MCDA for sustainability assessment of energy technologies – Exemplary HELDA Exercise

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Exemplary Agenda

Time	Item	Students Role	Description
5:00	Introduction	-	Motivation, MCDA for sustainability assessment, HELDA software, software-aided methodology, use case
5:20	Task 1	Stakeholder	Collection of individual preferences with online surveys in HELDA (reflecting on and weighting of criteria)
5:35			Group work (2 Groups): Deck of cards method (consensus in the weights) Resulting ranking + weights sets + sensitivity of weights Participants: Summarize main points in plenum
6:15			Collection of individual preferences with online surveys in HELDA (weights only)
6:25	Task 2	Analyst	Tasks (2 Groups)
7:00			Presentation and discussion of results
7:20	Wrap up	-	-
7:30	End of exercise	-	-

Agenda

Introduction

Task 1: Students act as stakeholders

Task 2: Students act as Analysts

Wrap-Up

Agenda

Introduction

Task 1: Students act as stakeholders

Task 2: Students act as Analysts

Wrap-Up

Introduction

Motivation

MCDA for sustainability assessment

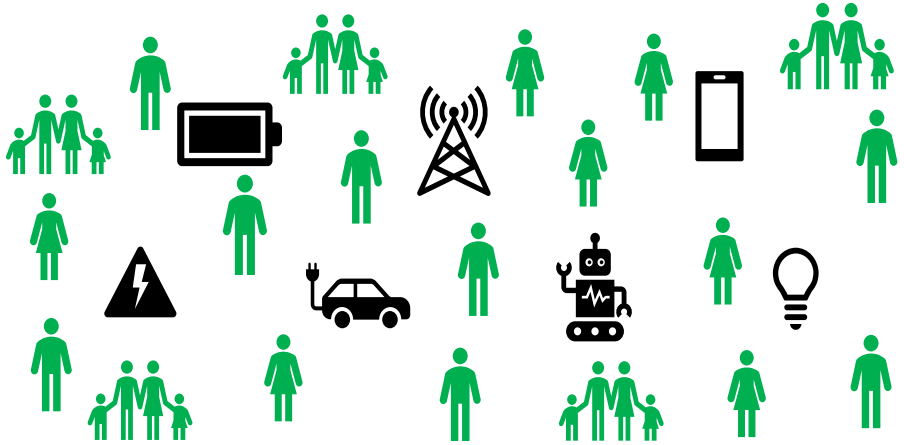
HELDA software

Software-aided methodology

Use case

Motivation

Transformation of the energy system



Science
Government
Society
Industry

How can these changes be realized in a **societally-feasible** manner?

Objective: Development of a software-aided methodology for sustainability assessment of energy technologies with a strong focus **on integration of stakeholders.**

2015
1500 stakeholders
4 Round tables, 6 months

JRC SCIENCE AND POLICY REPORTS

Scientific Support to Energy Transition from a European Perspective

JRC European Forum for Science and Industry

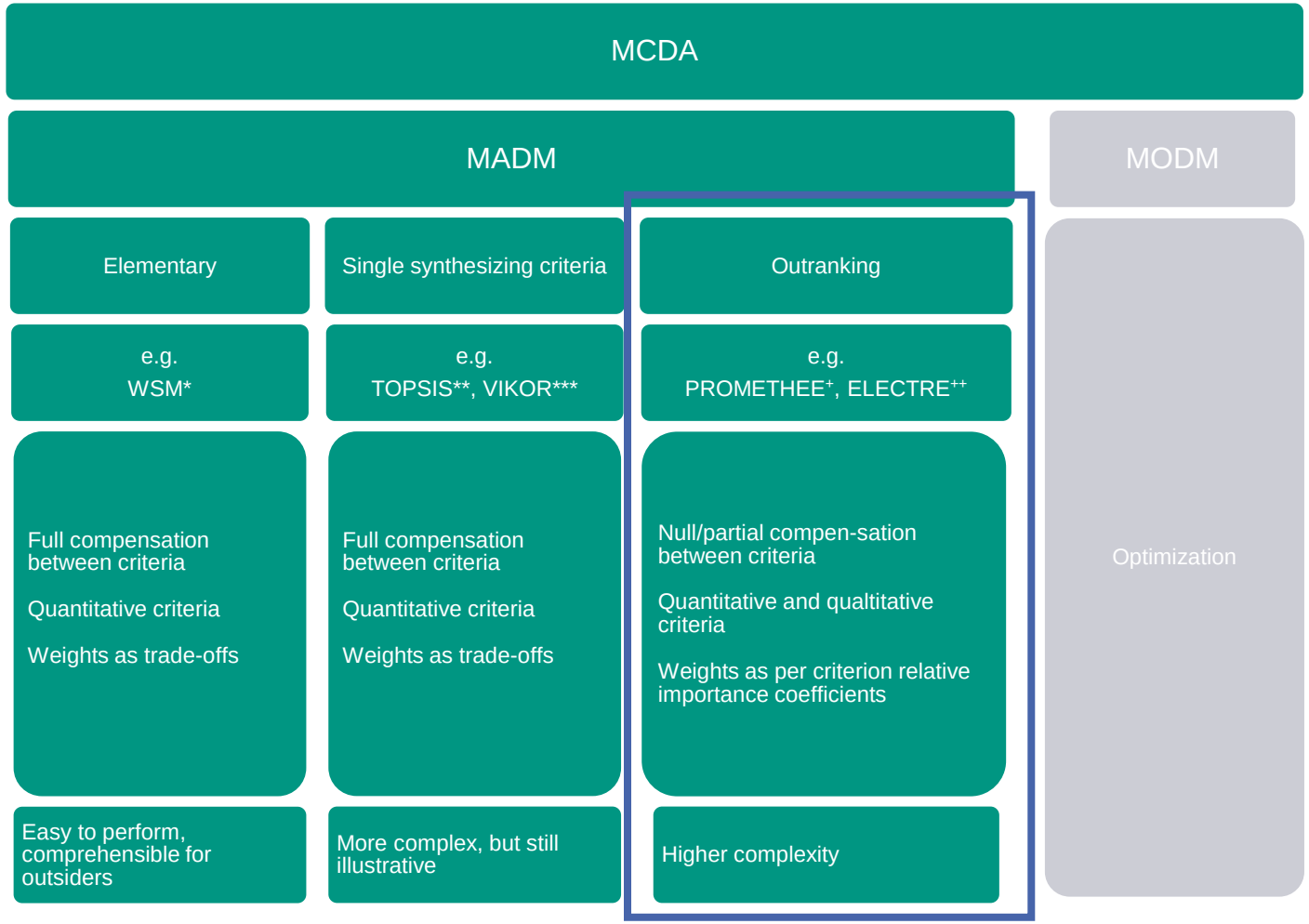
European Commission - Press release

Strategic Dialogue on the Future of the European Automotive Industry will be launched on 30 January

Brussels, 20 January 2025

"The Commission recognizes the urgent need for action to protect the European automotive industry and give it a future within the European Union"

