Decision support for climate change adaptation under uncertainty

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Outline

1. Introduction
2. Decision support system PRIMATE
3. Empirical assessment
4. Conclusion

Background

- Initiatives for climate change adaptation not only on strategic level but also increasingly adaptation **projects implemented**
- Focus on **existing vulnerabilities** (heavy precipitation, heat)
- Decision makers look for effective and **efficient adaptation measures** to limit or take advantage of changing climate conditions
- Choice between alternative options involves consideration of **manifold criteria**, **uncertain data**, **diverging stakeholder interests**

Background (continued)

- Demand for easy-to-use decision support systems (DSS)
- Increasing number of handbooks, assessment manuals, DSSs
- Uncertainties rarely adequately considered by DSSs

➡ Evaluation **guideline** & decision support tool **PRIMATE** (interactive software for Probabilistic Multi-Attribute Evaluation)

Sequence of the Evaluation & Prioritisation Process

1st step

Preliminary Risk Assessment

Investigation of specific climate change related threat

2nd step

Identification of adaptation measures

if applicable bundling of measures

3rd step

Selection of evaluation method & criteria

if applicable weighting of criteria

4th step

Data collection

e.g. expert judgment, modelling, information transfer from similar projects

5th step

Evaluation & Prioritisation

e.g. Cost-benefit analysis, Multi-criteria analysis

if necessary improvement of data used

if necessary adaptation of the criteria used

Evaluation guideline

Left column
--> what to consider at various steps

Right column
--> exemplification by empirical example

Stufe 1: Identifikation der Betroffenheit

Eingrenzen der Problemlage

➔ Welcher Problemlage soll mit den Maßnahmen begegnet werden?
➔ Welche Schäden sind bereits aufgetreten oder werden im Zuge des Klimawandels erwartet?
➔ Welche Sektoren und Gebiete sind betroffen?

1.1 Möglichkeiten der Abschätzung von Betroffenheiten

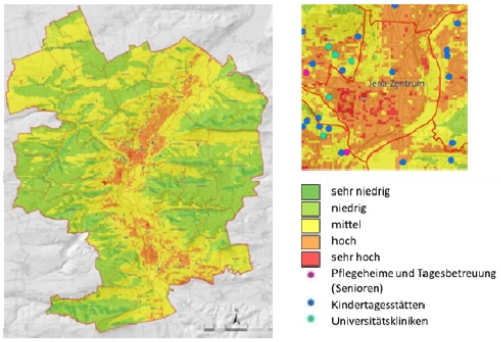
- Analyse vergangener Schadensereignisse, wie z.B. durch Auswertung der Einsatzprotokolle von Katastrophenschutz, Feuerwehr etc.
- Auswertung bestehender Risiko- und Vulnerabilitätsstudien
- Diskussion der möglichen Betroffenheit durch den Klimawandel mit Fachplanungen in Landkreis und Kommune: Stadtplanung, Bau, Verkehr, Katastrophenschutz, Gesundheit, Forst und Landwirtschaft

Fallbeispiel Stufe 1

FB Abschätzung der Betroffenheit

- Jena ist in den Sommermonaten, v.a. im Bereich der Stadtmitte, mit dem Problem der Überhitzung konfrontiert
- Geschützte Tallage und umliegende Kalksteinhänge befördern warmes Mikroklima
- Anstieg der Jahresmitteltemperatur um 1,2K in den letzten 100 Jahren
- Vorliegende Klimaprojektionen lassen weitere Verschärfung der thermischen Belastung erwarten
  - Verstärkter Temperaturanstieg projiziert
  - Zunahme der heißen Tage (T_{max} > 30°C) von 10-12 Tage/Jahr auf bis 19-20 Tage/Jahr bis 2050 (STAR, WETTREG2010)

Überhitzungsgefährdung Stadtgebiet Jena auf Basis von Versieglungsgrad, Baustruktur, Globalstrahlung, lokalen und regionalen Windsystemen



Quelle: ThINK (2011): JenKAS-Projekt.

Multi-Criteria Matrix

	C_1	C_2	C_3	C_n
A_1				
A_2				
A_m				

Multi-criteria method: PROMETHEE II

Multi-criteria method: PROMETHEE II

Multi-Criteria Matrix

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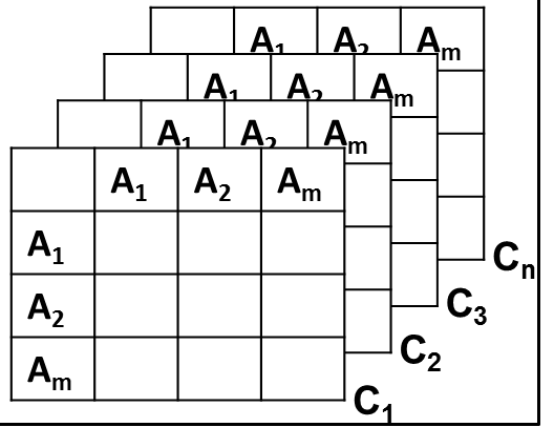
Pairwise comparison of all alternatives for each criterion

Criteria Matrices



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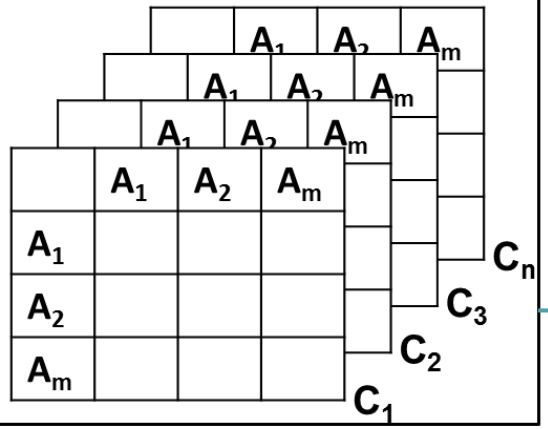
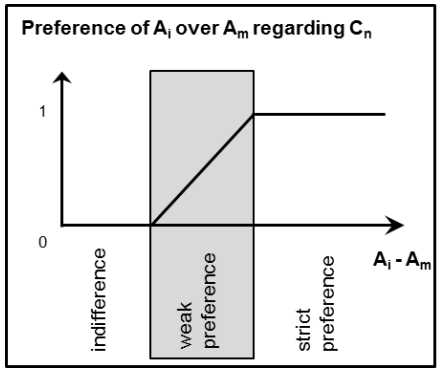
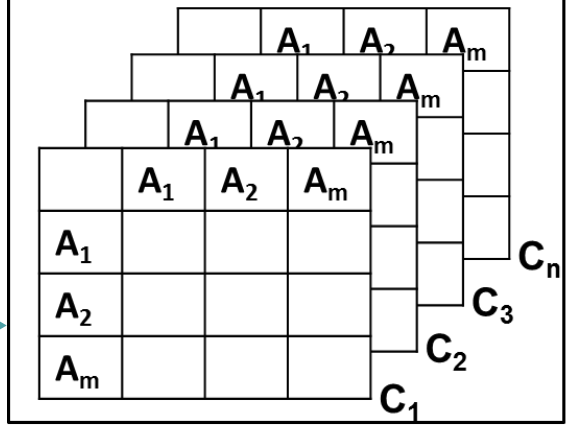




