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JÜLICH
FORSCHUNGSZENTRUM

Application of the Analytic Hierarchy Process to Facilitate the Cross-Impact Balance Analysis

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Contents

1. Fundamentals of cross-impact balance analysis

Predictive Scenarios	Explorative Scenarios	Normative Scenarios
• What will happen? • What can be expected?	• What is possible? • What happens if…?	• How to reach a specific target?
To predict the most ´likely´ future	To analyze possible futures	To analyze specific action paths
• Trend developments	• Identification of main drivers	• Assessment of possible of measures

Cross-Impact Balance (CIB) analysis

- They are a plausible view of the future described in a narrative form.
- They focus on a specific system (e.g. electricity system) in a specific location over a specific time horizon.
- Provide support for planning of decision makers.

1. Fundamentals of cross-impact balance analysis

- CIB allows for taking both **qualitative** and **quantitative** factors into account.
- It is a **structured** process for the deduction of **possible scenarios** based on **expert judgments** about systemic interactions (see e.g. Weimer-Jehle 2006, in *Technological Forecasting & Social Change*).
- CIB is related to the theory of **dynamic systems.**
- CIB is a tool to unite knowledge and expertise from diverse fields of science by structured experts communication.
- The balancing approach is in the core of the method allowing for evaluation of interconnections between qualitative and quantitative **factors** and providing with an internal check of consistency.

1. Fundamentals of cross-impact balance analysis

CIB analysis was developed by Weimer-Jehle (2006) on the basis of standard cross-impact methods to address the following questions (among others):

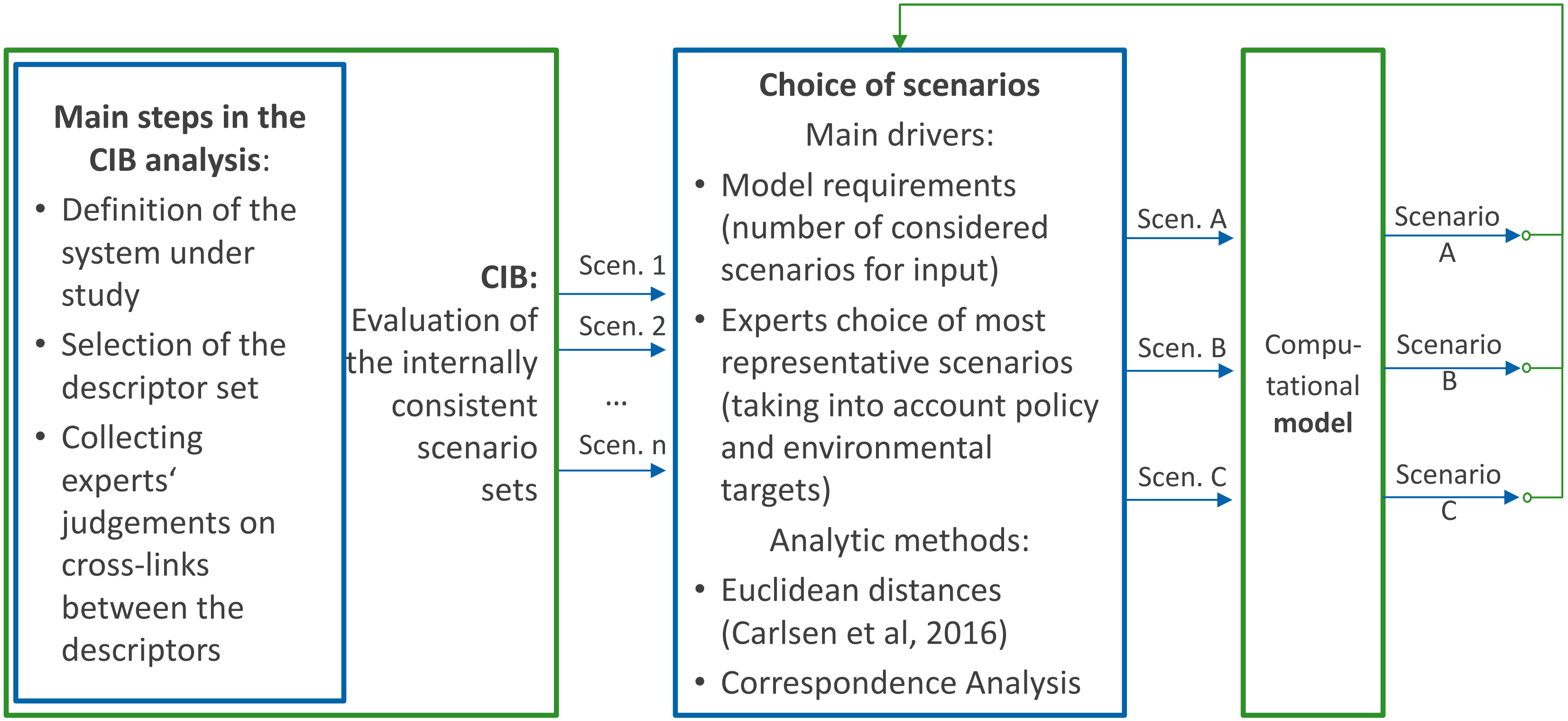
- Energy scenario analysis is incomplete if restricted only to technical and economic factors.
- Storyline development in climate research has been criticized for unsystematic construction.
- Data-picking: use of the data from different independent sources, ignoring feedbacks.
- Implicit assumptions: leaving assumptions undocumented and without checking their cross-links to each other.

