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APPLICATION OF THE ANALYTIC HIERARCHY PROCESS TO FACILITATE IMPLEMENTATION OF THE CROSS-IMPACT BALANCE APPROACH

Kristina GOVORUKHA[1], Paul KUNZ[2], Philip MAYER[1]

Content

Extensive scenario studies are commonly conducted to describe possible future developments of complex interdepended systems, like the energy system. During the last decades, a variety of scenario techniques have been elaborated to competently consult and inform politics, businesses and public. In this context, the Cross-Impact Balance (CIB) analysis was developed (Weimer-Jehle 2006) on the basis of standard cross-impact methods, allowing for larger methodological flexibility and transparency. The CIB analysis supports transparent construction of consistent scenarios, based on judgements of interdisciplinary experts and stakeholders about system elements and their systemic interactions (Weimer-Jehle 2006). Among others, the effectiveness of CIB was proven in multiple studies focused on development or validation of scenarios for the energy sector (Schweizer & Kriegler 2012; Vögele S. et al. 2017). These systems are often complex and sometimes comprise of a large number of system elements or even different subsystem levels (Hansen et al. 2014). Thus, CIB analysis is complicated by the challenge of consistent and thorough weighting of their multiple cross-impacts. This article introduces an extension to the CIB analysis with a multi-criteria-analysis tool, which solves the issue of possible weighting problems within the CIB. The new approach was initially applied in the CIB scenario construction process of the BMWi founded 4NEMO project. This article shows the under-lying idea of the approach, discusses the achieved improvements of the CIB analysis and displays its advantages.

Method

The CIB allows to formalize our knowledge about systems of different complexities, taking into consideration their elements, further called ‘descriptors’, which qualitatively and quantitatively describe the system under investigation. Each descriptor can have more than two ‘states’ that reflect the nature of it’s possible future changes, which complicates comprehensible evaluation process for large matrices. Experts are asked to give their judgements – they assign specific impact weights that characterize mutual relationships of descriptors and their states. Afterwards, the obtained evaluations of all identified ‘cross-impacts’ are collected in the cross-impact matrix (Figure 1) and the CIB algorithm defines combinations of descriptor states in such a manner that they reflect logics of experts’ judgements coded in the matrix (Weimer-Jehle W 2009).

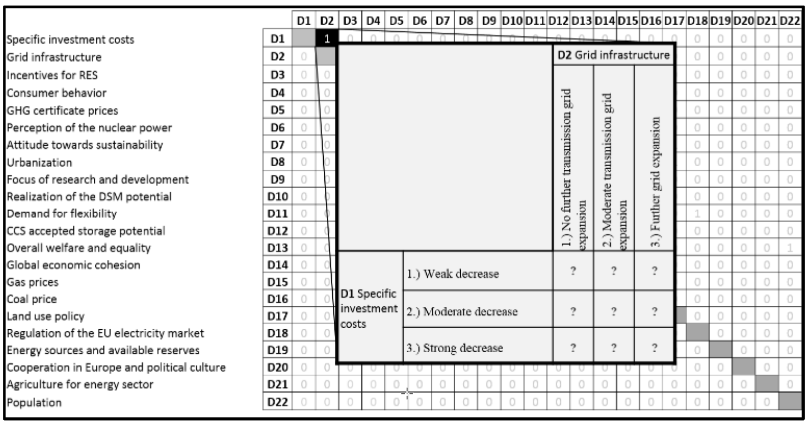

Figure 1: Cross-impact matrix and the judgment fields for evaluation of cross-impacts between the states of the descriptor D1 and D3

[1] Technische Universität Bergakademie Freiberg, Lehrstuhl für Allgemeine Volkswirtschaftslehre, Schloßplatz 1, 09596 Freiberg, Tel.: +49 3731 39-3547, kristina.govorukha@vwl.tu-freiberg.de
[2] Forschungszentrum Jülich GmbH, Institut für Energie und Klimaforschung, Wilhelm-Johnen-Straße, 52425 Jülich, Tel.: +49 2461 61 9835, p.kunz@fz-juelich.de

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The result is a scenario room, where each scenario contains a collection of descriptor states satisfying the consistency criteria. It can be used for further scenario analysis, for example, in combination with computational modelling methods. Scenarios are sensitive to the assigned impact weights, which is extremely important for large investigated systems with multiple elements. To solve the challenge of arbitrary descriptor weightings in large CIB matrices, the current article presents the analytic hierarchy process (AHP) introduced by Saaty (1980) as an intermediary step within the CIB. The combination of the methods is displayed exemplarily in the Figure 2.