Transformation of differences in criteria values into preference values

Partial Preference Matrices



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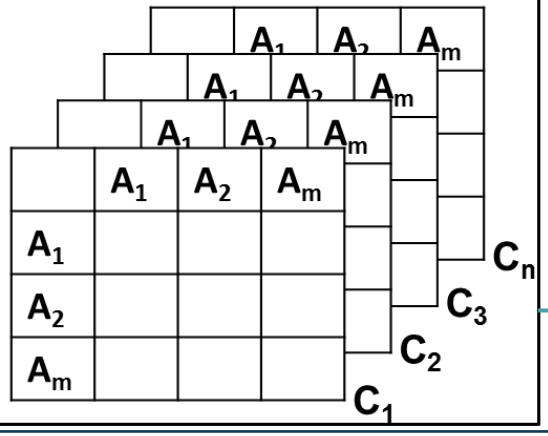

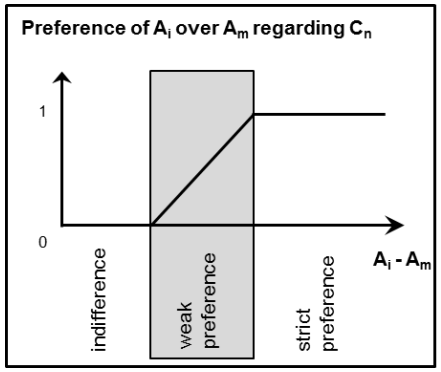

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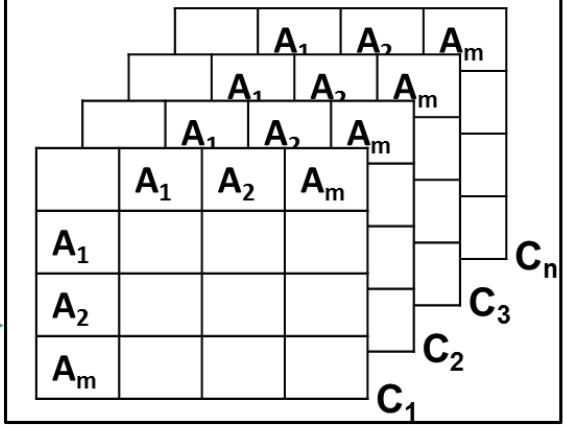

Weighted aggregation

Total Preference Matrix

	A_1	A_2	A_m	Φ^+
A_1				
A_2				
A_m				
Φ^-				

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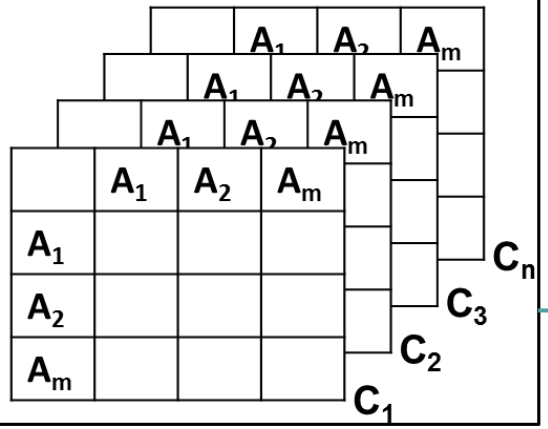

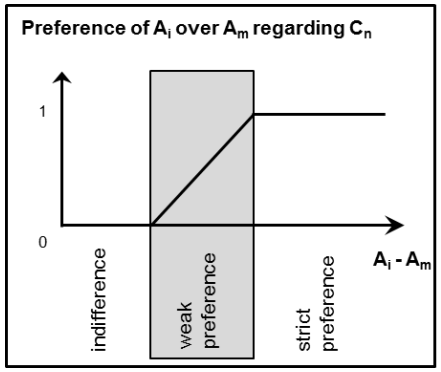

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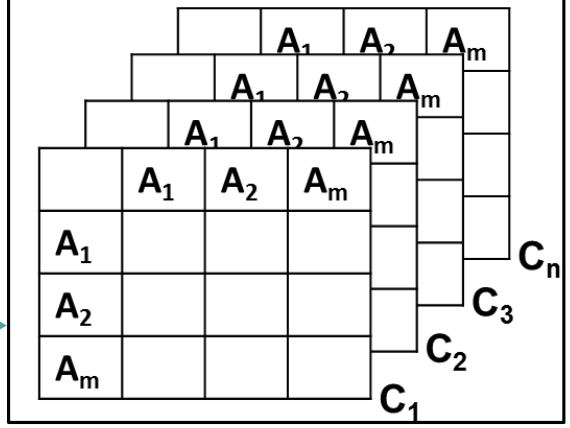

Weighted aggregation

Total Preference Matrix

	A_1	A_2	A_m	Φ^+
A_1				
A_2				
A_m				
Φ^-				

Positive votes

Negative votes

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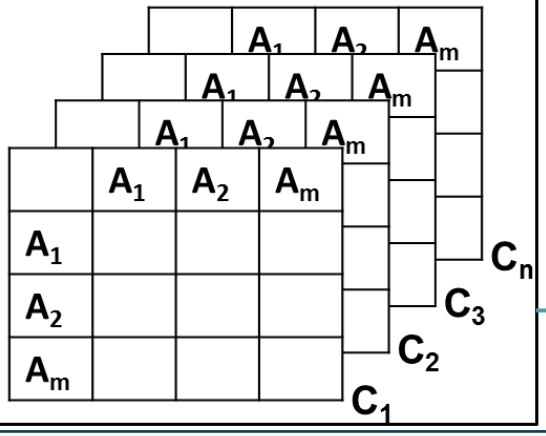
A_m				

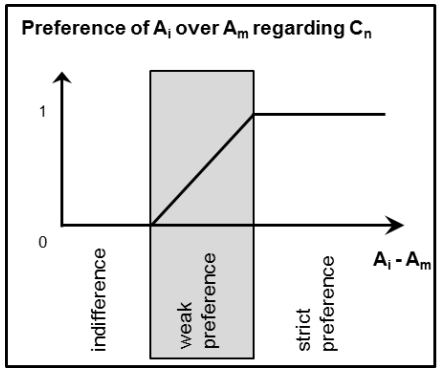
Pairwise comparison of all alternatives for each criterion

Criteria Matrices



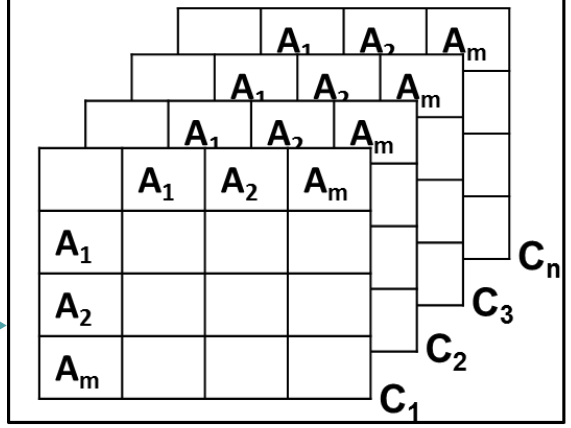
Transformation of differences in criteria values into preference values