MCDA for sustainability assessment
Methods for criteria aggregation



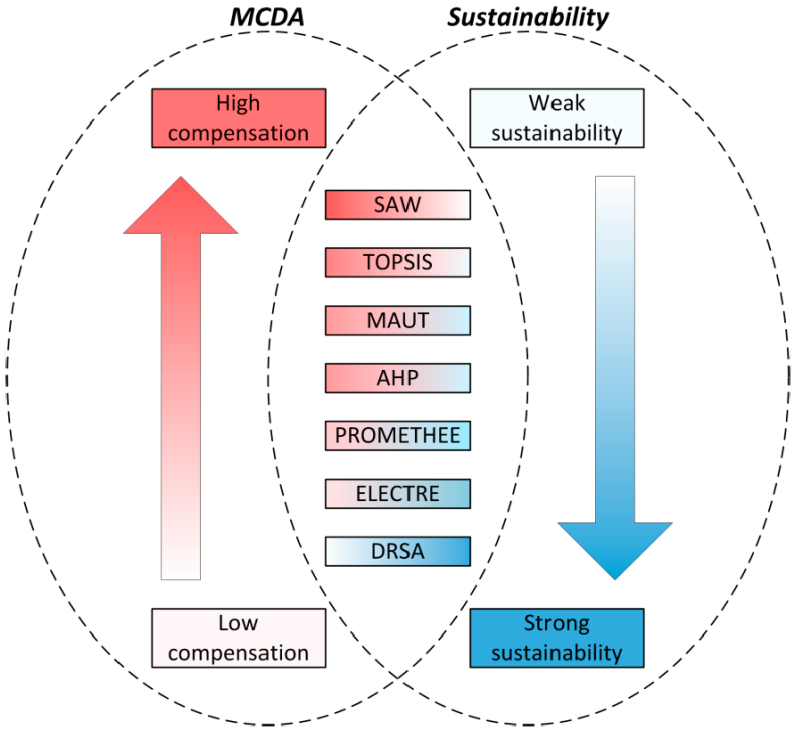
MCDA methods for criteria aggregation (based on Guitouni and Martel 1998, Wang et al. 2009)

*Weighted Sum Method **Technique for Order Preference by Similarity to Ideal Solution ***Multicriteria Optimization and Compromise Solution +Preference ranking organization method for enrichment evaluation ++ELimination and Choice Expressing REality

MCDA for sustainability assessment
Implications of different aggregation methods

Considerations for sustainability assessment

- For purely quantitative datasets, e.g. TOPSIS or Weighted Sum Method.
- For datasets with qualitative data e.g. from interviews or surveys, e.g. PROMETHEE, ELECTRE
- Strong sustainability concept
  - Good performance in one criterion cannot compensate for bad performance in another criterion, i.e. natural capital is not interchangeable with man-made capital
  - Aggregation methods with null/partial compensation are preferred e.g. PROMETHEE, ELECTRE



Compensation degree and sustainability strength for different MCDA methods

Source: Ziemba 2019

MCDA for sustainability assessment
Methods for criteria weighting

Category	Description	Method (examples)	Description
Objective	• weights elicitation by using measured data and information • reflect the difference degree of data and information	Entropy method	Relative importance of each criterion is assessed according to the difference between the observed values of each criterion.
Subjective	• weights elicitation by using stakeholders' preferences • reflect the judgments and knowledge of stakeholders	Pairwise comparison	Importance of two criteria is compared at a time and the relative importance is scored (Pairwise comparison ratios).
		AHP*	Builds on the pair-wise comparison model with a scale scale from 1 to 9 (Pairwise comparison ratios).
		SMART**	Direct assignment of importance on a 0-100 scale (Per criterion relative importance).
		SIMOS (Deck of cards)	Ranking of cards (criteria) from the least important to the most important according to their importance (Per criterion relative importance).
		n-point scale	Importance coefficients on a scale from 1 to 10 (Per criterion relative importance).
		Trade-offs	Trade-offs as percentages for each criterion summing up to 100%

Choice of method depending on aggregation method

(based on Wang et al. 2009)

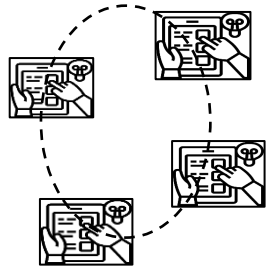
*Analytical hierrarchy process **Simple multi-attribute rating technique

HELDA software

1. **Real-time integration of stakeholder preferences** for MCDA-sustainability assessment
2. Analyse the influence of **weights uncertainties** in decision-making processes

HELDA
HELMHOLTZ MCDA TOOL

Mesa Estrada L., et al. (2026). Development and application of HELDA software: a multi-criteria decision analysis tool tailored for sustainable energy system transformations.(Under review in Experts systems with Applications).



Data collection

- Create **online Surveys**
- Reflection on criteria
- Weighting of criteria

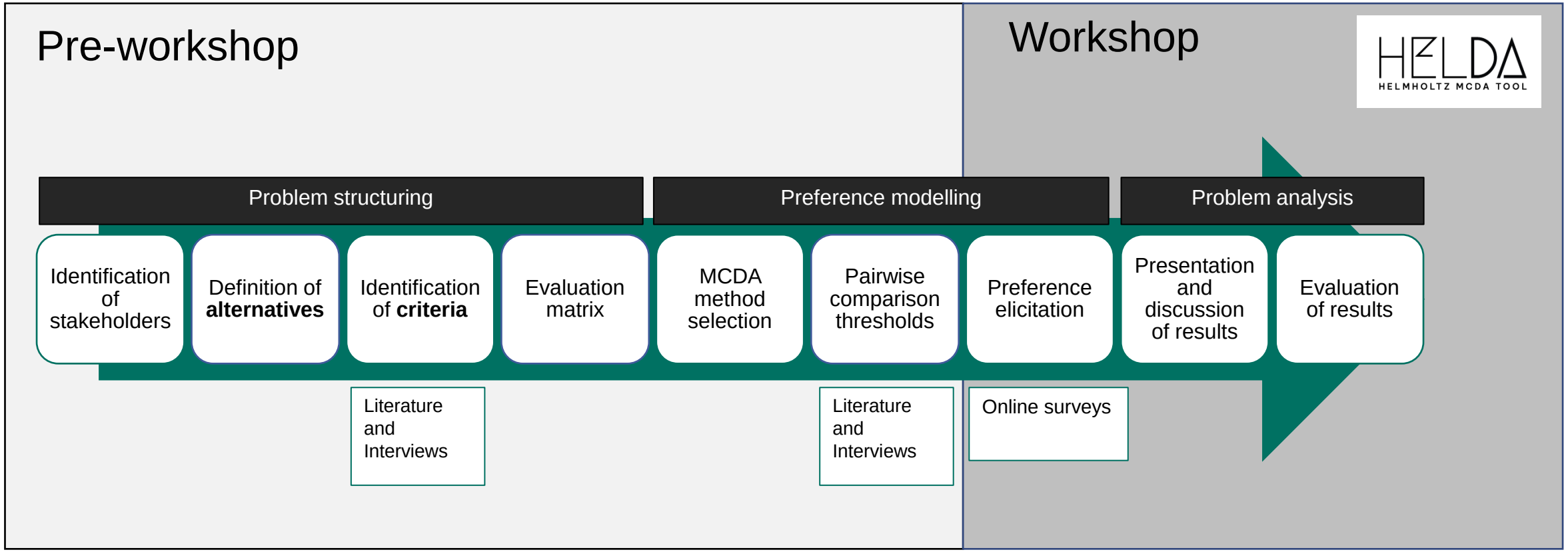
Data processing

- Process survey information
- Update MCDA model (weights and criteria)

