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Introduction to Multi-Criteria Analysis

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Learning goal and outline

LEARNING GOAL

- To understand the rationale, processes and practices of Multi-Criteria Analysis (MCA)

OUTLINE

- What is MCA?
- What are the steps of MCA and its decision models?
- How is MCA applied in environmental research?
- Strengths and weaknesses of MCA
- Reflections (brief exercise)

What is MCA?

- Human beings (and thus decision makers!) struggle to deal with complex problems involving **multiple assessment criteria**
- MCA provides a **structured method for making decisions** between a number of competing alternatives
- It considers multiple criteria
- Overcoming **limitations of conventional "monetary" valuation**: difficult to monetise "non-use" values
  - MCA allows **to integrate monetary-based techniques with non-monetary valuation** (e.g. comparing "pears" – $ values – with "apples" – qualitative ranking)
- Does not search for the "optimal" solution, but for the best "compromise" solution

General Properties of MCA

- Helps with large amounts of complex data
- Establishes **preferences between alternatives** by reference to an explicit set of **objectives** that decision makers have identified, and for which they have established measurable **criteria**
- Techniques may be used to:
  - **Identify** a single most-preferred alternative
  - **Rank** alternatives
  - **Short-list** a number of alternatives for further appraisal
  - **Distinguish** between acceptable and unacceptable alternatives
- Emphasis is on the judgement of decision makers (weighting)

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Impact Matrix for MCA of Road Building

Criteria

Alternatives

	Cost (£)	Forest lost (ha)	Effect on human health (deaths/year)
Straight through the nature reserve	25	1200	1
Through major cities	140	10	15
Avoiding both the nature reserve and cities	76	680	4

"Mixed-type" Data

- MCA is designed to deal with **information that cannot be easily converted to a single measurement unit** (e.g. $), and is therefore difficult to compare
- Can **include** very **different criteria** (e.g. economic, social, environmental, technical), which can be expressed in **quantitative** and **qualitative** terms
- This differentiates MCA from other methods, such as Cost-Benefit Analysis

Stakeholder Participation

- MCA enables the **inclusion of different stakeholders' views and interests**, which may embody conflicting priorities
- Helps to improve the **understanding** of a particular situation, including the perspectives of key players
- Increases the **transparency** and **quality** of decisions and helps **to avoid conflicts**

Applicability to Environmental Problems

- **Complex** and **multi-faceted**
  - Involves socioeconomic, ecological, and political issues
  - Entails a certain degree of **scientific and technical uncertainty**
- Demands the **inclusion** of stakeholders
- Often difficult to arrive at straightforward and unambiguous solutions
- MCA is a good tool for evaluating environmental problems and their solutions

Steps in a MCA

1. Establish the **decision context**
   - What are the aims of the MCA?
   - Who are the stakeholders?
2. Identify the **alternatives**
3. Identify the **criteria** and **objectives** for each
4. **Score** each alternative against the criteria (i.e. generate the performance/impact matrix)
5. Choose the **decision model**
   - MCA techniques are largely distinguished from one another by how they process the information in the performance matrix
6. Assign relative **weights** to each of the criteria
7. Combine the weights and scores for each of the alternatives to arrive at **rankings**
8. Perform a **sensitivity analysis**

Some Common Decision Models

- **Direct analysis**
  - Dominance occurs when one alternative performs as well as another on all criteria and better than the other on at least one criteria

- **Linear additive models**
  - Multiplies the value score on each criterion by the weight of that criterion, and adds all weighted scores together

- **Analytical Hierarchy Process (AHP)**
  - Uses procedures for deriving weights and scores by pairwise comparisons

- **Outranking methods**
  - One alternative outranks another if it outperforms the other on enough criteria of sufficient importance *and* does not record a low level of performance on any single criterion