Preference of A_i over A_m regarding C_n



Complete ranking based on net votes

Partial Preference Matrices



Weighted aggregation

Total Preference Matrix

	A_1	A_2	A_m	Φ^+
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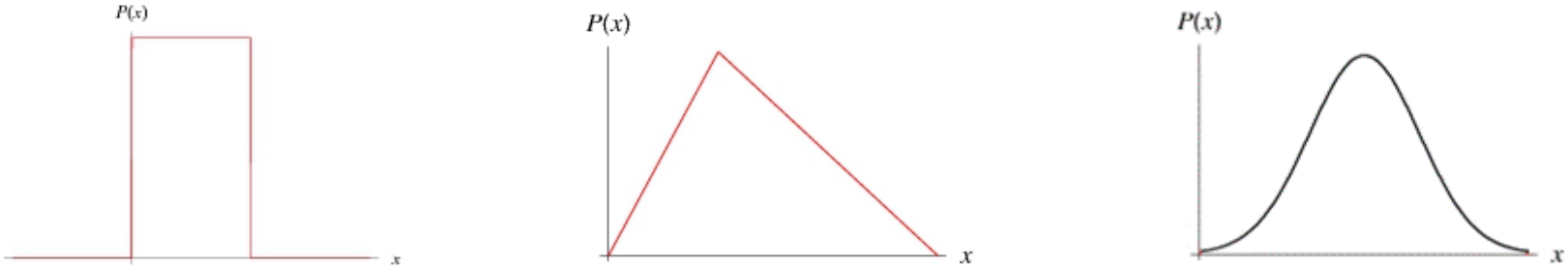
Positive votes

Negative votes

Uncertainty: Data input



uniform distribution – triangular distribution – any probab. distribution

Uncertainty regarding the alternatives‘ performance for specific criteria is accounted for probabilistically

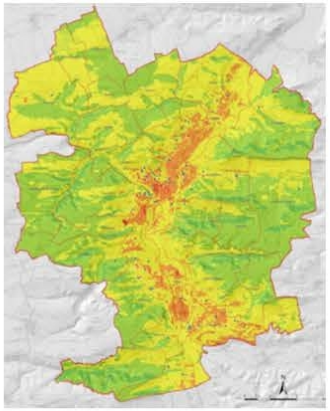
- By **including uncertainty in the preference function**
- By **using Monte-Carlo simulation**

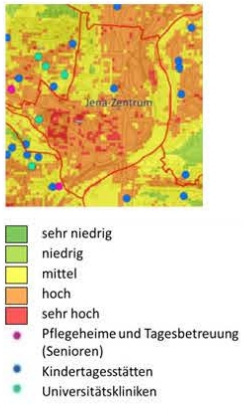
- Results of all evaluations are statistically analysed & documented.

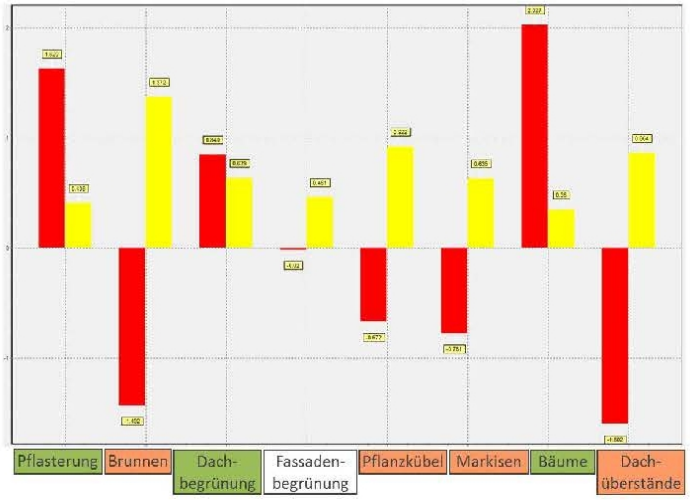
Uncertainty: Stakeholder Preferences

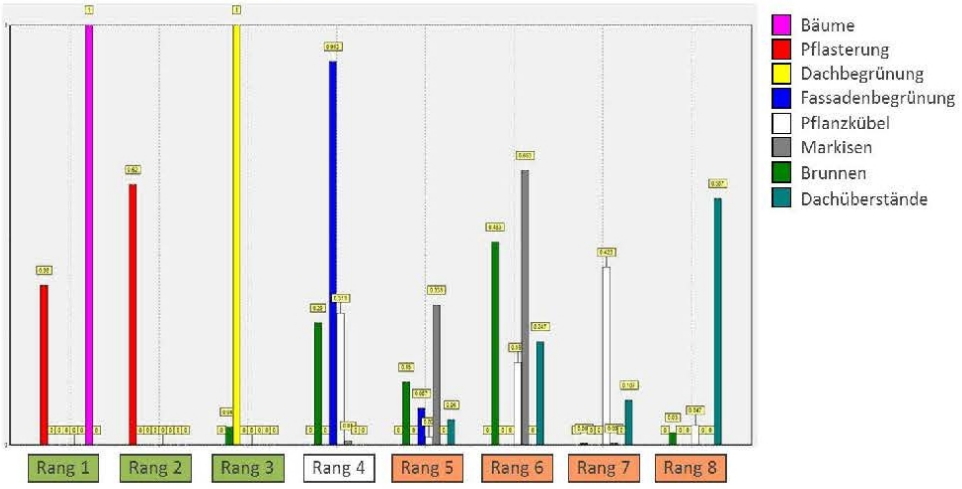
- **Global weighting**: random sampling of weights
- **Ordinal weighting**: random sampling of weights compatible with rank order specified by one decision maker/stakeholder.
- **Cardinal weighting**: assignment of precise numerical weights to criteria and criteria groups for every decision maker/stakeholder.
  - Varying preferences of different decision makers/stakeholders for each criterion (= weights) are considered simultaneously.
- Results of all evaluations are statistically analysed & documented.

