Decision support for climate change adaptation under uncertainty

ECCA 2013 Conference
Session: Decision-making under uncertainty – Decision support tools

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Outline

1. Introduction
2. Evaluation methods for decision support
3. Decision support tool PRIMATE
4. Case study
5. Conclusion

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1. Introduction

Background

- Initiatives for climate change adaptation not only on strategic level but also increasingly **adaptation projects implemented**
- Special 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**
- Demand for easy-to-use **decision support systems** (DSS)
- Increasing number of handbooks, assessment manuals, DSS

- **UFZ-Evaluation Guideline** and decision support tool **PRIMATE** (interactive software for **Pr**obabi**l**istic **M**ulti-**At**tribute **E**valuation)

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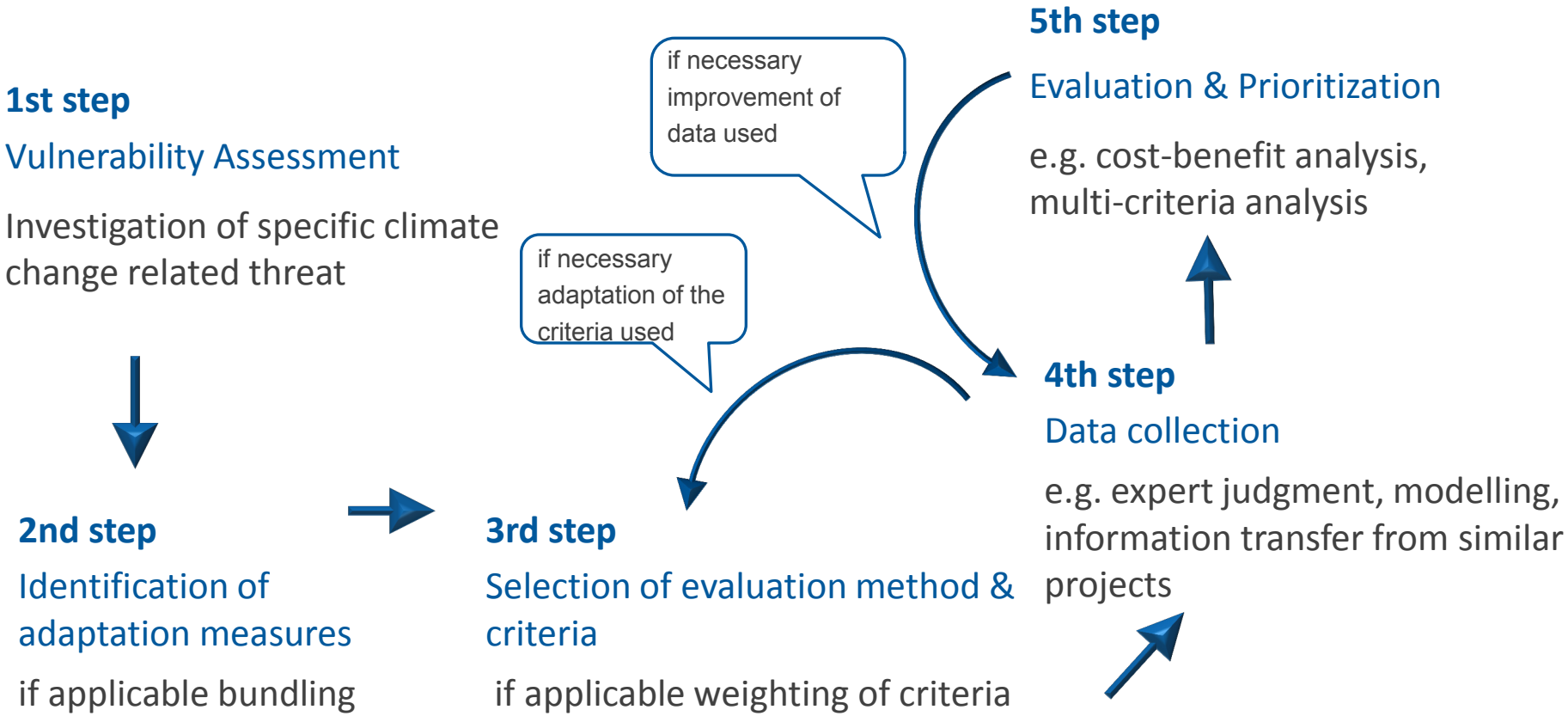
1. Introduction

Sequence of the Evaluation & Prioritization Process



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1. Introduction

UFZ- Evaluation Guideline

Left column
--> explanation of what to consider during the various steps

Right column
--> exemplification of explanations using a case study

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

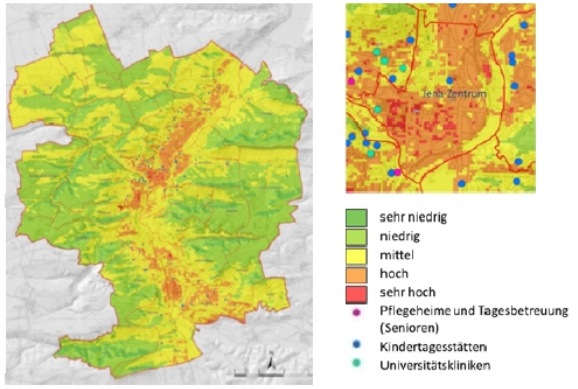
- Analyse vergangener Schadensereignisse, wie z.B. durch Auswertung der Einsatzprotokolle von Katastrophenschutz, Feuerwehr etc.
- Auswertung bestehender Risiko- und Vulnerabilitätsstudien
- Diskussion der möglichen Betroffenheit durch den Klimawandel mit Fachplanungen in Landkreis und Kommune: Stadtplanung,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

2. Evaluation methods for decision support

Uni-criterion Approaches, e.g. Cost-Benefit Analysis (CBA)

- Focus on a single objective, e.g. net benefit
- Search for optimal solutions

Multi-criteria Analysis (MCA), e.g. Weighted Sum, Multi-Attribute Utility Theory-Approaches, Outranking Methods

- Accounting for multiple (quantitative or qualitative) criteria simultaneously
- Due to conflicting criteria rather focusing on compromise than on optimal solutions

2. Evaluation methods for decision support

Weighted sum

- Allocation of weights to the evaluation criteria representing the priorities of the decision maker
- Computation of the weighted sum of the evaluations of every alternative over all criteria
- Ranking of the alternatives on the basis of weighted sum

– No information on conflicting criteria available due to unrestricted compensations between weakly and strongly performing criteria
– No good basis for balanced decisions

2. Evaluation methods for decision support

Multi-Attribute Utility Theory

- Identification of the decision maker's utility function integrating the different evaluation criteria with her preferences
- Determination of the alternatives' utility values
- Ranking of the alternatives on the basis of the utility values

– Assumptions:
  – utility function of the decision maker ascertainable
  – decisions taken on the basis of this utility function
– Aggregation of utility values allows for unrestricted compensation of weakly and strongly performing criteria

