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Supplement of

Methods for safety-related weighting and comparative assessment in the site selection process (MABeSt)

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Federal Office
for the Safety of
Nuclear Waste Management

Methods for safety-related weighting and comparative assessment in the site selection process

SafeND 2021, “Selecting a repository site”, 10.11.2021

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safeND
Interdisciplinary research symposium on the safety of nuclear disposal practices

Outline

1. Work steps according to the StandAG procedure
2. The MABeST project
3. Short introduction to the decision model and MCDM methods
4. Application of the methods in the site selection procedure
5. Summary and Outlook

Work steps according to the StandAG[1] procedure

Phase 1	**§13** – Determination of **sub-areas** (BGE[2])
	§14 – Determination of **siting regions** for surface exploration (BGE)
	§15 – **Decision** on surface exploration and exploration programs (**BASE**[3], BMU[4], German Federal Parliament and the Federal Council)
Phase 2	**§16** – **Surface exploration** and proposal for underground exploration(BGE) ➢ Surface exploration of the siting regions, socio-economic potential
	§17 – **Decision** on underground exploration and exploration programs (**BASE**, BMU, German Federal Parliament and the Federal Council)
Phase 3	**§18** – **Underground exploration** (BGE) ➢ Underground exploration of the locations, application of the assessment criteria, environmental impact assessment (UVP), comparative assessment of the identified sites
	§19 – Final site comparison and **site recommendation** (**BASE**, BMU) **§20** – **Site decision** by the German Federal Parliament and the Federal Council

- Exclusion Criteria
- Minimum requirements
- **Geoscientific weighting criteria**

+

- **Preliminary safety analysis**
- Planning scientific weighting criteria

[1]StandAG – Law on the search and selection of a site for a repository for high-level radioactive waste /STA 17/
[2]BGE – Federal Company for Radioactive Waste Disposal
[3]BASE – Federal Office for the Safety of Nuclear Waste Management
[4]BMU – Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

The MABeST project

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BASE research agenda 2020[1]: *„The StandAG does not specify how these comparisons and evaluations are to be carried out methodically, how uncertainties due to different data availability, quality and comparability are to be dealt with, how different data may be weighted and how host rock-specific and host rock-independent data are to be considered.“ “For the aforementioned evaluations and comparisons, existing methods must be checked and, if necessary, further developed.”*

Research project MABeST:

- Duration 02.2019 – 31.10.2019 (by GRS), Funded by BASE (FKZ 4718F1300)

AP 1:

- Identification of work steps in the StandAG in which safety-related weighting and comparative assessment must be carried out and
- which related challenges arise in the work steps.

AP 2:

- Literature search on German and international publications with regard to weighting and comparative assessment methods that were applied to a site selection of a repository and other disciplines.
- Description and summary of the identified methods.

- **Evaluation of the applicability of the methods for the identified work steps in the StandAG.**

[1]https://www.base.bund.de/SharedDocs/Downloads/BASE/DE/broschueren/bfe/forschungsagenda_final.

Literature research to identify suitable methods

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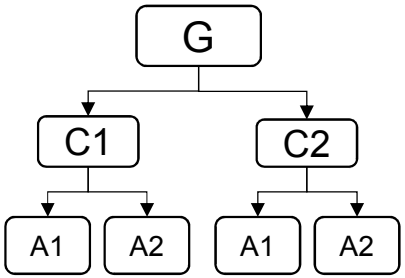
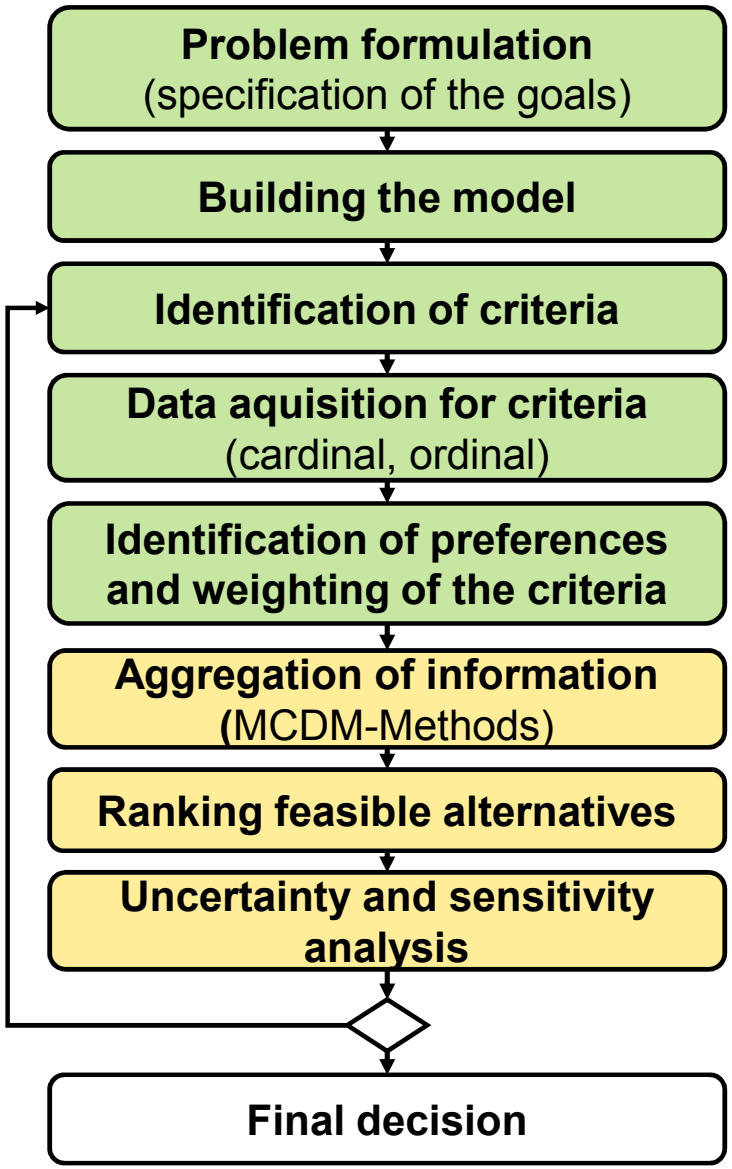
1. /BOL 11/ (EUGENIA) emphasizes that: *"... the **transfer** of the **concepts** and procedures for a repository site selection developed in other countries to Germany is only possible to a **limited extent**."*