Selected case studies: Heat stress reduction

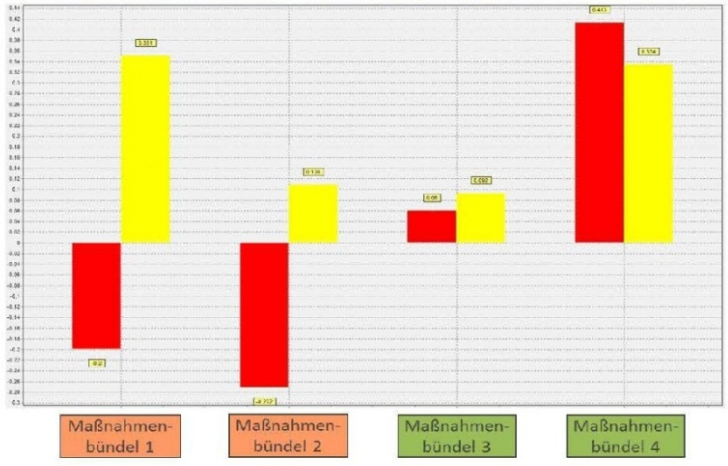


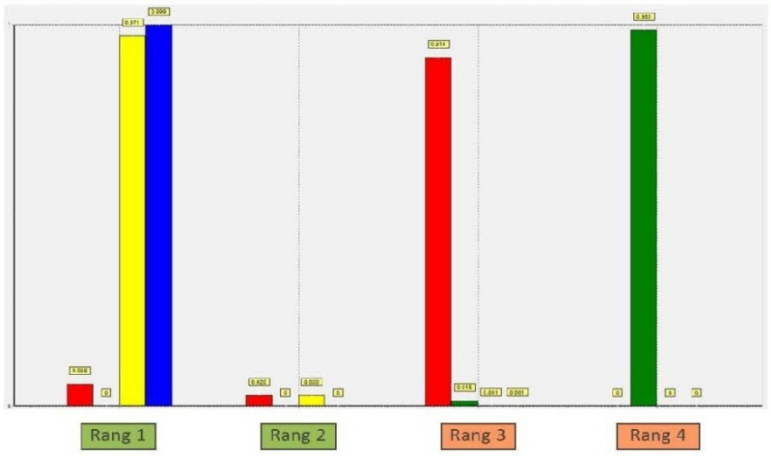






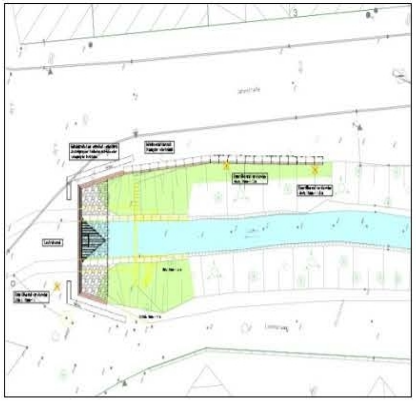
Selected case studies: Private flood protection

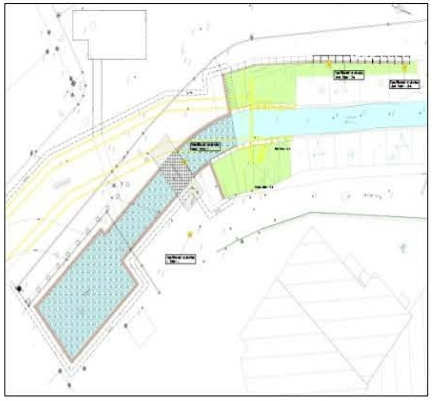


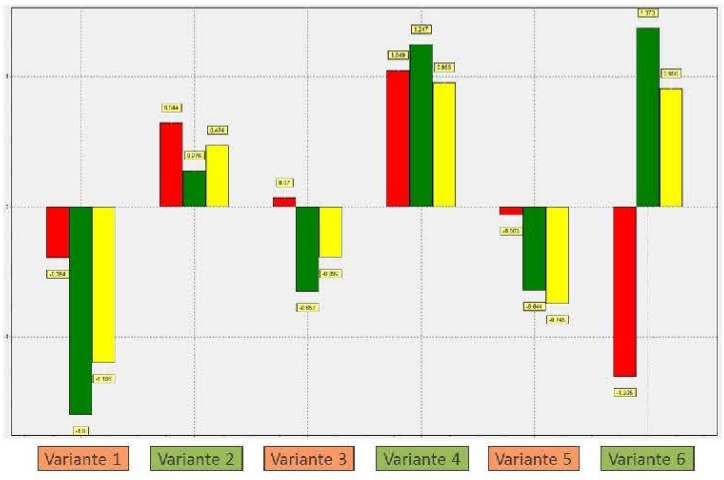


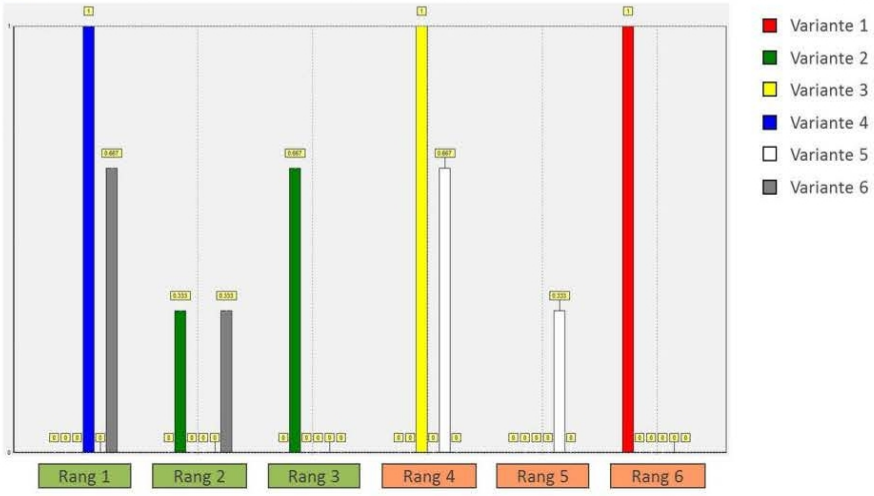
Maßnahmenündel 1
Maßnahmenündel 2
Maßnahmenündel 3
Maßnahmenündel 4

Selected case studies: Urban flood protection



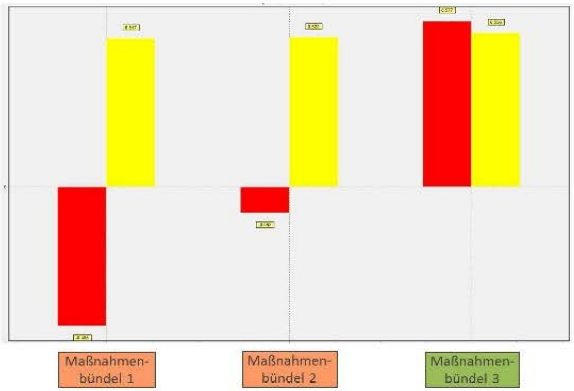


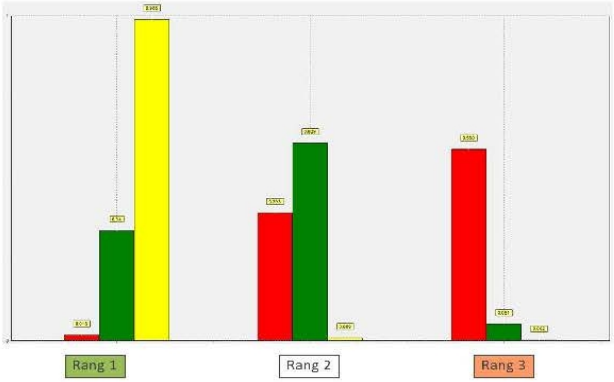


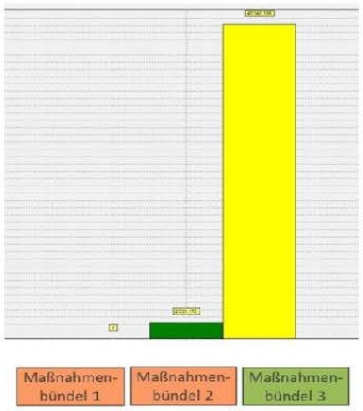


Selected case studies: Rainwater management

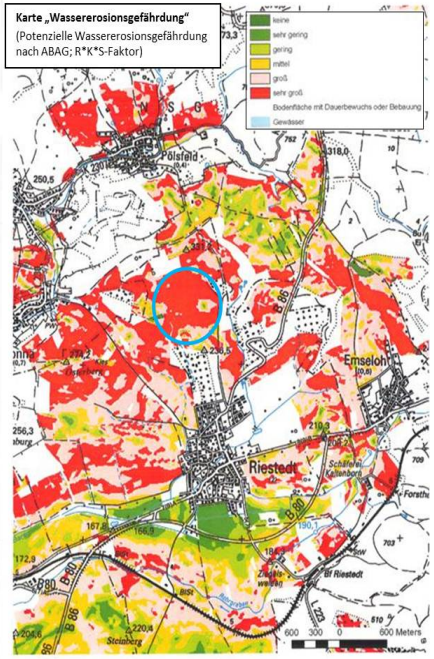
1.	**Kosten**	Kosten-Nutzen-Analyse	Multikriterien-Analyse
1.1	Kostenbarwert • Investitions-, Reinvestitionskosten • Unterhaltungskosten		
2.	**Nutzen**		
2.1	Nutzenbarwert • Einsparungen Niederschlagswassergebühr • Einsparungen Energiekosten		
2.2	Kleinklimatische Aspekte		
2.3	Gestalterische Aspekte		
2.4	Zusatznutzen		

