Karlsruher Institut für Technologie

FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

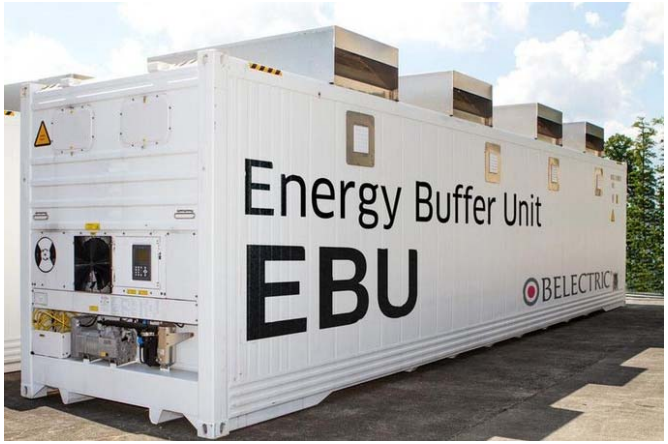
Prospective System analysis of stationary battery systems under the frame of Constructive Technology Assessment

Manuel Baumann

Supervisors:
Dr.-Ing. Marcel Weil
Prof. Dr. Antonio Moniz

Introduction

- German Energy transition
- 80%-100% renewables until 2050
- Mainly based on wind & solar
- Low correlation between RES to load
- Balancing technologies required
- Battery systems are one potential option
- High competition → several technologies



http://www.apricum-group.com

Problem:

- Storage in general depends on other system developments and does not represent a separately identifiable dominant system (Grünewald 2012)
- High uncertainty about general needs and requirements regarding energy storage and sustainability within a large socio-technical regime change → Energiewende

Research Question & Peer Group

- **Research aim:**

Carry out prospective system analysis based on CTA principles **to open technology design processes** to related **societal requirements & concerns** to bring about **sustainable improvements** of emerging grid battery storage technologies to provide a broader basis for decision making and technology support.

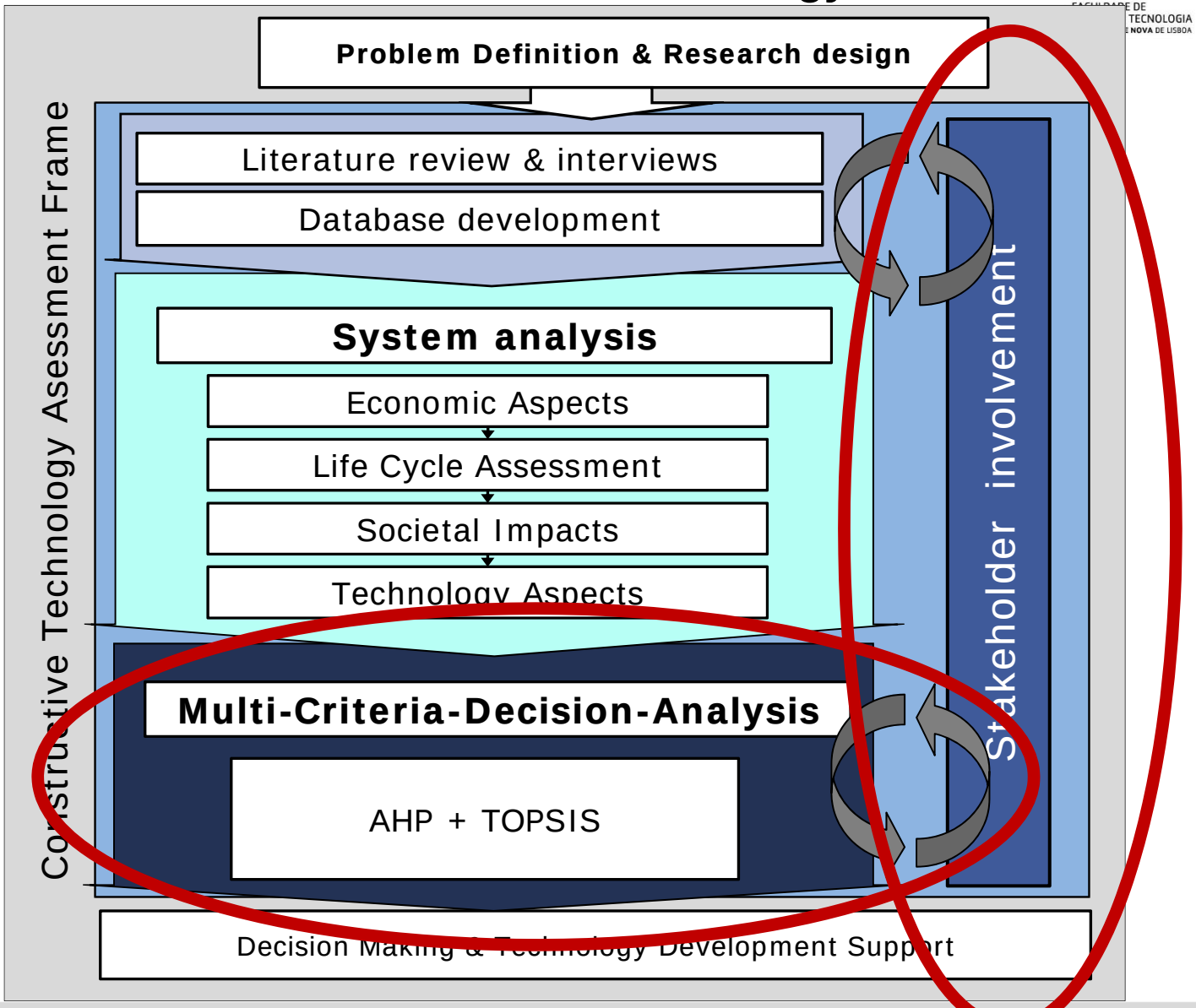
- **Peer Group:**
  Broad spectrum: Technology developers, decision makers & research in the field of stationary battery storage and the energy system

Theoretical background: Constructive Technology Assessment

- CTA → grounded it theory of **co-evolution** of technology and society, emerging irreversibilities + endogenous futures (Grunwald 1999)
- CTA → several methods → **broaden design process** of new technology **identify undesired impacts** → or make it more **reflexive** (Shot & Rip, 1997)
- If necessary, → **modification** of it → e.g. more **sustainable design** → better fit the **needs of society** (Guston and Sarewitz 2002)
- CTA kernel → **stakeholder participation activities** → surveys, interviews, interactive workshops etc. → increase **social learning**

Source: busyteacher.org

Research Methodology



Explorative research for Stakeholder involvement

Supervised master thesis of Thom Versteeg → exploratory work about CTA to battery storage (qualitative, interviews & survey)

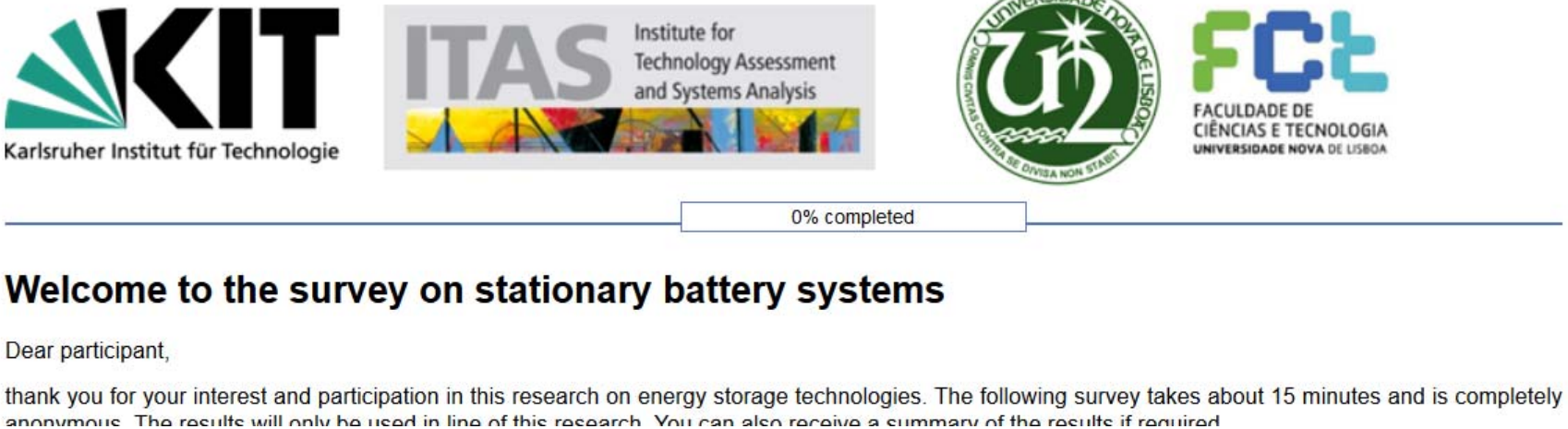
- 8 interviews, 220 invitiations → 33 responses
- Versteeg, T., Baumann, M., Weil, M., Moniz. A. B. "*CTA of Emerging Battery Technology for Grid-Connected Energy Storage*" Submission to "*Technological Forecasting and Social Change*"

Stakeholder involvement: Survey

- Online Survey
- 2 Languages, spreaded globally
- Stakeholders within dominant socio-technical system (energy system)

English

Deutsch



Stakeholder involvement: Starting point/stakeholder identification

- Dominant socio-technical regime concept - 7 sub regimes and corresponding stakeholder groups in energy storage + exploratory work Thom (Geels & Verbong 2010 & Grünewald 2012, Versteeg 2014)

ST-regime dimension	Stakeholder group
Industry	Utility companies, networks operators, developers
Technology	Developers, Academia
Infrastructure	Transmission & Distribution System operators (TSO & DSO), utilities, academia
Policy	Policy makers, regulators, academia
Culture	Society
Science	Academia, Industry
Market User preferences	Utilities, TSO´s, DSO´s, demand Aggregators, End users,

Based on Grünewald et. Al 2012

Survey:
Methodological proceedure

- 1st Pretest phase: In ITAS (about 10 persons performed technical tests, individual, informal discussion with 5 participants), presentation of criteria & stakeholder groups in the working group + short feedback

- 2nd Pretest phase: consultation of **11 external experts** → research and industry, → to make a **critical review** and to participate in interview → **8 pre-test interviews*** → identify problems regarding questions, **relevance of stakeholders &** used criteria for MCDA Methods

- 3rd Pretest phase, technical pretest (working group → 5 tests)

- Release of survey

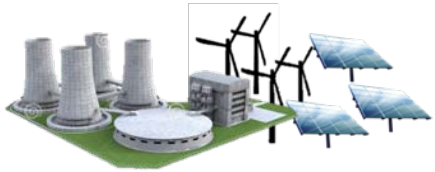
- Follow-up interviews

Source: prosoft-technology.com

*cognitive interviews :probing (comprehension, category selection,) (Schuman 1966 & Belson 1981) / Semi structured 30 to 120 minutes per telefone & personal

Survey
Structure after pretest phases

The survey is structured in 3 „parts“



1.General questions regarding the „Energiewende“
- Potential impact of RES on markets & system safety
- Structure of the future energy system (central vs. decentral)
- Relevance of different balancing technologies
- ….