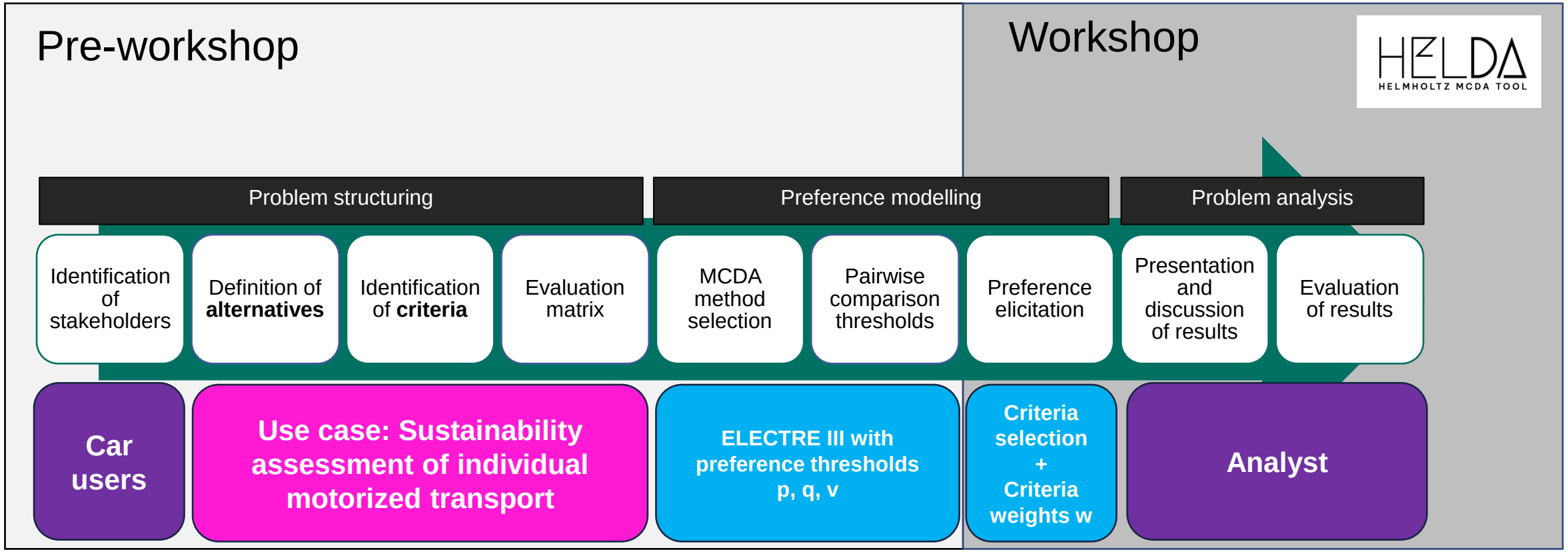
Results analysis

- Weighting sets for different stakeholders
- Indicative rankings
- Uncertainty analysis

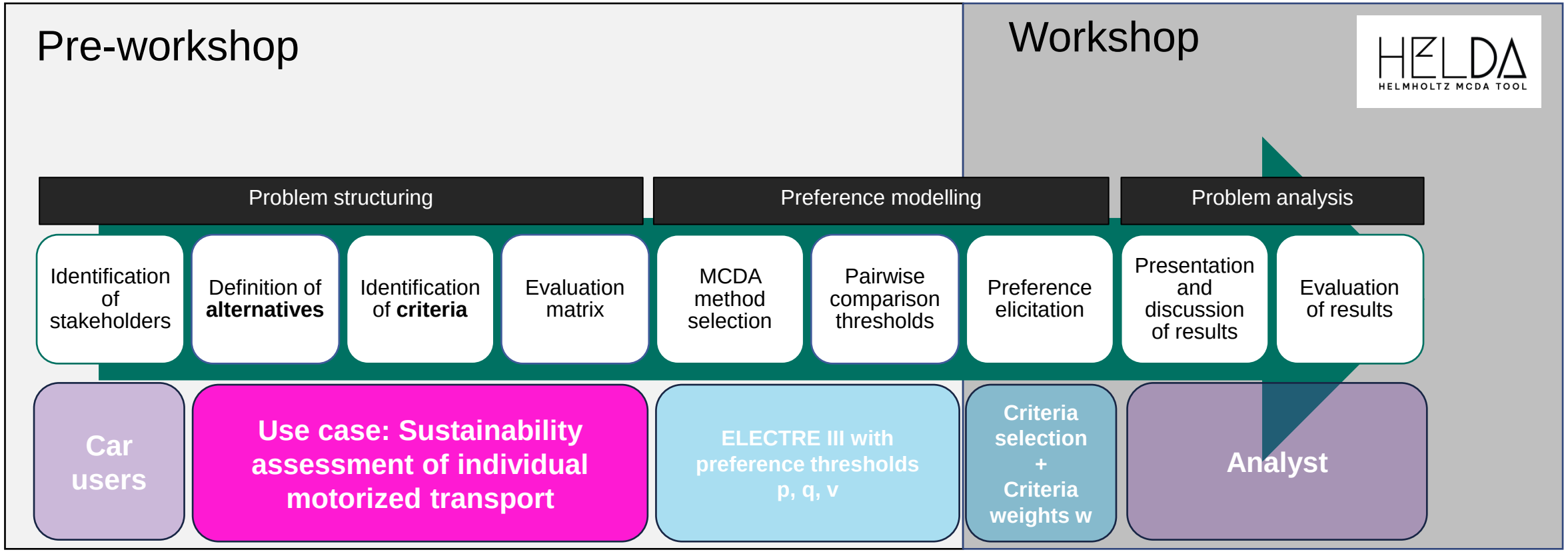
Software-aided methodology
Overview



Software-aided methodology
Teaching exercise



Software-aided methodology
Teaching exercise



Use case: Sustainability assessment of individual motorized transport

Alternatives

Alternative	Technology	Fuel	Power	Costs for acquisition
ICEV-fossil	Internal combustion engine vehicle (ICEV)	Gasoline fossil	100 kw	23.210 €
ICEV-straw		Synthetic biofuel from straw		
BEV-wind	Battery electric vehicle (BEV)	Electricity – wind power		
BEV-Mix_DE		Electricity – production mix Germany		
FCEV-wind	Fuel cell electric vehicle (FCEV)	Hydrogen from wind power		

Haase et al. (2022)

Use case: Sustainability assessment of individual motorized transport

Criteria

Criterion	Preference direction	Sub-criteria	Comment
Damage to ecosystems	Minimize	Acidification Eutrophication (freshwater, marine, terrestrial) Ecotoxicity	**Composite indicator summarizing five indicators of original study (qualitative)**
Climate Change	Minimize	-	
Damage to human health	Minimize	Particulate matter Human toxicity (cancer effects, non-cancer effects) Ionising radiation Ozone depletion Photochemical ozone formation	**Composite indicator summarizing six indicators of original study (qualitative)**
Ressource depletion	Minimize	-	
Costs	Minimize	-	
Value added	Maximize	-	

Haase et al. (2022)