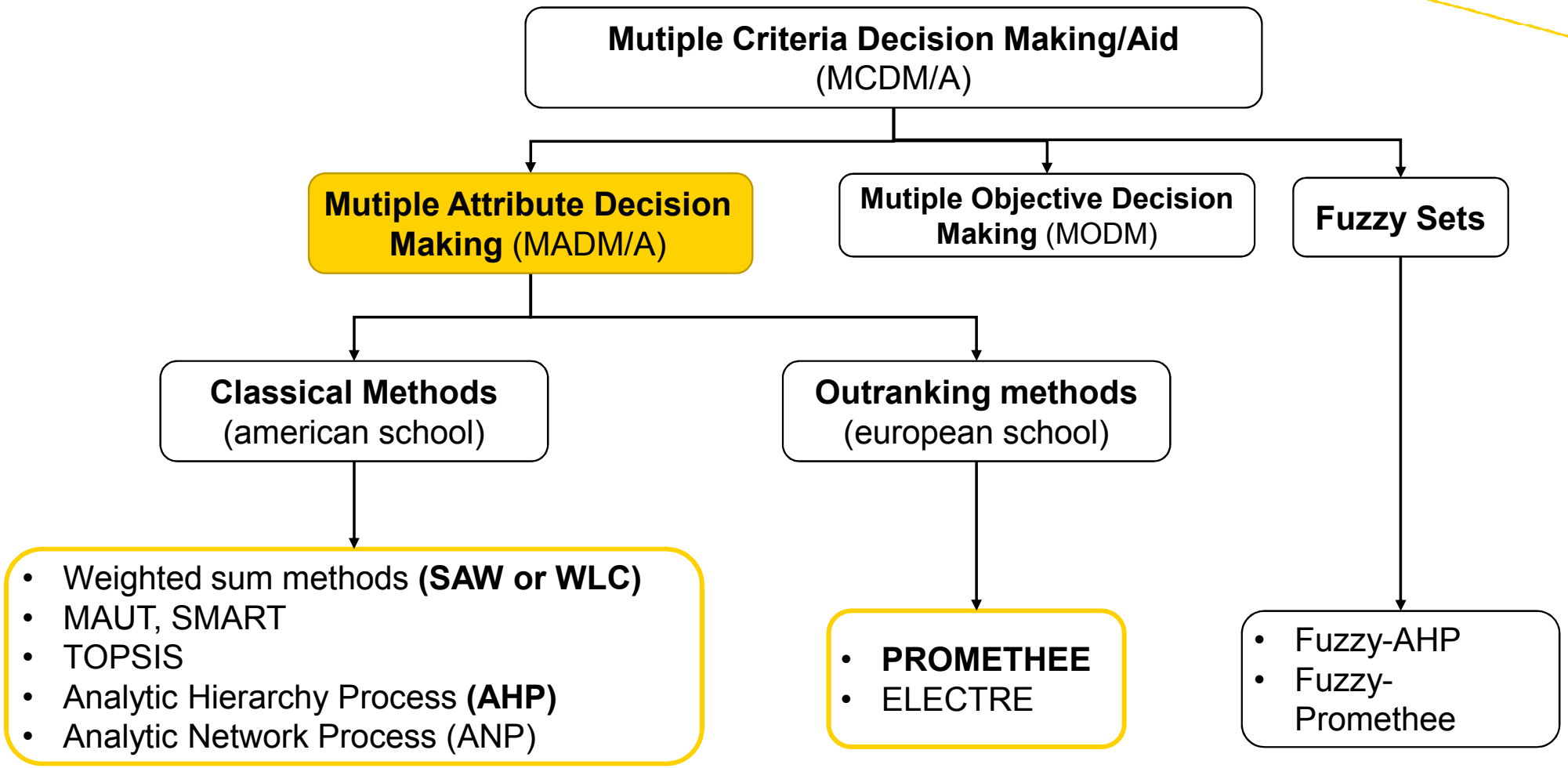
2. Methods from the decision theory, especially **Multi-Criteria Decision Making/Aid** (MCDM) tools are applicable for (all) types of decision-making problems, also for a repository site selection.
   - ➢ MCDM deals with structuring and solving decision and planning problems based on several criteria.

Decision model





Hierarchy of MCDM methods (-categories)



Applicability of the methods for the site selection procedure

- **Step 1 (screening):** Find **areas with favorable geological conditions** (alternatives). Delimitation of large areas, e.g. sub-regions to siting regions and finally sites.