2. Evaluation methods for decision support

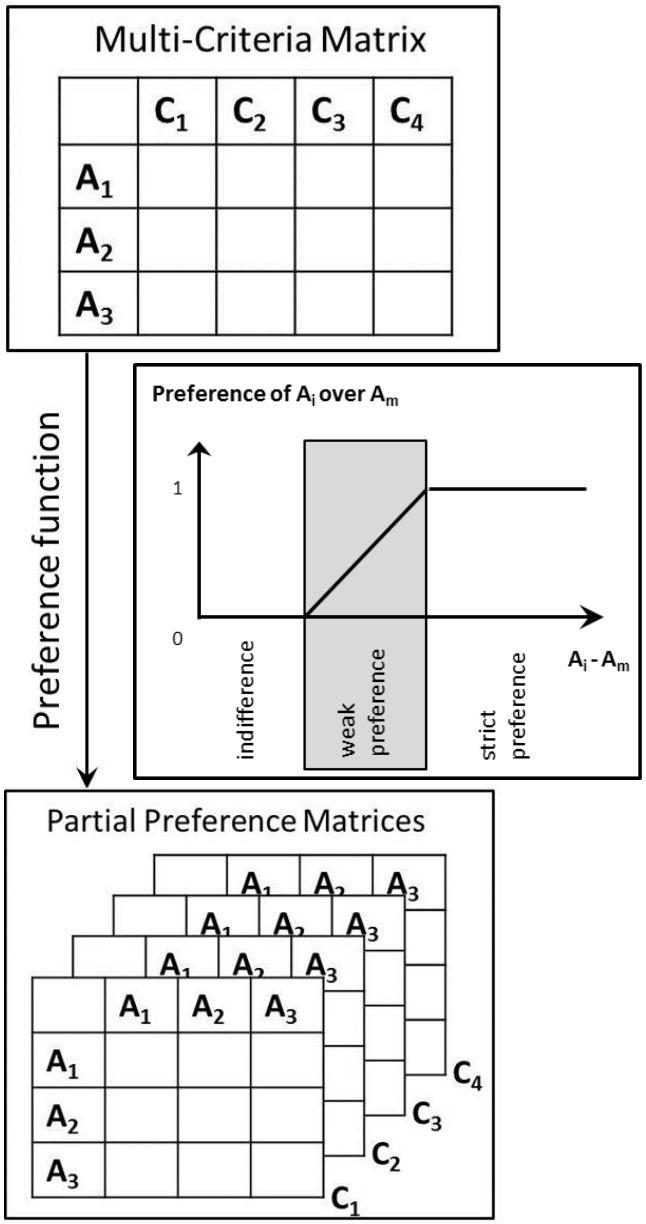
PROMETHEE (**P**reference **R**anking **O**rganisation **Meth**od for **E**nrichment **E**valuations)

- Pairwise comparison of all alternatives across all criteria
- Transformation of (pairwise) differences into (pairwise) preference values for each criterion
- Weighted aggregation of all preference values
- Computation of preference flows ("votes" in favor and "votes" against each alternative)
- Ranking of alternatives on the basis of preference flows

- **UFZ-DSS *PRIMATE* -** CBA, PROMETHEE implemented

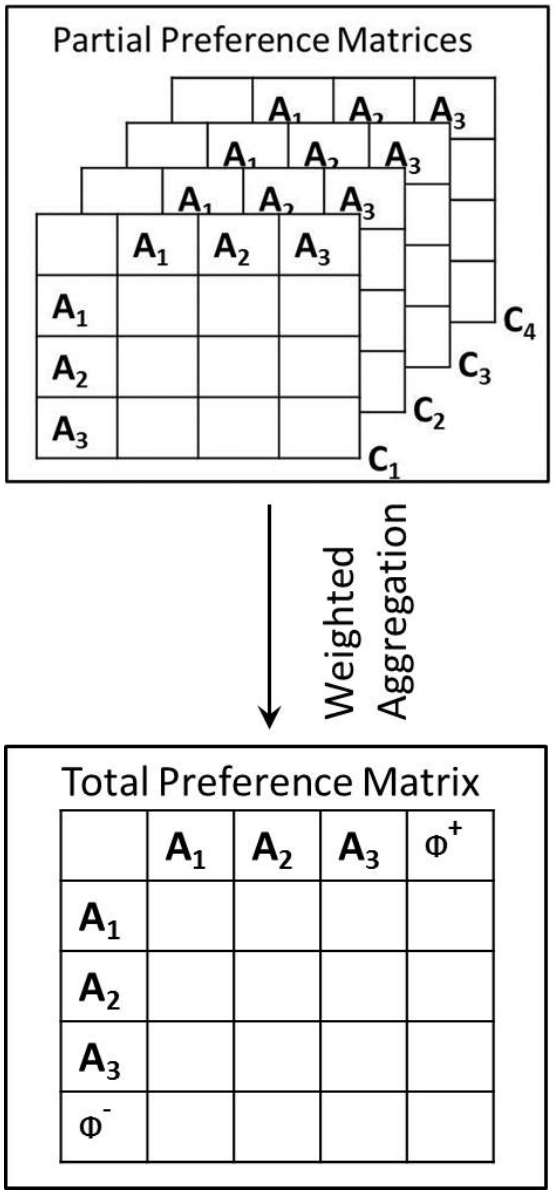
3. Decision support tool PRIMATE: PROMETHEE

- **Structuring the decision problem**
  - Identification of **alternative measures** $A_i=\{A_1,\ldots,A_m\}$ to be compared
  - Definition of the set of evaluation **criteria** $C_j=\{C_1,\ldots,C_n\}$
  - Alternatives (rows) and criteria (columns) form an **evaluation matrix**
  - Specification of the **preference function** (shape, thresholds) of the decision maker(s) for each criterion
  - **Weighting** of criteria
- **Collection of input data** on the performance of the alternatives for each evaluation criterion



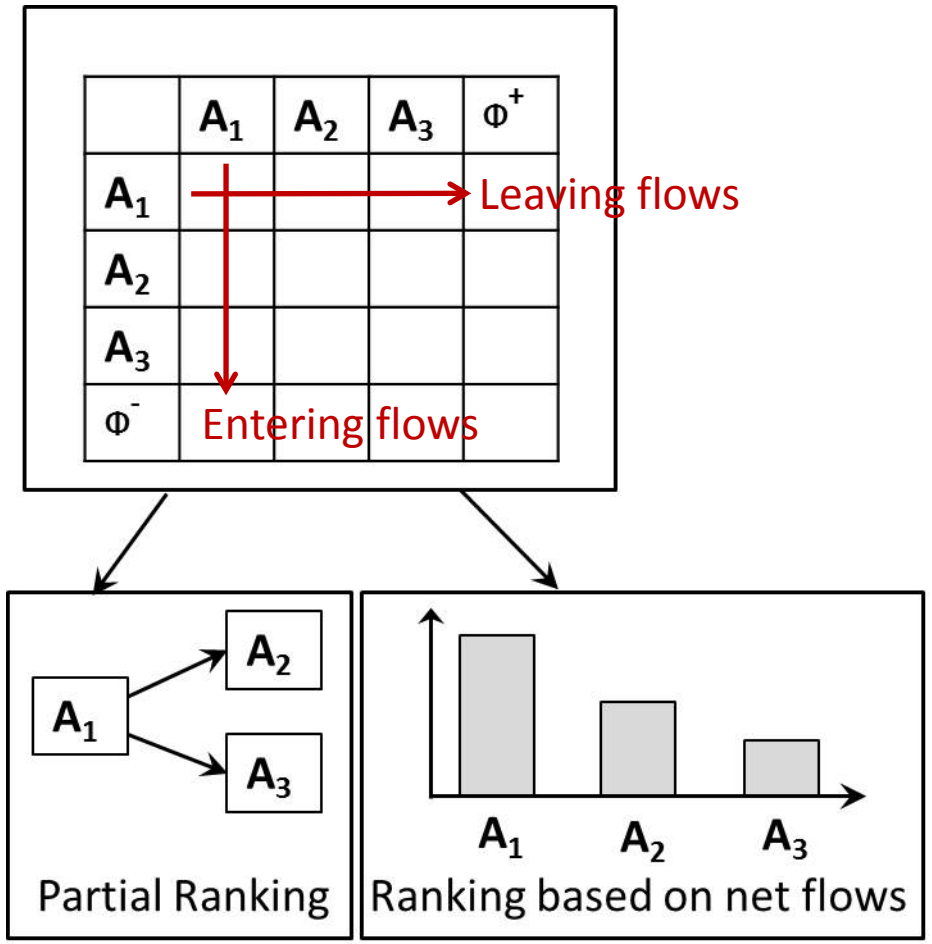
3. Decision support tool PRIMATE: PROMETHEE

- **Pairwise comparison** of all alternatives for each criterion
- **Transformation of differences in criteria values into preference values** ranging from 0 to 1 using the preference function specified
- **Computation of a partial preference matrix** for each criterion
- **Computation of the total preference matrix** (TPM) as weighted sum of the preference matrices of all criteria



3. Decision support tool PRIMATE: PROMETHEE

- Computation of **leaving flows** (≙ line total TPM):
  sum of the preferences of the respective alternative to all other alternatives
- Computation of **entering flows** (≙ column total of TPM):
  sum of the preferences of all other alternatives over the respective alternative
- PROMETHEE I: **Ranking** based on **leaving** & **entering flows**
- PROMETHEE II: **Ranking** based on **net flows** (≙ difference between leaving & entering flows)



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3. Decision support tool PRIMATE: Data uncertainty

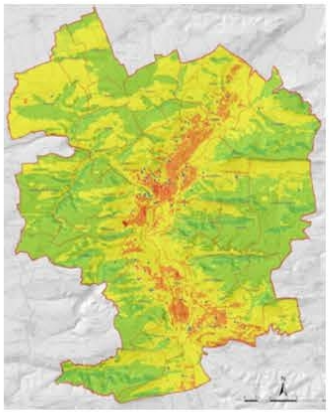
- **Uncertainty** regarding the alternatives‘ performance for specific criteria is accounted for **probabilistically** by the use of stochastic preference functions.
- Use of uniform distributions (minimum, maximum value) OR triangular distribution (minimum, most likely, maximum value)
- PRIMATE randomly selects **up to 10.000** values out of the defined range.
- Results of all evaluations are statistically analyzed (arithmetic mean, standard deviation, ranking order) and documented.