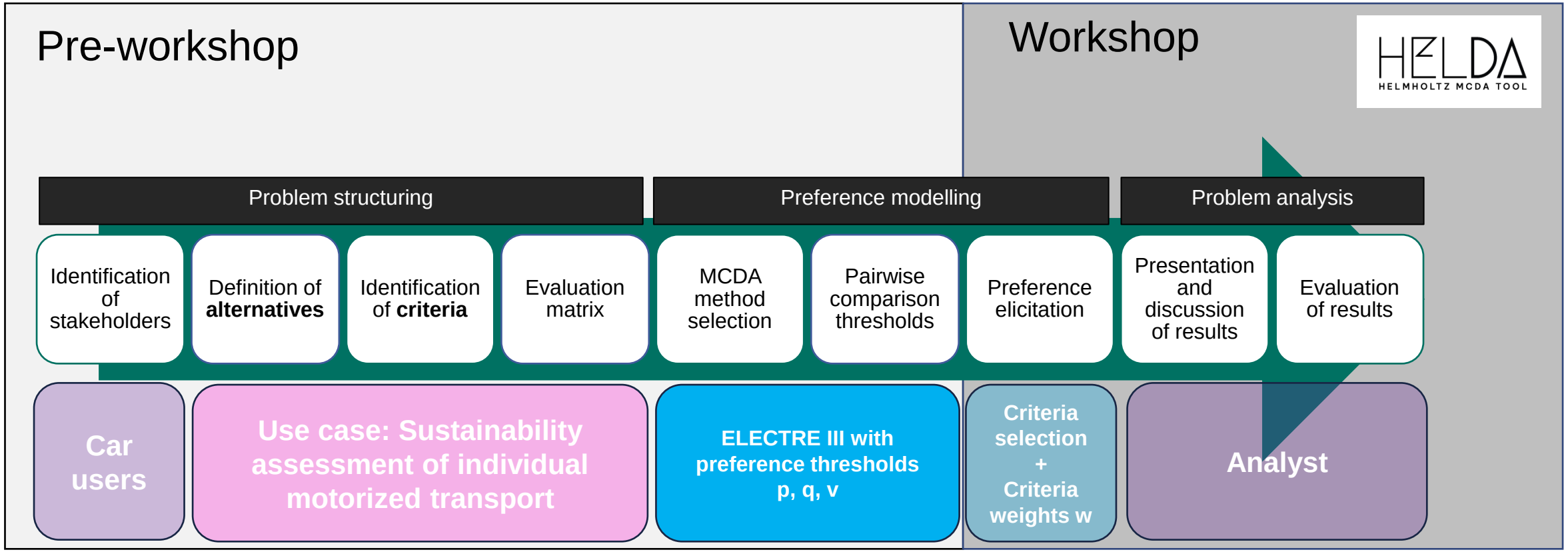
Use case: Sustainability assessment of individual motorized transport

Evaluation matrix: Qualitative and quantitative data

Criteria	Weights	Direction	Unit	Alternatives				
				ICEV-straw	BEV-Mix_DE	FCEV-wind	ICEV-fossil	BEV-wind
Damage to ecosystems	Stakeholders preferences	Min	Qualitative scale 1-5	5	4	3	2	1
Climate Change		Min	kg CO_2-eq./km	0,05947456	0,08202	0,08017	0,22381	0,0568
Damage to human health		Min	Qualitative scale 1-5	3	4	2	5	1
Resource depletion		Min	kg Sb eq./km	5,05395E-05	2,25741E-05	1,99315E-05	4,28669E-05	2,22E-05
Costs		Min	Cent/km	30	25,74	23,86	28,6	24,82
Value added		Max	%	69,2	61,88	62,9	67,7	69,1

Haase et al. (2022)

Software-aided methodology
Teaching example



ELECTRE III for criteria aggregation

1) Outranking degree between alternatives

(0 ≤ Ck(ai, aj) ≤ 1)

$$C_k(a_i,a_j)=\begin{cases}0 & \text{if} \quad f_k(a_j)-f_k(a_i)>p(f_k)\\ 1 & \text{if} \quad f_k(a_j)-f_k(a_i)\le q(f_k)\\ \dfrac{p(f_k)+f_k(a_i)-f_k(a_j)}{p(f_k)-q(f_k)} & \text{otherwise}\end{cases}$$

p Preference threshold

q Indifference threshold

2) Outranking index:

$$C(a_i,a_j)=\frac{\sum_{k=1}^{q} w_k C_k(a_i,a_j)}{\sum_{k=1}^{q} w_k}$$

Reasons **FOR**

Criteria weights w_k

3) Discordance index:

Reasons **AGAINST**

$$D_k(a_i,a_j)=\begin{cases}0 & \text{if} \quad f_k(a_j)-f_k(a_i)\le p(f_k)\\ 1 & \text{if} \quad f_k(a_j)-f_k(a_i)>v(f_k)\\ \dfrac{f_k(a_j)-f_k(a_i)-p(f_k)}{v(f_k)-p(f_k)} & \text{otherwise}\end{cases}$$

p Preference threshold

v Veto threshold

4) Credibility degree:

$$=\begin{cases}C(a_i,a_j) & \text{if} \quad D_k(a_i,a_j)\le C(a_i,a_j)\ \forall k\in J\\ C(a_i,a_j)\times\prod_{k\in J(a_i,a_j)}\dfrac{1-D_k(a_i,a_j)}{1-C(a_i,a_j)} & \text{otherwise}\end{cases}$$