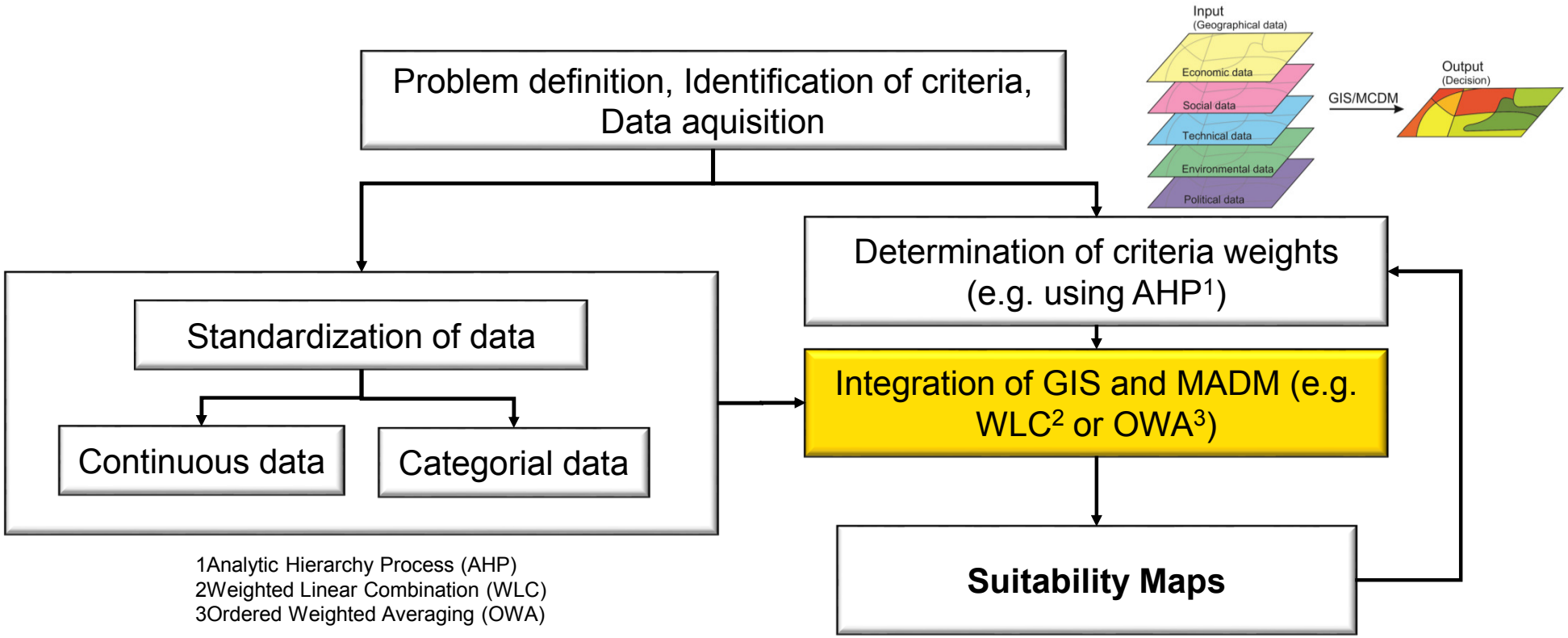
  ➢ **Method(s) for phase 1 and 2 – Spatial MCDM (GIS + MADM)**

- **Step 2 (evaluation):** Selection of the **"best possible" alternative(s)**. Comparative assessment of discrete locations.

  ➢ **Method for phase 3 (2) – Outranking methods**

Method(s) for phase 1 and 2 – Spatial MCDA (GIS + MADM)

- Spatial MCDA can also be called "**Overlay Analysis**", that combines several layers (geographical data) with the decision-maker's preferences to a "**decision map**".