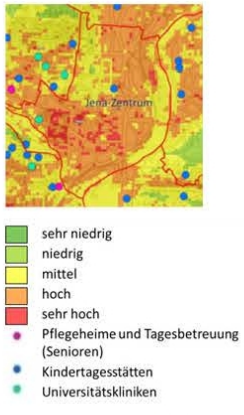
3. Decision support tool PRIMATE: Preferences

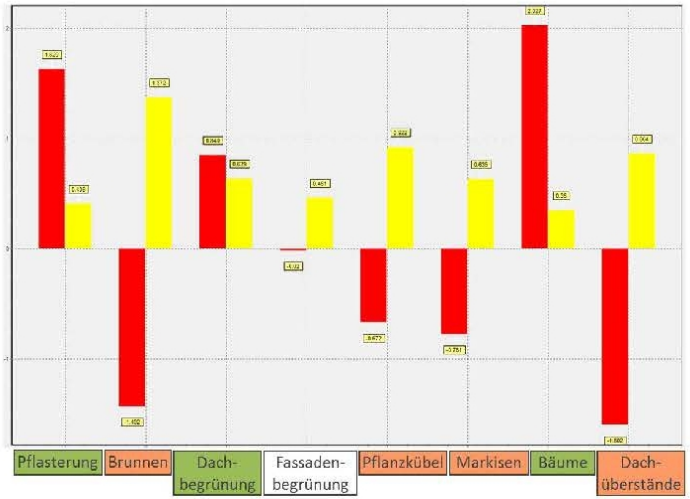
- **Varying preference functions** of different decision makers **for each criterion** are considered **simultaneously.**
- **Weighting** of up to **16 criteria** and **5 criteria groups** for up to **6 decision makers**
- Number of weight replicates determined by number of decision makers.
- Results of all evaluations are statistically analyzed (arithmetic mean, standard deviation, ranking order) and documented.

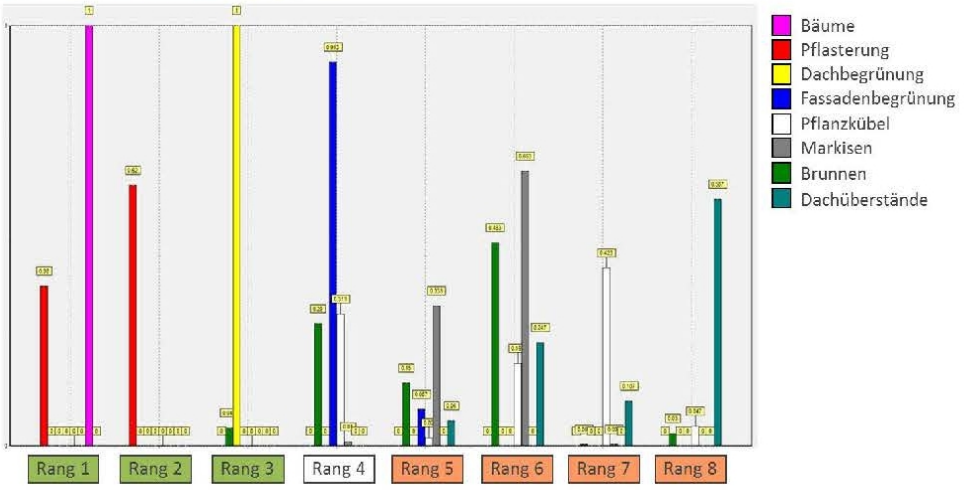
3. Decision support tool PRIMATE: Selected case studies

Heat stress reduction







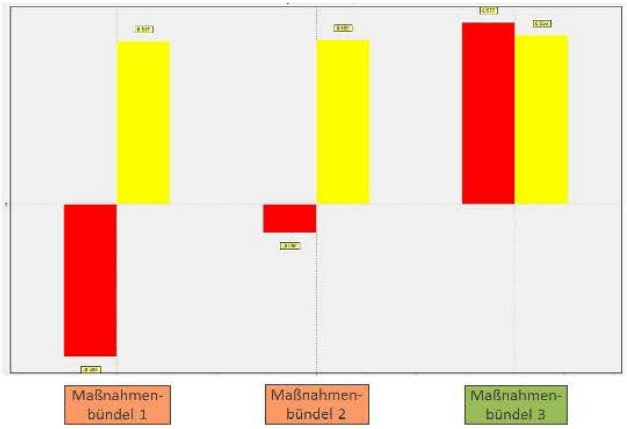


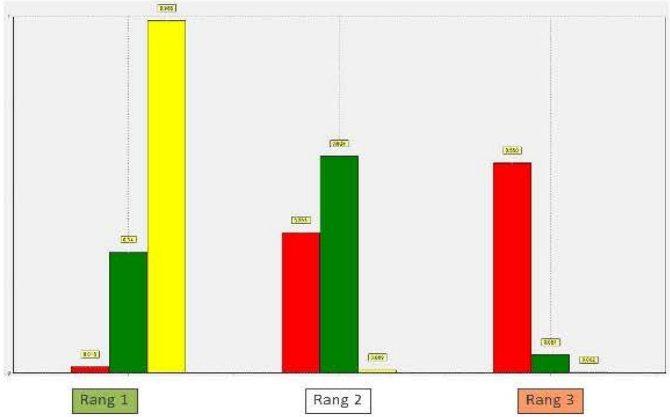
3. Decision support tool PRIMATE: Selected case studies

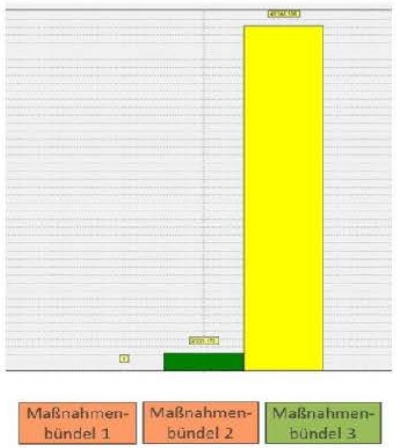
Heat stress reduction

Rainwater management (percolation, retention, drainage)

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		





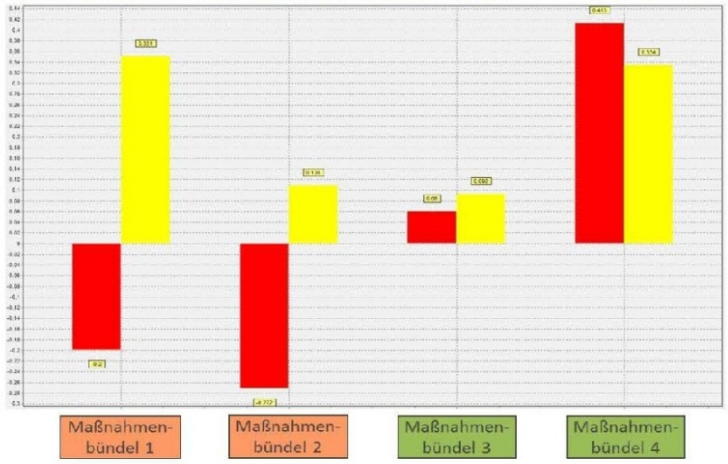


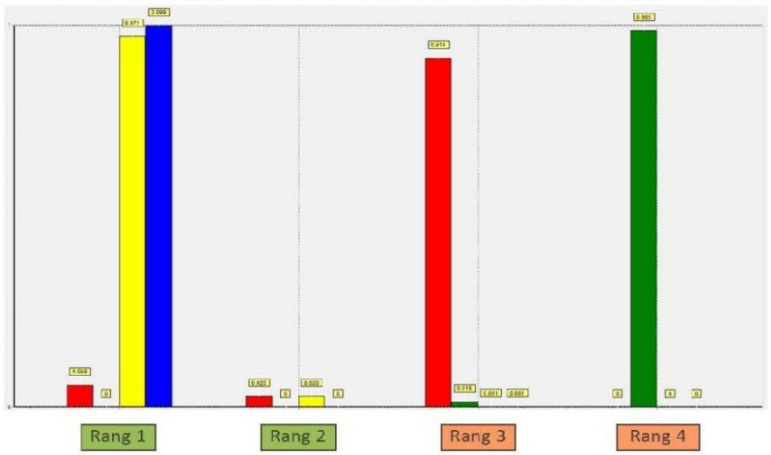
3. Decision support tool PRIMATE: Selected case studies