2.Stationary battery related questions
- Level of system integration
- Application fields
- ...

3.Multi-criteria decision analysis (MCDA)

Identification of sustainability hotspots regarding balancing technologies through MCDA

Survey:
Participants of the survey

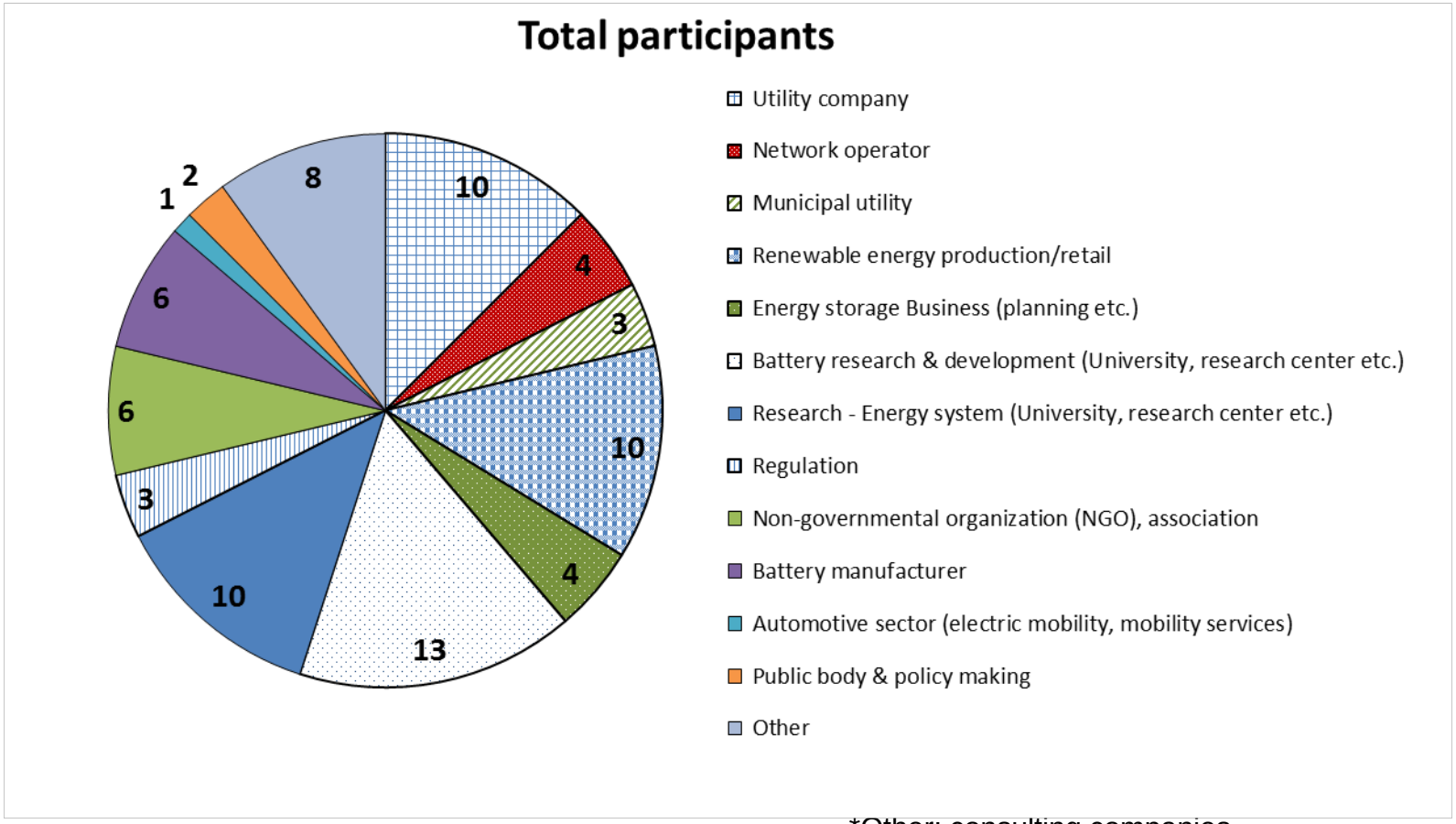
- After external reviews 13 Stakeholder groups
- A relevance list of SH was developed, (internet research, personal contact, business contacts)
- > 80 individual invitations …3 days of email writing
- PIs, higher management, project leaders
- Snow-ball principle
- Target: 6 participants per stakeholder group

Source: hardwaresecrets.com

Survey results:
Participants of the survey

Survey: Participants

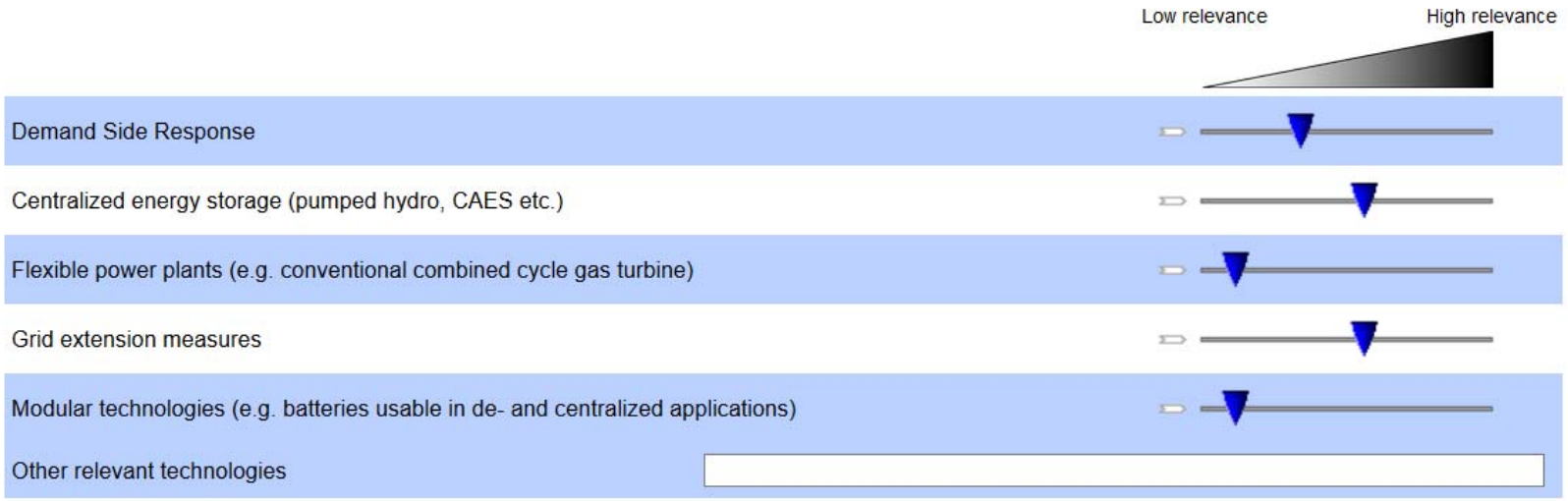
- Since 27.10.2015 - > 50 responses (> 40 completed entire survey, including usable external pretests) – survey deadline 30th of November



*Other: consulting companies

Survey results:
1. General part (excerpt) I

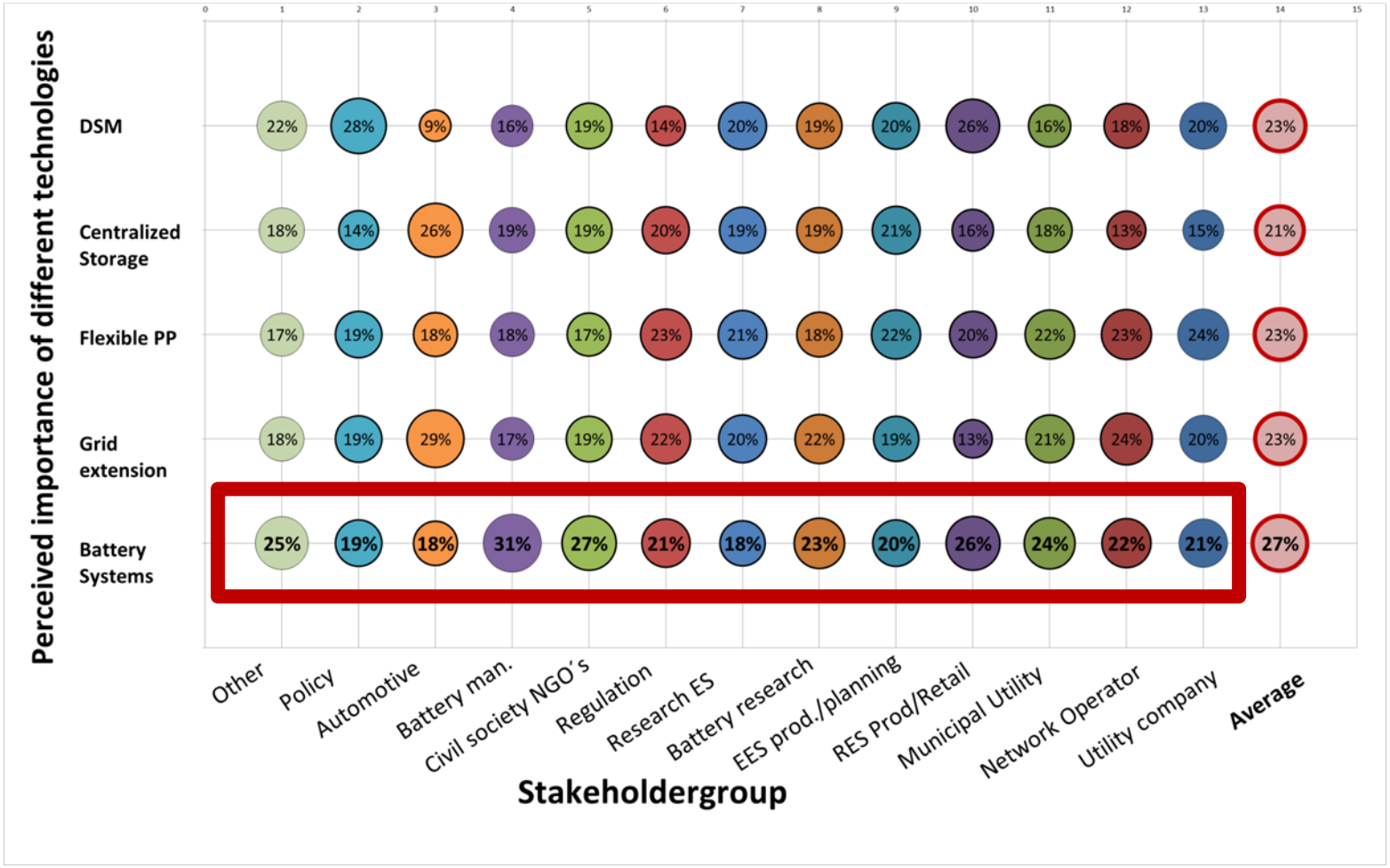
- Stakeholders where asked to rate the importance of different given technologies for a successful „Energiewende“



- Other named technologies are: V2G (3 times), P2G, P2H etc.
- Other measures: regulation of RES, tarif systems etc.