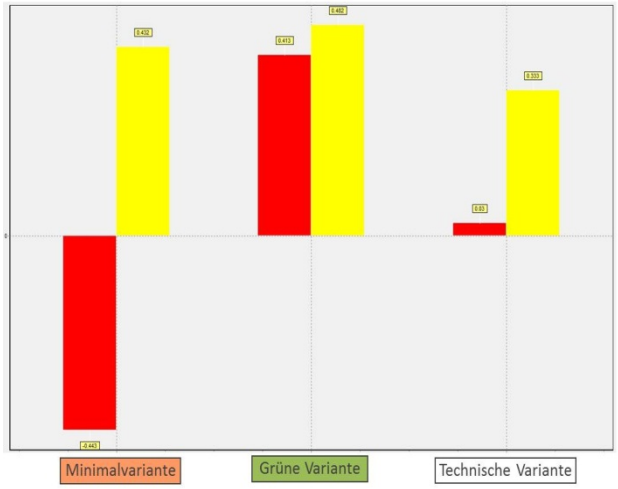


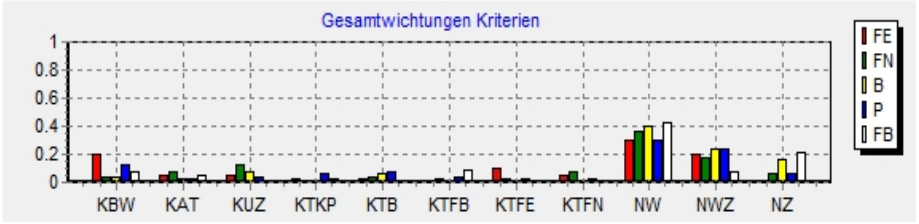




Selected case studies: Protection against soil erosion







Background

- **Heavy precipitation events** in rural settlement in Eastern Germany (24.8.2011, 4./5.9.2011, 11.9.2011)
  - **Soil degradation** at a 60 hectare plot of agricultural crop land,
  - **Damage** of infrastructure, estates, houses due to flooding/mudslide
- Administrative authorities coordinated a working group looking for an **effective and efficient bundle of adaptation measures** to prevent or limit the impacts of such events in future.

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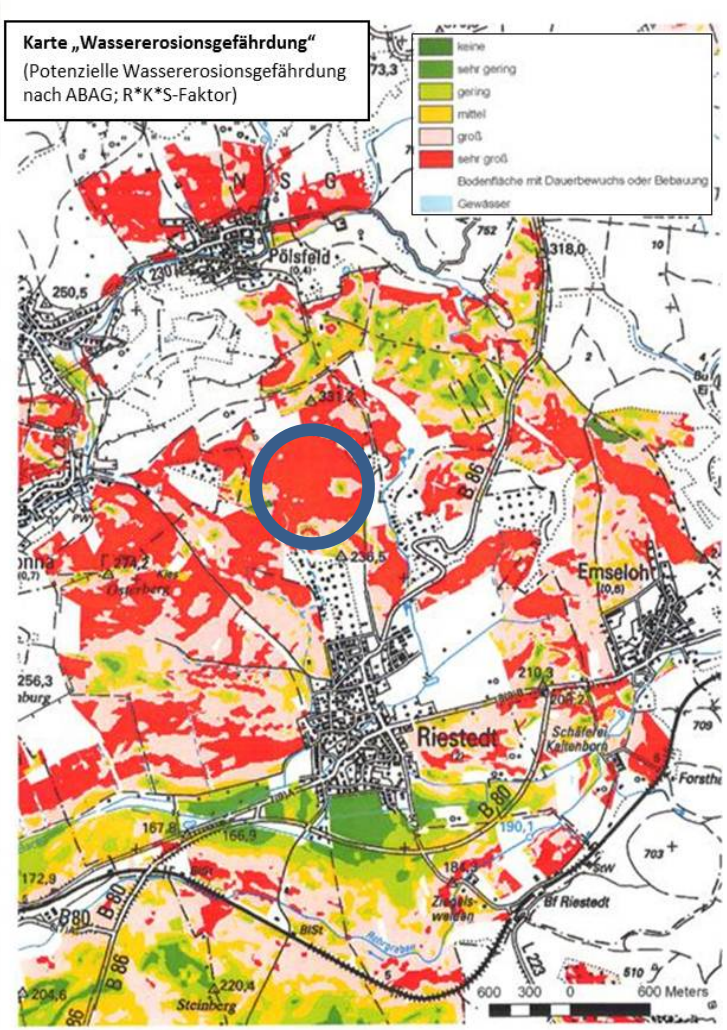
if necessary adaptation of the criteria used

if necessary improvement of data used

Preliminary Risk Assessment

- Increased frequency of occurrence of statistically most extreme precipitation events in Central and South Saxony-Anhalt expected. (CEC 2011)
- Threat of soil erosion due to heavy precipitation for specific plot considered to be very strong. (LAGB 2011)



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Identification of adaptation measures

Cultivation Practices
Compartmentation of the plot & crop rotation
Structuring of the cultivated area
Hedge for soil erosion protection I
Hedge for soil erosion protection II
Protective barrier
Drainage
Transverse ditch (simple) incl. protective barrier
Transverse ditch (fortified) incl. protective barrier
Lengthwise ditch (simple)
Lengthwise ditch (fortified)
Retention areas
Rainwater retention basin (near-natural)
Rainwater retention basin (technical)