CIB aims to capture socio-technical system complexity introducing “context scenarios”, allowing for a more systematic approach in the style of “Story and Simulation” (Alcamo 2008), e.g. Special Report on Emissions Scenarios by the International Panel of Climate Change's (2000).

2. CIB analysis as an approach in 4NEMO project

The project is supported by the Federal Ministry for Economic Affairs and Energy (BMWi)

Milestones of the CIB procedure within the 4NEMO project



Main steps in the CIB analysis:

- Definition of the system under study
- Selection of the descriptor set
- Collecting experts‘ judgements on cross-links between the descriptors

CIB: Evaluation of the internally consistent scenario sets

Choice of scenarios

Main drivers:

- Model requirements (number of considered scenarios for input)
- Experts choice of most representative scenarios (taking into account policy and environmental targets)

Analytic methods:

- Euclidean distances (Carlsen et al, 2016)
- Correspondence Analysis

Compu-tational **model**

2. CIB analysis as an approach in 4NEMO project

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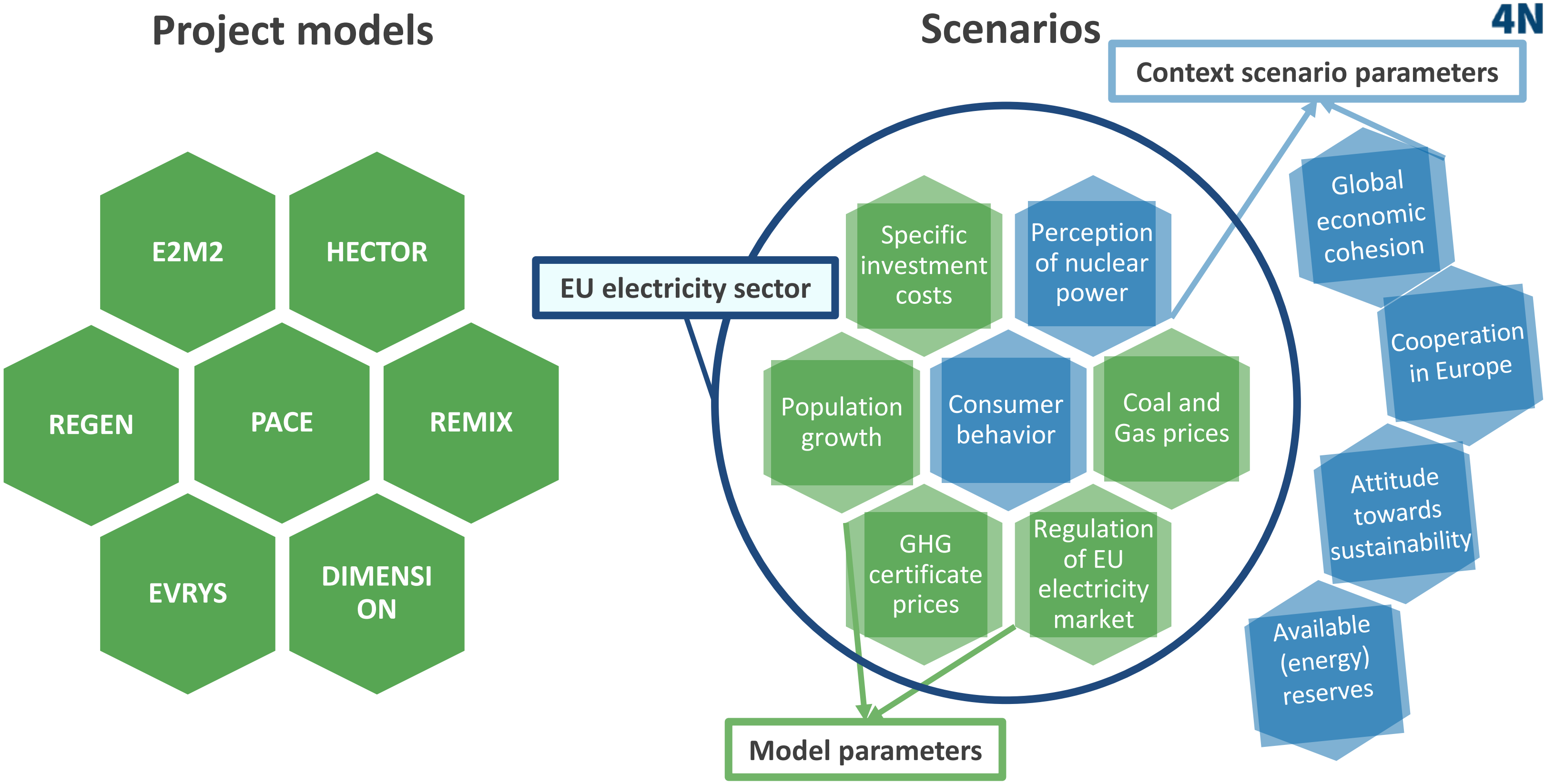

Project models

- E2M2
- HECTOR
- REGEN
- PACE
- REMIX
- EVRYS
- DIMENSION

Scenarios

EU electricity sector

- Specific investment costs
- Perception of nuclear power
- Population growth
- Consumer behavior
- Coal and Gas prices
- GHG certificate prices
- Regulation of EU electricity market

