Wuppertal Institute
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Sustainable use of excess wind power shares

A multi criteria analysis of different grid- and storage options

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SUSTAINABLE USE OF EXCESS WIND POWER SHARES – A MULTI CRITERIA ANALYSIS OF DIFFERENT GRID- AND STORAGE OPTIONS

Christine Krüger
Research Group “Future Energy and Mobility Structures”

International Renewable Energy Storage Conference IRES

Excess wind power shares
Grid restrictions or negative residual loads

Two possible definitions:

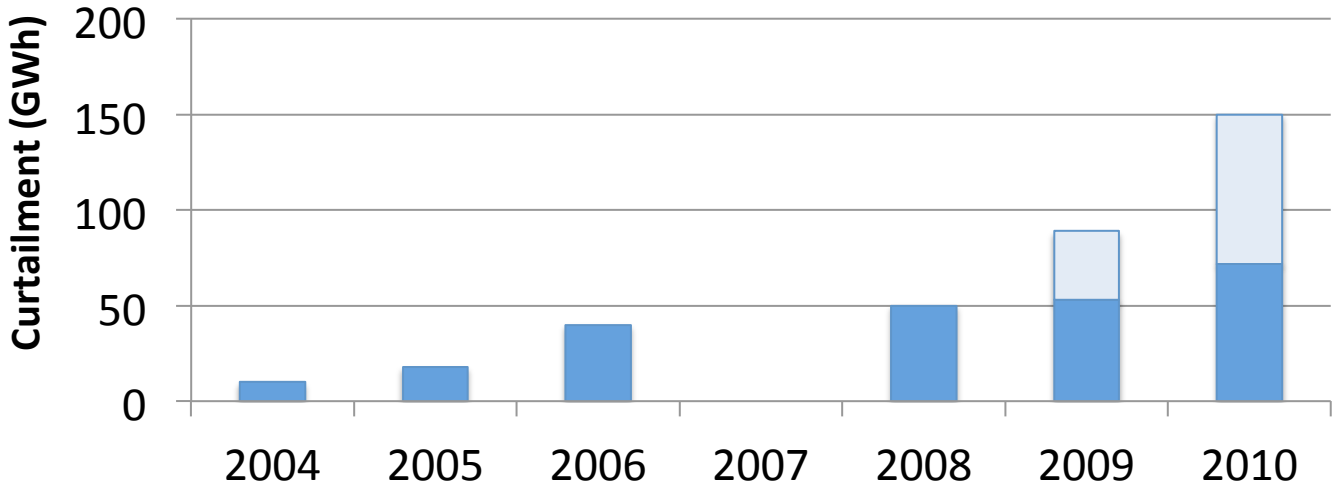
1) Renewable energy that cannot be used due to grid restrictions
   → Local problem
   → Energy must be curtailed

2) Renewable feed-in that exceeds electricity demand
   → Negative residual loads - “global” problem

Here: Focus on situation in 2020

Development of surplus energy amounts
Rapid increase in curtailed wind energy

- Grid extension cannot keep up with growth in installed renewable capacities
- ➢ Curtailment



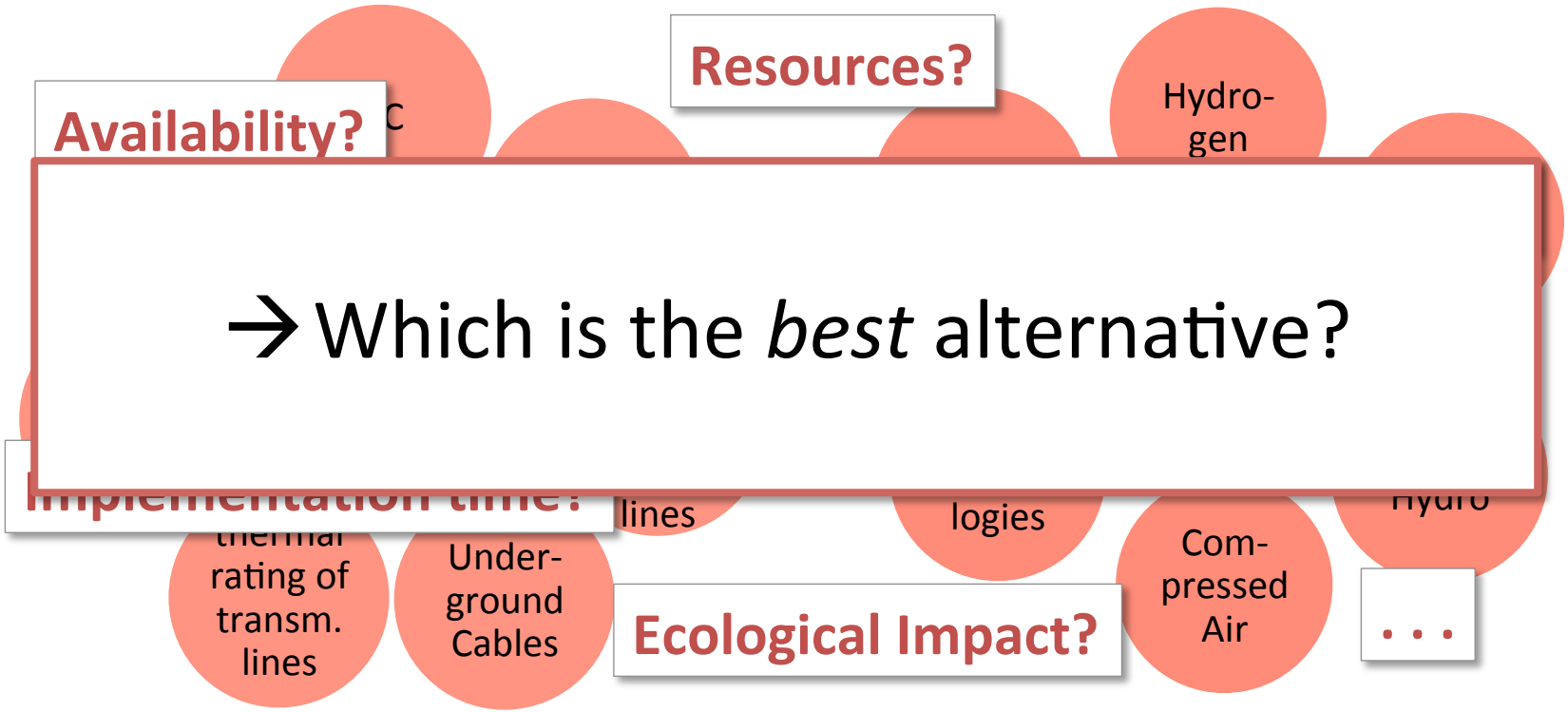
- Bottlenecks: distribution grid (110 kV), since 2009: also transmission grid (220/380 kV)