$$\phi^+(a_i)=\sum_{x\in A} S(a_i,x) \qquad \phi^-(a_i)=\sum_{x\in A} S(x,a_i)$$

Net flow score

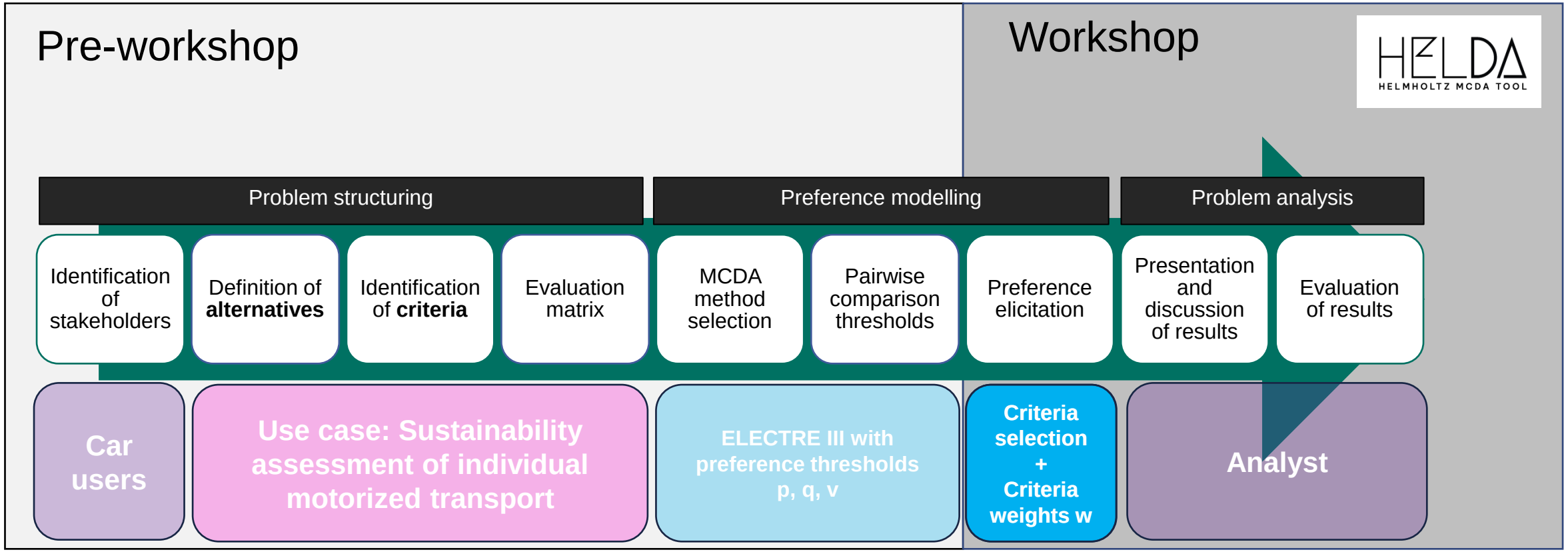
$$\phi(a_i)=\phi^+(a_i)-\phi^-(a_i)$$

Sarmas et al. (2020)

ELECTRE III for criteria aggregation
Preference thesholds p, q

Criteria	Weights	Direction	Unit	Thresholds		Alternatives				
				q	p	ICEV-straw	BEV-Mix_DE	FCEV-wind	ICEV-fossil	BEV-wind
Damage to ecosystems	Stakeholders preferences	Min	Qualitative scale 1-5	0	1	5	4	3	2	1
Climate Change		Min	kg CO_2-eq./km	0,0028	0,0056	0,0594	0,0820	0,0801	0,2238	0,0568
Damage to human health		Min	Qualitative scale 1-5	0	1	3	4	2	5	1
Resource depletion		Min	kg Sb eq./km	9,96E-7	1,99E-6	5,05E-05	2,25E-05	1,99E-05	4,28E-05	2,22E-05
Costs		Min	Cent/km	1,19	2,38	30	25,74	23,86	28,6	24,82
Value added		Max	%	3,09	6,18	69,2	61,88	62,9	67,7	69,1

Software-aided methodology
Teaching example



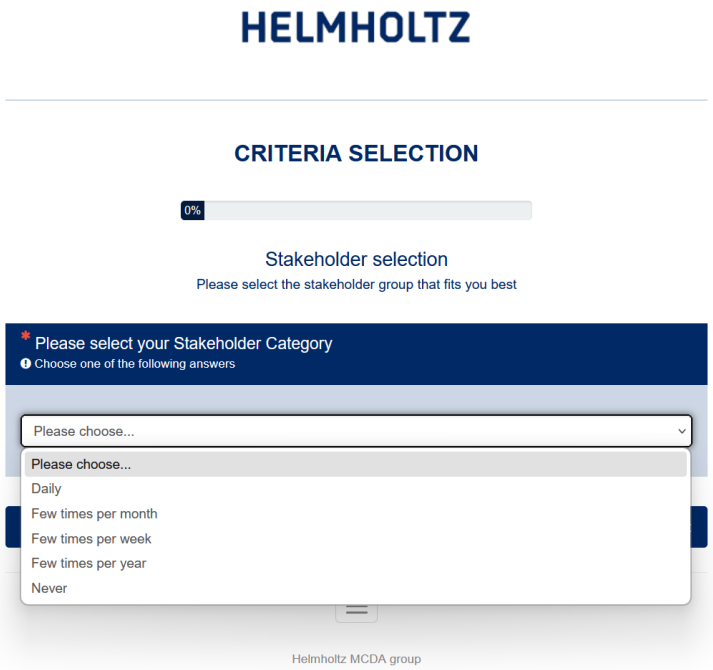
Preference elicitation (individual preferences)

Sustainability criteria selection

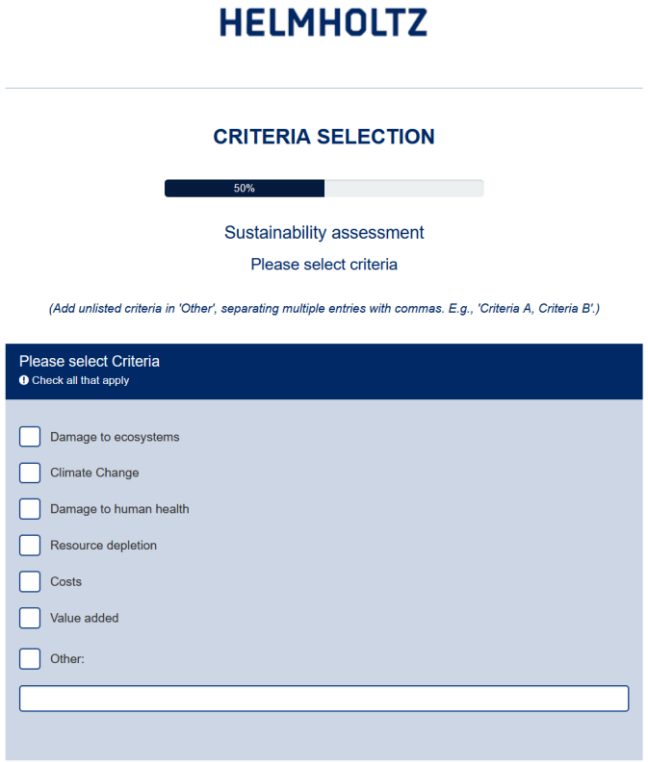
1. Scan QR code

HELDA
HELMHOLTZ MCDA TOOL

2. Select your category



3. Select criteria

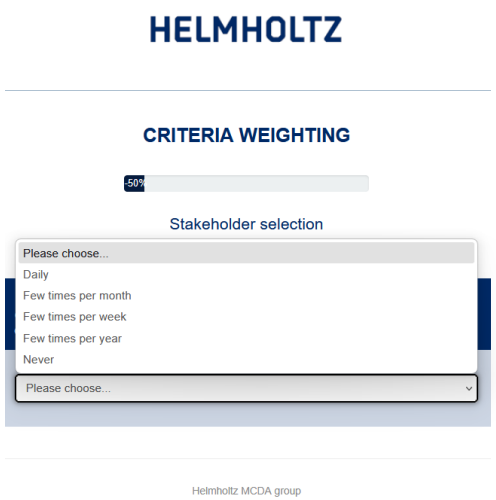


Preference elicitation (individual preferences)

Sustainability criteria weighting

1. Scan QR code

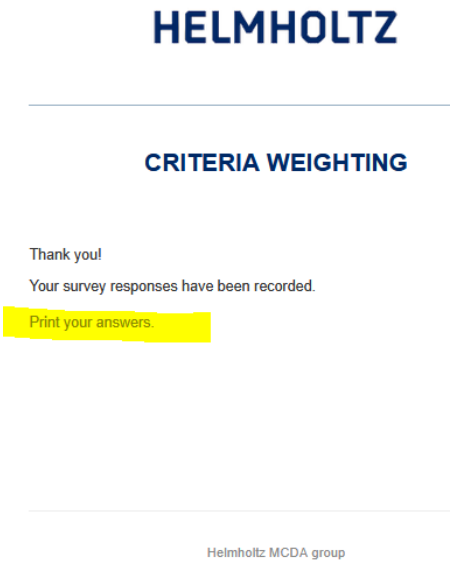
2. Select your category



3. Assign relative importance

6-point scale: 6 is 6 times more important than 1

4. Print your answers



HELDA
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Preference elicitation (group preferences)