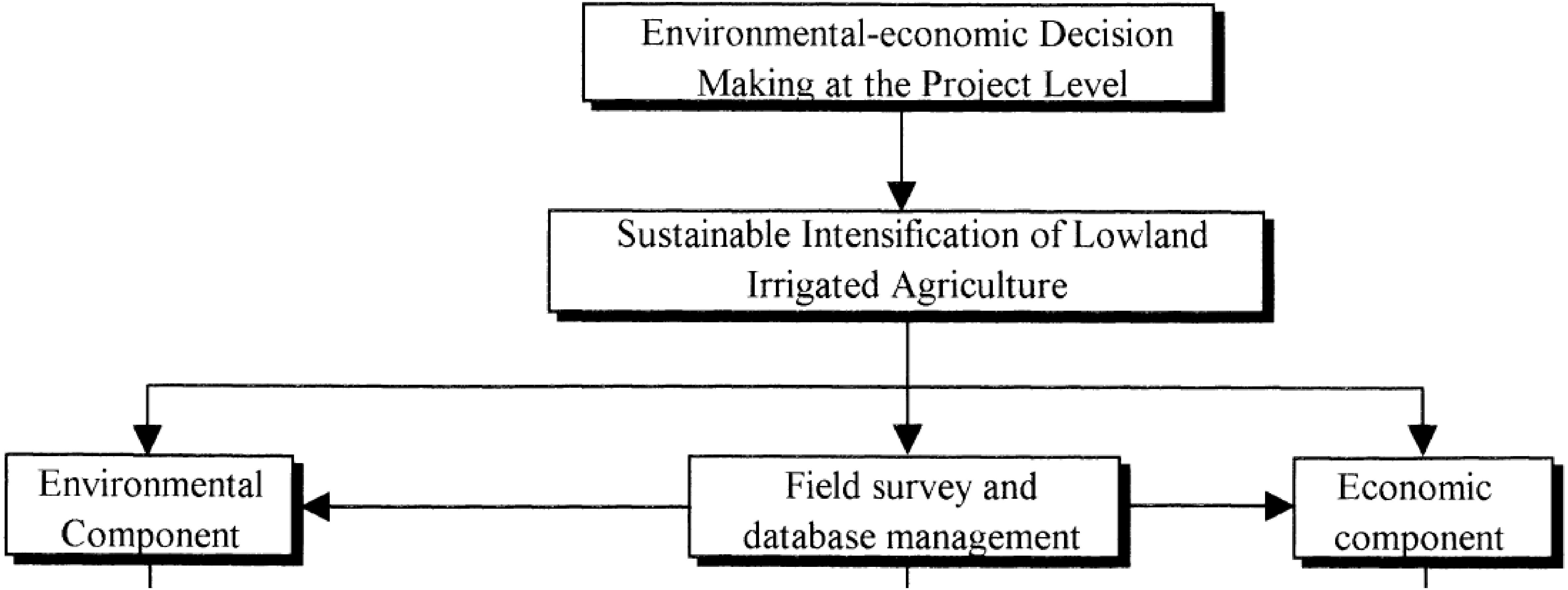
MCA in Action

- Tiwari et al. (1999) conducted a MCA for an agricultural cropping project in the Phitsanulok province of Thailand

- The local authorities wished to modify existing cropping patterns in order to optimise the use of the available productive land, while assuring the sustainability of the region

Tiwari et al. 1999. Environmental-economic decision-making in lowland irrigated agriculture using multi-criteria analysis techniques. Agricultural Systems 60(2), p. 99-112

MCA in Action (conceptual framework, Tiwari et al. (1999))



MCA in Action

- **Step 1: Establish the decision context**
  - **Aims**: Determine the best cropping pattern to optimise the use of the land while assuring regional sustainability
  - **Stakeholders**: Mainly farmers and local villagers

- **Step 2: Identification of alternatives**

Table. *Different alternatives for cropping patterns*

Source: Marco Sakai, based on Tiwari et al. (1999)

A1	Continuation of existing cropping patterns
A2	Priority for non-rice crops in highly suitable areas
A3	No cultivation in low-resource areas
A4	Rice cultivation in all areas
A5	Cropping patterns according to farmers' preferences

MCA in Action

- **Step 3: Identification of criteria and objectives**
  - Through a series of **participatory meetings** and **expert consultations**, a list of relevant criteria was agreed

Table. *Different criteria for evaluating alternatives*

Source: Marco Sakai, based on Tiwari et al. (1999)

Criterion	*Objective*	*Units*
Land capability	Maximise	Ha
Water requirement	Minimise	Millions of cubic metres
Energy output-input ratio	Maximise	Ratio
Environmental costs	Minimise	Monetary
Farmers' NPV	Maximise	Monetary
Societal NPV	Maximise	Monetary

MCA in Action

- **Step 4: Assess each alternative against each of the criteria (create the *performance matrix*)…**

Table. *Performance matrix* (Note: Numbers are fictitious and for purposes of illustration only)

	Land capability (ha)	Energy output-input ratio	Water requirement (million m³)	Environmental costs ($)	Farmers' NPV ($)	Societal NPV ($)
A1	27,190	4.8	271	21.47	66.85	-206.98
A2	33,775	5.7	209	9.98	345.63	382.57
A3	27,734	5.3	213	11.92	175.40	109.19
A4	34,765	4.8	355	28.68	166.19	-280.82
A5	34,757	5.6	239	10.89	684.89	607.14

Source: Marco Sakai, based on Tiwari et al. (1999)

