beneficial for several reasons including the establishment of enhanced trust and partnership, increased involvement and contributions, better awareness and information of stakeholders, and inclusion of results in decision-making processes for potential ownership (Fraser et al. 2006; Lichty et al. 2014). The feedback mechanism is also beneficial to scientists since it will enrich their understanding of the obtained results and allow fine tuning of research questions and hypotheses. In our final workshop, which was organized on 21 June 2018 in Douz, Tunisia, we were able to invite local stakeholders not only from the Tataouine region but also from other neighboring governorates such as Kebili and Médenine, both located in Southern Tunisia. Our objectives were twofold, firstly to present and discuss results with local partners and actors and secondly to inform other actors who might be interested in up-scaling successful practices at regional and national levels.

The most important feedbacks we got from local stakeholders were related to the importance of the participatory approach for an effective understanding of good governance and sustainable rangeland management. They insisted on the need to assess the role of the GDA and conduct a careful analysis of its deficiency, weakness and strengths (in terms of financial resources, transport, human resources). Local actors also emphasized and agreed about the need for effective and smooth coordination between the GDA and the management councils and the coordination between the state and the end users. We were able to present and discuss with the participants three scenarios related to the status of governance in relation to land tenure, the performance of the GDA and the level of income in Tataouine Governorate. The participants endorsed the obtained results and provided further arguments to support them. Other obtained results from simulations were used to demonstrate to farmers and GDAs that they can do better in terms of governance even if their land tenure systems are constraining.

Conclusions and perspectives

Bayesian Belief Network (BBN) is an integrated modeling method and holistic approach with broad applicability due to its high flexibility of use of underlying data; it is easy, quick to use, and recognized as an established analytical approach for broad ranges of logical research questions. Although BBN structures should be based on theory, they are not data intensive, because only discrete variables are used and uncertainty is managed. Overall, this approach offers an opportunity to characterize complex causalities and attribute realistic weights to specified causal linkages, as is relevant for the study of natural resource governance.

One of the weaknesses of the BBN is the need to discretize continuous variables: this reduces the content and quality of information. Direct integration of feedback loops is not possible, due to the structure of parent nodes that affects the conditional probabilities of their respective child nodes (Drees and Liehr 2015), and the scope of the BBN structure lacks explicit temporal and spatial representations of the results, which forces the construction of separate networks for individual periods and regions, thereby dramatically reducing the data bias (Uusitalo 2007).

For this reason, the tendency is to deploy the BBN's capability of using real data for structural learning by letting the data determine how unbiased the results are not just with respect to the probability distributions of the variables but also with regards to the structure of the BBN itself (Yoon 2003). This is currently a future promising research area in this field.

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Annex 1. List of primary and secondary variables used in the Bayesian Belief Network implemented in our case study in Tataouine

Type of Variable	Variables	Index Variable in NETICA Software (Figure 6)	States: Indication	Description
Indicators related to Governance	Governance	GOV	Good Medium Weak	Good governance should have a clear official vocation, the farmer is satisfied about the LMC and GDA
Primary variable	GDA/LMC relationship	V010	1: Yes 2: No	Is the GDA receiving enough support from the local administration?
Secondary variables related to GDA/LMC relationship	Common member in GDA and LMC	V021	1: Yes 2: No	A member of the GDA who is also part of the LMC
	GDA president sociability	V022	1: Yes 2: Partly 3: No	The GDA president is socially acceptable by the local community
	Local administration support to the GDA	V020	1: Very good 2: Fair enough 3: Medium 4: Weak	Level of support of local administrations to your GDA
Primary variable	Land tenure	V004	1: Collective and Private 2: Collective 3: Private	The different forms of land ownership
Secondary variables related to land tenure	Competition in rangeland using	V011	1: Yes 2: Partly 3: No	Is there a competition from agriculture, urbanism or other sectors in the rangeland area where you are grazing?
	Overlapping ownership area	V012	1: Yes 2: Partly 3: No	The rangeland you are using located in an overlapping ownership area
	Existence of boundaries between the rangeland	V013	1: Yes 2: Partly 3: No there is conflict about it	The boundaries between the rangeland of your community and those of other communities completely clear

Type of Variable	Variables	Index Variable in NETICA Software (Figure 6)	States: Indication	Description
Primary variable	Farmer's income	V005	1: Less than 5,000 DT 2: 5,000 to 10,000 DT 3: > 10,000 DT	The average annual income
Secondary variables related to farmer's income	Local administration support to the livestock activity	V017	1: Very good 2: Fair enough 3: Medium 4: Weak	The level of support (providing feeds [mainly barley] during the critical period, veterinary services, etc.) of the regional and local administration to the livestock activity
	Farmer activity	V018	1: Agro-pastoral 2: Pastoral 3: Pastoral-fattening 4: Fattening	The type of your activity
	Rainfall	V019	1: Very good 2: Average 3: Lacking	Describe the rainfall during the previous five years
Primary variable	Farmers' organization	V006	1: Very good 2: Medium 3: Weak	The capacity of farmers to organize
Secondary variables related to farmers' organization	Regional administration support to the GDA	V015	1: Very good 2: Fair enough 3: Medium 4: Weak	The level of support from regional administration to the GDA
	GDA location	V016	1: Yes 2: No	The GDA has a suitable (distance, road, infrastructure) from the farmer rangeland
Primary variable	GDA performance	V007	1: Highly performant 2: Performant 3: Weak	How performant is the GDA to which you belong in managing rangeland and controlling overgrazing?

Type of Variable	Variables	Index Variable in NETICA Software (Figure 6)	States: Indication	Description
Secondary variables related to GDA performance	Beneficiary from PRODESUD	V014	1: Yes 2: No	The farmer is benefiting from PRODESUD project or not
	Management capacity of GDA human resources	V023	1: Very good 2: Fair enough 3: Medium 4: Weak	The quality of human resources managing your GDA
	The level of support and training provided to the GDA members	V024	1: Very good 2: Fair enough 3: Medium 4: Weak	The level of support and training provided to the GDA by the local and regional agricultural administrations
	GDA ability to mobilize funds	V025	1: Good 2: Not bad 3: Weak	The capacity of GDA in mobilizing funds for achieving the development objectives of the community (Rangeland management, Infrastructure, etc.)

GDA = Groupement de Développement Agricole; LMC = Land Management Council; PRODESUD = Programme de développement agro-pastoral et de promotion des initiatives locales pour le sud-est

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