Deck of Cards Method for criteria weighting

Objective

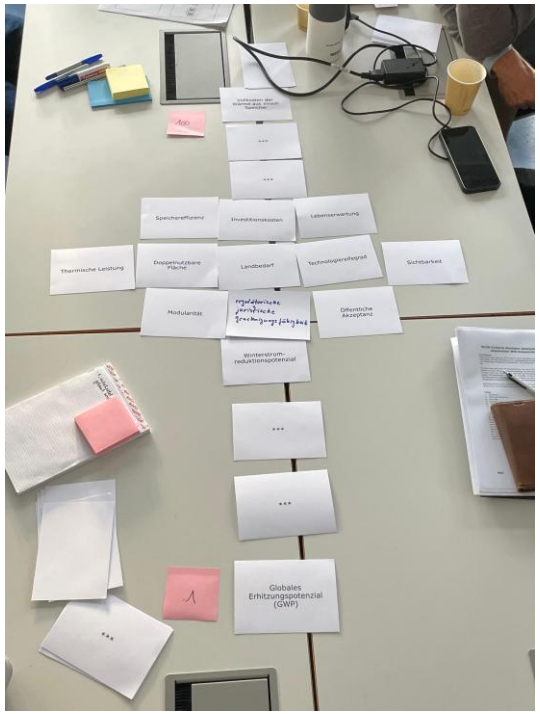
Group consensus for criteria weighting

Materials

- Set of criteria cards (one card per criterion)
- Set of blank cards

Procedure

- Order criteria according to importance
- Put blanks cards in between criteria whenever differences are higher
- Indicate how much more important is most important criterion compared to least important one



Deck of Cards method applied at a stakeholder workshop, Zurich, December 2024 (source: Own picture)

Figueira and Roy (2002)

Agenda

Introduction

Task 1: Students act as stakeholders

Task 2: Students act as Analysts

Wrap-Up

Task 1: Students act as stakeholders

- Stakeholder categories: Frequency of use of vehicles (private use)
  - Daily
  - Few times per month
  - Few times per week
  - Few times per year
  - Never

Task 1: Preference elicitation (individual I)

Sustainability criteria selection

http://paris.ites.kit.edu:80/621699

Task 1: Preference elicitation (individual I)

Sustainability criteria weighting – Part 1

http://paris.ites.kit.edu:80/766468

Task 1: Preference elicitation (group work I)

Group 1	Group 2
Participant 1	Participant 5
Participant 2	Participant 6
Participant 3	Participant 7
Participant 4	Participant 8

Task: Deck of cards online exercise using “Concept Board”

Task 1: Preference elicitation (group work II)

Group 1	Group 2
Participant 1	Participant 5
Participant 2	Participant 6
Participant 3	Participant 7
Participant 4	Participant 8

Task: Summarise the main points of agreement and disagreement (group work)

Task 1: Preference elicitation (individual II)

Sustainability criteria weighting – Part 2

http://paris.ites.kit.edu:80/454592

Agenda

Introduction

Task 1: Students act as stakeholders

Task 2: Students act as Analysts

Wrap-Up

Task 2: Students act as analysts (Group work III)

Analyst Group 1	Analyst Group 2
Participant 1	Participant 5
Participant 2	Participant 6
Participant 3	Participant 7
Participant 4	Participant 8

Task: Use HELDA software to analyze results from exercise 1.

Task 2: Exemplary analyst tasks

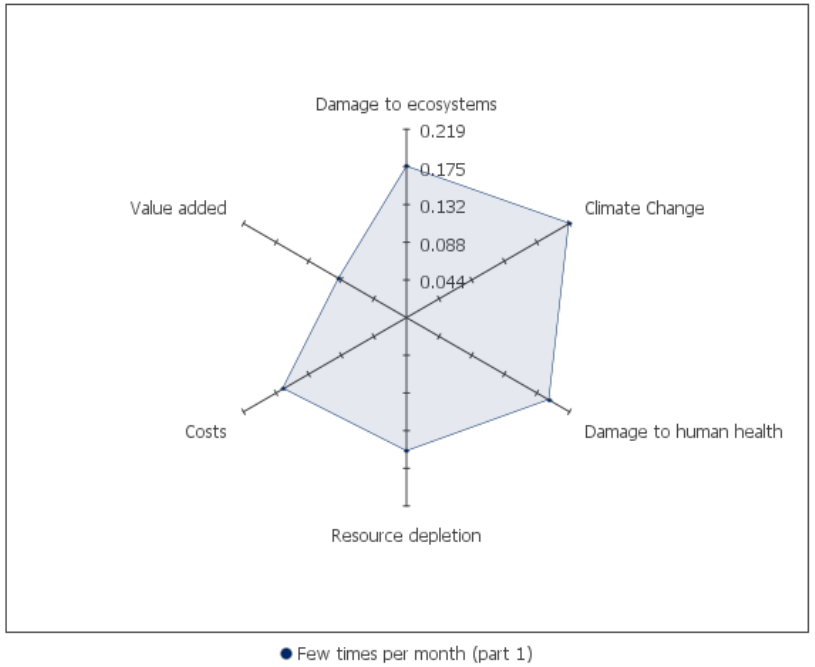
1. Which criteria is the ranking more sensitive to? Consider different stakeholders groups (sensitivity analysis of individual weights)

2. How was the impact of the group work on the individual stakeholders preferences? (Weight sets analysis of individual weights before and after group work, ranking changes?)

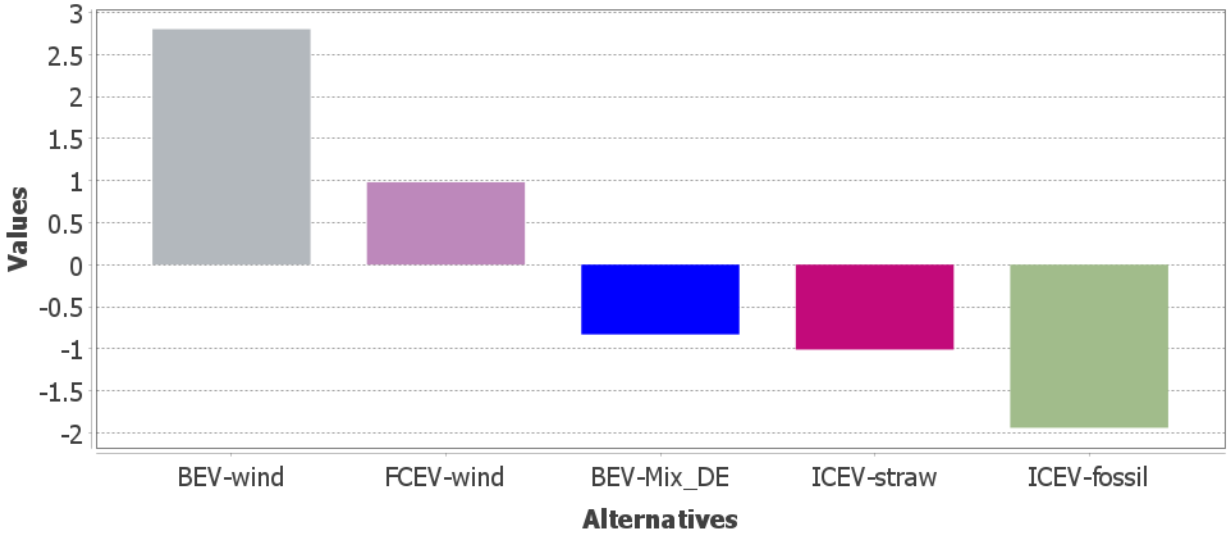
Task 2: Exemplary analyst results

1. **To which criteria weight is the ranking more sensitive? Consider different stakeholder groups (sensitivity analysis of individual weights)**