Survey results:
1. General part (excerpt) II

- Importance of batteries for RES-based system



Survey results:
1. General part (excerpt) IV

Interviews → understand what are the concerns of stakeholders regarding different technolgies → Focus batteries

DSM:

> „*I don´t see a high potential in this technology, ….. smart meters are to expensive, no valuable business case……acceptance problem also in industry*“

- Centralized storage:

> „*Difficult…, really very difficult to implement new projects due to high environmental standards…… and public oppinion against new projects…. No real alternative… markets are not sufficient*“

- Grid extension:

> „*Well very necessary… but I think we all know the problems…. NIMBY…*“

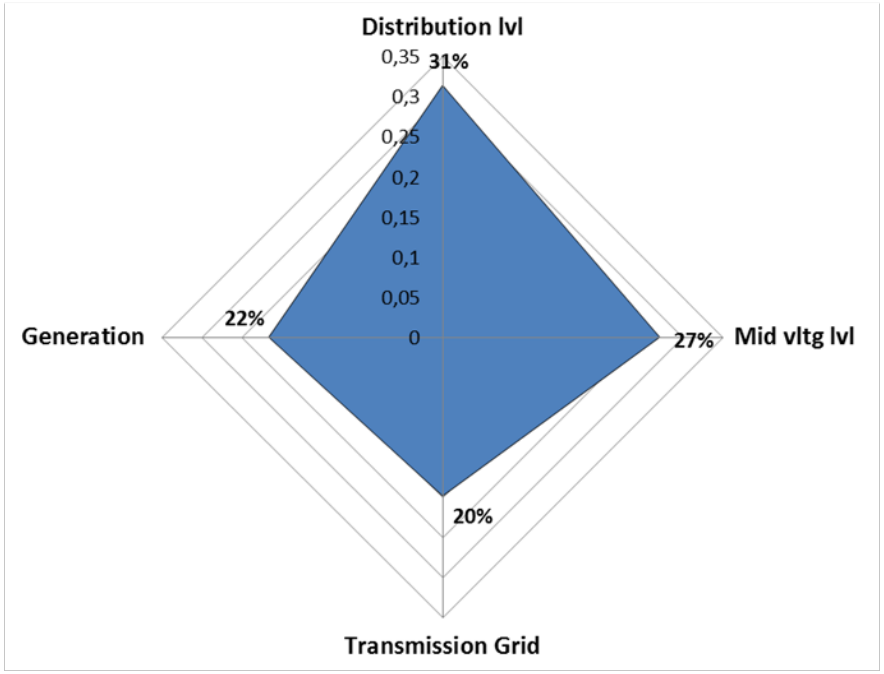
- **Battery storage:**

> „*We are already at the minimum edge of profitability with pumped hydro – how should new concepts as batteries then be economically viable?*“

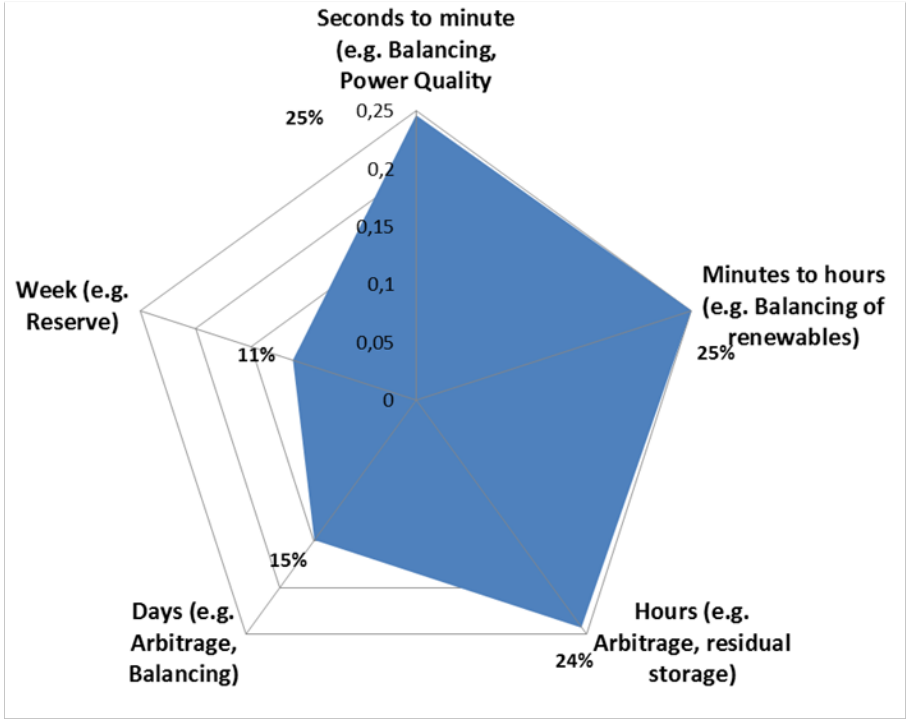
Survey results:
2. Battery specific part (excerpt)

- Visions from SH → stationary battery systems application & system integration in the future

Where will system integration take part?



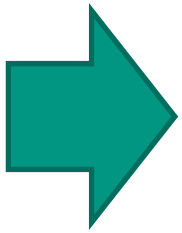
What kind of application is probable?



Survey
3. Multi-Criteria-Decision-Analysis (MCDA)

- Assumption → way of **designing & selecting** technology according to **sustainability factors** relies on the **preferences** from different actors embedded in different "worlds" (sub-regimes) → **complex decision problem → temporarily dominant ST-regime**

- **Dilemma** uncertainty of the desirable technology "shape target" → **weighting of results** →environmental vs. economic vs. social aspects → what is **relevant** → factors to improve embedding in society



MCDA serves as integral part to link qualitative and quantitave results

MCDA - AHP:
Multi-Criteria-Decision-Analysis (MCDA)

What is MCDA?

- Conjunction of mathematical procedures to systematically visualize the optimum choice of alternatives for a decision maker

http://www.meetjerryspangler.com/wp-content/uploads/2011/05/executive_decision_making_1920x1200.jpg

Why use it?

- Complexity of decisions due to
  - Multiple objectives (min cost, max benefit)
  - Complex structure (several alternatives, views etc.)
  - Sequence of decisions (decision dependent on former decisions)
  - Multiple decision makers (various views, objectives etc.)
- Often appear in combination with high uncertainty

Based on Chibeles 2014

MCDA - AHP:
MCDA – Model

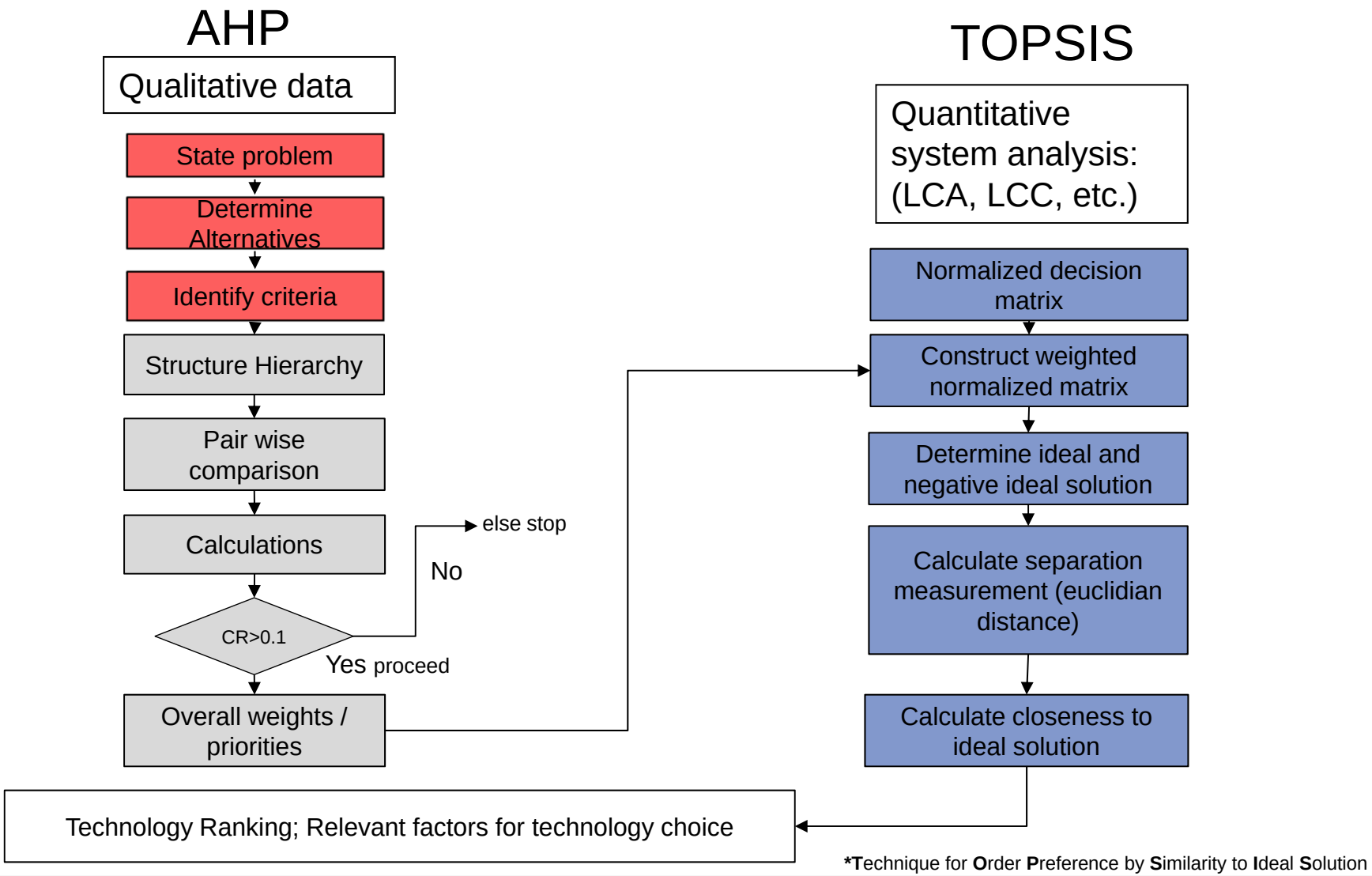
- Several methods available (ELECTRE, SMART, ORESTE etc.)
- Which one is suitable for my approach?

Analytic Hierarchy process AHP

Source: http://www.ftlcomm.com/ensign/desanti-sArticles/2002_600/desantis673/gametheory.html

- AHP method based on mathematics and principles of psychology
- Allows to obtain physical factors + allows to acces psychological realm
- Non-linear framework, considers several factors simultaneously, allows for tradeoffs to arrive at a synthesis (Saaty 1990).