Context scenario parameters

- Global economic cohesion
- Cooperation in Europe
- Attitude towards sustainability
- Available (energy) reserves

Model parameters

2. CIB analysis as an approach in 4NEMO project

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4NEMO CIB Descriptors			
D1: Global economic cohesion	D6: Specific invest. costs	D11: Demand for flexibility	D16: Consumer behavior
D2: Energy sources and available reserves	D7: Focus of research and development	D12: Realization of the DSM potential	D17: Overall welfare and equality
D3: Coal price	D8: Regulation of the EU electricity market	D13: Grid infrastructure	D18: Land use policy
D4: Gas- and Oil Prices	D9: Incentives for RES	D14: CCS accepted storage potential	D19: Urbanization
D5: Perception of nuclear power	D10: Cooperation in Europe and political culture	D15: Population growth	D20: Attitude towards sustainability
D21: GHG certificate prices		D22: Agriculture for energy sector	

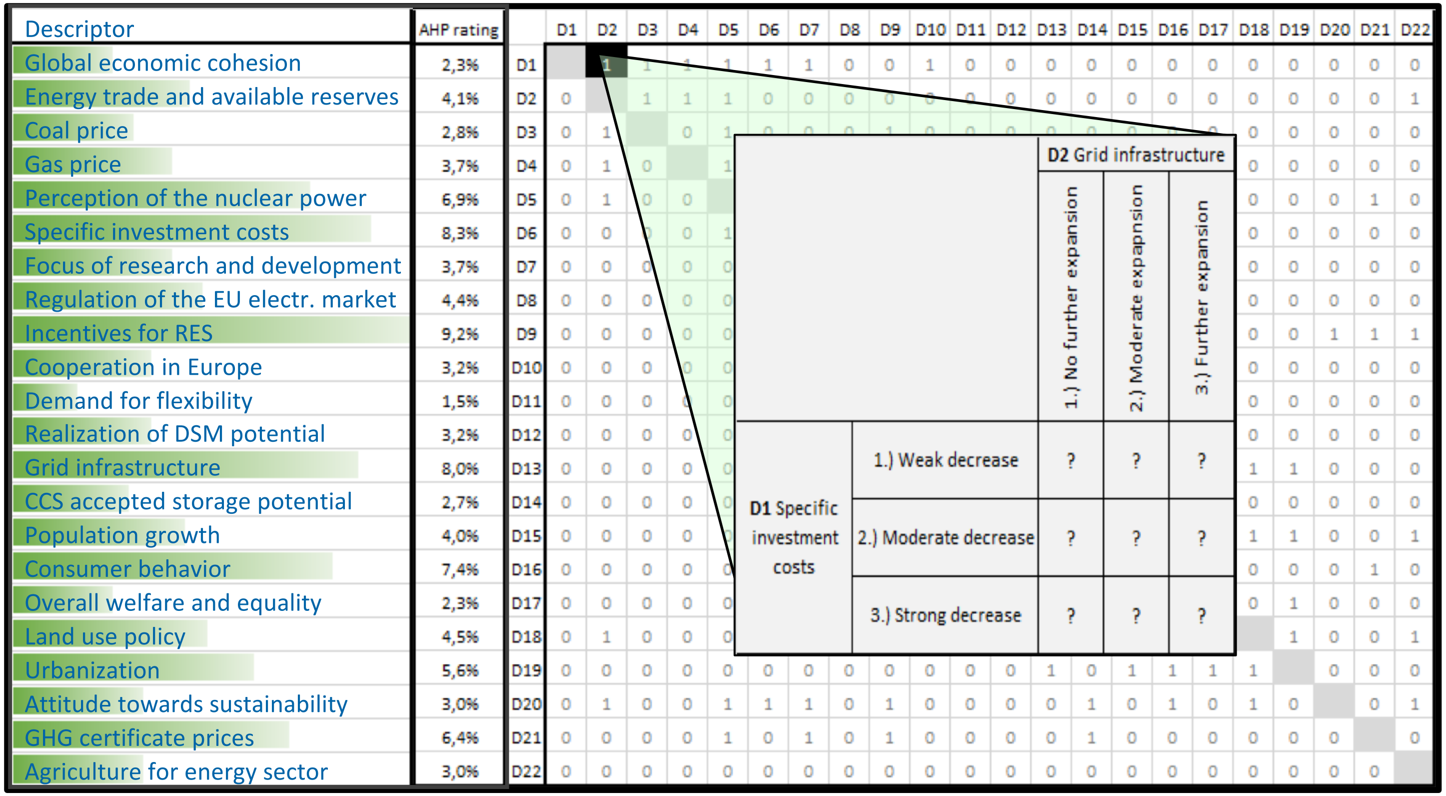
3. Weighting of descriptors in the CIB analysis

- CIB analysis allows for constructing consistent scenarios based on the evaluation of direct interconnections between a range of system factors (descriptors).
- However, CIB process does not directly include transparent way of assigning impact weights to descriptors → it requires a extensive participation of experts. A non trivial task, especially for large matrixes.

So far: there is a lack of formalized approach for an assessment of the impact scores.

→ Analytic Hierarchy Process (AHP) represents a novel approach in the context of CIB to facilitate experts’ judgements on the range of impact scores.