Source: J. Bömer (ecofys) "Abschätzung der Bedeutung des Einspeisemanagements nach EEG 2009 - Auswirkungen auf die Windenergieerzeugung in den Jahren 2009 und 2010", Berlin, Oktober 2011

What can be done?

Alternatives to handle surplus energy amounts

- Different options:



Multi Criteria Analysis
One method for assessing such problems

- The Multi Criteria Analysis (MCA) is a method to face complex problems where one-dimensional approaches fall short

- In the MCA, the analyst structures the problem, evaluetes the possible solutions and creates a basis for decision-making

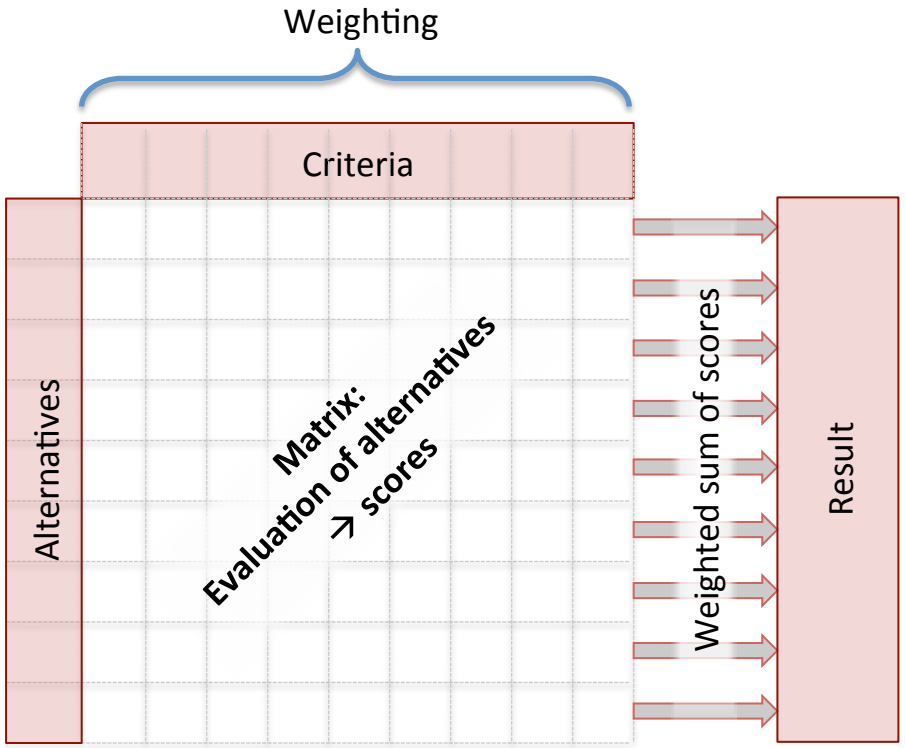
- Results of the MCA:
  - Ranking of alternatives
  - Awareness of influences in decision making
  - Consciousness of priorities

Multi Criteria Analysis
Procedure

- Four steps:

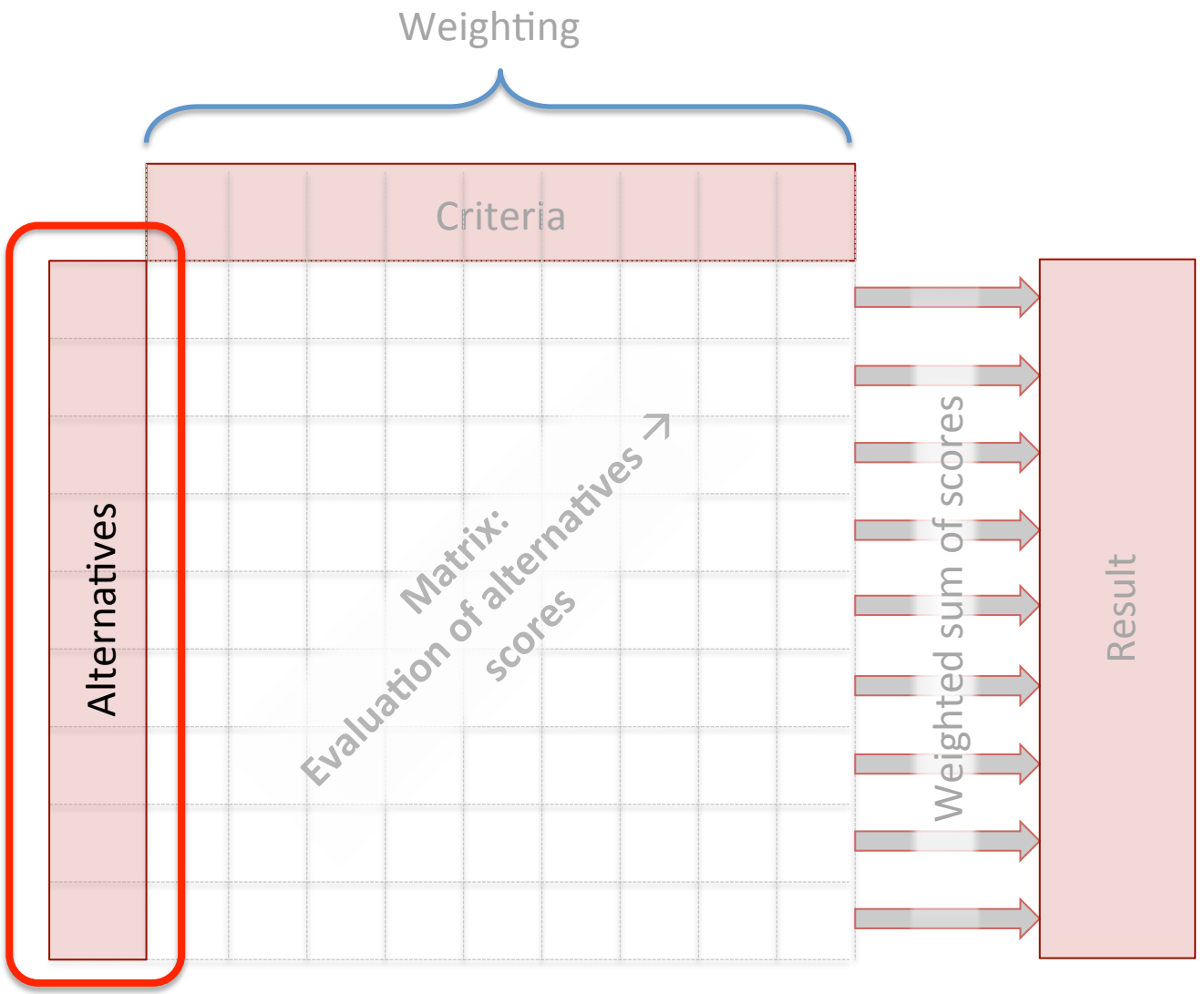
1. Determine **alternatives** suitable for the problem
2. Define **criteria** which fit the alternatives
3. **Evaluate** the alternatives against the criteria
4. **Weighting** of the criteria