MCDA - AHP:
MCDA – Model



***T**echnique for **O**rder **P**reference by **S**imilarity to **I**deal **S**olution

MCDA - AHP:
Definition of Alternatives

- Battery technologies → based on survey & interviews
  - Redox-flow-Vanadium-battery
  - Lithium-Iron-Phosphate-Battery
  - Lead-acid (VRLA)
  - High-temperature-battery (Zebra)

- Alternative technologies for comparison
  - Pumped Hydro Storage
  - Combined cycle gas turbine
  - Not possible to include all flexibility options

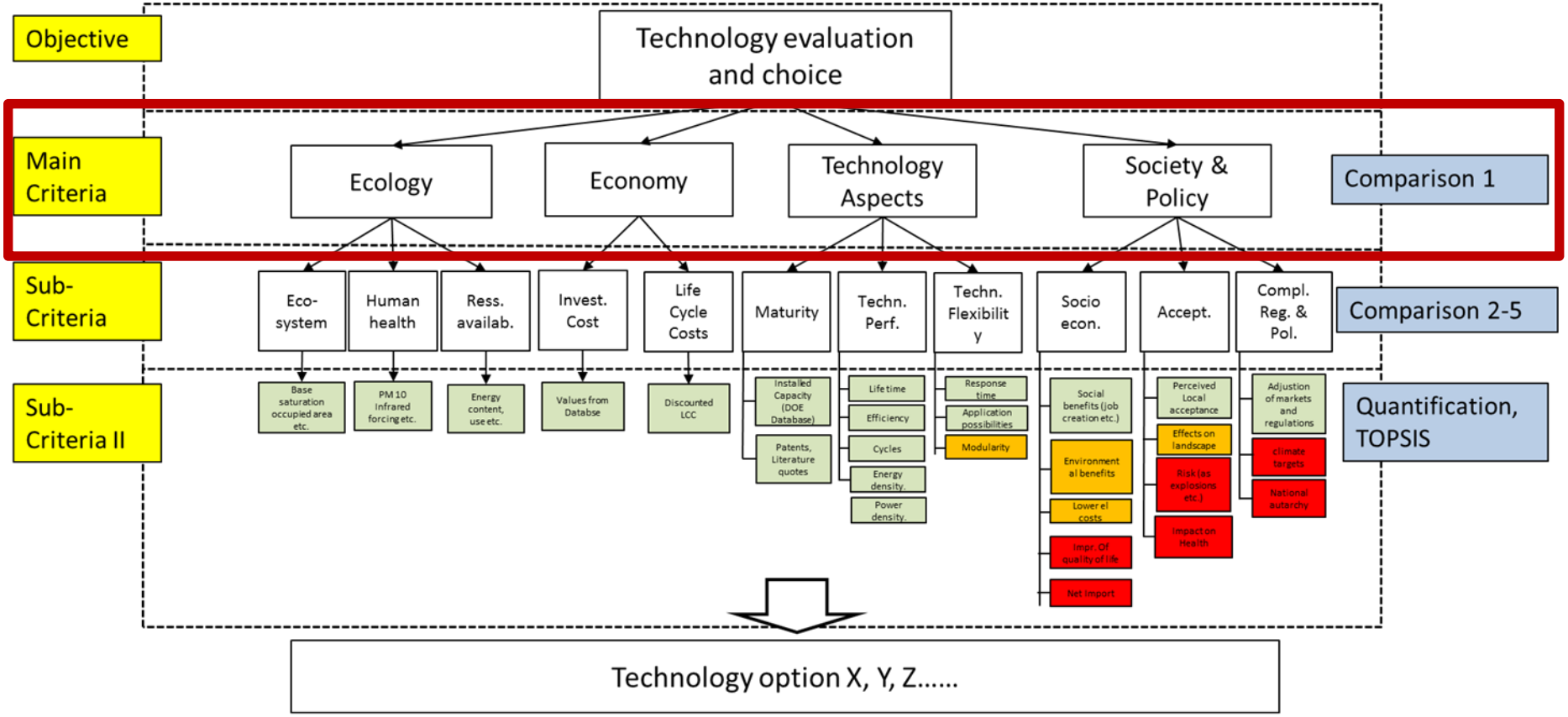
MCDA - AHP: Definition of Criteria

- Start with a comprehensive literature review to get over-view
  - **4 main criteria**
  - **11 sub-criteria**
- First set of criteria – was then discussed inter-nal & reformulated
- Presented to pre-testing SH group

Aspects	Criteria	Literature	Total number
Environ-ment	Resources	[108], [42], [116], [117], [109],	5
	GHG emissions	[108], [118], [42], [119], [120]	5
	Impact on ecosystems	[42], [117]	2
	Risk in cause of failure	[117]	1
	CO2 Emission	[42], [121], [109]	3
	CED	[108], [122]	2
	Land use	[108], [121], [118], [119], [120], [115]	6
	SO2	[109]	1
	NOx	[109], [122]	2
	Particles	[122]	1
	Others	[119], [120], [115]	3
Economic	Specific cost, LCOE, LCC	[121], [117] [109], [118] [122], [120], [115]	7
	Enh. Of comp.	[117]	1
	Investment Cost	[42], [121], [109], [122], [119]	5
	O & M Cost	[42],	1
	Fuel Cost	[119]	1
	Payback method	[42], [123], [119]	3
	NPV	[119]	1
	Others	[117], [118], [122], [42], [119]	5
Social	Compliance with pol goals	[108], [117]	2
	Nat. indep.	[117]	1
	Employm. Pot., new jobs	[117], [109], [123], [119], [120], [115]	6
	Social accept.	[42], [108], [117], [119], [115]	5
	Effects on landscape	[117], [118]	2
	Social Benefits	[42], [119]	2
	Risk	[108], [115]	2
	Contribution to regional dev.	[123]	1
	Other	[118], [122]	2
Technical	Efficiency	[121], [108], [117], [122], [123], [119]	6
	Excergy efficiency	[116],	1
	PER	[116]	1
	Safety	[119]	1
	Reliability	[42], [118], [119]	3
	Maturity	[42], [116], [118], [123]	4
	System life	[119]	1
	Availability	[119]	1
	Fatalities	[120]	1
	Flexibility	[115]	1
	Others	[117], [118], [120], [115]	4

MCDA – AHP: Final set of criteria

- **Interviews** and **external reviews** have led to stepwise alterations and changes → final set of criteria



MCDA - AHP: Pairwise Comparisons

1. Please state your preferences regarding sustainability aspects of storage or balancing technologies (e.g. battery storage, gas turbines, pumped hydro storage, etc). Rate the following aspects by <u>pairwise comparisons</u> for the AHP evaluation. The categories represent the three pillars of sustainability and are supplemented with a fourth category "technology".

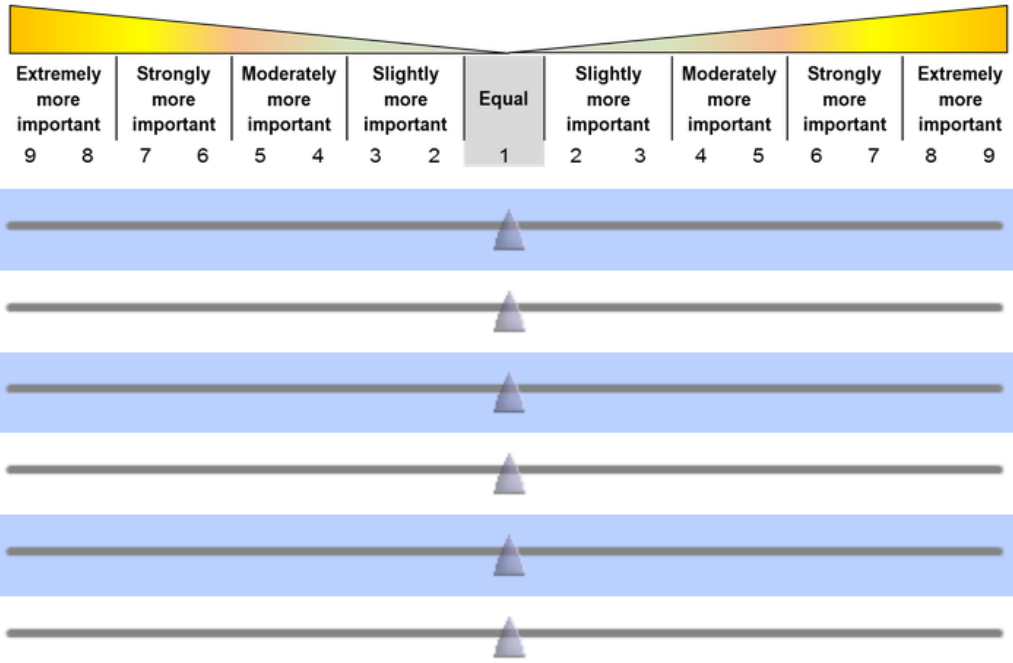
Sustainability criteria overview:

<u>Ecology</u> = Subcriteria: Damage to ecosystem diversity, damage to human health and ressource availability

<u>Economy</u> = Subcriteria: Capital cost and lifecycle costs

<u>Society & Policy</u> = Subcriteria: Social acceptance, availability of regulations, compliance with political goals

<u>Technology</u> = Subcriteria: Technological maturity, performance and flexibility



MCDA - AHP: Pairwise Comparisons

1. Please state your preferences regarding sustainability aspects of storage or balancing technologies (e.g. battery storage, gas turbines, pumped hydro storage, etc). Rate the following aspects by <u>pairwise comparisons</u> for the AHP evaluation. The categories represent the three pillars of sustainability and are supplemented with a fourth category "technology".

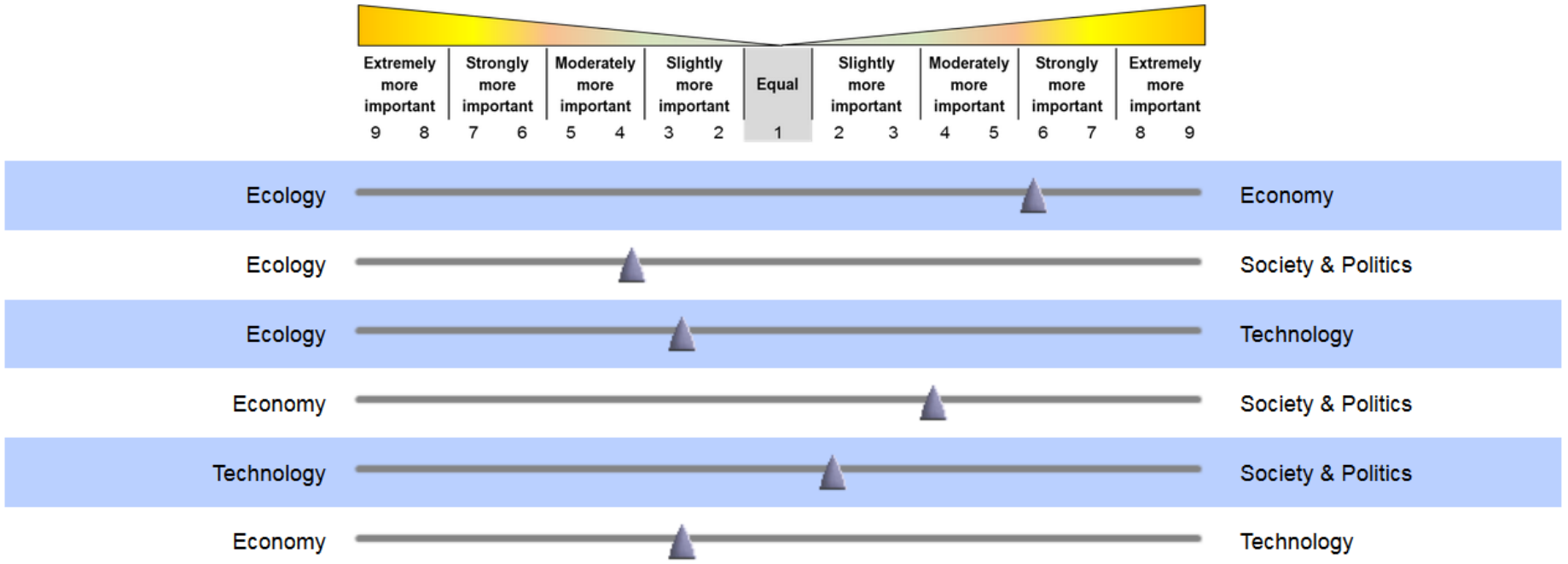
Sustainability criteria overview:

<u>Ecology</u> = Subcriteria: Damage to ecosystem diversity, damage to human health and ressource availability

<u>Economy</u> = Subcriteria: Capital cost and lifecycle costs

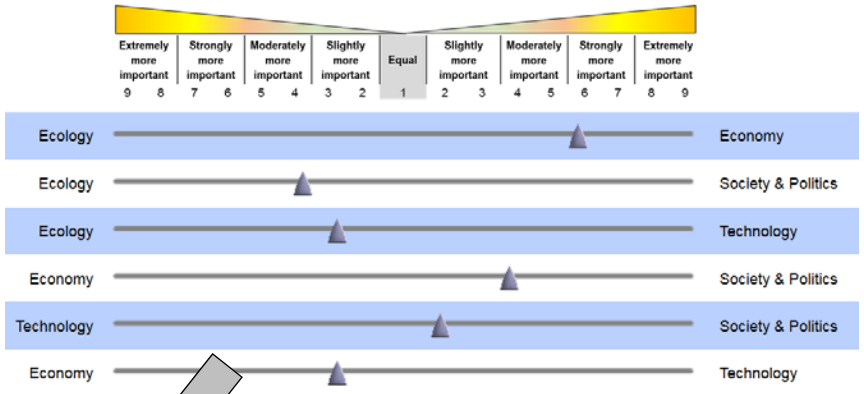
<u>Society & Policy</u> = Subcriteria: Social acceptance, availability of regulations, compliance with political goals

<u>Technology</u> = Subcriteria: Technological maturity, performance and flexibility



MCDA - AHP: Pairwise Comparisons

- Results from the survey
- Transformation in suitable scale
- For each stakeholder



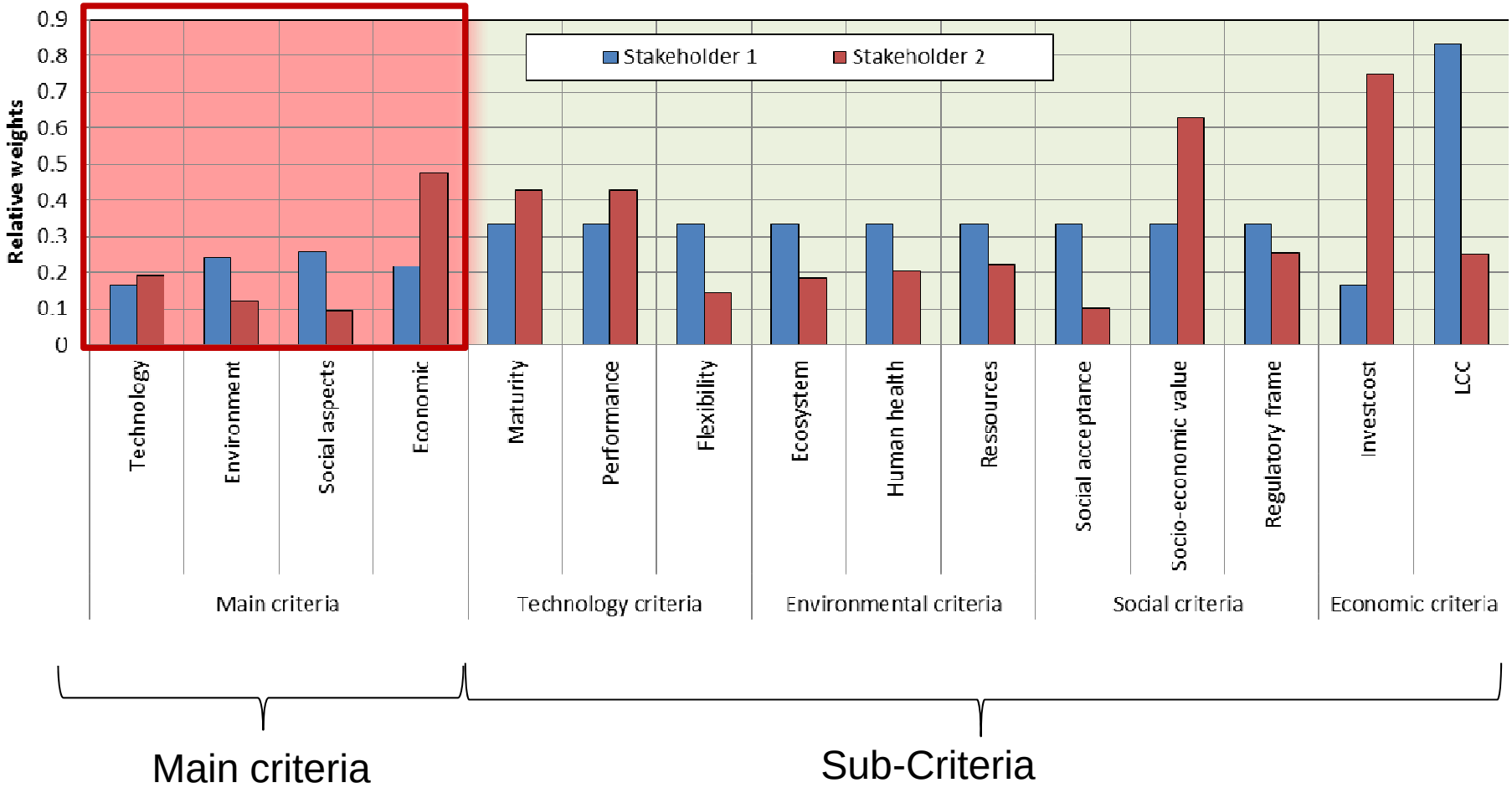
Stakeholder	Ecology/Technology	Economy/Society & Politics	Techn./Society & Politics	Economy/Technology	Ecosystem/Human health	Ecosystem/Resource use	Human health/Resource use	S…/Socio-econ. value	Socio-econ. value/Regulatory frame	Social acc./Regulatory frame	Techn. maturity/Techn.flexibility	Techn. Perf./Techn. flexibility	Techn. maturity/Techn. Perf.	Investment Cost/Life Cycle Cost
1	1	0,33333333	0,25	3	1	3	3	0,25	0,25	3	0,2	3	0,33333333	3
2	2	1	0,5	1	2	1	0,25	1	4	1	1	1	2	1
3	0,14285714	7	0,2	6	0,33333333	9	0,2	5	6	6	0,14285714	0,16666667	9	6

MCDA - AHP: The math….