MCA in Action

- **Step 4: (...continued) Score** each alternative against the criteria
  - HOMOGENEOUS MCA score

Source: N Favretto, based on Tiwari et al. (1999)

Table. *MCA score (min=0 ; max=100)*

Note: Numbers are fictitious and for purposes of illustration only

	Land capability	Energy output-input ratio	Water requirement	Environmental costs	Farmers' NPV	Societal NPV
A1	52	12	44	98	10	5
A2	90	81	59	76	21	46
A3	89	92	76	53	43	14
A4	42	48	88	42	72	2
A5	34	22	97	21	80	25

MCA in Action

- **Step 5: Choose the decision model**
  - CP and AHP (but let's pretend it's a linear additive model)

MCA in Action

- **Step 6: Assign relative weights to each of the criteria**
  - Two sets of weights were formulated.

Table. *Criteria weighting*

Source: Marco Sakai, based on Tiwari et al. (1999)

Note: Numbers are fictitious and for purposes of illustration only

Criterion	w1	w2
Land capability	10%	10%
Energy output-input ratio	10%	20%
Water requirement	**30%**	20%
Environmental costs	10%	**30%**
Farmers' NPV	**30%**	10%
Societal NPV	10%	10%
TOTAL	100%	100%

The first gave priority to **water savings and farmers' welfare** (w1), while the second prioritised **environmental issues** (w2)

MCA in Action

- **Step 7: Combine the weights and scores for each of the alternatives to arrive at rankings**

Figure 1*. Ranking of alternatives using w1 weightings*

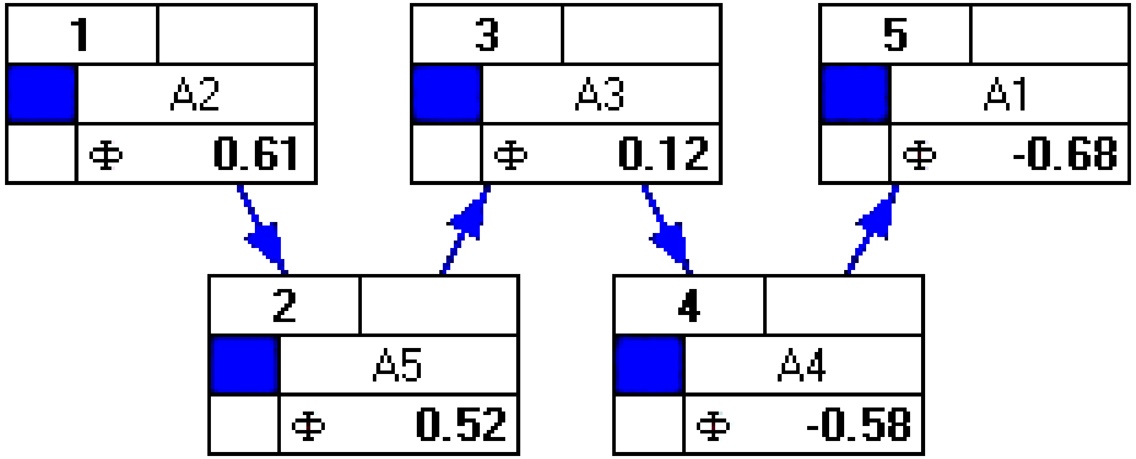
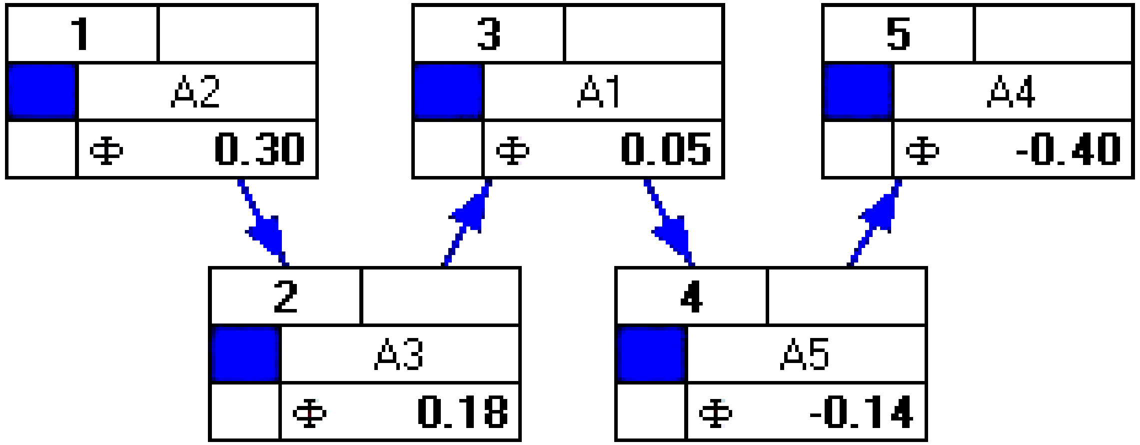