Bundling of adaptation measures

	Measures	Description
Bundle I „minimum“	Compartmentation of the plot & crop rotation	Teilung in 3 Schläge: Hanglängenverkürzung, unterschiedliche Bewirtschaftungsrichtung und Fruchtfolge
	Hedge for soil erosion protection I	Heckenpflanzung mit einheimischen Strauchgruppen und Einzelbäumen an der quer zum Hang verlaufenden Schlaggrenze, 1 Gehölz pro 6 m², Breite ca. 8 m
	Retention areas	zwei Flächen am Fuße der Abflussbahnen, ca. 1 und 2 ha
Bundle II „near-natural“	Compartmentation of the plot & crop rotation	Teilung in 3 Schläge: Hanglängenverkürzung, unterschiedliche Bewirtschaftungsrichtung und Fruchtfolge
	Transverse ditch (simple) incl. protective barrier	Graben entlang der Schlaggrenze, Aushub als Wall, profiliert und mit Blühgräsern, Länge ca. 450 m, Querschnittsfläche Graben/Wall ca. 1,5 m²
	Hedge for soil erosion protection II	mehrreihige Schutzhecke parallel zum Quergraben, heterogene Bepflanzung von niedrigen, bodendeckenden Gewächsen bis Bäumen (Heister) mit 14 Prozent Baumanteil, 1 Gehölz pro 1,8 m², Breite ca. 12 m
	Lengthwise ditch (simple)	an den Flanken (siehe Abbildung), Länge insgesamt ca. 2250 m, Querschnittsfläche ca. 1,5m²
	Retention areas	zwei Flächen am Fuße der Abflussbahnen, ca. 1 und 2 ha
	Rainwater retention basin (near-natural)	zwei Regenrückhaltebecken (R) innerhalb der Retentionsflächen in Erdbauweise, R1 ca. 25 m *25 m* 2 m (1250 m³), R2 ca. 35 m *30 m* 2 m (2100 m³)
Bundle III „technical“	Compartmentation of the plot & crop rotation	Teilung in 3 Schläge: Hanglängenverkürzung, unterschiedliche Bewirtschaftungsrichtung und Fruchtfolge
	Transverse ditch (fortified) incl. protective barrier	Graben entlang der Schlaggrenze, Befestigung an der Schnittstelle, Aushub als Wall profiliert und mit Blühgräsern versehen, partielle Befestigung des Walls, Länge ca. 450 m, Querschnittsfläche Graben/Wall ca. 3 m²
	Lengthwise ditch (fortified)	an den Flanken (siehe Abbildung), an Gefälle/Kurven/ Schnittstellen partiell gepflastert mit Rasengitter bzw. Wasserbaupflaster, Länge insgesamt ca. 2250 m, Querschnittsfläche ca. 3 m²
	Retention areas	zwei Flächen am Fuße der Abflussbahnen, ca. 1 und 2 ha
	Rainwater retention basin (technical)	zwei ausgebaute (Stahl-/Betonbauweise) Regenrückhaltebecken (R) inklusive technischer Einbauten innerhalb der Retentionsflächen, R1 ca. 25 m *25 m* 2 m (1250 m³), R2 ca. 35 m *30 m* 2 m (2100 m³)
	Protective barriers	befestigte Wälle in den Abflussbahnen vor den Retentionsflächen, Querschnittsfläche ca. 2,1 m²

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4th step

Data collection

e.g. expert judgment, modelling, information transfer from similar projects

5th step

Evaluation & Prioritisation

e.g. Cost-benefit analysis, Multi-criteria analysis

if necessary improvement of data used

if necessary adaptation of the criteria used

Selection of evaluation criteria

Cost-related criteria

Net present value (discount rate 3% p.a., 100 years)
• Investment costs:
  ○ Compensation for depreciation of land value due to change of use
  ○ Implementation costs of adaptation measures, reinvestment costs (if applicable)
• Running costs:
  ○ Maintenance costs (if applicable)
  ○ Compensation of the leaseholder until the end of the leasing contract
  ○ Increased cultivation costs due to change of cultivation practices

Technical effort of implementation
Time of implementation
Feasibility of implementation (assessment by local politicians, citizens, administrative authorities, owner and leaseholder of the plot)
Benefit-related criteria
Effectiveness to reduce damage
Time span for measures to be effective
Co-Benefits

Selection of Evaluation Method

- PRIMATE provides support for Cost-benefit Analysis, Multi-Criteria Analysis
- Consideration of multiple criteria for evaluating the alternative bundles
- Use of differently scaled evaluation criteria (monetary, other quantitative, qualitative)

➡ Multi-criteria analysis

Weighting of evaluation criteria

Exemplary weighting of criteria for stakeholders involved in the evaluation process by point allocation

	Criteria	Weights (%)				
		Stakeholder 1 Owner	Stakeholder 2 Leaseholder	Stakeholder 3 Citizens	Stakeholder 4 Politicians	Stakeholder 5 Authority
1.	Costs	50	40	20	40	30
1.1	Net present value	40	10	20	30	25
1.2	Technical effort	10	20	10	5	15
1.3	Time of implementation	10	30	35	10	5
1.4	Assessment feasibility (politician)	5	0	0	15	10
1.5	Assessment feasibility (citizens)	5	10	30	20	5
1.6	Assessment feasibility (authorities)	0	5	5	10	30
1.7	Assessment feasibility (owner)	20	5	0	5	5
1.8	Assessment feasibility (leaseholder)	10	20	0	5	5
	Sum	*100*	*100*	*100*	*100*	*100*
2.	Benefit	50	60	80	60	70
2.1	Effectiveness to reduce damage	60	60	50	50	60
2.2	Time span for measures to be effective	40	30	30	40	10
2.6	Co-Benefits	0	10	20	10	30
	Sum	*100*	*100*	*100*	*100*	*100*

Sequence of the Evaluation & Prioritisation Process

1st step

Preliminary Risk Assessment

Investigation of specific climate change related threat

2nd step

Identification of adaptation measures

if applicable bundling of measures

3rd step

Selection of evaluation method & criteria

if applicable weighting of criteria

4th step

Data collection

e.g. expert judgment, modelling, information transfer from similar projects

5th step

Evaluation & Prioritisation

e.g. Cost-benefit analysis, Multi-criteria analysis

if necessary improvement of data used

if necessary adaptation of the criteria used

Data collection

Data sources

- Consultation of experts from the following sectors: landscape planning, agriculture, (environmental) geology
- Secondary sources: additional and validating information from databases, consultative bulletins, scientific publications

Sequence of the Evaluation & Prioritisation Process

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if necessary adaptation of the criteria used

Evaluation & Prioritisation: PRIMATE data mask

cost-related criteria

benefit-related criteria

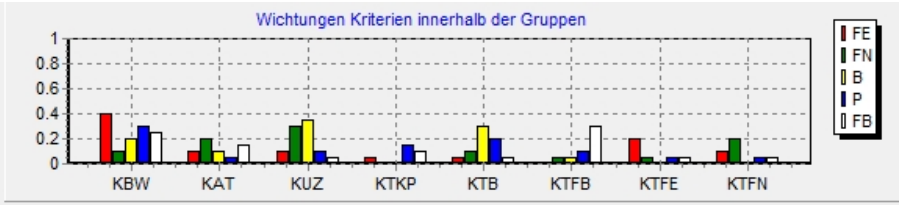
#	1	2	3	4	5	6	7	8	9	10	11
Name of criterion	Kostenbarw	technischer	zeitliche Um	Einschätzun	Einschätzun	Einschätzun	Einschätzun	Einschätzun	Wirksamkeit	Zeit Eintrete	Zusatznutze
Short	KBW	KAT	KUZ	KTKP	KTB	KTFB	KTFE	KTFN	NW	NWZ	NZ
Aspiration (maX/miN)	N	N	N	N	N	N	N	N	N	N	N
Unit											
Indifference threshold	508363	0	0	0	0	0	0	0	0	0	0
Preference threshold	2152523	3	1	1	1	2	1	2	1	2	2
Uncertainty (y/n)	y	n	n	n	n	n	n	n	n	y	n
Edit uncertainty	Edit	Edit	Edit	Edit	Edit	Edit	Edit	Edit	Edit	Edit	Edit