Heat stress reduction

Rainwater management (percolation, retention, drainage)

Private flood protection





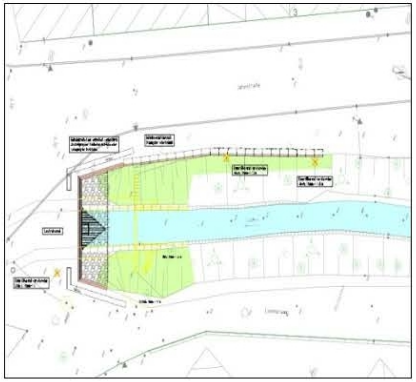
3. Decision support tool PRIMATE: Selected case studies

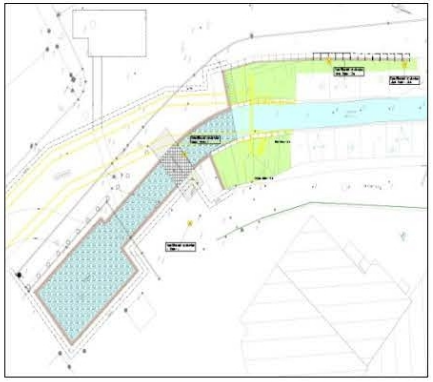
Heat stress reduction

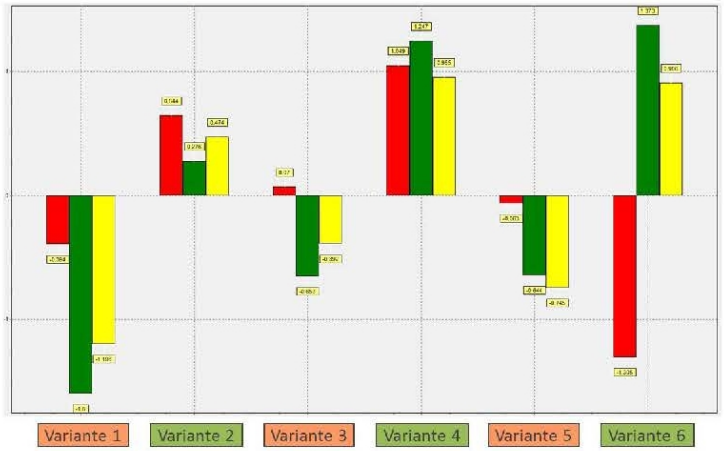
Rainwater management (percolation, retention, drainage)

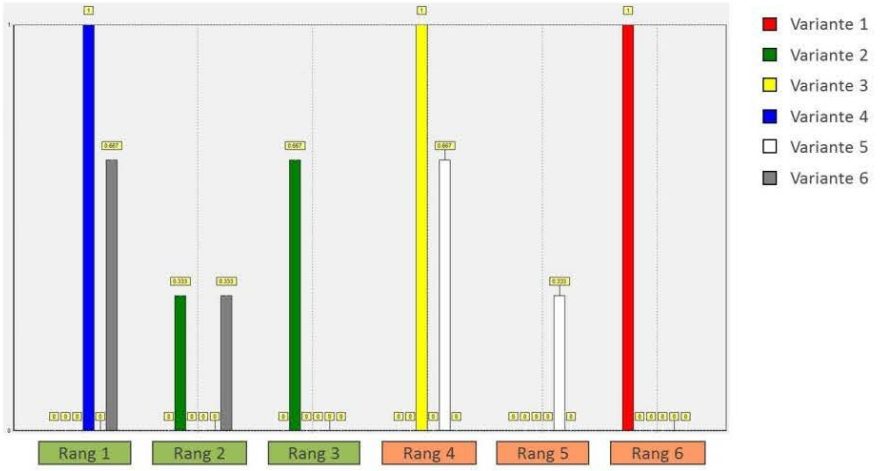
Private flood protection

Urban flood protection









3. Decision support tool PRIMATE: Selected case studies

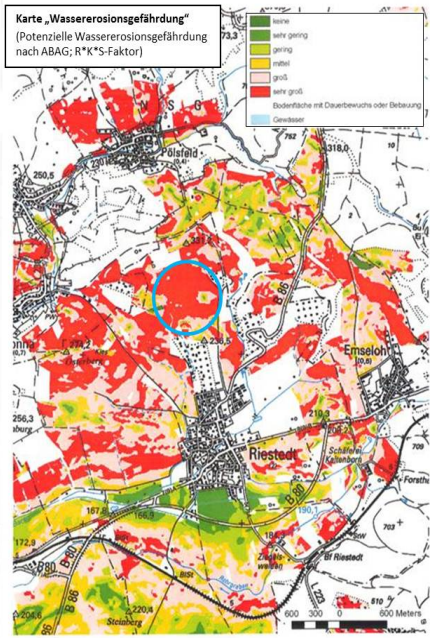
Heat stress reduction

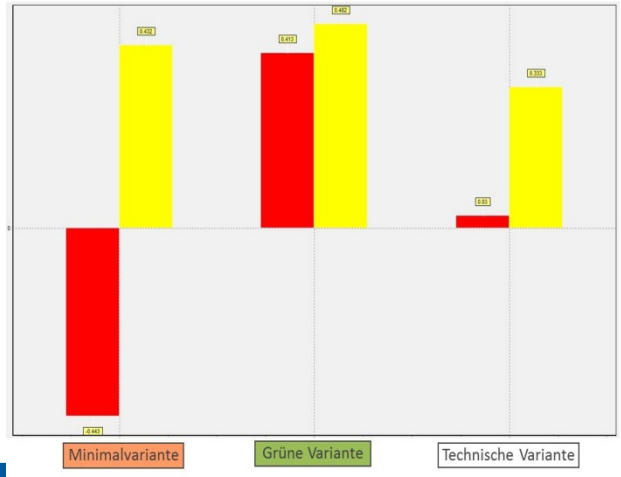
Rainwater management (percolation, retention, drainage)