Figure 2*. Ranking of alternatives using w2 weightings*



Source: Marco Sakai, based on Tiwari et al. (1999)

Note: Numbers are fictitious and for purposes of illustration only

Sensitivity analysis

- Changing the values of the parameters: checking the indicators give the same results, e.g.
  - Double or halve the **weighting** of "one" or "multiple" criteria … *will the ranking change?*
  - Double (BLUE) or halve (RED) the **score** of "one" or "multiple" criteria

	Land capability	Energy output-input ratio	Water requirement	Environmental costs	Farmers' NPV	Societal NPV
A1	52	12	44	98	10	5
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ELD case study: use of MCA in Botswana’s Kalahari

- **Aim**: To assess the costs, benefits and trade-offs associated with different land uses and management strategies in rangeland systems
- Integration of policy and price data analysis with 12 ecological assessments (piosphere based sampling approach and satellite data), 37 semi-structured interviews, literature review & secondary data analysis, and benefit transfer method

*"Which **land uses and land management strategies** are best placed to **deliver specific ES** in Kalahari rangelands in Botswana's southern Kgalagadi district?"*

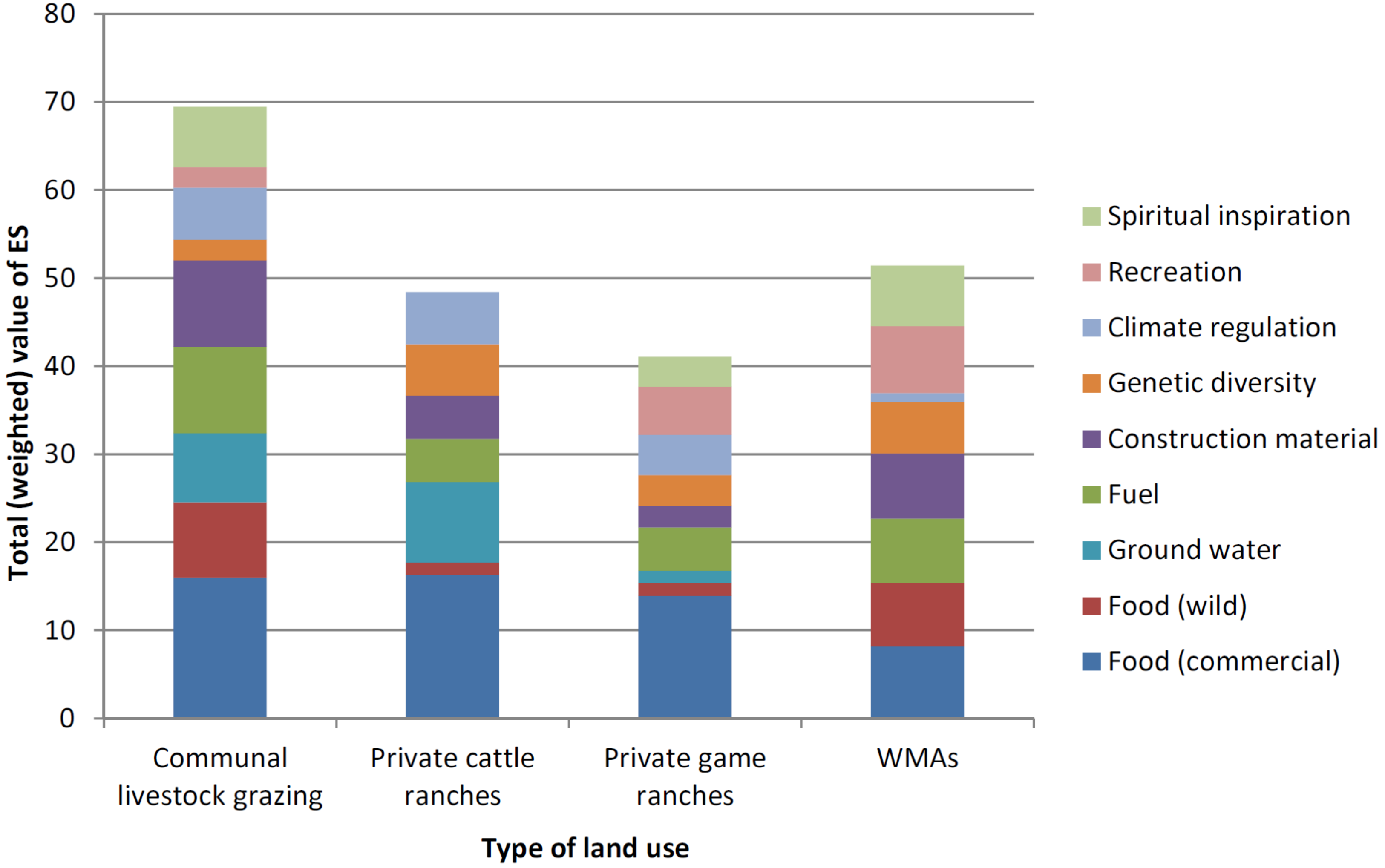
Criteria definition & assessment

Food (commercial)	• Net profit of meat production (US$/ha/yr) • Stocking level (Ha/Livestock Unit)
Food (wild)	• Gathering of veld products • Subsistence hunting
Fuel	• Firewood collection
Construction material	• Collection of thatching grass and poles for fencing
Ground water	• Value of water extracted (US$/ha/yr)
Genetic diversity	• Genetic diversity between forage species • Genetic diversity between livestock breeds
Climate regulation	• Value of carbon sequestration (US$/ha/yr)
Recreation	• Revenues from Community Based Natural Resource Managem trophy hunting & photographic safari (US$/ha/yr) • Ecotourism potential • Wild animal diversity
Spiritual inspiration	• Presence of landscape features or species with spiritual value

Criteria performance

Criterion	Indicator / ecosystem service category	Communal livestock grazing	Private cattle ranches	Private game ranches	Wildlife Management Areas	Valuation/collection methods used to inform the MCDA
	Provisioning					
Food (commercial)	Net profit of meat production (US$/ha/yr)	(-0.56 ; 1.95) Mean: 0.64	(0.66 ; 1.75) Mean: 1.21	(-7.89 ; 3.75) Mean: -2.07	0	Interviews & market prices
	Stocking level (Ha/LSU)	9-13 Mean: 11	8-20 Mean: 14	7-12 Mean: 9.5	120-200 Mean: 160	Interviews & literature
Food (wild)	Gathering of veld products	High	Low	Low	Medium	Interviews & literature