➢ The result is the weighted sum of evaluations



Multi Criteria Analysis

1) Determine **alternatives** suitable for the problem



Multi Criteria Analysis

1) Determine **alternatives** suitable for the problem

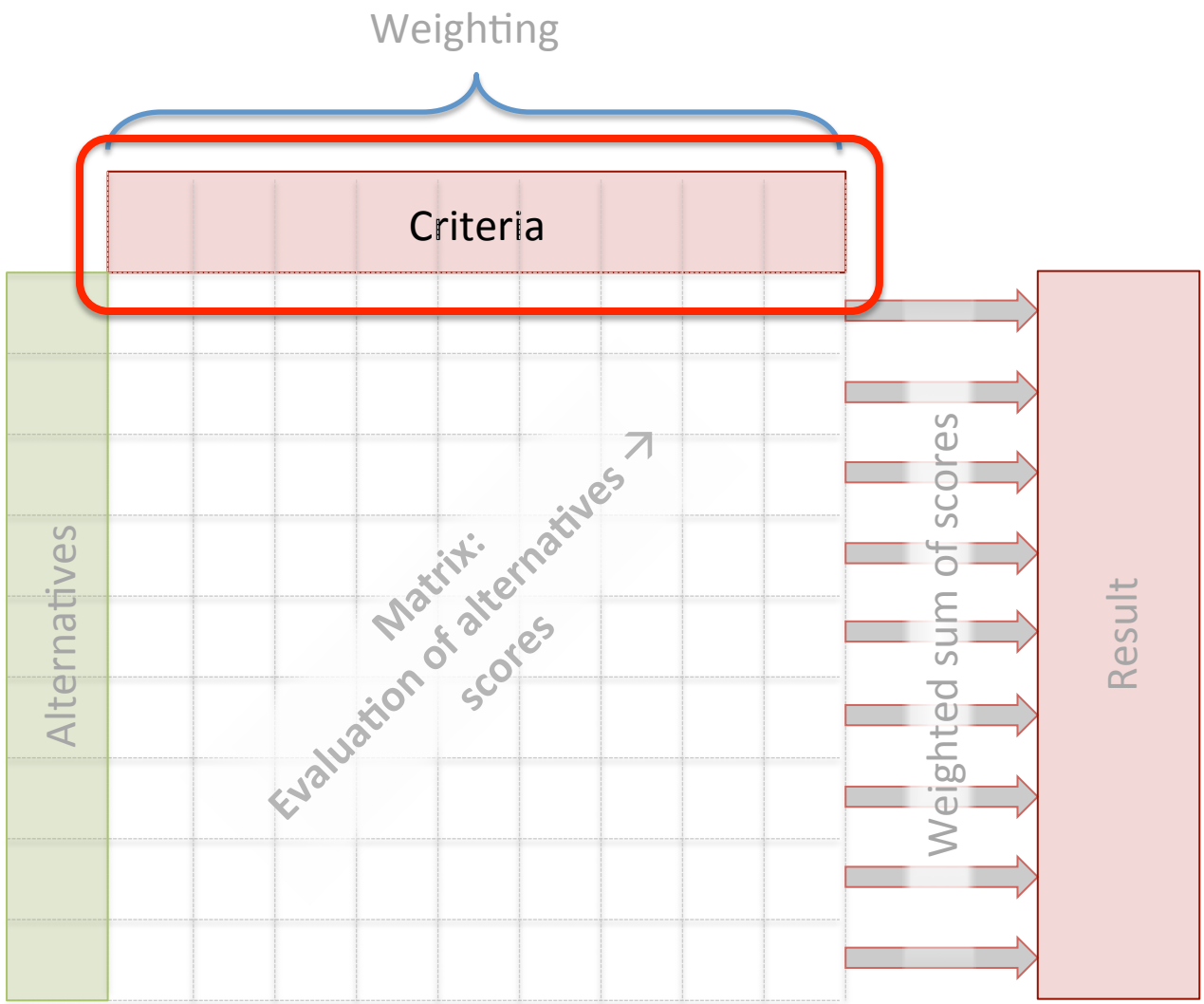
Curtailment	Hydrogen (cavern storage)
	Hydrogen (gas grid)
DC overhead lines	Redox-Flow-Batteries
DC underground cables	NaS-Batteries
AC overhead lines	CAES (status)
AC underground cables	CAES (adiabatic)
Dynamic thermal rating *	Pumped hydro (status)
High temp. transmission lines	Pumped hydro (new concepts)

* dt: Freileitungsmonitoring

DC: Direct Current
AC: Alternating Current
CAES: Compressed Air Energy Storage
NaS: Sodium Sulphur