RESULTS

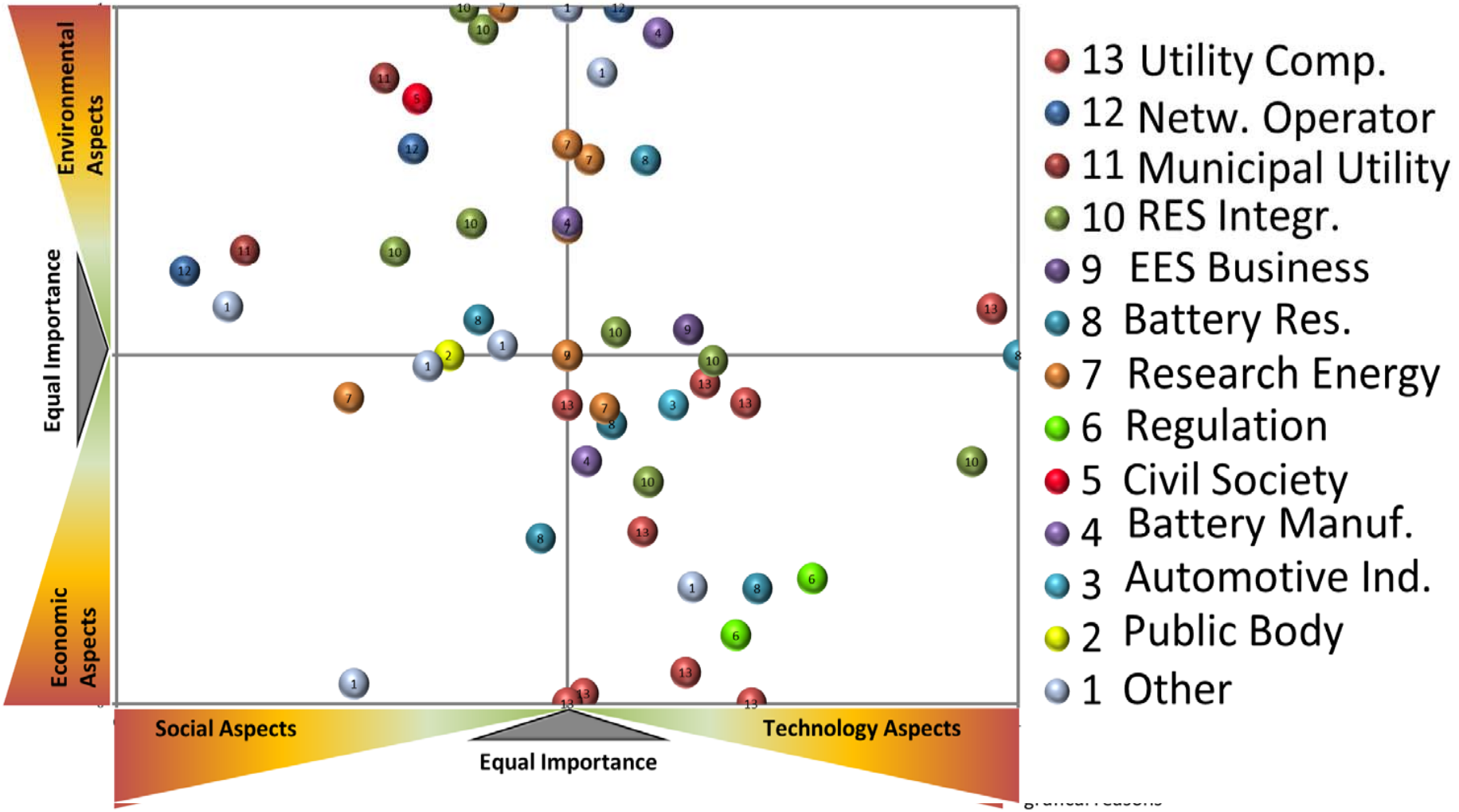
MCDA-AHP: Result example

- Example of preferences of 2 stakeholders that participated



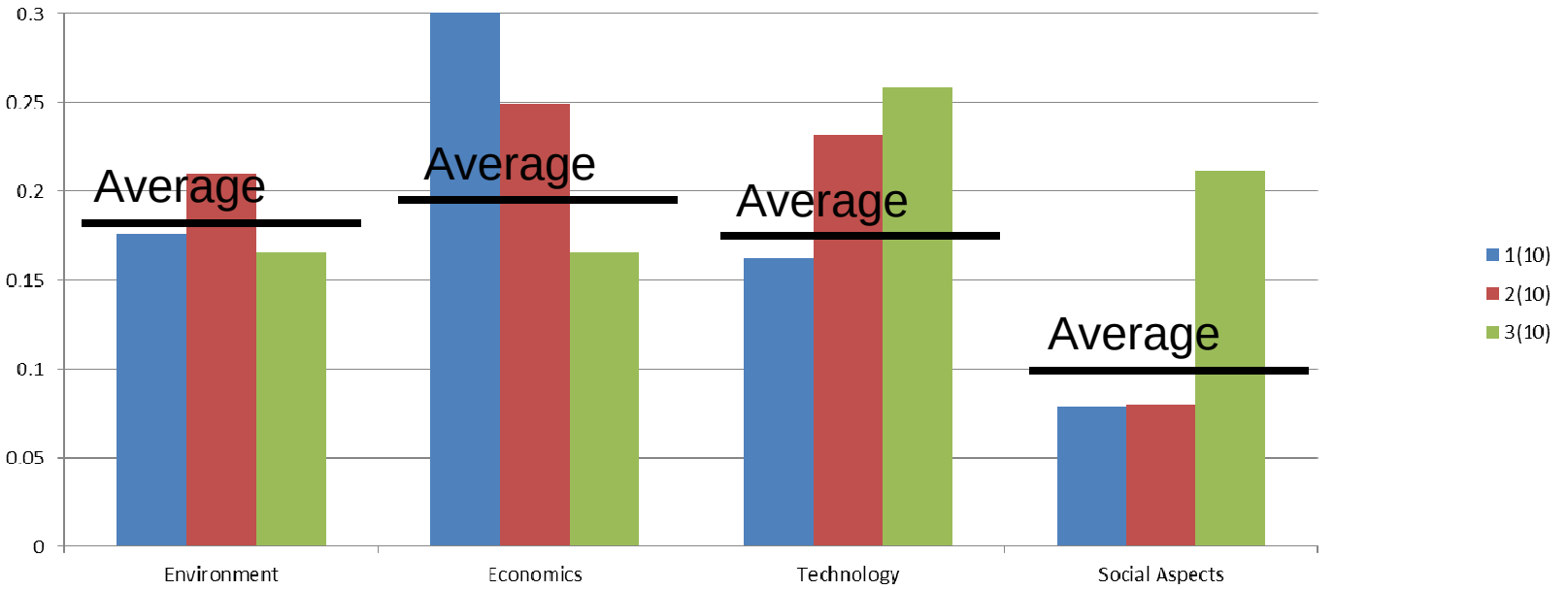
MCDA – AHP:
Group decision making

- Creation of BCG like matrice for main criteria



MCDA – AHP: Group decision making

- Aim of this AHP is to come to **group decisions** to
  - select key performance parameters
  - To agree on common strategies for future developments
  - How to derive →average → unclear if stakeholder agree with each other



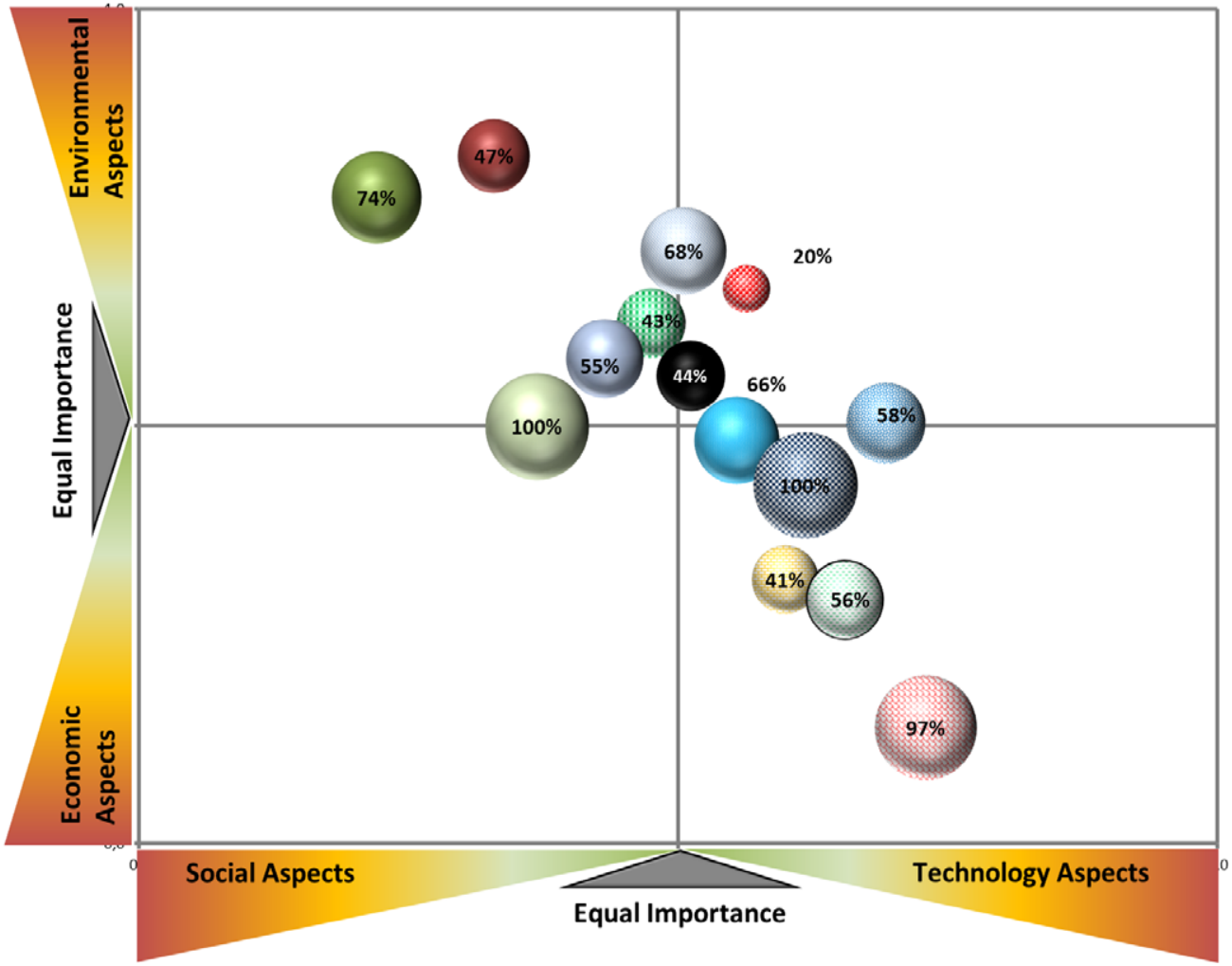
MCDA – AHP: Consensus factor

- Concept of diversity → shannon entropy* S (Shannon** 1948)
- S + alpha & gamma diversity → biology (Jost, 2006).
- Result is a homogeneity index → **consensus indicator**
- Consensus will be 0 when priorities are completely **distinct** and 1 when they are **identical** (Goepel 2013)
  - 0 % no consensus → 75% high consensus →100 % absolute consensus
  - This can be used to analyze how strong consensus is among stakeholder groups

* to measure of *unpredictability* of *information content* **Inventor of the bit*

MCDA-AHP: Results per group

- 4 field matrice to identify main criteria relevant for techn. choice/design



- Network operator
- Energy storage Business (planning etc.)
- Regulation
- Civil society
- Battery manufacturer
- Research - Energy system
- Municipal utility
- Renewable energy production/retail
- Automotive sector
- Battery research R&D (University, etc.)
- Average
- Utility company
- Other
- Public body & policy making

Acceptable value of consistency > 75 %
Groups agree to a high degree within them selves; minimum consistency is 20 % due to grafical reasons

MCDA-AHP:
Detailed Stakeholder analysis

- Gather deeper insight in Stakeholder decisions
- Shared Interest →pairwise kxk-Matrice →spot pot. „alliances“

Stakeholder	Ut. Comp.; 1	Ut. Comp.; 2	Ut. Comp.; 3	Other; 4	ESS; 5	Other; 6	Ut. Comp.; 7	Bat R&D; 8
Ut. Comp.; 1	1,0	0,8	0,7	0,4	0,9	0,9	0,9	0,7
Ut. Comp.; 2	0,8	1,0	1,0	0,7	0,8	0,8	0,9	0,3
Ut. Comp.; 3	0,7	1,0	1,0	0,7	0,8	0,8	0,9	0,2
Other; 4	0,4	0,7	0,7	1,0	0,6	0,5	0,5	0,0
ESS; 5	0,9	0,8	0,8	0,6	1,0	0,9	1,0	0,7
Other; 6	0,9	0,8	0,8	0,5	0,9	1,0	1,0	0,7
Ut. Comp.; 7	0,9	0,9	0,9	0,5	1,0	1,0	1,0	0,6
Bat R&D; 8	0,7	0,3	0,2	0,0	0,7	0,7	0,6	1,0