3. Weighting of descriptors in the CIB analysis



Descriptor	AHP rating		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22
Global economic cohesion	2,3%	D1		1	1	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Energy trade and available reserves	4,1%	D2	0		1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Coal price	2,8%	D3	0	1		0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Gas price	3,7%	D4	0	1	0		1													0	0	0	0	0
Perception of the nuclear power	6,9%	D5	0	1	0	0														0	0	0	1	0
Specific investment costs	8,3%	D6	0	0	0	0	1													0	0	0	0	0
Focus of research and development	3,7%	D7	0	0	0	0	0													0	0	0	0	0
Regulation of the EU electr. market	4,4%	D8	0	0	0	0	0													0	0	0	0	0
Incentives for RES	9,2%	D9	0	0	0	0	0													0	0	1	1	1
Cooperation in Europe	3,2%	D10	0	0	0	0	0													0	0	0	0	0
Demand for flexibility	1,5%	D11	0	0	0	0	0													0	0	0	0	0
Realization of DSM potential	3,2%	D12	0	0	0	0	0													0	0	0	0	0
Grid infrastructure	8,0%	D13	0	0	0	0	0													1	1	0	0	0
CCS accepted storage potential	2,7%	D14	0	0	0	0	0													0	0	0	0	0
Population growth	4,0%	D15	0	0	0	0	0													1	1	0	0	1
Consumer behavior	7,4%	D16	0	0	0	0	0													0	0	0	1	0
Overall welfare and equality	2,3%	D17	0	0	0	0	0													0	1	0	0	0
Land use policy	4,5%	D18	0	1	0	0	0														1	0	0	1
Urbanization	5,6%	D19	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1		0	0	0
Attitude towards sustainability	3,0%	D20	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	1	0	1	0		0	1
GHG certificate prices	6,4%	D21	0	0	0	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0		0
Agriculture for energy sector	3,0%	D22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

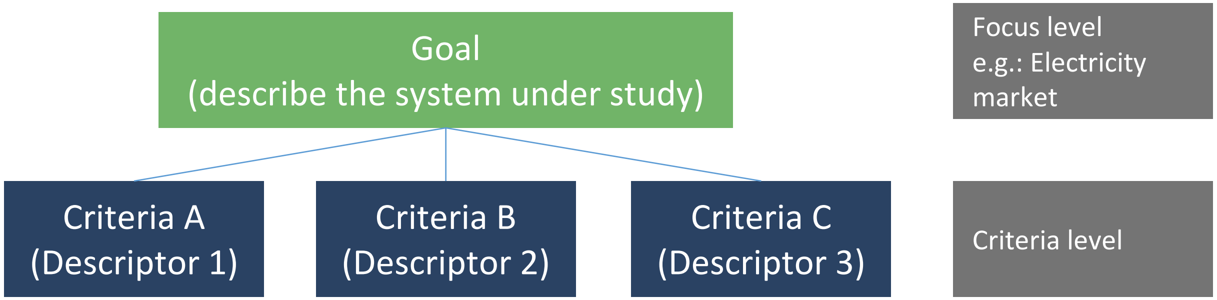
		D2 Grid infrastructure		
		1.) No further expansion	2.) Moderate expapnsion	3.) Further expansion
D1 Specific investment costs	1.) Weak decrease	?	?	?
	2.) Moderate decrease	?	?	?
	3.) Strong decrease	?	?	?

*

- Potential direct interdependencies of the descriptors.
- 108 intersection points with each 9-16 judgement fields (intersections between the states of descriptors).

3.1 Fundamentals of the AHP

- Multi Criteria Analysis (MCA) tools allow for multiple criteria analysis in decision making and are widely implemented in policy assessment studies (e.g. Volkart et al. 2016 in *International Journal of Greenhouse Gas Control).*
- AHP is recognized as one of the most applied tools for decision making among MCA (see e.g. Buchholz et al. 2009 in *Energy Policy*), specifically potent in criteria weighting and assessment of scenarios.
- AHP was first introduced by Thomas L. Saaty (1980).
- AHP is a formalized approach to consistently include experts’ in the decision making process.
- AHP is based on a pairwise comparison of criteria with regard to the overall goal:



3.2 Application of AHP in the context of CIB

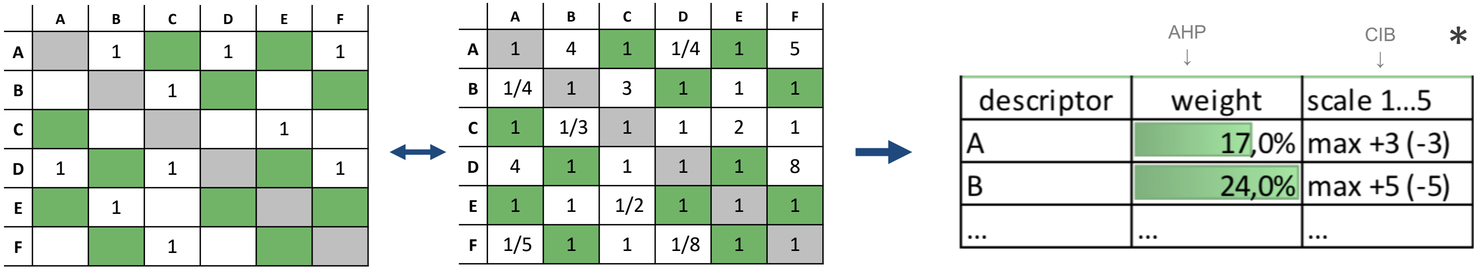
- The AHP matrix A contains paired reciprocal comparisons, so that $a_{i,j} = 1/a_{j,i}$.
- With a CIB matrix of n descriptors AHP requires maximum $n(n-1)/2$ judgements.
- The CIB impact matrix gives an overview of the direct links that exist between the elements of the scenarios (descriptors A, B, … F).
- This is an intermediary step before constructing a CIB matrix with impact scores, that characterize the magnitude and direction of links between descriptor states.