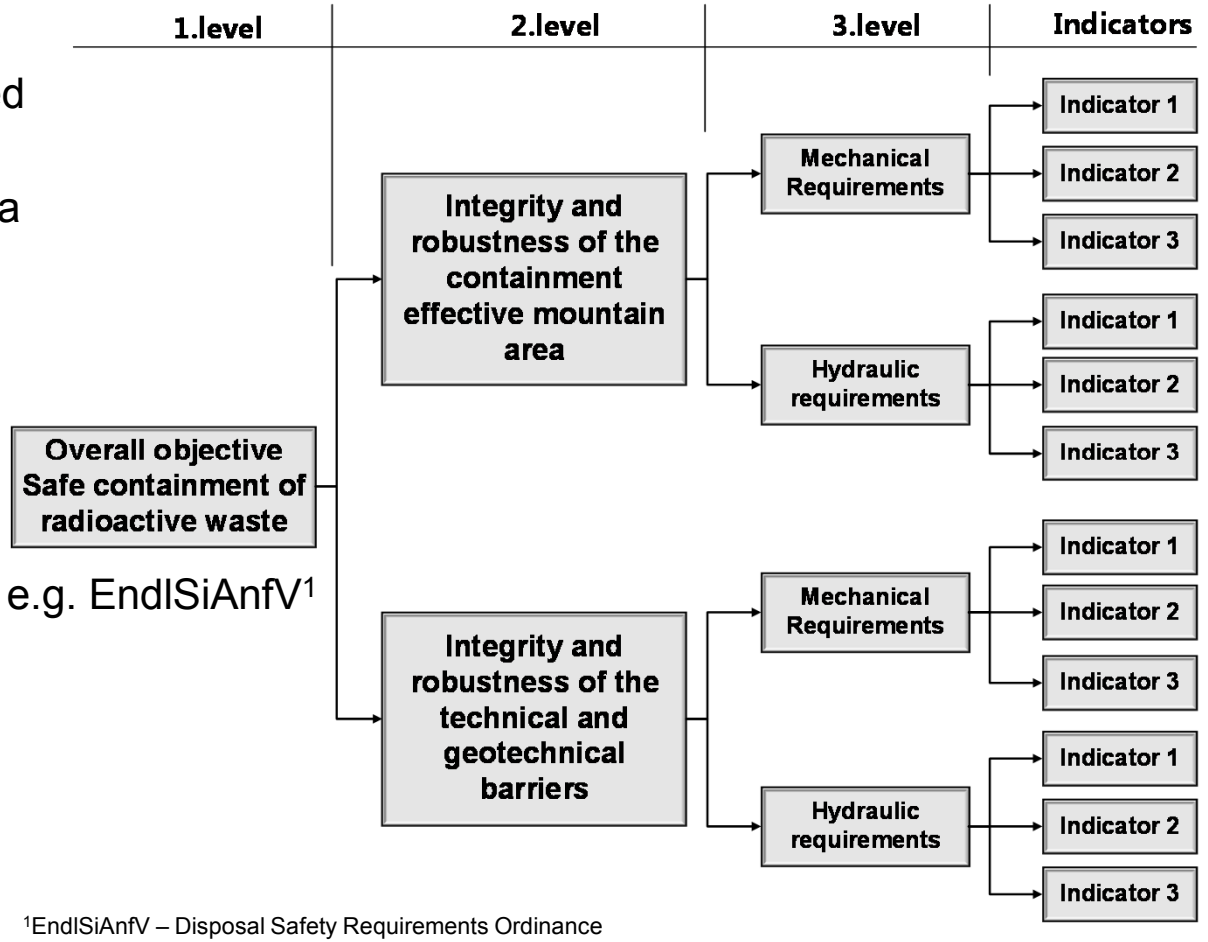


1Analytic Hierarchy Process (AHP)
2Weighted Linear Combination (WLC)
3Ordered Weighted Averaging (OWA)

modified after https://www.researchgate.net/publication/280768547_105937jaes12-4938_GIS_based_multi-criteria_decision_analysis_for_industrial_site_selection_The_state_of_the_art
modified after https://www.sciencedirect.com/science/article/pii/S2215016119301669

A hierarchical goal system

- Structuring of the problem based on the goal system.
- Support for weighting the criteria (AHP or ANP method)
- Evaluation or aggregation on different hierarchical levels.



→ e.g. EndlSiAnfV[1]

[1]EndlSiAnfV – Disposal Safety Requirements Ordinance
EndlSiUntV – Disposal Safety Analysis Ordinance.

Method for phase 3 (2) – Outranking methods

- Outranking methods compare the alternatives **pairwise** for each criterion, finding the strength of preferring one over the other.
- **Low compensation:** an aggregation of the criteria data is only partially necessary.
- Outranking methods were developed to optimize the disadvantages of the classic methods. The decision maker can have **“fuzzy” preferences** (preference functions).
- For example: **PROMETHEE** (**P**reference **R**anking **O**rganisation **Meth**od for **E**nrichment **E**valuation) method.

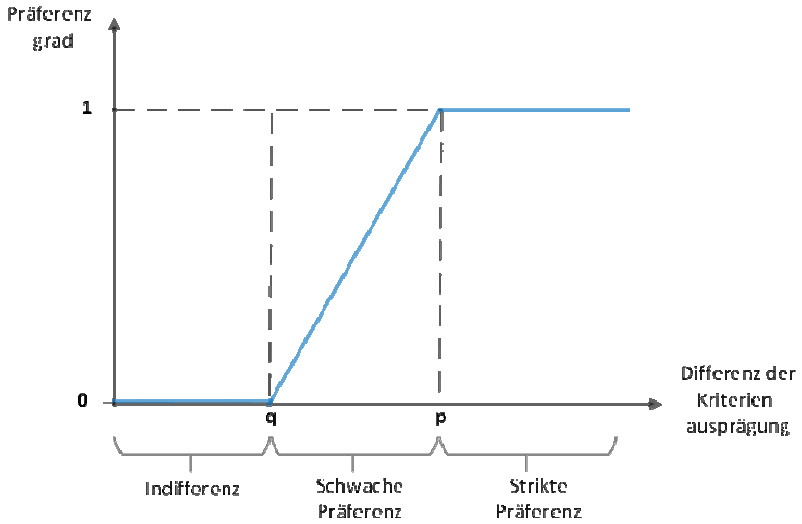
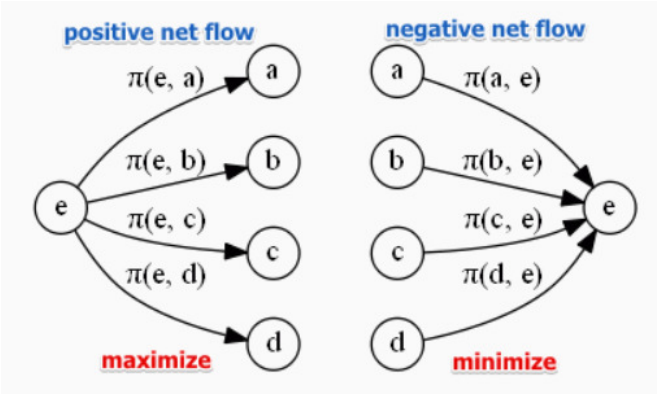