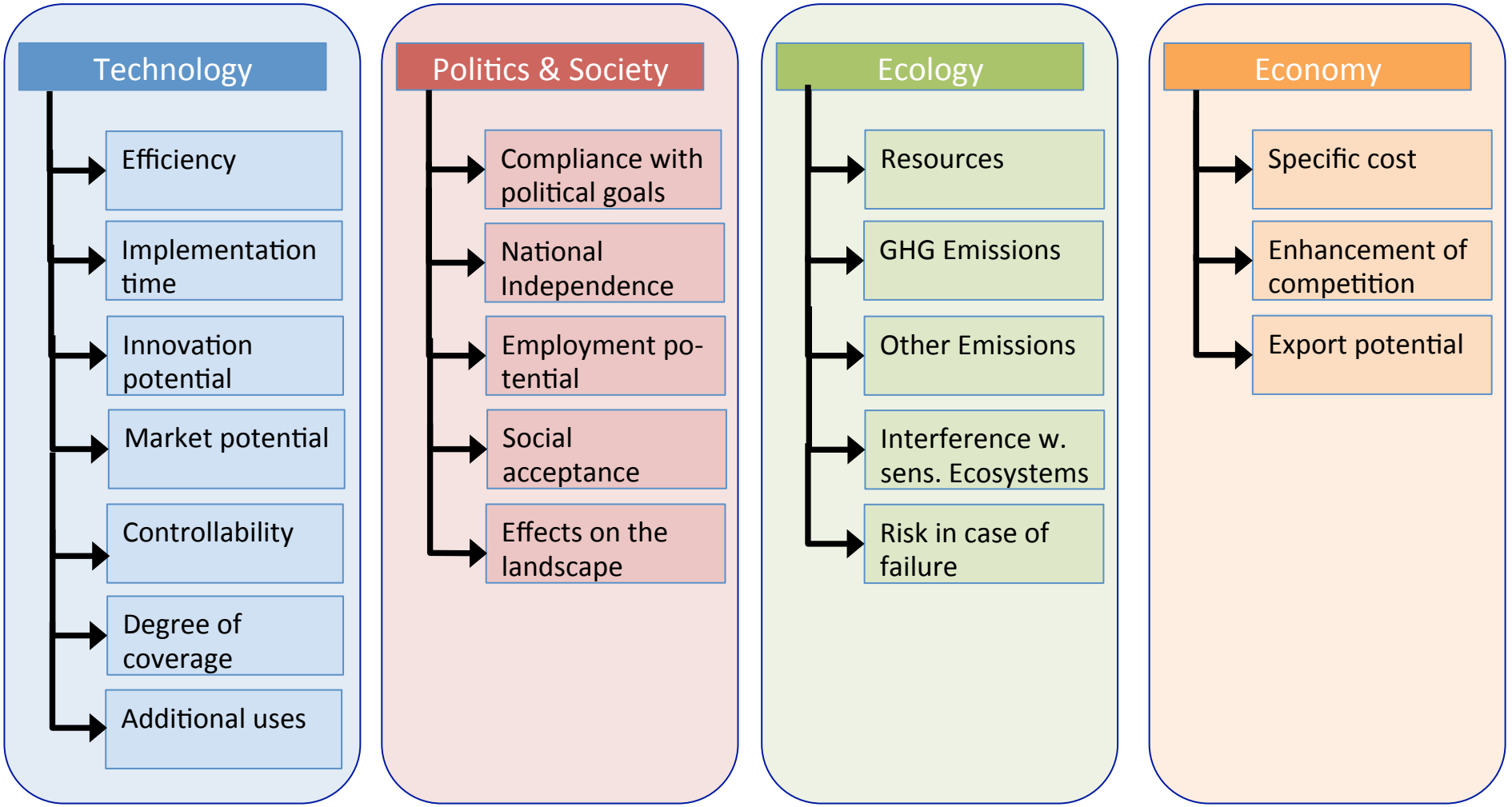
Multi Criteria Analysis

2) Define **criteria**



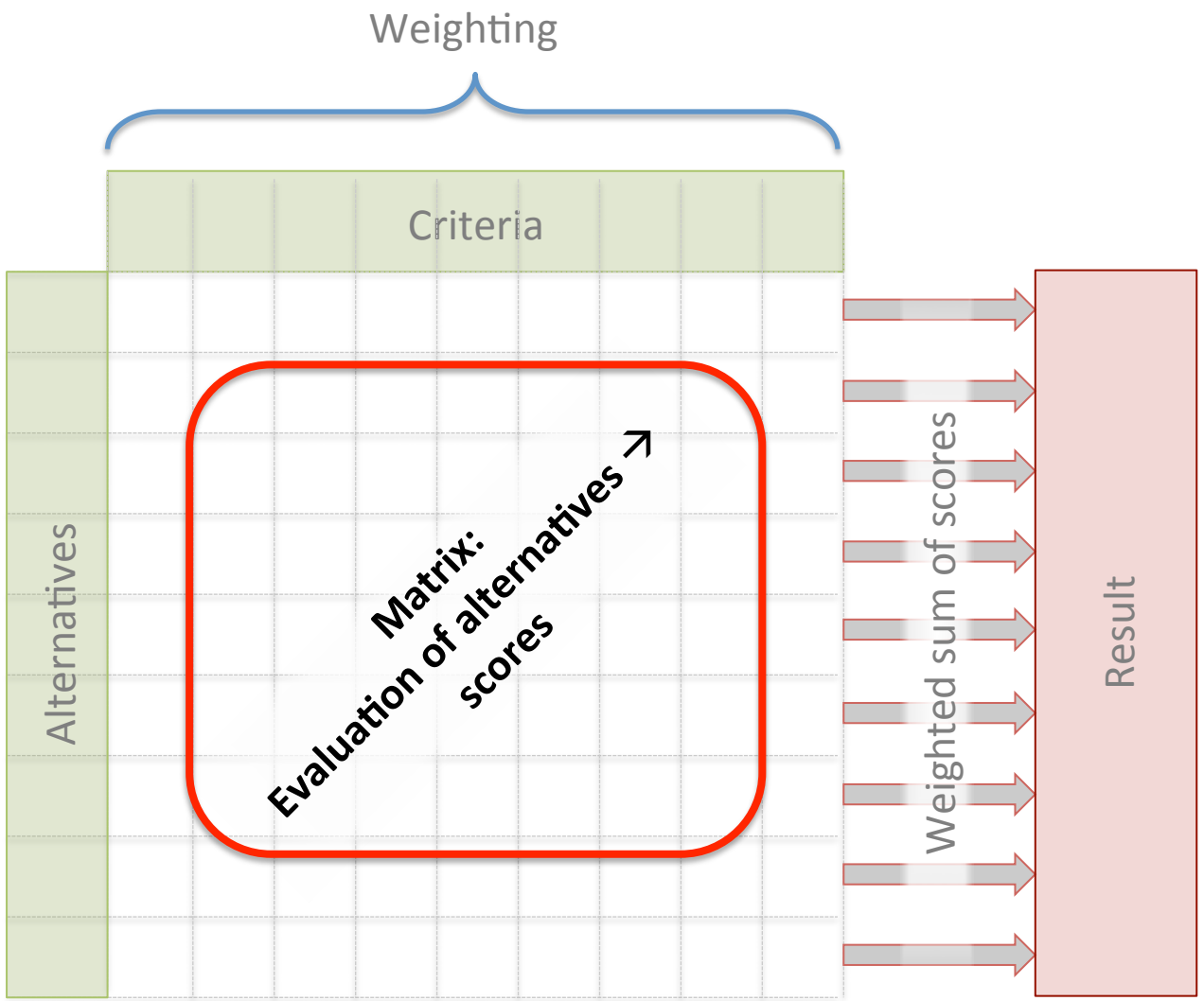
Multi Criteria Analysis

2) Define **criteria**



Multi Criteria Analysis

3) **Evaluate** the alternatives against the criteria



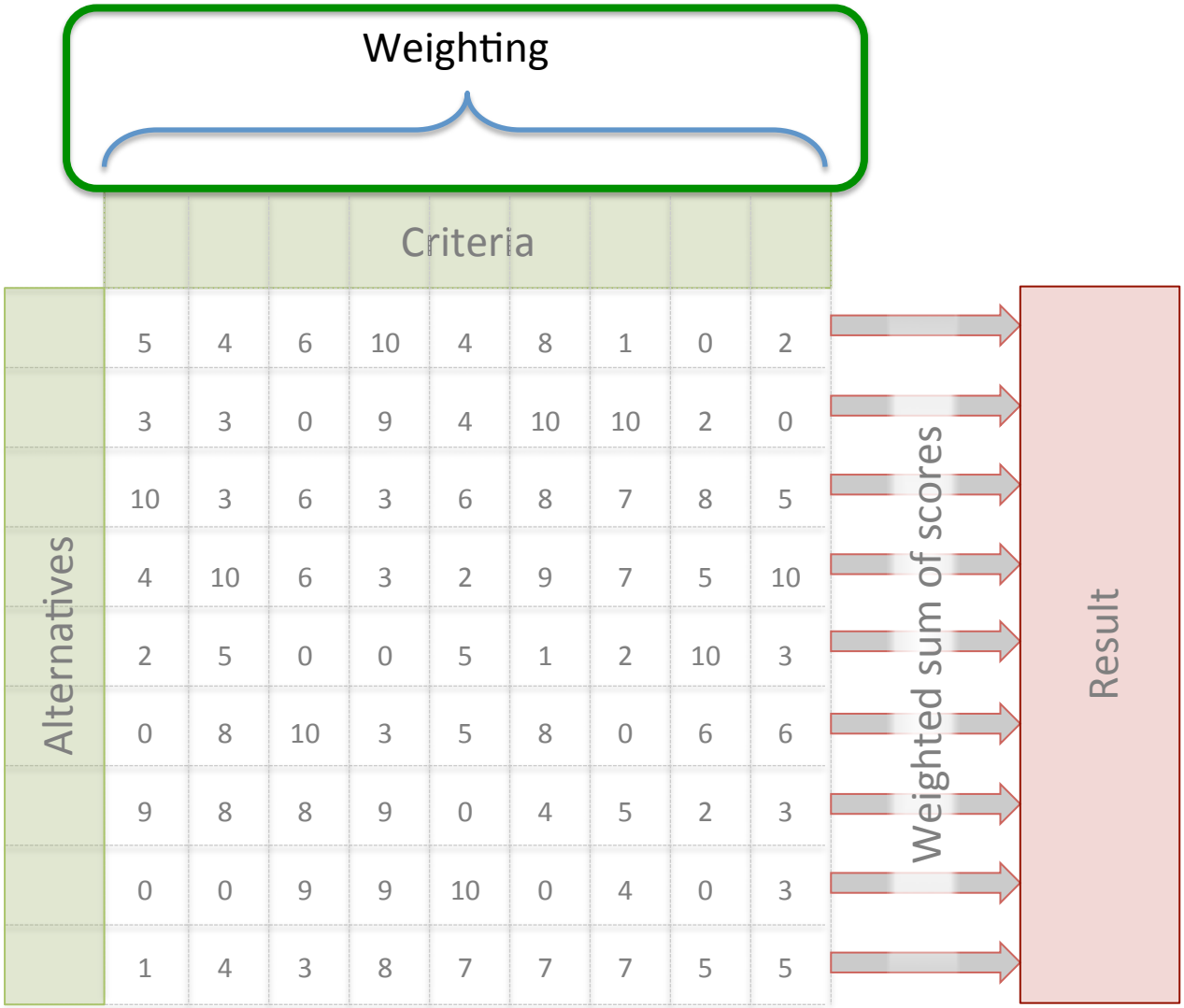
3) **Evaluate** the alternatives against the criteria

- Evaluate the alternatives
  - Calculations
  - Inquiries
  - Expert interviews
  - …
- Fit indicators for each criterion
  - “0” for the weakest, “10” for the strongest alternatives
  - linear values for other alternatives
  - “5” if evaluation is not possible