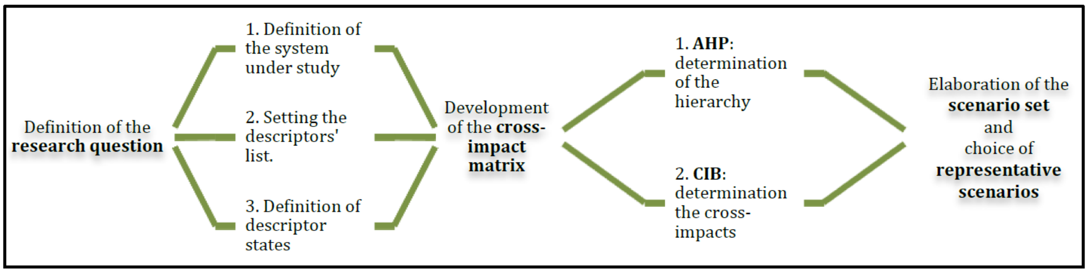

Figure 2: Steps in CIB and AHP complementary process

The complementary AHP step allows to identify and display the hierarchy of the CIB descriptors. It helps to reveal their perceived ability to in-fluence other system elements and the system as a whole. Within the AHP, weightings are obtained by the pairwise comparison of the descriptors by experts with regard to their relative importance within the system under investigation. The AHP provides descriptors' weights in a range from 1-100 %, revealing their internal hierarchy. It becomes especially relevant if extraordinary large CIB matrices are taken into account.

The identified individual weights of all descriptors allow not to focus on their relative importance during the following phase of the CIB analysis, when evaluating cross-impacts between the descriptors (see Figure 2). Hence, in the following phase only the distribution and balancing of impact-weights between the descriptor states have to be taken into account. Figure 3 shows how the AHP ratings (r_A,…r_X) of the descriptors (A,…X) can be applied to develop individual rating (F(r)) for each respective judgement field in the cross-impact matrix. These ratings take into consideration unequal relative importance of descriptors.

			D_1		D_2		… D_n	
			r_1		r_2		… r_n	
			s_1	s_2	s_1	s_1	s_2	s_1
					$F(r_{A,B})$		$F(r_{A,X})$	
A	r_A	v_1			$J_{(A1,B1)}$	$J_{(A1,B2)}$	$J_{(A1,X1)}$	$J_{(A1,X2)}$
		v_2			$J_{(A2,B1)}$	$J_{(A2,B2)}$	$J_{(A2,X1)}$	$J_{(A2,X2)}$
			$F(r_{B,A})$				$F(r_{B,X})$	
B	r_B	v_1	$J_{(B1,A1)}$	$J_{(B1,A2)}$			$J_{(B1,X1)}$	$J_{(B1,X2)}$
		v_2	$J_{(B2,A1)}$	$J_{(B2,A2)}$			$J_{(B2,X1)}$	$J_{(B2,X2)}$
			$F(r_{X,A})$		$F(r_{X,B})$			
… X	… r_X	v_1	$J_{(X1,A1)}$	$J_{(X1,A2)}$	$J_{(X1,B1)}$	$J_{(X1,B2)}$		
		v_2	$J_{(X2,A1)}$	$J_{(X2,A2)}$	$J_{(X2,B1)}$	$J_{(X2,B2)}$		

A,B,…X x descriptors
r_n descriptor weighting/ combined weighting
v_{1-2} descriptor states (in the above example just two states are considered)
J impact strength (defined by expert judgements)
F(r) combined weighting of each descriptor intersection

Figure 3: Exemplary application of the AHP weightings in the CIB-matrix

Result

The opportunity of the AHP - CIB tandem is to eliminate the limitations of both approaches without making the process more complicated. It helps to incorporate expert judgments in a consistent manner and avoids misunderstandings during the judgement procedure on the intensity of the impacts in the CIB matrix. This article demonstrates how the AHP can be applied to improve the CIB analysis and how the CIB results differ due to the implementation of the AHP.

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Results shown on the Figure 4 come from the 4NEMO project, which aims, among other goals, to develop consistent socio-economic scenarios for the EU electricity market until 2050. The task is challenging due to the fact, that there are seven participating models with different requirements for the context framework, which is delivered by the CIB. While Figure 1 shows the identified descriptor list and the cross-impact matrix, Figure 4 represents the associated AHP weightings and reveals the tendency of the experts' perception towards the influence of the considered system elements.

D3	Incentives for RES	9.2%
D1	Specific investment costs	8.3%
D2	Grid infrastructure	8.0%
D4	Consumer behavior	7.4%
D6	Perception of the nuclear power	6.9%
D5	GHG certificate prices	6.4%
D8	Urbanization	5.6%
D17	Land use policy	4.5%
D18	Regulation of the EU electricity market	4.4%
D19	Energy sources and available reserves	4.1%
D22	Population	4.0%
D15	Gas prices	3.7%
D9	Focus of R&D	3.7%
D10	Realization of the DSM potential	3.2%
D20	Cooperation in Europe and political culture	3.2%
D21	Agriculture for energy sector	3.0%
D7	Attitude towards sustainability	3.0%
D16	Coal price	2.8%
D12	CCS accepted storage potential	2.7%
D13	Overall welfare and equality	2.3%
D14	Global economic cohesion	2.3%
D11	Demand for flexibility	1.5%

Figure 4: Received AHP weights for the descriptor list identified for the 4NEMO project

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