Bundles of measures

Values	1	2	3	4	5	6	7	8	9	10	11
Alternative V1	1.5E+5	2.0E+0	2.0E+0	1.0E+0	1.0E+0	1.0E+0	3.0E+0	1.0E+0	3.0E+0	2.0E+0	2.0E+0
Alternative V2	7.4E+5	3.0E+0	3.0E+0	1.0E+0	1.0E+0	1.0E+0	3.0E+0	3.0E+0	2.0E+0	2.0E+0	1.0E+0
Alternative V3	2.2E+6	5.0E+0	3.0E+0	1.0E+0	1.0E+0	3.0E+0	3.0E+0	3.0E+0	2.0E+0	1.0E+0	3.0E+0

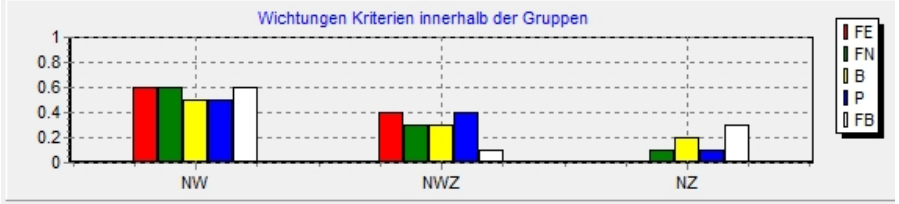
Evaluation & Prioritisation: Criteria weighting

Weighting of cost criteria



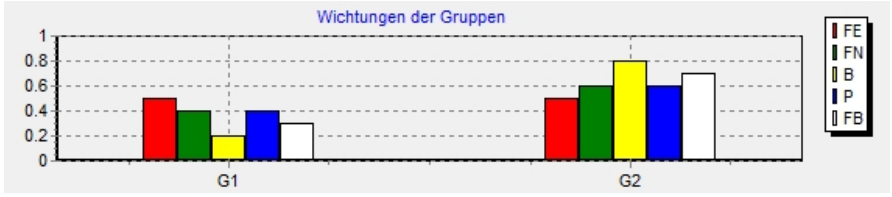
DM		Name Entscheider	Kurz	KBW	KAT	KUZ	KTKP	KTB	KTFB	KTFE	KTFN
1	x	Stakeholder 1	FE	0.4	0.1	0.1	0.05	0.05	0	0.2	0.1
2	x	Stakeholder 2	FN	0.1	0.2	0.3	0	0.1	0.05	0.05	0.2
3	x	Stakeholder 3	B	0.2	0.1	0.35	0	0.3	0.05	0	0
4	x	Stakeholder 4	P	0.3	0.05	0.1	0.15	0.2	0.1	0.05	0.05
5	x	Stakeholder 5	FB	0.25	0.15	0.05	0.1	0.05	0.3	0.05	0.05

Weighting of benefit criteria

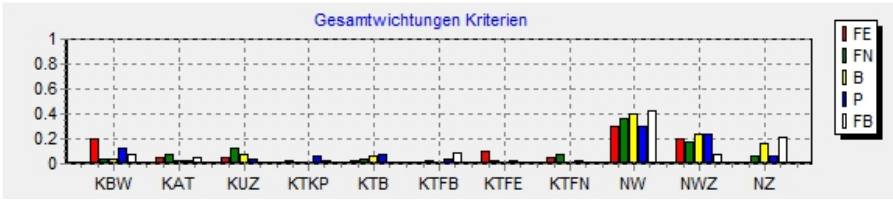


DM		Name Entscheider	Kurz	NW	NWZ	NZ
1	x	Stakeholder 1	FE	0.6	0.4	0
2	x	Stakeholder 2	FN	0.6	0.3	0.1
3	x	Stakeholder 3	B	0.5	0.3	0.2
4	x	Stakeholder 4	P	0.5	0.4	0.1
5	x	Stakeholder 5	FB	0.6	0.1	0.3

Weighting of criteria groups

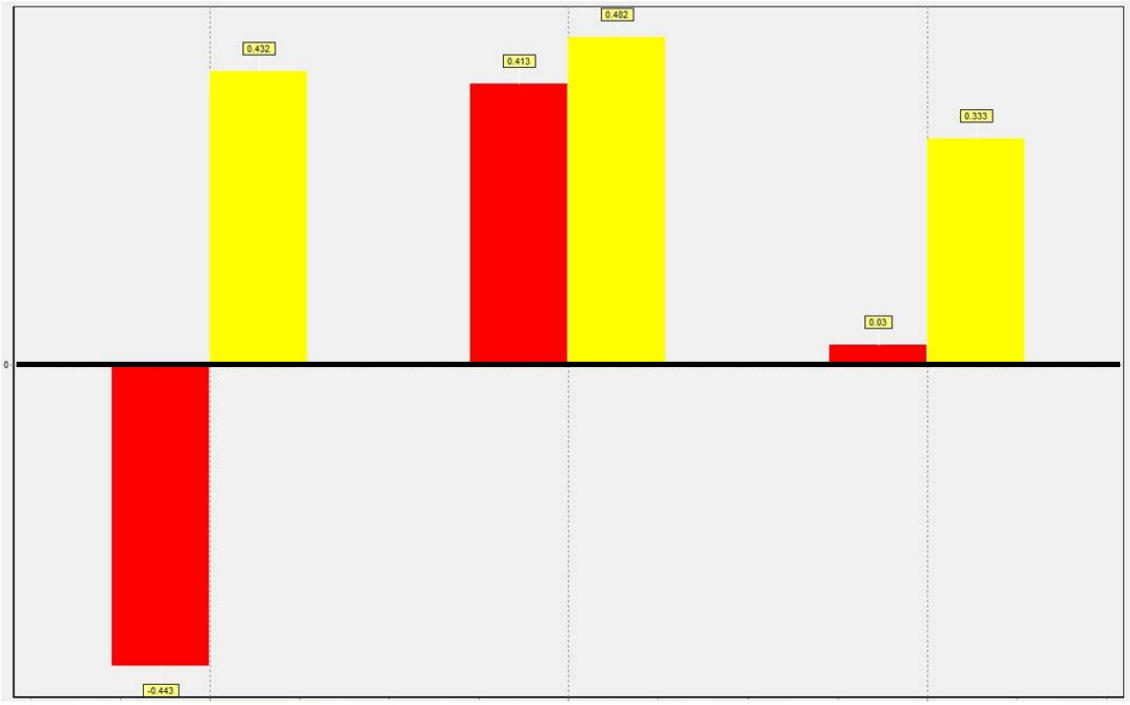


Overall weighting of criteria



Evaluation & Prioritisation: Results

- Bundle II receives highest number of net votes.
- Uncertainty is due to value ranges & varying stakeholder preferences.