Figure modified from Gelderman /GEL 14/

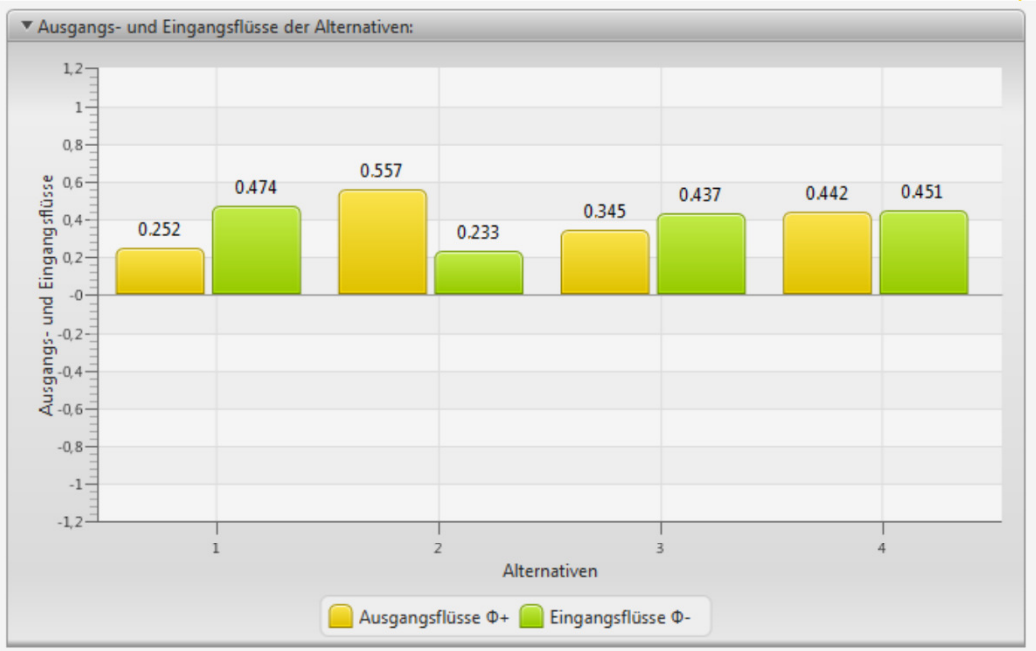
PROMETHEE results

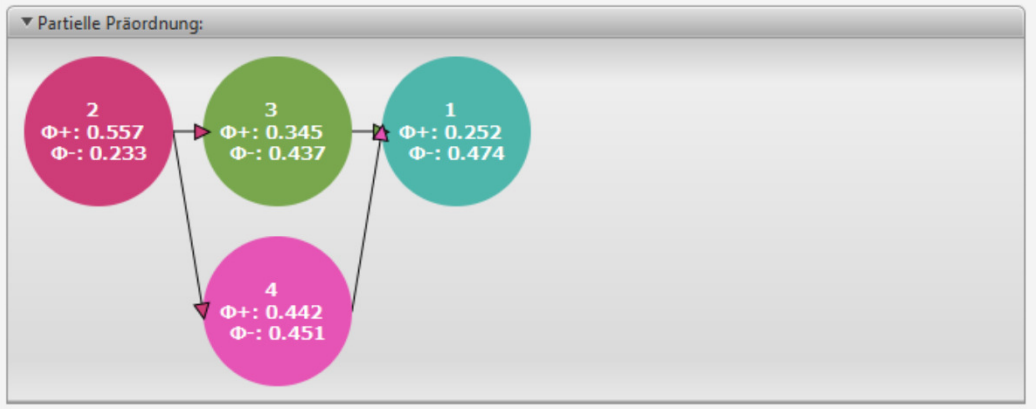
- Outranking flows



http://mlwiki.org/index.php/PROMETHEE

- Preference, Indifference, Incomparability





Gelderman /GEL 14/

Consideration of uncertainties in MADM methods

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A basic distinction is made between two general types of uncertainty:

Epistemic (internal uncertainties): uncertainties that arise during the creation of the decision model, e.g. "subjective" survey of preferences and criteria weights.

Aleatory (external uncertainties)**:** uncertainties resulting from environmental conditions, including the quality of the input data (e.g. measurement errors), future developments of the environment (Scenario analysis).

There are different approaches to dealing with uncertainties in MCDA methods:

- Preference functions
- Fuzzy theory, Fuzzy sets
- Bayesian belief nets

➢ The effects of the various criteria and environmental conditions on the results can/must be examined by **sensitivity analysis** (e.g. check robustness of the ranking).

Summary

Phase 1 and 2 StandAG: Delimitation of large areas

- The delimitation of large areas is mainly based on geoscientific weighting criteria.
- First approaches how to aggregate the geoscientific weighting criteria were examined in the RESUS[1] project.

Phase 3 (2): Comparison of individual regions/sites or respectively repository systems

- For a comparison of repository systems, the geoscientific weighting criteria are maybe not suitable.
- The preliminary safety analysis can only be applied to a limited extent, if several sites meet the regulatory requirements, they are deemed to be eligible for approval.
- The VerSi[2] 1-2 (3) project provides a methodology for comparing repository systems on the basis of a robustness assessment.

- For phase 1 and 2 – **Spatial MADM** (e.g. WLC, OWA, AHP) and
- for phase 3 (2) – **Outranking methods (**e.g. PROMETHEE, ELECTRE**)** appear to be suitable.
- The consideration of uncertainties through **fuzzy methods** needs to be further examined.

[1]https://www.grs.de/publikationen/grs-567
[2]https://www.researchgate.net/publication/326345410_Weiterentwicklung_einer_Methode_zum_Vergleich_von_Endlagerstandorten_in_unterschiedlichen_Wirtsgesteinsformationen
EndlSiAnfV – Disposal Safety Requirements Ordinance or EndlSiUntV – Disposal Safety Analysis Ordinance.