Stakehodler category: Few times per month



Weights



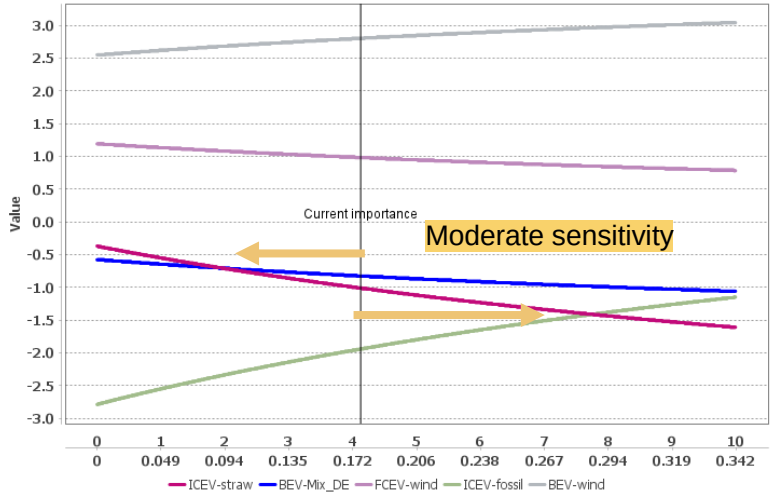
Ranking

Task 2: Exemplary analyst results

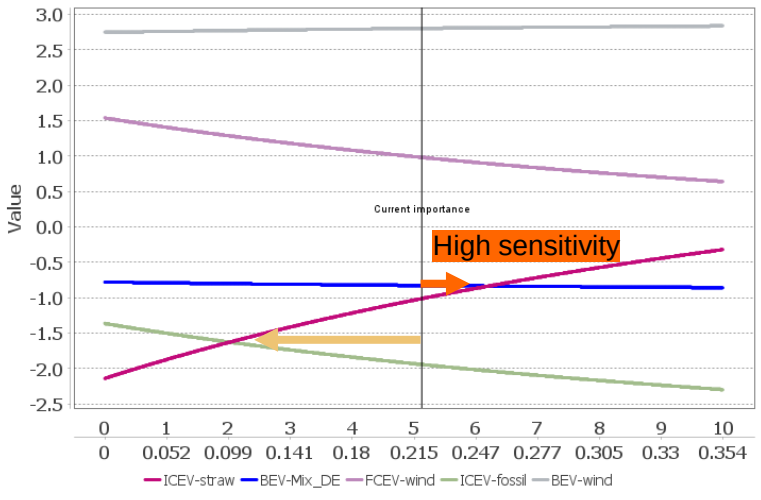
1. **To which criteria weight is the ranking more sensitive? Consider different stakeholder groups (sensitivity analysis of individual weights)**

Stakeholder category: Few times per month

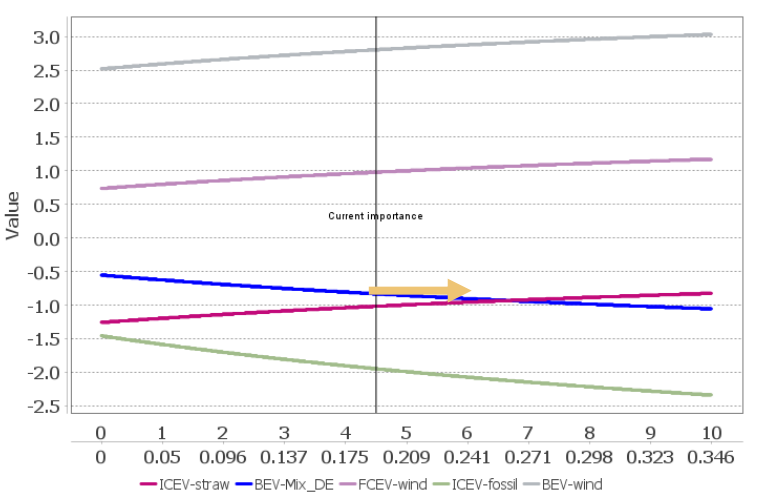
Damage to ecosystems



Climate change



Damage to human health



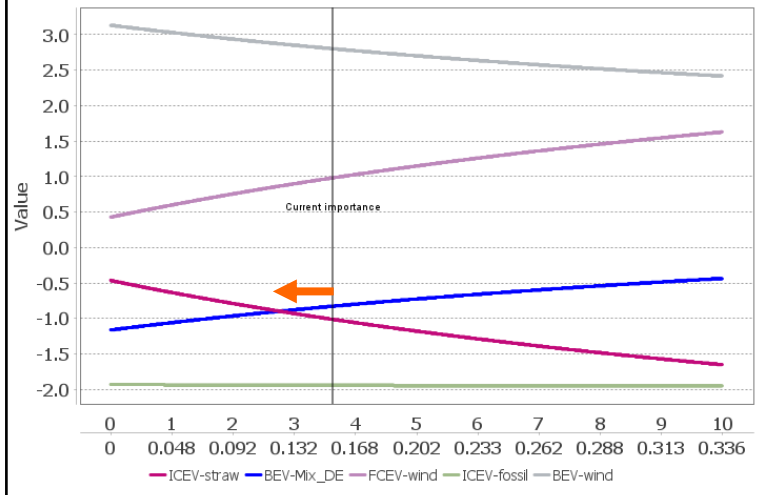
Sensitivity analysis part 1

Task 2: Exemplary analyst results

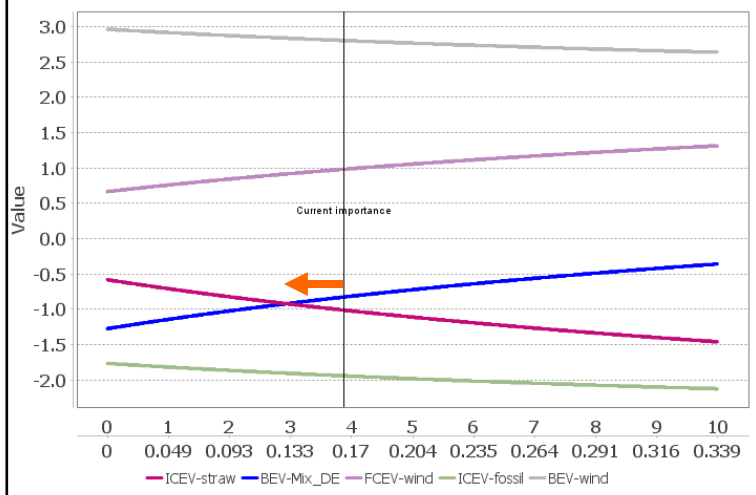
1. **To which criteria weight is the ranking more sensitive? Consider different stakeholder groups (sensitivity analysis of individual weights)**