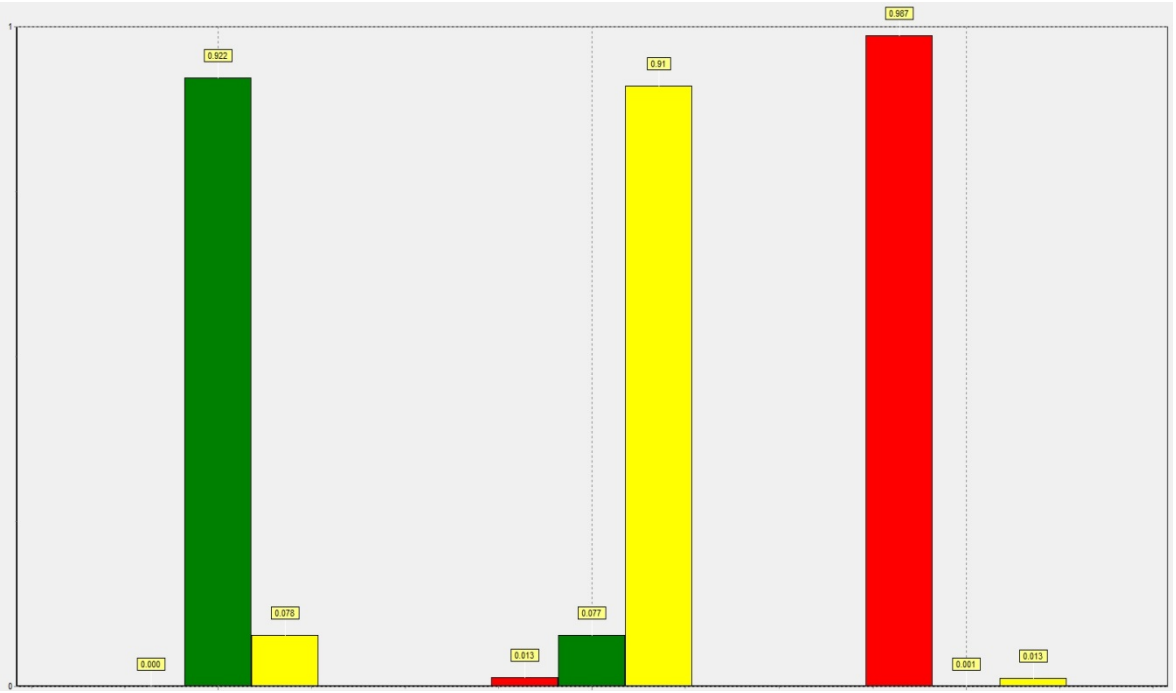


Overall net votes of bundles & uncertainty margin

- Mean of net votes
- 2* standard deviation

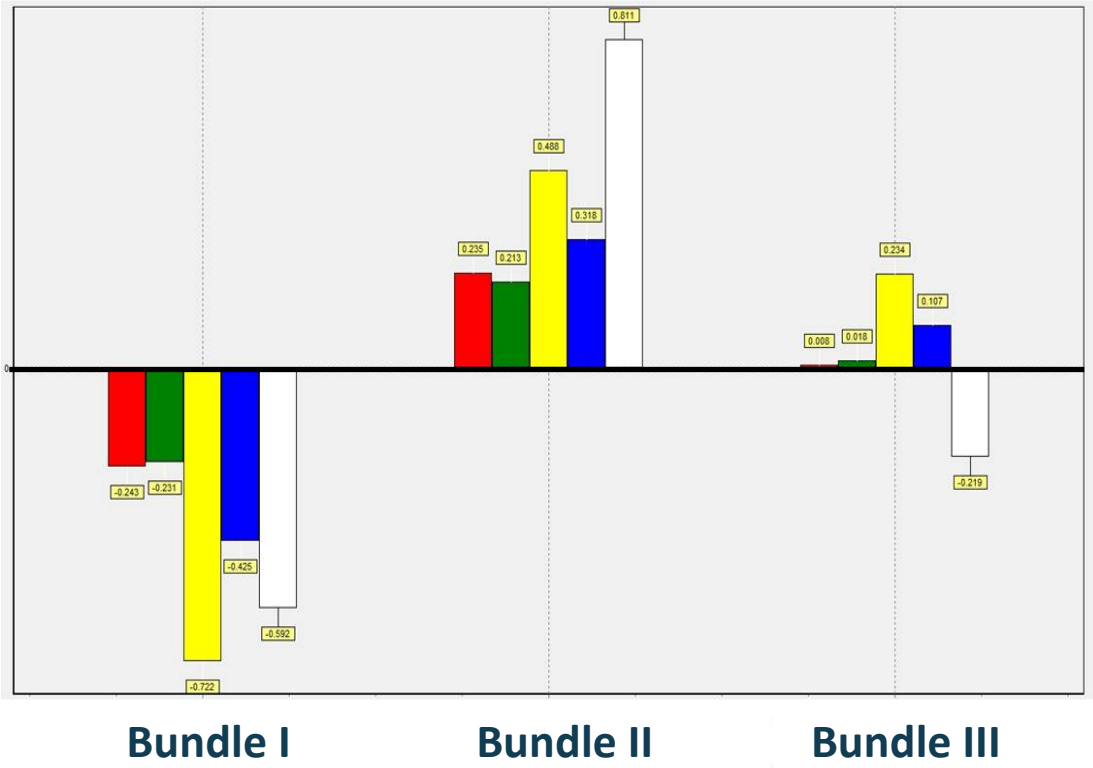
Evaluation & Prioritisation: Results

- Bundle II has highest probability of being the most appropriate solution on the basis of the preferences of all stakeholders.



Evaluation & Prioritisation: Results

- Bundle II obtains highest number of net votes by all stakeholders.



Net votes by individual stakeholders

- Stakeholder 1
- Stakeholder 2
- Stakeholder 3
- Stakeholder 4
- Stakeholder 5

Evaluation Guideline …

- supports decision making for climate change adaptation by providing a **step-by-step manual** describing and illustrating typical evaluation processes.
- focuses on **participatory evaluation processes** involving stakeholders and decision makers.

PRIMATE …

- provides **CBA & MCA support**
- accounts for **data input uncertainty** probabilistically
- allows for the simultaneous and explicit consideration of the **preferences of several decision makers/stakeholders**.
- illustrates the effects of varying preferences on the evaluation result and thereby actively **supports group decision making** processes.
- enhances the **transparency** of the decision making process.
- facilitates the identification of **compromise solutions**.

Thank you!

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Additional material

Multi-criteria method: PROMETHEE in a nutshell

PROMETHEE II (Preference Ranking Organisation Method for Enrichment Evaluations)

- Pairwise comparison of all alternatives across all criteria
- Transformation of (pairwise) differences into (pairwise) preference values for each criterion
- Weighted aggregation of partial preference matrices of each criterion to total preference matrix
- Determination of preference flows ("votes" in favor and "votes" against each alternative) on the basis of total preference matrix
- Ranking of alternatives based on net "votes" (≙ net preference flows)

Data uncertainty

- Definition of range of criteria values for specific alternative by the use of uniform distributions, triangular distribution or any other probability distribution, e.g. coming from some model
- Uncertainty regarding the alternatives‘ performance for specific criteria is accounted for probabilistically

1. By **including uncertainty in the preference function**
   - PRIMATE performs pairwise comparison of the probability distributions given.
   - Rationale:
     - If distributions don’t overlap, then strict preference of superior option.

Data uncertainty (continued)

- If distributions overlap but mean of one distribution is higher, then assignment of preference value between 0 and 1.

- Differences in performance values are transformed into preference values by the use of a stochastic preference function.

2. By **using Monte-Carlo simulation**

- Uncertainties are not included in the preference function.
- PRIMATE randomly selects criteria values out of the defined range and runs up to 10.000 standard PROMETHEE MCAs.

- Results of all evaluations are statistically analysed & documented.