	A	B	C	D	E	F
A	▨	1		1		1
B		▨	1			
C			▨		1	
D	1		1	▨		1
E		1			▨	
F			1			▨

CIB impact matrix with
n=6 descriptors

	A	B	C	D	E	F
A	1	4	1	1/4	1	5
B	1/4	1	3	1	1	1
C	1	1/3	1	1	2	1
D	4	1	1	1	1	8
E	1	1	1/2	1	1	1
F	1/5	1	1	1/8	1	1

AHP pairwise comparison matrix A
(n×n)



	A	B	C	D	E	F
A	▨	1	🟩	1	🟩	1
B		▨	1	🟩		🟩
C	🟩		▨		1	
D	1	🟩	1	▨	🟩	1
E	🟩	1		🟩	▨	🟩
F		🟩	1		🟩	▨

↔

	A	B	C	D	E	F
A	1	4	1	1/4	1	5
B	1/4	1	3	1	1	1
C	1	1/3	1	1	2	1
D	4	1	1	1	1	8
E	1	1	1/2	1	1	1
F	1/5	1	1	1/8	1	1

→

descriptor	weight	scale 1…5
A	17,0%	max +3 (-3)
B	24,0%	max +5 (-5)
…	…	…

3.2 Application of AHP in the context of CIB

I - Implementation of the AHP rating to explore the completed cross-impact matrix

			D_1		D_n	
			r_1		r_n	
			v_1^1	v_2^1	v_1^n	v_2^n
D_1	r_1	v_1^1			$J(v_1^1, v_1^n) \cdot w_{(1,n)}$	$J(v_2^1, v_2^n) \cdot w_{(1,n)}$
		v_2^1			$J(v_2^1, v_1^n) \cdot w_{(1,n)}$	$J(v_2^1, v_2^n) \cdot w_{(1,n)}$
D_n	r_n	v_1^n	$J(v_1^n, v_1^1) \cdot w_{(n,1)}$	$J(v_2^n, v_2^1) \cdot w_{(n,1)}$		
		v_2^n	$J\left(v_2^i, v_1^1\right) \cdot w_{(n,1)}$	$J(v_2^n, v_2^1) \cdot w_{(n,1)}$		

D_n	descriptors, where n is the total number of descriptors
m	number of variations for descriptor D_n, with $m = \{1, 2\}$
v_m^n	variation m of descriptor D_n, with $n = \{D_1, D_2, \dots, D_n\}$
$J(v_m^i, v_m^j)$	Judgement field with impact strength defined by experts' of v_m^i on v_m^j

$$w_{(i,j)} = r_n^i * r_n^j + {r_n^i}^2 * \frac{r_n^j}{\left(1 - r_n^i\right)} = r_n^i * (r_n^j + \frac{r_n^i * r_n^j}{1 - r_n^i})$$

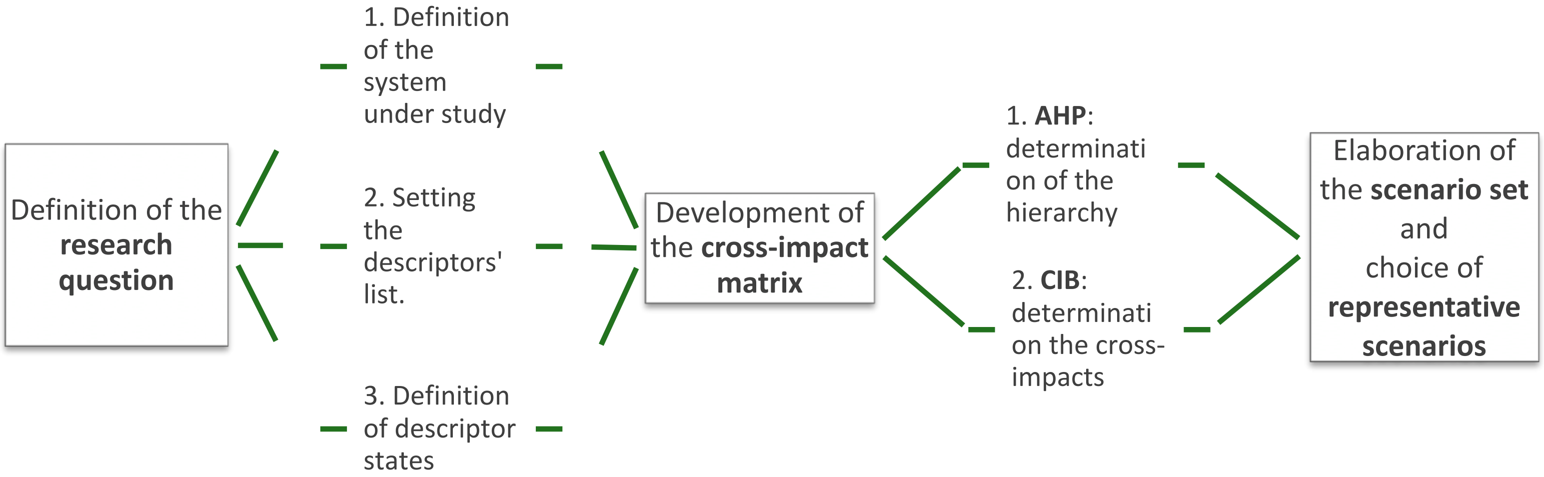
$w_{(i,j)}$	multiplier for judgement field of a cross impact between the active and passive descriptors, where i denotes an active descriptor and j – a passive descriptor, $i, j \in \mathbb{N}$ and $i \neq j$, where $i, j = 1 \dots n$
r_n	AHP rating for a descriptor D_n

