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

Kristina Govorukha\textsuperscript{1}, Paul Kunz\textsuperscript{2}, Philip Mayer\textsuperscript{1}

\textsuperscript{1} TU Bergakademie Freiberg, Schloßplatz 1, 09599 Freiberg, Tel.: +49 (0)3731 39 4082

\textsuperscript{2} Forschungszentrum Jülich, Institut für Energie- und Klimaforschung (IEK-STE), Wilhelm-Johnenstraße, 52425 Jülich, Tel.: +49 (0)2461 61 9835
Contents

1. Fundamentals of cross-impact balance analysis
2. Cross-impact balance analysis as an approach for context scenarios in 4NEMO
3. Weighting of descriptors in the cross-impact balance analysis
   3.1 Fundamentals of the analytic hierarchy process
   3.2 Application of the analytic hierarchy process in the context of the cross-impact balance analysis
4. Results and conclusions
1. Fundamentals of cross-impact balance analysis

**Predictive Scenarios**
- What will happen?
- What can be expected?

To predict the most ‘likely’ future
- Trend developments

**Explorative Scenarios**
- What is possible?
- What happens if...?

To analyze possible futures
- Identification of main drivers

**Normative Scenarios**
- How to reach a specific target?

To analyze specific action paths
- Assessment of possible 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

Computational model

Scenarios:
- Scenario A
- Scenario B
- Scenario C
2. CIB analysis as an approach in 4NEMO project

The project is supported by the Federal Ministry for Economic Affairs and Energy (BMWi)
2. CIB analysis as an approach in 4NEMO project

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

<table>
<thead>
<tr>
<th>4NEMO CIB Descriptors</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1: Global economic cohesion</td>
</tr>
<tr>
<td>D2: Energy sources and available reserves</td>
</tr>
<tr>
<td>D3: Coal price</td>
</tr>
<tr>
<td>D4: Gas- and Oil Prices</td>
</tr>
<tr>
<td>D5: Perception of nuclear power</td>
</tr>
<tr>
<td>D21: GHG certificate prices</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>AHP rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global economic cohesion</td>
<td>2.3%</td>
</tr>
<tr>
<td>Energy trade and available reserves</td>
<td>4.1%</td>
</tr>
<tr>
<td>Coal price</td>
<td>2.8%</td>
</tr>
<tr>
<td>Gas price</td>
<td>3.7%</td>
</tr>
<tr>
<td>Perception of the nuclear power</td>
<td>6.9%</td>
</tr>
<tr>
<td>Specific investment costs</td>
<td>8.3%</td>
</tr>
<tr>
<td>Focus of research and development</td>
<td>3.7%</td>
</tr>
<tr>
<td>Regulation of the EU electr. market</td>
<td>4.4%</td>
</tr>
<tr>
<td>Incentives for RES</td>
<td>9.2%</td>
</tr>
<tr>
<td>Cooperation in Europe</td>
<td>3.2%</td>
</tr>
<tr>
<td>Demand for flexibility</td>
<td>1.5%</td>
</tr>
<tr>
<td>Realization of DSM potential</td>
<td>3.2%</td>
</tr>
<tr>
<td>Grid infrastructure</td>
<td>8.0%</td>
</tr>
<tr>
<td>CCS accepted storage potential</td>
<td>2.7%</td>
</tr>
<tr>
<td>Population growth</td>
<td>4.0%</td>
</tr>
<tr>
<td>Consumer behavior</td>
<td>7.4%</td>
</tr>
<tr>
<td>Overall welfare and equality</td>
<td>2.3%</td>
</tr>
<tr>
<td>Land use policy</td>
<td>4.5%</td>
</tr>
<tr>
<td>Urbanization</td>
<td>5.6%</td>
</tr>
<tr>
<td>Attitude towards sustainability</td>
<td>3.0%</td>
</tr>
<tr>
<td>GHG certificate prices</td>
<td>6.4%</td>
</tr>
<tr>
<td>Agriculture for energy sector</td>
<td>3.0%</td>
</tr>
</tbody>
</table>

- 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:

  ![AHP Diagram](image)

  - **Goal**: *(describe the system under study)*
  - **Criteria level**: *(e.g.: Electricity market)*
  - **Focus level**: *(Criteria level)*

  - **Criteria A** *(Descriptor 1)*
  - **Criteria B** *(Descriptor 2)*
  - **Criteria C** *(Descriptor 3)*
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.

AHP pairwise comparison matrix $A$ ($n\times n$)

CIB impact matrix with $n=6$ descriptors

AHP pairwise comparison matrix $A$ ($n\times n$)
### 3.2 Application of AHP in the context of CIB

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

<table>
<thead>
<tr>
<th></th>
<th>$D_1$</th>
<th>$D_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$D_1$</td>
<td>$D_n$</td>
</tr>
<tr>
<td></td>
<td>$r_1$</td>
<td>$r_n$</td>
</tr>
<tr>
<td></td>
<td>$v_1^1$</td>
<td>$v_i^n$</td>
</tr>
<tr>
<td></td>
<td>$v_2^1$</td>
<td>$v_2^n$</td>
</tr>
<tr>
<td></td>
<td>$J(v_1^1, v_1^n) \cdot w_{(1,n)}$</td>
<td>$J(v_2^1, v_2^n) \cdot w_{(1,n)}$</td>
</tr>
<tr>
<td></td>
<td>$J(v_1^n, v_1^1) \cdot w_{(n,1)}$</td>
<td>$J(v_2^n, v_2^1) \cdot w_{(n,1)}$</td>
</tr>
</tbody>
</table>

- $D_n$ 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 $n = \{D_1, D_2, ..., D_n\}$
- $J(v_m^i, v_m^j)$ Judgement field with impact strength defined by experts’ of $v_m^i$ on $v_m^j$
- $w_{(i,j)} = r_n^i \cdot r_n^j + r_n^i \cdot \frac{r_n^j}{1 - r_n^i}$
- $w_{(i,j)}$ 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 $i, j = 1 ... n$
- $r_n$ 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.
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:

<table>
<thead>
<tr>
<th>descriptor</th>
<th>weight</th>
<th>scale 1...5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>17,0%</td>
<td>max +3 (-3)</td>
</tr>
<tr>
<td>B</td>
<td>24,0%</td>
<td>max +5 (-5)</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

- 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

- 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 greater variability of scenarios, bringing in nuances, which were not presented by the initial scenario room.

<table>
<thead>
<tr>
<th>Number of scenarios</th>
<th>Variations included</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIB</td>
<td>26</td>
</tr>
<tr>
<td>AHP 5</td>
<td>25</td>
</tr>
<tr>
<td>AHP 10</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relative frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
</tr>
<tr>
<td>50%</td>
</tr>
<tr>
<td>0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CIB</th>
<th>AHP 5</th>
<th>AHP 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>81%</td>
<td>91%</td>
<td>76%</td>
</tr>
</tbody>
</table>
4. Results

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

- **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.