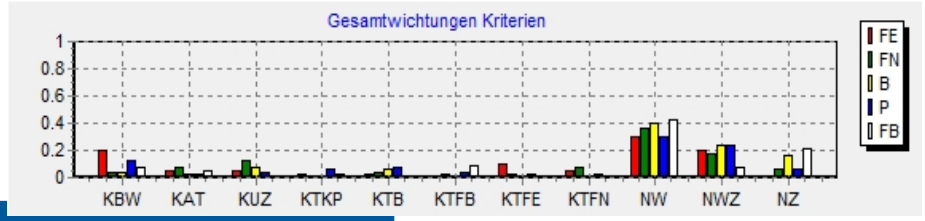
Private flood protection

Urban flood protection

Protection against soil erosion





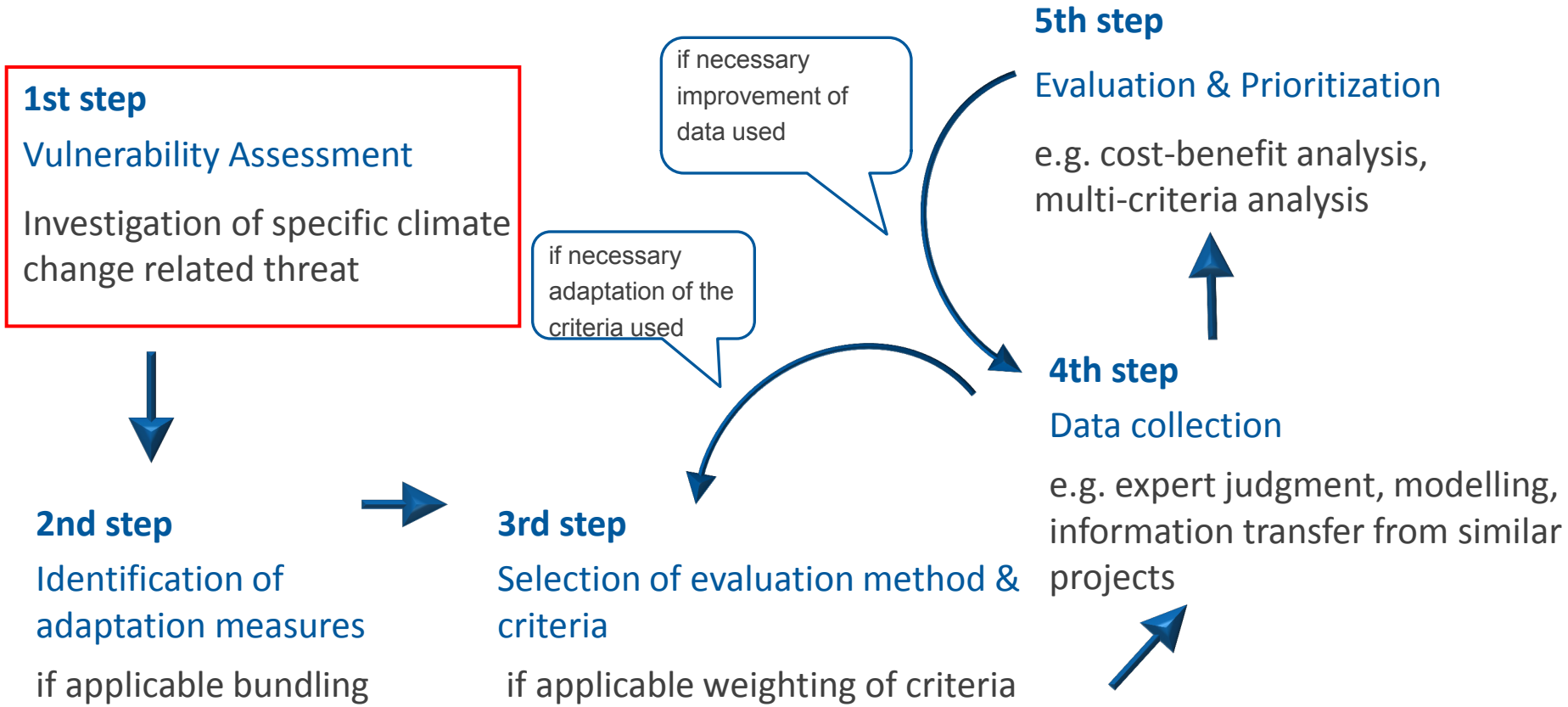


4. Case study: Background

- **Heavy precipitation events** in Riestedt (1.430 inhabitants, Saxony-Anhalt) 24.8.2011, 4./5.9.2011, 11.9.2011
- **Impacts**:
  - **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

Flooding of Riestedt, Plot of agricultural crop land after discharge

Evaluation & Prioritization of Adaptation Measures



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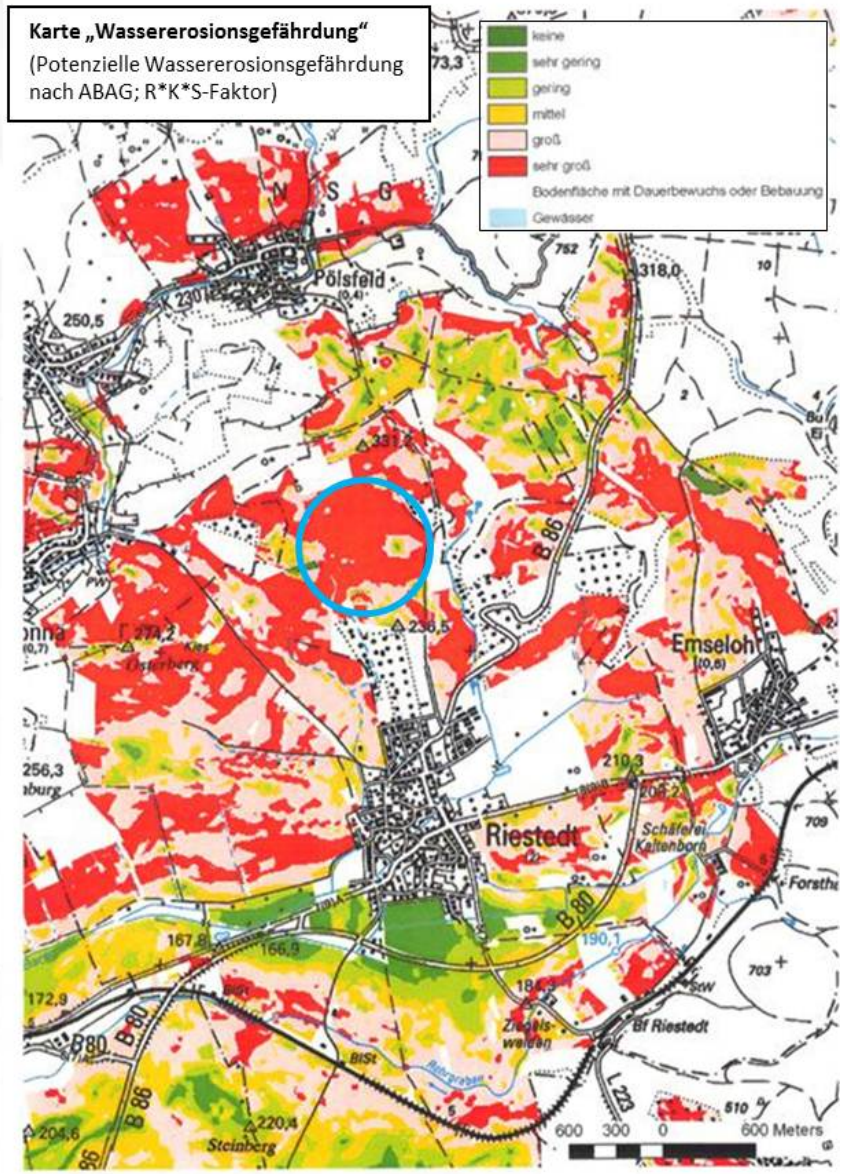
4.1 Case study: Vulnerability Assessment

- **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.** (LAGB2011)



Evaluation & Prioritization of Adaptation Measures

1st step

Vulnerability 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 & Prioritization

e.g. cost-benefit analysis, multi-criteria analysis

if necessary improvement of data used

if necessary adaptation of the criteria used

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4.2 Case study: Identification of adaptation measures