3.2 Application of AHP in the context of CIB

II - Implementation of the AHP rating to complement the CIB analysis

AHP can be complementarily implemented within the CIB analysis:

- At the stage of definition of the descriptor list, in order to facilitate the choice and priority of factors for the consequent CIB analysis. *
- At the stage of the expert interviews and CIB workshops – to facilitate the planning.
- To define the suitable evaluation scale for cross-impacts.



Definition of the **research question**

1. Definition of the system under study

2. Setting the descriptors' list.

3. Definition of descriptor states

Development of the **cross-impact matrix**

1. **AHP**: determination of the hierarchy

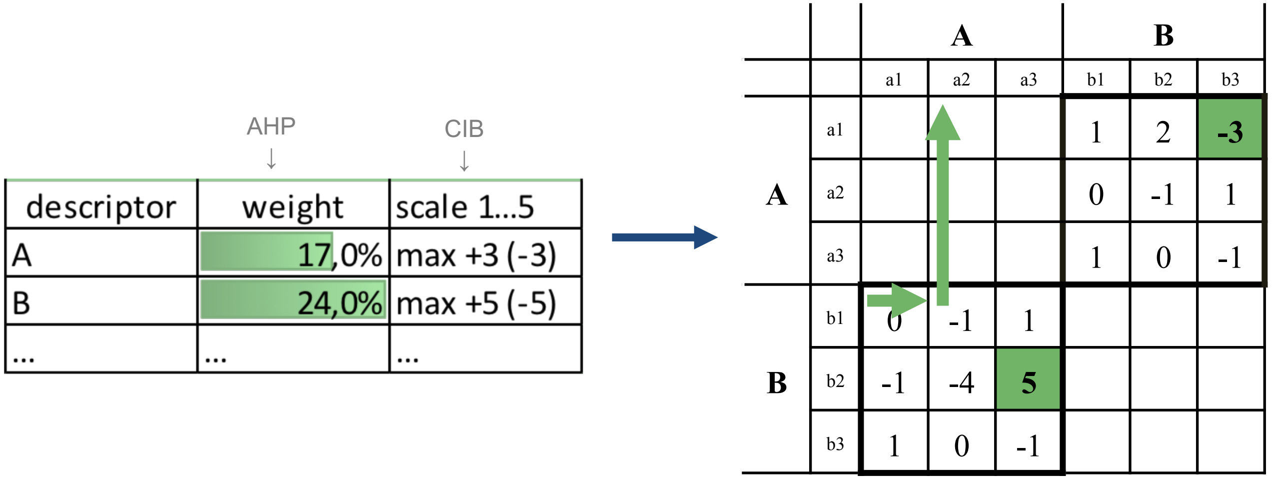
2. **CIB**: determination the cross-impacts

Elaboration of the **scenario set** and choice of **representative scenarios**

3.2 Application of AHP in the context of CIB

II - Implementation of the AHP rating to complement the CIB analysis

An application of estimated AHP weights to the impact score within the CIB matrix:



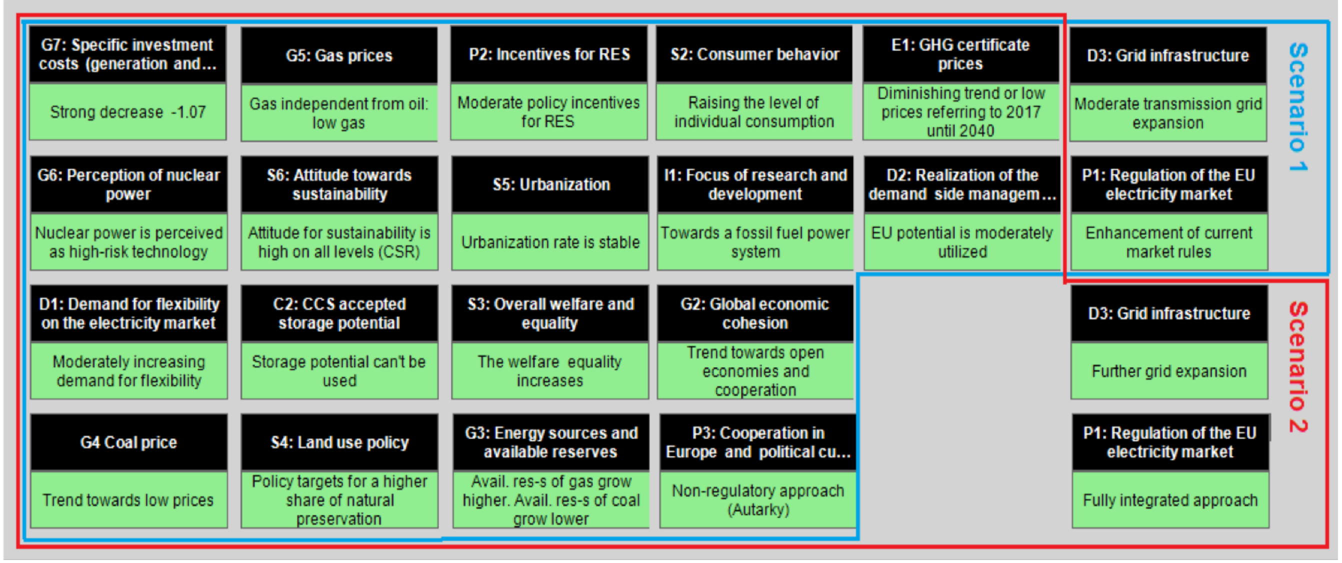
descriptor	weight	scale 1…5
A	17,0%	max +3 (-3)
B	24,0%	max +5 (-5)
…	…	…