	Criteria								
Alternatives	5	4	6	10	4	8	1	0	2
	3	3	0	9	4	10	10	2	0
	10	3	6	3	6	8	7	8	5
	4	10	6	3	2	9	7	5	10
	2	5	0	0	5	1	2	10	3
	0	8	10	3	5	8	0	6	6
	9	8	8	9	0	4	5	2	3
	0	0	9	9	10	0	4	0	3
	1	4	3	8	7	7	7	5	5

Multi Criteria Analysis

4) **Weighting** of the criteria



4) **Weighting** of the criteria

Many different weighting methods. Examples:

- Equal weights ($w_1 = w_2 = \ldots = w_n = 1/n$)
- Subjective weighting methods
  - Rank-order weighting ($w_1 \geq w_2 \geq \ldots \geq w_n$, $\Sigma w_i = 1$)
  - Analytical Hierarchy Process (AHP)
  - …
- Objective weighting methods
  - …

Here: use the AHP

→ Analytical

→ Good documentation of weighting steps

→ Identify inconsistent weightings

Analytical Hierarchy Process (AHP)
Procedure

1. Categorise the criteria in two or more levels

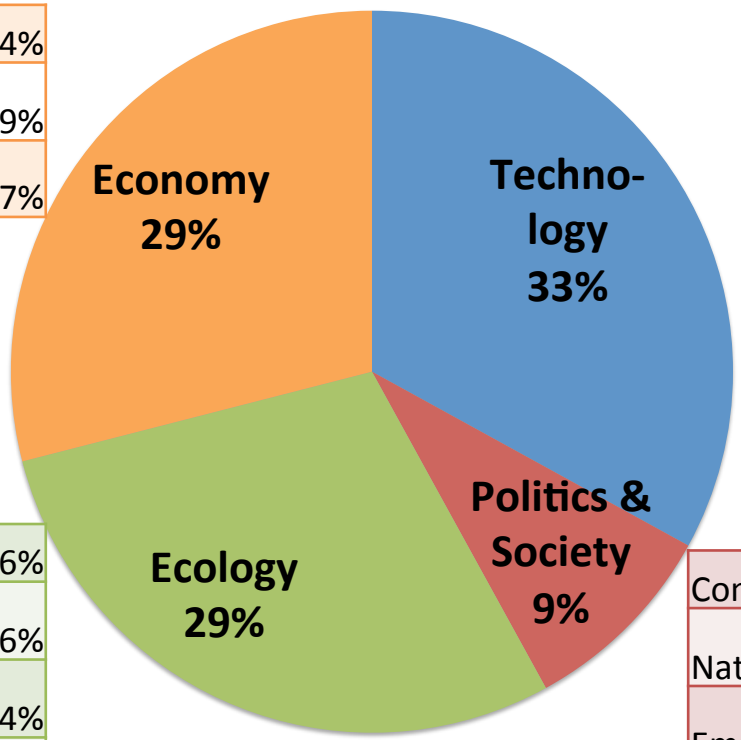
2. Pairwise comparison of criteria in each category
   - "How much more important is criterion I in comparison to criterion II ?"
   - Scale: 1/9 (much less important) … 1 (equal) … 9 (much more important)

```
Matrix =
    1.0000    3.0000    0.3333    1.0000
    0.3333    1.0000    0.3333    0.3333
    3.0000    3.0000    1.0000    1.0000
    1.0000    3.0000    1.0000    1.0000

Eigenwerte =
   4.1545 + 0.0000i
  -0.0773 + 0.7974i
  -0.0773 - 0.7974i
   0.0000 + 0.0000i

CR =
    0.0579

Konsistenzmaßzahl ok, keine größeren Widersprüche in der Matrix
 Gewichtung: normierter Eigenvektor zum Eigenwert
    4.1545

Gewichtung =
    0.2234
    0.0956
    0.3943
    0.2867
```