Final assessment and Outlook

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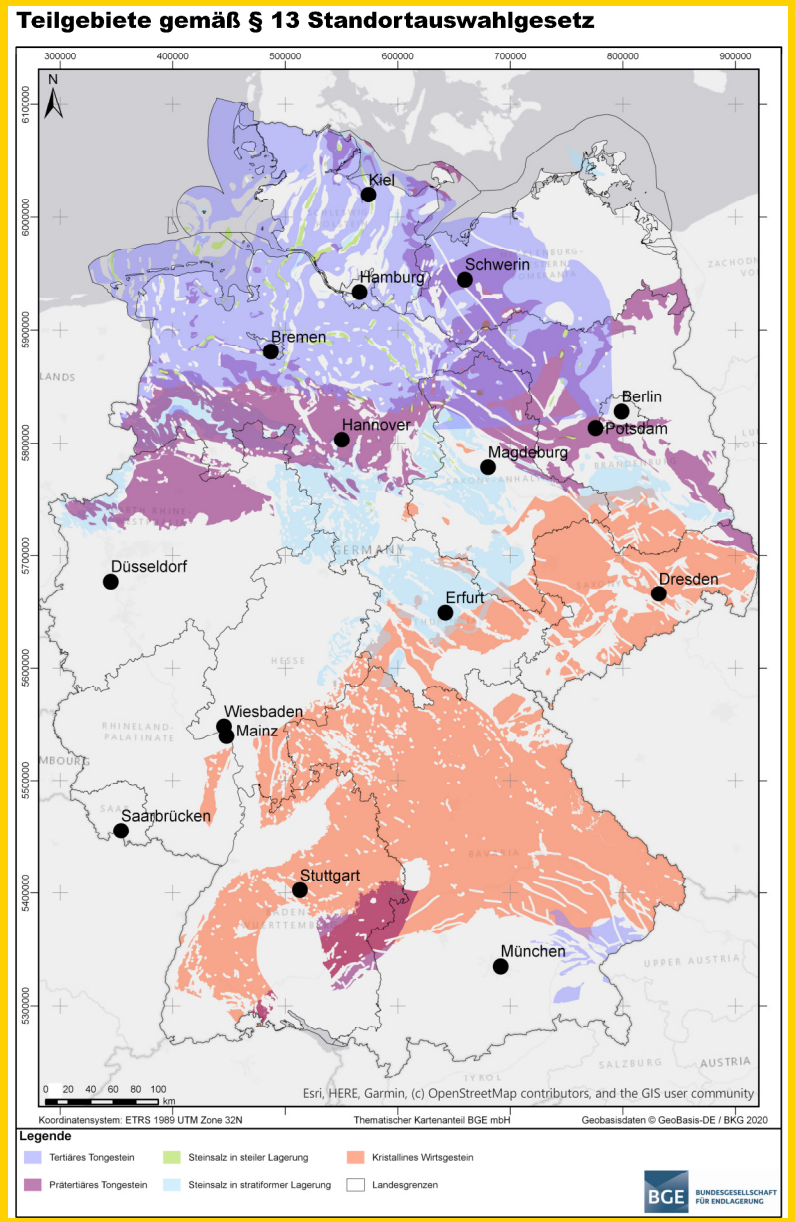
- MADM helps to achieve comprehensible and transparent decision-making. It should be understood as a **decision "support" tool**, not decision make.
- The applicability and suitability of the methods mentioned should be tested **on a specific decision problem**.
- A combination of **MADM methods** and the **verbal argumentative method** should be investigated.
- A certain amount of "Aggregation" of the data is always necessary, also in the verbal argumentative method. A compensation of information cannot completely be avoided.

Thank you for your Attention!

MABeST Report download:
https://www.base.bund.de/SharedDocs/Downloads/BASE/DE/fachinfo/fa/MaBest_Abschlussbericht_2020.pdf;jsessionid=30D37C6891B2862671FC2FF79F10DC61.1_cid365?__blob=publicationFile&v=4



https://www.bge.de/fileadmin/user_upload/Standortsuche/Wesentliche_Unterlagen/Zwischenbericht_Teilgebiete/Karte_Teilgebiete_A4.jpg

Literature

- /STA 17/ Gesetz zur Suche und Auswahl eines Standortes für ein Endlager für hochradioaktive Abfälle (Standortauswahlgesetz - StandAG) in der Fassung vom 5. Mai 2017 (BGBl. I 2017, Nr. 26, S. 1074-1100), zuletzt geändert 20. Juli 2017 (BGBl. I 2017, Nr. 52, S. 2808-2838).
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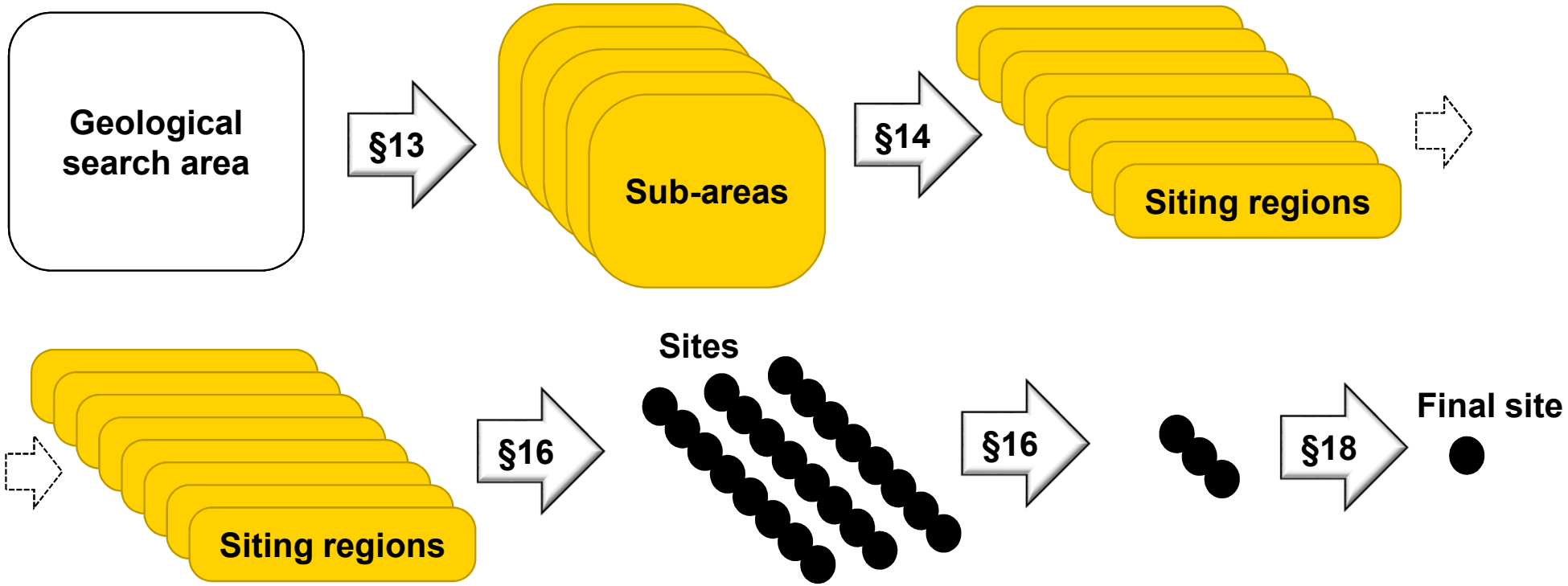
Elements of the decision problem