		A			**B**		
		a1	a2	a3	b1	b2	b3
A	a1				1	2	**-3**
	a2				0	-1	1
	a3				1	0	-1
B	b1	0	-1	1			
	b2	-1	-4	**5**			
	b3	1	0	-1			

- We are able to consistently and transparently assign impact weights to the descriptors’ states, which is especially important for large matrixes.
- We differentiate between passive and active influences between the descriptors in the CIB matrix, amplifying the impact on the passive descriptor by its weight (AHP defined).

4. Results

I - Implementation of the AHP rating to explore the completed cross-impact matrix



G7: Specific investment costs (generation and… — Strong decrease -1.07
G5: Gas prices — Gas independent from oil: low gas
P2: Incentives for RES — Moderate policy incentives for RES
S2: Consumer behavior — Raising the level of individual consumption
E1: GHG certificate prices — Diminishing trend or low prices referring to 2017 until 2040
D3: Grid infrastructure — Moderate transmission grid expansion

G6: Perception of nuclear power — Nuclear power is perceived as high-risk technology
S6: Attitude towards sustainability — Attitude for sustainability is high on all levels (CSR)
S5: Urbanization — Urbanization rate is stable
I1: Focus of research and development — Towards a fossil fuel power system
D2: Realization of the demand side managem… — EU potential is moderately utilized
P1: Regulation of the EU electricity market — Enhancement of current market rules

Scenario 1

D1: Demand for flexibility on the electricity market — Moderately increasing demand for flexibility
C2: CCS accepted storage potential — Storage potential can't be used
S3: Overall welfare and equality — The welfare equality increases
G2: Global economic cohesion — Trend towards open economies and cooperation
D3: Grid infrastructure — Further grid expansion

G4 Coal price — Trend towards low prices
S4: Land use policy — Policy targets for a higher share of natural preservation
G3: Energy sources and available reserves — Avail. res-s of gas grow higher. Avail. res-s of coal grow lower
P3: Cooperation in Europe and political cu… — Non-regulatory approach (Autarky)
P1: Regulation of the EU electricity market — Fully integrated approach

Scenario 2

- High amount of non-varying descriptors.
- Two scenarios are similar (except D3: Grid infrastructure and P1: Regulation of the EU electricity market) and have a high internal consistency. Results prove to be stable.
- Scenarios with AHP (as it is implemented) can be tighter in terms of their internal argumentation and are therefore less assailable.