Resulting weighting vector

Analytical Hierarchy Process (AHP)
Weighting results in this project

Specific cost	74%
Enhancement of competition	9%
Export potential	17%

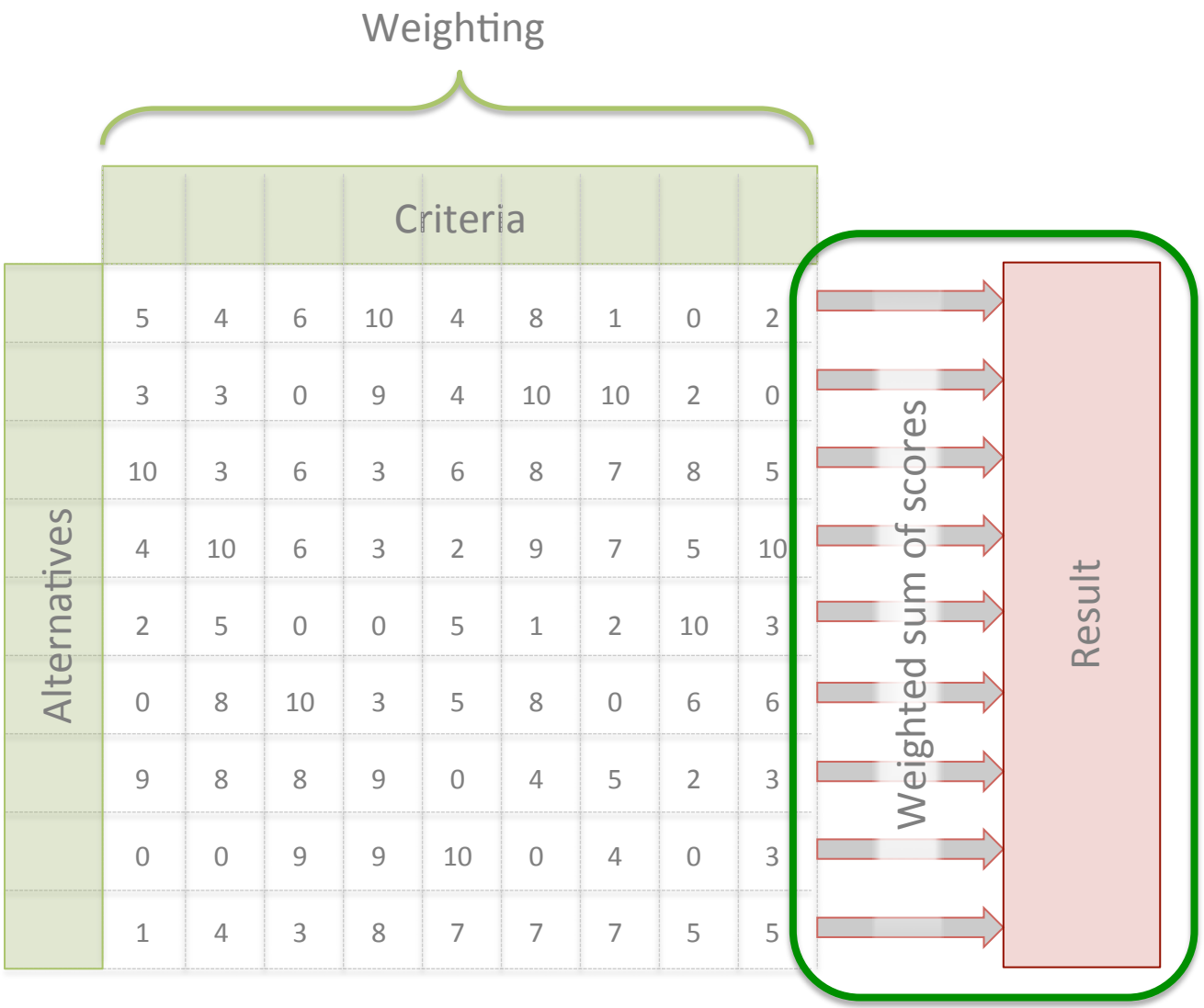


Efficiency	22%
Implementation time	5%
Innovation potential	12%
Market potential	29%
Controllability	3%
Degree of coverage	21%
Additional uses	8%

Resources	16%
GHG Emissions	56%
Other Emissions	4%
Interference w. Ecosystems	18%
Risk in case of failure	7%

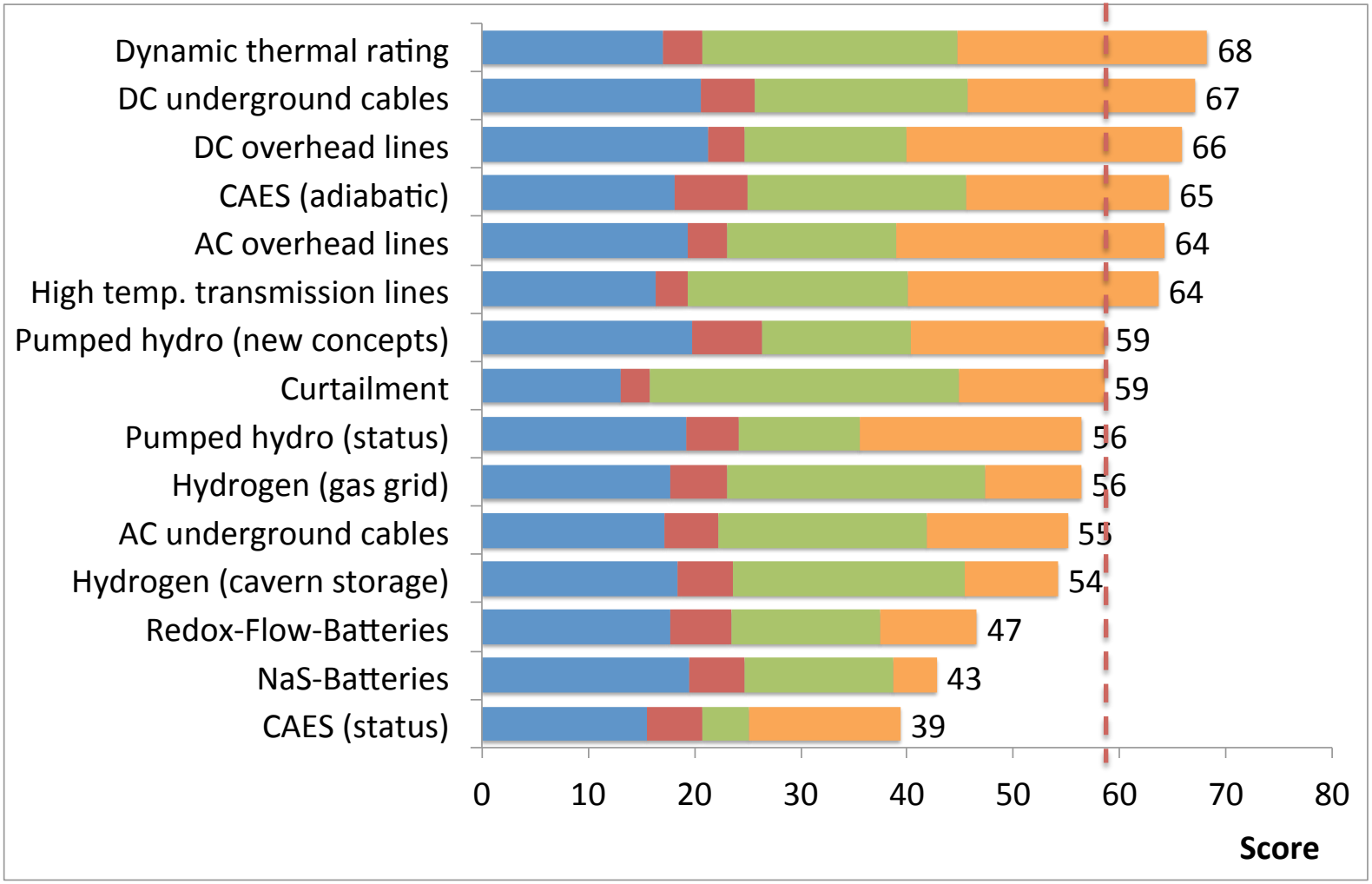
Compliance with political goals	4%
National independence	17%
Employment potential	52%
Social acceptance	20%
Effects on the landscape	8%