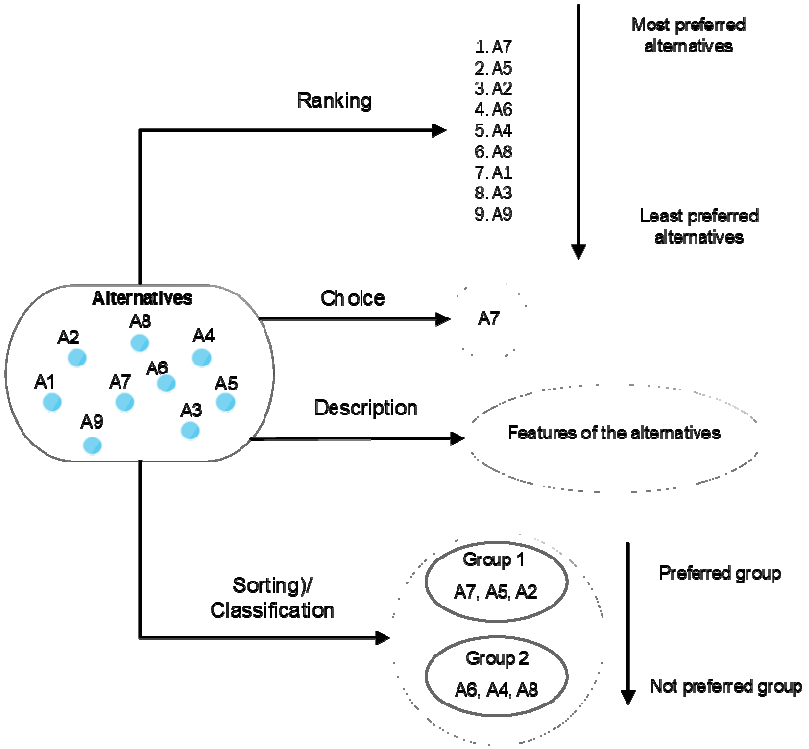
- **Laws and guidelines** (e.g. StandAG, Governmental directives (EndlSiAnfV, EndlSiUntV))
  - Provide the general framework (e.g. definition of assessment criteria)
- **Actors (scientists, stakeholders, public**)
  - Different preferences and goals
- **Goal system (main and secondary goals)**
  - Conflicts of objectives, e.g. retrievability vs. long-term safety
- **Geological boundary conditions**
  - e.g. rock salt in steep (diapir) or flat stratification
- **Various repository systems (host rock-specific)**
  - containment-providing rock zone, engineered barriers system, disposal in drifts or boreholes
- **Environmental conditions (FEP and Scenario development)**
  - e.g. marine transgressions, glaciation
- **Evaluation criteria**
  - Criteria data/values (heterogeneous data situation, cardinal, ordinal), weighting
- **Uncertainties (developing)**
  - Uncertain Data, preferences (weighting of criteria)

Schematic view of the work steps according to StandAG



- **Weighing/Weighting:** comparative consideration and checking of advantages and disadvantages
- **Comparative assessment:** choosing the "best" or most preferred option from a number of available alternatives