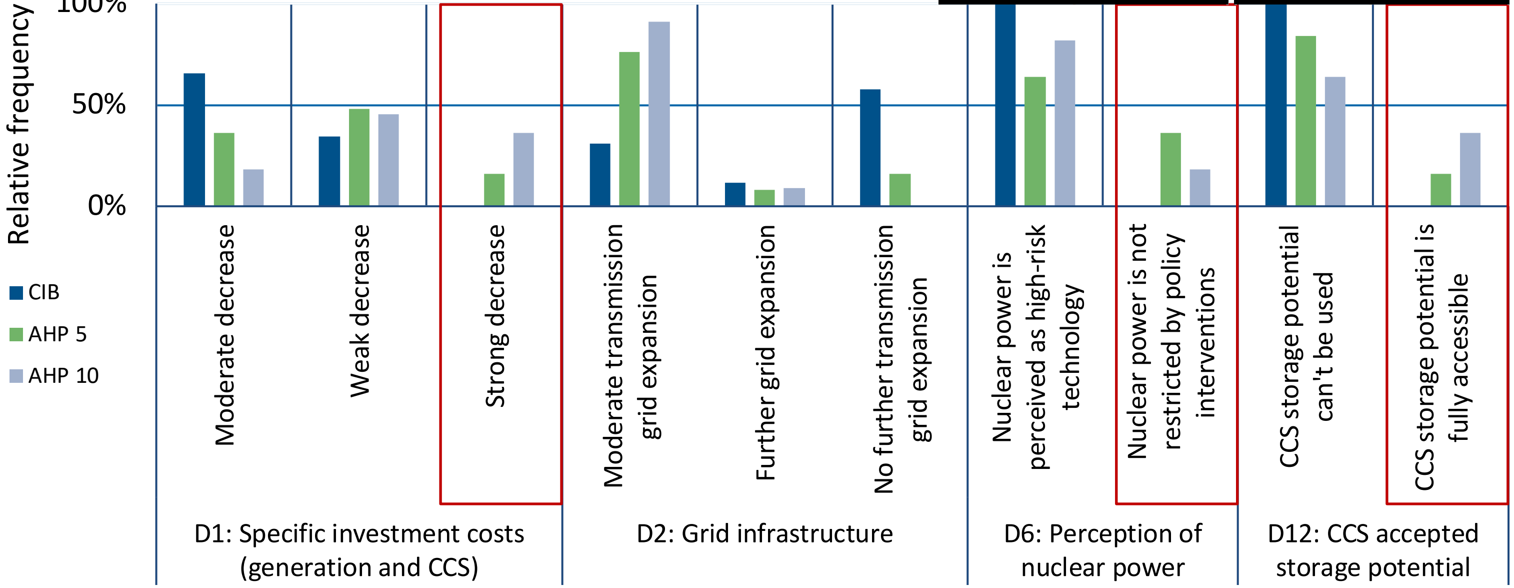
4. Results

II - Implementation of the AHP rating to complement the CIB analysis

- Allows to have more power over the variation frequencies of descriptor states and to explore the boundaries of the CIB cross impact matrix in a comprehensible manner.
- Allowing for grater variability of scenarios, bringing in nuances, which were not presented by the initial scenario room.

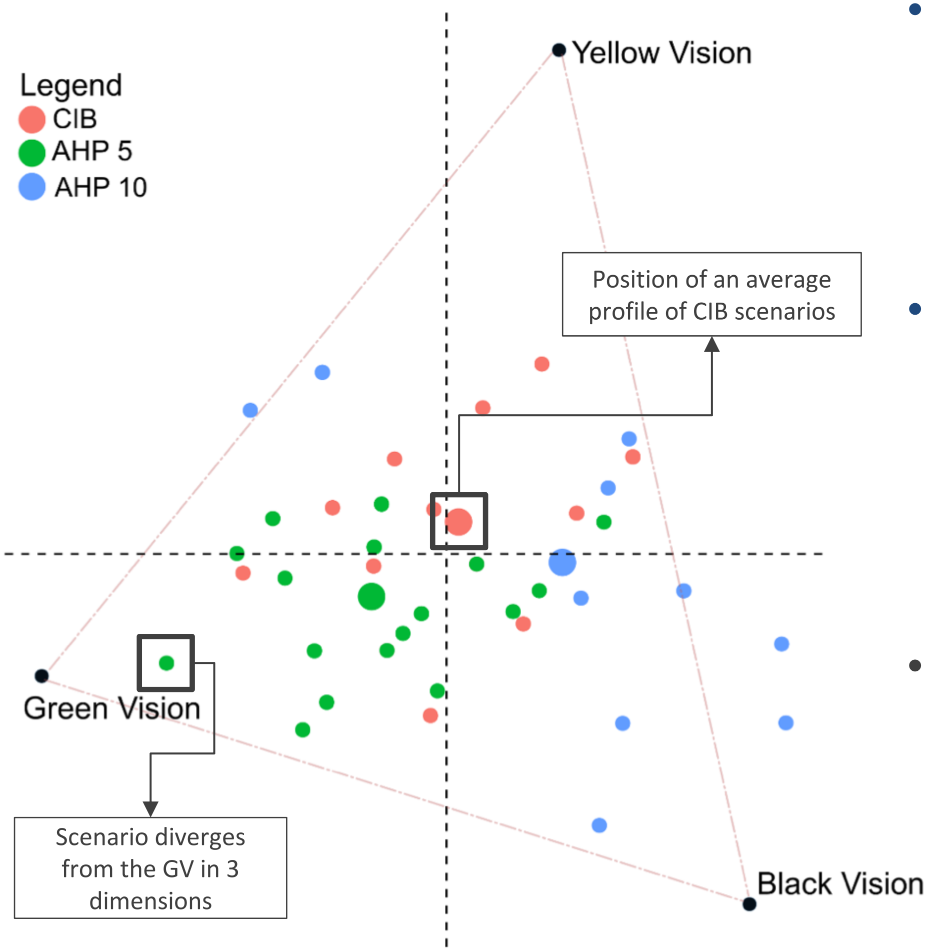
Number of scenarios	
CIB	26
AHP 5	25
AHP 10	11

Variations included	
CIB	81%
AHP 5	91%
AHP 10	76%



4. Results

II - Implementation of the AHP rating to complement the CIB analysis



Position of an average profile of CIB scenarios

Scenario diverges from the GV in 3 dimensions

- **CIB** tends to represent a central scope of the scenarios that do not offer “*extreme*” combinations of descriptor states.
- **AHP 5**, although being very close to the expert’s CIB, aligns more to the Green Vision, while **AHP 10** brings in scenarios close to the pessimistic development defined by the Black Vision.
- Changes occur due to a scale choice, which determined whether the low rated (via AHP) descriptors receive a greater poser to influence the cross-impact matrix. *

4. Results

Opportunities of the combination of AHP to the CIB process:

- Novel advancement proposed to facilitate of the CIB analysis.
- Elimination of limitations of both approaches (AHP & CIB), without further complication of the process.
- Facilitation of experts’ decision process and workshop planning.
- Transparent and systematic justification of impact score choices.
- Different application methods of the AHP to the CIB analysis and procedure have to be discussed further.