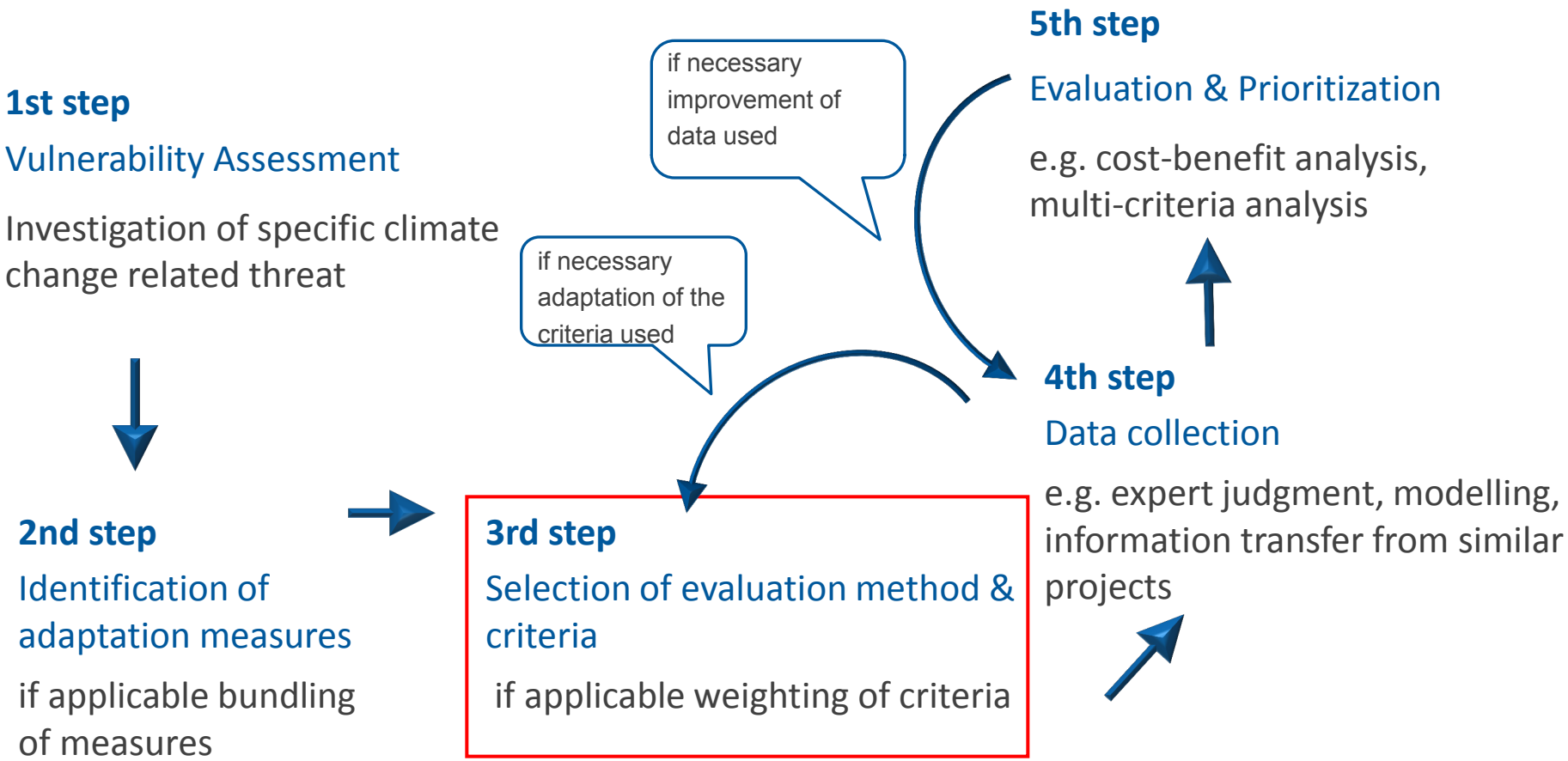
Cultivation Practices
Compartmentation of the plot & crop rotation
Structuring of the cultivated area
Hedge for soil erosion protection I
Hedge for soil erosion protection II
Protective barrier
Drainage
Transverse ditch (simple) incl. protective barrier
Transverse ditch (fortified) incl. protective barrier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

Source: Agrar Office AgroWIN

4.2 Case study: Bundling of adaptation measures

Bundles 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

Evaluation & Prioritization of Adaptation Measures



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4.3 Case study: Selection of Evaluation Criteria

Costs

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)
Benefits
Effectiveness to reduce damage
Time span for measures to be effective
Co-Benefits

4.3 Case study: Selection of Evaluation Method

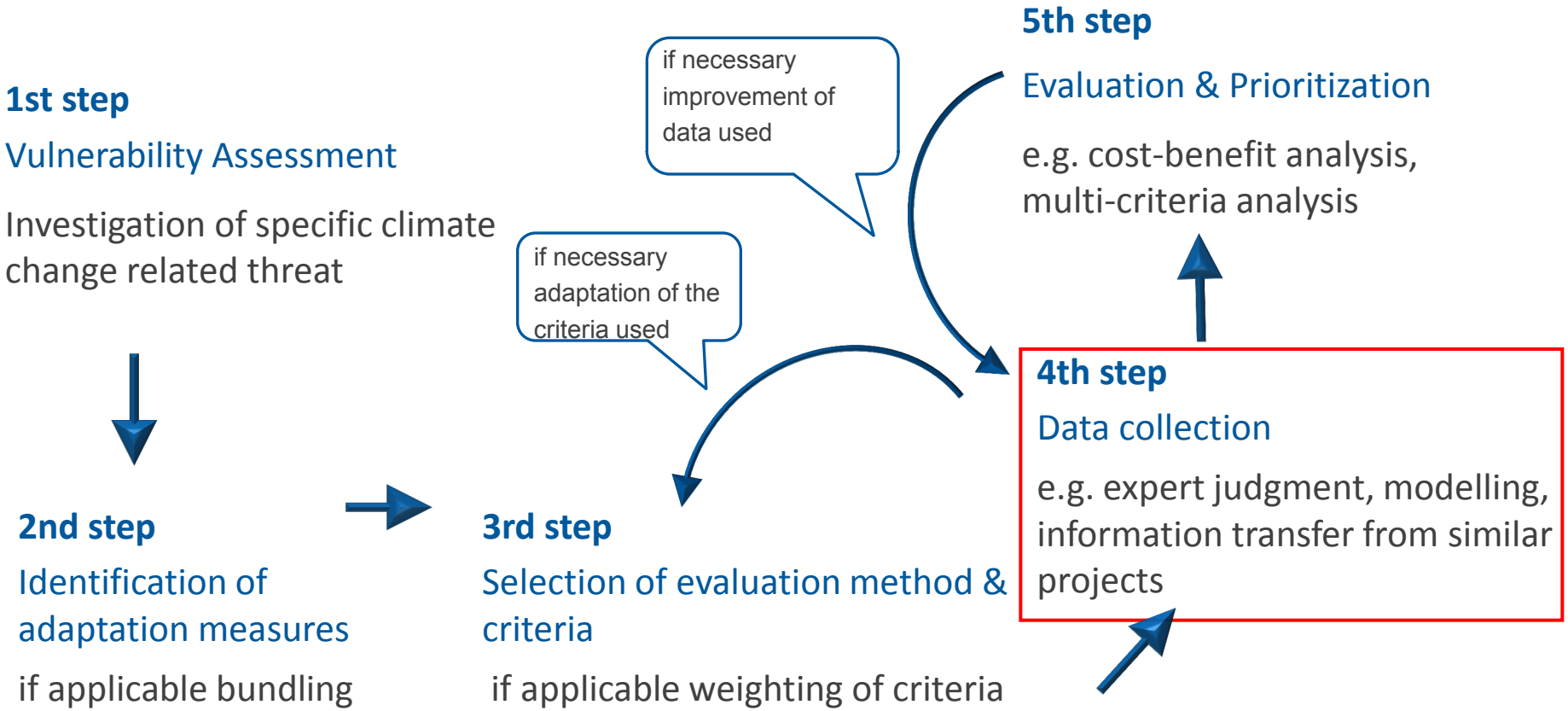
- Consideration of multiple criteria for evaluating the alternative bundles
- Use of differently scaled evaluation criteria (monetary, other quantitative, qualitative)

→ Multi-criteria analysis

Exemplary weighting of criteria for stakeholders involved in the evaluation process