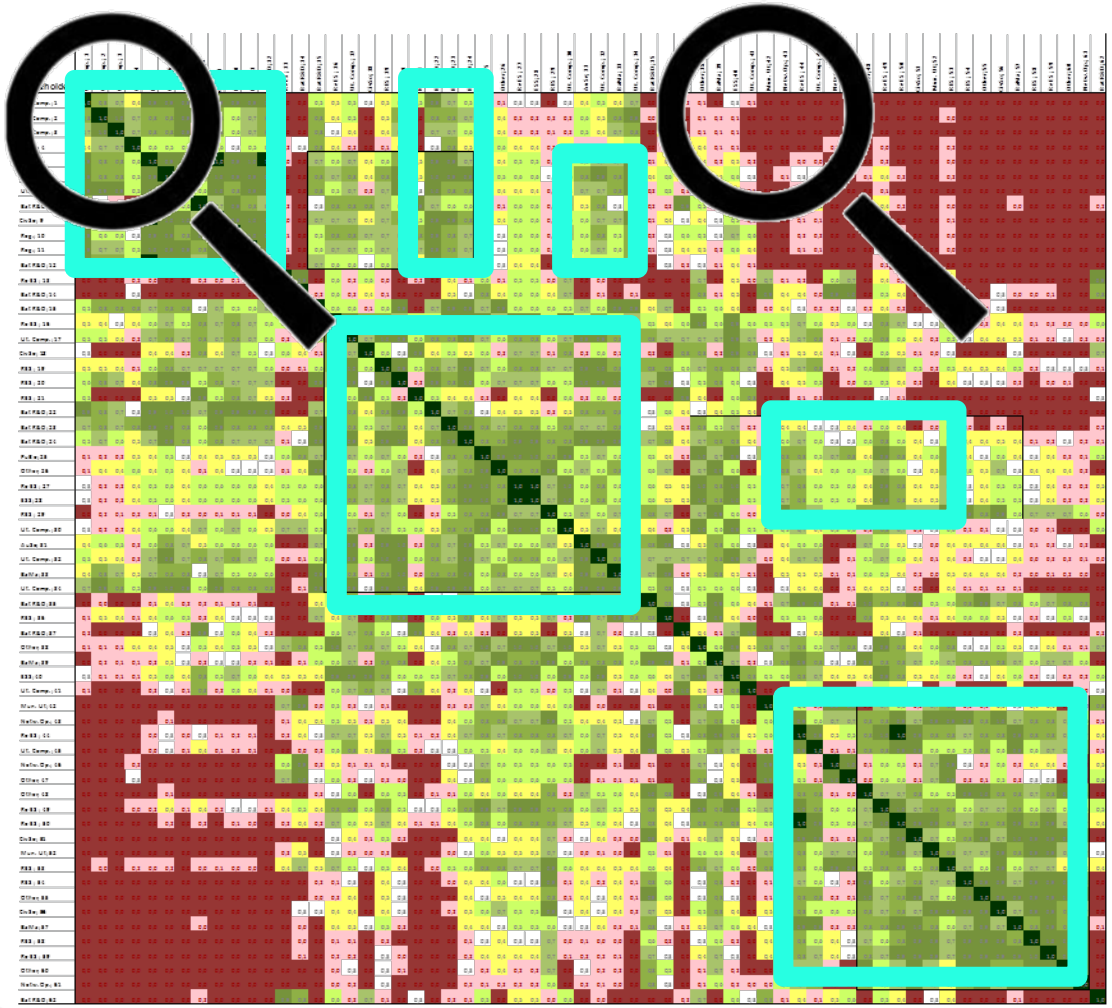
Degree of consensus

Absolute	1,0
Very Strong	0,9
Strong	0,8
Good	0,7
Moderate	0,5
Low	0,3
Very Low	0,2
None	-1,0

- Further discussion → develop new alternatives for given problem

MCDA-AHP:
Detailed Stakeholder analysis

- For all Stakeholders, multiple interest clusters k=62, common priorities



Interest clusters

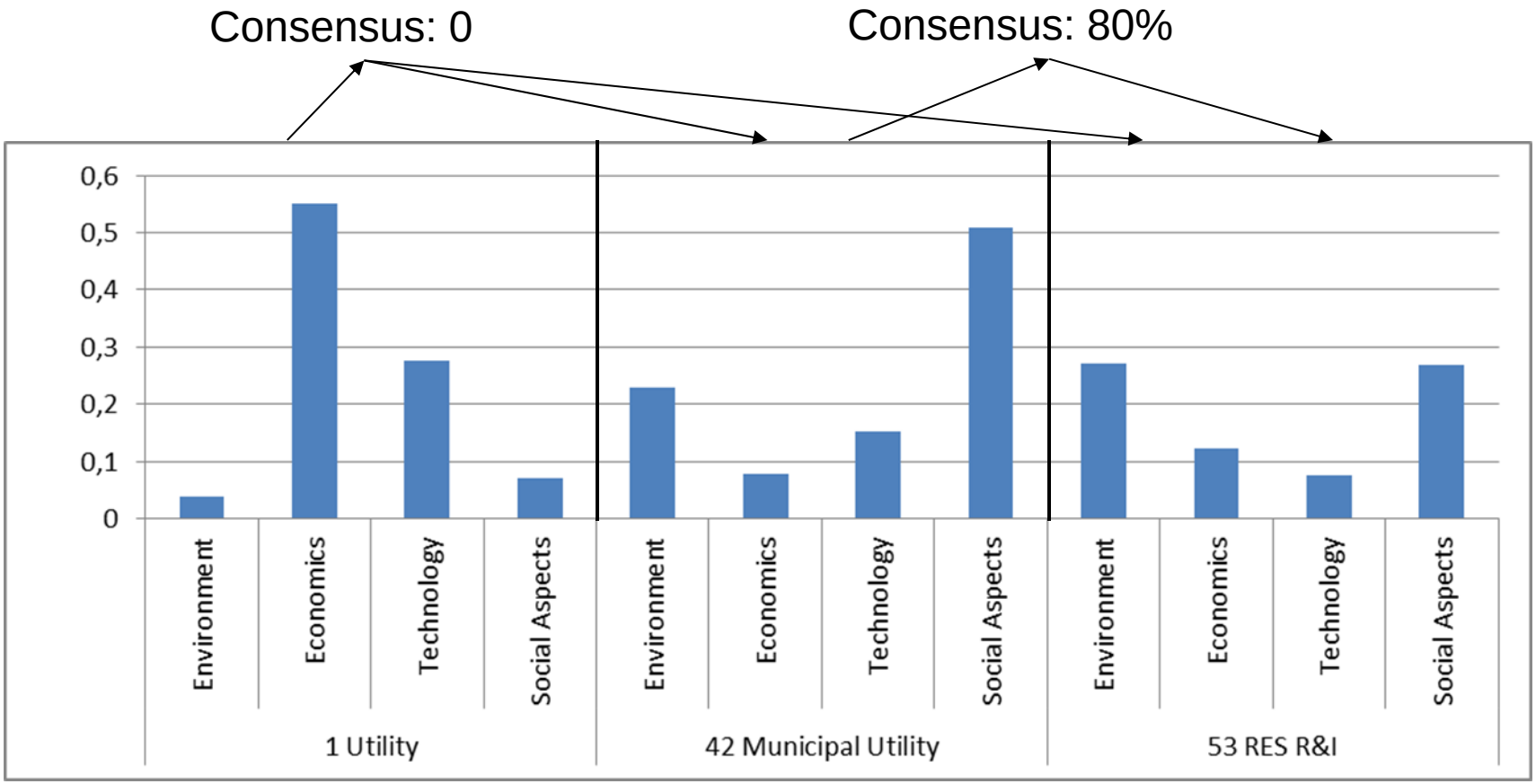
Degree of consensus

Absolute	1,0
Very Strong	0,9
Strong	0,8
Good	0,7
Moderate	0,5
Low	0,3
Very Low	0,2
None	-1,0

Analysis pending…

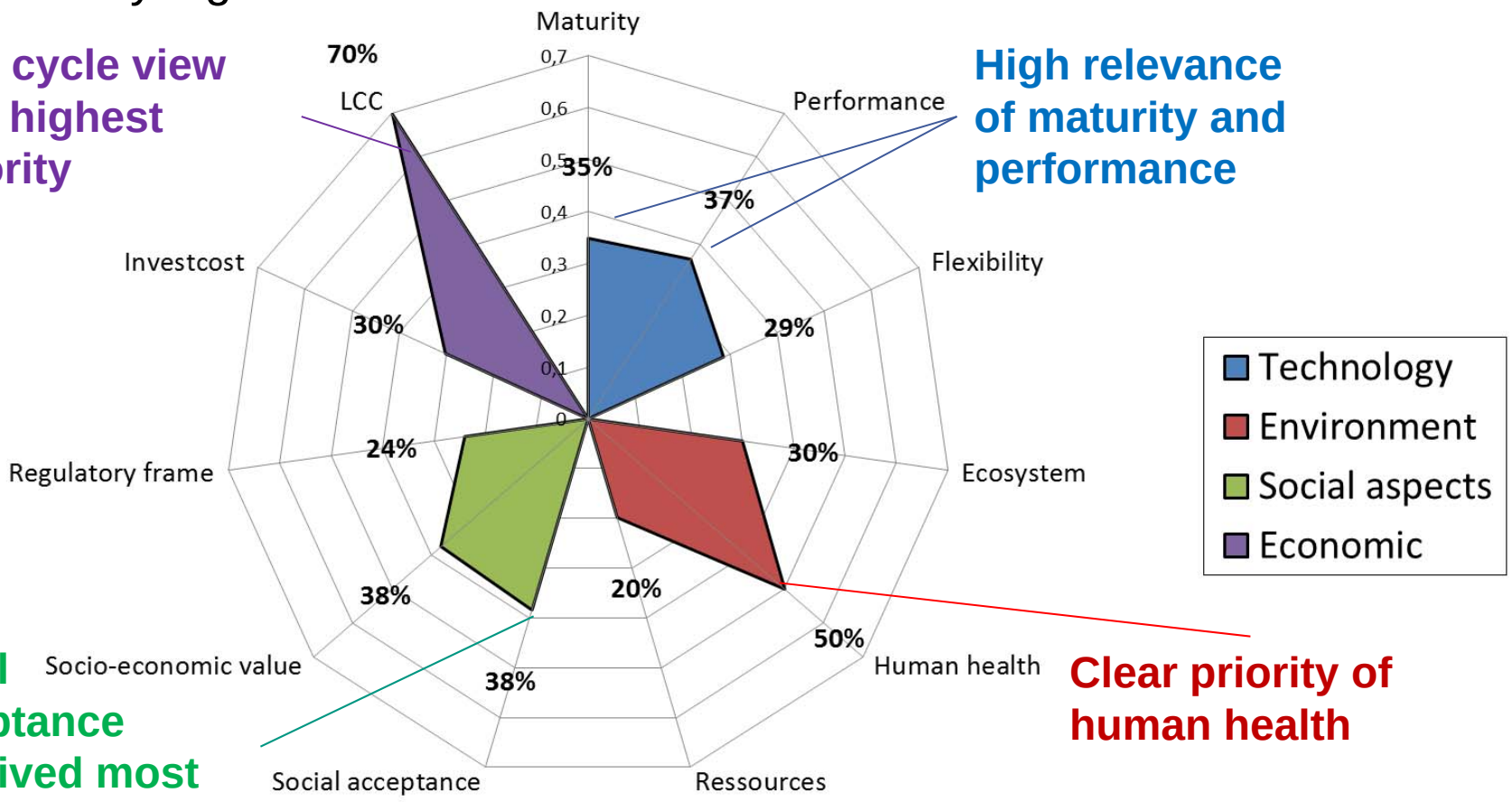
MCDA-AHP:
Detailed Stakeholder analysis

- Relation of priorities in technology design/Invest decision



MCDA-AHP
Sub-criteria

- Vector summation for sub-criteria weights for all SH→ consensus relatively high



Life cycle view has highest priority

High relevance of maturity and performance

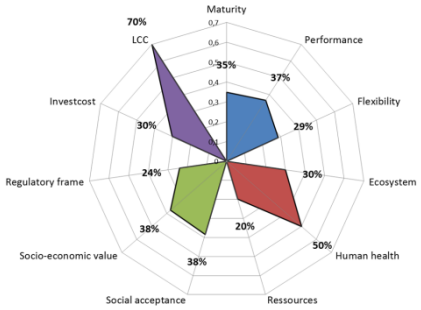
Social Acceptance perceived most critical

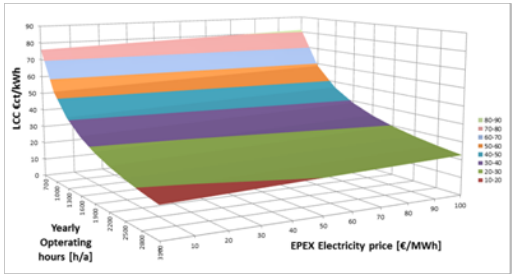
Clear priority of human health

MCDA-AHP
Combination of models

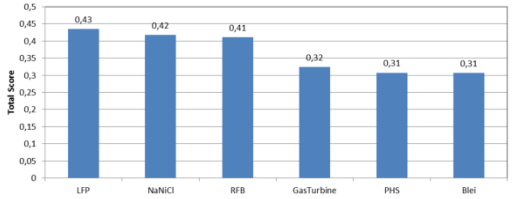
Qualitative data: Stakeholder weights

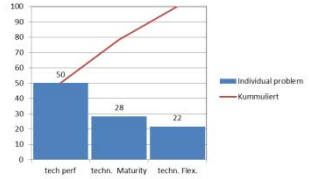
Quantitative system analysis: (LCA, LCC, etc.)