	Subsistence hunting	High	Very low	Very low	Very high	Interviews & literature
Fuel	Firewood collection	Very high	Medium	Medium	High	Interviews & literature
Construction material	Collection of thatching grass and poles for fencing	Very high	Medium	Low	High	Interviews & literature
Ground water	Value of water extracted (US$/ha/yr)	(0.63 ; 1.05) Mean: 0.84	(0.22 ; 1.71) Mean: 0.97	0.15	0	Interviews & market prices
Genetic diversity	Genetic diversity between forage species	Low	Medium	High	Very high	Ecological assessments
	Genetic diversity between livestock breeds	Low	High	Very low	Low	Interviews
	Regulating					
Climate regulation	Value of carbon sequestration (US$/ha/yr)	6.1	6.1	4.9	1.2	Benefit transfer & market prices
	Cultural					
Recreation	Revenues from CBNRM trophy hunting and photographic safari (US$/ha/yr)	0	0	0	0.04	Interviews & benefit transfer
	Ecotourism potential	Low	Very low	High	Very high	Interviews
	Wild animals diversity	Medium	Very low	Very high	Very high	Literature
Spiritual inspiration	Presence of landscape features or species with spiritual value	Very high	Very low	Medium	Very high	Interviews

Weighted performance of the four alternative land uses



Strengths of MCA

- Inclusion of a wide array of **heterogeneous data**, as well as alternatives and objectives
- Ability to include **mixed types of data** makes it a good approach to address complex issues
- Allows **broad participation**, and gives the opportunity for stakeholders to learn from the process
- A **flexible, open, consistent, and transparent** procedure that helps to legitimise decision-making activities
- Objectives and criteria are open to analysis and change (as are scores and weights)

Weaknesses of MCA

- Results are only as good as the data, weights, and scores used
- Implementation can be a time-consuming process, due to the **technical complexity** involved, especially in eliciting parameters
- Different decision models (or stakeholder groups) can lead to different outcomes
- **Inter-comparison** of case studies can be **difficult** due to methodological differences

Conclusions

- MCA helps to provide insight into the nature of complex problems
- Proven to be very useful when dealing with environmental issues
- Its usefulness explains why governments in several countries have increased attention to this method (e.g. the US currently requires it by law for issues such as water planning)
- Development of new methods and improvement of existing ones, along with the **potential to combine MCA with other techniques**, will strengthen its future application