	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*

Evaluation & Prioritization of Adaptation Measures



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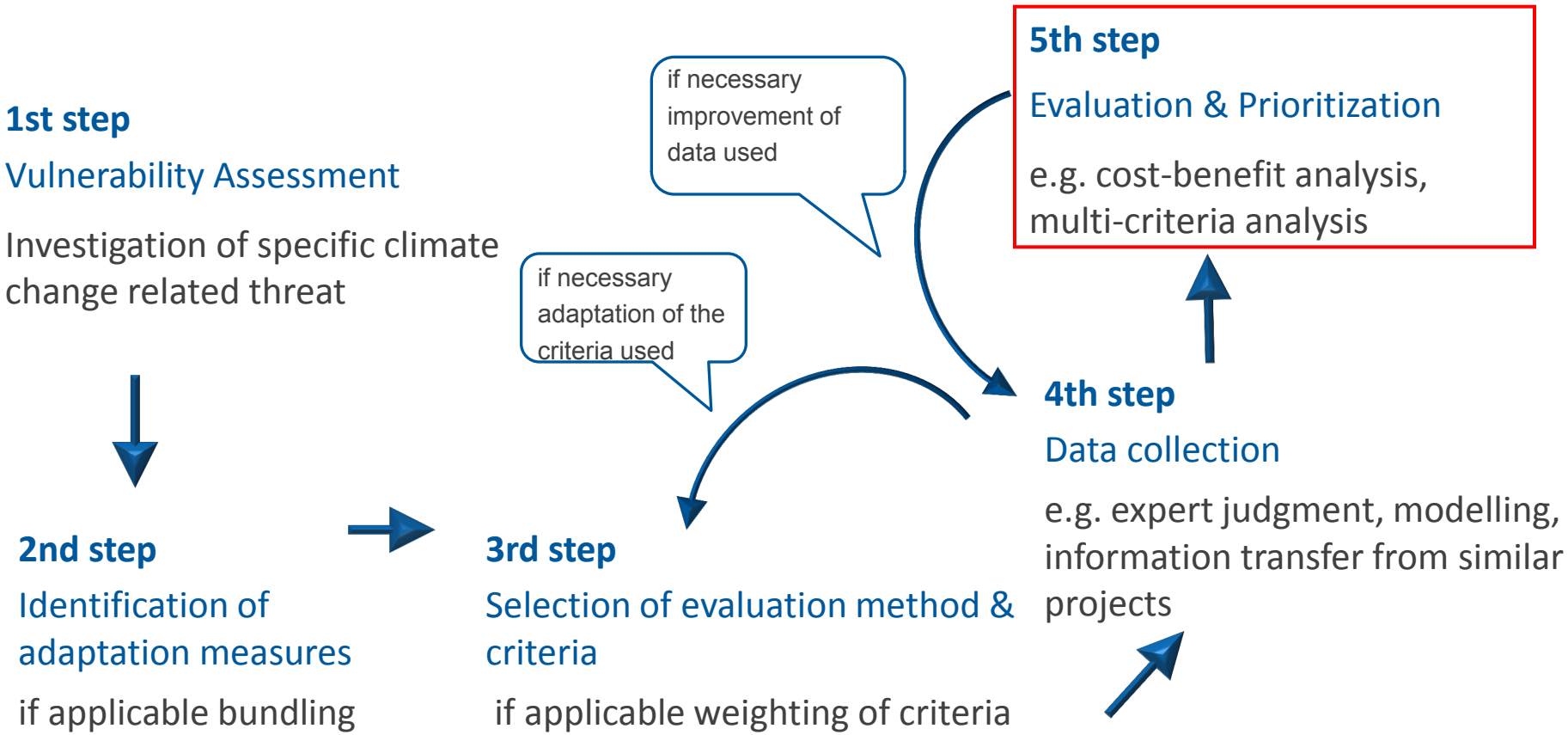
4.4 Case study: Data collection

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

Evaluation & Prioritization of Adaptation Measures



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4.5 Case Study: Evaluation & Prioritization

PRIMATE data mask

cost criteria

benefit criteria

#	1	2	3	4	5	6	7	8	9	10	11
Name des Kriteriums	Kostenbarw	technischer	zeitliche Um	Einschätzun	Einschätzun	Einschätzun	Einschätzun	Einschätzun	Wirksamkeit	Zeit Eintrete	Zusatznutze
Kurz	KBW	KAT	KUZ	KTKP	KTB	KTFB	KTFE	KTFN	NW	NWZ	NZ
Zielsetzung (maX/miN)	N	N	N	N	N	N	N	N	N	N	N
Einheit											
Grenzwert Indifferenz	508363	0	0	0	0	0	0	0	0	0	0
Grenzwert Präferenz	2152523	3	1	1	1	2	1	2	1	2	2
Unsicherheiten (y/n)	y	n	n	n	n	n	n	n	n	y	n
Unsicherheiten bearb.	Bearb.	Bearb.	Bearb.	Bearb.	Bearb.	Bearb.	Bearb.	Bearb.	Bearb.	Bearb.	Bearb.

Werte	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

Bundles of measures

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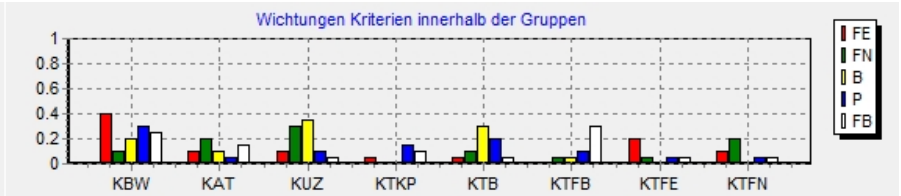
4.5 Case Study: Evaluation & Prioritization

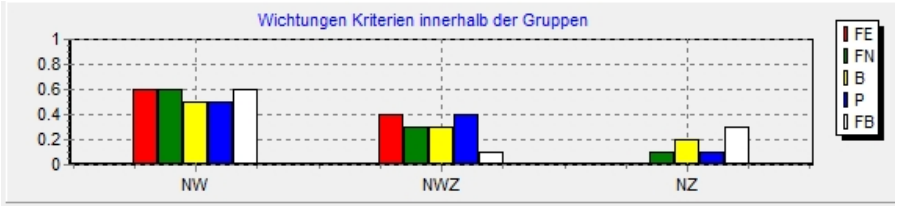
Criteria weights - 5 stakeholder groups

Weighting of cost criteria



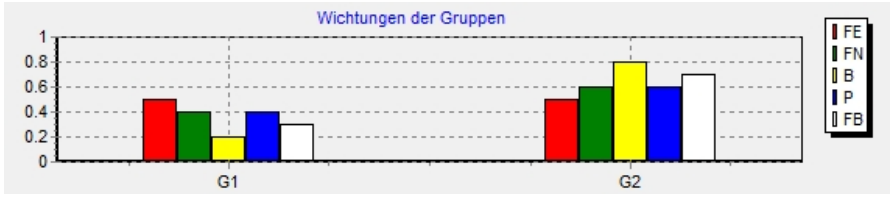
DM		Name Entscheider	Kurz	KBW	KAT	KUZ	KTKP	KTB	KTFB	KTFE	KTFN
1	x	Stakeholder 1	FE	0.4	0.1	0.1	0.05	0.05	0	0.2	0.1
2	x	Stakeholder 2	FN	0.1	0.2	0.3	0	0.1	0.05	0.05	0.2
3	x	Stakeholder 3	B	0.2	0.1	0.35	0	0.3	0.05	0	0
4	x	Stakeholder 4	P	0.3	0.05	0.1	0.15	0.2	0.1	0.05	0.05
5	x	Stakeholder 5	FB	0.25	0.15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

Weighting of benefit criteria

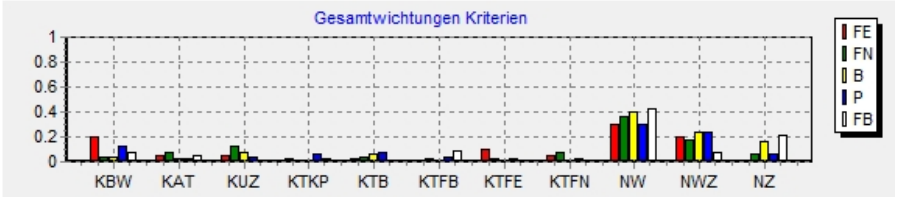


DM		Name Entscheider	Kurz	NW	NWZ	NZ
1	x	Stakeholder 1	FE	0.6	0.4	0
2	x	Stakeholder 2	FN	0.6	0.3	0.1
3	x	Stakeholder 3	B	0.5	0.3	0.2
4	x	Stakeholder 4	P	0.5	0.4	0.1
5	x	Stakeholder 5	FB	0.6	0.1	0.3