Decision model



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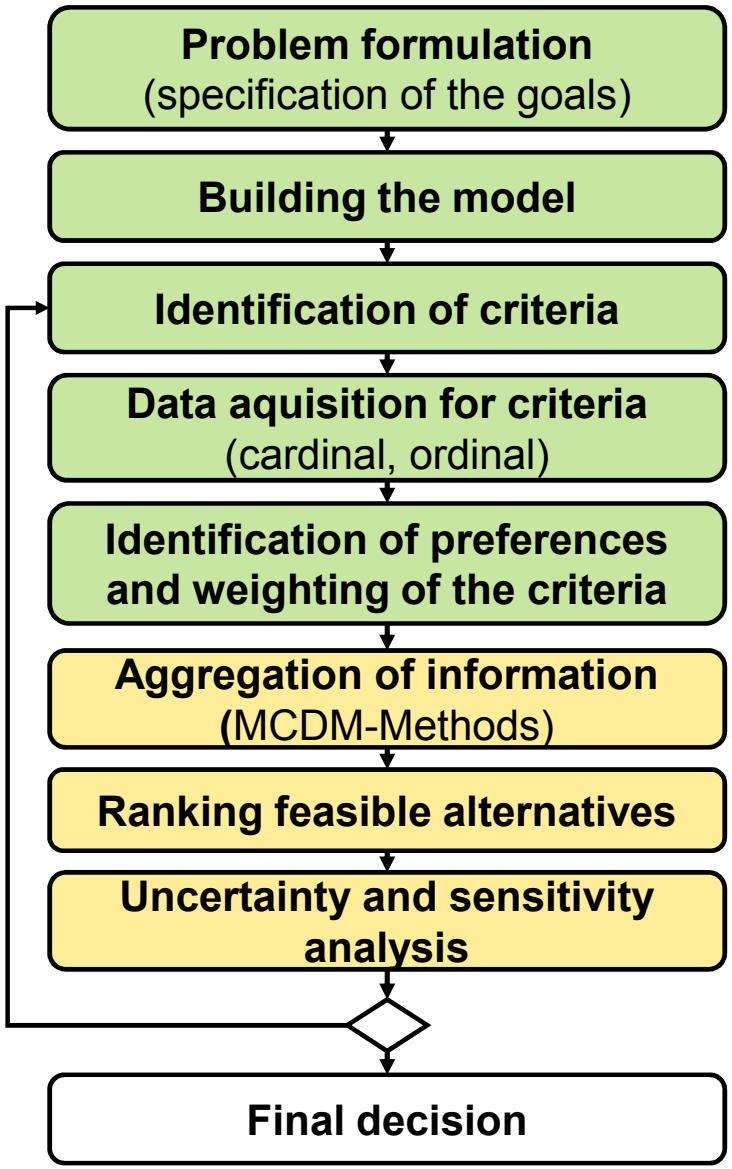

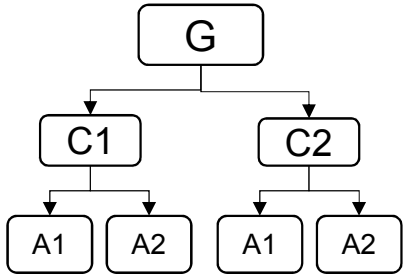

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Aggregation of information - Decision matrix

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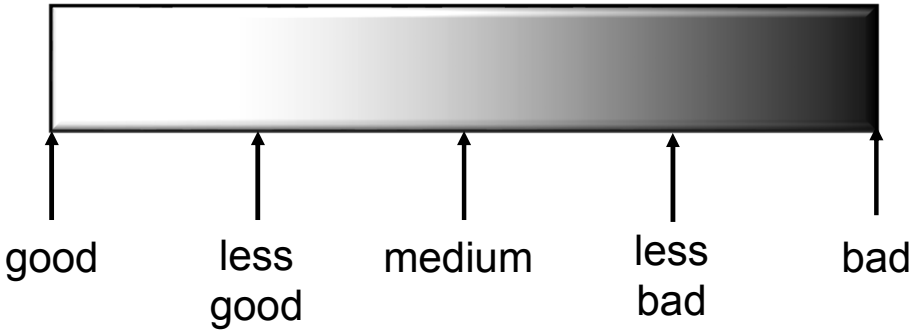
Kriterien	C1	C2	C3	C4	C5
Gewichtung	0,1	0,3	0,1	0,2	0,3
Alternative A	33	2	5	15	0,6
Alternative B	7	10	12	25	1,05
Alternative C	15	5	2	28	0,4
Alternative D	29	0,5	6	12	0,2
Alternative E	10	11	22	7	0,05

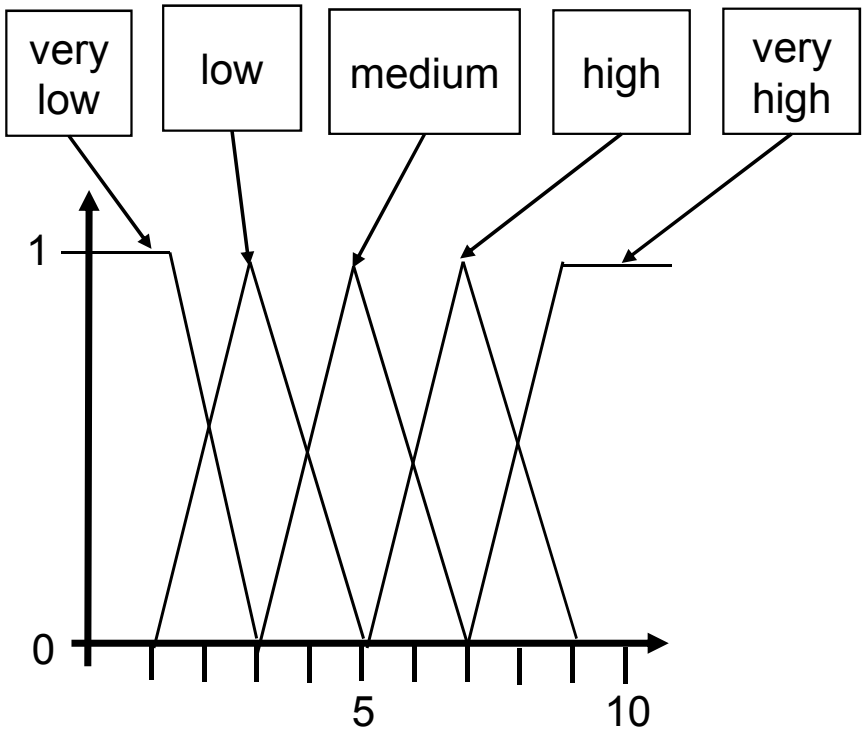
Fuzzy theorie

Classic set theory

Fuzzy set theorie



Linguistic uncertainty



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