Stakeholder category: Few times per month

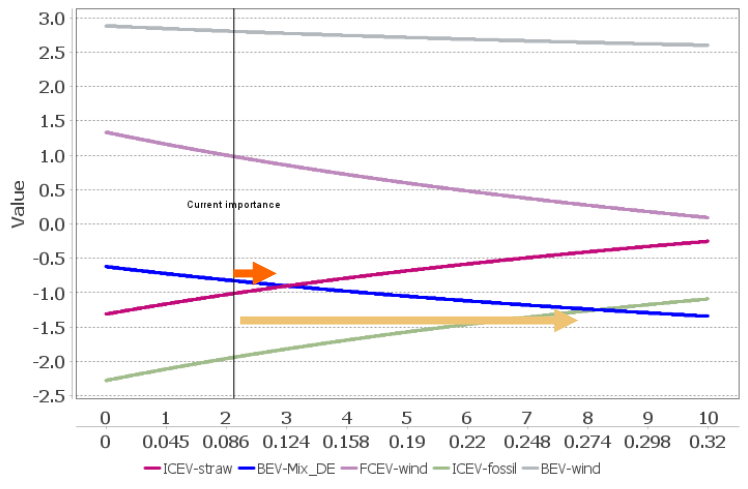
Resource depletion



Costs



Value added



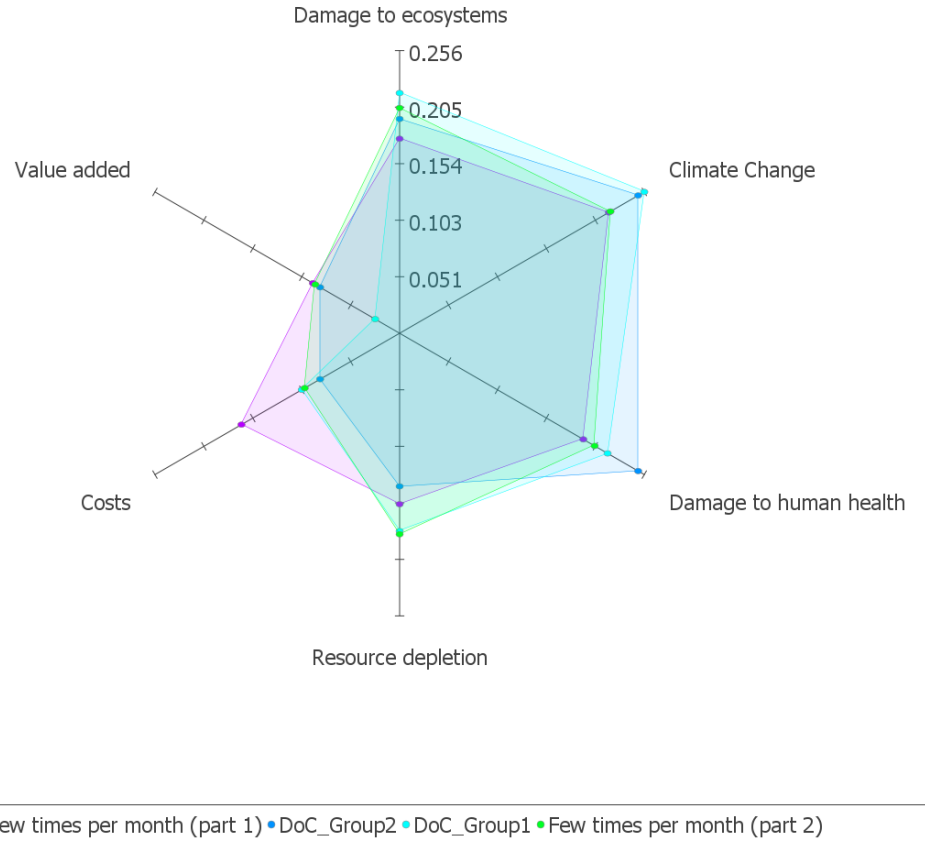
Sensitivity analysis part 2

Task 2: Exemplary analyst results

2. How was the impact of the group work on the individual stakeholders preferences? Weight sets analysis of individual weights before and after group work.

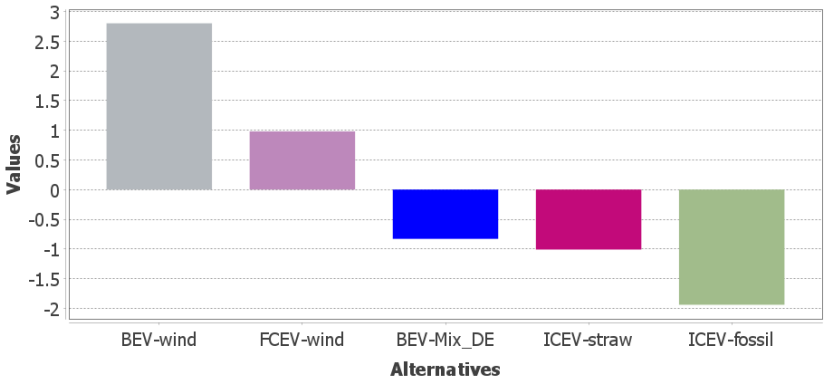
Stakeholder category: Few times per month:

- Lower importance for costs after group work
- Importance of damage to ecosystems and resource depletion increase
- Importance of value added, climate change and damage to human health remain rather unchanged

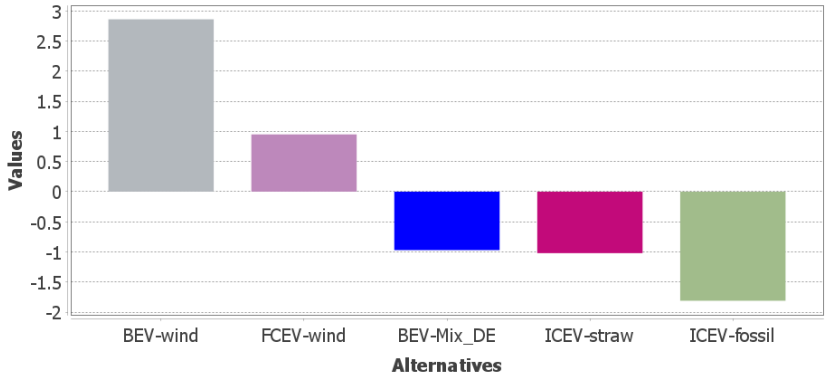


Task 2: Exemplary analyst results

2. **How was the impact of the group work on the individual stakeholders preferences? (Ranking before and after group work.)**



Before



After

- No significant changes in the preferences
- Homogeneous groups
- No significant change in the net flow scores and ranking

References

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- Haase, M.; Wulf, C.; Baumann, M.; Ersoy, H.; Koj, J. C.; Harzendorf, F.; Mesa Estrada, L. S. (2022). *Multi criteria decision analysis for prospective sustainability assessment of alternative technologies and fuels for individual motorized transport*. Clean technologies and environmental policy, 24 (10), 3171–3197. doi:10.1007/s10098-022-02407-w
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