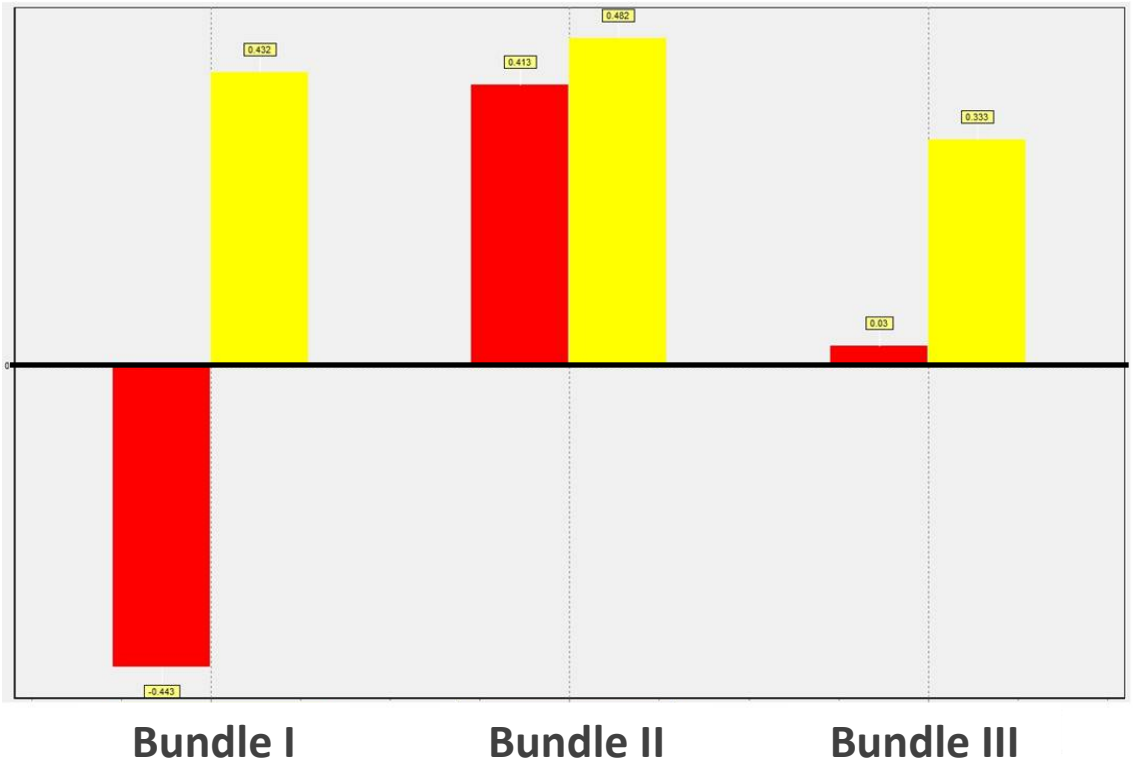
Weighting of criteria groups



Weighting of all criteria



4.5 Case Study: Evaluation & Prioritization



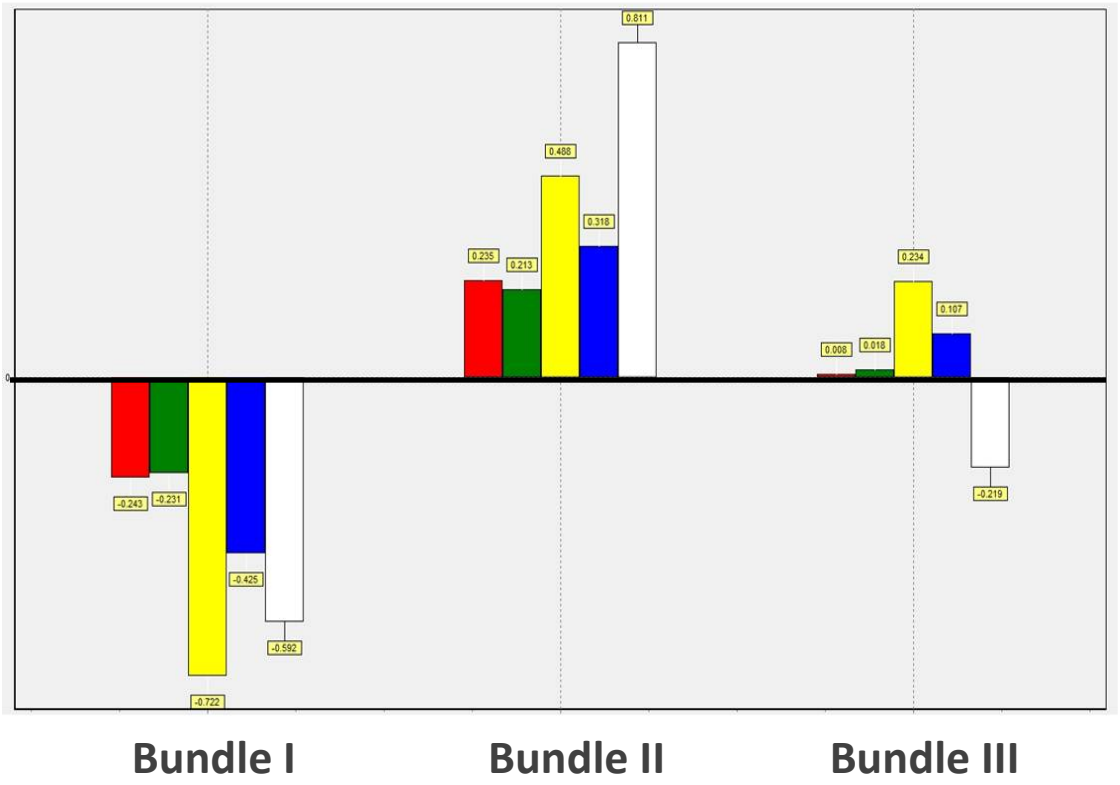
Net preference flows (all stakeholder)

Mean of net flows

2* standard deviation

- **Bundle II** has **highest net flow** considering the preferences of all stakeholders involved in the decision making process.
- The high level of uncertainty can be attributed to the **value margins** used and the **varying stakeholder preferences**.

4.5 Case Study: Evaluation & Prioritization



Net preference flows by individual stakeholders

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

- **Bundle II** obtains highest net flows, i.e. is **preferred by all stakeholders.**
- Bundle III is valued higher by all stakeholders than bundle I.

5. Conclusion

UFZ-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.

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5. Conclusion

PRIMATE …

- **accounts for uncertainty** with regard to the performances of the alternatives by offering probabilistic pairwise comparison of alternatives.
- allows for the simultaneous and explicit **consideration of the preferences** of several decision makers.
- **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 for your attention!

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3. Decision support tool PRIMATE: PROMETHEE

Exemplary Total Preference Matrix in PRIMATE

Measures

Entering flows

Leaving flows

	AP	W	BD	BF	BP	VM	VB	VD	F+
AP	0	0.422	0.169	0.252	0.310	0.297	0.080	0.453	1.985
W	0.027	0	0.134	0.201	0.184	0.184	0.054	0.241	1.028
BD	0.064	0.435	0	0.125	0.218	0.276	0.032	0.375	1.527
BF	0.044	0.387	0.025	0	0.140	0.172	0.037	0.292	1.100
BP	0.028	0.270	0.029	0.066	0	0.161	0.048	0.249	0.855
VM	0	0.254	0.068	0.078	0.159	0	0.054	0.164	0.779
VB	0.144	0.487	0.190	0.304	0.367	0.391	0	0.502	2.389
VD	0.047	0.202	0.060	0.091	0.145	0.074	0.054	0	0.677
F-	0.356	2.460	0.678	1.120	1.526	1.560	0.363	2.279	

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F-	0.356	2.460	0.678	1.120	1.526	1.560	0.363	2.279	
	Rank 1	Rank 8	Rank 3	Rank 4	Rank 5	Rank 6	Rank 2	Rank 7	

Leaving flows

Rank 2
Rank 5
Rank 3
Rank 4
Rank 6
Rank 7
Rank 1
Rank 8

- **PROMETHEE I**: Ranking based on leaving flows (F+) & entering (F-) flows
- **PROMETHEE II**: Ranking based on net flows

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3. Decision support tool PRIMATE: PROMETHEE

Exemplary Total Preference Matrix in PRIMATE

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F-	0.356	2.460	0.678	1.120	1.526	1.560	0.363	2.279	
Net flow	**1.629**	**-1.432**	**0.849**	**-0.020**	**-0.671**	**-0.781**	**2.026**	**-1.602**	

Rank based on net flows

Rank 2
Rank 7
Rank 3
Rank 4
Rank 5
Rank 6
Rank 1
Rank 8

- **PROMETHEE I**: Ranking based on leaving flows (F+) & entering (F-) flows

- **PROMETHEE II**: Ranking based on net flows

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