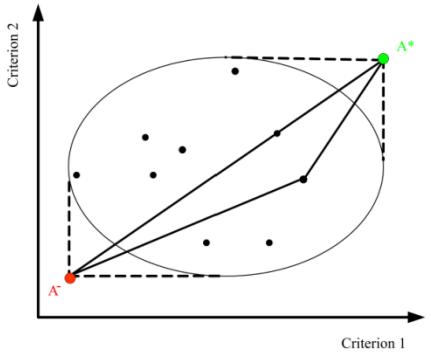




AHP → **TOPSIS**



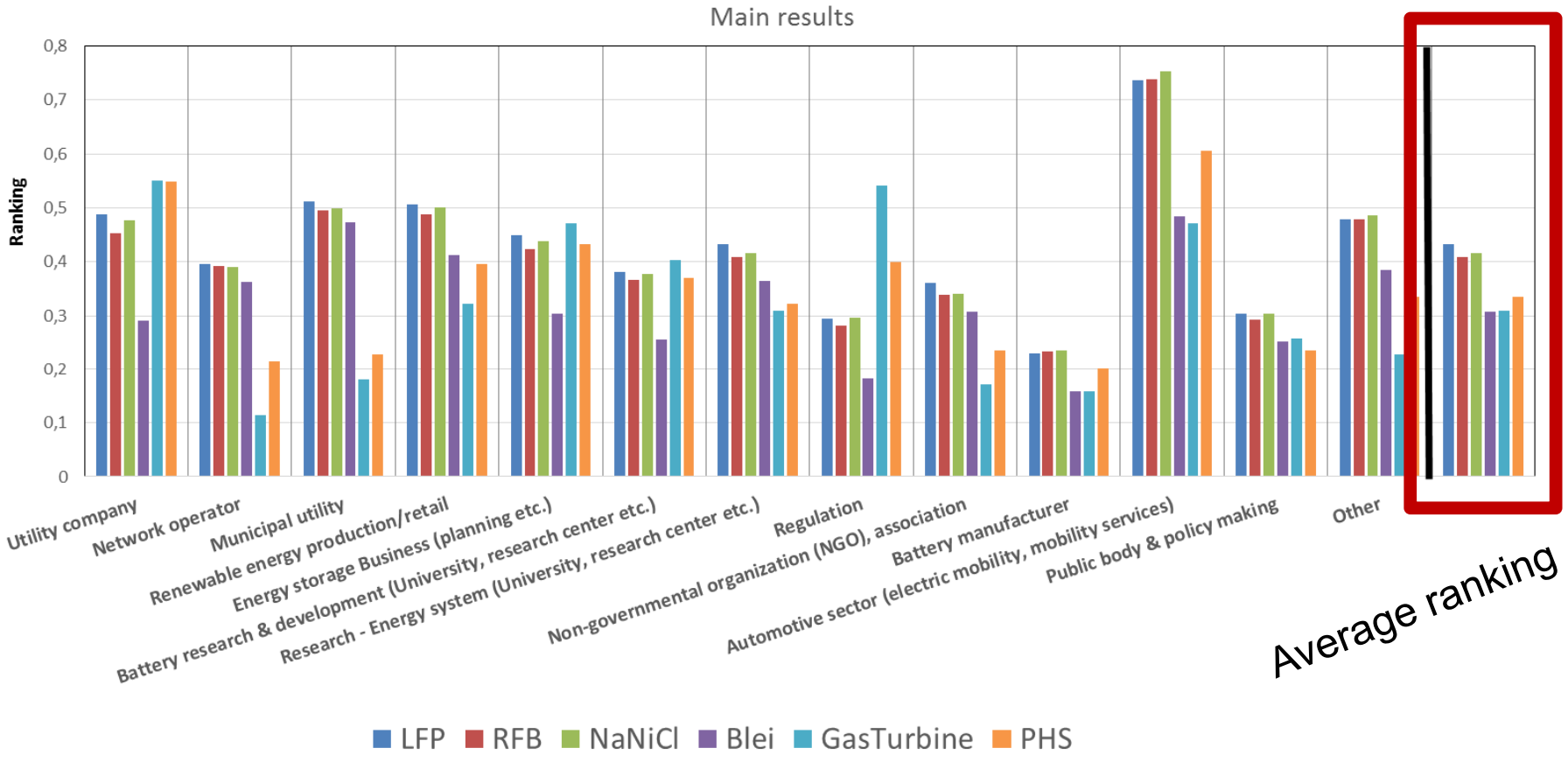




Technology Ranking; Relevant factors for technology choice

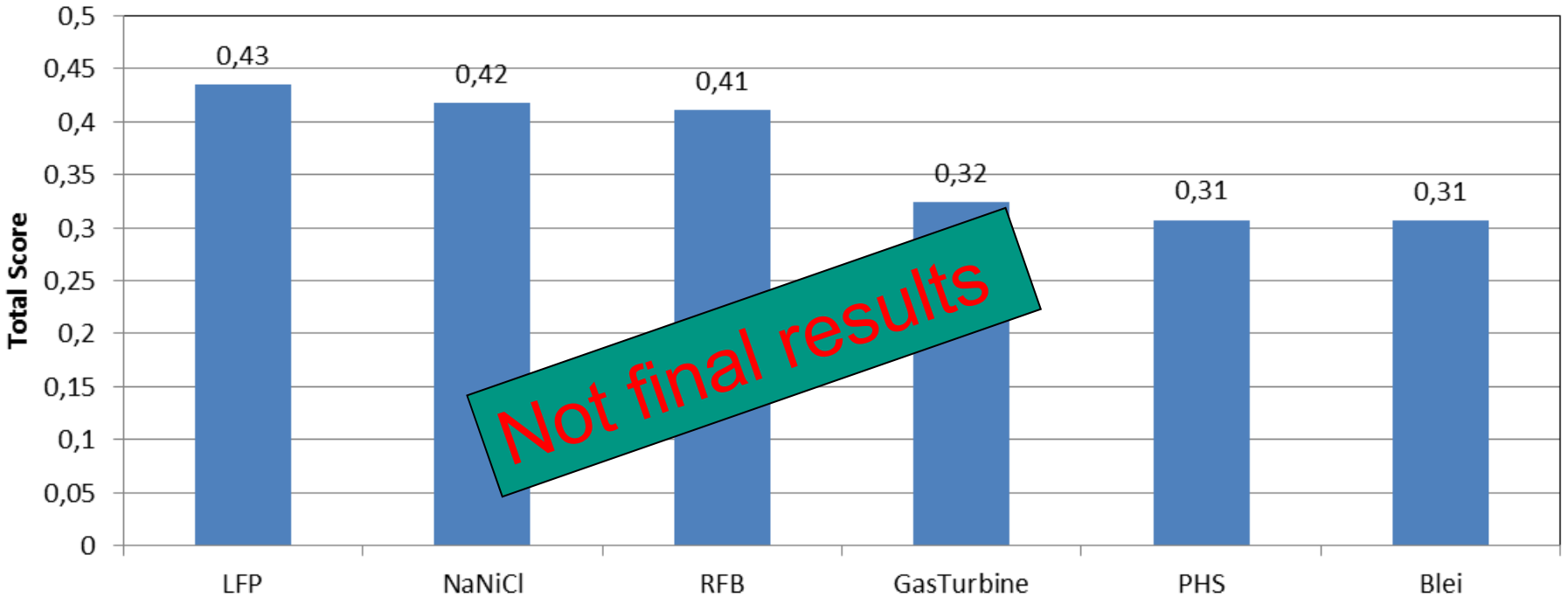
MCDA-AHP: Results

- Comparison of technologies based on mcda and stakeholder groups
- Obtain average optimum of technology (LCA results not real)



MCDA-AHP: Results

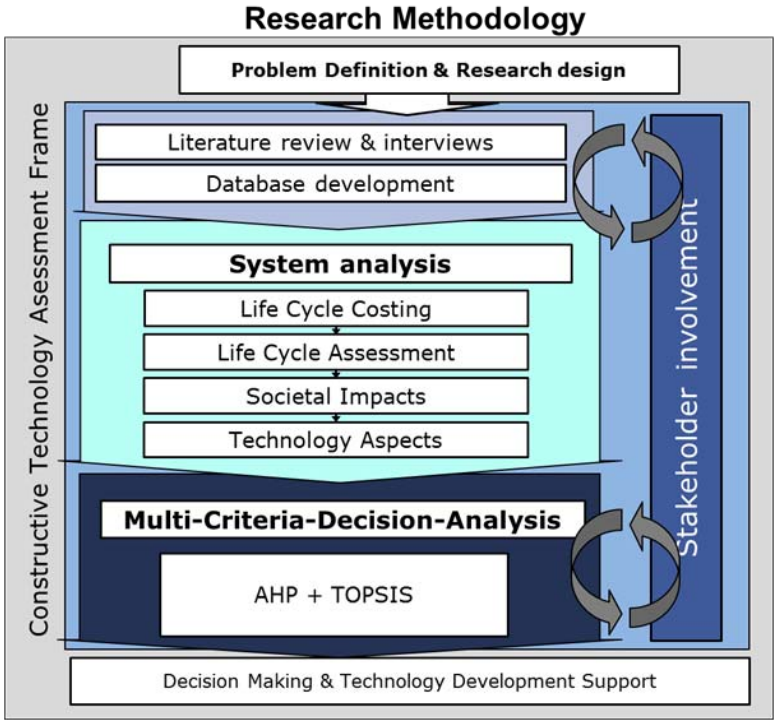
- Ranking of Storage technologies base on obtained sustainability criteria and weights
- Enables in depths analysis of criteria contribution to final result



Conclusion & Outlook

- AHP → **multiple constructed realities** in differences within perceptions, attitudes, judgements and practices of various actors and makes them **transparent and debatable**.

- Solid base for SH modulation following the principles of CTA by allowing **differences in opinions** to develop a **best construct** of technology



- **Integrative approach** → combine CTA & quantitative system analysis tools to explore potential sustainability implications

Outlook

- Interpretation of survey results
- Quantification of results (LCA under construction)
- Continue writing