Applying values and weights
Results of the MCA



Result of the MCA

Ranking of technologies for sustainable handling of excess wind power



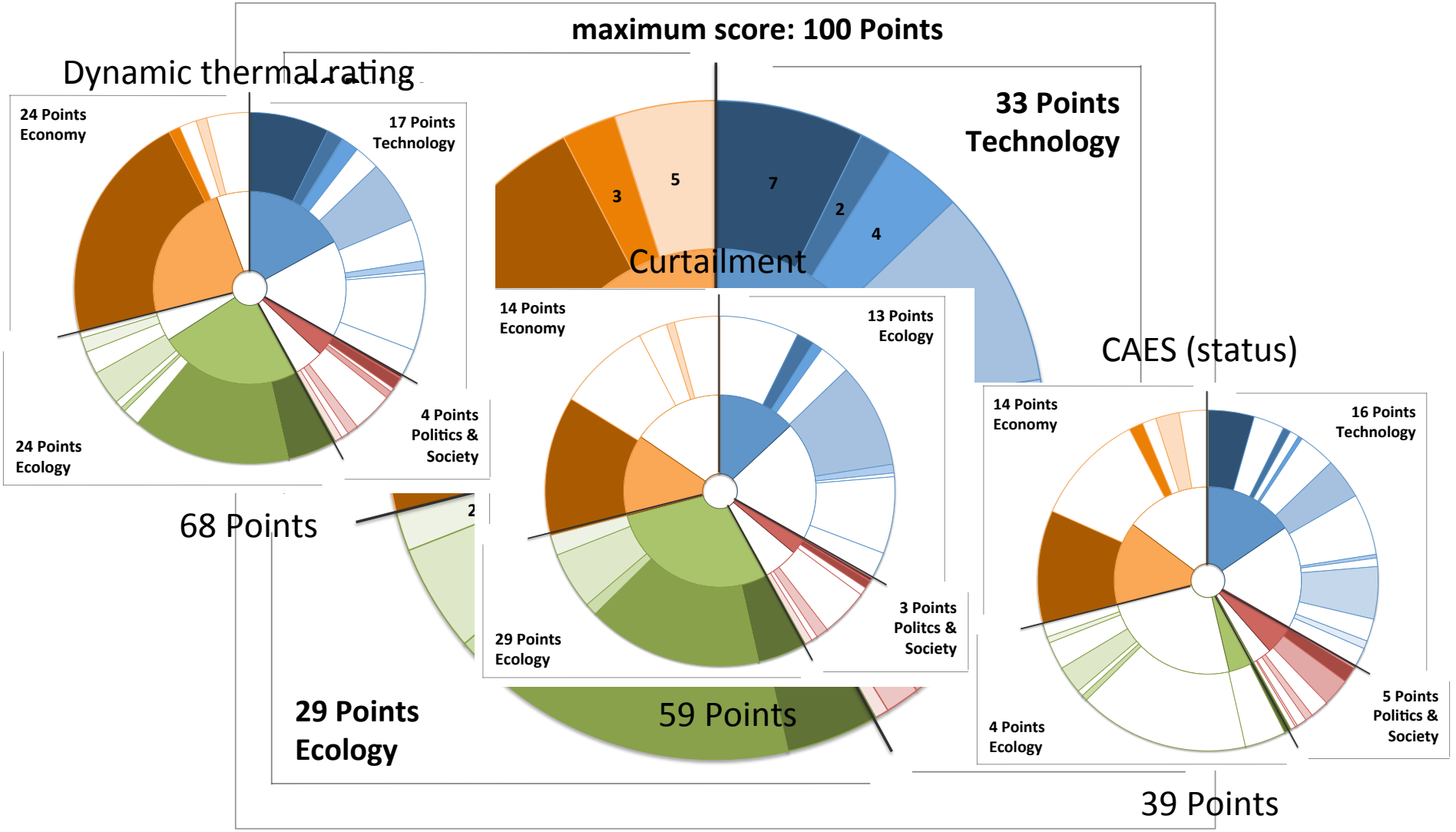
Further Results
Analyses based on the MCA

The MCA offers many different analysis options:

- **Why did a technology "win" the MCA? Why did another score less?**
  - e.g. thermal rating vs. curtailment vs. CAES
- What are the advantages of different technologies in different regards?
  - e.g. ecological vs. economical scores
- Is one kind of technologies suited better than another?
  - e.g. grid extension vs. storage
- **Are the results robust against changing priorities?**
- …

Analysis of results

Comparison among thermal rating, curtailment and CAES



Analysis of results
Robustness of ranking

Are the results robust against changing priorities?

- Apply different weightings

	Basis weights	Equal weights	Eco-logical	highly Eco-logical	Eco-nomical	highly Eco-nomical	Robust ?
Dynamic thermal rating	1	1	2	2	3	3	✓
DC underground cables	2	2	5	6	5	5	✓
DC overhead lines	3	9	10	10	1	1	✗
CAES (adiabatic)	4	4	4	4	6	7	✓
AC overhead lines	5	12	9	9	2	2	✗
High temp. transm. lines	6	7	7	7	4	4	✓
Pumped hydro (new concepts)	7	10	11	11	8	8	✓
Curtailment	8	6	1	1	9	9	-
Pumped hydro (status)	9	14	13	14	7	6	-
Hydrogen (gas grid)	10	3	3	3	12	12	✗
AC underground cables	11	13	8	8	10	10	✓
Hydrogen (cavern storage)	12	11	6	5	13	13	-
Redox-Flow-Batteries	13	5	12	12	14	14	-
NaS-Batteries	14	8	14	13	15	15	-
CAES (status)	15	15	15	15	11	11	-

Conclusions

Sustainable use of excess wind energy shares (focus on 2020)

- The process of the MCA helps to structure and assess the reasons behind decision making and leads to a well documented finding
- Dynamic thermal rating systems for overhead transmission lines are considered one of the best options to deal with surplus energy
- DC underground cables, high temperature transmission lines and adiabatic CAES are also well suited
- Storage options (except adiabatic CAES) score rather low
  - Time horizon 2020 – results would be different for longer timescale (shift from spatial to temporal challenges new storage technologies will improve technologically and economically)

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Thank you for your kind attention!